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A FRAMEWORK FOR OPTIMAL SCHEDULING OF ELECTRIC VEHICLES AND DEMAND RESPONSE TO SMART GRIDS

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Dissertation submitted to the Graduate Program in Electrical Engineering from the Federal University of Paraná, as partial requirement for the degree of Master of Science in Electrical Engineering.

Advisor: Prof. Dr. Clodomiro Unsihuay Vila

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This dissertation has been accepted and approved in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering at the Federal University of Paraná, Brazil.

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Curitiba, February 26, 2015.

DEDICATION

This dissertation is dedicated to my God who knew how to guide me in the right road, give me the strength to keep me going and not give in problems arising, teaching me how to address the adversity without losing dignity or falter in the attempt.

To my family who for them I am what I am. To my parents for their encouragement, advice, understanding, love, support in difficult times, and for helping me with the necessary resources to study. They gave me everything I am as a person, values, principles, character, effort, perseverance and courage to achieve my goals.

I also dedicate this dissertation to my friends who have supported me throughout the process.

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To all my friends, thank you for your understanding and encouragement. Your friendship makes my life a wonderful experience. I cannot list all the names here, but you are always on my mind.

“Happiness is when what you think, what you say,
and what you do are in harmony.”

Mahatma Ghandi

ABSTRACT

Microgrids and distribution systems holds a very important position in the power system since are the main points of link between bulk power and consumers. Due to the convergence of several trends in the energy sector, smart grids are emerging as a solution for the modernization of the electric grid, integrating large shares of distributed and intermittent renewable energy sources, energy storage and electric vehicles, as well as the promise to give consumers more control on their energy consumption. This dissertation presents a computational method for an optimal scheduling for demand response and electric vehicle for a typical house under a microgrid environment and its impact on the electric power distribution network along a 24 hours-daily horizon. The proposed method is a System of Systems (SoS) based framework for optimally operating active distribution grids. The proposed SoS framework defines both; distribution company (DISCO) and microgrids (MGs) as autonomous systems, and recognizes the exchange information process among them. The proposed mathematical algorithm uses a separated optimization process that aim maximizing the benefit of each independent system. A hierarchical optimization algorithm is presented to coordinate the independent systems and to find the optimal operating point of the SoS-based active distribution grid. Therefore, the proposed model considers a special emphasis on variables that impact the total behavior of the system for both the energy supplier and the final consumer. The proposed optimization problem is divided in two sub-problems: the demand response problem-based time for a daily horizon, that is modeled as a mixed integer linear programming and the second problem is the electric distribution network problem that is modeled with an optimal power flow. The proposed method allows an optimized schedule of demand response to end-user level and considers their impacts on the distribution network simultaneously. It also examined the additional benefits of demand response programming, micro-distributed generation, integration of electric vehicles modeling in the microgrid. A case of study containing three scenarios reveals the usefulness and effectiveness of the proposed model. Firstly showing the normal operation without any type of optimization, secondly conducting an optimization process inside of the microgrid with the insertion of the electric vehicle just modeled as a load and managing the distribution system, thirdly inserting renewable distributed generation, electric vehicles for both process: charging and discharging. Finally, making the optimization process for the junction of the microgrid and the distribution network.

Key-words: Smart grid. Electric Vehicle. Optimal power flow. Mixed integer linear programming. Distribution system.

RESUMO

As microredes e os sistemas de distribuição têm uma posição de importância no sistema de energia, sendo os principais pontos de ligação entre a energia em grandes quantidades e os consumidores finais. Devido à convergência de várias tendências próprias do setor, as redes inteligentes estão emergindo como uma solução para a modernização da rede elétrica, integrando percentagens cada vez maiores de fontes de energia renováveis e intermitentes, armazenamento de energia e veículos elétricos, assim como o compromisso de oferecer aos consumidores maior controle no seu consumo de energia. Esta dissertação apresenta uma metodologia computacional que estabelece um agendamento ótimo para a resposta à demanda no caso de uma casa padrão inserida em um ambiente de microrede, além de determinar o seu impacto sobre a rede de distribuição de energia elétrica ao longo de um horizonte de 24 horas por dia. Este trabalho apresenta também um Sistema de Sistemas (SoS) contextualizado para uma operação ótima de redes de distribuição ativas. O SoS proposto define tanto a companhia de distribuição (DISCO) e a microrede (MGs) como sistemas autônomos, e reconhece o processo de troca de informações entre eles. O algoritmo matemático proposto utiliza um processo de otimização separado que visa maximizar o benefício de cada sistema independente. Adicionalmente, um algoritmo de optimização hierárquica é apresentado para coordenar os sistemas independentes e para determinar o ponto de funcionamento óptimo da rede ativa de distribuição baseada no SoS. O modelo proposto considera uma ênfase especial sobre as variáveis que afetam o comportamento total do sistema, tanto para o fornecedor de energia como para o consumidor final. O problema de otimização proposto é dividido em dois itens: o problema da resposta à demanda baseado no tempo para um horizonte diário, que é modelado como uma programação linear inteira mista e o segundo problema é o problema de rede radial que é modelado com um fluxo de potência ótimo. A metodologia proposta permite um agendamento otimizado para a resposta à demanda ao nível de usuário final e considera simultaneamente seu impacto na rede de distribuição. Além, nesta dissertação foram analisados os benefícios da programação da resposta à demanda, micro-geração distribuída e integração de veículos elétricos modelado na microrede. Um caso de estúdio contendo três distintos cenários revela a utilidade e eficácia do modelo proposto. Em primeiro lugar, mostrando o funcionamento normal, sem qualquer tipo de otimização, em segundo lugar, conduzindo um processo de otimização dentro da microrede com a inserção do veículo elétrico apenas modelado como uma carga e gerenciando o sistema de distribuição, e em terceiro lugar considerando a inserção de geração renovável distribuída, e processos tanto de carga como descarga dos veículos elétricos. Finalmente, foi efetuado um processo de otimização para a junção da microrede e da rede de distribuição.

Palavras-chave: Rede inteligente. Veículo elétrico. Fluxo de potência ótimo. Programação linear inteira mista. Sistema de distribuição.

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LIST OF ACRONYMS

AMI	Advanced Metering Infrastructure
AMR	Automatic Meter Reading
BEV	Battery Electric Vehicle
CPP	Critical Peak Pricing
DG	Distributed Generation
DISCO	Distribution Company
DR	Demand Response
DSM	Demand Side Management
EINL	Elastic Interruptible Load
EV	Electric Vehicle
HAN	Home Area Network
HVAC	Heating Ventilation Air Conditioning
IBP	Incentive Based Program
ICE	Internal Combustion Engine
IL	Inelastic Loads
LAN	Local Area Network
LSE	Load Serving Entity
PBP	Price Based Program
PHEV	Plug-in Hybrid Electric Vehicle
RTP	Real Time Pricing
SCADA	Supervisory Control And Data Acquisition
SG	Smart Grid
SoS	System of Systems
TOU	Time Of Use
V2G	Vehicle 2 (to) Grid
VPP	Virtual Power Plant
WAN	Wide Area Network

NOMENCLATURE

$Consumption_t^{Max\_Hourly}$	: Maximum consumption at hour t in W
$Cycles_j^{EV\_Charging}$	: Number of charging cycles for the EV j
$Cycles_j^{EV\_Discharging}$	: Number of discharging cycles for the EV j
$Cycles_k^{Elast\_Load}$	: Number of cycles for the elastic interruptible load k
$Cycles_k^{Ine\_Load}$	: Number of cycles for the inelastic load k
$Demand_t^{Total}$	: Total demand of the house (including elastic Interruptible and Inelastic loads) at hour *t* (W)
$Duration_j^{EV\_Charging}$	: Duration of the charging cycle of the EV j (hour)
$Duration_j^{EV\_Discharging}$	: Duration of the discharging cycle of the EV j (hour)
$Duration_k^{Elast\_Load}$	: Duration of the cycle of use for the elastic interruptible load k (hour)
$Duration_k^{Ine\_Load}$	: Duration of the cycle of use for the inelastic load k (hour)
$Energy_t^{Buy\_Cost}$	: Energy purchase price
$Energy_t^{Sale\_Cost}$	: Energy sale price
$EV_{j,(t-1)}^{Energy\_Stored}$	: Initial state of charge, Stored energy in the battery of vehicle j, at hour (t-1) (Wh)
$EV_{j,t}^{Energy\_Stored}$	: State of charge, Stored energy in the battery of vehicle j, at hour t (Wh)
$EV_{j,t}^{Energy\_trip}$	: Energy consumption of vehicle j for traveling at hour t (Wh)
$EV_{j,t}^{Energy\_Trip}$	: Energy consumption for traveling in time t (Wh)
$EV_{j,t}^{Max\_Power\_Charged}$	: Rated hourly max power charged for vehicle j, at hour t (W)
$EV_{j,t}^{Max\_Power\_Discharged}$	: Rated hourly max power injected or discharged for vehicle j, at hour t (W)
$EV_{j,t}^{Power\_Charged}$	: Power charged for vehicle j at hour t (W)
$EV_{j,t}^{Power\_Discharged}$	: Power discharged from vehicle j at hour t (W)
$Gen_t^{Energy\_Type}$	: Energy generation from any source (Solar, Wind) at hour *t* (Wh)
N_{Elast_Load}	: Number of elastic interruptible loads

N_{EV} : Number of electric vehicles

N_{Ine_Load} : Number of inelastic loads

$Net_t^{Energy\_Consumed}$: Net energy consumption at hour *t* (Wh)

$P_{k,t}^{Elast\_Load}$: Power consumption of elastic interruptible load k at hour t (W)

$P_{k,t}^{Ine\_Load}$: Power consumption of inelastic load k at hour t (W)

$X_{j,t}^{EV}$: EV charging status, Binary variable that takes the following values $\begin{cases} 0 \text{ if EV is not being charged} \\ 1 \text{ if EV is being charged} \end{cases}$;

$X_{k,(t-1)}^{Elast\_Load}$: Elastic interruptible load status for load k at hour (t-1), Binary variable that takes, 0 if is not operating or 1 if it is

$X_{k,t}^{Elast\_Load}$: Elastic load status for elastic inerruptible load k at hour t that presents the following behavior. $\begin{cases} 0 \text{ if is not operating} \\ 1 \text{ if it is operating} \end{cases}$

$Y_{j,t}^{EV}$: EV Discharging or injection status, Binary variable that takes the following values $\begin{cases} 0 \text{ if EV is not discharging} \\ 1 \text{ if EV is discharging} \end{cases}$

$Y_{k,t}^{Aux\_ON}$: Binary variable for device k (Elastic interruptible load), that is equal to $\begin{cases} 1 \text{ if the device is ON at hour t} \\ 0 \text{ if the device is OFF at hour t} \end{cases}$

$Z_{k,t}^{Aux\_OFF}$: Binary variable for device k (Elastic interruptible load), that is equal to $\begin{cases} 1 \text{ if the device is OFF at hour t} \\ 0 \text{ if the device is ON at hour t} \end{cases}$

β_j^{max} : Energy battery maximum limit of EV j (Wh)

β_j^{min} : Energy battery minimum limit of EV j (Wh)

$\eta_j^{EV\_Charging}$: Charging efficiency of electric vehicle j

$\eta_j^{EV\_Discharging}$: Discharging efficiency of electric vehicle j

ψ_j^{max} : Maximum percentage limit of battery capacity for EV j

ψ_j^{min} : Minimum percentage limit of battery capacity for EV j

l : Auxiliary index

MUT : Minimum up time for elastic interruptible loads

N_Energy_Type : Number of micro generators units in the house

CONTENTS

1 INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

Three main topics have motivated this study: Smart grid, Demand Response & Electric Vehicles. These topics are related, as their technologies are advancing relatively fast. Smart grid has brought several challenges and also opportunities in the electric infrastructure that allows the operation of the conventional electric power systems to be more reliable, consistent and efficient.

This concept and technology, firstly makes possible at different levels of the electrical system the incorporation of diverse distributed energy sources, smart sensors, frequency monitoring devices, intelligent substation and distribution equipment. It is also found at the costumer level the use of smart appliances. At the same time, software to handle all the information that comes from the parts of the system interaction is present, initially these software are required to quantifiably evaluate, monitor the progress and plan the operability of the smart grid [1].

With the implementation of this concept, it is possible to perform load control, applying innovative and diverse demand response algorithms. One of the main outcomes of the use of smart grids is the relieving stress condition of the power system. Although, the term Demand Side Management (DSM) has been widely used since the 1980's [2], and several studies have been conducted on this path, the term Demand Response has recently been introduced together with the smart grid concept. Demand response (DR) is a customer action to control loads in order to meet certain peak reduction and energy savings aims. With demand response, the customer chooses which loads are to be controlled and for how long. This is the main difference from Demand Side Management, where the electric supplier controls the loads and the final user has no control over the process. In this context have also appeared some scientific knowledge gaps in the implementation of smart grids that have being treated in [3] , [4] .

In addition to demand response and smart grid technology, appears on the scenario the electric vehicle. The automobile, as normally known, is the basic mode of propulsion for the human and has worked since its invention with a gasoline fueled internal combustion engine. Throughout the past 100 years, various social and international political factors have encouraged interest in other technologies, but the gasoline powered internal combustion engine has continued to dominate the automobile horizon. However, recent policies have placed a new emphasis on the sale of the concept of an electric vehicle with no pollution levels residues. In pursuance of this objective, electric vehicle have emerge as reliable and viable option, firstly, just as a vehicle that need to be charged and more recent models with features that allow them to inject energy to the grid [5].

The approach of the electric vehicle as energy storage source, is based on the ability to storage energy in its battery when the energy has a low price and also to inject energy to the grid when the energy presents a higher price [6]. This feature allows researchers on this field to experiment whether or not is viable to schedule or manage the interaction of the electric vehicles with the system that is supporting them [7]. The automobile sector is constantly looking for a way to make “cleaner” technologies and economically competitive with the traditional internal combustion engine [8].

This dissertation emphasizes in the interaction of the elements inside of the microgrid (Micro Distributed Generation, Electric Vehicles and Demand Response) and how they affect the behavior of the distribution system. Load profile and comparative curves are also the target in order to show the variations that appears while the distribution system and the microgrid are under stress conditions.

1.2 OBJECTIVE AND SCOPE

1.2.1 General Objective

The main objective in this dissertation is to present a computational method to optimal scheduling for demand response and electric vehicle of a typical house in a microgrid environment and its impact on the electric power distribution network along a 24 hours horizon. The mathematical model takes in consideration the insertion of micro distributed renewable energy generation and its interaction with the electric power distribution network using the System of Systems (SoS) concept.

1.2.2 Specific Objectives

To develop a solving technique for the integrated (Microgrid + Distribution network) optimization process based on the SoS concept.

To develop the computational model for residential controllable (Elastic interruptible) and uncontrollable (Inelastic) loads that will be the base for the demand response algorithm, applied to the appliance level along the 24 hours horizon.

To study the daily demand variation curve due the optimal shifting behavior of the controllable loads and validate the optimization process based on its objective function.

To develop an operational behavior model for the electric vehicle that represents the storage, charge and discharge characteristics for the majority of the electric vehicles (BEVs, HEVs, PHEVs) available at this time. Also, several brands and models will be described.

To expand the inputs as much as possible for the electric vehicle modeling, for instance, introducing driving patterns, electric vehicle storage and charge/discharge state after driving, starting hour trip, end hour trip, charging start time, charging rate and develop the load profile of the electric vehicle at the microgrid level.

To analyze the total behavior and interaction of the parts of the microgrid and also insert efficiently sources of micro distributed renewable generation, mainly solar sources, and analyze the way in which this feature of the system affects the micro grid system itself and the distribution system.

1.3 CONTRIBUTIONS

1.3.1 The Integrated Microgrid and Distribution Network Modeling

The first contribution in this dissertation is the presentation of a novel algorithm for the interaction among the components of the microgrid (that for the purpose of this dissertation is not used in its isolated form) and the distribution network. In this section is proposed an optimal scheduling for demand response and electric vehicle of a typical house in a microgrid environment and their impact on the electric power distribution network along a 24 hours horizon. A hierarchical optimization algorithm is presented to coordinate the independent systems and to find the optimal operating point of the SoS-based active distribution grid. Two different tools are used in order to get this objective: A Mixed Integer Linear Programming (MILP) model for the microgrid and for the distribution network an optimal power flow (OPF) is applied. Both process are iterative and interlinked. With this new method, that optimize each part, is ensured that the system will be also optimized, as seen in the final results, graphs and tables on chapter 4. The proposed method is a computationally improved in comparison with existing methods about optimization of the distribution network under a smart grid environment. The proposed algorithm is tested on a radial distribution network with generators connected into the buses and proved its efficiency solving together both systems, the microgrid level and the distribution level.

1.3.2 Electric Vehicle Modeling

The second contribution in this dissertation includes the development of a model for managing the operation of the electric vehicle along a 24 hours horizon, through an algorithm that controls the amount of energy charged/discharged hour by hour, the amount of charging cycles and the duration of the cycles.

1.3.3 Residential Loads Management and Classification Model

The third contribution in this dissertation includes the residential load modeling for every type of load. In this part of the work, residential customers can influence their load demand by shifting loads from high tariff to low tariffs, reducing the overall load demand along the 24 hours horizon. Additionally, they can locally produce electricity using distributed generation. The benefits for the customers are mainly reductions of the energy bill. However, customers have to change their consumption habits and as a consequence their living comfort may be decreased. The classification proposed in this dissertation is such that the customer can decide, first of all how many loads will participate in the optimization process; configure the basic settings for every load to optimize. Also, enable or not the possible working hours or left to the algorithm to choose after the optimization process, whether or not operate according to the surrounding system conditions.

1.4 OUTLINE OF THE DISSERTATION

The dissertation is divided into the following Chapters, which include separates brief introductions.

Chapter 2 introduces to the readers the main topics and concepts that will be addressed on this dissertation through a brief outline to the subjects smart grids, electric vehicles, radial distribution system, demand response and system of system.

Chapter 3 contains an approach over the method that is applied in each part of the system; a brief explanation of the optimization tools is performed. Subsequently, a general framework is derived from the sum of all the tools that are explained. Structure, restrictions and equations are detailed. Finally the complete system arises. Boundaries, scope, and expected results are explained.

Chapter 4 introduces all the tested scenarios and provides a comparative chart with the results for each scenario, pointing out the main improvements with the method applied over the complete system.

Last but not least, the conclusions for every part of the system that is used in this dissertation are stated in Chapter 5. Applicability of the method proposed, summary of the main findings are given, an outlook for possible future work are also provided in this chapter.

2 STATE OF ART

This chapter condenses the state of art of all the topics that are included in this dissertation. A thorough investigation was conducted in order to provide the basic information and research that have been done in these areas; smart grid (SG), demand response (DR), electric vehicles (EVs), distributed generation (DG) and the distribution network. Several knowledge gaps are identified and then discussed.

2.1 SMART GRID (SG)

The term “Smart Grid” can be described as bi-directional electric and communications network that improves the reliability, security, and efficiency of the electric system for small to large scale generation, transmission, distribution, and storage [9], [10]. FIGURE 1 shows how a smart grid looks like in the present and near future.

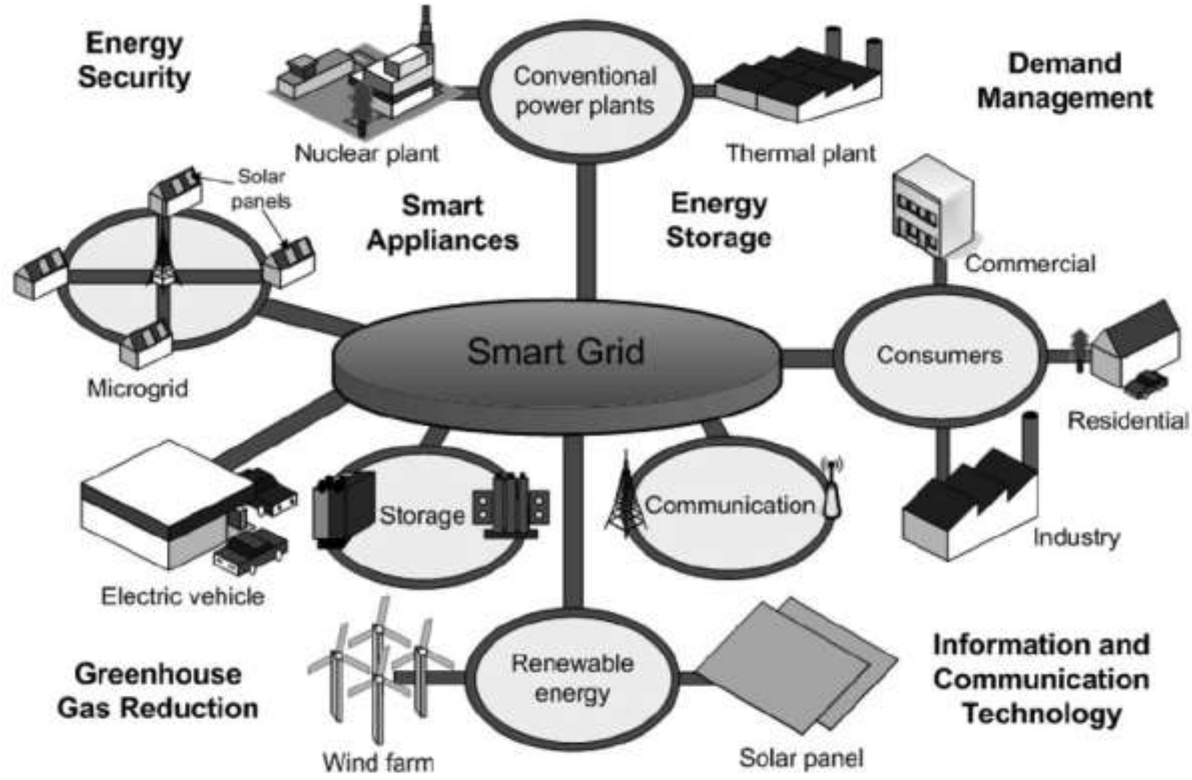

FIGURE 1 - Future electric smart grid architecture [11]

2.1.1 Smart Grids Benefits

Smart grid can provide several benefits compared with the existing grid. The present grid is planned in a hierarchical system with centralized power plants on the top and the supplied customers on the bottom through distribution stations [12]. This structure is built on one-way communication (top to bottom) and has no real-time information of the demand. As a result the system is dimensioned to enable sufficient supply at demand peaks [13]. The roll-out of smart grid technology also implies a fundamental re-engineering of the electricity services industry, although typical usage of the term is focused on the technical infrastructure [14]. The smart grid represents the full suite of current and proposed responses to the challenges of electricity supply. Due to the diverse range of factors, there are numerous competing taxonomies and no agreement on a universal definition.

The advantages of Smart Grid compared with the existing grid are illustrated in TABLE 1

TABLE 1 - Comparison between Smart Grids architecture and existing grid [13]

Existing Grid	Perfect Smart Grid
Electromechanical	Digital
One-Way Communication	Two-Way Communication
Centralized Generation	Distributed Generation
Hierarchical	Network
Few Sensors	Sensors Throughout
Blind	Self-Monitoring
Manual Restoration	Self-Healing
Failures and Blackouts	Adaptive and Islanding
Manual Check/Test	Remote Check/Test
Limited Control	Pervasive Control
Few Customer Choices	Many Customer Choices

Beside of the technological advantages that this concept presents, every system is also characterized for some features that appear intrinsic in its operation. For instance, the system studied and analyzed in [15], stated that the U.S. smart grid is characterized by the following features that appear in TABLE 2. It is clear that the technological advances, helps to improve each of those features, but in this case the smart grid strategy is motivated by concepts of innovation with regard to social and environmental reforms for an interactive economy.

TABLE 2 - U.S. Smart Grid Characteristics [15]

Smart Grid Characteristics	Increased digital information and controls
	Dynamic optimization of grid operations, including cyber security
	Deployment of distributed resources, including renewable resources
	Incorporation of demand-side resources and demand response
	Deployment of “smart” technologies and integration of “smart” appliances and consumer devices
	Deployment of storage and peak-shaving technology, including plug-in hybrid electric vehicle (PHEV)
	Provision of timely information and control options to consumers
	Standard development for communication and interoperability of equipment
	Identification and lowering of unreasonable barriers to adopt smart grid technology, practices, and services

According to [16], the benefits of smart grid can be briefly resumed as follows:

Digitalization: The smart transmission and distribution grid will employ a unique, digital platform for fast and reliable sensing, measurement, communication, computation, control, protection, visualization, and maintenance of the entire transmission system. This is the fundamental feature that will facilitate the realization of the other smart features. This platform is featured with user-friendly visualization for sensitive situation awareness and a high tolerance for man-made errors.

Flexibility: The flexibility for the future smart transmission and distribution grid is featured in four aspects: 1) expandability for future development with the penetration of innovative and diverse generation technologies; 2) adaptability to various geographical locations and climates; 3) multiple control strategies for the coordination of decentralized control schemes among substations and control centers; and 4) seamless compatibility with various market operation styles and plug-and-play capability to accommodate progressive technology upgrades with hardware and software components.

Intelligence: Intelligent technologies and human expertise will be incorporated and embedded in the smart transmission and distribution grid. Self-awareness of the system operation state will be available with the aid of online time-domain analysis such as voltage/angular stability and security analysis. Self-healing will be achieved to enhance the security of transmission and distribution grid via coordinated protection and intelligent control schemes.

Resiliency: The smart transmission and distribution grid will be capable of delivering electricity to customers securely and reliably in the case of any external or internal disturbances or hazards. A fast self-healing capability will enable the system to reconfigure itself dynamically to recover from attacks, natural disasters, blackouts, or network component failures. Online computation and analysis will enable the fast and flexible network operation and controls such as intentional islanding in the event of an emergency.

Sustainability: The sustainability of the smart transmission and distribution grid is featured as sufficiency, efficiency, and environment-friendly.

2.1.2 Enabling Technologies

In order to implement this technology, all over the actual grid, some other technologies must be enabled and matured [17], [18]:

2.1.2.1 Distributed Generation

Distributed Generation refers to small rated electricity sources that are normally decentralized and situated close to end-user facilities on the distribution side of the electric grid. Is available to include conventional as well as renewable energy sources. The interconnection of distributed generation to the grid offers a diversity of benefits, including on demand power quality of supply and enhanced reliability. However, the interconnection of distributed generation is a challenge due to the safety, control, and protection issues associated with its bidirectional flows of electricity. Standard of the distributed generation inter-connectivity and technical information are stated in [19]. Some extra information about this type of generation is available in [20] .

2.1.2.2 Energy Storage

Electricity is a fragile product that must be consumed within a very short period of time that normally is not easy stored, mainly in excessive amounts. Alternatively, it may be converted into other forms such as mechanical or electrochemical energy [21]. Storage technologies allow these procedures and are among the wanted features for the smart grid.

FIGURE 2 shows a comparison among batteries storage based on their materials and rated power and storage duration. Better characteristics can provide to the grid the following advantages: makes the grid more efficient; enables load leveling and peak shaving, while it reduces dependence on spinning reserve; improves grid reliability and power quality; provides ancillary services; supplying reactive power for voltage regulation and supports transmission and distribution (T&D) [22].

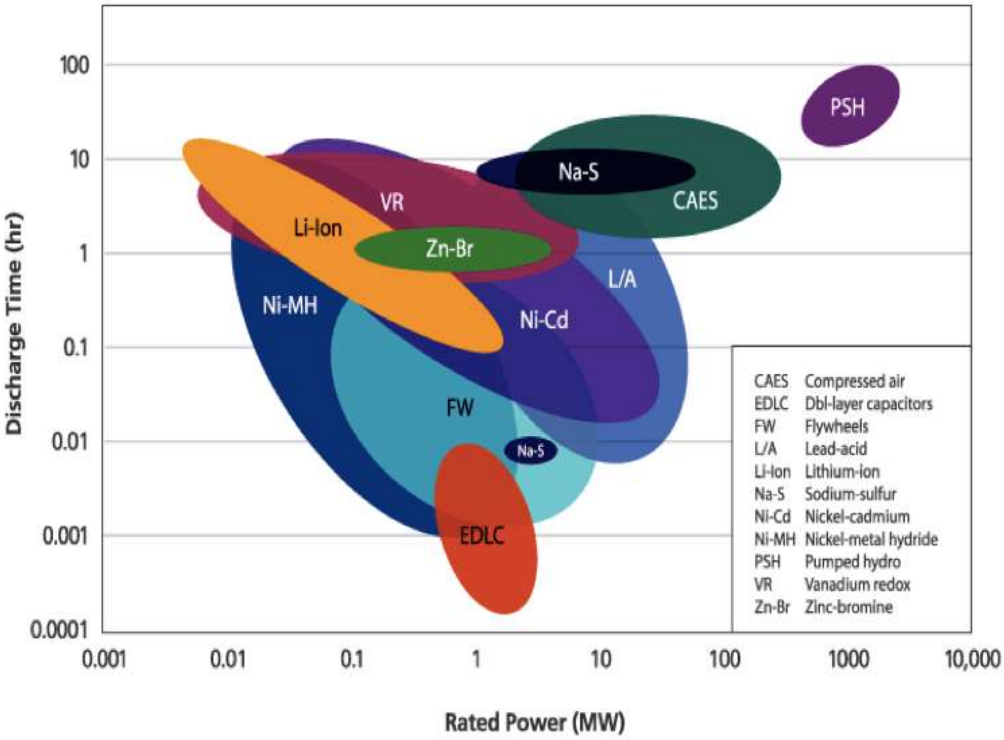

FIGURE 2 - Comparison of electricity storage technologies [23].

2.1.2.3 Power Electronic

Power electronics is essential in the expansion of smart grids because a greater penetration of renewable and alternative energy sources needs complex power systems converter. Usually, a power converter is an interface between the smart grid and local power sources [24]. Solar photovoltaic and wind energy systems play an important function as alternative sources for incorporation in smart grids, that are progressively being installed in residential and commercial locations (typically with a power range of a few kilowatts). Some important characteristics for power electronics systems in smart grids are: High efficiency, Optimal energy transfer, Bidirectional power flow, High reliability, Electromagnetic interference filtering, Smart metering, Real-time information, Communications, Fault tolerance/self-healing.

2.1.2.4 Control Automation and Monitoring

A smart grid is an extremely complex nonlinear dynamic network of distributed-energy properties with bidirectional power flow and information that presents several theoretical and practical challenges. Sensing and control systems are key problems that need to be addressed to make it more intelligent and equip it with self-healing, self-organizing, and self-configuring capabilities. This necessitates more complex control, sensing, and computer-oriented monitoring than in the current network, human operators execute these critical tasks. Consequently, some modern control techniques have been claimed to be the best fit for smart grids, for example, agent-oriented programming, multiagent system and implementing computational intelligence into distributed system operation [25]; however, most of these are yet to transcend the investigation domain into large-scale implementation.

2.1.2.5 Communication Systems

Self-healing systems have sought to be incorporated into power systems, particularly as the complexity and interactions of several market players significantly increase the risk for large-scale failures. Reconfiguring the system in islanded mode may require hit it to unknown rate and amount of data exchange, two-way communication links, and advanced central computing facilities. Decentralized intelligent control could enable islands to accommodate their native load and generation in a more reliable and efficient way. Local controllers may ensure that each island is operating within the security limits, safeguarding the electricity supply to their customers [26].

2.2 DEMAND RESPONSE (DR)

The re-modeling of the present network towards a smarter opens opportunities for end users in adjusting their demand in order to relieve the grid and minimize costs. This section describes demand response and presents several management alternatives with focus on the benefits for operators and final users. According to the U.S. Department of Energy (DEO) demand response is defined as:

"Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized" [27].

Nowadays, most consumers in power market are not exposed to actual power prices and consequently have no incentive to react to the power market condition. An electricity tariff with an hourly power price might now help to encourage customers to think about the scheduling of their electricity utilization. However, since most of the customers are unaccustomed to acting at critical times this might not be enough. Creating consciousness it may help to introduce incentives when reducing load at critical times. It is also possible start introducing penalty fees for not reducing load at critical times or both. Demand response can understands both reduction and increase of electrical usage depending on market conditions[28].

2.2.1 Demand Response Benefits and Costs

The benefits can be separated in direct, collateral and other benefits (TABLE 3 from the DEO). Direct benefits regard all members who implement demand response; collateral and other benefits regard all members of the electric system. The collateral benefits have system-wide impacts which that encourage policy makers to incentive demand response.

Demand Response costs can be divided into participants and system costs and within those two groups into initial and ongoing costs. The U.S. Department of Energy published an overview explaining the costs in the mentioned groups, which can be seen in TABLE 4 [29].

TABLE 3 - Benefits of demand response [29]

Type of Benefits	Recipient (s)	Benefit	Description/Source
Direct Benefits	Customers undertaking demand response actions	Financial benefits	Bill savings Incentive Payments (IBP)
		Reliability benefits	Reduced exposure to forced outages; Opportunity to assist in reducing risk of system outages
Collateral Benefits	Some or all consumers	Market impacts (short-term)	Cost-effectively reduced marginal costs/prices during events; Cascading impacts on short-term capacity requirements and load serving entities (LSEs) contract prices
		Market impacts (long-term)	Avoided (or deferred) capacity costs; Avoided (or deferred) grid infrastructure upgrades; Reduced need for market interventions (e.g. price caps) through restrained market power
		Reliability benefits	Reduced likelihood and consequences of forced outages; Diverse resources available to maintain system reliability
Other Benefits	Some or all consumers, LSE, Grid Operator	More robust retail markets	Market-based options provide opportunities for innovation in competitive retail markets
		Improved choice	Customers and LSE can choose desired degree of hedging; Options for customers to manage their electricity costs, even where retail competition is prohibited
		Market performance benefits	Elastic demand reduces capacity for market power; Prospective demand response deters market power
		Possible environmental benefits	Reduced emissions in system with high-polluting peak plants
		Energy independence / security	Local resources within states or regions reduce dependence in outside supply

TABLE 4 - Costs of demand response [29]

Type of Costs		Cost	Responsibility/Recovery Mechanism
Participant Costs	Initial costs	Enabling technology investment	Customer pays; incentives may be available from public benefit or utility DR programs to offset portion of costs
		Establishing response plan or strategy	Customer pays; technical assistance may be available from public benefits or utility demand response programs
	Event specific costs	Comfort/inconvenience costs	Customer bears “opportunity costs" of foregone electricity use
		Reduced amenity/lost Business	
		Rescheduling costs (e.g. overtime pay)	
		Onsite generator fuel and maintenance	
System Costs	Initial costs	Metering/communication system upgrades	Level of costs and cost responsibility vary according to the scope of the upgrade (e.g., large customers vs. mass market), the utility business case for advanced metering system or upgrades, and state legislation/policies
		Utility equipment or software costs, billing system upgrades	Utility typically passes cost through to customers in rates
		Customer education	Ratepayers, public benefits funds
	Ongoing program costs	Program administration/-management	Costs are incurred by the administering utility, transmission/distribution operator and are recovered from ratepayers
		Marketing/recruitment	
		Payments to participating customers	
		Program evaluation	
		Metering/communication	

2.2.2 Demand Response Classification

“Demand response contains all planned electricity consumption pattern changes by end-use customers that are intended to modify the timing level of instantaneous demand, or total electricity consumption“ [30] [31]. DR programs can be organized in two groups: incentive-based demand response (IBP) and price-based demand response (PBP). The U.S. Department of Energy recommends introducing demand response with incentive-based programs. But, if the end-users are used to demand response, the Department recommends to transfer the program to price-based DR [29]. There are several tariff and program selection within these two classes. The most commonly implemented ones are described below [31].

2.2.2.1 Incentive-Based Demand Response Programs

The IBP are divided in two classes, classical and market-based programs. The classical programs include direct control and interruptible/curtailable programs and the market-based programs include demand bidding, emergency DR programs, capacity market and ancillary services market. In the classical programs end-users are rewarded for participating in DR by a bill credit or discount rates. In market-based programs end-users are rewarded with money depending on the amount of load reduction during DR events [31].

Direct Control: This program is mainly offered to residential or small business customers. The operator has the opportunity to shut down electrical devices such as space heating/cooling or water heating of customers on a short period of time.

Interruptible/Curtailable Programs: This program is usually offered to large industry or commercial customers. In the case of system contingencies, customers in this program are asked to reduced demand to a predefined value and receive payment for this. If customers do not respond as contracted, they can face penalty charges or removal from the program.

Demand Bidding: This program is also most suitable for larger customers like industry or commercial customers. Participants can bid in the wholesale market for load reduction at a price they are willing to reduce load for. If the bid goes through they must reduce load or face penalty charges. There are also cases where the operator is offering a utility-set price and the customer is defining how much load can be reduced for this price (Buyback program).

Emergency Demand Response: In case of a reliability-triggered event, customers are offered incentive-based payments, for measured load reduction by the operator. If the customers are not reducing load they may or may not face penalty charges [29].

Capacity Market: Customers in this program have agreed to a predefined load reduction in case of system contingencies. They are usually notified on a day- ahead basis and face penalties if they not respond. They get upfront reservation payments, based on capacity market price and optionally a further payment in case of the actual contingency event based on the load reduction [29].

Ancillary Services Market: In this program customers have the opportunity to bid as operating reserve in the transmission operator (balancing) market. If the bid goes through they are paid the market price to be on stand-by. In the case of a DR event the system operator calls the customer to reduce load [29].

2.2.2.2 Price-based Demand Response Programs

Price-Based Demand Response Programs: The PBP has dynamic pricing rates in which electricity prices are not flat. The tariffs follow the fluctuations of real-time costs of electricity. The major idea is to flatten the demand curve by offering high prices at peak demand times and low prices at off-peak times [31].

Time of Use (TOU): TOU tariffs are unit prices divided into different blocks during a 24h day. These blocks are usually Off-peak, peak and shoulder (which is prior to and after the peak). Each block has its own price, which is the average of production and distribution costs at this time. These prices are typically pre- determined for several months and vary during the seasons. FIGURE 3 shows a 24h schedule of a TOU tariff with OFF-peak, peak and shoulder blocks.

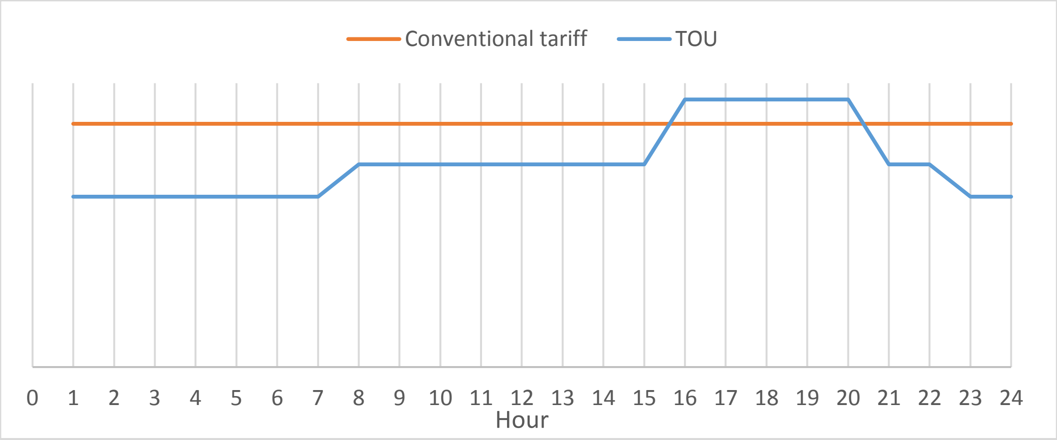

FIGURE 3 - 24 hour schedule for a TOU tariff with different priced blocks [32]

Critical Peak Pricing (CPP): CPP is a rate which is only used during contingencies or high wholesale prices a few days or hours a year [32]. This tariff is usually superimposed on another tariff (e.g. TOU or flat) and customers are informed on a day-ahead basis, (See, FIGURE 4).

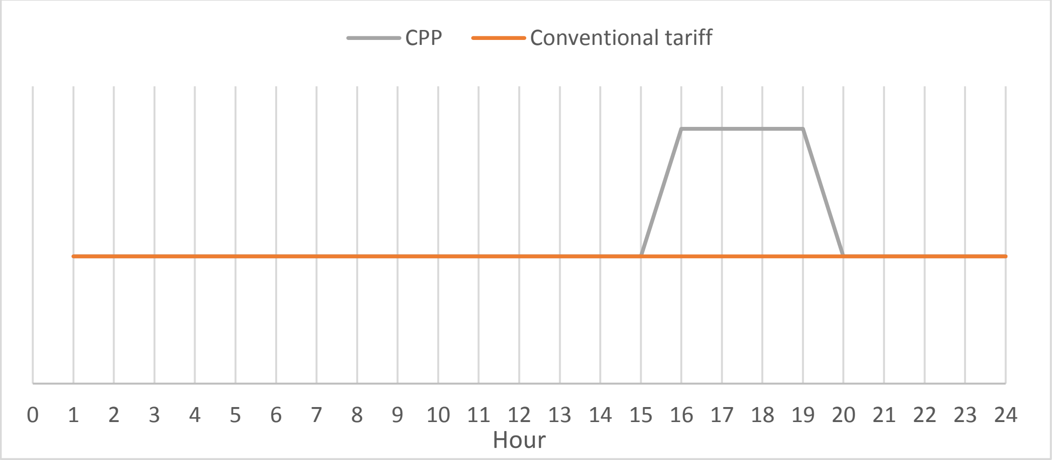

FIGURE 4 - Critical peak pricing tariff, covered by a flat-tariff [32]

Real Time Pricing (RTP): RTP is a tariff with hourly changing prices reflecting real costs of the wholesale market. see FIGURE 5. Customers are informed about the prices on a day-ahead or hour-ahead basis. This is the most direct and transparent tariff and suitable for competitive electricity markets [11].

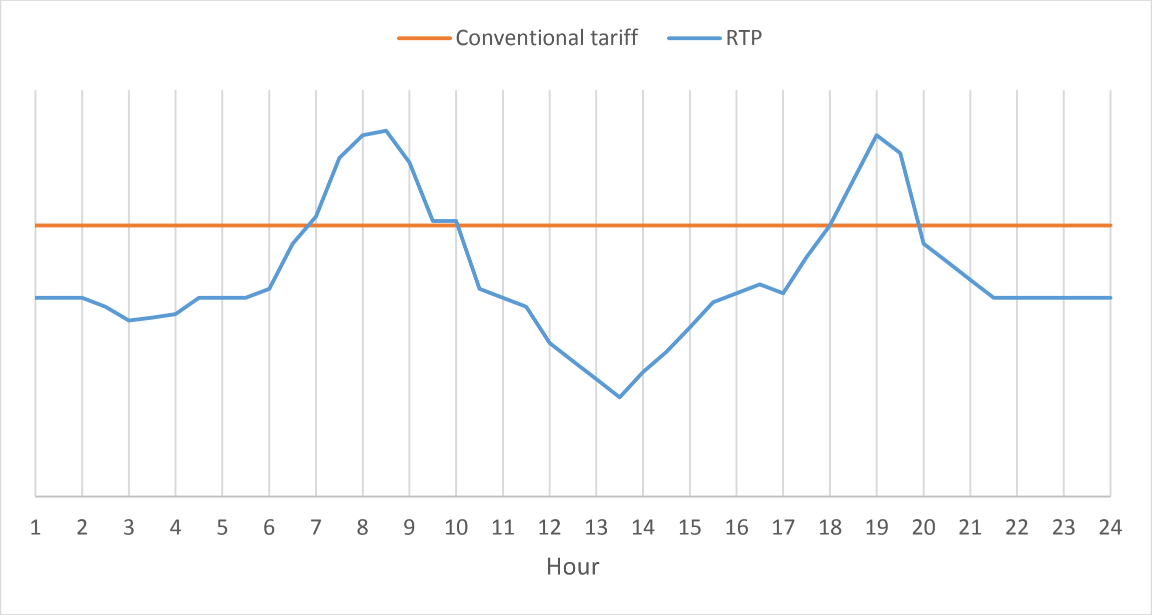

FIGURE 5 - Representation of a real time pricing tariff [32]

2.3 ELECTRIC VEHICLE (EV)

According to the National Renewable Energy Laboratory (NREL) [33], a plug-in hybrid-electric vehicle (PHEV) is a vehicle with the ability to recharge its electrochemical energy storage with electricity from an off-board source. FIGURE 6 [34] shows the pictures of battery electric vehicle (BEV, i.e. EV), HEV and PHEV.

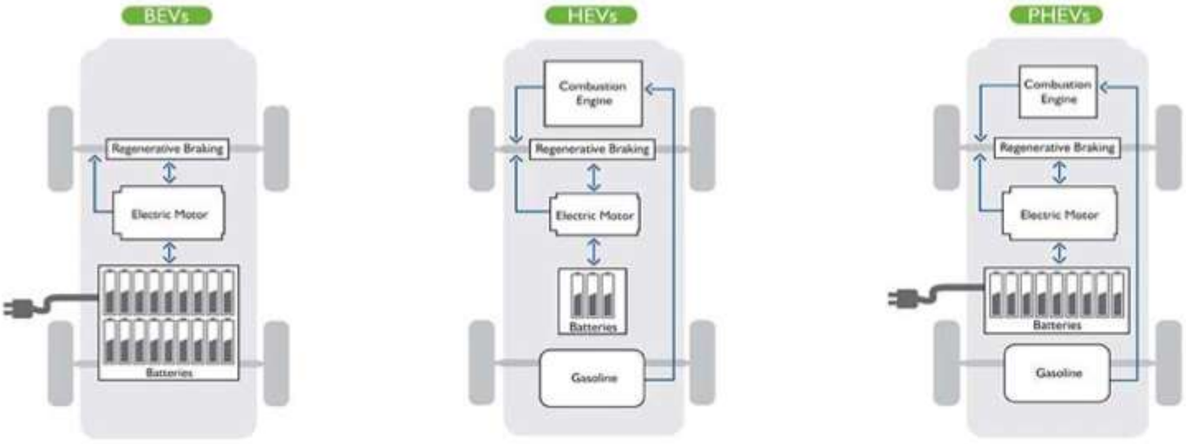

FIGURE 6 - Schematic architecture for a BEVs, HEV and PHEV [35]

FIGURE 7, illustrate two schematic for a typical EV architecture: series and parallel. Series drive train architecture powers the vehicle only by an electric motor using electricity from a battery. The battery is charged from an electrical outlet, or by the gasoline engine via a generator. A parallel drive train adds a direct connection between the engine and the wheels, adding the potential to power the vehicle by electricity and gasoline simultaneously and by gasoline only.

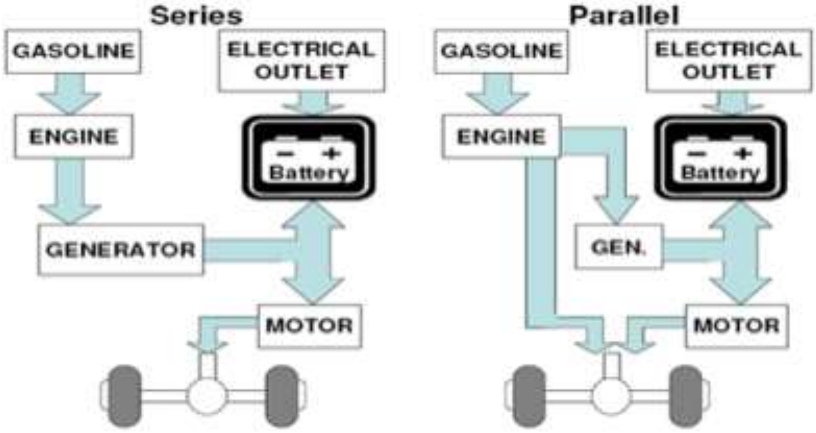

FIGURE 7 - Basic PHEV drive train series (EV) vs Parallel design [35]

2.3.1 Current EV Technology

The electric network as a power source for vehicles offers many advantages over traditional fossil fuel-powered vehicles. However, it has two main disadvantages that call into question its applicability for use in personal automotive transportation. In [36] is done the classification of these disadvantages as storage and recharging. *“Storing it [electricity] is more bulky and expensive (Batteries versus a sheet metal gas tank) and refueling is slow”.* These difficulties suggest that EVs, when related to gasoline vehicles, will initially experience from higher costs, reduced range and refueling challenges when commuting/traveling significant distances [36].

Present electric vehicle technology is completely dependent on internal battery storage systems; when used in EV applications, batteries are generally the heaviest component of the powertrain, accounting for over one third of a vehicles weight in some cases [36]. Battery recharging for electric vehicles is also now restricted mostly to households, as few charging stations exist along roads and highways, different those available for fossil fuel-powered vehicles. Battery technology is continuously improving, however, and will likely decrease in weight and size, with simultaneous increases to capacity and recharge speed with new research and development [37].

2.3.2 Vehicle to Grid (V2G) System

Besides of the normal charging process, Vehicle-to-grid (V2G) technology is one of various potential energy storage technologies that can be modified to support flexible energy systems through the enhanced use of renewable energy sources (e.g. wind and solar) [38]. V2G technology, via a real-time signal, combines the automobile (specifically the vehicles battery) with existing grid utility systems [39], providing EVs the capacity to transport power from the vehicles Energy Storage System to the grid, coordinated in part by the needs of the electric system [38]. This two-way communication system enables functions to better management of the electricity resources and control peak energy demand requirements placed on the grid [39]. V2G systems could also offer financial welfares to holders, thus reducing the overall costs of acquiring an electric vehicle. Vehicle to Grid systems allow vehicle holders to generate revenue from selling power back to the grid [39]. As identified by [40] “The batteries in these vehicles can store cheaper valley value power and deliver it back to the grid during daytime hours when demand for electricity and prices are highest”.

The plug-in hybrid electric vehicles (PHEV) and battery electric vehicles (BEV) are the two major types of electric vehicles. Several models of these electric vehicles are now commercially available in the market. The PHEVs are equipped with a combination of battery storage system chargeable from the grid and conventional internal combustion engine (ICE) [41]. A battery electric vehicle (BEV) is a type of electric vehicle (EV) that uses chemical energy stored in rechargeable battery packs. BEVs use electric motors and motor controllers instead of internal combustion engines (ICEs) for propulsion. Some of the models available in the actual market for PHEV & BEV appear in APPENDIX A with their characteristics.

The market for purely electric vehicles is in its infancy. The Nissan Leaf was the first to become available in the U.S., with Ford, Toyota, and Honda rolling out models in 2011 and 2012. The Nissan Leaf sold 8,720 in its first 11 months [42]. Nissan expects to sell over 10,000 of the Leaf within the first year of rollout [42]. The Tesla Model S, a luxury BEV, received considerable attention including Motor Trend’s “Car of the Year" award in 2012. In the long term, pike research projects that BEVs will account for 0.8% of U.S. car sales by 2017 [43].

The market for PEVs and HEVs is more developed, nevertheless, still has to reach a rapid deployment. Hybrids have been retrofitted for plug-in capability since they were introduced in the early 2000s. The Chevy Volt was the first HEV on the market, but it was soon followed by Toyota and Ford models in 2011 and 2012 [44]. Through August 2012, 13,479 Volts were sold [45]. The Volt topped Consumer Reports' Owner Satisfaction Survey for both 2011 and 2012, with 92 percent of owners saying they would make the same purchase again [46]. Although PEVs and HEVs do not have the same mileage range limitations that battery electric vehicles do, they tend to be more expensive than battery electric vehicles and gas cars because they must incorporate both gas and electric power systems. Pike Research projects estimates that by 2017 plug-in hybrids will comprise 1.2% of U.S. car sales [47].

Since BEVs, PEVs, and HEVs are still relatively news, it difficult to accurately project how fast these markets will expand. The performance of the traditional hybrid market can give some insight into how these emerging markets will mature. While these markets will face different challenges than traditional hybrids (notably adequate charging infrastructure), many of the same market and consumer demands will play a role in how fast these younger markets develop.

Several insistent targets have been set worldwide by many nations for the widespread use and acceptance of the plug-in hybrids and battery electric vehicles. FIGURE 8 [41] portrays the international sales targets set by various countries for electric vehicles by 2020. Most of these announcements were made in the last year, which establishes the importance given to electric vehicle deployment in the international level. If these targets were achieved, 4 million electric vehicles would be sold by 2020.

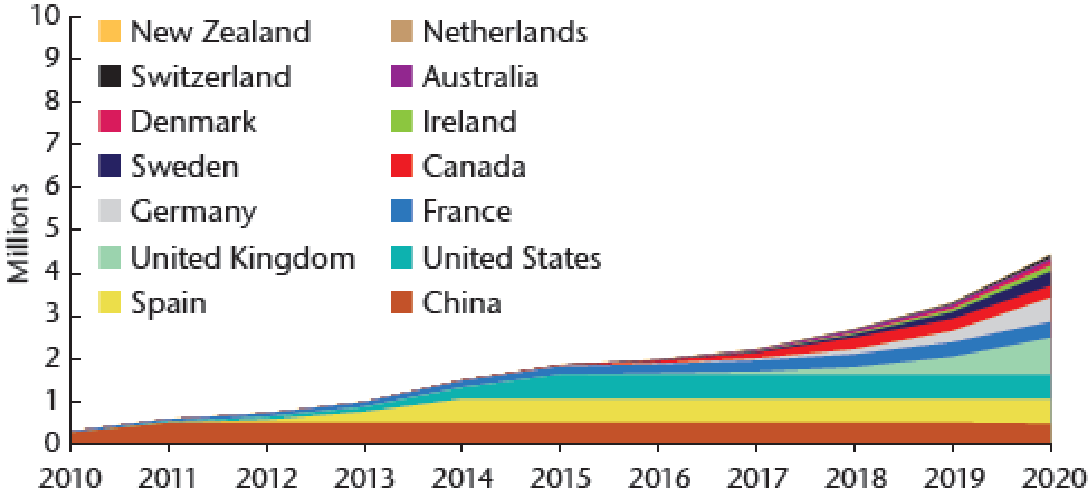

FIGURE 8 - International electric vehicle sales targets, 2010-20 [41].

By September 2014, cumulative global sales of plug-in electric passenger cars and utility vans was over 604,000 units, consisting of 356,232 all-electric cars and utility vans, and 247,700 plug-in hybrids [48]. The global stock of PEVs grew from 100,000 units on the road in 2011, to more than 180,000 units in 2012, to 405,000 at the beginning of 2014. During 2012, sales of pure electric cars were led by Japan with a 28% market share of global sales, followed by the United States with a 26% share, China with 16%, France with 11%, and Norway with 7%. Plug-in hybrid sales in 2012 were led by the United States with a 70% share of global sales, followed by Japan with a 12%, and the Netherlands with 8% [41].

In terms of global sales of LDV electric vehicles (Light Duty Vehicle) estimated by the International Energy Agency roadmap for the period 2010-2050 appear in FIGURE 9 [41]. The sale targets set for electric vehicles by 2050 are expected to meet a share of 50% of the total cars available worldwide.

But, for a full-scale adoption of electric vehicles, there are several challenges to be attended. The major issues like vehicle range; battery energy density and battery life are projected to progress further in the coming years with modern technologies and technical breakthroughs. The current high purchase price of electric vehicles could be made reasonable to the end user by applying different government subsidies, rebates and incentive schemes. The batteries of electric vehicles are normally expected to plug-in and charge at home during the off- peak hours (night hours) and when the electricity prices are low. This corresponds to slow charging of batteries which may take 6-8 hours [49].

The charging infrastructure, battery charging or swapping stations and smart grids for coordinated charging have to be mobilized in joint with the targets of EVs set by the utilities and the respective governments. International standards play a key role in reducing research and development costs and place a strong foundation for innovation and rapid implementation and deployment of a product in the market. Some of the international standards which are relevant to EVs that deals with the important aspects like vehicular communications, EV charging/discharging, power transfer with grid and battery performance are the SAE standards (SAE J1772, SAE J2847 etc.) and IEC standards (IEC 61851, IEC 62196) [50].

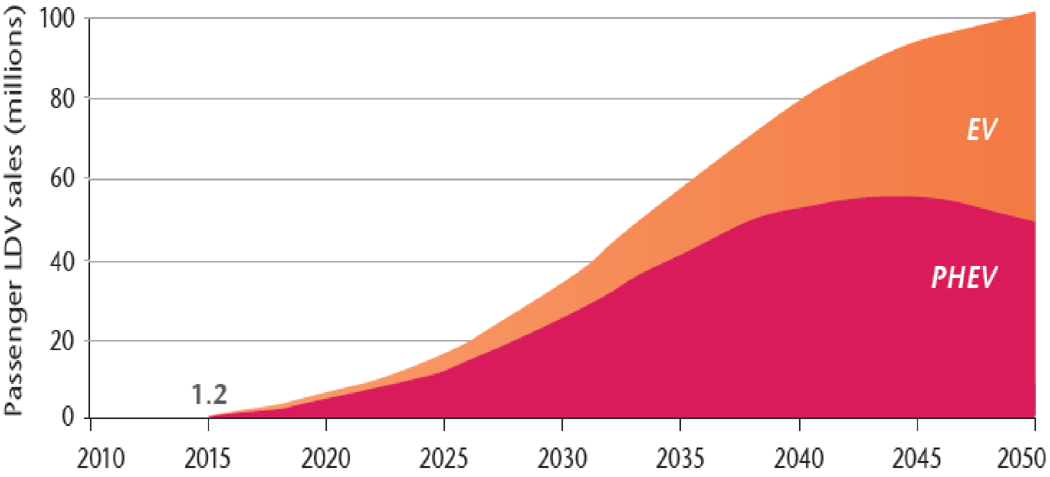

FIGURE 9 - International sales estimation of EV and PHEV, 2010-2015 [41].

2.4 SYSTEM OF SYSTEMS

The original notions of system, a word derived from Latin *systēma*, dates back to Plato and Aristotle. Its meaning and intent was connecting a composition of inter-related and inter-working parts or components. The principal characteristic of a system is its ability to emerge with new features starting from its initial configuration, a property that is manifested through the composition (purposeful or un-intended) and interworking of parts that cannot be readily traced or reduced to the parts in isolation. In the words of Aristotle in Metaphysica, “the whole is greater than the sum of its parts”, a notion often referred to as strong emergence. The components in a system give rise to a structure, relationship that in turn generates behavior and emergence. The general characteristics of systems were formalized in models and principles by biologist Ludwig Von Bertalanffy [51] during middle of 20th century.

The concept of “System of Systems (SoS)” is a more recent notion that is gaining prominence in science and technology largely due to its highly desirable properties and emergence. In a SoS, components are replaced by complex and largely autonomous systems that render emergence in a more collaborative and resilient manner [52].

These notions underpin our approach to understanding of complex natural phenomena such as global warming as well as empower us to engineer increasingly advanced products and services through systems engineering [53].

2.4.1 The Notion of a System

General systems are characterized by the philosophers Plato and Fredrich Hegel as integrated whole in which [54]:

The whole is more than the sum of the parts.
The whole defines the nature of the parts.
The parts cannot be understood by studying the whole
The parts are dynamically interrelated or interdependent.

In general terms, a system should ideally be characterized through recognition and characterization of its principal emergent properties in preference to the traditional focus on structure or intrinsic behavior. Surprisingly, many definitions of systems and their properties are devoid of systematic structure thus lacking a systems approach.

The concept of “System of Systems” (SoS), a federation of autonomous complex systems that in turn collaborate to generate an emergent property at macro level, has gained prominence in the last ten years [55].

In general, System of systems it’s a group of task-oriented or dedicated systems that collect their resources and capabilities together to generate a different and new, more complex system which offers more functionality and performance than simply the summation of the component systems.

Presently, System of Systems is a critical research discipline for which frames of reference, thought processes, quantitative analysis, tools, and design methods. The method for defining, abstracting, modeling, and analyzing system of systems problems is typically referred as system of systems engineering [56].

The SoS paradigm [57] offers many desirable properties chiefly enhanced functionality, resilience and adaptability that is being exploited and developed in many diverse fields from air traffic control to future combat systems. In the same vein as general systems above, the definition of SoS is best pursued as a class [58].

2.4.2 System of Systems Description

Emerging next generation smart environments such as Smart Grids, Smart Cities, and Smart Enterprises are complex systems that require a complete and holistic knowledge of their operations for effective decision-making. Multiple systems currently operate within these environments and real-time decision support will require a System of Systems (SoS) approach to provide a functional view of the entire environment to understand, optimize, and reinvent processes. The required system of systems will need to connect systems that cross organizational boundaries, that come from multiple domains, (i.e. finance, manufacturing, facilities, IT, water, traffic, waste, etc.) and operate at different levels (i.e. region, district, neighborhood, building, business function, individual) [59].

The differing SoS types present different interoperability requirements. On the one hand a Directed SoS with dedicated resources and central coordination can implement an Integrated or Unified approach to interoperability. On the other extreme a Virtual SoS has no central authority or resources and may require a Federated approach to interoperability, in such scenarios a constitute system may not even be aware they are involved in a SoS.

The existing system design mind-set views interoperability as an external responsibility, and outsources interoperability to external systems. Within SoS, interoperability needs to be a fundamental requirement to their design and operation. The key challenge is to simplify interoperability without increasing complexity, hierarchy, control, or acquisition cost. This will require a change in mind-set of system design to embrace interoperability concerns. An effective interoperability approach for SoS will minimize complexity and ensure constituent systems do not need to be re-engineered as other constituent systems are added, removed, modified, or replaced. To this end, a common interoperability infrastructure is needed to support flexible SoS information interoperability. However, improving the conceptual and technical interoperability of systems is an important step to support organizational interoperability.

A SoS is an expression often used to describe the internet, a defense communications network, a smart electrical grid, or other complex assembly of distributed, stand-alone parts operating as an integrated entity. [60] Have determined that systems of systems generally have three distinguishing traits: physically distributed systems, prime dependency of overall system functionality on the linkages between the distributed systems, and system heterogeneity. According to [61] modern systems of systems have five common characteristics: operational independence of the individual systems, managerial independence of the systems, geographical distribution, emergent behavior, and evolutionary development. From these descriptions it is possible to converge on a generalized conception of a SoS as comprising a collection of dispersed, independent, current and developing systems that function holistically through SoS defined interfaces and performance parameters to achieve a new level of performance and capability.

2.4.3 System of Systems Research Fields

Current research into effective approaches to system of systems problems includes:

- Establishment of an effective frame of reference
- Crafting of a unifying lexicon
- Developing effective methodologies to visualize and communicate complex systems
- Study of designing architecture
- Interoperability
- Formal modeling language with integrated tools platform
- Study of various modeling, simulation, and analysis techniques
- Network theory
- Agent-based modeling
- General system theory
- Probabilistic robust design (including uncertainty modeling/management)

- Object oriented simulation and programming
- Multi-objective optimization
- Study of various numerical and visual tools for capturing the interaction of system requirements, concepts, and technologies

2.4.4 Applications

Systems of systems, while still being investigated predominantly in the defense sector, is also seeing application in such fields as national air and auto transportation and space exploration. Other applications where it can be applied include health care, design of the Internet, software integration, and energy management.

Within system of systems significant technical challenges exist in terms of information interoperability that require overcoming conceptual (syntax and semantics) and technological barriers

3 METHODOLOGY

This section is emphasized on the different methodologies, optimization tools and mathematical techniques that were used in this dissertation. Starting from the load classification process that decides which of the householder loads will enter into the first optimization process inside the microgrid. Then, depending on the cases that are analyzed on this dissertation, the EV and the DG will be included or not.

On the first scenario, named as Scenario A, that will be described on chapter 4, the loads are treated without any kind of restriction; normal householder behavior is analyzed and used as a comparative base for others scenarios ‘B’ and ‘C’.

Right after load classification process for the elastic interruptible loads, these are filtered through a set of restrictions with the charging/discharging modeling for the EV. In addition, injection from the EV (discharging) and sources of GD (Solar, Eolic) are included according to the scenario studied. Then, matrices with equality and inequality constraints are formed, in order to start the iterative process into the optimization algorithm for the microgrid.

Finally a SoS architecture is used in order to solve the integrated framework, that in this case is made up with the distribution system and the microgrids with all of its components.

3.1 LOADS MODELING

In this dissertation, the scheduling or optimal allocation of residential loads aims to minimize the daily or monthly cost due the electricity tariff from the distribution concessionaire. In this problem the decision variables are just the equipment’s treated as elastic interruptible loads, scattered and represented along the 24 hours corresponding to the hours of the day in which the residential electrical appliances or devices are scheduled.

The scheduling of the electrical devices, reflecting the average consumption habits of residential users will be inserted on the study and entered as constraints of the problem, except for the scenario ‘A’, Base case, that is used as the main comparison pattern for the scenarios proposed. The following formulation is intended to be as general as possible in order to facilitate the future introduction of variables to optimize with this method. A full list with all the elastic and inelastic loads is detailed in APPENDIX D.

For the calculation of the net consumption is considered that the residence has its own micro generation (solar or wind), it is assumed that these plants have a zero operating/fuel costs. It should be noted that this dissertation is not considering the investment cost of these micro generation units, and studies of economic feasibility. This work considers a future scenario for the popularization of micro generation (which in Brazil still depends on increased government incentives).

In addition to the micro generation, the use of electric vehicles as an energy source, restricted to peak periods, will also be considered in the model. This restriction will be imposed in order to minimize the number of charge and discharge cycles of the vehicle, which directly affect the battery life of the EV. So, besides the solar energy generation, the residence will also take in consideration the energy available in the electric vehicle battery bank.

Therefore, the net energy consumed from the DISCO, $Net_t^{Energy\_Consumed}$ is formulated as follow:

$$Net_t^{Energy\_Consumed} = Demand_t^{Total} - Gen_t^{Total} \qquad \forall\, t = 1 \dots 24 \qquad \text{Eq 1}$$

Where:

$Net_t^{Energy\_Consumed}$	:	Net energy consumption from DISCO at hour *t* (in Wh);
$Demand_t^{Total}$	:	Total demand of the house (including elastic and inelastic loads) at hour *t* (in Wh)
$Gen_t^{Energy\_Type}$	:	Power injection from any source (Solar, Wind) at hour *t* (in Wh)

The equations for this section starts with the definition for the total load consumption Eq 2, that is formed for the algebraic sum of inelastic and elastic interruptible loads. It should be noted that a total of 36 inelastic loads (See APPENDIX E) are analyzed for all the scenarios and only the elastic interruptible loads enter into the optimization process.

$$
\begin{aligned}
Demand_t^{Total} = {} & \sum_{k=1}^{N_{Ine\_Load}} P_{k,t}^{Ine\_Load} * Duration_k^{Ine_{Load}} * Cycles_k^{Ine_{Load}} \\
& + \sum_{k=1}^{N_{Elast\_Load}} P_{k,t}^{Elast\_Load} * X_{k,t}^{Elast\_Load} \\
& \forall\, t = 1 \dots 24
\end{aligned}
\qquad \text{Eq 2}
$$

Eq 3, represents the total generation that considers all the micro energy DG types (solar, wind, etc), for the system.

$$
Gen_t^{Total} = \sum_{k=1}^{N\_Energy\_Type} Gen_{t,k}^{Energy\_Type} \qquad \forall\, t = 1 \dots 24 \qquad \text{Eq 3}
$$

Where:

$P_{k,t}^{Ine\_Load}$: Power consumption of inelastic load *k* at hour *t* (in W);

$P_{k,t}^{Elast\_Load}$: Power consumption of elastic interruptible load *k* at hour *t* (in W);

$Duration_k^{Ine\_Load}$: Duration of the cycle of use for the inelastic load *k* (in hours);

$Duration_k^{Elast\_Load}$: Duration of the cycle of use for the elastic interruptible load *k* (in hours);

$Cycles_k^{Ine\_Load}$: Number of cycles for the inelastic load *k* ;

$Cycles_k^{Elast\_Load}$: Number of cycles for the elastic interruptible load *k*;

$X_{k,t}^{Elast\_Load}$: Elastic load status for elastic interruptible load *k* at hour *t* that presents the following behavior $\begin{cases} 0 \text{ if is not operating} \\ 1 \text{ if it is operating} \end{cases}$;

N_{Ine_Load} : Number of inelastic loads;

N_{Elast_Load} : Number of elastic interruptible loads.

N_Energy_Type : Number of micro generators units in the house.

3.2 ELECTRIC VEHICLE MODELING

To explore the impacts of EVs penetration into the microgrids on the distribution network system, it is important to get a thorough understanding of the EV individual charging pattern. Several characteristics were presented in **Erro! Fonte de referência ão encontrada.**. This section describes the EV modeling method applied to the injection and charging procedure. In order to reach this objective the following parameters are essential: The charging/discharging power rate, the battery total capacity as shown FIGURE 10.

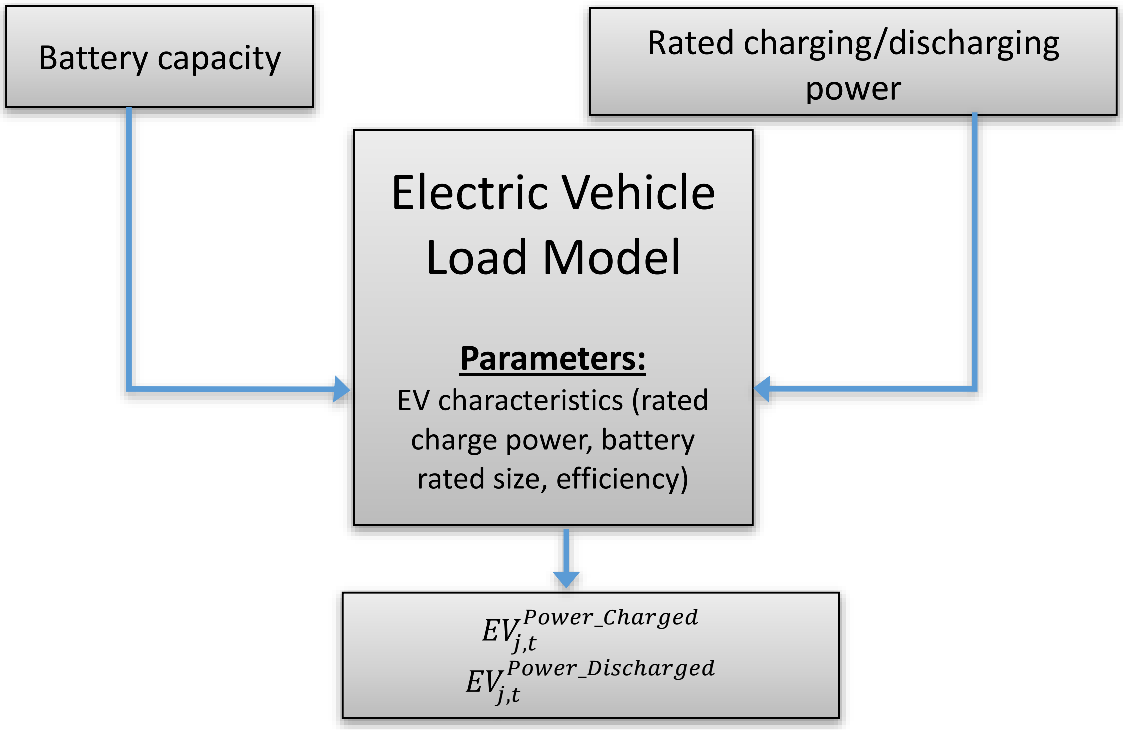

FIGURE 10 - Block diagram for the electric vehicle model

The battery energy balance for each vehicle is now considered in Eq 4 as formulated in [51]. The state of charge variable $EV_{j,t}^{Energy\_Stored}$ represents the stored energy in the EV j at time t.

$$EV_{j,t}^{Energy\_Stored} = EV_{j,(t-1)}^{Energy\_Stored} + \eta_{j}^{EV\_Charging} \times EV_{j,t}^{Power\_Charged} - EV_{j,t}^{Energy\_Trip} - \left[\frac{1}{\eta_{j}^{EV\_Discharging}}\right] \times EV_{j,t}^{Power\_Discharged} \qquad \text{Eq 4}$$

$$\forall t \in \{1, \dots, T\}; \quad \forall j \in \{1, \dots, N_{EV}\}$$

Where

$EV_{j,t}^{Energy\_Stored}$: State of charge, Stored energy in the battery of vehicle *j*, at hour *t* (Wh)

$EV_{j,(t-1)}^{Energy\_Stored}$: State of charge, Stored energy in the battery of vehicle *j*, at hour (*t*-1) (Wh).

$EV_{j,t}^{Power\_Charged}$: Power charged of vehicle *j* at hour *t* (Wh);

$EV_{j,t}^{Power\_Discharged}$: Power discharged of vehicle *j* at hour *t* (Wh);

$EV_{j,t}^{Energy\_trip}$: Energy consumption of vehicle *j* for traveling at hour *t* (Wh);

$\eta_{j}^{EV\_Charging}$: Charging efficiency of electric vehicle *j*;

$\eta_{j}^{EV\_Discharging}$: Injecting or Discharging efficiency of electric vehicle *j*.

N_{EV} : Number of electric vehicles;

The discharge and charge limits $EV_{j,t}^{Power\_Discharged}$ and $EV_{j,t}^{Power\_Charged}$ for each EV considering the battery discharge rate are given in Eq. 5 and Eq. 6.

$$EV_{j,t}^{Power\_Discharged} \leq EV_{j,t}^{Max\_Power\_Discharged} \times Y_{j,t}^{EV} \qquad \text{Eq 5}$$

$$\forall t \in \{1, \dots, T\}; \quad \forall j \in \{1, \dots, N_{EV}\}$$

$$EV_{j,t}^{Power\_Charged} \leq EV_{j,t}^{Max\_Power\_Charged} \times X_{j,t}^{EV} \qquad \text{Eq 6}$$

$$\forall t \in \{1, \dots, T\}; \quad \forall j \in \{1, \dots, N_{EV}\}$$

Where:

$EV_{j,t}^{Max\_Power\_Charged}$	: Rated hourly max power charged for vehicle *j*, at hour *t* (W);
$EV_{j,t}^{Max\_Power\_Discharged}$	: Rated hourly max power injected or discharged for vehicle *j*, at hour *t* (W);
$X_{j,t}^{EV}$	: EV charging status, Binary variable that takes the following values $\begin{cases} 0 \text{ if EV is not being charged} \\ 1 \text{ if EV is being charged} \end{cases}$;
$Y_{j,t}^{EV}$	: EV Discharging or injection status, Binary variable that takes the following values $\begin{cases} 0 \text{ if EV is not discharging} \\ 1 \text{ if EV is discharging} \end{cases}$

Eq 7 appears to restrict the charging or discharging of the EV, both processes can not be executed at the same time.

$$X_{j,t}^{EV} + Y_{j,t}^{EV} \leq 1$$
$$\forall\, t \in \{1, \dots, T\};\ \forall\, j \in \{1, \dots, N_{EV}\};\quad X, Y \in \{0,1\}$$

Eq 7

Reduction of battery life due to the reaching of a maximum limit β_j^{max} and a minimum limit β_j^{min} of charging are restricted by Eq 8 and Eq 9, to prevent loss of the battery characteristics. These limits are defined on the battery capacity limit for each EV as in Eq 10 and Eq 11. The EV battery discharge and charge limits consideres respectively, the battery state of charge and the battery capacity and the previous period of stored energy are given by Eq 12 and Eq 13.

$$EV_{j,t}^{Energy\_Stored} \leq \beta_j^{max} \qquad \forall t \in \{1, \dots, T\}; \quad \forall j \in \{1, \dots, N_{EV}\}$$

Eq 8

$$EV_{j,t}^{Energy\_Stored} \geq \beta_j^{min} \qquad \forall t \in \{1, \dots, T\}; \quad \forall j \in \{1, \dots, N_{EV}\}$$

Eq 9

$$\beta_j^{max} = \psi_j^{max} \times EV_j^{Battery\_Capacity} \qquad \forall j \in \{1, \dots, N_{EV}\}$$

Eq 10

$$\beta_j^{min} = \psi_j^{min} \times EV_j^{Battery\_Capacity} \qquad \forall j \in \{1, \dots, N_{EV}\}$$

Eq 11

$$\left[\frac{1}{\eta_j^{EV\_Discharging}}\right] \times EV_{j,t}^{Power\_Discharged} \leq EV_{j,(t-1)}^{Energy\_Stored} \qquad \text{Eq 12}$$

$$\forall t \in \{1, \dots, T\}; \quad \forall j \in \{1, \dots, N_{EV}\}$$

$$\eta_j^{EV\_Charging} \times EV_{j,t}^{Power\_Charged} \leq \beta_j^{max} - EV_{j,(t-1)}^{Energy\_Stored} \qquad \text{Eq 13}$$

$$\forall t \in \{1, \dots, T\}; \quad \forall j \in \{1, \dots, N_{EV}\}$$

Where:

β_j^{max} : Energy battery maximum limit of EV j (Wh);

β_j^{min} : Energy battery minimum limit of EV j (Wh).

ψ_j^{max} : Maximum percentage limit of battery capacity for EV j;

ψ_j^{min} : Minimum percentage limit of battery capacity for EV j.

3.3 INTEGRATED LOAD AND EV FORMULATION

One of the main contributions of this dissertation is the modeling of the loads using Unit Commitment theories where the minimum operational time or minimum uptime for every load must be satisfied for an optimal operation.

This part of the model is formulated as a deterministic optimization problem where estimated revenue is maximized using the 0/1 mixed integer linear programming. The effectiveness of the proposed model in optimizing load scheduling is verified through the scenarios proposed and further analyzed with detailed discussion.

Eq14 to Eq 17 presents the self-scheduling load problem of determining the unit commitment status for the loads operation before submitting it in a day head pattern to the next step of the optimization process.

Eq14 shows the restriction hour by hour for the maximum amount of energy that can be consumed by the house that is being optimized. Eq 15 presents the restriction in order to reach the minimum operating time for the elastic loads, Eq 16 and Eq 17 are placed in order to respect the amount of cycles and the duration of every cycle for the charging and discharging process of the EV.

$$\sum_{k=1}^{N_{Elast\_Load}} P_{k,t}^{Elast\_Load} * X_{k,t}^{Elast\_Load} + \sum_{j=1}^{N_{EV}} \eta_j^{EV\_Charging} * EV_{j,t}^{Power\_Charged} * X_{j,t}^{EV} \leq Consumption_t^{Max\_Hourly} \quad \forall\, t = 1 \ldots 24 \qquad \text{Eq14}$$

$$\sum_{k=1}^{24} X_{k,t}^{Elast\_Load} \leq Duration_k^{Elast\_Load} * Cycles_k^{Elast\_Load} \quad \forall\, k = 1 \ldots N_{Elast\_Load} \qquad \text{Eq 15}$$

$$\sum_{t=1}^{24} X_{j,t}^{EV} \leq Duration_j^{EV\_Charging} * Cycles_j^{EV\_Charging} \quad \forall\, j = 1 \ldots N_{EV} \qquad \text{Eq 16}$$

$$\sum_{t=1}^{24} Y_{j,t}^{EV} \leq Duration_j^{EV\_Discharging} * Cycles_j^{EV\_Discharging}$$ Eq 17

$$\forall\, j = 1 \ldots N_{EV}$$

Where

$Consumption_t^{Max\_Hourly}$	: Maximum consumption at hour *t* in Wh.
$Duration_k^{Elast\_Load}$	: Duration of the of cycle of the elastic interruptible load *k* (hour);
$Cycles_k^{Elast\_Load}$	: Number of cycles for the elastic interruptible load *k* ;
$Duration_j^{EV\_Discharging}$	: Duration of the discharging cycle of the EV *j* (hour);
$Cycles_j^{EV\_Discharging}$	: Number of discharging cycles for the EV *j*.
$Duration_j^{EV\_Charging}$	: Duration of the charging cycle of the EV *j* (hour);
$Cycles_j^{EV\_Charging}$	: Number of charging cycles for the EV *j*;

From Eq 18 to Eq 20 auxiliary variables are declared to respect the minimum up time or minimum time of use for each load, at the same time restriction boundaries of the initial and final time of use are introduced.

$$X_{k,t}^{Elast\_Load} + X_{k,(t-1)}^{Elast\_Load} = Y_{k,t}^{Aux\_ON} - Z_{k,t}^{Aux\_OFF}$$

$$\forall\, t = 1 \ldots 24\ \forall\, k = 1 \ldots N_{Elast\_Load}$$ Eq 18

$$Y_{k,t}^{Aux\_ON} - Z_{k,t}^{Aux\_OFF} \leq 1$$

$$\forall\, t = 1 \ldots 24\ \forall\, k = 1 \ldots N_{Elast\_Load}$$ Eq 19

$$Y_{k,t}^{Aux\_ON} + \sum_{l=1}^{MUT-1} Z_{k,(t+l)}^{Aux\_OFF} \leq 1$$

$$\forall\, t = 1 \ldots 24\ \forall\, k = 1 \ldots N_{Elast\_Load}\ \forall\, l = 1 \ldots MUT - 1$$ Eq 20

Where

$Y_{k,t}^{Aux\_ON}$: Binary variable for device *k* (Elastic interruptible load),

$$\begin{cases} 1 \text{ if the device is ON at hour t} \\ 0 \text{ if the device is OFF at hour t'} \end{cases}.$$

$Z_{k,t}^{Aux\_OFF}$	: Binary variable for device *k* (Elastic interruptible load), $\begin{cases} 1 \text{ if the device is OFF at hour t.} \\ 0 \text{ if the device is ON at hour t'} \end{cases}$
$X_{k,(t-1)}^{Elast\_Load}$	: Elastic load status for elastic interruptible load *k* at hour *t*, Binary variable that takes, 0 if is not operating or 1 if it is;
MUT	:Minimum up time for every elastic load;
l	: Auxiliary index.

3.4 DISTRIBUTED GENERATION

Implementing DGs in the migrogrids has several benefits, but at the same time it faces many restrictions and limitations. DG units, being scalable, can be built to meet immediate needs and later be scaled upwards in capacity to meet future demand growth [62]. Scalability allows DG units to reduce their capital and operations costs and thus large capital is not tied up in investments or in their support infrastructure. However, on the other hand, installing DG in the microgrid can also increase the complexity of the system [63].

For this dissertation only two types of distributed generation were used, the solar and the injection process from the EV in the energy discharging period of the battery, resulted from the optimization process. On FIGURE 11 a not optimized EV injecting profile.

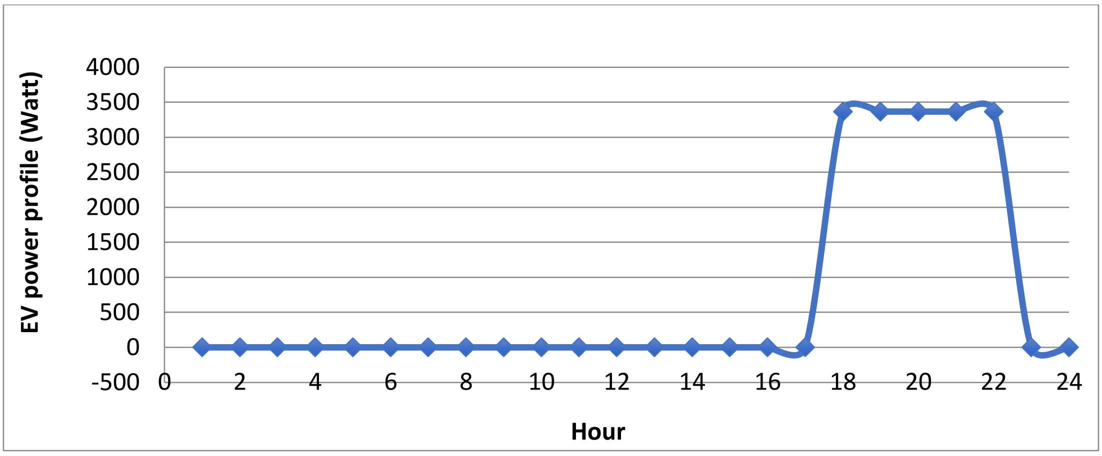

FIGURE 11 - General power profile for EV

In FIGURE 12 is exemplified a typical daily generation profile for a photovoltaic panel, that will be added on the scenario ‘C’. Also a part of the microgrid structure is shown in FIGURE 13 with different DG insertion levels.

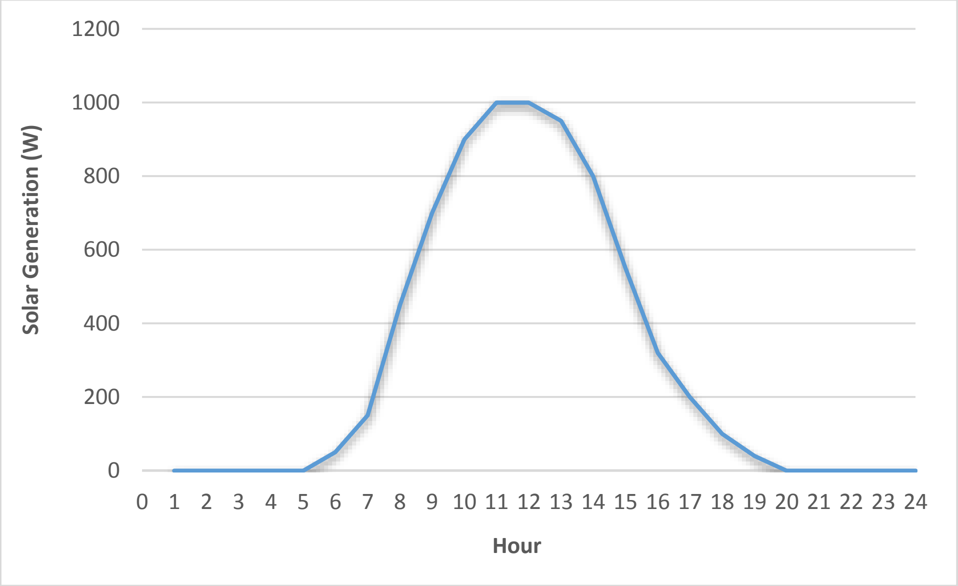

FIGURE 12 - Typical generation profile of a solar panel

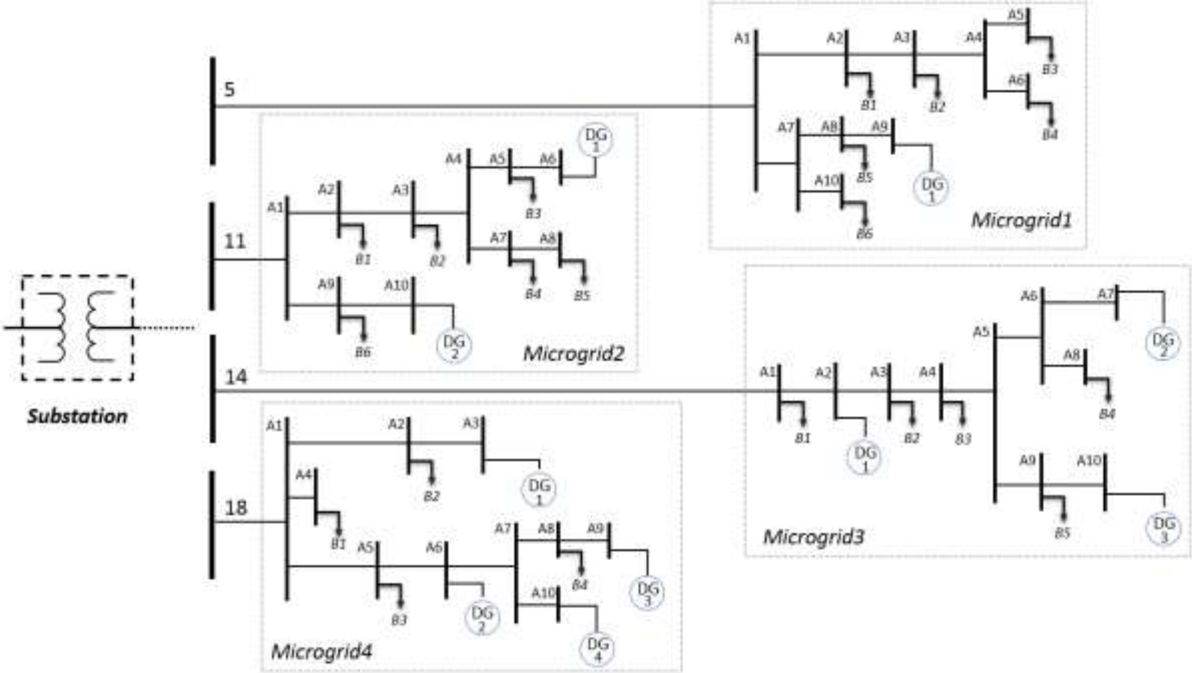

FIGURE 13 - DG example of the penetration levels in the microgrids

3.5 MIXED INTEGER LINEAR PROGRAMMING (MILP) PROBLEM FORMULATION FOR MICROGRIDS (MGS)

In this dissertation it is assumed that microgrids are represented by sets of residencies and each residency has a set of loads, EVs and DGs, as was formulated in the previous sections. Distribution power flow constraints are not considered between residencies of the same microgrid. The overall and integrated formulation of the microgrids problem is modeled as a Mixed Integer Linear Programming problem. A typical MILP formulation is explained in APPENDIX C, that was presented in [64]. Due to practical and didactical reasons, in the following formulation it is assumed that the microgrid is conformed only by one house. Then, the formulation to a MG formed by several residential houses is generalized.

Objective function:

$$\begin{aligned} &Minimize: \\ &Energy_t^{Buy\_Cost} * \left(\sum_{t=1}^{24} Demand_t^{Total} + \sum_{t=1}^{24} \sum_{j=1}^{N_{EV}} EV_{j,t}^{Power\_Charged} \right) \\ &\quad + Energy_t^{Sale\_Cost} \\ &\quad * \left(- \sum_{t=1}^{24} \sum_{j=1}^{N_{EV}} EV_{j,t}^{Power\_Discharged} - Gen_t^{Total} \right) \end{aligned} \qquad \text{Eq 21}$$

Subject to the following constraints:

$$\begin{aligned} Demand_t^{Total} &= \sum_{k=1}^{N_{Ine\_Load}} P_{k,t}^{Ine\_Load} * Duration_k^{Ine\_Load} * Cycles_k^{Ine\_Load} \\ &\quad + \sum_{k=1}^{N_{Elast\_Load}} P_{k,t}^{Elast\_Load} * X_{k,t}^{Elast\_Load} \\ &\qquad \forall\, t = 1 \dots 24 \end{aligned} \qquad \text{Eq 2}$$

Eq 4

$$
\begin{aligned}
EV_{j,t}^{Energy\_Stored} \\
&= EV_{j,(t-1)}^{Energy\_Stored} + \eta_j^{EV\_Charging} \times EV_{j,t}^{Power\_Charged} \\
&- EV_{j,t}^{Energy\_Trip} - \left[\frac{1}{\eta_j^{EV\_Discharging}}\right] \times EV_{j,t}^{Power\_Discharged}
\end{aligned}
$$

$$\forall t \in \{1,\dots,T\}; \quad \forall j \in \{1,\dots,N_{EV}\}$$

$$EV_{j,t}^{Power\_Discharged} \le EV_{j,t}^{Max\_Power\_Discharged} \times Y_{j,t}^{EV}$$

Eq 5

$$\forall t \in \{1,\dots,T\}; \quad \forall j \in \{1,\dots,N_{EV}\}$$

$$EV_{j,t}^{Power\_Charged} \le EV_{j,t}^{Max\_Power\_Charged} \times X_{j,t}^{EV}$$

Eq 6

$$\forall t \in \{1,\dots,T\}; \quad \forall j \in \{1,\dots,N_{EV}\}$$

$$X_{j,t}^{EV} + Y_{j,t}^{EV} \le 1$$

Eq 7

$$\forall\, t \in \{1,\dots,T\};\ \forall\, j \in \{1,\dots,N_v\}; \quad X,Y \in \{0,1\}$$

$$EV_{j,t}^{Energy\_Stored} \le \beta_j^{max} \qquad \forall t \in \{1,\dots,T\}; \quad \forall j \in \{1,\dots,N_{EV}\}$$

Eq 8

$$EV_{j,t}^{Energy\_Stored} \ge \beta_j^{min} \qquad \forall t \in \{1,\dots,T\}; \quad \forall j \in \{1,\dots,N_{EV}\}$$

Eq 9

$$\beta_j^{max} = \psi_j^{max} \times EV_j^{Battery\_Capacity} \qquad \forall j \in \{1,\dots,N_{EV}\}$$

Eq 10

$$\beta_j^{min} = \psi_j^{min} \times EV_j^{Battery\_Capacity} \qquad \forall j \in \{1,\dots,N_{EV}\}$$

Eq 11

$$\left[\frac{1}{\eta_j^{EV\_Discharging}}\right] \times EV_{j,t}^{Power\_Discharged} \le EV_{j,(t-1)}^{Energy\_Stored}$$

Eq 12

$$\forall t \in \{1,\dots,T\}; \quad \forall j \in \{1,\dots,N_{EV}\}$$

$$\eta_j^{EV\_Charging} \times EV_{j,t}^{Power\_Charged} \le \beta_j^{max} - EV_{j,(t-1)}^{Energy\_Stored}$$

Eq 13

$$\forall t \in \{1,\dots,T\}; \quad \forall j \in \{1,\dots,N_{EV}\}$$

$$
\begin{aligned}
\sum_{k=1}^{N_{Elast\_Load}} P_{k,t}^{Elast\_Load} * X_{k,t}^{Elast\_Load} + \sum_{j=1}^{N_{EV}} \eta_j^{EV\_Charging} * EV_{j,t}^{Power\_Charged} * X_{j,t}^{EV} \\
\le Consumption_t^{Max\_Hourly}
\end{aligned}
$$

Eq 14

$$\forall\, t = 1 \dots 24$$

$$\sum_{k=1}^{24} X_{k,t}^{Elast\_Load} \le Duration_k^{Elast\_Load} * Cycles_k^{Elast\_Load}$$

Eq 15

$$\forall\, k = 1 \dots N_{Elast\_Load}$$

$$\sum_{t=1}^{24} X_{j,t}^{EV} \leq Duration_j^{EV\_Charging} * Cycles_j^{EV\_Charging}$$

Eq 16

$$\forall\, j = 1 \ldots N_{EV}$$

Eq 17

$$\sum_{t=1}^{24} Y_{j,t}^{EV} \leq Duration_j^{EV\_Discharging} * Cycles_j^{EV\_Discharging}$$

$$\forall\, j = 1 \ldots N_{EV}$$

$$X_{k,t}^{Elast\_Load} + X_{k,(t-1)}^{Elast\_Load} = Y_{k,t}^{Aux\_ON} - Z_{k,t}^{Aux\_OFF}$$

Eq 18

$$\forall\, t = 1 \ldots 24\ \forall\, k = 1 \ldots N_{Elast\_Load}$$

$$Y_{k,t}^{Aux\_ON} - Z_{k,t}^{Aux\_OFF} \leq 1$$

Eq 19

$$\forall\, t = 1 \ldots 24\ \forall\, k = 1 \ldots N_{Elast\_Load}$$

Eq 20

$$Y_{k,t}^{Aux\_ON} + \sum_{l=1}^{MUT-1} Z_{k,(t+l)}^{Aux\_OFF} \leq 1$$

$$\forall\, t = 1 \ldots 24\ \forall\, k = 1 \ldots N_{Elast\_Load}\ \forall\, l = 1 \ldots MUT - 1$$

$\{X_{k,t}^{Elast\_Load}, Y_{k,t}^{Aux\_ON}, Z_{k,t}^{Aux\_OFF}, X_{j,t}^{EV}, Y_{j,t}^{EV}\}$ Binary variables

Where:

$Energy_t^{Buy\_Cost}$	Energy purchase price
$Energy_t^{Sale\_Cost}$	Energy selling price

3.6 Tested Distribution System

As clients keep increasing day by day, the distribution system has become more complex. Therefore, it is important to improve the reliability of the system. Reliable electric power system serves client loads without interruptions in power supply [65], and has the ability to deliver uninterrupted services to clients [66]. Electricity is produced and delivered to customers through three main subsystems; generation, transmission and distribution, as presented in FIGURE 14.

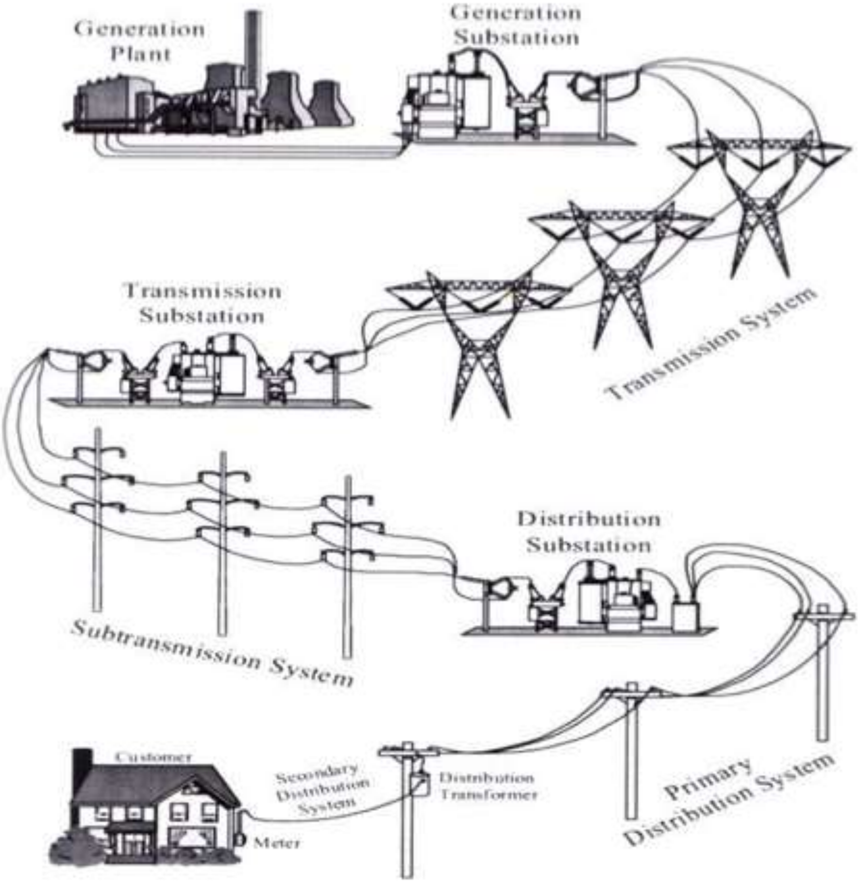

FIGURE 14 - Typical electric network system [65]

The generation subsystem is responsible for the electrical energy production. This can be generated by conversion of any energy sources available, kinetic, potential, mechanical, nuclear etc.… [67].

Normally, typical distribution system designs are divided into three different types: radial, loop and mesh systems. However, in practice, all these designs are normally combined or incorporated together [68]. Due to its flexibility and configurability a 33 buses radial system have been considered in this dissertation to demonstrate the efficiency of the proposed algorithm that is presented in the next chapter. FIGURE 15 presents the physical structure of the system, details and system data are available in [69].

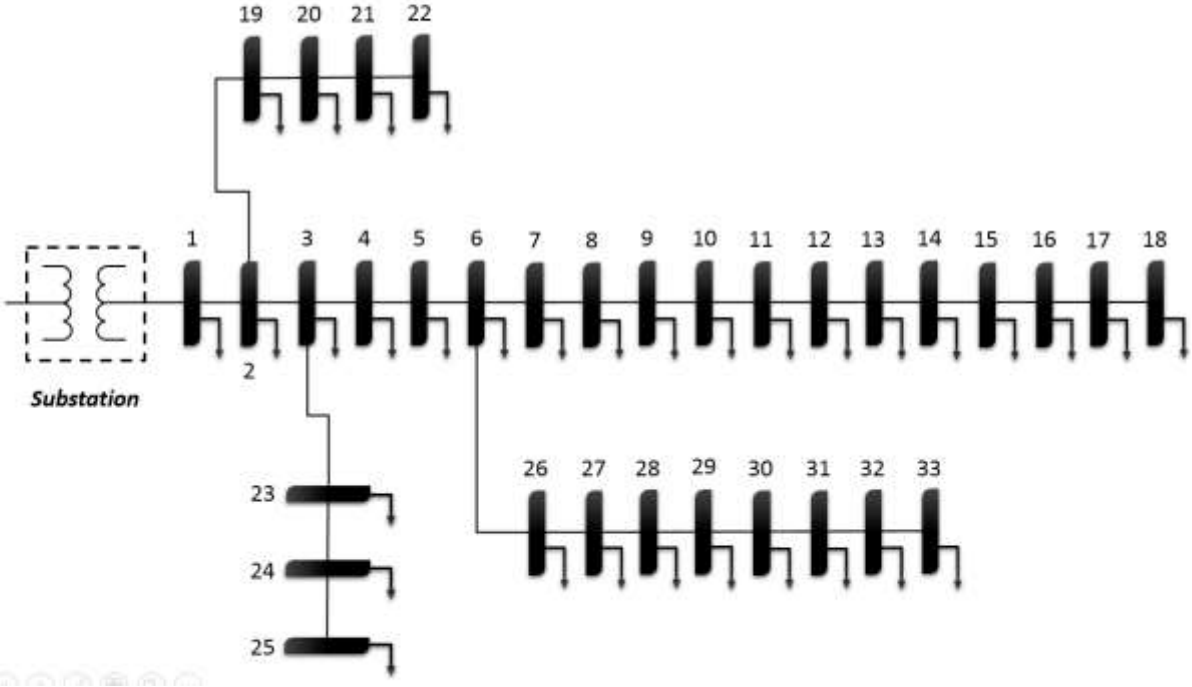

FIGURE 15 - 33 buses radial distribution system

3.7 OPTIMAL POWER FLOW PROBLEM FORMULATION FOR DISTRIBUTION NETWORK USING MATPOWER

For most of the optimal power flow problems a methodical answer is difficult to find. The most popular numerical methods for solving the optimal power flow problem are interior points and Newton’s (or Newton-Raphson’s) method. For the purposes of this dissertation the interior point used in Matpower [5], under a matlab environment, is used to solve the iterative optimal power flow over the radial network.

Matpower includes code to solve the optimal power flow problem. The standard version of each takes the form, from [70], that is included in APPENDIX E.

3.8 SYSTEM OF SYSTEMS BASED METHOD SOLUTION

In modernized power systems, the transmission and distribution grids are separately used by independent system operator (ISO) and distribution companies (DISCOs). As the working condition of one-grid impacts the decisions made by operators of other grids, the ISO and DISCOs should cooperate and collaborate with each other in order to run the entire power system in a safe and economic way, according to the concept of system of systems (SoS) engineering [71].

Then, is presented a system of systems (SoS) based framework for optimally operating active distribution grids. The proposed SoS framework presented in this dissertation defines both distribution company (DISCO) and microgrids (MGs) as autonomous systems, and recognizes the process of information interchange among them as showed in FIGURE 16. As the DISCO and MGs are physically connected, the operational condition of one might impact the operating point of other systems [72] as showed in FIGURE 17 and FIGURE 18.

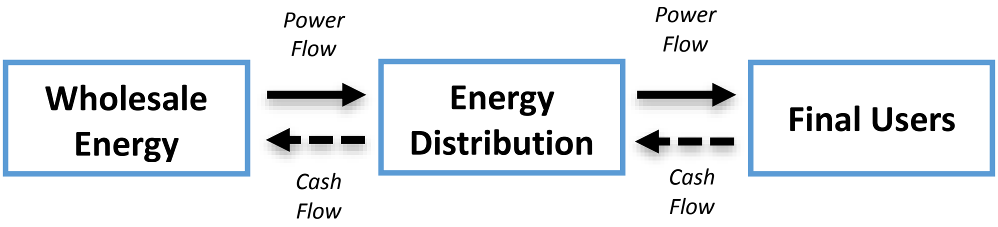

FIGURE 16 – Distribution system with passive MG integration adapted of [56]

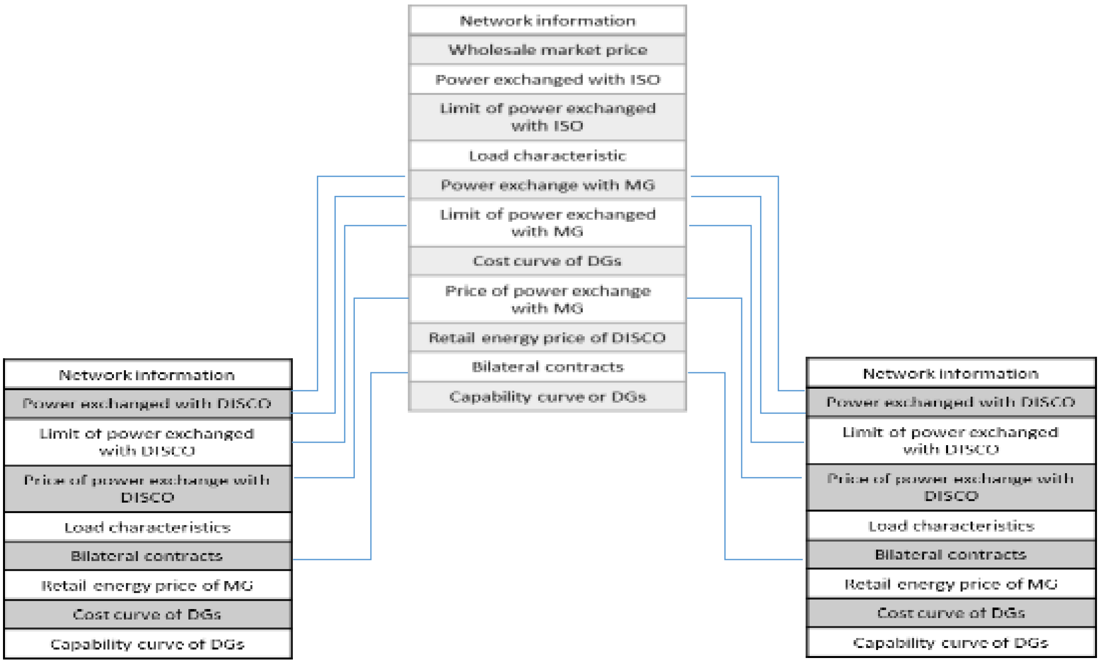

FIGURE 17 - Characteristics between the MGs and the distribution network [56].

The proposed mathematical algorithm uses a separated optimization process that aim maximizing the benefit of each independent system. A hierarchically algorithm, first running an optimal power flow (OPF) for the general operating system values for the distribution system using Matpower tool and then creating a loop that involves the MILP microgrids (MGS) problem. A hierarchical optimization algorithm is formulated to coordinate the independent systems and to find the optimal operating point of the SoS-based active distribution grid. The mathematical and graphical results show the efficiency of the proposed SoS framework and resolution method.

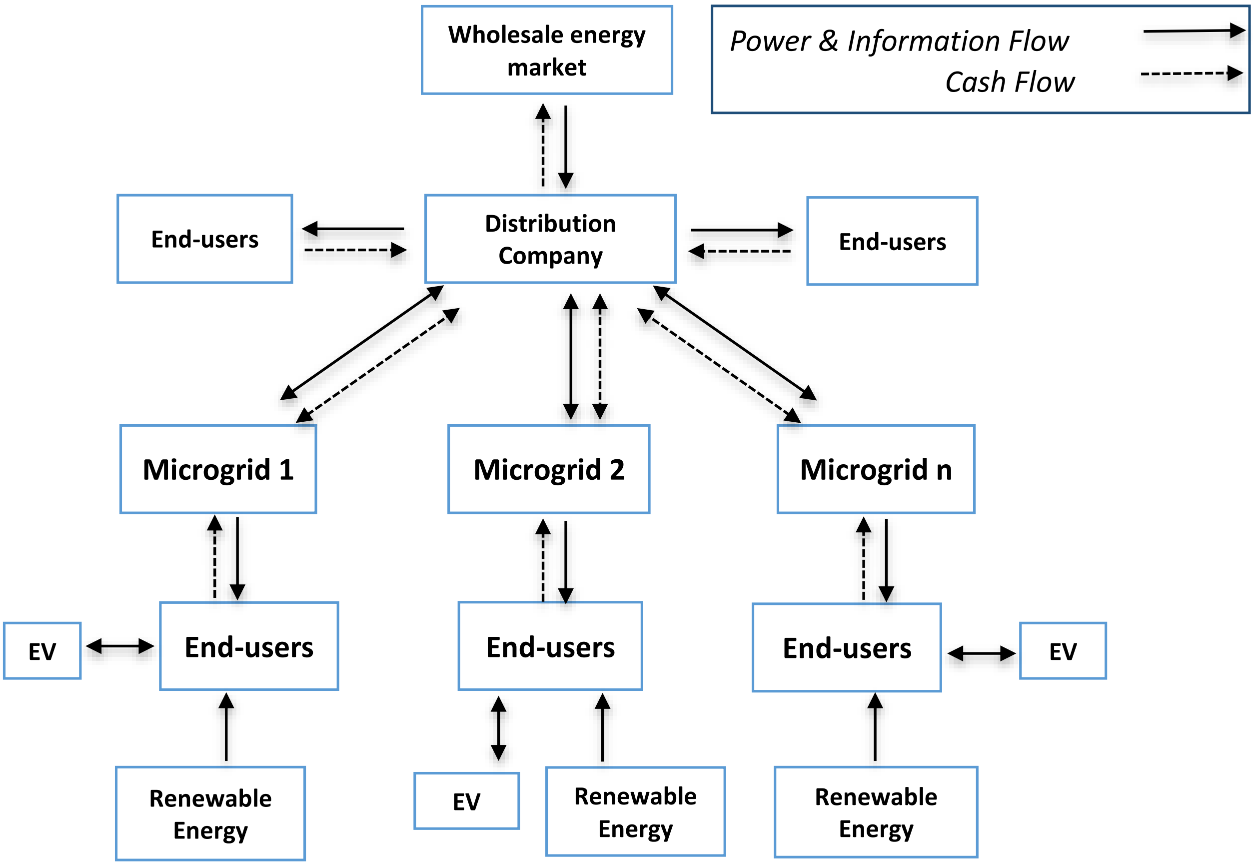

FIGURE 18 - Distribution system with active microgrid integration [56].

FIGURE 19 presents the flowchart that is used to solve the optimization problem stated in this work. Firstly are define the tolerance convergence values that controls the iterative optimization process for every part of the system, are also defined the active and reactive power hour by hour, the white tariff is then entered in the simulation accompanied with the objective function restriction values for the OPF and MILP. The iterative processes for the MGs and for the distribution system are then started, respecting the tolerance values. A pseudocode is also included in APPENDIX F.

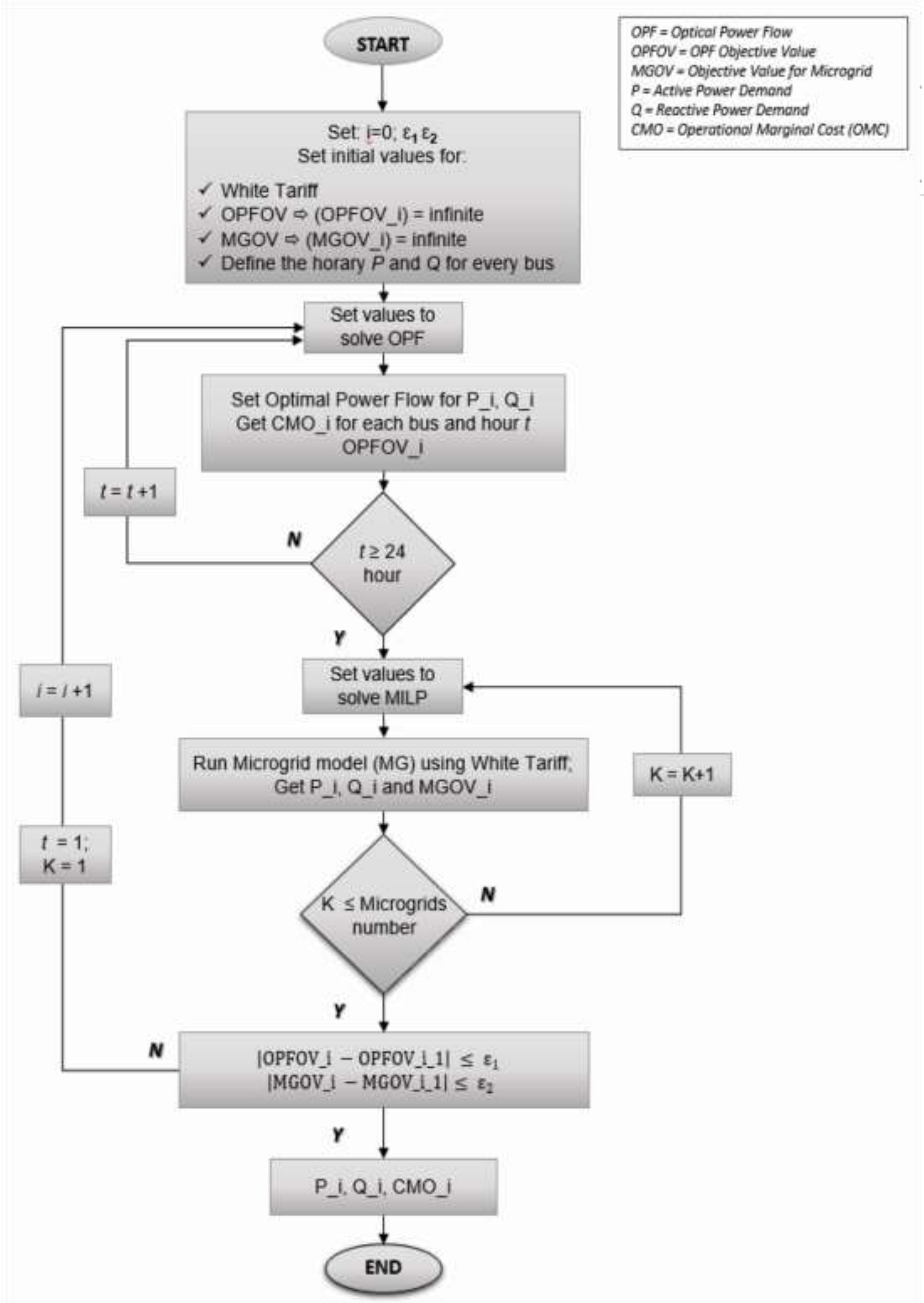

FIGURE 19 Proposed flowchart for the optimization problem solution.

4 EXPERIMENTAL RESULTS, DISCUSSION AND SIMULATIONS

The algorithms, models and optimization procedures tested in this dissertation were discussed and analyzed in the previous chapter. Also, the database, the preliminary basic configuration for every scenario, the parameters and the variables needed also were introduced. In this section will be examined in detail the variables needed in order to correctly implement and apply the system of system modeling for the entire network.

Is also analyzed the behavior of the OPF for the radial distribution system and the introduction of renewable energy, acting in the same scenario with the inclusion of the EV as a V2G. Active and reactive power consumption, consumption costs and generation are analyzed and explained. All the results will be discussed and related. The proposed method is implemented using MATLAB as main programmatic tool. The algorithms were performed and ran partly on an Intel(R) Core(TM) i3-2375M 1.50 GHz and also was used an 1.7 GHz Intel Core i7, OS X 10.9.5 (13F34). Beside, the MATPOWER (runopf) simulator is used to test the distribution systems to evaluate the results coming from the MILP program for the microgrid.

For the sake of simplicity, is used a white tariff with UM (Units of Money) values, without any numerical alteration in scale from the original white tariff in R$ (Brazilian Real) or (US Dollar) as presented in FIGURE 20.

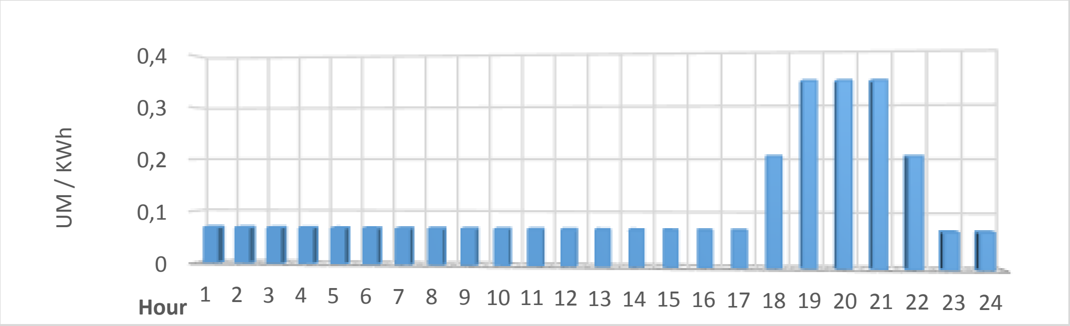

FIGURE 20 - White Tariff in UM/kWh

Based on the 33 buses radial distribution system, a classification is performed according to its physical positioning. All the buses are then classified into low consumers branch, medium consumer branch, high consumers and optimization branch. Four generators (See APPENDIX B) are distributed along the system as it’s seen in FIGURE 21. Low consumers are allocated from buses 19 to 22 (Secondary branch ‘A’), medium consumers from buses 26 to 33 (Secondary branch ‘C’), high consumer from buses 23 to 25 (Secondary branch ‘B’), finally in the main line from bus 1 to 18 (Primary branch) are placed the microgrids that are being part of the optimization process. The total behavior of this base configuration is discussed on the following tables.

The classification proposed for the branches will be kept along all the scenarios; this sorting was effectuated with the primary goal of showing in better detail the results of all the system. The complexity and the amount of data was not facilitating the displaying of the results. Three secondary branches and one primary are introduced and manipulated. The reference of each graphic appears on every table or graphic from now on.

On FIGURE 22 is presented the load profile for individual householders that will be introduced into every microgrid, in this graphics appear the consumption of the inelastic loads and the consumption of the elastic interruptible loads, also appear the amount of energy charged by the EV. FIGURE 23 shows its respective energy costs. In the meantime the energy costs are calculated based on the white tariff with UM/kWh values. Notice that a set of 50 houses is used and inserted in the buses that are being part of the optimization process, values from FIGURE 22 are multiplied by a factor of 50, simulating an equal behavior for all the users, in order to insert it into the respective buses.

4.1 CASE STUDIES

On this section the results of implementing the proposed system of system strategy at various user penetration levels is presented. Also, the introduction of the EV as a V2G or G2V is considered, for the 33 buses distribution system (See APPENDIX B). Different configurations are proposed to show the results of the method proposed. The “scenario A” that is the basic comparison pattern for the others scenarios, the “scenario B” that is considering the EV just as a load that is included in the optimization process, The “scenario C” will consider the insertion of a photovoltaic source also the EV in its both characteristics (Charging and Injecting energy).

Some results are presented in a 2D format and the others in 3D format that visibly, displays all the changes on the distribution network, according to the scenario that is under analysis.

4.1.1 Scenario A: "Base Case"

In this scenario the main idea is to show the basic configuration for the system studied. A 33 buses radial distribution system is analyzed and reconfigured in order to implement the algorithm proposed.

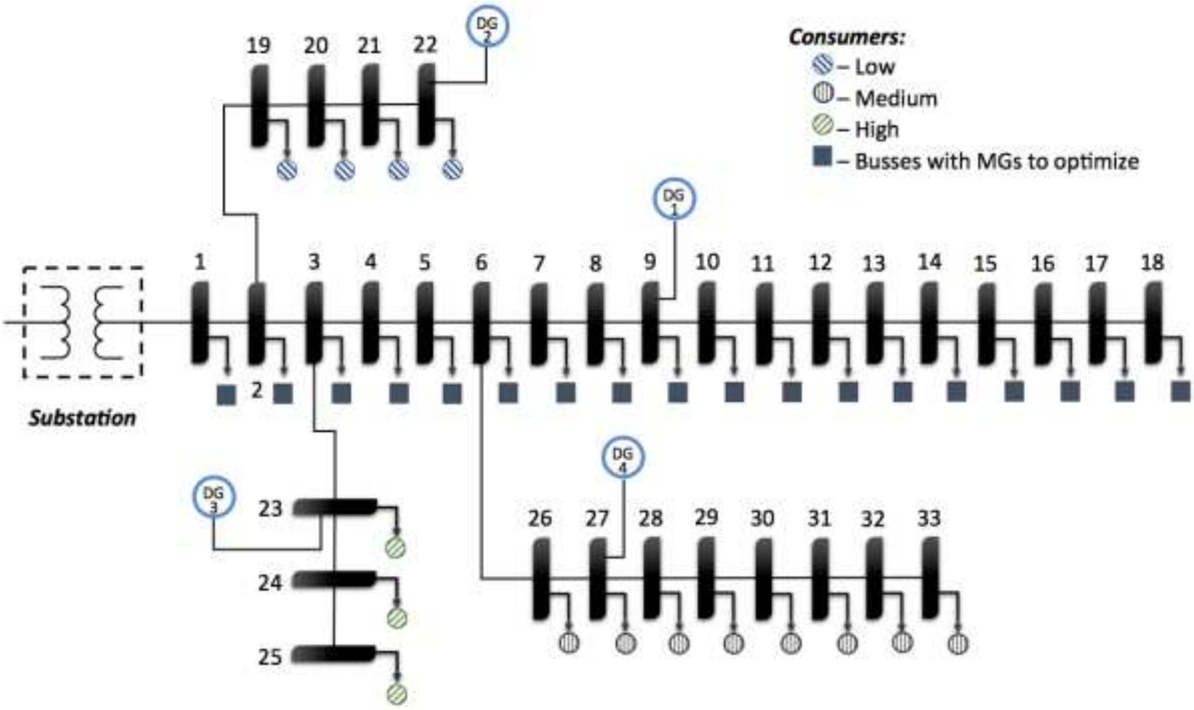

FIGURE 21 - System architecture for scenario 'A'

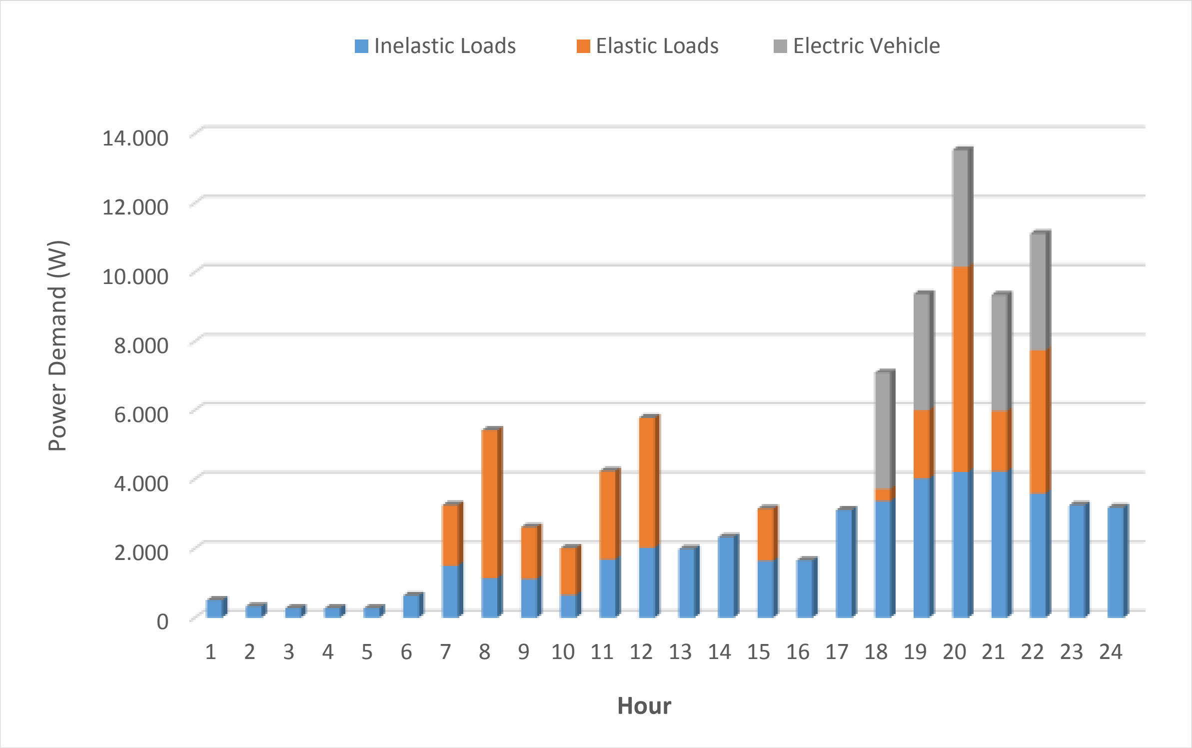

FIGURE 22 - Power demand of a house for the scenario A.

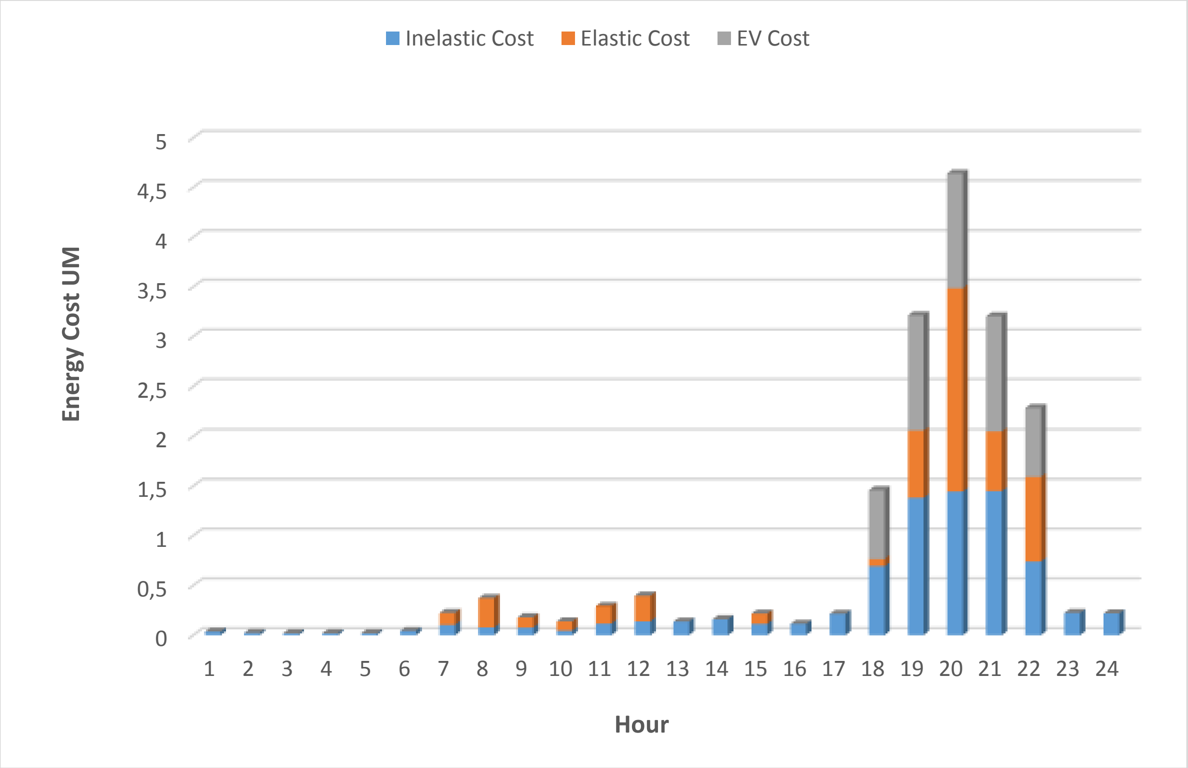

FIGURE 23 – Energy cost for a typical house used on scenario A

FIGURE 24 - FIGURE 26 presents the total load profile for every type of user (Low, Medium, High) on a 24-hour horizon [73].

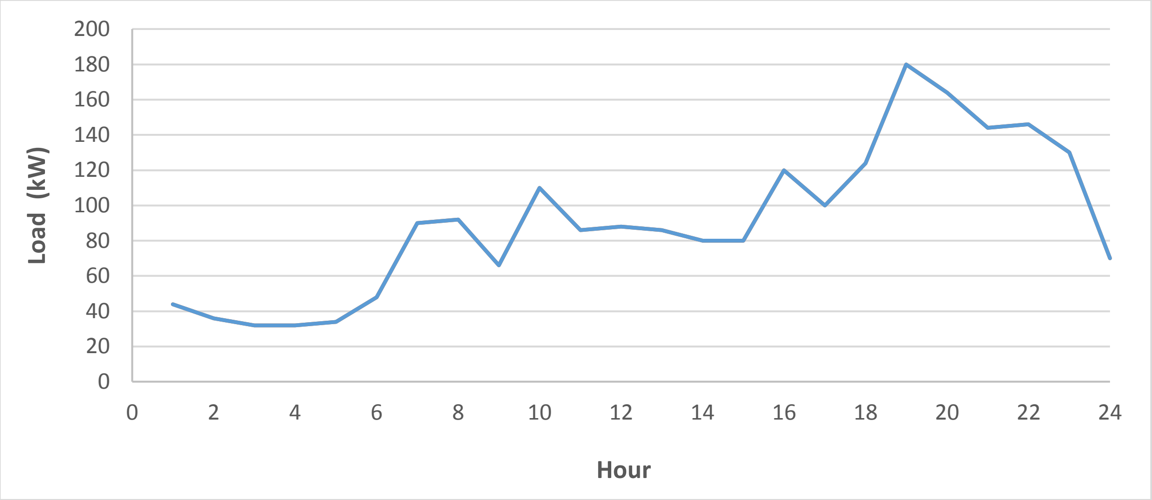

FIGURE 24 - Total active power profile for buses with low consume.

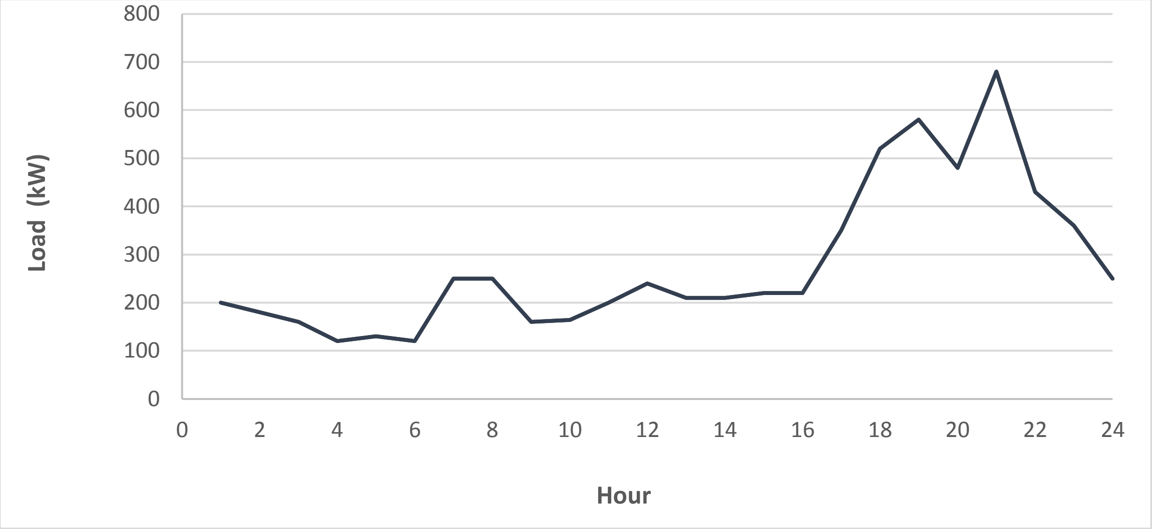

FIGURE 25 - Total active power profile for buses with medium consume.

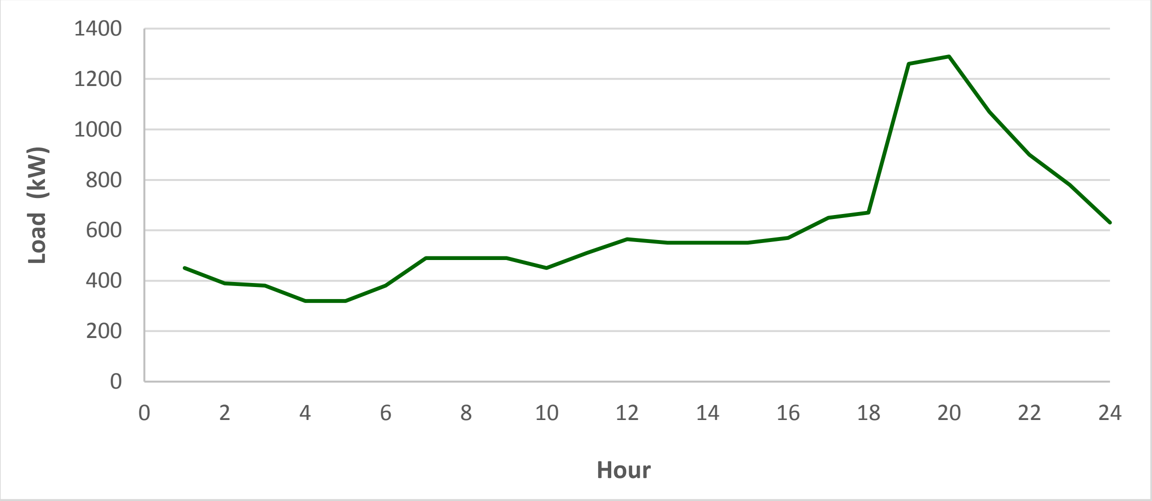

FIGURE 26 - Total active power profile for buses with high consume.

All the simulations are executed in a 24 hours line time, and all the data from every bus and branch is collected and displayed. Basically in this dissertation are shown the voltage variation in every bus hour-by-hour, Operating Marginal Cost or Lambda values (UM/MWh), active power losses in the branches and the generation for the generator buses, and in the end, all the graphics are discussed. According to the characteristic and previous configuration presented for the scenario ‘A’, graphically are shown its variations and response for “scenario B” and ”scenario C”. Subsequently, the parameters of interest for this study are briefly discussed hour by hour. The graphics are presented in the following order: Buses voltage magnitude, Lambda values, Active power losses, and Generation.

In general, the format chosen in order to give a better understanding of the results is a 3D format that in its ‘Y axis’ presents: the voltage magnate in (pu), the lambda values obtained from the optimization of the distribution system and the active power losses for every bus. In its ‘X axis’ presents the total 24 hours horizon and finally, in its ‘Z axis’ appears every bus or branch of the system with its own characteristics. Also all the numerical data that appears in all the graphics of this dissertation can be found in the APPENDIX I.

Due to the big amount of data tabulated the total system is divided into 4 different set of branches, it is possible to see in FIGURE 21, that one optional sorting due to the system physical structure is to group the buses respect to the branch in which they are located. For instance the buses in the first superior branch of the system can be part of the group that in this dissertation we call it as ‘Secondary branch ‘A’’. The second superior line from the top to the bottom and the longest one that appear on the system will be grouped, and called in this dissertation as ‘Primary branch’. The third proposed division for the system will group the buses that are located in the branch where appear the buses from number 23 to 25, for this branch the name that will receive in this dissertation will be ‘Secondary branch ‘B’. Finally the fourth proposed division is presented and introduced with the buses that go from bus number 26 till bus 33, that are graphically located in the inferior line of the system.

For this scenario ‘A’, in the case of the lambda values or Operating Marginal Cost for the system and the active power losses, the same classification structure is used in each case. On this scenario will be emphasized where the maximum values of each of the parameters plotted are located in the branches; i.e., for the scenario where voltage magnitude is analyzed, will be identified where the maximum values appears and at what time they appeared. Exactly the same process will be done for the graphics where the lambda values are analyzed and also for the active power losses.

From now on the classification effectuated will be used at will for all the plots in 3D, always accompanied of the scenario where are they being used and its respective units. TABLE 5 presents the nomenclature defined for the branches that is mainly used in the analysis of the losses for the three different scenarios.

TABLE 5 - Branch nomenclature

Branch #	From	To
1	1	2
2	2	3
3	3	4
4	4	5
5	5	6
6	6	7
7	7	8
8	8	9
9	9	10
10	10	11
11	11	12
12	12	13
13	13	14
14	14	15
15	15	16
16	16	17
17	17	18
18	2	19
19	19	20
20	20	21
21	21	22
22	3	23
23	23	24
24	24	25
25	6	26
26	26	27
27	27	28
28	28	29
29	29	30
30	30	31
31	31	32
32	32	33

4.1.1.1 Buses Voltage Magnitude for Scenario A (pu)

FIGURE 27 show a mostly constant behavior along the 24 hours for buses 1, 2 and 3, small or not variation at all is displayed. For buses 4 to 7, variations in the order of 1.05 pu to 1.1 pu are found. From buses 8 to 18 minimum values are located around 19 and 21 hours, with a minimum value of 0.90 pu, and with a 1.08 pu constant values from 12:00 am until 6:00 am.

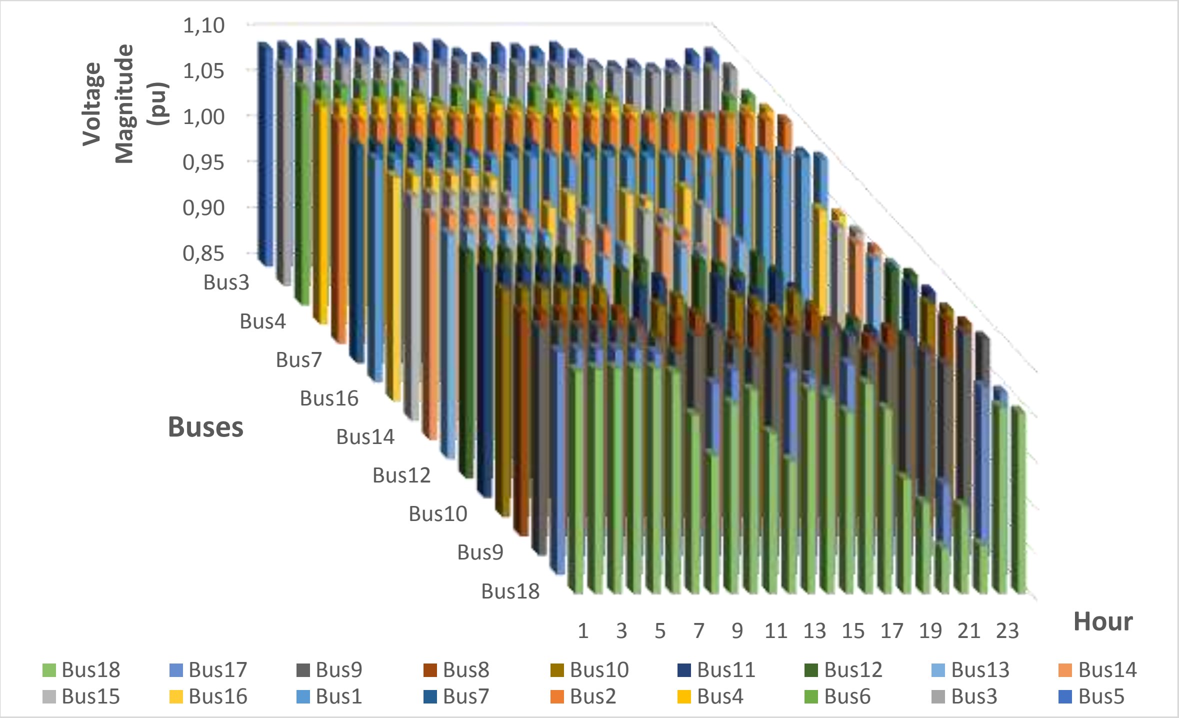

FIGURE 27 - Voltage magnitude for primary branch on sce A

FIGURE 28 shows the secondary ‘A’ branch voltage magnitude for each of its buses. For bus 22 an almost constant behavior is observed from 7:00 am till 12: 00 pm due that is directly connected to generator number 2, for the buses 2, 19, 20, 21 and almost symmetric and proportional behavior is shown.

FIGURE 58 shows the secondary ‘B’ branch voltage magnitude for each of its buses, this branch is presenting its lowest voltage values in the bus 25 and the higher for this branch are presented in bus 23 where generator number 3 is connected.

FIGURE 59 presents the voltage magnitude for the secondary branch ‘C’, in this case the highest and more consistent voltage magnitude appears in the bus 26 almost for all the 24 hours, the lowest voltage magnitude are presented in bus 32.

FIGURE 28 - Voltage magnitude for buses on secondary ‘A’ branch for sce. A

4.1.1.2 Lambda Values for Scenario A (UM/MWh)

3D graphic describing the behavior of the operational cost into every bus of the primary branch appears in FIGURE 29 where a symmetric behavior according to the amount of load connected to the system along the day is seen. Lambda values for the primary branch in this scenario get its higher values around 18 hours to 20 hours, this is due to the amount of loads that are being allocated at that hour into the system and the price of the energy at that hour. In this branch for all the buses hour by hour are observed similar behaviors with small variations among buses.

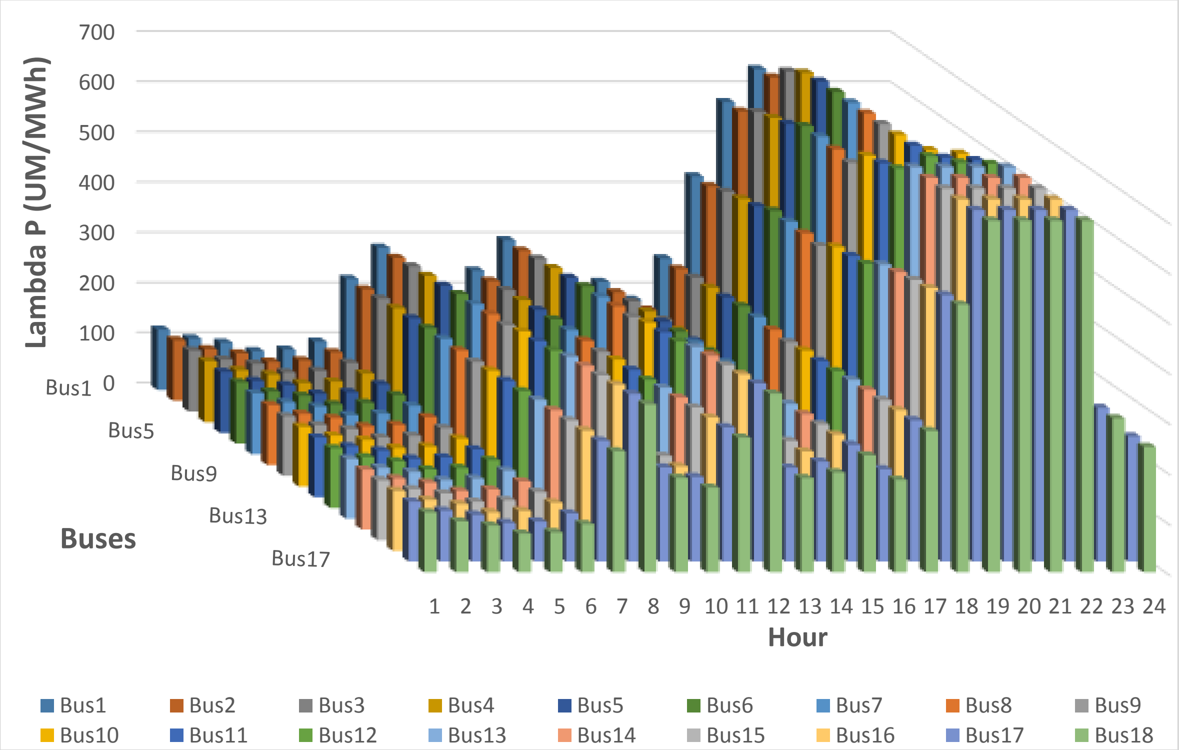

FIGURE 29 – Lambda values for the primary branch for scenario A.

FIGURE 30 presents the Lambda values for the secondary ‘A’ branch, for this scenario; apparently no higher distinctive value in this graph can be found, the max value is around 643.76 UM/MWh at 20 hours, almost a parametric behavior along the day for every hour can be observed.

FIGURE 60 shows the Lambda values for the secondary ‘B’ branch for this scenario, this graph presents a behavior that changes according to the amount of loads optimized in the 24 hours horizon. In comparison with FIGURE 61 where Lambda values for the secondary ‘C’ branch are showed, almost the same behavior is found, with similar variations during the day. This happens mainly to the energy prices and the high and medium consumer loads.

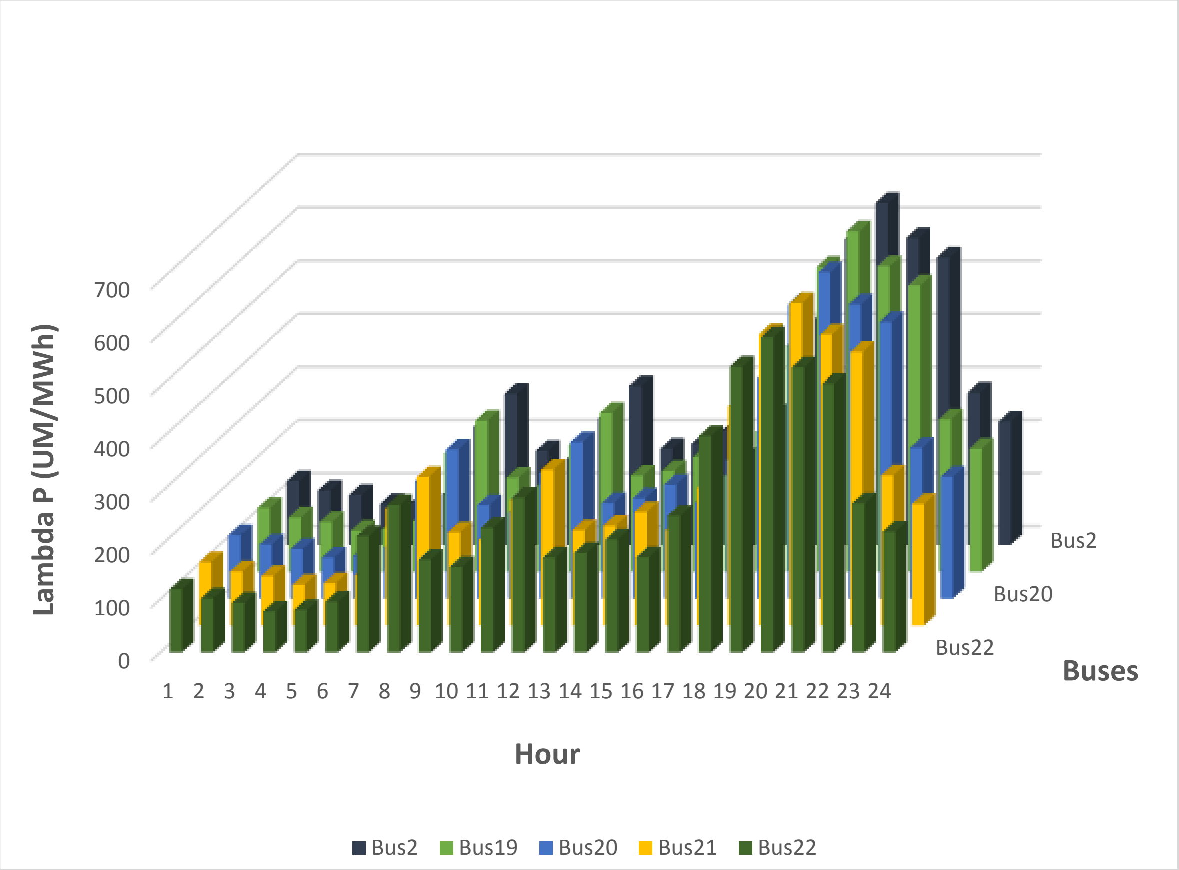

FIGURE 30 - Lambda values for the secondary ‘A’ branch for scenario A

4.1.1.3 Branches Active Power Losses for Scenario A (kW)

In the following graphs are presented the losses in the different branches of the system (See TABLE 5), according to the previous classification effectuated for the buses. FIGURE 31 presents the Active power losses for the primary branch, in this scenario presents its higher losses among branches 9-10 due to allocation of the generator number 1, reaching its peak value with 288.97 kW around 20 hours, in this figure several branches appear with almost no considerable losses throughout the day.

FIGURE 32, where Active power losses for secondary ‘A’ branch are presented for scenario “A”, can be seen from the graph that is presenting its higher branch losses right through the branches from bus19 to bus 20 at 20 hours with 30.12 kW, mainly due to the distance and operational cost of the generator number 2 in the secondary branch A.

FIGURE 62, where Active power losses for secondary ‘B’ branch are presented for scenario A, presenting its higher branch losses through the branches 22 and 23, around 20 hours, For the same hour FIGURE 63, where Active power losses for secondary ‘C’ branch is presented, shows branch from bus 27 to bus 28 also with the maximum value for this branch.

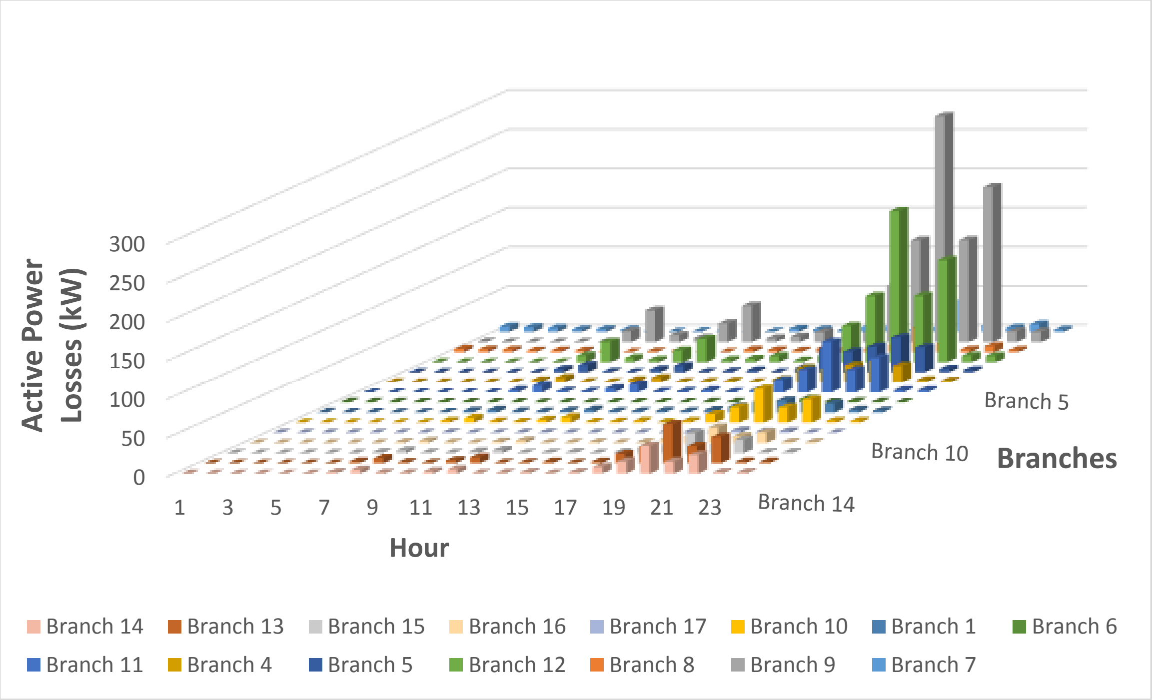

FIGURE 31 - Active power losses for primary branch for scenario A

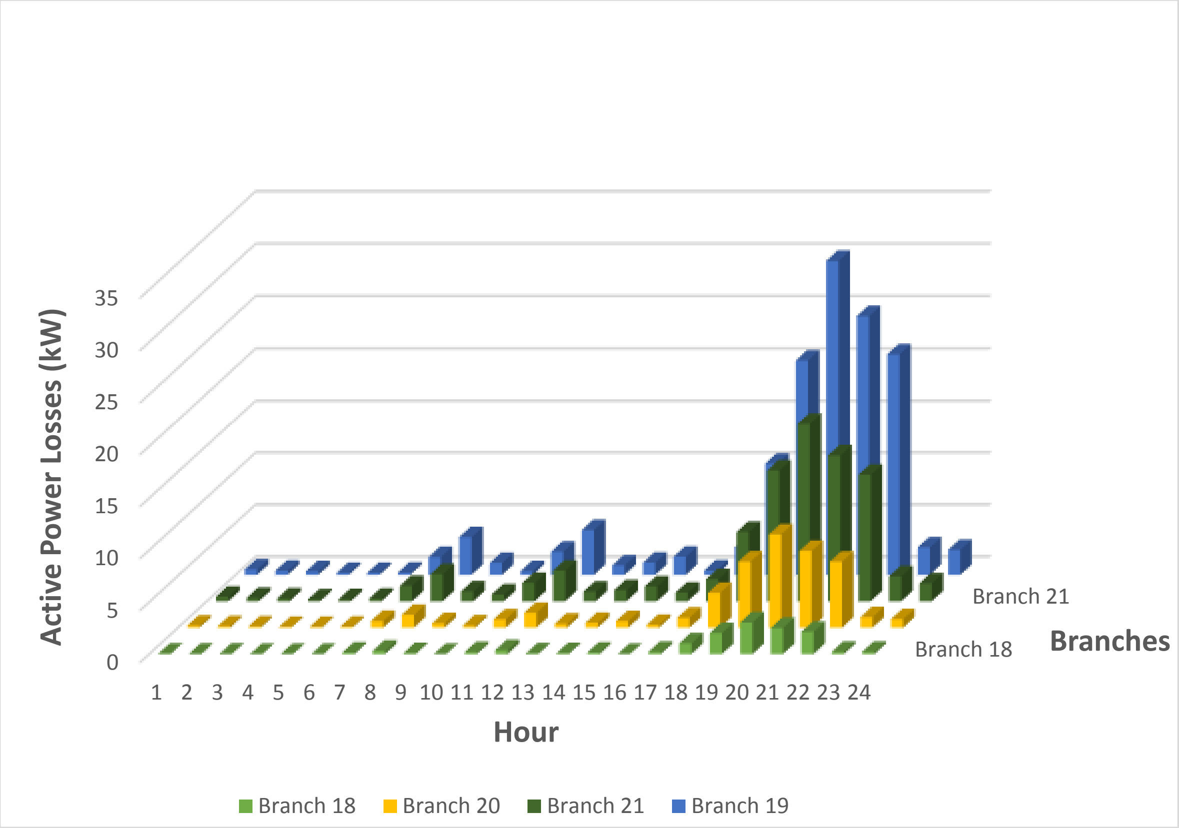

FIGURE 32 - Active power losses for secondary ‘A’ branch for scenario A

4.1.1.4 Active Power Generation for Scenario A (MW)

FIGURE 33 presents the GD in distribution system and how much those generators are producing hour by hour. A generation peak is found around 20 hours, as was expected to be, due to the loads placed at that hour. Due to its generation prices can be notice that the generator placed on bus 9 and the substation that is transmitting energy into the bus 1 are the generators that are producing most of the energy consumed by the system.

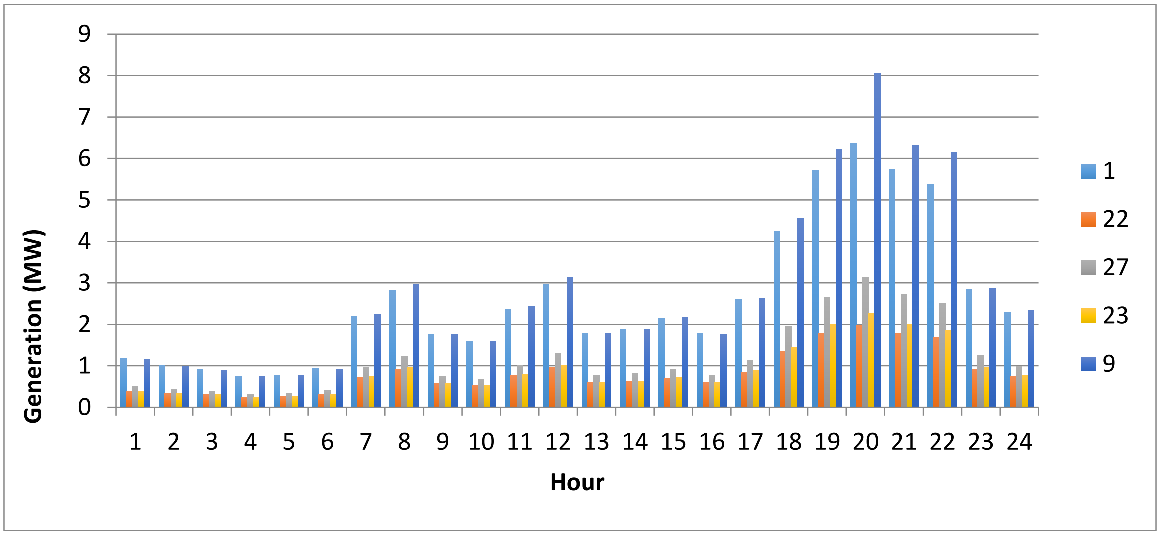

FIGURE 33 - Active generation for scenario A

4.1.1.5 Objective function for OPF in Scenario A

FIGURE 34 shows the variation of the objective function for the final OPF with the optimal values for this scenario along the 24 hours.

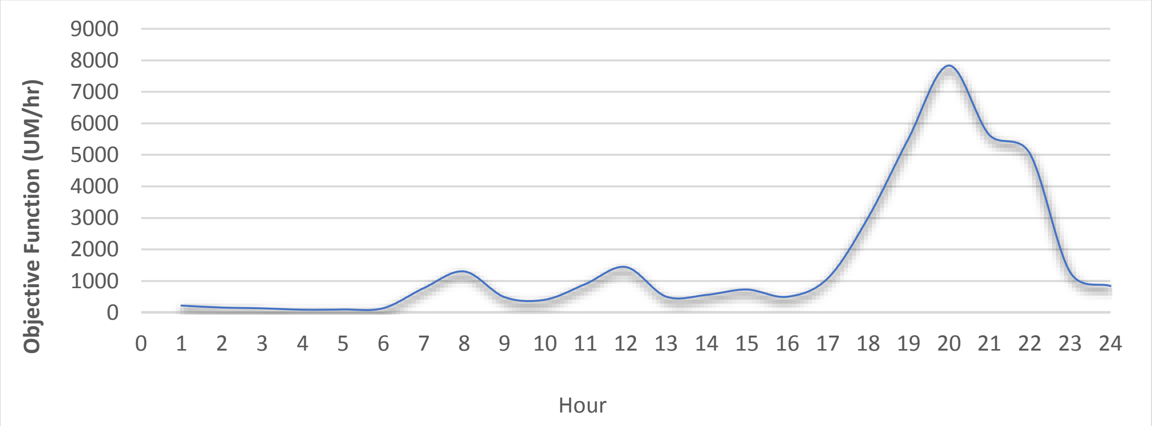

FIGURE 34 - Objective function for the final OPF performed in scenario A

TABLE 6 - Primary variables analyzed for scenario A

		Voltage Magnitude				P Losses (I^2*R)		Lambda P			
		Min		Max		Max		Min		Max	
Hour	Objective Function	Value (pu)	Bus	Value (pu)	Bus	Value (MW)	Branches From-To	Value (UM/MWh)	Bus	Value (UM/MWh)	Bus
1	220.46	1.058	33	1.1	9	0.01	27-28	117.98	9	126.52	33
2	160.17	1.062	33	1.1	9	0.01	27-28	100.67	9	107.21	33
3	135	1.066	33	1.1	9	0.01	27-28	92.46	9	97.85	33
4	91.26	1.074	33	1.1	9	0.01	27-28	76.2	9	79.53	33
5	98.33	1.072	33	1.1	9	0.01	27-28	79.08	9	82.79	33
6	140.5	1.074	33	1.1	9	0.01	27-28	94.58	9	98.64	33
7	777.82	1.044	33	1.1	22	0.01	27-28	218.39	22	241.63	33
8	1305.26	1.001	18	1.1	22	0.04	9-10	277.16	22	334.02	18
9	488.5	1.058	18	1.1	22	0.01	9-10	174.55	22	187.51	18
10	408.09	1.067	33	1.1	22	0.01	27-28	160.86	22	170.22	33
11	904.44	1.026	18	1.1	22	0.02	9-10	234.03	22	267.43	18
12	1445.65	0.995	18	1.1	22	0.05	9-10	290.81	22	355.16	18
13	506.43	1.057	33	1.1	22	0.01	27-28	178.49	22	192.33	33
14	560.38	1.055	33	1.1	22	0.01	27-28	187.15	22	202.4	33
15	731.71	1.049	18	1.1	22	0.01	9-10	212.28	22	232.39	18
16	502.78	1.057	33	1.1	9	0.01	27-28	178.51	9	192	33
17	1084.17	1.026	33	1.1	22	0.03	27-28	256.89	22	294.55	33
18	3010.82	0.976	18	1.1	22	0.07	9-10	406.92	22	532.48	18
19	5519.7	0.95	18	1.1	22	0.13	9-10	538.07	22	767.55	18
20	7839.44	0.9	18	1.1	1	0.29	9-10	593.1	22	1227.24	18
21	5640.3	0.946	18	1.1	22	0.13	9-10	536.64	22	781.25	18
22	5058.57	0.903	18	1.1	22	0.2	9-10	505.39	22	810.38	18
23	1287.71	1.025	33	1.1	22	0.03	27-28	280.29	22	321.78	33
24	842.5	1.044	33	1.1	22	0.02	2-3	227.21	22	251.5	33

Is observed from the graphics and TABLE 6 that the objective function for the system reaches its lowest value at 3 hours and its higher value at 20 hours as it seen, due to the operative cost of the system, the bus with the minimum voltage value appears at the same hour that the objective function reaches its higher value, with a 0.9 pu in bus 18, For that hour a 1.1 pu voltage value appears as max value in bus 1. The higher values for the losses were focalized on two branches, the first one that goes from bus 27 to bus 28 and the other one that goes from bus 9 to bus 10, in this branch the peak for the losses of the system were also reached at 20 hours, almost 0.29 MW. Basically the lowest lambda values were obtained on the buses 9 and 22, almost varying its frequency along the proposed horizon.

4.1.2 Scenario B: “Optimization of loads and charging of EVs scheduling”

Departing from the scenario ‘A’ the main idea for the scenario ‘B’ is to show the changes due to the reallocation and optimization realized for the basic configuration of the system studied. Once again the 33 buses distribution system is analyzed in order to implement the algorithm proposed. Based on the 33 buses radial distribution system, a classification is performed according to its physical positioning as in the scenario A, but with the difference that in this case the charging periods for the electrical vehicle are optimized. It is not anymore charged without restrictions. All the buses for low consumers branch, medium consumer branch, high consumers and optimization branch, are loaded with the same demand, but for the primary branch a previous MILP optimization is effectuated in every microgrid. The system used for this scenario ‘B’ is presented in FIGURE 35. In the same way that in the scenario ‘A’, once again Low consumers are allocated from buses 19 to 22, secondary ‘A’ branch, medium consumers from buses 26 to 33 in what we call as secondary ‘C’ branch, high consumer from buses 23 to 25 in what we call as secondary ‘B’ branch, finally in the main branch from bus 1 to 18 where the primary branch is placed with the microgrid to optimize, FIGURE 36 presents the total power demand profile and FIGURE 37 the energy costs. The behavior and variations for this scenario are shown in the following graphs and tables.

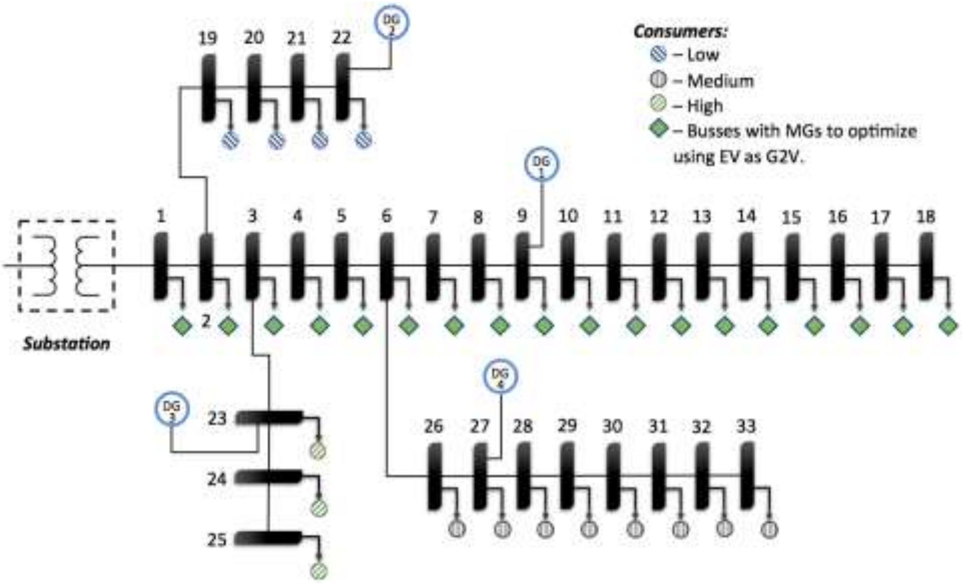

FIGURE 35 - System architecture for scenario B

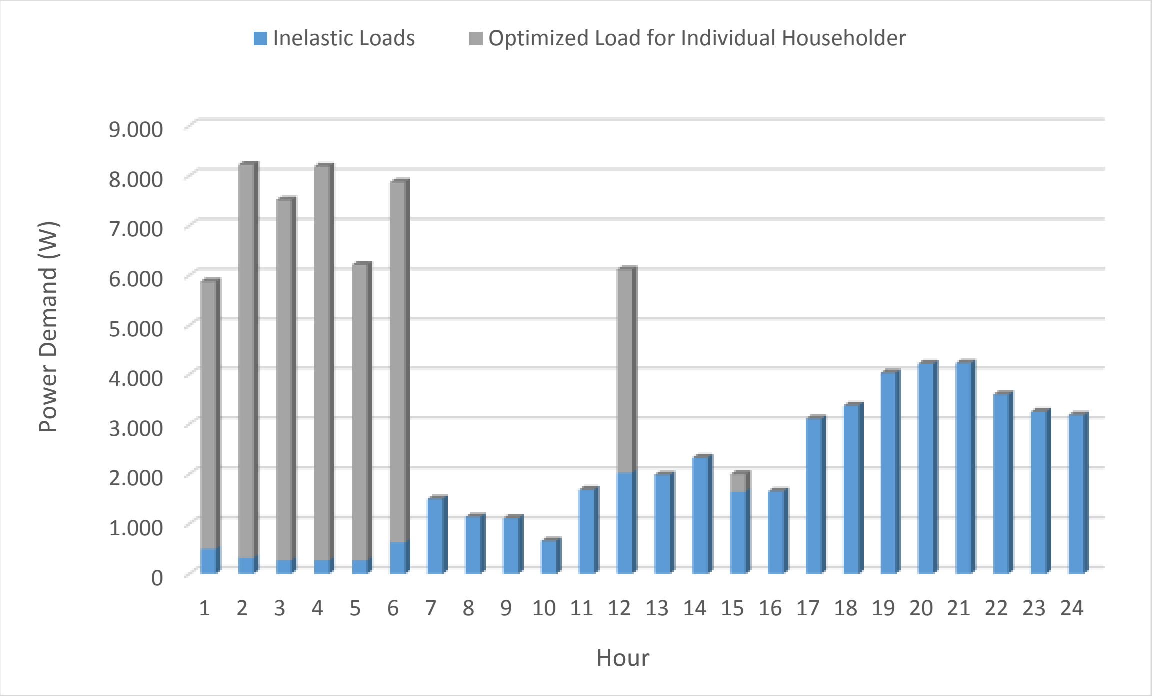

FIGURE 36 - Power demand of a typical house for the scenario B.

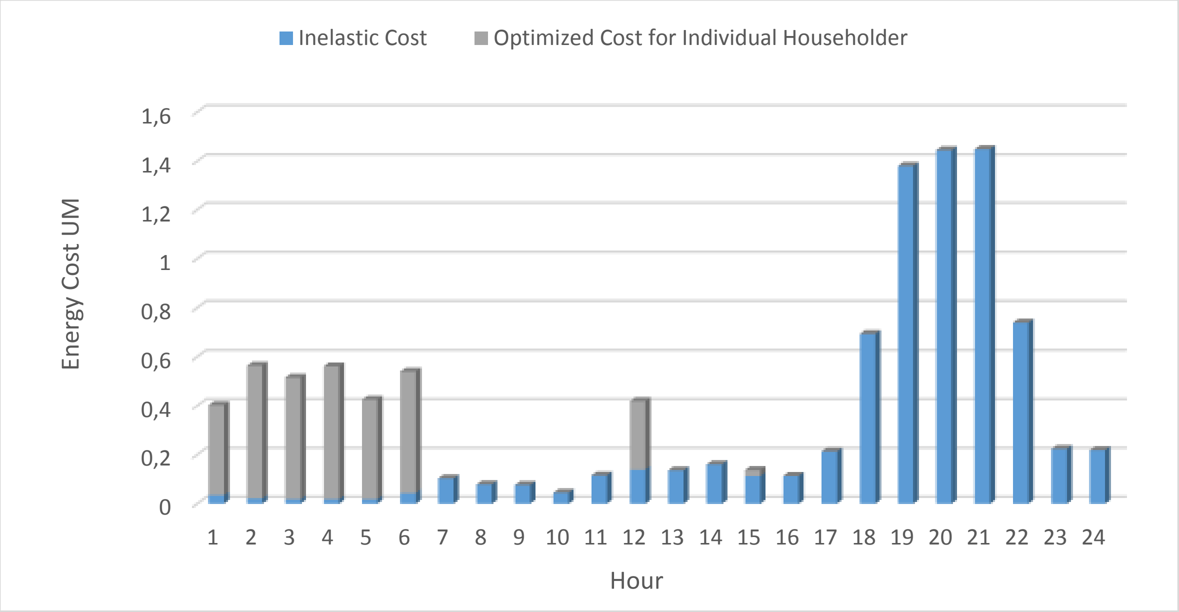

FIGURE 37 - Energy cost for a typical house used on scenario B

4.1.2.1 Buses Voltage Magnitude for Scenario B (pu)

FIGURE 38 shows more voltage variations in comparison with that is showed in FIGURE 27, where the base case is presented. In this scenario buses 17 and 18 presents the lowest voltage value for the primary branch, around 2:00 am and 4:00 am with a 0.93 pu value, due to the shifting of the loads after the optimization process and the distance to closer generator that is located in bus number 9. Higher and more constant values in this case are presented in buses 1, 2, 3 and 4 due to the voltage stability that provides the sub-station.

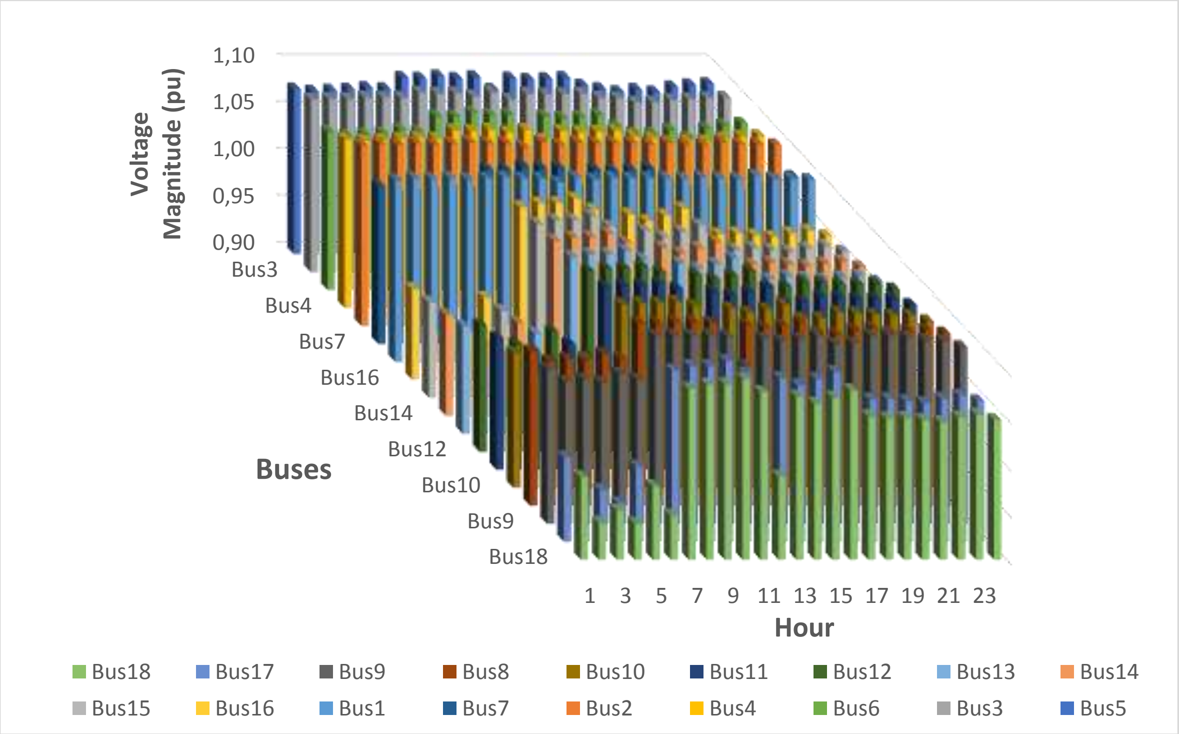

FIGURE 38 - Voltage magnitude for primary branch in scenario B

FIGURE 39 is presenting variations in the voltage from 1.090 pu to 1.1 pu, the lowest voltage magnitude is found at bus number 2 around 10:00 am, highest values are found at bus 22 with an almost stable value at 1.1 pu all day long. FIGURE 64 presents the voltage magnitude for secondary branch ‘B’ in scenario B, in this figure can be appreciated the pattern modification in the graphic in comparison with the scenario ‘A’. The lowest voltage magnitude is observed in bus 25 around 19:00 hours, buses 23 and 3 are presenting a similar graphical behavior; the highest voltage magnitude is 1.09 that is presented at bus 3. FIGURE 65 presents the voltage magnitude for secondary branch ‘C’ in scenario B, in this branch the higher voltage magnitude values are located in bus number 6 with a 1.08 pu, the lowest values for this simulation are found at bus number 33, around 21:00 hours with 0.96 pu value, this variations occurs mainly due to the proximity or the distance between the buses and the generators. For buses 26 and 27 a similar graphic can be observed, due to the stability provided by the generator number 4 in bus 27.

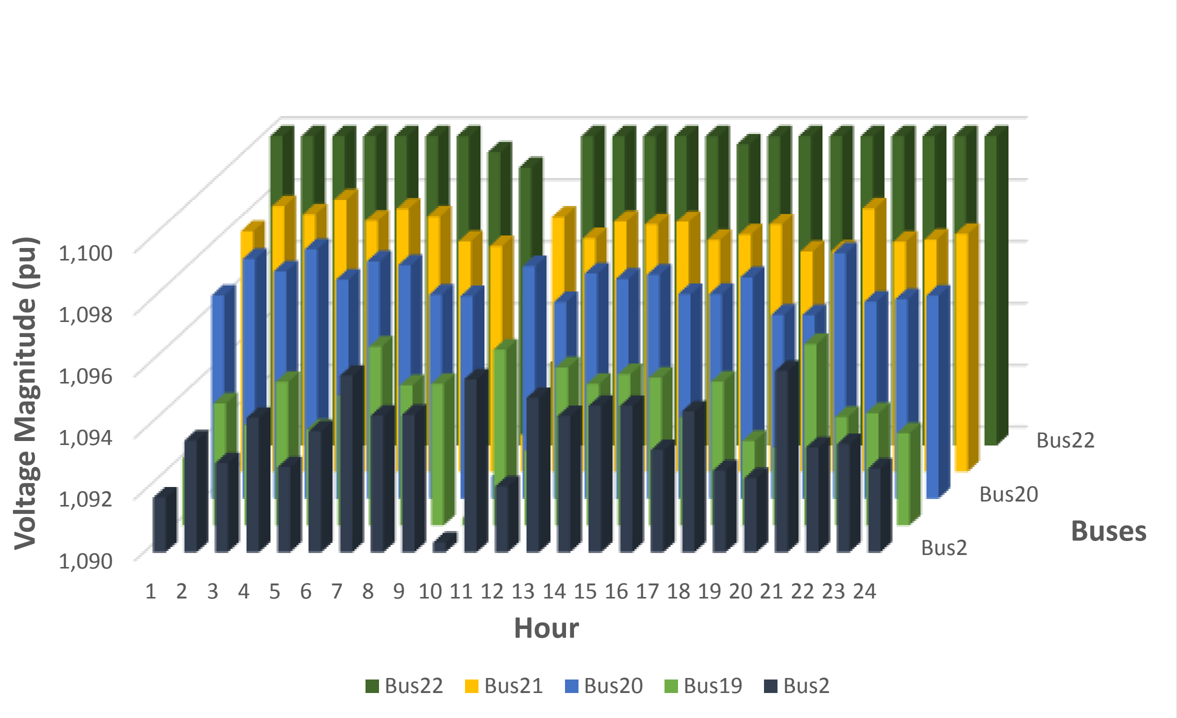

FIGURE 39 - Voltage magnitude for secondary branch ‘A’ in scenario B

4.1.2.2 Lambda for Scenario B (UM/MWh)

As can be seen in FIGURE 40, after the optimization process a better peak reduction and a proportional distribution according to the amount of loads optimized by the algorithm can be observed. The highest operational values are found in bus 18 with an amount of 479.19 UM/MWh in comparison with the peak for the scenario 'A', this almost represents a 41 % peak reduction in its congested hour (21:00), mainly due to its load optimization.

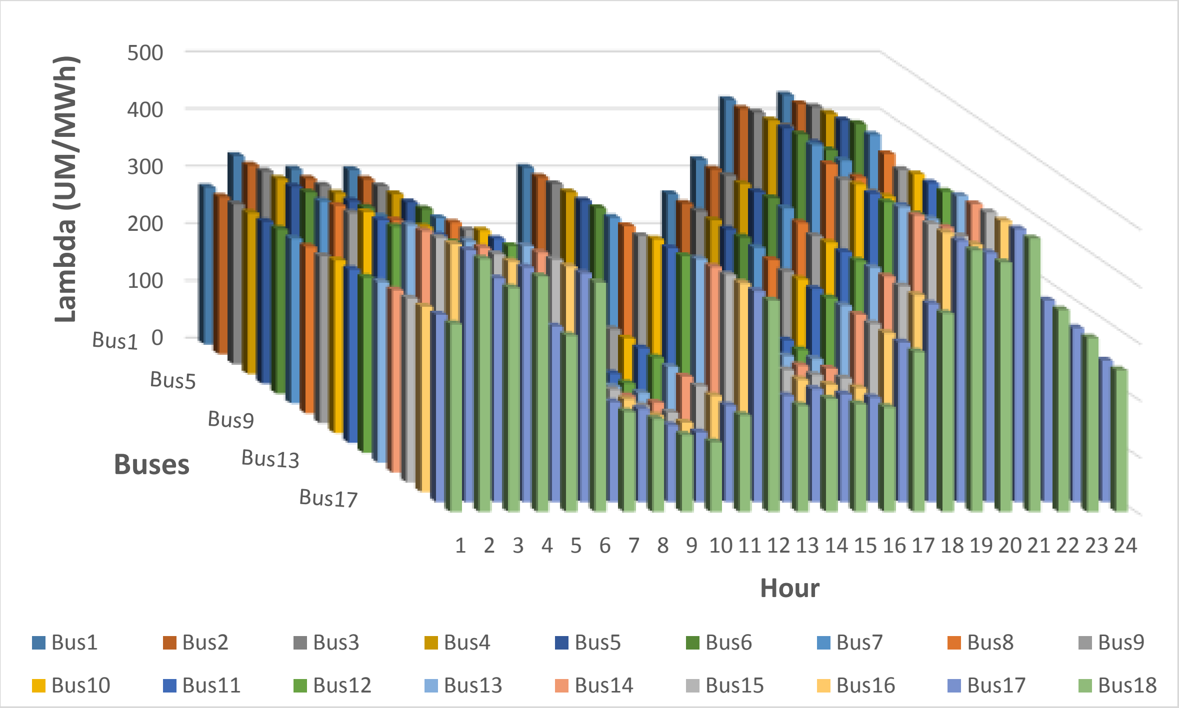

FIGURE 40 - Lambda values for primary branch in scenario B

FIGURE 41 presents the Lambda values for secondary 'A' branch in scenario B, for this branch the higher values are found around 19:00 and 21:00 hours with a maximum value close to 435.5 UM/MWh, the lowest values can be observed around 10:00 hours with a cost of 123.59 UM/MWh in almost all the branch. In comparison with its counterpart in the Scenario 'A' a peak reduction of almost 32 % can be appreciated, but a rising of almost 60% can be observed in its minimum value, that in Scenario 'A' was at 4:00 am.

FIGURE 66 presents the Lambda values for secondary 'B' branch in scenario B, in this case the lowest values appear in bus 23 at 10:00 hours close to the 124.87 UM/MWh, highest values will appear on bus 25 at 21 hours with a value of 467.37

UM/MWh. Comparing the highest and the lowest values for this scenario with the scenario ‘A’, can be noticed that a reduction of almost 35% in the peak of the graphic was reached, but a 38% increasing was perceived for the lowest value that was kept in bus 23.

FIGURE 67 presents Lambda values for secondary ‘C’ branch in scenario B, in this case, lowest values are always found in bus number 26, while the highest values for the scenario ‘A’ were allocated over the bus 33 and for the scenario ‘B’ over the bus number 6.

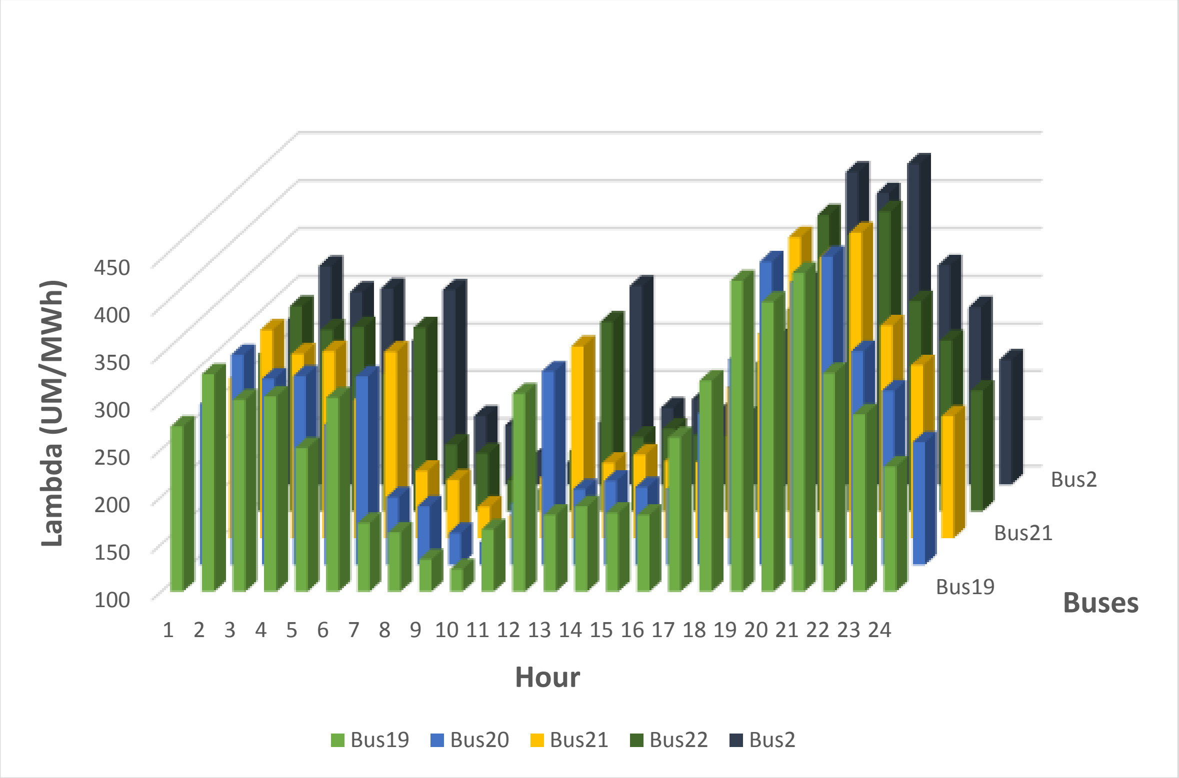

FIGURE 41 - Lambda values for secondary ‘A’ branch in scenario B

4.1.2.3 Branches Active Power Losses for Scenario B (kW)

In the following graphs are presented the losses in the different branches of the system, according to the previous classification effectuated for the buses (See TABLE 5). FIGURE 42 presents the active power losses for the primary branch in this scenario, with its higher value among buses 9-10 but with a considerable shifting peak due to the optimization process that has been effectuated till this point. Several branches in this figure appear with almost no considerable losses through the day.

FIGURE 43, where active power losses for secondary ‘A’ branch, appears presenting its higher branch losses right through the branches from bus19 to bus 20 with a peak of 11.31 kW at 21 hours, for this branch other power losses peak is found around 1:00 am, but with a value of 8.98 kW. The lowest losses are presented in branch 18 where a maximum peak for this branch of 1.09 kW can be seen, that in comparison with scenario ‘A’ have presented a considerable reduction from 2.51 kW, due to the shifting load as result of the optimization process..

FIGURE 68, where active power losses for secondary ‘B’ branch are presented, this scenario shows its higher branch losses through the branches 23 with maximum losses of 37.29 kW at 20:00 hours, in comparison with the scenario ‘A’ for the same hour that initially was working with a value of 37 kW an increase of 0.29 kW cab be appreciated for this hour. The lowest losses values remain for both cases at branch 18, which at the beginning of the day, presents a 1.28 kW at 7:00 am as maximum value.

FIGURE 69 where, active power losses for secondary ‘C’ branch are presented. From this figure can be observed that no losses are presented in branch 32 along the day, almost the same behavior that was seen for this branch in the scenario ‘A’. The highest values remains in the branch 27 with total losses of 126.71 kW at 20 hours, a reduction for this branch can be observed from its original value in case ‘A’ of 129.66 kW.

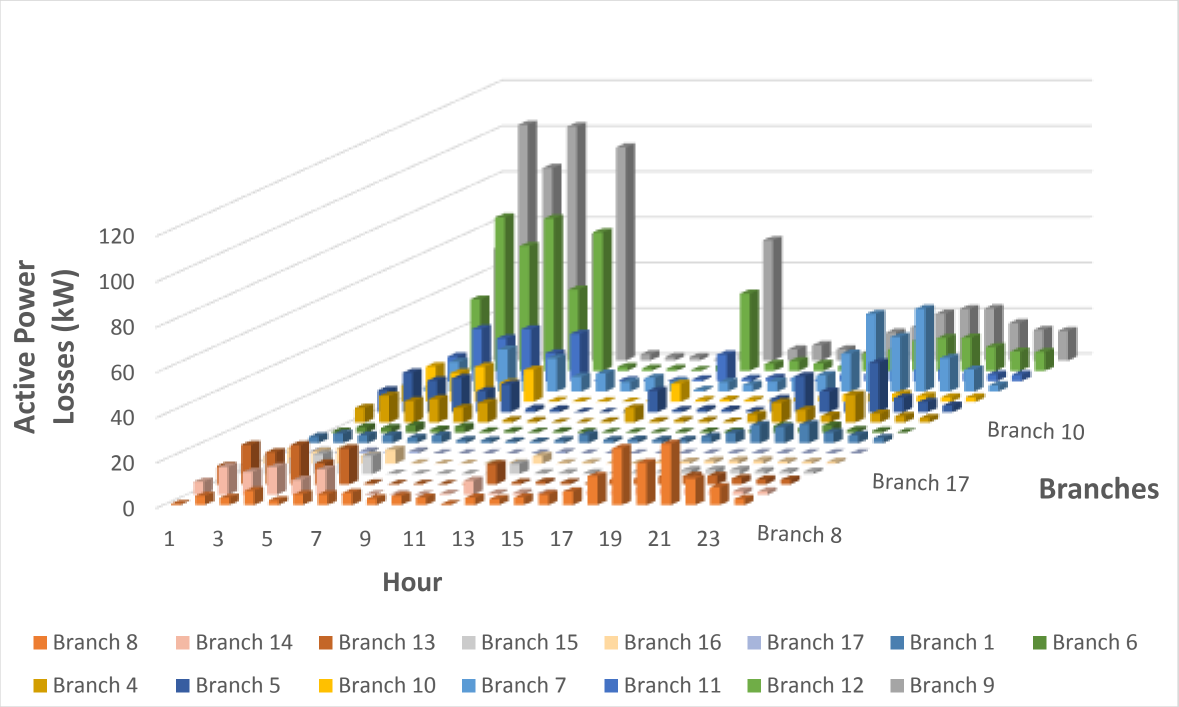

FIGURE 42 - Active power losses for primary branch in scenario B

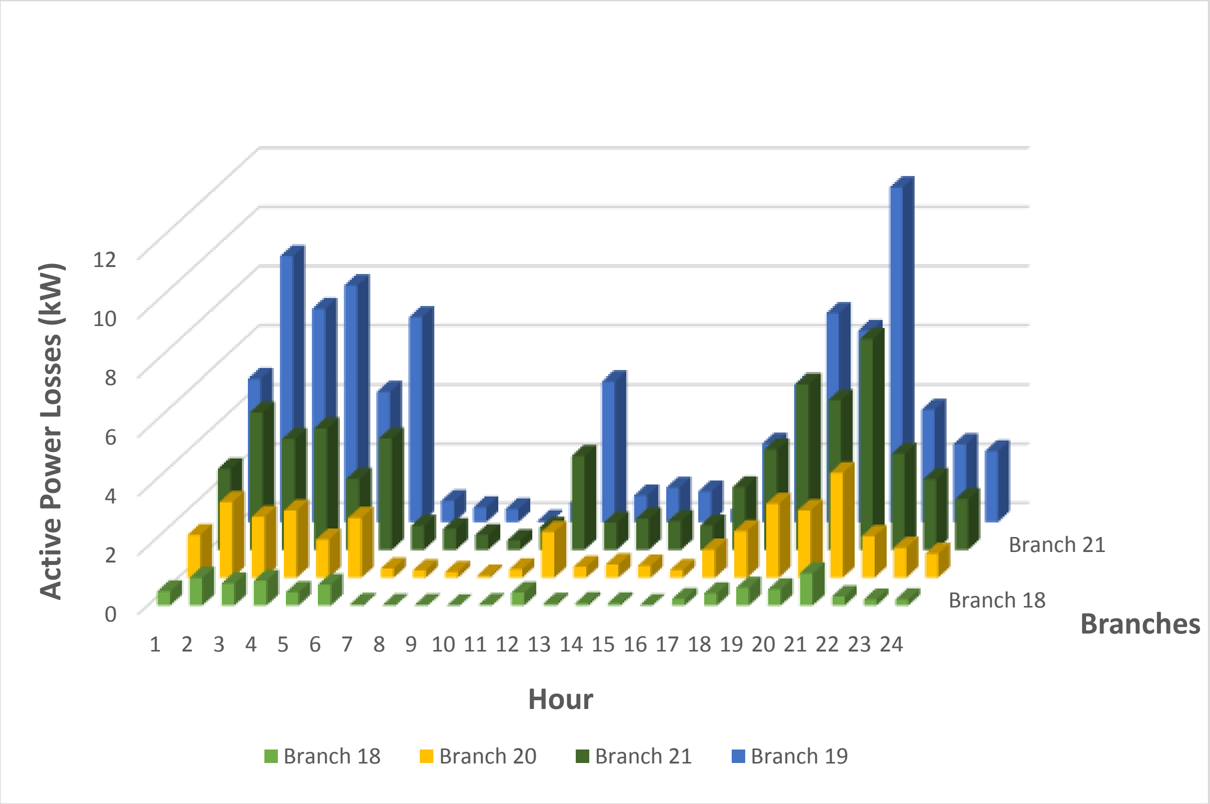

FIGURE 43 - Active power losses for secondary ‘A’ branch in scenario B

4.1.2.4 Active Power Generation for Scenario B (MW)

In comparison with FIGURE 33, FIGURE 44 presents a better distribution in the generation hours and also in the peaks reduction for all the generators. Must be reminded that the load through the secondary branches is the same with almost no alterations in comparison with the scenario “A”. This graphic is used as pattern to know how the losses, lambda values, and voltage magnitude can vary.

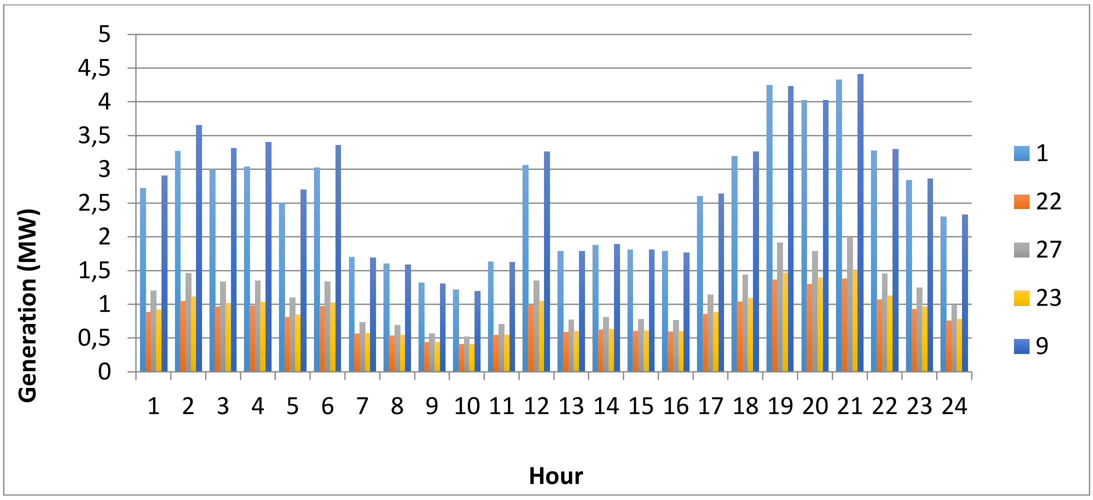

FIGURE 44 - Active power generation for scenario B

4.1.2.5 OPF Objective Function for Scenario B

FIGURE 45 shows the variation of the objective function for the final OPF with the optimal values for this scenario along the 24 hours.

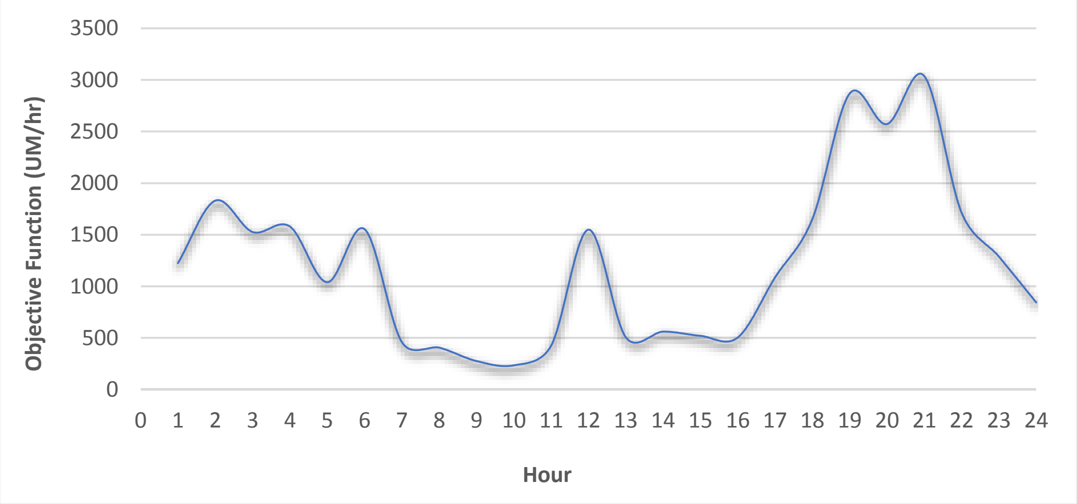

FIGURE 45 - Objective function for the final OPF performed in scenario ‘B’

TABLE 7 - Primary variables analyzed for scenario B

Hour		Voltage Magnitude (pu)				Active Power Losses (MW)		Lambda P (UM/MWh)			
		Min		Max		Max		Min		Max	
	Objective Function	Value (pu)	Bus	Value (pu)	Bus	Value (MW)	Branches From-To	Value (UM/MWh)	Bus	Value (UM/MWh)	Bus
1	1223.78	0.988	18	1.10	22	0.05	9-10	266.49	22	330.37	18
2	1829.16	0.939	18	1.10	22	0.10	9-10	315.99	22	443.61	18
3	1525.68	0.953	18	1.10	22	0.08	9-10	291.6	22	393.97	18
4	1578.73	0.938	18	1.10	22	0.10	9-10	294.09	22	413.16	18
5	1038.66	0.978	18	1.10	22	0.06	9-10	244.83	22	309.97	18
6	1553.51	0.947	18	1.10	22	0.09	9-10	293.8	22	403.07	18
7	458.69	1.051	33	1.10	22	0.01	27-28	170.12	22	185.26	33
8	405.24	1.05	33	1.10	9	0.01	27-28	160.09	9	174.05	33
9	275.17	1.067	33	1.10	9	0.01	27-28	132.27	9	139.62	33
10	233.32	1.064	33	1.10	9	0.01	27-28	121.2	9	128.63	33
11	423.46	1.06	33	1.10	22	0.01	27-28	163.66	22	175.3	33
12	1547.68	0.988	18	1.10	22	0.05	9-10	299.78	22	371.94	18
13	506.43	1.057	33	1.10	22	0.01	27-28	178.49	22	192.33	33
14	560.38	1.055	33	1.10	22	0.01	27-28	187.15	22	202.4	33
15	519.39	1.055	33	1.10	22	0.01	27-28	180.55	22	195.41	33
16	502.78	1.057	33	1.10	9	0.01	27-28	178.51	9	192	33
17	1084.17	1.026	33	1.10	22	0.03	27-28	256.89	22	294.55	33
18	1649.46	0.992	33	1.10	22	0.07	27-28	312.45	22	385.92	33
19	2866.62	0.982	33	1.10	22	0.09	27-28	411.5	22	519.11	33
20	2571.17	1.003	33	1.10	22	0.06	27-28	390.9	22	473.59	33
21	3036.63	0.961	33	1.10	22	0.13	27-28	415.2	22	557.36	33
22	1713.44	1.012	33	1.10	22	0.05	27-28	312.23	22	380.14	33
23	1287.71	1.025	33	1.10	22	0.03	27-28	280.29	22	321.78	33
24	842.5	1.044	33	1.10	22	0.02	2-3	227.21	22	251.5	22

Is observed from the graphics and TABLE 7 that the objective function for the system reaches its lowest value at 10 hours and its higher value at 21 hours. The bus with minimum voltage values appears at 4 hours with a 0.938 pu in bus 18, for that exactly hour a 1.1 pu voltage value appear as max value in bus 22. The higher values for the losses were focalized on two branches, the first one, that goes from bus 9 to bus 10 and the other one, that goes from bus 27 to bus 28, and is in this branch that the peak for the losses of the system is reached at 21 hours, almost 0.13 MW. Basically the lowest lambda values were obtained on the buses 9 and 22, almost varying its frequency of appearance along the day.

4.1.3 Scenario C: “Optimization of Loads considering Micro-DG, EV charging and injection ”

In this scenario (See FIGURE 46) the insertion of the EV, as a V2G, and Micro-DG are considered as main target for the optimization process. The load profile and costs for a typical house that is situated inside of the microgrid are shown in FIGURE 47 and FIGURE 48, graphs and tables are shown to describe the buses voltage profile, branch losses and lambda power values. Finally a resume is done with a comparative for the buses behavior throughout the complete optimization process.

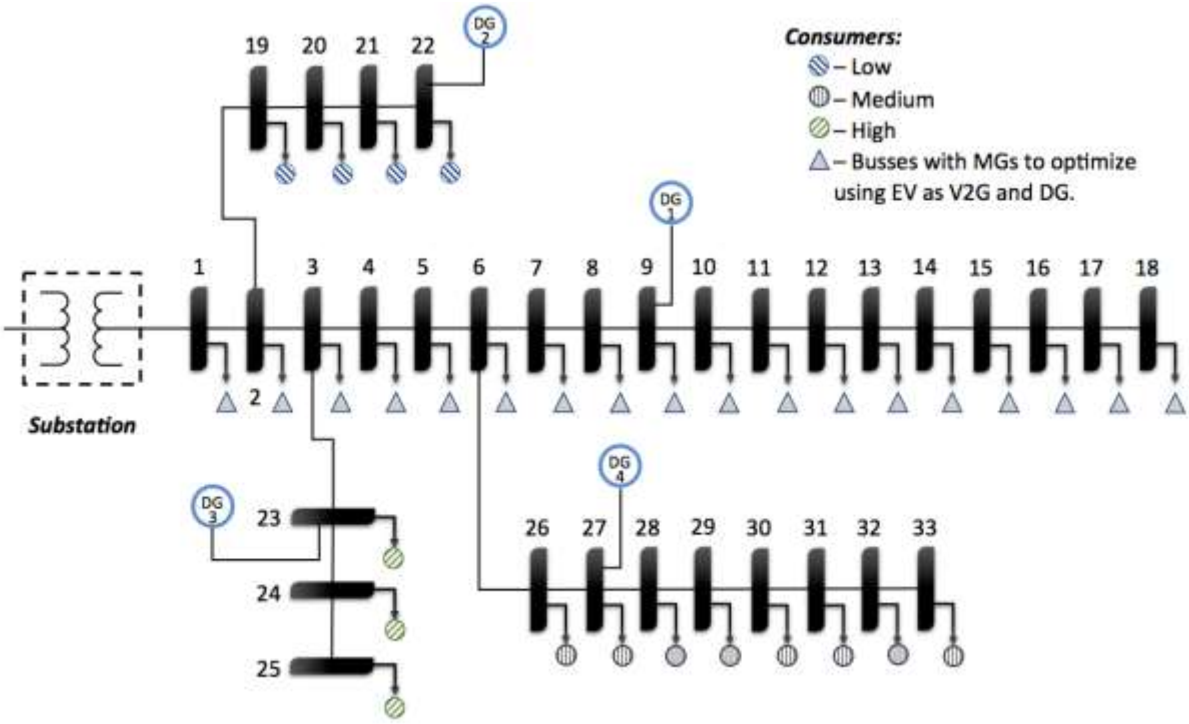

FIGURE 46 - System architecture for scenario C

FIGURE 47 shows the displacement final profile for the loads, EV and the Micro-DG. In comparison with the scenario ‘A’ a visible shifting from the optimized loads in scenario ‘C’ due to the optimized scheduling process previously done using the proposed model it can be visualized. Also in this figure can be appreciated in which hours of the day the house is consuming or generating and injecting to the grid, the points where the house is autonomous of the energy consumption from the grid appears at 10 and 18 hours. Also the energy injection coming from the EV on peak hours reduce the total energy consumption in those hours, where a bigger amount of energy is needed.

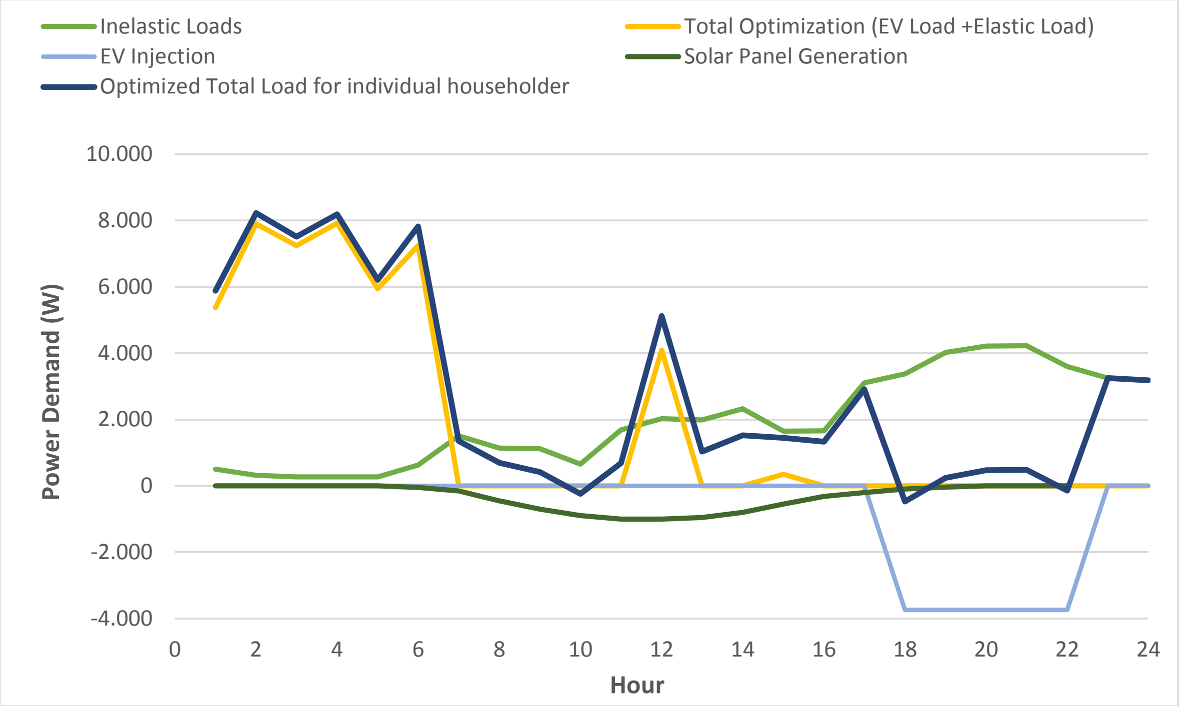

FIGURE 47 - Power demand for a typical house for scenario C

FIGURE 48 presents the cost related to the inelastic loads, elastic loads, EV and solar panel. Negative values represent an injection point into the system, positive values represents a direct consumption by the different type of loads.

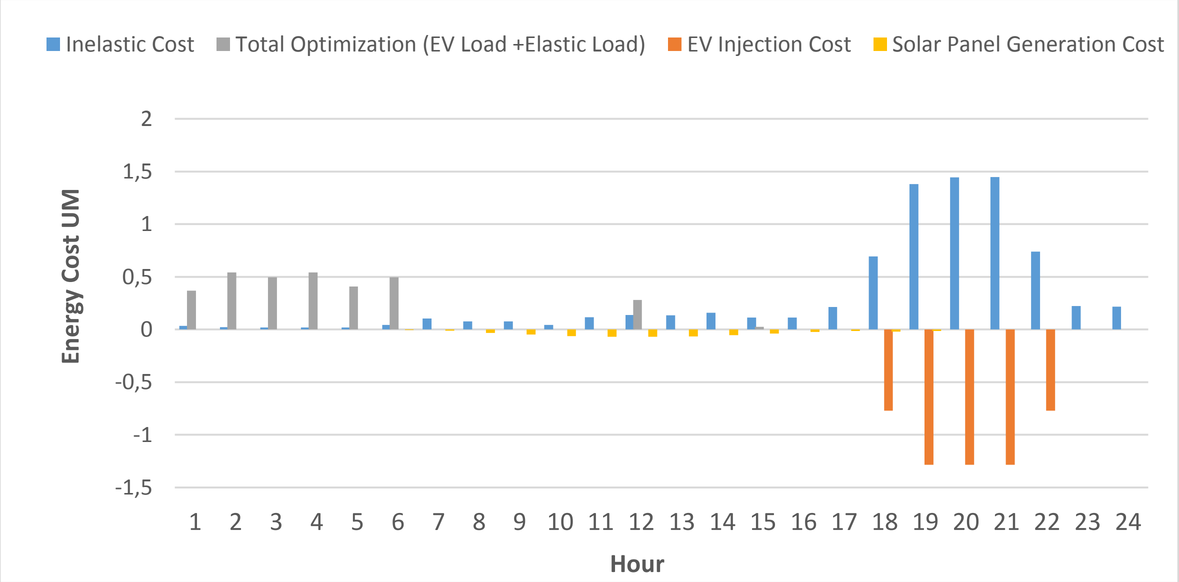

FIGURE 48 - Energy cost for a typical house used on scenario C

4.1.3.1 Voltage Magnitude for Scenario C (pu)

FIGURE 49 present the Voltage magnitude for primary branch in scenario C. In this figure can be noticed that a decreasing of the voltage values in buses 15, 16, 17 and 18, from 0 hours till 6 hour occurs, this happen due to the shifting of the loads to this hours where the energy price is lower. Buses from 1 to 6 present more stability along the day with almost no voltage variations at all. In comparison with the scenario ‘A’ for this branch the characteristics of the curve have presented bigger changes in the periods from 00:00 to 6:00 am and also from 18:00 to 22:00 hours

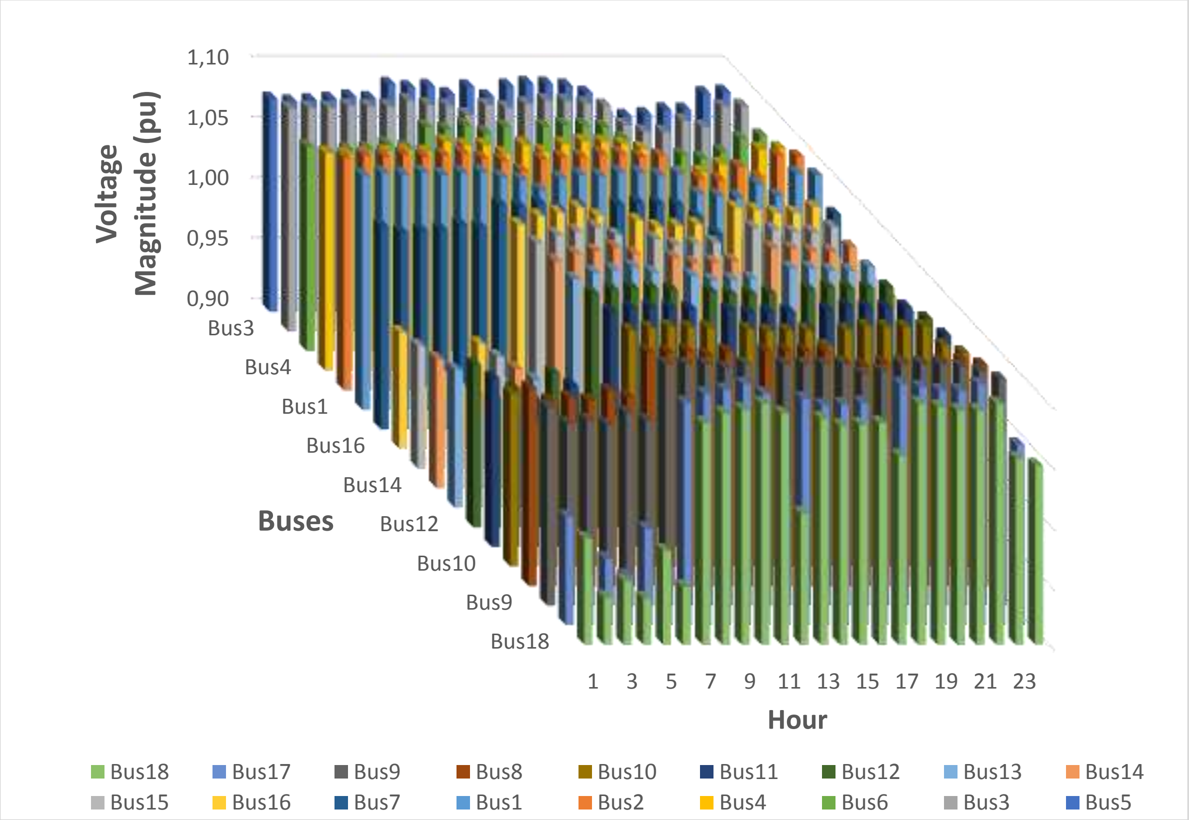

FIGURE 49- Voltage magnitude for primary branch in scenario C

In FIGURE 50, FIGURE 70 and FIGURE 71 are graphed the voltage magnitude variation along the three secondary branches showing its highest and lowest values respectively, and at what period of time are this happening.

For secondary branch ‘A’ in scenario ‘C’, the voltage magnitude in all its busses is presented in the following figure, where minimum voltage magnitude are found at 20 hours at bus 19, as was seen in scenario ‘A’ this bus was working with 1.09 pu voltage magnitude and due to the optimization process has suffered a decreasing in its magnitude to 1.07 pu, for the rest of the buses can be appreciated a similar behavior, higher voltage magnitude on scenario ‘A’ at night hours and lower voltage magnitude at night hours in scenario ‘C’.

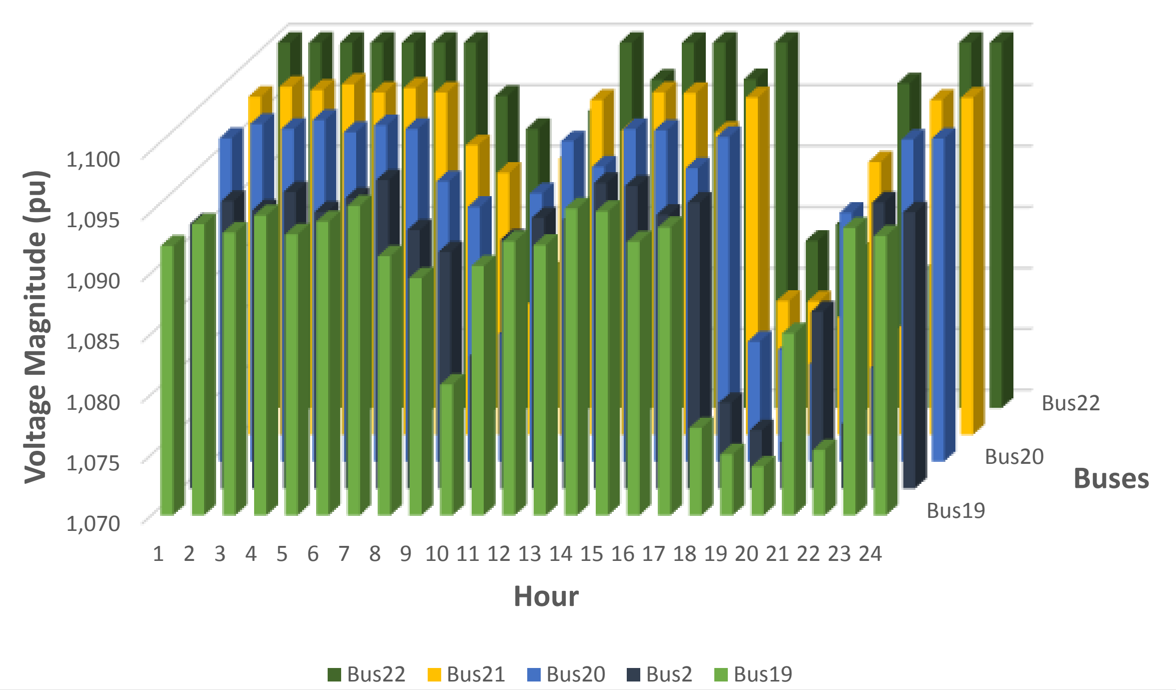

FIGURE 50 - Voltage magnitude for secondary branch ‘A’ in scenario C

4.1.3.2 Lambda Values for Scenario C (UM/MWh)

In FIGURE 51, appear the results for the operational cost values, which are showing a considerable displacement from the scenario ‘A’. For this scenario a maximum peak of 443 UM/MWh at bus 18 can be seen, in comparison with scenario ‘A’ where was possible to find values in the order of 785 UM/MWh at nights hours, where a higher energy price take place.

FIGURE 52, presents the resulting operational values for the secondary ‘A’ branch in scenario C, peak reduction at night hours and a better distribution in the cost along the day in comparison with the scenario ‘A’, can be appreciated. Taking as example bus number 2, this bus have presented a decreasing behavior, in the operational costs, since started working at 643,76 UM/MWh in scenario ‘A’ and for the scenario ‘C’ has a working point in 336 UM/MWh at 20:00 hours.

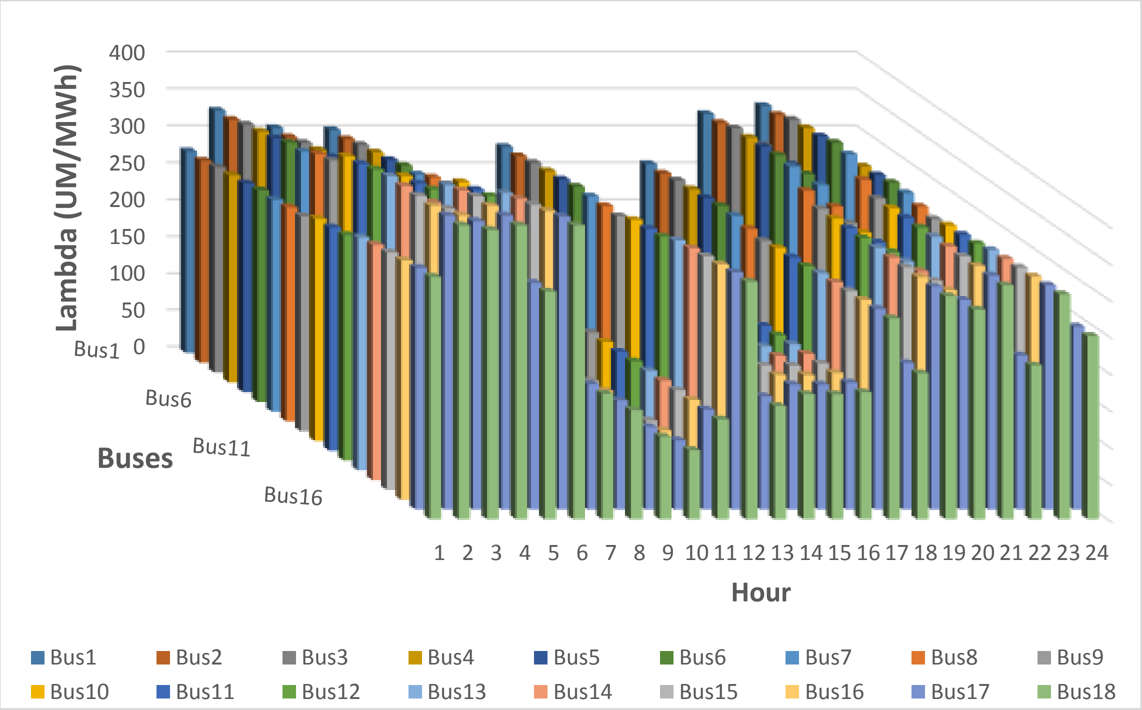

FIGURE 51 - Lambda values for primary branch in scenario C

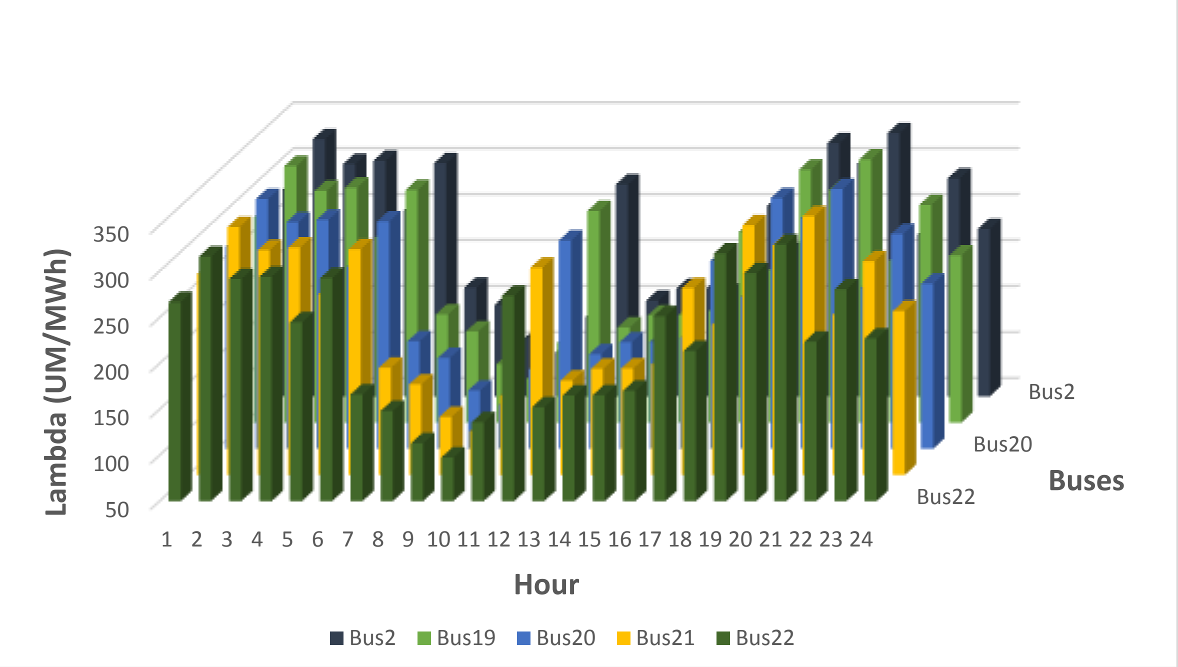

FIGURE 52 - Lambda values for secondary ‘A’ branch in scenario C

4.1.3.3 Branches Active Power Losses for Scenario C (kW)

FIGURE 53, FIGURE 54, FIGURE 74 and FIGURE 75 presents the active power losses for the branches of the system.

For the primary branch can be observed that branches that use to not have losses in scenario ‘A’ are now in scenario ‘C’ presenting. In the first scenario most of the losses were just active at night, meanwhile in this last scenario, can be observed from the graphics that a displacement in these values have occurred. According to the figure that represents the active power losses for the scenario ‘C’, can also be observed that the highest losses values are found in the primary branch and in the secondary ‘C’ branch.

Branches 17, 26 and 31 have the characteristics that are not presenting considerable losses at any time, for this scenario. Maximum losses appear at branch 27 and branch number 9.

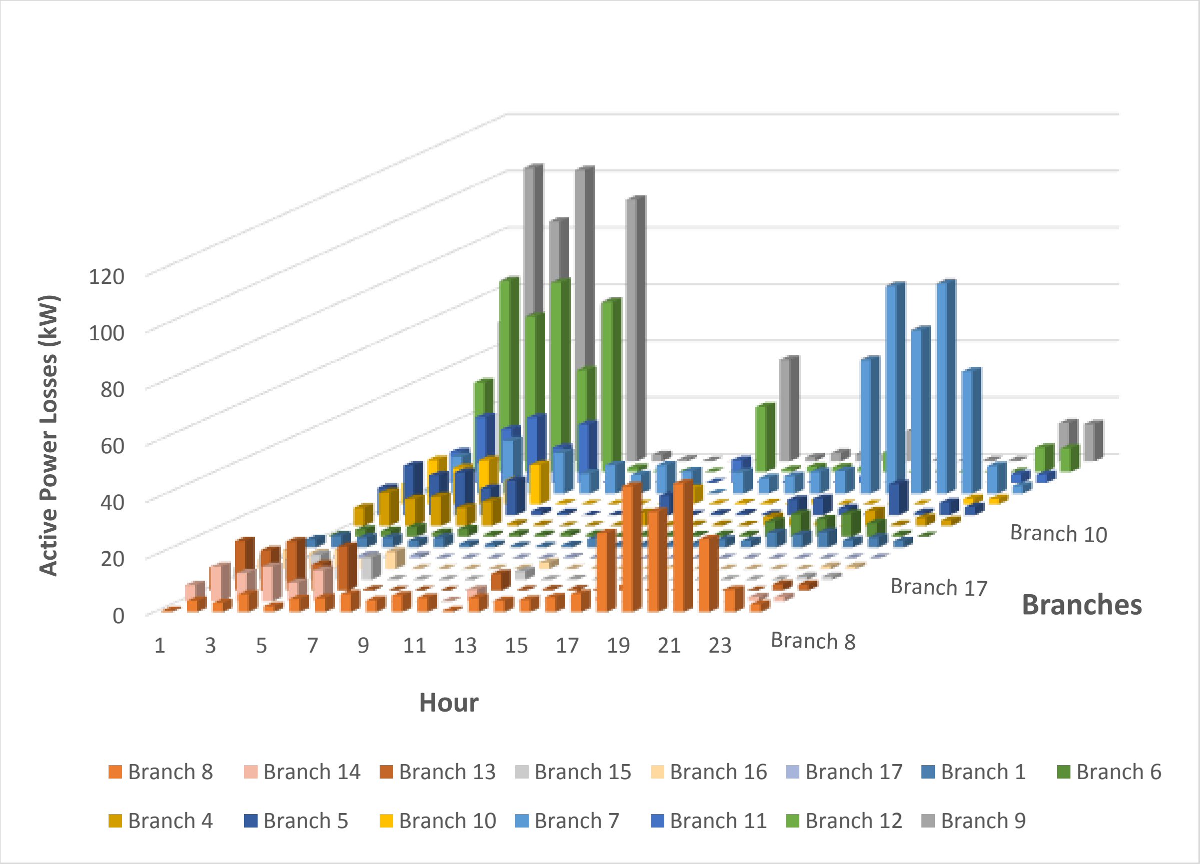

FIGURE 53 - Active power losses for primary branch in scenario C

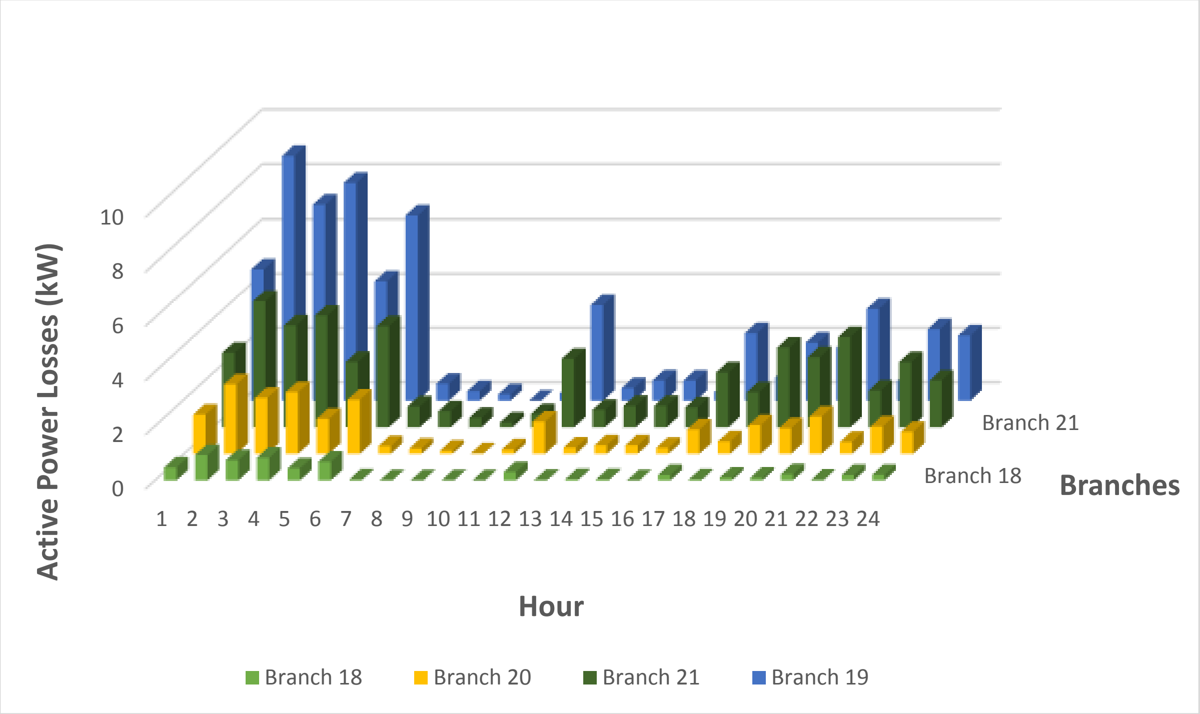

FIGURE 54 - Active power losses for secondary ‘A’ branch in scenario C

4.1.3.4 Active Power Generation for Scenario C

The following graph shows the active power generation for scenario C.

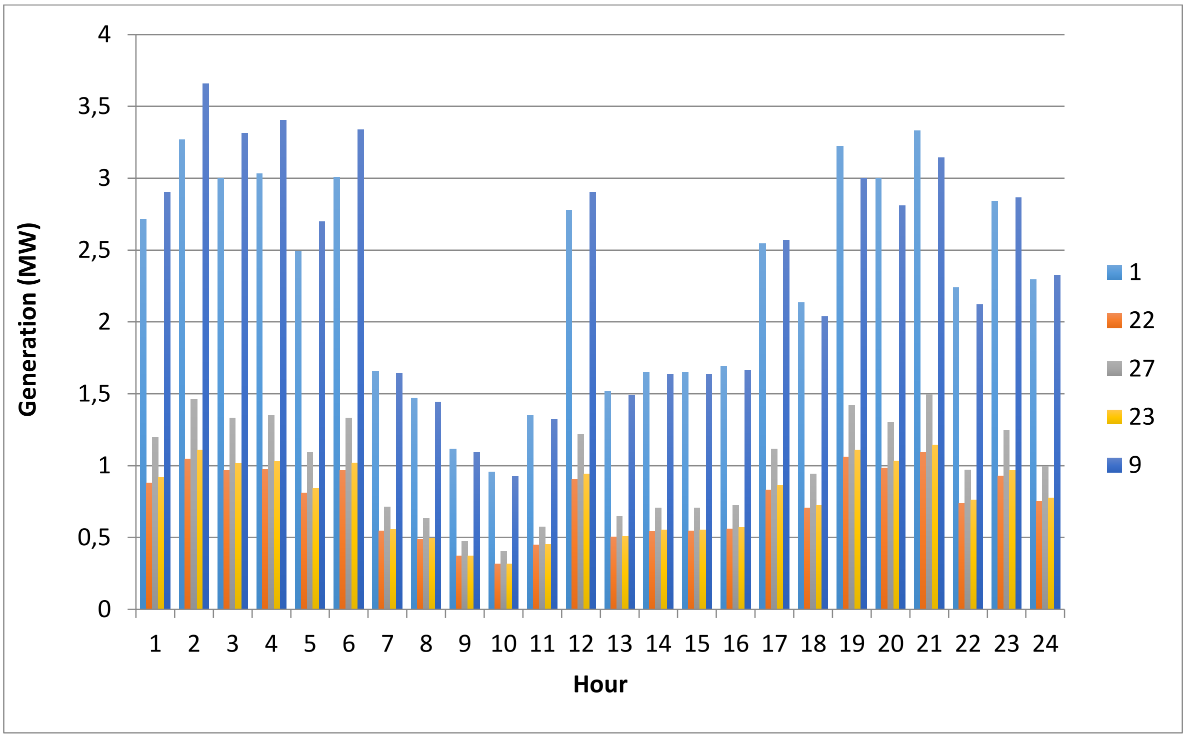

FIGURE 55 - Active power generation for scenario C

4.1.3.5 OPF Objective Function for Scenario C

The following figure shows the objective function variation for scenario C.

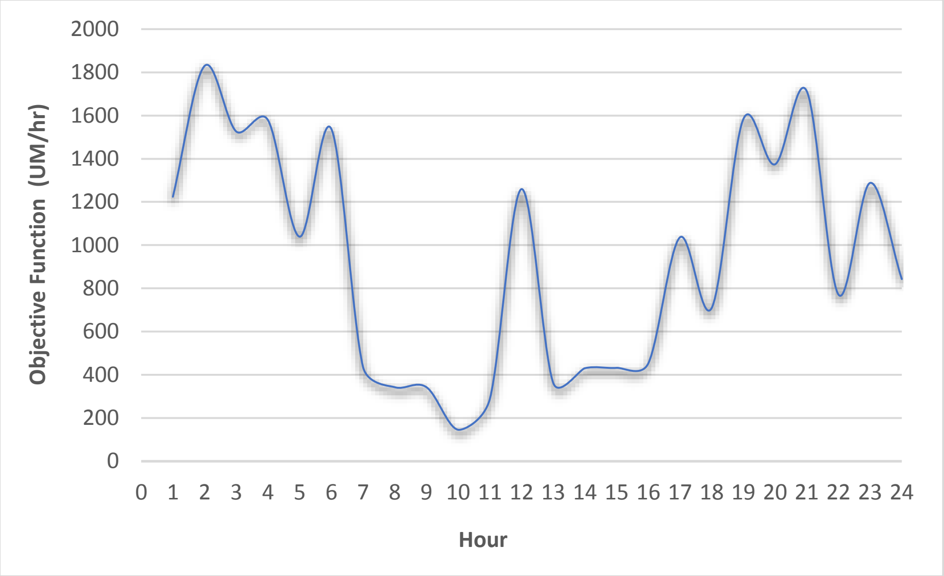

FIGURE 56 - Objective function for the final OPF performed in scenario ‘C’

TABLE 8 - Primary variables analyzed for scenario C

Hour		Voltage Magnitude (pu)				Active Power Losses (MW)		Lambda P (UM/MWh)			
		Min		Max		Max		Min		Max	
	Objective Function	Value (pu)	Bus	Value (pu)	Bus	Value (MW)	Branches From-To	Value (UM/MWh)	Bus	Value (UM/MWh)	Bus
1	1223.78	0.988	18	1.1	22	0.05	9-10	266.49	22	330.37	18
2	1829.16	0.939	18	1.1	22	0.10	9-10	315.99	22	443.61	18
3	1525.68	0.953	18	1.1	22	0.08	9-10	291.6	22	393.97	18
4	1578.73	0.938	18	1.1	22	0.10	9-10	294.09	22	413.16	18
5	1038.66	0.978	18	1.1	22	0.06	9-10	244.83	22	309.97	18
6	1537.69	0.984	18	1.1	22	0.09	9-10	292.51	22	400.19	18
7	435.5	1.051	33	1.1	9	0.01	27-28	166.19	22	180.48	33
8	342.11	1.048	33	1.1	9	0.01	27-28	146.55	9	159.93	33
9	342.11	1.064	33	1.1	9	0.01	7-8	111.36	9	118.24	33
10	144.78	1.057	33	1.1	18	0.01	7-8	94.02	18	101.34	33
11	286.8	1.057	33	1.1	9	0.01	27-28	134.25	9	144.21	33
12	1258.91	1.009	18	1.1	22	0.04	9-10	273.27	22	324.01	18
13	362.19	1.057	33	1.1	9	0.01	27-28	151.1	9	162.55	33
14	429.82	1.058	33	1.1	22	0.01	27-28	165.06	22	177.13	33
15	431.54	1.056	33	1.1	9	0.01	27-28	165.52	22	178.02	33
16	451.79	1.055	33	1.1	9	0.01	27-28	168.76	9	182.01	33
17	1035.71	1.026	33	1.1	22	0.03	27-28	251.5	22	287.83	33
18	708.29	0.982	33	1.1	18	0.07	27-28	198.66	18	253.00	33
19	1583.14	0.972	33	1.1	9	0.09	27-28	302.27	9	386.07	33
20	1373.75	0.992	33	1.1	9	0.06	27-28	283.04	9	346.19	33
21	1712.78	0.956	33	1.1	9	0.13	27-28	316.19	9	418.08	33
22	771	1.002	33	1.1	18	0.05	27-28	209.25	18	254.95	33
23	1287.71	1.025	33	1.1	22	0.03	27-28	280.29	22	321.78	33
24	842.5	1.044	33	1.1	22	0.02	2-3	227.21	22	251.5	33

Is observed from the graphics that the objective function for the system reaches its lowest value at 10 hours and its higher value around 2 hours. The bus with the minimum voltage value appears at 4 hours with a 0.938 pu in bus 18, for that exactly hour a 1.1 pu voltage value appear as max value for this parameter in bus 22. The highest values for the losses were focalized on two branches, the first one that goes from bus 9 to bus 10 and the other one that goes from bus 27 to bus 28, and is in this branch that the peak for the losses of the system is reached at 21 hours, almost 0.13 MW. Basically the lowest lambda values were obtained on the buses 9, 18 and 22, almost varying its frequency of showing along the proposed horizon.

4.2 FINAL ANALYSIS OF THE RESULTS

In this part of the chapter a compilation of the output data from the algorithm is effectuated, principally comparing the results of the scenarios among them.

TABLE 9 presents the convergence values for the two iterative processes that are effectuated for the algorithm proposed. Four different convergence targets were evaluated for ε1 and ε2. For each of these were tested values in the order of: 0.1, 0.01, 0.001 and 0.001. For this dissertation was chosen the following configuration ε1=0,01 and ε2=0,01. The number of iterations in order to reach the convergence limit can be seen in the third column with its respective time spent in the operations.

TABLE 9 - Iterative convergence values for the optimization processes

Value of ε_1	**Value of ε_2**	***Iterations***	***T* (sec.)**
0.1	0.1	3	45
0.01	0.01	6	69
0.001	0.001	19	89
0.0001	0.0001	37	227

In

TABLE 10 a comparison of the power consumed in every scenario and energy reductions are presented, negative values means that an energy injection is taking place. For the three different scenarios similar configurations are set for the amount of inelastic loads and elastic loads, 2.35 MW and 2.30 MW respectively. In terms of amount of power consumed or saved, the scenarios ‘A’ & ’B’ presents the same characteristics, this is because no external sources of energy are considered for this scenarios. For the scenario ‘C’, the EV is considered as an energy source that is available in hours where the energy price is higher, also is considered the energy coming from the solar panel, which is normally available in morning hours. Can be seen on this table that a relief for the power system, due to the combination of the EV injection and the solar panel generation is taking place with a reduction of 1.30 MW daily for all the microgrid.

TABLE 11, the equivalent operational costs are presented using the white tariff as base for the three scenarios. This table resume the monetary behavior for the system and includes the energy purchase cost for the inelastic loads, consumption costs for the elastic loads with the inclusion or not of the EV, depending of the scenario and barely used as a rechargeable battery. Also are analyzed the cost that are involved with the energy generation coming from the EV and the solar panel that was used for the scenario ‘C’. Due to the target of this dissertation, can be appreciated that in this case the value assigned to the inelastic loads remains constant for the three scenarios. It is worth noting that for scenarios ‘B’ & ’C’ the operational costs for the elastic interruptible loads are the same, this happens because of the total loads taken in account in the optimization process, for both cases, is the same. For scenario ‘C’ are presented the costs, that in this scenario, that value represents a direct income to the user, who is able to inject energy to the grid or even to consume it at will. For the scenario ‘B’ a reduction of UM 353.86 is the result for a simple microgrid after have applied the algorithm proposed, almost a 40% comparing it with the scenario ‘A’. For the scenario ‘C’ a reduction of UM 649.17 can be seen, that in comparison with the scenario ‘A’ represents a reduction of 73%, showing the usefulness of the method applied.

Finally, TABLE 12 compares the objective function values and the active power losses and how its behavior is along the day for the three scenarios. Also presents the percentage reduction for both cases. An initial objective function with a value of 38,759.99 UM, which is the result for the optimization process in the scenario ‘A’. Scenarios ‘B’ & ‘C’, with the algorithm proposed presents improvements in their objective functions, 24% and 41% respectively. The initial losses for the system were calculated in scenario ‘A’ giving as result a total of 5,991.45 kW/day, which includes the losses due to the electrical equipment’s and the EV as a rechargeable battery with typical behaviors. The algorithm proposed applied to the scenario ‘B’ and scenario ‘C’ gave as results for the electric power losses a reduction 14% and 18% respectively, in comparison with scenario ‘A’.

As can be seen, TABLE 10, TABLE 11 and TABLE 12 present an executive brief of the main results of this dissertation.

TABLE 10 - Daily energy saving for specific microgrid

Sce	Inelastic Loads (MWh/day)	Elastic Loads + EV Charging (MWh/day)	EV Injection (MWh/day)	Solar Panel Generation (MWh/day)	Total Energy (MWh/day)	Energy Reduction (MW/day)
A	2.35	2.30	-	-	4.65	-
B	2.35	2.30	-	-	4.65	-
C	2.35	2.30	-0.94	-0.36	3.36	1.30

TABLE 11 - Energy comparative costs (UM/day) for specific microgrid

Sce	Inelastic Costs (UM/day)	Elastic Costs + EV Charge Costs (UM/day)	EV Injection Costs (UM/day)	Solar Panel Generation Cost (UM/day)	Total Costs (UM/day)	Reduction (UM/day)
A	379.81	511.81	-	-	891.62	-
B	379.81	157.95	-	-	537.76	353.86
C	379.81	157.95	-269.35	-25.96	242.45	649.17

TABLE 12 - Comparison of objective functions & total active power losses

Sce	Total Objective Function (UM/day)	Objective Function Reduction (%)	Total Active Power Losses (kW/day)	Active Power Losses Reduction (%)
A	38,759.99	-	5,991.45	-
B	29,233.76	24.58	5,101.91	14.85
C	22,534.13	41.86	4,889.99	18.38

As can be seen in FIGURE 57 is shown the three objective functions plotted over the same axes, in order to compare its behavior through the three scenarios. For scenario “A” a peak at night can be observed with a value close to the 8000 UM/hr, for scenario “B” a maximum value of 3000 UM/hr and for scenario “C” a maximum value of 2000 UM/hr is

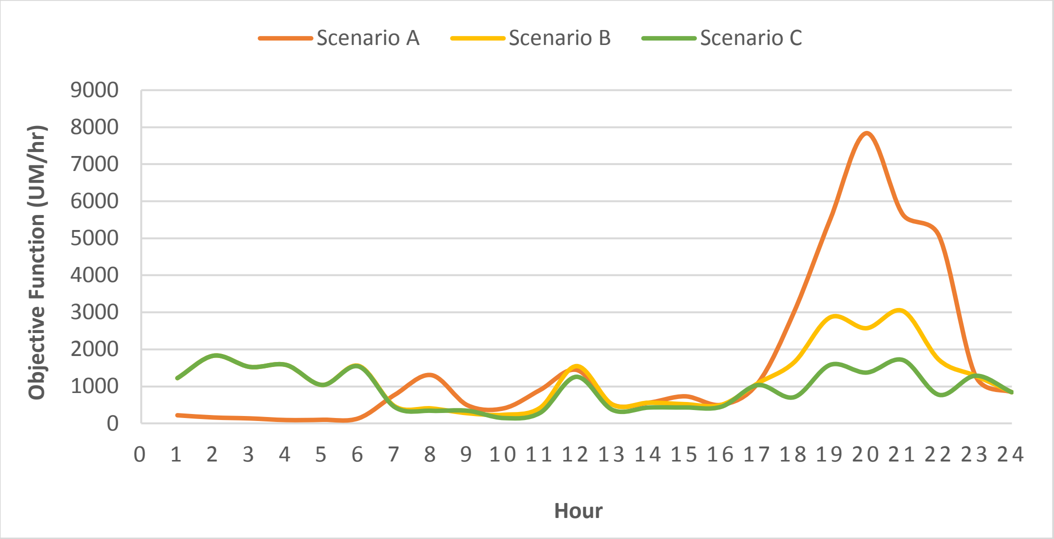

FIGURE 57 Objective Functions for Scenarios A, B and C.

5 CONCLUSION AND FUTURE WORK

A summary of this dissertation and the main findings are presented in this Chapter. An analytical evaluation of the method used is also given along with proposals for future investigations.

5.1 CONCLUDING REMARKS

In this dissertation a computational method for an optimal scheduling for demand response and electric vehicle in a typical house under a microgrid environment and its impact on the electric power distribution networks along a 24 hours-daily horizon has been presented. The proposed method is a system of systems (SoS) based framework for optimally operating an active distribution grid. The proposed SoS framework defines both distribution company (DISCO) and microgrids (MGs) as autonomous systems, and recognizes the exchange information process among them. A hierarchical optimization algorithm is presented to coordinate the independent systems in order find the optimal operating point of the SoS-based active distribution grid.

The proposed method allows an optimized scheduling of demand response to end-user in the microgrid level, with the development of the computational model for residential controllable (Elastic interruptible) and uncontrollable (Inelastic) loads, also were considered their impacts on the distribution network simultaneously. Also examine the additional benefits of demand response programming, distributed generation, integration of electric vehicles modeling in the microgrid. A case of study containing three scenarios, have revealed the usefulness and effectiveness of the proposed model.

This dissertation also analyses current researches on System of Systems, smart grid, load modeling, electric vehicle and demand response. A demand response scheme is proposed to manage residence and microgrid jointly. Residential loads, as well as EVs and solar panels, are modeled, into the different scenarios. Scenarios of study are executed at diverse load scheduling levels. The focus is to set the best possible optimized values that will enter into the distribution network. Also to study the daily demand variation curve due the optimal shifting behavior of the controllable loads and validate the optimization process based on its objective function.

In specific, this dissertation examined the interaction of the microgrid, its elements and the distribution network, also examined the scheduling operations problems inside the microgrid and how this affects into the radial distribution network systems.

A case of study containing three scenarios reveals the usefulness and effectiveness of the proposed model. The reduction of the active power losses and the reduction of the objective function value are some of the main contributions of the algorithm proposed, besides of the savings that were observed in every simulation.

5.2 FUTURE WORKS

Future investigations and research work will be underlined on numerous features of the recommended method and its respective applications, due to the amplitude of the study field.

An economic dispatch could be run for future scenarios with and without the Electric Vehicle demand and varying the types of renewable energy, the outputs of this study could be used to analyze the total system costs with and without EV.

The quantification of benefits and costs related to EV coordination for ancillary services and local grid support are not addressed. Such analysis can bring to light which of the different concepts applied on the SoS, are the most immediately applicable, considering the needs of the different places where the algorithm could be applied.

Although the use of smart appliances was not considered in the proposed dissertation, it could be included with such price-based DR methods. Mixing additional elements in the grid is another aspect that could provide interesting results. First, integrating distributed energy storage at the distribution level would provide additional elasticity, and could contribute to temporarily reduce the net load during demand peaks, by serving as a buffer and a complement or competitor to DR. Second, the integration of larger shares of DG resources could enable microgrid islanding. Although distribution PV resources are currently considered, larger DG sources could be added, and their impact on the operation of the system evaluated.

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APPENDIX A – EV PHEV & models on the actual market

Automotive Brand	Model	Production	Battery Size (kW)	Battery Type	Charging Capacity (kWh)	Certified Battery Range (Km)	Charging Time (h)	Charging Type	Ref
Mitsubishi	i-MiEV	2009-present	16	Lithium-ion	3.6	160	7	SAE J1772-2009 inlet, adapters for domestic AC sockets (110-240 V)	[74]
Nissan	Leaf	2013	24	Lithium-ion	3.3	200	8	240 V AC on SAE J1772-2009 inlet, adapters for domestic AC sockets (110-240 V)	[75]
Renault	Fluence Zoe	2013-present	22	Lithium-ion	3.5	185	7	On-board charger (230 V 15 A), optional upgrade to Zoe's Chameleon charger (43 kW)	[76]
Honda	Fit EV	2013	20	Lithium-ion	7	132	3	240-volt outlet	[77]
Tesla	Model S	2013-present	85	Lithium-ion	11	426	4.6	85-265 V onboard charger for 1φ 40 A or 3φ 16 A [5] on IEC Type 2 inlet[6]	[78]
Chevrolet	Spark EV	2013	21,3	Nano phosphate lithium-ion	3	132	7	240-volt charging station	[79]
Volkswagen	e-Up!	2010-present	18,7	Lithium-ion	3.3	160	5	Regular 230 volt plug	[80]
Ford	Focus Electric	2011-present	23	Lithium-ion	6.6	122	4	Onboard charger on SAE-J1772-2009 inlet	[81]

Automotive Brand	Model	Production	Battery Size (kW)	Battery Type	Charging Capacity (kWh)	Certified Battery Range (Km)	Charging Time (h)	Charging Type	Ref
BMW	i3	2014	18.8	Lithium-ion	7.4	240	3	On-board charger on IEC Combo AC, optional Combo DC	[82]
Toyota	iQ	2013	12	Lithium-ion	4	85	3	On-board charger on IEC Combo AC, optional Combo DC	[83]
Fiat	500e	2013/2014	24	Lithium iron phosphate	6	120	4	Level 2 (240 volt) on-board charging module	[84]
Daimler AG	Smart ED	2009-present	16.5	Lithium-ion	3.3	135	4	On-board charger	[85]
Toyota	Prius	2011-present	4.4	Lithium-ion	1.3	870	3	On-board charger	[86]
Mitsubishi	Outlander	2012-present	12	Lithium-ion	3.5	990	3	On-board charger	[87]

APPENDIX B – Modified case for the 33 buses radial distribution network.

```
function mpc = T_case33
%   CASE33    Power flow data for 33 bus modified, 4 generator case.
%   Please see CASEFORMAT for details on the case file format.
%% MATPOWER Case Format : Version 2
mpc.version = '2';
%%-----  Power Flow Data  -----%%
%% system MVA base
mpc.baseMVA = 100;
Vbase = 12.66*(10^3);
Sbase = 100*(10^6);
Zbase = (Vbase^2)/Sbase;

%% bus data
%  BUS_TYPE (1 = PQ. Load Bus
%            2 = PV. Generation Bus
%            3 = ref. Swing Bus
%            4 = isolated
%
%             bus_i   type    Pd      Qd       Gs       Bs area  Vm         Va    baseKV  zone  Vmax    Vmin
mpc.bus = [
                1       3   0.0000  0.0000      0       0   1   1.00         0      12.66   1   1.10    0.90;
                2       1   0.1000  0.0600      0       0   1   1.00         0      12.66   1   1.10    0.90;
                3       1   0.0900  0.0400      0       0   1   1.00         0      12.66   1   1.10    0.90;
                4       1   0.1200  0.0800      0       0   1   1.00         0      12.66   1   1.10    0.90;
                5       1   0.0600  0.0300      0       0   1   1.00         0      12.66   1   1.10    0.90;
                6       1   0.0600  0.0200      0       0   1   1.00         0      12.66   1   1.10    0.90;
                7       1   0.2000  0.1000      0       0   1   1.00         0      12.66   1   1.10    0.90;
                8       1   0.2000  0.1000      0       0   1   1.00         0      12.66   1   1.10    0.90;
                9       2   0.0600  0.0200      0       0   1   1.00         0      12.66   1   1.10    0.90;
                10      1   0.0600  0.0200      0       0   1   1.00         0      12.66   1   1.10    0.90;
                11      1   0.0450  0.0300      0       0   1   1.00         0      12.66   1   1.10    0.90;
                12      1   0.0600  0.0350      0       0   1   1.00         0      12.66   1   1.10    0.90;
                13      1   0.0600  0.0350      0       0   1   1.00         0      12.66   1   1.10    0.90;
                14      1   0.1200  0.0800      0       0   1   1.00         0      12.66   1   1.10    0.90;
                15      1   0.0600  0.0100      0       0   1   1.00         0      12.66   1   1.10    0.90;
                16      1   0.0600  0.0200      0       0   1   1.00         0      12.66   1   1.10    0.90;
```

```
            17     1   0.0600  0.0200     0      0   1   1.00       0      12.66   1   1.10    0.90;
            18     1   0.0900  0.0400     0      0   1   1.00       0      12.66   1   1.10    0.90;
            19     1   0.0900  0.0400     0      0   1   1.00       0      12.66   1   1.10    0.90;
            20     1   0.0900  0.0400     0      0   1   1.00       0      12.66   1   1.10    0.90;
            21     1   0.0900  0.0400     0      0   1   1.00       0      12.66   1   1.10    0.90;
            22     2   0.0900  0.0400     0      0   1   1.00       0      12.66   1   1.10    0.90;
            23     2   0.0900  0.0500     0      0   1   1.00       0      12.66   1   1.10    0.90;
            24     1   0.4200  0.2000     0      0   1   1.00       0      12.66   1   1.10    0.90;
            25     1   0.4200  0.2000     0      0   1   1.00       0      12.66   1   1.10    0.90;
            26     1   0.0600  0.0250     0      0   1   1.00       0      12.66   1   1.10    0.90;
            27     2   0.0600  0.0250     0      0   1   1.00       0      12.66   1   1.10    0.90;
            28     1   0.0600  0.0200     0      0   1   1.00       0      12.66   1   1.10    0.90;
            29     1   0.1200  0.0700     0      0   1   1.00       0      12.66   1   1.10    0.90;
            30     1   0.2000  0.6000     0      0   1   1.00       0      12.66   1   1.10    0.90;
            31     1   0.1500  0.0700     0      0   1   1.00       0      12.66   1   1.10    0.90;
            32     1   0.2100  0.1000     0      0   1   1.00       0      12.66   1   1.10    0.90;
            33     1   0.0600  0.0400     0      0   1   1.00       0      12.66   1   1.10    0.90;
];
%% generator data
%          bus  Pg  Qg  Qmax  Qmin  Vg  mBase  status  Pmax  Pmin  Pc1 Pc2 Qc1min  Qc1max  Qc2min  Qc2max  ramp_agc
ramp_10 ramp_30 ramp_q  apf
mpc.gen = [
           1   7   0   7   -7   1   100     1      10  0  0   0  0  0  0  0  0  0  0  0  0;
          22   2   0   2   -2   1   100     1      3   0  0   0  0  0  0  0  0  0  0  0  0;
          27   3   0   3   -3   1   100     1      4   0  0   0  0  0  0  0  0  0  0  0  0;
          23   2   0   3   -3   1   100     1      3   0  0   0  0  0  0  0  0  0  0  0  0; % era 23
           9   7   0   7   -7   1   100     1      10  0  0   0  0  0  0  0  0  0  0  0  0;
           ];
%% branch data
%fbus tbus        r              x           b  rateA rateB   rateC   ratio   angle   status  angmin  angmax
mpc.branch = [
    1   2   0.0922/Zbase   0.0477/Zbase   0   0   0   0   0   0   1   -360    360;
    2   3   0.4930/Zbase   0.2511/Zbase   0   0   0   0   0   0   1   -360    360;
    3   4   0.3660/Zbase   0.1840/Zbase   0   0   0   0   0   0   1   -360    360;
    4   5   0.3811/Zbase   0.1941/Zbase   0   0   0   0   0   0   1   -360    360;
    5   6   0.8190/Zbase   0.0700/Zbase   0   0   0   0   0   0   1   -360    360;
    6   7   0.1872/Zbase   0.6188/Zbase   0   0   0   0   0   0   1   -360    360;
    7   8   1.7114/Zbase   1.2351/Zbase   0   0   0   0   0   0   1   -360    360;
    8   9   1.0300/Zbase   0.7400/Zbase   0   0   0   0   0   0   1   -360    360;
    9   10  1.0400/Zbase   0.7400/Zbase   0   0   0   0   0   0   1   -360    360;
```

```
    10  11  0.1966/Zbase    0.0650/Zbase    0   0   0   0   0   0   1   -360    360;
    11  12  0.3744/Zbase    0.1238/Zbase    0   0   0   0   0   0   1   -360    360;
    12  13  1.4680/Zbase    1.1550/Zbase    0   0   0   0   0   0   1   -360    360;
    13  14  0.5416/Zbase    0.7129/Zbase    0   0   0   0   0   0   1   -360    360;
    14  15  0.5910/Zbase    0.5260/Zbase    0   0   0   0   0   0   1   -360    360;
    15  16  0.7463/Zbase    0.5450/Zbase    0   0   0   0   0   0   1   -360    360;
    16  17  1.2890/Zbase    1.7210/Zbase    0   0   0   0   0   0   1   -360    360;
    17  18  0.7320/Zbase    0.5740/Zbase    0   0   0   0   0   0   1   -360    360;
    2   19  0.1640/Zbase    0.1565/Zbase    0   0   0   0   0   0   1   -360    360;
    19  20  1.5042/Zbase    1.3554/Zbase    0   0   0   0   0   0   1   -360    360;
    20  21  0.4095/Zbase    0.4784/Zbase    0   0   0   0   0   0   1   -360    360;
    21  22  0.7089/Zbase    0.9373/Zbase    0   0   0   0   0   0   1   -360    360;
    3   23  0.4512/Zbase    0.3083/Zbase    0   0   0   0   0   0   1   -360    360;
    23  24  0.8980/Zbase    0.7091/Zbase    0   0   0   0   0   0   1   -360    360;
    24  25  0.8960/Zbase    0.7011/Zbase    0   0   0   0   0   0   1   -360    360;
    6   26  0.2030/Zbase    0.1034/Zbase    0   0   0   0   0   0   1   -360    360; %%
    26  27  0.2842/Zbase    0.1447/Zbase    0   0   0   0   0   0   1   -360    360;
    27  28  1.0590/Zbase    0.9337/Zbase    0   0   0   0   0   0   1   -360    360;
    28  29  0.8042/Zbase    0.7006/Zbase    0   0   0   0   0   0   1   -360    360;
    29  30  0.5075/Zbase    0.2585/Zbase    0   0   0   0   0   0   1   -360    360;
    30  31  0.9744/Zbase    0.9630/Zbase    0   0   0   0   0   0   1   -360    360;
    31  32  0.3105/Zbase    0.3619/Zbase    0   0   0   0   0   0   1   -360    360;
    32  33  0.3410/Zbase    0.5302/Zbase    0   0   0   0   0   0   1   -360    360;
    ];
%%-----  OPF Data  -----%%
%% generator cost data
%               1   startup shutdown    n   x1  y1  ... xn  yn
%               2   startup shutdown    n   c(n-1)  ... c0
mpc.gencost = [
                2   0   0   3   50      2       0;
                2   0   0   3   150     1.75    0;
                2   0   0   3   120     1       0;
                2   0   0   3   150     3.25    0;
                2   0   0   3   50      2       0;
               ];
end
```

APPENDIX C – Matrix structure for MG resolution applying MILP

$$
\left[\begin{array}{cccccccc}
\sum_{k=1}^{N_{Elast_Load}} P_{k,t}^{Elast_Load} * X_{k,t}^{Elast_Load} & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] \\
[0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & \sum_{j=1}^{N_{EV}} \eta_j^{EV_Charging} * EV_{j,t}^{Power_Charged} * X_{j,t}^{EV} & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] \\
[0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & \sum_{j=1}^{N_{EV}} \eta_j^{EV_Discharging} * EV_{j,t}^{Power_Discharged} * Y_{j,t}^{EV} & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] \\
\sum_{k=1}^{N_{Elast_Load}} P_{k,t}^{Elast_Load} * X_{k,t}^{Elast_Load} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \sum_{j=1}^{N_{EV}} \eta_j^{EV_Charging} * EV_{j,t}^{Power_Charged} * X_{j,t}^{EV} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} \\
-\sum_{k=1}^{N_{Elast_Load}} X_{k,t}^{Elast_Load} & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] \\
[0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & \sum_{j=1}^{N_{EV}} X_{j,t}^{EV} & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] \\
[0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & [0\;\dots\;0] & \sum_{j=1}^{N_{EV}} Y_{j,t}^{EV} & [0\;\dots\;0] & [0\;\dots\;0] \\
X_{k,t}^{Elast_Load} + X_{k,(t-1)}^{Elast_Load} & -Y_{k,t}^{Aux_ON} & Z_{k,t}^{Aux_OFF} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} \\
\begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & Y_{k,t}^{Aux_ON} & -Z_{k,t}^{Aux_OFF} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} \\
\begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & Y_{k,t}^{Aux_ON} & \sum_{l=1}^{MUT-1} Z_{k,(t+l)}^{Aux_OFF} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} \\
\begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & X_{j,t}^{EV} & Y_{j,t}^{EV} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} \\
\begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & -\eta_j^{EV_Charging} * EV_{j,t}^{Power_Charged} & \left[\frac{1}{\eta_j^{EV_Discharging}}\right] * EV_{j,t}^{Power_Discharged} & V_{j,t}^{Energy_Stored} - EV_{j,(t-1)}^{Energy_Stored} + EV_{j,t}^{Energy_T} \\
\begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & -EV_{j,t}^{Max_Power_Charged} * X_{j,t}^{EV} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & EV_{j,t}^{Power_Charged} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} \\
\begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & EV_{j,t}^{Max_Power_Discharged} * Y_{j,t}^{EV} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & EV_{j,t}^{Power_Discharged} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} \\
\begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \left[\frac{1}{\eta_j^{EV_Discharging}}\right] * EV_{j,t}^{Power_Discharged} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & -EV_{j,(t-1)}^{Energy_Stored} \\
\begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \eta_j^{EV_Charging} * EV_{j,t}^{Power_Charged} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & \begin{pmatrix}0&\cdots&0\\ \vdots&\ddots&\vdots\\ 0&\cdots&0\end{pmatrix} & EV_{j,(t-1)}^{Energy_Stored}
\end{array}\right]
\begin{array}{c}
\leq \\ \leq \\ \leq \\ \leq \\ \leq \\ \leq \\ \leq \\ = \\ \leq \\ \leq \\ \leq \\ = \\ \leq \\ \leq \\ \leq \\ \leq
\end{array}
\left[\begin{array}{c}
P_{k,t}^{Elast_Load} * Duration_k^{Elast_Load} * Cycles_k^{Elast_Load} \\
EV_{j,t}^{Power_Charged} * Duration_j^{EV_Charging} * Cycles_j^{EV_Charging} \\
EV_{j,t}^{Power_Discharged} * Duration_j^{EV_Discharging} * Cycles_j^{EV_Discharging} \\
Consumption_t^{Max_Hourly} \\
-Duration_k^{Elast_Load} * Cycles_k^{Elast_Load} \\
-Duration_j^{EV_Charging} * Cycles_j^{EV_Charging} \\
Duration_j^{EV_Discharging} * Cycles_j^{EV_Discharging} \\
0 \\
1 \\
1 \\
1 \\
0 \\
0 \\
0 \\
0 \\
\beta_j^{max}
\end{array}\right]
$$

APPENDIX D – Mixed integer linear programming formulation.

Mixed-integer linear programming (MILP) problems can be solved in a centralized fashion using the powerful solvers nowadays available. Branch and cut techniques that have been developed during the last decade of the twen- tieth century allow us, using personal computers, to solve problems at least two orders of magnitude larger than those problems solvable before the devel- opment of such branch and cut techniques [42]. Alternatively, MILP problems can be decomposed to separate integer and continuous variables, which is equivalent to considering the integer variables as complicating variables. The resulting continuous subproblem may be decomposed by blocks. In this case, such decomposable structure can be usually exploited computationally to develop efficient algorithms. This situation often arises in practice, particularly, in long-term multiperiod investment planning problems. Investment decisions are integer while operation decisions are continuous and often separable by a time period.

The case of complicating constraints in MILP problems is not so common in practice. A decomposition technique similar to the Dantzig-Wolfe decom- position for such type of problems is denominated “Branch and Price.” This rather specific decomposition technique is computationally involved and is not addressed in this book.

A general MILP problem has the form

Objective function:

$$\min_{x_1,\dots,x_n;y_1,\dots,y_m} \sum_{i=1}^{n} c_1 x_1 + \sum_{j=1}^{m} d_j y_j \qquad \text{Eq 22}$$

Subject to

$$\sum_{i=1}^{n} a\ell_1 x_1 + \sum_{j=1}^{m} e\ell_j y_j = b_\ell;\ \forall \ell = 1,\dots,q \qquad \text{Eq 23}$$

$$x_i^{down} \le x_i \le x_i^{up}, x_i \in \mathbb{N};\ i = \{1,\dots,n\} \qquad \text{Eq 24}$$

$$y_i^{down} \le y_i \le y_i^{up}, y_i \in \mathbb{R};\ j = \{1,\dots,m\} \qquad \text{Eq 25}$$

Note that upper and lower bounds have been imposed on optimization variables. This reflects what happens in most engineering and science problems and simplifies the mathematical treatment required. The most common integer variables in real world applications are binary variables. Note that any integer variable can be substituted by a set of binary variables, as shown below.

$$\mathrm{x} = \{\,\mathrm{a}_1\ \mathrm{a}_2, \ldots, \mathrm{a}_\mathrm{n}\} \qquad \text{Eq 26}$$

Can be substituted by n binary variables as follows:

$$\mathrm{x} = \sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{a}_\mathrm{i}\,\mathrm{u}_\mathrm{i} \qquad \text{Eq 27}$$

$$\sum_{\mathrm{i}=1}^{\mathrm{n}} \mathrm{u}_1 = 1 \qquad \text{Eq 28}$$

$$\mathrm{u}_\mathrm{i}\ \in \{0,1\};\ \ \mathrm{i} = \{1, \ldots, \mathrm{n}\}$$

APPENDIX E - Electrical Equipment Consumption

Electrical equipment	Type of Load	Consumption kWh/h	Consumption Wh/h
Air conditioner (compact or split) 2300 fg / h	Inelastic	0.99	990
Vacuum (large)	Elastic	0.35	350
Blender (arm)	Inelastic	0.2	200
Heater (large)	Inelastic	2.5	2500
Water Heater Tank	Inelastic	1.5	1500
Heater (medium)	Inelastic	2	2000
Computer	Inelastic	0.36	360
DVD	Inelastic	0.025	25
Audio Equipment (small)	Inelastic	0.018	18
Stereo	Inelastic	0.075	75
Exhaust Fan (kitchen)	Inelastic	0.12	120
Freezer (1100 fg / h)	Inelastic	0.15	150
Microwave	Inelastic	1.3	1300
100 W Lamp	Inelastic	0.1	100
60 W Lamp	Inelastic	0.06	60
75 W Lamp	Inelastic	0.075	75
Automatic Washing Machine	Elastic	2.2	2200
Semiautomatic or Manual Washing	Elastic	0.7	700
Blender	Inelastic	0.35	350
Cleaner Polishes	Elastic	0.3	300
Sewing Machine	Elastic	0.075	75
Iron (for clothes) Automatic	Elastic	1	1000
Iron (clothes) Common	Elastic	0.55	550
Food Processor	Inelastic	0.25	250
Air Purifier	Inelastic	0.1	100
Radio	Inelastic	0.08	80
Tape Recorder (small)	Inelastic	0.008	8
Tape Recorder with CD	Inelastic	0.038	38
Refrigerator (13 feet)	Inelastic	0.265	265
Refrigerator with Freezer (¼ HP)	Inelastic	0.184	184
Refrigerator with Freezer (½ HP)	Inelastic	0.368	368
Ventilator	Inelastic	0.065	65
Medium Hair Dryer	Elastic	0.7	700
Centrifugal Dryer	Elastic	0.2	200
Dryer with Resistance	Elastic	2	2000
TV (21 ")	Inelastic	0.115	115
TV (29 ")	Inelastic	0.205	205
Toaster	Inelastic	0.8	800
Fluorescent Tube (105 Wh)	Inelastic	0.135	135
Turbofan	Inelastic	0.184	184
Ceiling Fan (small)	Inelastic	0.1	100
Fan (large)	Inelastic	0.2	200
Fan (medium)	Inelastic	0.1	100
Shower	Elastic	3.5	3500
Juicer	Inelastic	0.25	250
Water Pump	Inelastic	0.4	400

Coffee Pot	Inelastic	0.7	700
Dish Washer	Elastic	1.5	1500

APPENDIX F – Optimal Power Flow Formulation using Matpower.

Objective function

$$\min_{\mathrm{x}} \mathrm{f(x)} \qquad \text{Eq 29}$$

Subject to

$$g(x) = 0 \qquad \text{Eq 30}$$

$$h(x) \leq 0 \qquad \text{Eq 31}$$

$$x_{min} \leq x \leq x_{max} \qquad \text{Eq 32}$$

The optimization vector x for the standard AC OPF problem consists of the $\mathrm{n_b}$ x 1 vectors of voltage angles Θ and magnitudes $\mathrm{V_m}$ and the $\mathrm{n_g}$ x 1 vectors generator real and reactive power injections $\mathrm{P_g}$ and $\mathrm{Q_g}$.

$$x = \begin{bmatrix} \Theta \\ V_m \\ P_g \\ Q_g \end{bmatrix} \qquad \text{Eq 33}$$

The objective function is simply a summation of individual polynomial cost functions $\mathrm{f_P^i}$ and $\mathrm{f_Q^i}$ of real and reactive power injections, respectively, for each generator:

$$\min_{\Theta, V_m, P_g, Q_g} \sum_{i=1}^{n_g} f_P^i(p_g^i) + f_P^i(q_g^i) \qquad \text{Eq 34}$$

The equality constraints in Eq 30. are simply the full set of 2*$\mathrm{n_b}$ nonlinear real and reactive power balance equations. The inequality constraints Eq 32 consist of two sets of $\mathrm{n_l}$ branch flow limits as nonlinear functions of the bus voltage angles and magnitudes, one for the from end and one for the to end of each branch:

$$h_f(\Theta, V_m) = \left|F_f(\Theta, V_m)\right| - F_{max} \leq 0 \qquad \text{Eq 35}$$

$$h_t(\Theta, V_m) = |F_t(\Theta, V_m)| - F_{max} \leq 0 \qquad \text{Eq 36}$$

The flows are typically apparent power flows expressed in MVA, but can be real power or current flows, yielding the following three possible forms for the flow constraints:

$$F_f(\Theta, V_m) = \begin{matrix} S_f(\Theta, V_m), & \textit{apparent power} \\ P_f(\Theta, V_m), & \textit{real power} \\ I_f(\Theta, V_m)\,, & \textit{current} \end{matrix} \qquad \text{Eq 37}$$

Where $\mathrm{I_f}$ (Current at the ‘from’ bus) is defined by the admittance matrix multiplied by the voltage node, $\mathrm{S_f}$ is the complex power injection, $\mathrm{P_f} = \mathrm{R}\{\mathrm{S_f}\}$ and the vector of flow limits $\mathrm{F_{max}}$ has the appropriate units for the type of constraints. It is like for $\mathrm{F_t}(\Theta, \mathrm{V_m})$. The variable limits Eq 33 include an equality constraint on any reference bus angle and upper and lower limits on all bus voltage magnitudes and real and active generator injections.

$$\theta_i^{ref} \leq \theta_i \leq \theta_i^{ref}, \qquad i \,\epsilon\, \Im_{ref} \qquad \text{Eq 38}$$

$$v_m^{i,min} \leq v_m^i \leq v_m^{i,max}, \qquad i = 1, \dots, n_b \qquad \text{Eq 39}$$

$$p_g^{i,min} \leq p_g^i \leq p_g^{i,max}, \qquad i = 1, \dots, n_g \qquad \text{Eq 40}$$

$$q_g^{i,min} \leq q_g^i \leq q_g^{i,max}, \qquad i = 1, \dots, n_g \qquad \text{Eq 41}$$

APPENDIX G – Pseudocode for SoS application and resolution

```
Step 0:

Set: iteration count, i=0; convergence target error ε1and ε2 at (0,01)
Set Initial Values for OPF Objective function Values (OPFOV_i) = Infinite
Set White tariff for each hour.
Set initial Objective Function value  for Microgrid  (MGOV_i)=Infinite
Define appropriately the horary Active and Reactive Power Demand for every bus (P_i, Q_i)
Set MG counter: K=1, hour counter: t=1

Step 1: For t=1:24 hours:
    -   Solve Optimal Power Flow for each P_i, Q_i
    -   Get CMO_i for each bus and hour t.
    -   Get OPFOV_i

Step 2: For k=1: K microgris number
    -   Run Microgrid  model (MG) using White tariff ;
    -   Get P_i , Q_i  and MGOV_i

Step 3: Test the convergence criteria:
    -   $|OPFOV\_i - OPFOV\_i\_1| \leq \varepsilon 1$
    -   $|MGOV\_i - MGOV\_i\_1| \leq \varepsilon 2$

    If step 3 is true, then go to step 4; else go to step 1.

Step 4 Save optimal values of P_i , Q_i  , CMO_i, Loads, EV, etc
Step 5 End.
```

APPENDIX H – Complementary for scenarios A, B and C.

Supplementary graphics from Scenario A

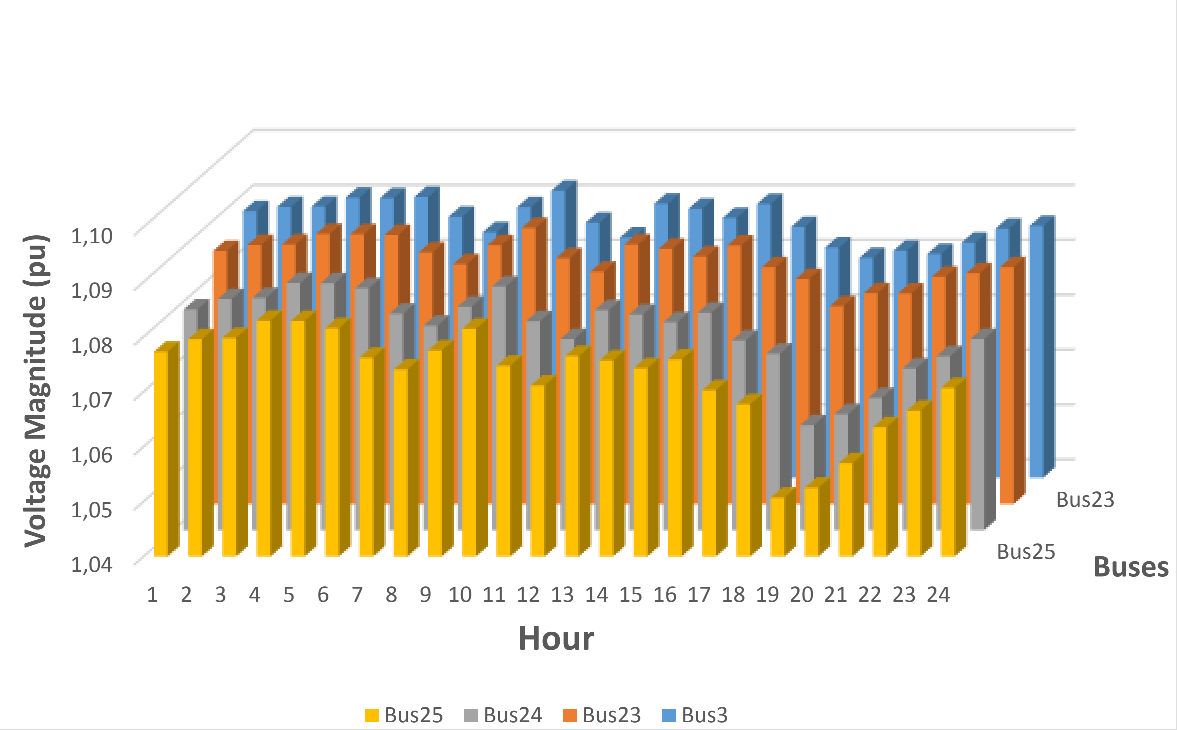

FIGURE 58 - Voltage magnitude for buses on secondary ‘B’ branch for sce. A.

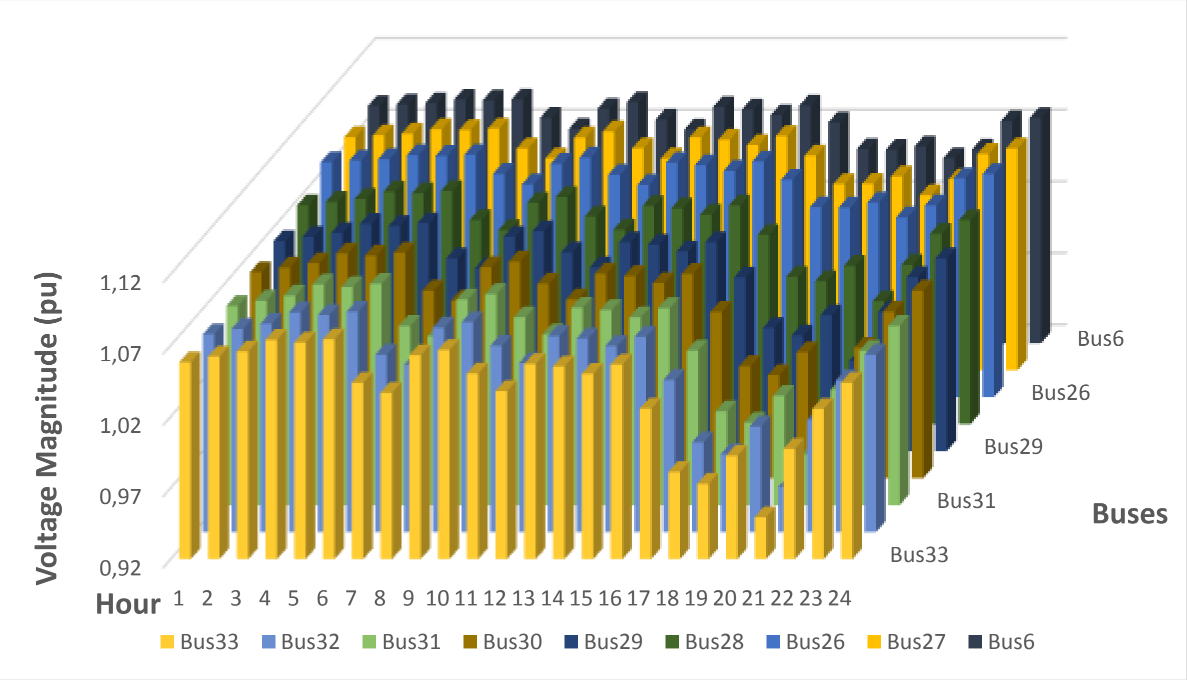

FIGURE 59 - Voltage magnitude for buses on secondary ‘C’ branch for sce. A

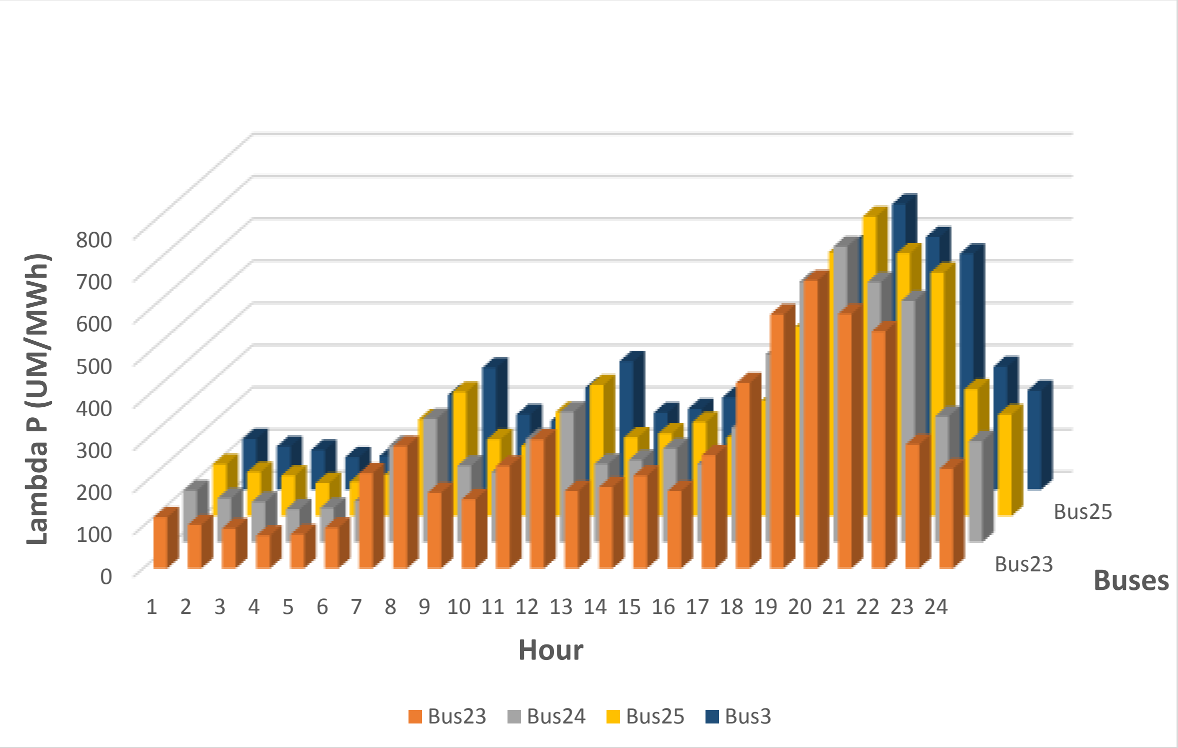

FIGURE 60 - Lambda values for the secondary ‘B’ branch for scenario A.

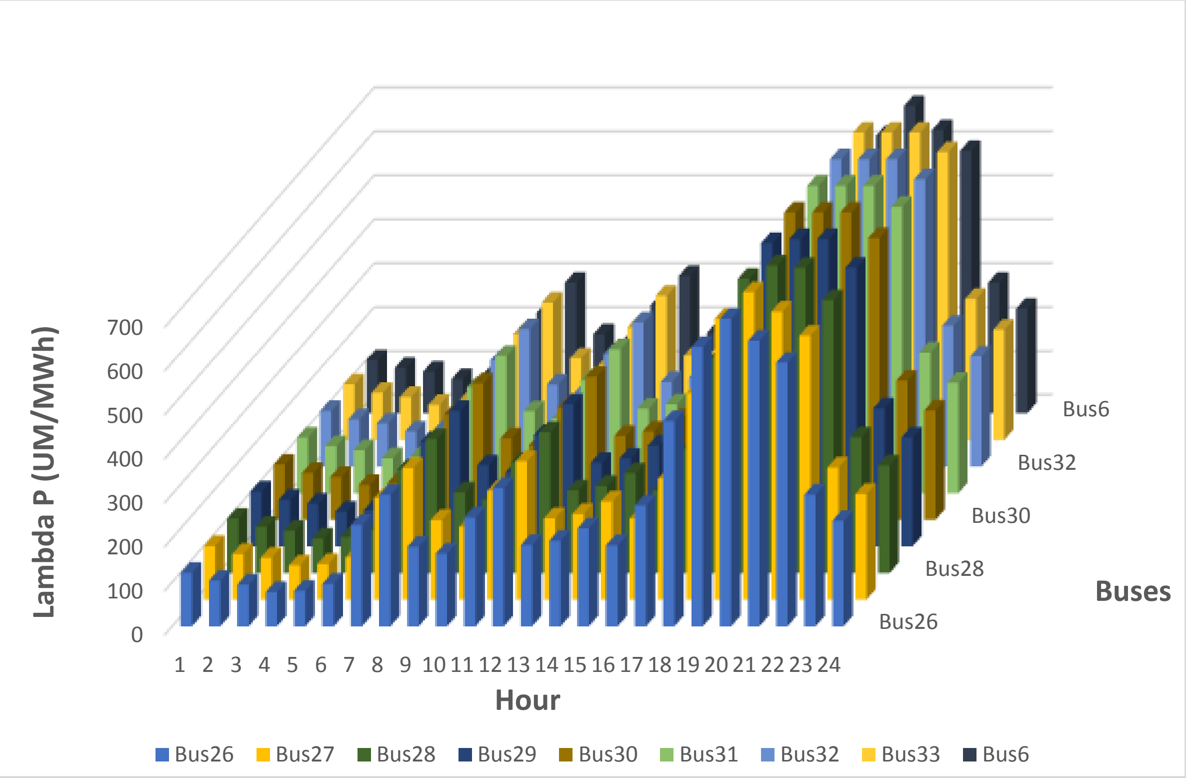

FIGURE 61 - Lambda values for the secondary ‘C’ branch for scenario A

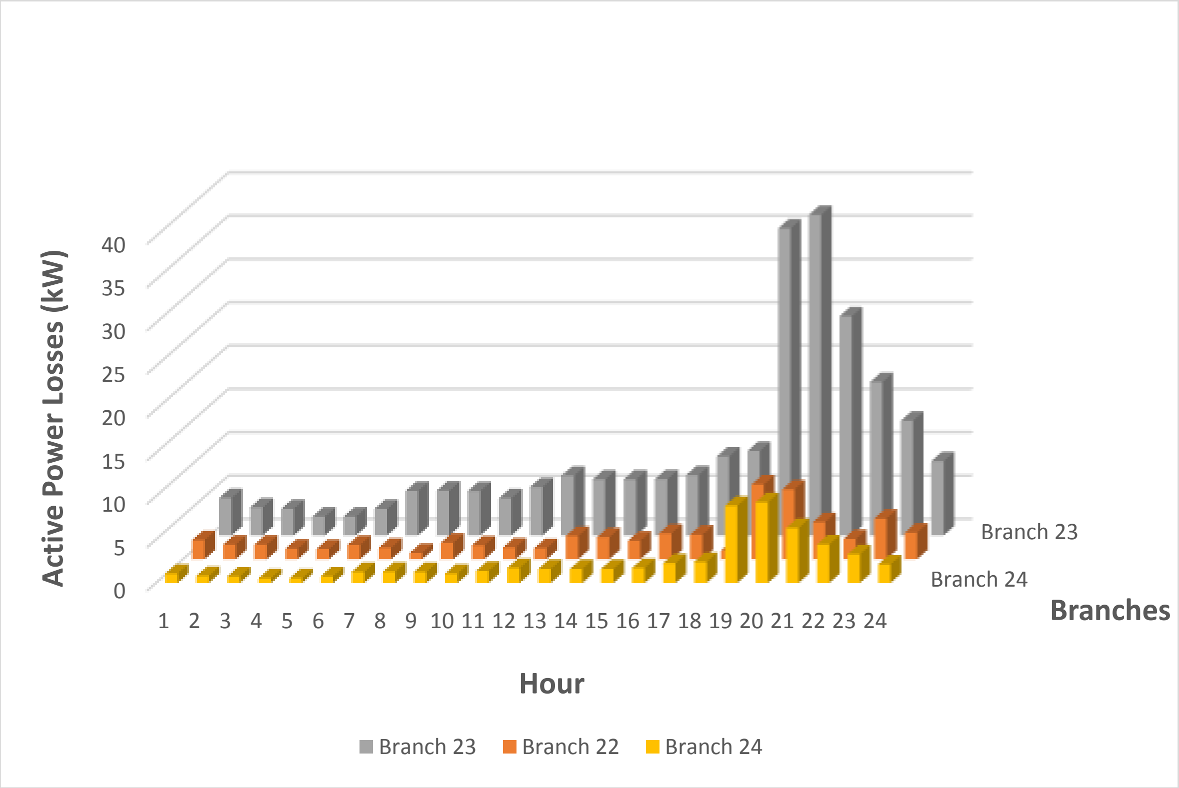

FIGURE 62 - Active power losses for secondary ‘B’ branch for scenario A

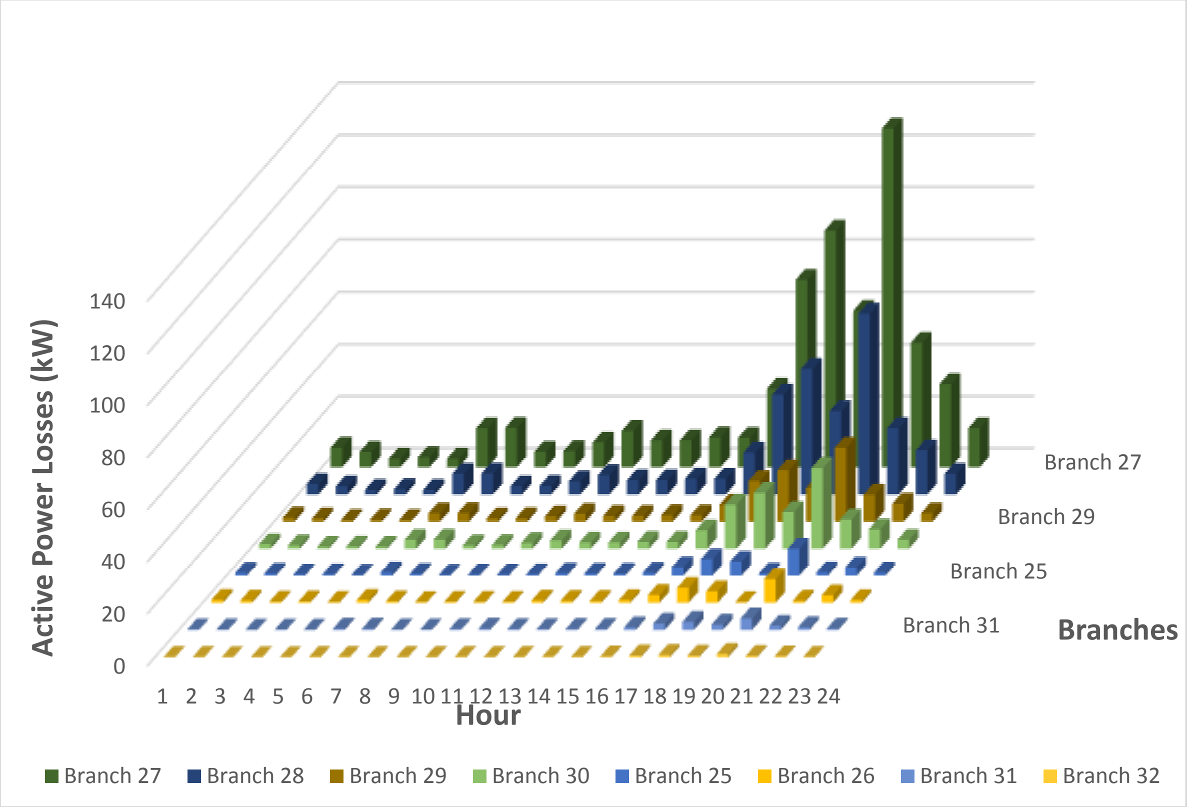

FIGURE 63 - Active power losses for secondary ‘C’ branch for scenario A

Supplementary graphics from Scenario B

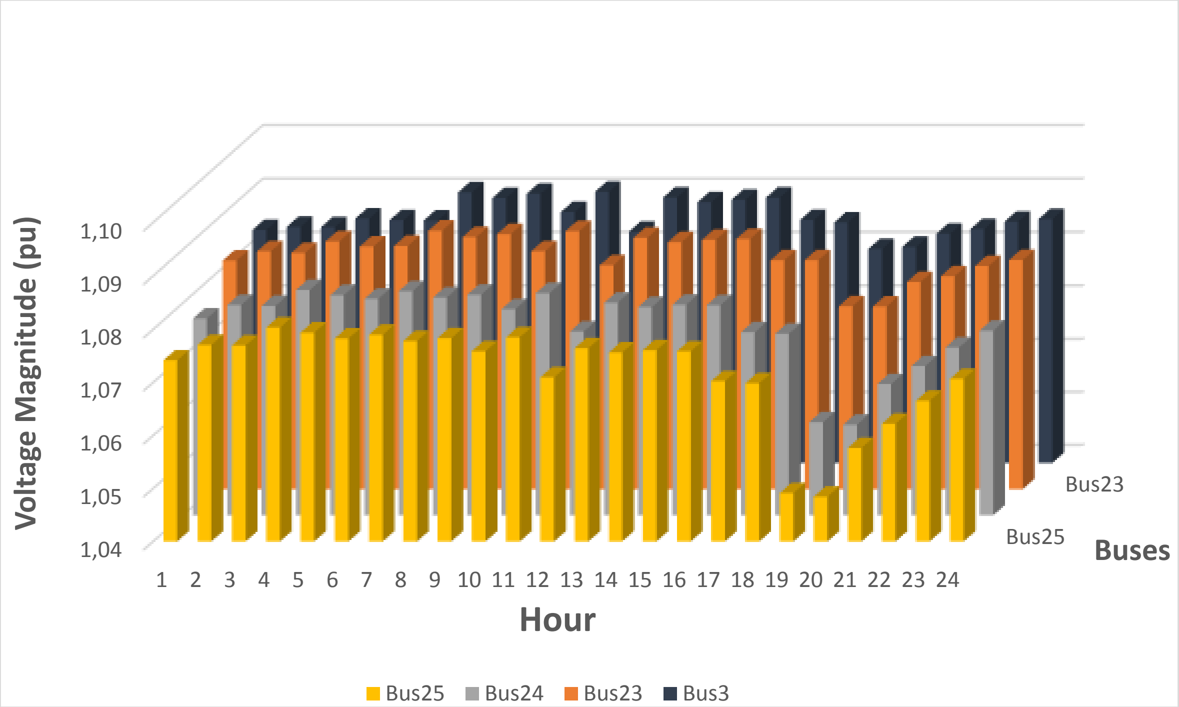

FIGURE 64 - Voltage magnitude for secondary branch ‘B’ in scenario B

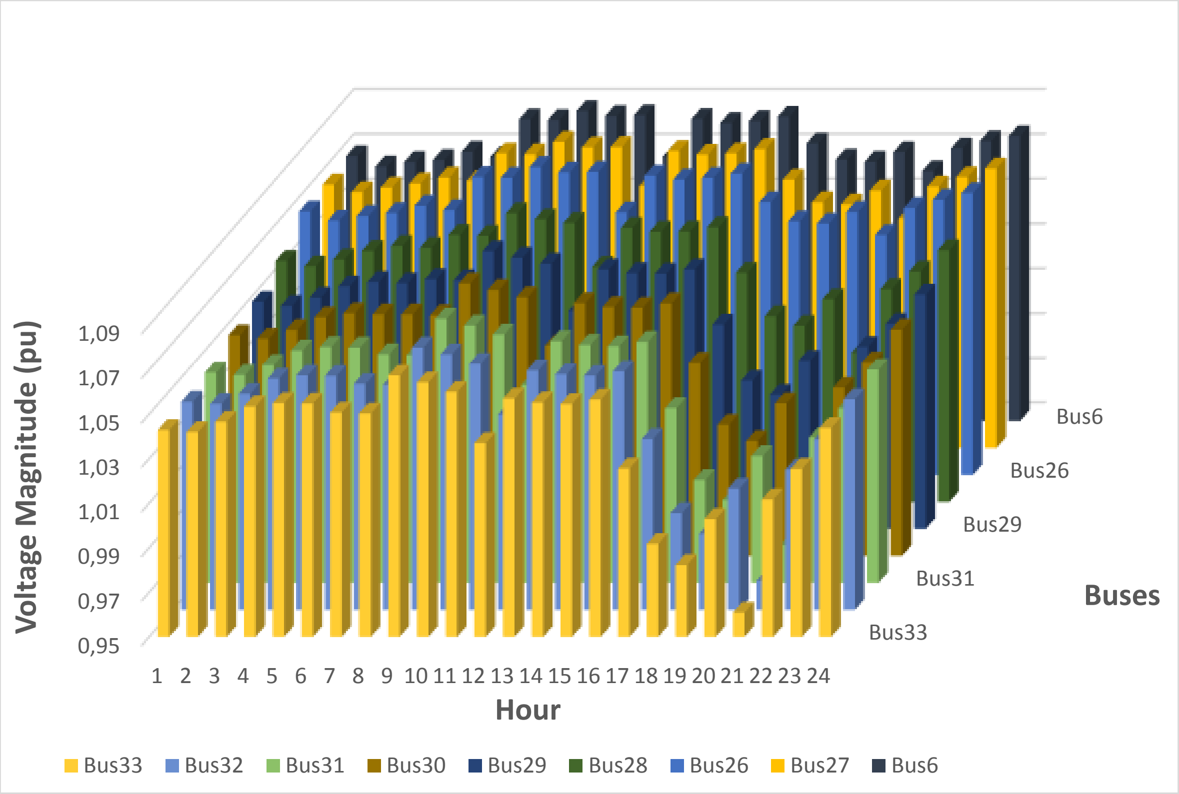

FIGURE 65 - Voltage magnitude for secondary branch ‘C’ in scenario B

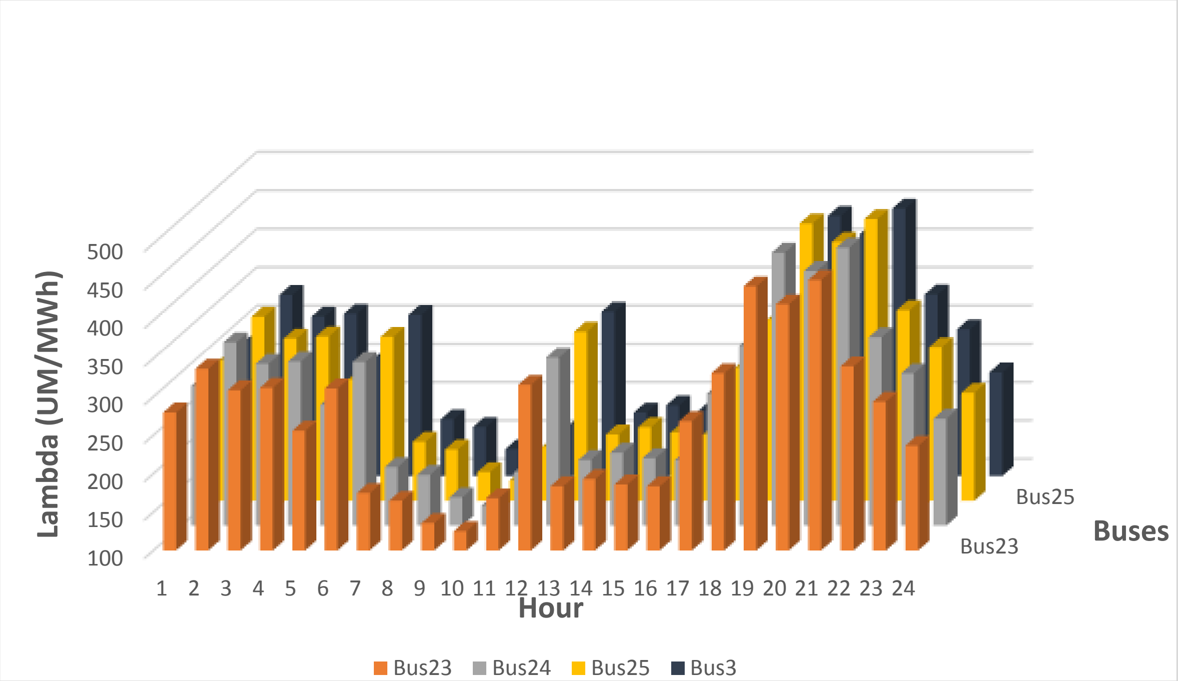

FIGURE 66 - Lambda values for secondary ‘B’ branch in scenario B

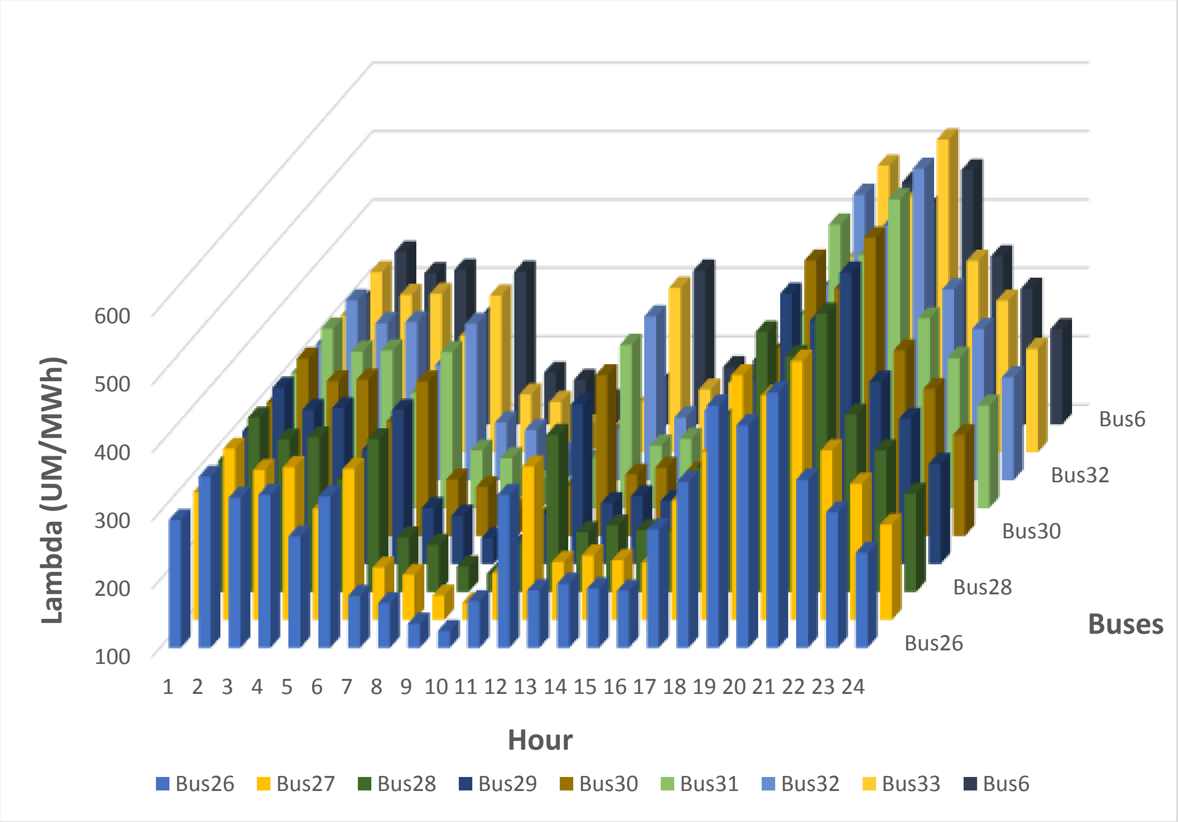

FIGURE 67 - Lambda values for secondary ‘C’ branch in scenario B

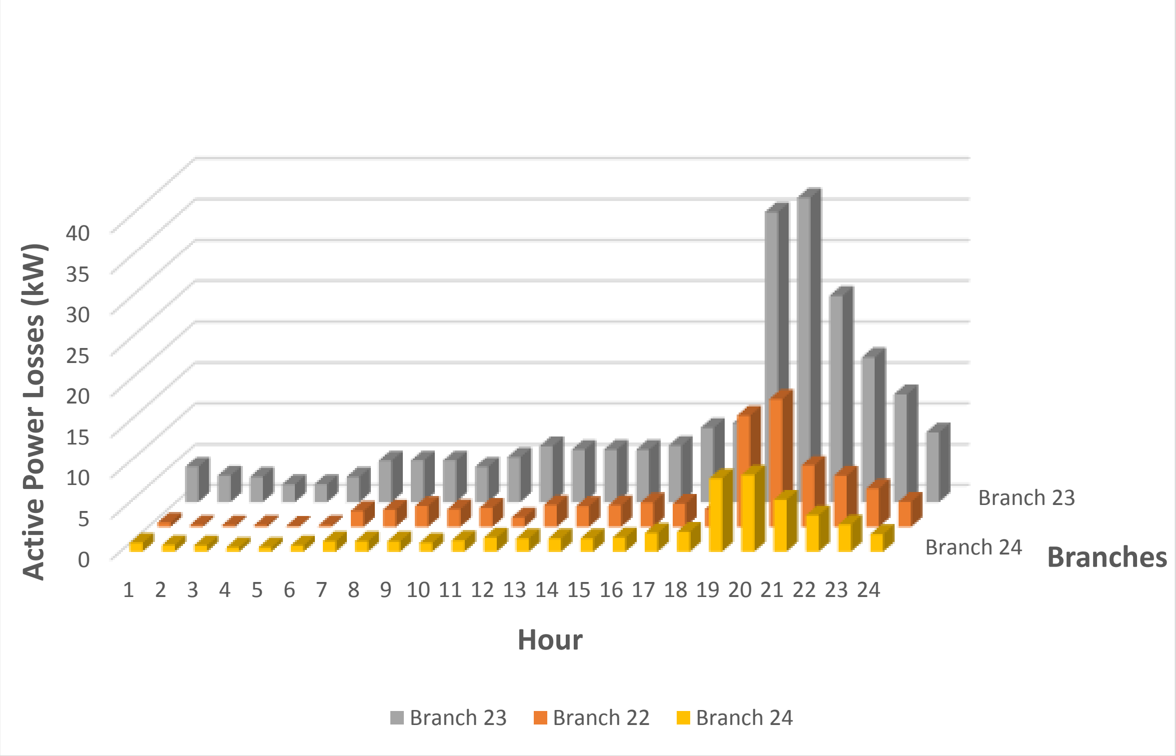

FIGURE 68 - Active power losses for secondary ‘B’ branch in scenario B

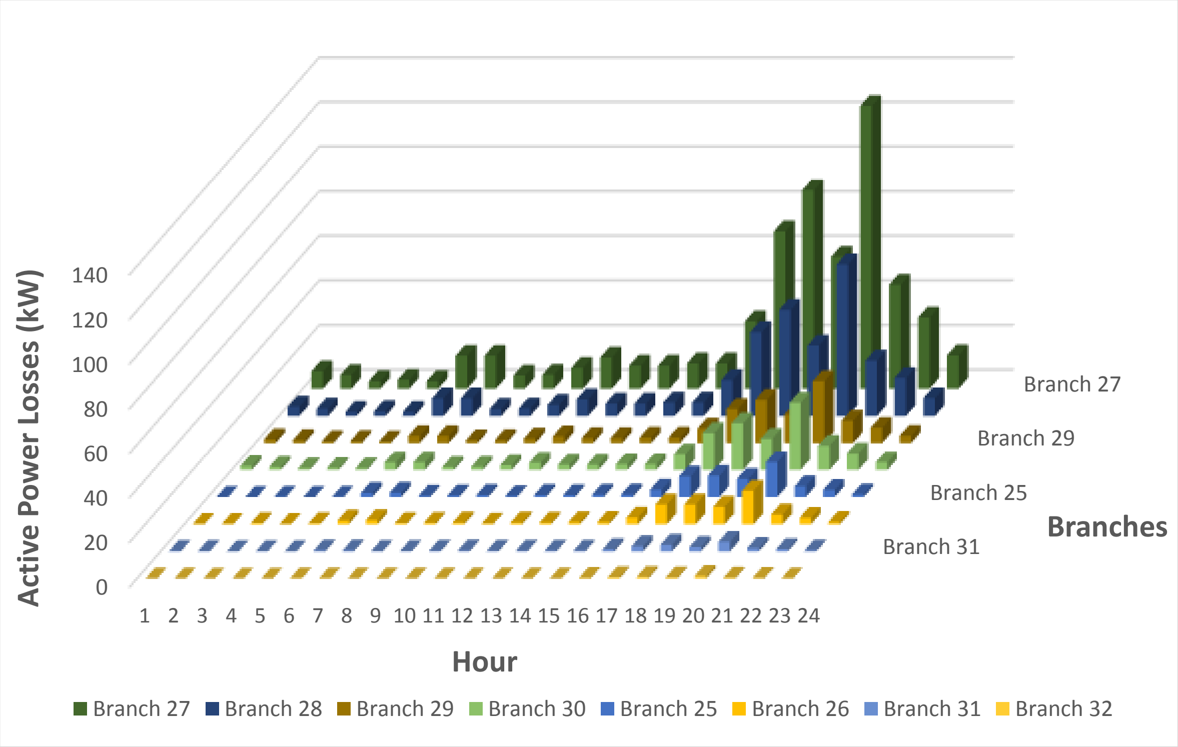

FIGURE 69 - Active power losses for secondary ‘C’ branch in scenario B

Supplementary graphics from Scenario C

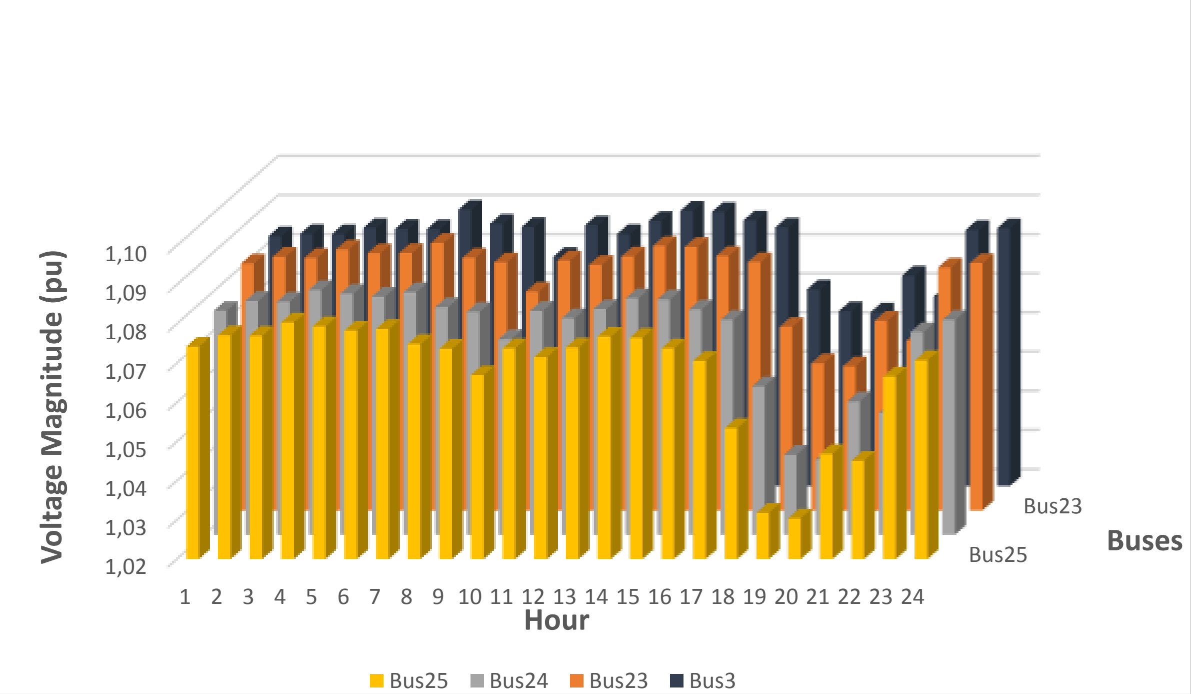

FIGURE 70 - Voltage magnitude for secondary branch ‘B’ in scenario C

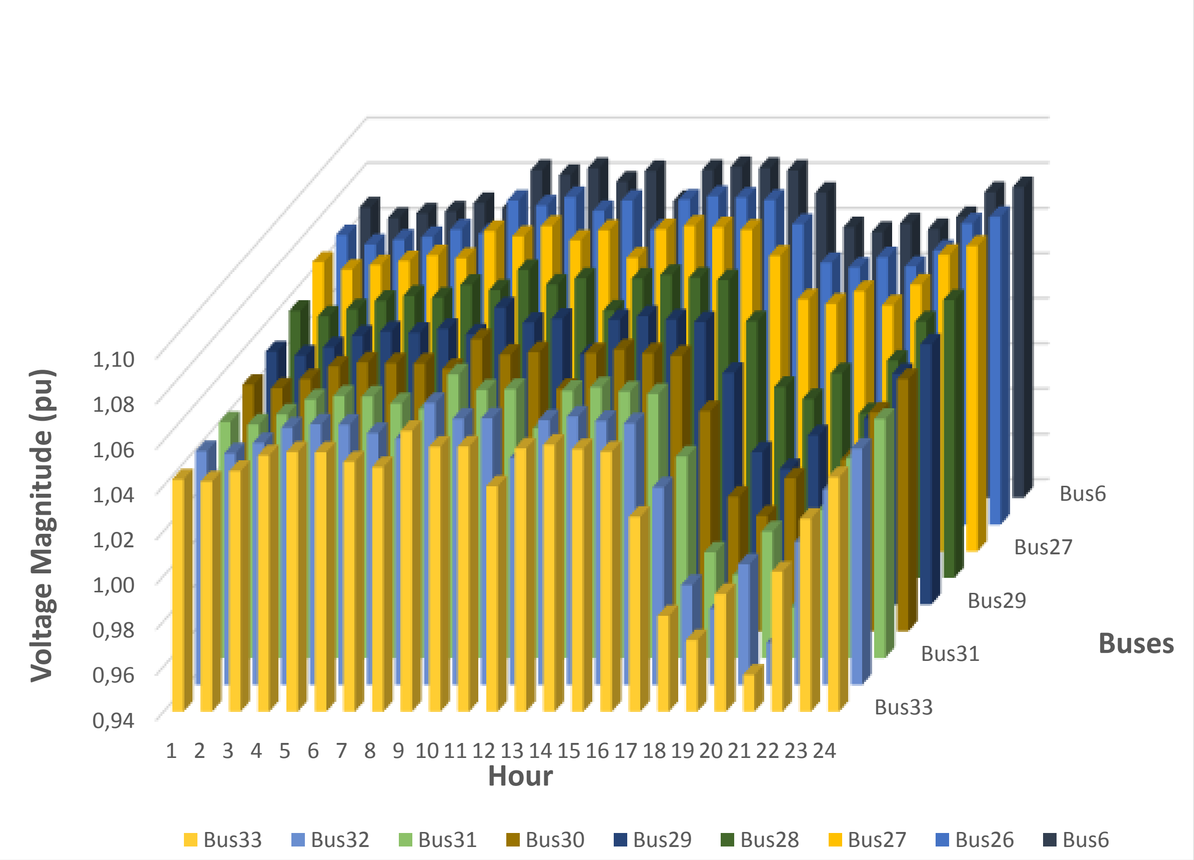

FIGURE 71 – Voltage magnitude for secondary branch ‘C’ in scenario C

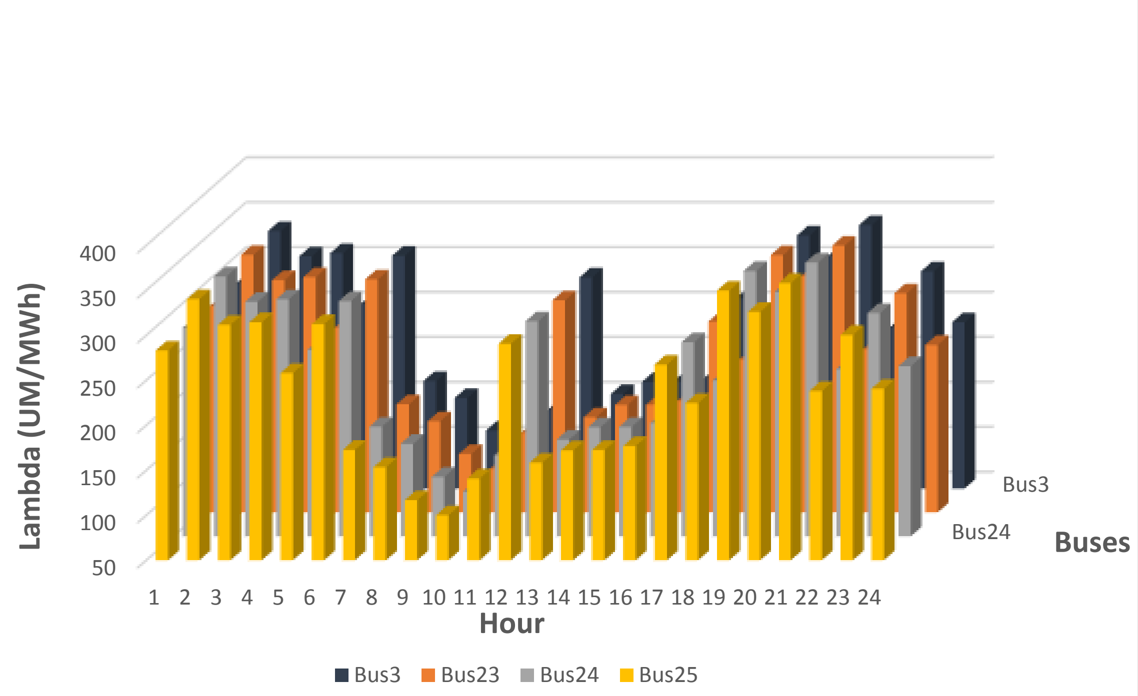

FIGURE 72 - Lambda values for secondary ‘B’ branch in scenario C

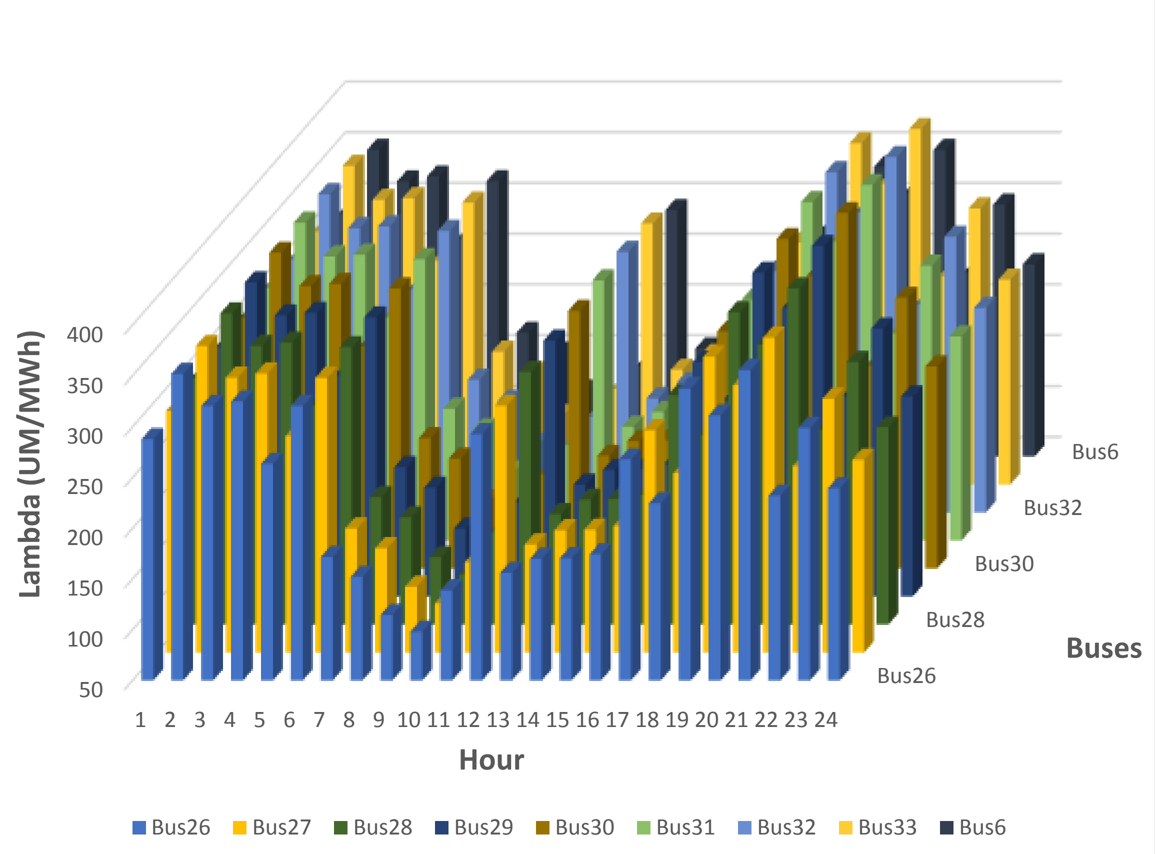

FIGURE 73 - Lambda values for secondary ‘C’ branch in scenario C

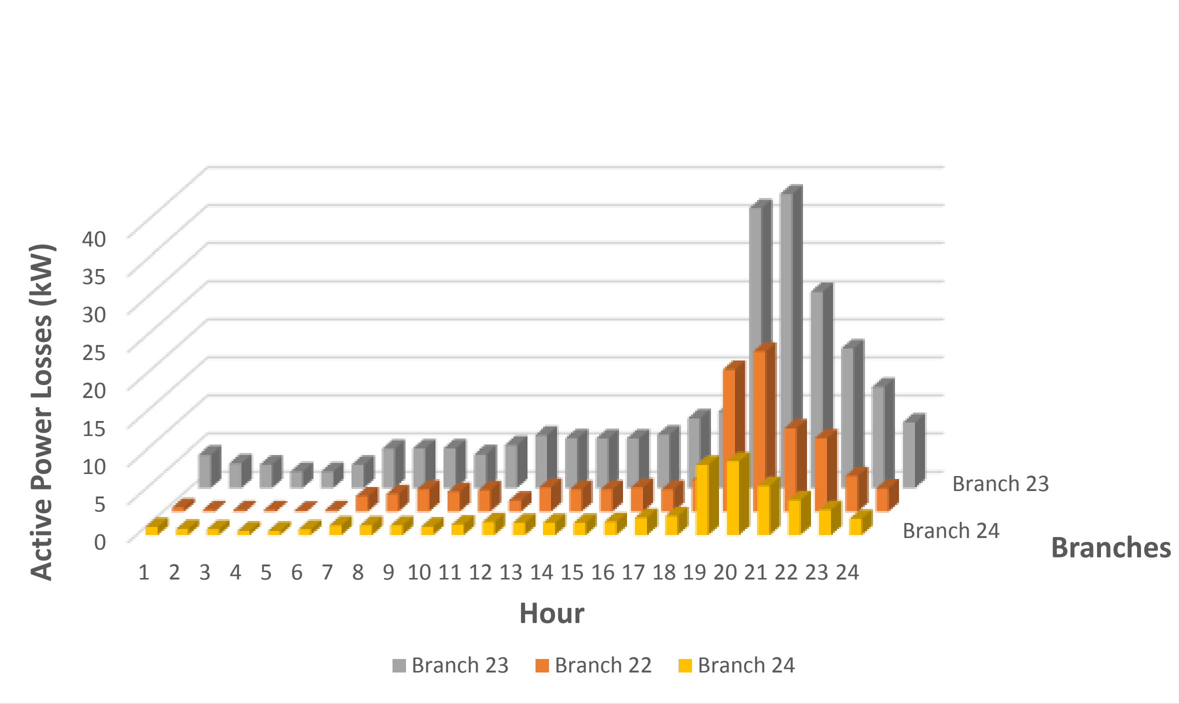

FIGURE 74 - Active power losses for secondary ‘B’ branch in scenario C

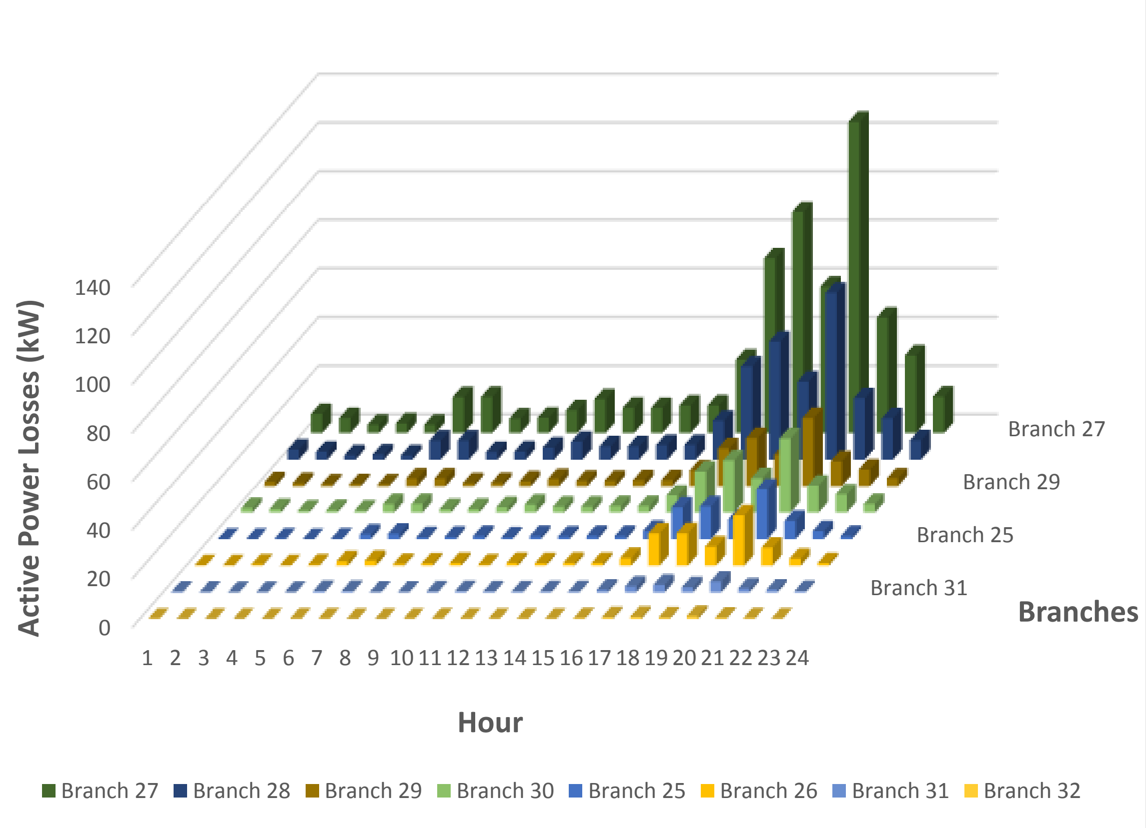

FIGURE 75 - Active power losses for secondary ‘C’ branch in scenario C

APPENDIX I – Numerical Values for Graphics from Scenarios A, B and C.

Voltage Magnitude for Scenario A

Time	1	2	3	4	5	6	7	8	9	10	11	12
Bus1	1.0929	1.093120613	1.092877591	1.093790821	1.093811028	1.094404171	1.094936582	1.094064245	1.095225764	1.097275978	1.094308735	1.093656654
Bus2	1.0923	1.092592868	1.092393484	1.093395407	1.093399925	1.093915782	1.093805276	1.092624386	1.09433383	1.09644907	1.093105573	1.092142181
Bus3	1.0885	1.089322949	1.089377718	1.091007455	1.090925041	1.091109686	1.087523512	1.084697188	1.089266577	1.092258705	1.086434346	1.083737504
Bus4	1.0878	1.088682008	1.0889176	1.090751633	1.090583683	1.090825071	1.084688015	1.080387677	1.087605391	1.091037218	1.083414586	1.079477277
Bus5	1.0870	1.088055392	1.088472895	1.090519626	1.090262617	1.09060874	1.082152408	1.076598591	1.086209142	1.090020452	1.080813378	1.075786066
Bus6	1.0856	1.086819895	1.08761154	1.090107573	1.089660426	1.0903252	1.07750981	1.069767157	1.083869419	1.088342826	1.076271595	1.069246176
Bus7	1.0864	1.087548976	1.088306693	1.090663905	1.090242038	1.090822087	1.077742781	1.069416412	1.084000004	1.088701125	1.076080432	1.068852931
Bus8	1.0948	1.095239238	1.095501983	1.096341521	1.096189545	1.096345059	1.082183802	1.069119619	1.087202074	1.093570581	1.077081566	1.068164674
Bus9	1.1000	1.099999998	1.099944451	1.099865161	1.099876474	1.099905808	1.086053383	1.070952485	1.090086479	1.097235445	1.079245146	1.069897593
Bus10	1.0984	1.098943484	1.099052427	1.098973072	1.098984394	1.097826066	1.074961038	1.051819927	1.081249954	1.090531279	1.064574093	1.049403234
Bus11	1.0981	1.098783971	1.098917748	1.098838384	1.098849707	1.097512071	1.073286595	1.048932114	1.07991599	1.08951918	1.062359548	1.046309928
Bus12	1.0977	1.098518113	1.098693288	1.098613907	1.098625233	1.096988639	1.070490297	1.044101308	1.077689306	1.087830487	1.058658536	1.041133859
Bus13	1.0961	1.097503363	1.097836607	1.097757164	1.097768499	1.094989932	1.059772263	1.02551778	1.069162876	1.081370032	1.044450284	1.021209645
Bus14	1.0955	1.09714818	1.097536759	1.097457294	1.097468632	1.094290227	1.056014269	1.018991856	1.066174524	1.079106618	1.039465201	1.014211002
Bus15	1.0951	1.096868443	1.097300603	1.097221121	1.097232461	1.093739157	1.05305488	1.013853164	1.063821161	1.077324108	1.035539639	1.008700145
Bus16	1.0947	1.096614251	1.097086015	1.097006517	1.09701786	1.093238371	1.050363586	1.009176634	1.061681397	1.075703668	1.031968589	1.003684286
Bus17	1.0942	1.096274586	1.096799276	1.096719758	1.096731103	1.092569102	1.046762251	1.002910869	1.058819036	1.073536676	1.027187405	0.996962383
Bus18	1.0940	1.096190284	1.096728109	1.096648586	1.096659932	1.092403002	1.045868804	1.001356987	1.05810885	1.07299897	1.026001443	0.995295489
Bus19	1.0925	1.092752874	1.092544464	1.093495123	1.093500259	1.094005871	1.093996774	1.092888217	1.094538657	1.096440823	1.093347033	1.092443501
Bus20	1.0947	1.094630828	1.094294161	1.094773711	1.094807259	1.095377594	1.096837864	1.096481401	1.097200236	1.097634497	1.096612258	1.096350902
Bus21	1.0954	1.095255606	1.094871297	1.095222215	1.095269754	1.095901576	1.097824672	1.09761604	1.09809511	1.098273568	1.097693188	1.097546109
Bus22	1.0969	1.096551249	1.096060568	1.096188143	1.09627172	1.097092718	1.099999829	1.099999847	1.099999791	1.099999782	1.099999824	1.099999877
Bus23	1.0861	1.087179908	1.087235453	1.089185996	1.089129712	1.089000637	1.085819763	1.083670062	1.087115062	1.09026636	1.08476288	1.082274759
Bus24	1.0802	1.082084616	1.08227188	1.085017808	1.084961306	1.08404521	1.079399281	1.077236637	1.080702354	1.084398281	1.078071503	1.074837609
Bus25	1.0773	1.079545216	1.079798183	1.08294079	1.08288418	1.081575579	1.076198704	1.074029593	1.077505661	1.081473362	1.074735728	1.071129565

Bus26	1.0844	1.085636661	1.086574417	1.089364728	1.088837988	1.089681911	1.076312895	1.068934223	1.083288053	1.087638438	1.075656039	1.068590655
Bus27	1.0830	1.08432392	1.085427691	1.088552985	1.087933988	1.089009443	1.075118837	1.068252826	1.082780093	1.086964688	1.075179461	1.068138267
Bus28	1.0733	1.075679892	1.077768059	1.082848563	1.081744322	1.08330747	1.062915555	1.055966824	1.075101113	1.079121809	1.065469627	1.05635528
Bus29	1.0672	1.070220552	1.072930839	1.079246684	1.077835894	1.079707139	1.055205861	1.04820476	1.070251658	1.074168794	1.059336557	1.048911342
Bus30	1.0644	1.067718501	1.070713985	1.077596086	1.076044788	1.07805725	1.051672005	1.044646878	1.068029195	1.071898859	1.056525619	1.04549934
Bus31	1.0599	1.063623344	1.067086274	1.074895976	1.073114571	1.075358303	1.045884147	1.038819493	1.064392279	1.068184169	1.051923928	1.039911422
Bus32	1.0589	1.062715177	1.066281766	1.074297171	1.072464738	1.074759756	1.044600629	1.037527211	1.06358573	1.067360372	1.050903438	1.03867224
Bus33	1.0583	1.062170276	1.065799068	1.073937905	1.072074853	1.074400645	1.043830468	1.036751789	1.063101807	1.0668661	1.05029113	1.037928686

Voltage Magnitude for Scenario A

Time	13	14	15	16	17	18	19	20	21	22	23	24
Bus1	1.095949734	1.095409499	1.094611147	1.095692081	1.094690478	1.096188328	1.098928145	1.099999959	1.099999922	1.099999848	1.095020638	1.093902293
Bus2	1.095023183	1.094440681	1.093514401	1.094765523	1.093330666	1.093958927	1.09589322	1.096933249	1.096943969	1.097191682	1.093530458	1.092719727
Bus3	1.089882306	1.088987531	1.087315895	1.089862663	1.085673856	1.081913784	1.080020927	1.081328948	1.080761672	1.08278416	1.085370138	1.085844286
Bus4	1.088453728	1.087296489	1.084961977	1.088712302	1.082516726	1.074738699	1.07284468	1.07415416	1.072069721	1.074794932	1.082504096	1.08338501
Bus5	1.087219009	1.085832566	1.082913511	1.087724651	1.079629233	1.068194246	1.066596522	1.068475463	1.064248556	1.067927568	1.079937288	1.081231995
Bus6	1.085062399	1.083269988	1.079296474	1.086072715	1.07416967	1.055704723	1.055148639	1.057499566	1.049325997	1.055440071	1.075196339	1.077394404
Bus7	1.08563543	1.083721997	1.079518244	1.08664167	1.074928056	1.056123365	1.056149608	1.063225754	1.050476234	1.055708265	1.076106693	1.077764825
Bus8	1.092419505	1.089639978	1.083819948	1.094594429	1.084021318	1.062364206	1.065989527	1.076589962	1.061559875	1.055197661	1.086649254	1.083422612
Bus9	1.097233322	1.094056846	1.087564658	1.099999788	1.09064846	1.068768443	1.075397109	1.089777749	1.071722781	1.059092773	1.094202702	1.087999182
Bus10	1.090611414	1.086244585	1.076862107	1.09450833	1.080111067	1.043249742	1.041086441	1.038530632	1.037374284	1.016734757	1.083214184	1.077180566
Bus11	1.089611732	1.085065223	1.075246496	1.093679292	1.078520382	1.039398315	1.035908493	1.030797353	1.032190632	1.010342698	1.08155541	1.075547436
Bus12	1.087943783	1.083097016	1.072548663	1.092296366	1.075864277	1.032946692	1.027218328	1.017769536	1.023490594	0.999593596	1.078785381	1.072820291
Bus13	1.081562907	1.075563683	1.062209833	1.087008373	1.065686204	1.00805444	0.993550764	0.966875726	0.989782215	0.957767666	1.068168879	1.062368626
Bus14	1.079327405	1.072923876	1.05858506	1.085156114	1.062117917	0.999301671	0.981690088	0.948874163	0.97790674	0.943002394	1.064446609	1.058704221
Bus15	1.077566875	1.070844972	1.055730569	1.083697381	1.059307901	0.992409855	0.972351599	0.934700811	0.968556606	0.931377217	1.061515346	1.055818522
Bus16	1.075966427	1.068954916	1.053134756	1.082371407	1.056752575	0.986134085	0.963840484	0.921759219	0.960034737	0.920771911	1.05884967	1.053194306
Bus17	1.073826194	1.06642697	1.049661395	1.080598503	1.053333484	0.977716688	0.952407548	0.904318231	0.948587029	0.906502039	1.055282714	1.049682882
Bus18	1.073295127	1.065799729	1.048799682	1.080158562	1.052485228	0.975629853	0.949574335	0.900000069	0.945750179	0.902967462	1.05439779	1.048811731
Bus19	1.095148323	1.094612322	1.09374186	1.094816112	1.093534755	1.094104924	1.095831722	1.096850954	1.09689848	1.097125957	1.093663996	1.093015143

Bus20	1.097308741	1.097135771	1.096792573	1.096642068	1.096645222	1.097233241	1.097961543	1.098812639	1.098865178	1.098857864	1.096477354	1.096590166
Bus21	1.098123142	1.098027357	1.097814294	1.097515147	1.097695228	1.098104831	1.098518094	1.099137183	1.099193583	1.099171131	1.097528147	1.097711554
Bus22	1.099999735	1.099999778	1.099999825	1.099736227	1.099999746	1.099999956	1.099999955	1.099999922	1.099999995	1.099999982	1.099999764	1.099999909
Bus23	1.087276373	1.086476072	1.085076193	1.087076018	1.083096835	1.080978397	1.076014593	1.078379609	1.078352982	1.081391733	1.082001486	1.083125377
Bus24	1.080072385	1.079266681	1.077857332	1.079606193	1.074535279	1.072132758	1.059129929	1.061123472	1.064093996	1.069467848	1.071694444	1.074830256
Bus25	1.076480758	1.075672354	1.07425827	1.075881859	1.070265799	1.067721383	1.050697381	1.052504886	1.056976151	1.063518139	1.066552958	1.070693833
Bus26	1.084012532	1.082272136	1.078351611	1.084934925	1.072209029	1.053019196	1.052712969	1.05630175	1.045915271	1.05433191	1.073264866	1.076242274
Bus27	1.082944275	1.08127732	1.077451649	1.083762445	1.070141793	1.050286066	1.050447455	1.055565543	1.042493389	1.053625774	1.071257055	1.075110887
Bus28	1.072814502	1.071131239	1.066771639	1.073147515	1.052781672	1.023416936	1.020254107	1.031024482	1.006302726	1.031729294	1.053400842	1.06290751
Bus29	1.066415991	1.06472241	1.060025219	1.066442279	1.041808826	1.006416978	1.001144155	1.015501435	0.983380871	1.01788267	1.042113926	1.055197756
Bus30	1.06348336	1.061785046	1.056933064	1.063369014	1.036778279	0.998620146	0.99237833	1.00838271	0.972863496	1.011533417	1.036939297	1.051663872
Bus31	1.058682138	1.056976048	1.051870109	1.058337107	1.028530864	0.985812025	0.977968403	0.996694448	0.955550953	1.001114054	1.028454879	1.045875969
Bus32	1.057617401	1.055909588	1.050747334	1.057221216	1.026701977	0.982971961	0.974773215	0.994102664	0.951712278	0.998803603	1.026573442	1.044592441
Bus33	1.056978542	1.055269693	1.050073643	1.056551658	1.025604471	0.981267333	0.972855311	0.992547129	0.949407825	0.997416987	1.025444391	1.043822274

Lambda P (UM/MWh) for Scenario A												
Time	1	2	3	4	5	6	7	8	9	10	11	12
Bus1	119.8176088	102.1443386	93.81151115	77.12681297	80.04508283	95.64721489	221.8959265	283.9075297	176.7007487	162.0846295	238.2953293	298.5242203
Bus2	119.9507547	102.2412956	93.8932903	77.18154907	80.10413621	95.73039555	222.3300117	284.6038743	176.9748977	162.3172	238.788388	299.2938893
Bus3	120.7818953	102.8517694	94.41073919	77.51790081	80.46596497	96.2194544	225.0194657	289.0792994	178.6663646	163.5959686	241.8650481	304.3038142
Bus4	120.9371328	102.964285	94.48369187	77.55014385	80.51192933	96.26182002	226.2432703	291.5383804	179.2201754	163.9682467	243.2683713	306.8829196
Bus5	121.0868021	103.0749325	94.55457584	77.57952492	80.55545035	96.29380753	227.3748945	293.7956432	179.7041045	164.2908358	244.5280369	309.2256715
Bus6	121.3827486	103.2987799	94.69600714	77.63364864	80.63964954	96.33645087	229.4977933	297.9851907	180.5432779	164.8434825	246.7965992	313.5113325
Bus7	121.17028	103.1328089	94.55462345	77.54403215	80.54175386	96.23110355	229.3971153	298.284322	180.488945	164.7244285	246.9067553	313.8818664
Bus8	119.1908381	101.5982534	93.24904292	76.71093755	79.63295622	95.21960957	227.7994535	299.5022375	179.5666996	163.3459561	246.9466132	315.5651207
Bus9	117.9824369	100.6677652	92.45816844	76.20267187	79.07930729	94.5838966	226.4402266	299.3224065	178.7600751	162.3471873	246.3918523	315.5507333
Bus10	118.2701567	100.8247906	92.57960746	76.30293207	79.18333377	94.87514941	230.3030507	308.4741734	181.1649173	163.98361	252.0454815	325.9400788
Bus11	118.3186099	100.8512136	92.60003862	76.3197993	79.20083466	94.92421837	230.9613416	310.0505601	181.5735472	164.260904	253.0135036	327.7328921
Bus12	118.3994537	100.8952796	92.63410955	76.34792547	79.23001754	95.00610559	232.067099	312.7150394	182.2587858	164.7251695	254.6439724	330.7664358

Bus13	118.6720419	101.0436869	92.74882536	76.44261931	79.32826941	95.28241344	235.865441	322.0262304	184.6018034	166.3057831	260.286889	341.3988534
Bus14	118.756154	101.0894208	92.78416519	76.47179009	79.3585363	95.36775148	237.0629514	325.0206195	185.3365804	166.7990114	262.081406	344.8299101
Bus15	118.8296191	101.1293581	92.81502546	76.49726246	79.38496587	95.44229532	238.1119808	327.6514558	185.9797644	167.230456	263.6554011	347.8459895
Bus16	118.8992531	101.1672017	92.84426648	76.52139759	79.41000798	95.51296538	239.1110585	330.1684874	186.5915889	167.6404088	265.1574092	350.7339261
Bus17	118.9796619	101.2108563	92.87798894	76.54923093	79.43888733	95.59462977	240.2843739	333.1710815	187.3071219	168.1179837	266.9334262	354.188345
Bus18	119.0024779	101.2232462	92.88756076	76.5571311	79.44708439	95.61779779	240.6160008	334.0169379	187.5095494	168.2532123	267.4346606	355.1609563
Bus19	119.907051	102.208558	93.86498444	77.16551077	80.08726735	95.71098632	222.1516531	284.2342776	176.8633579	162.2797017	238.5626758	298.8631092
Bus20	119.4242454	101.8510921	93.55869355	76.97989558	79.89007627	95.46127822	220.2069519	280.4450956	175.6603282	161.6575402	236.177173	294.513105
Bus21	119.2707577	101.7383633	93.46273267	76.91895148	79.82491244	95.37392252	219.5950569	279.3078976	175.2846235	161.412979	235.4438378	293.2236865
Bus22	118.9670062	101.5165966	93.27488745	76.79547545	79.69229226	95.18930935	218.3944025	277.1583049	174.5513027	160.8605917	234.0303617	290.8111038
Bus23	121.3408441	103.266502	94.79040043	77.78213384	80.73650047	96.60236076	225.8175114	289.8122638	179.4305743	164.2360164	242.7301137	305.3382009
Bus24	122.3972163	104.0421794	95.48378363	78.25837001	81.23087561	97.30667345	227.9628162	292.5766818	181.1310551	165.6547186	245.1369611	308.7158025
Bus25	122.9303326	104.4330227	95.83307135	78.49789408	81.47952299	97.66145562	229.046612	293.9733208	181.9901023	166.3706266	246.353551	310.4256513
Bus26	121.680419	103.5310233	94.88185984	77.74208858	80.7644622	96.4548352	230.0543687	298.5290219	180.759728	165.0743552	247.1280635	313.9797086
Bus27	122.0246551	103.800742	95.09691289	77.86621588	80.90803709	96.58617389	230.6588276	299.0593248	180.9755472	165.3167176	247.4408435	314.4016402
Bus28	123.7447898	105.1085759	96.15514615	78.50683195	81.63149902	97.38010852	234.8316399	304.5433101	182.9997015	167.1984952	250.9818866	319.9250027
Bus29	124.8551135	105.9510084	96.83540524	78.91696856	82.09513949	97.88839874	237.5400687	308.1039877	184.3009778	168.4085757	253.2682597	323.5074396
Bus30	125.4205861	106.3796523	97.18121919	79.1250904	82.33051576	98.14632722	238.9228166	309.9221127	184.9625116	169.0238232	254.4328307	325.3358141
Bus31	126.2465306	107.0047958	97.68481412	79.42728408	82.67252951	98.52083786	240.9506491	312.5890993	185.9259303	169.9200127	256.1342011	328.0157545
Bus32	126.4235393	107.1386459	97.79254066	79.49181123	82.7455919	98.60080644	241.3863167	313.1621734	186.1320273	170.1117514	256.4988715	328.5913363
Bus33	126.5213986	107.212592	97.85201269	79.52738482	82.78588477	98.64489269	241.6276358	313.47964	186.2458092	170.2176166	256.7005003	328.9100752

Lambda P (UM/MWh) for Scenario A												
Time	13	14	15	16	17	18	19	20	21	22	23	24
Bus1	180.5413537	189.5583118	215.6330855	180.5402732	262.2038785	425.4779278	573.0839495	638.7937892	574.9556673	538.736493	286.2309527	231.392277
Bus2	180.8332155	189.878349	216.0432804	180.8351241	262.8205903	427.0621292	575.9549889	643.7655287	577.8835115	541.2725015	286.9680085	231.8677725
Bus3	182.6001769	191.8474707	218.6061458	182.4448615	266.7811112	438.0444681	596.1454706	676.8144086	599.160561	559.2932656	291.5927323	234.9389927
Bus4	183.0972878	192.4634382	219.5870055	182.7927543	268.4536419	444.7320385	605.9064019	695.5097404	611.1897393	569.7851656	293.2725504	236.0525529
Bus5	183.5431878	193.0164924	220.4727185	183.0949962	270.0353449	451.1339414	615.0217004	713.274165	622.7247828	579.554081	294.8368673	237.0646601
Bus6	184.3464163	194.0139238	222.0820843	183.6149211	273.0895036	463.6751907	632.2950473	747.5868314	645.3489755	597.9780437	297.7983975	238.9201146

Bus7	184.1430576	193.8424696	221.9864192	183.3229789	272.7107408	463.7552371	632.4791981	752.9319597	645.3819073	600.1147585	297.3079237	238.7541199
Bus8	181.9702075	191.8788098	220.4798251	180.4059101	268.5112257	461.3544837	628.5348053	791.344563	639.9257533	613.1539528	292.0007867	236.5538427
Bus9	180.4829639	190.4676501	219.2017282	178.5125472	265.5673579	458.0751874	622.9014022	807.9041699	633.3301022	617.035989	288.3479823	234.8321395
Bus10	182.2794659	192.7182301	222.800541	179.9778779	269.8456051	477.1812496	658.6573376	894.0903277	669.8698469	662.9087845	293.1819854	238.7290527
Bus11	182.5838542	193.1001373	223.4135226	180.2257979	270.5741329	480.5003448	664.9406169	909.7895602	676.2922016	671.0651656	294.0055866	239.392904
Bus12	183.093453	193.7400741	224.4428649	180.6405192	271.7973302	486.1388159	675.6892054	937.506416	687.2801055	685.1201351	295.3888339	240.5077603
Bus13	184.8281276	195.9236168	227.9758242	182.0490787	275.9940002	506.1207714	714.5291922	1044.16387	726.9991058	736.9615091	300.1385887	244.3350878
Bus14	185.3693302	196.6067335	229.0886167	182.4874079	277.3152461	512.6520329	727.515361	1082.747138	740.2847388	754.7164953	301.6354048	245.5409122
Bus15	185.8427274	197.2044938	230.0633004	182.8706837	278.4724371	518.4049477	738.9970901	1118.475622	752.0320848	770.4819139	302.9465471	246.5971208
Bus16	186.2925245	197.7728021	230.9913744	183.2346441	279.5741782	523.9302329	750.0858363	1155.540938	763.378542	785.8011685	304.1951345	247.6028804
Bus17	186.8164398	198.4361849	232.0804945	183.6577234	280.8666407	530.6066692	763.7283358	1208.211281	777.3427651	805.0142718	305.6609742	248.783408
Bus18	186.9647949	198.6239396	232.388375	183.7775813	281.2320324	532.4828069	767.5500199	1227.235645	781.2543623	810.3810142	306.0753118	249.1171131
Bus19	180.7371884	189.7586432	215.8678538	180.8014257	262.5408996	426.0146174	573.9985889	641.0615961	575.6749845	539.3691108	286.674275	231.6361747
Bus20	179.615216	188.425827	213.9929659	180.1535041	259.5712344	415.5988481	554.4424795	614.6120021	554.1227155	520.6797233	283.402454	229.2649255
Bus21	179.2449852	188.0000519	213.411612	179.885674	258.6552427	412.5519691	548.6996587	606.9866369	547.9199291	515.2713866	282.357843	228.5537976
Bus22	178.4929031	187.1549324	212.2833798	179.2651933	256.8856032	406.9223646	538.0726654	593.1048299	536.6386713	505.3866208	280.2872245	227.2097424
Bus23	183.5292894	192.7967164	219.5968697	183.4272984	268.1810098	439.274618	601.6184053	682.4293434	602.8799919	561.6825223	293.5717349	236.2228359
Bus24	185.4857981	194.8551179	221.9475946	185.4562548	271.6006138	445.0763178	617.0913636	700.3389608	615.8794584	571.7365484	298.0976713	239.1396795
Bus25	186.475723	195.896619	223.1370482	186.4833761	273.3355631	448.0215914	625.0749697	709.5860649	622.5508983	576.8718917	300.4019383	240.6187698
Bus26	184.7271824	194.3990047	222.5102367	184.0281445	274.1690932	466.3670493	635.7551801	749.2431289	650.3200689	599.5425816	298.9625672	239.4789402
Bus27	185.1440092	194.8152833	222.9610951	184.4856544	275.389202	469.3755271	639.4356881	750.4228829	655.8828539	600.9123275	300.265952	240.0792446
Bus28	187.8905081	197.7145773	226.4708851	187.3544305	282.5985081	489.2451004	670.1186662	779.1079129	694.5569027	621.3085283	308.3520689	244.4225499
Bus29	189.6651512	199.5880731	228.7415813	189.2099233	287.3299834	502.5712576	690.8507101	798.2418651	721.0623241	634.8358167	313.6644223	247.2416409
Bus30	190.569362	200.542679	229.8991842	190.155744	289.757481	509.4746452	701.6263755	808.1297812	734.9269257	641.8085226	316.3911794	248.6808859
Bus31	191.8910596	201.9381072	231.5928181	191.5392619	293.3466048	519.8485175	717.9110405	822.9275119	756.1101448	652.1987132	320.4258183	250.7915733
Bus32	192.1744435	202.2373086	231.9561537	191.8360328	294.1215946	522.1110694	721.475165	826.1467191	760.7778123	654.4530791	321.2974137	251.2450419
Bus33	192.3311677	202.4027843	232.157182	192.0002169	294.5525189	523.3787054	723.4772648	827.9468909	763.4130333	655.7111887	321.7822268	251.4962211

Active Power Losses (I^2*R) (Watt) for Scenario A												
Time	1	2	3	4	5	6	7	8	9	10	11	12
Branch 1	0.64	0.47	0.39	0.26	0.28	0.39	2.01	3.19	1.26	1.09	2.26	3.52
Branch 2	4.64	3.45	2.93	1.84	1.98	2.53	12.78	20.44	8.26	5.67	14.37	23.00
Branch 3	0.23	0.17	0.09	0.03	0.05	0.03	3.36	7.80	1.13	0.61	3.78	7.61
Branch 4	0.21	0.16	0.08	0.02	0.04	0.02	2.68	6.06	0.80	0.42	2.82	5.76
Branch 5	0.38	0.30	0.14	0.03	0.07	0.02	4.26	9.28	1.09	0.56	4.10	8.53
Branch 6	0.71	0.61	0.53	0.32	0.36	0.29	0.07	0.15	0.03	0.14	0.02	0.20
Branch 7	6.89	5.78	5.03	3.10	3.41	2.94	1.62	0.21	0.85	2.10	0.07	0.37
Branch 8	4.38	3.62	3.14	1.95	2.14	1.97	1.91	0.37	1.07	1.85	0.49	0.36
Branch 9	0.31	0.13	0.09	0.09	0.09	0.48	13.74	40.76	8.73	5.03	24.01	46.75
Branch 10	0.05	0.02	0.01	0.01	0.01	0.07	2.06	6.13	1.31	0.75	3.60	7.03
Branch 11	0.07	0.03	0.02	0.02	0.02	0.11	3.02	9.01	1.91	1.10	5.29	10.34
Branch 12	0.19	0.08	0.06	0.06	0.06	0.30	8.74	26.18	5.53	3.18	15.33	30.07
Branch 13	0.05	0.02	0.01	0.01	0.01	0.08	2.24	6.74	1.42	0.82	3.94	7.75
Branch 14	0.03	0.01	0.01	0.01	0.01	0.05	1.57	4.73	0.99	0.57	2.76	5.44
Branch 15	0.02	0.01	0.01	0.01	0.01	0.04	1.12	3.38	0.71	0.41	1.97	3.88
Branch 16	0.02	0.01	0.01	0.01	0.01	0.03	0.86	2.60	0.54	0.31	1.52	3.00
Branch 17	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.37	0.08	0.04	0.22	0.43
Branch 18	0.04	0.03	0.03	0.01	0.01	0.01	0.13	0.32	0.09	0.02	0.18	0.39
Branch 19	0.52	0.39	0.34	0.19	0.19	0.22	1.71	3.63	1.15	0.34	2.22	4.31
Branch 20	0.19	0.14	0.12	0.07	0.08	0.10	0.64	1.23	0.42	0.21	0.79	1.42
Branch 21	0.44	0.32	0.28	0.18	0.19	0.26	1.48	2.60	0.95	0.65	1.76	2.95
Branch 22	2.21	1.68	1.68	1.21	1.18	1.65	1.32	0.73	1.90	1.60	1.35	1.26
Branch 23	4.32	3.23	3.07	2.16	2.16	3.06	5.13	5.15	5.12	4.29	5.57	6.89
Branch 24	1.08	0.81	0.77	0.54	0.54	0.76	1.28	1.29	1.28	1.07	1.39	1.72
Branch 25	1.34	1.14	0.87	0.45	0.55	0.35	1.28	0.72	0.33	0.44	0.40	0.49
Branch 26	1.28	1.09	0.83	0.42	0.52	0.31	1.10	0.55	0.25	0.36	0.30	0.35
Branch 27	9.32	7.50	5.89	3.27	3.85	3.27	14.92	15.12	5.92	6.18	9.46	13.91
Branch 28	4.93	3.97	3.12	1.73	2.04	1.73	7.91	8.01	3.13	3.27	5.01	7.37
Branch 29	2.00	1.61	1.26	0.70	0.82	0.70	3.20	3.25	1.27	1.32	2.03	2.99

Branch 30	2.16	1.74	1.36	0.76	0.89	0.76	3.47	3.52	1.37	1.43	2.20	3.24
Branch 31	0.31	0.25	0.19	0.11	0.13	0.11	0.49	0.50	0.19	0.20	0.31	0.46
Branch 32	0.08	0.07	0.05	0.03	0.03	0.03	0.14	0.14	0.05	0.06	0.09	0.13

Active Power Losses (I^2*R) (Watt) for Scenario A

Branch	13	14	15	16	17	18	19	20	21	22	23	24
Branch 1	1.37	1.50	1.90	1.40	2.91	7.45	13.64	15.45	13.77	11.56	3.49	2.21
Branch 2	8.58	9.63	12.42	7.67	19.22	48.70	85.91	104.40	90.43	71.93	21.88	15.34
Branch 3	0.84	1.18	2.30	0.52	4.23	22.27	22.56	29.72	33.44	28.24	3.48	2.52
Branch 4	0.63	0.89	1.74	0.38	3.52	18.56	17.47	22.20	27.42	21.50	2.79	1.93
Branch 5	0.92	1.30	2.59	0.53	5.90	31.14	26.72	33.40	45.13	32.18	4.46	2.92
Branch 6	0.33	0.22	0.06	0.57	0.53	0.02	0.11	4.25	0.19	1.24	0.75	0.15
Branch 7	4.12	3.09	1.53	6.33	7.22	2.54	6.14	40.45	7.94	5.13	9.73	2.71
Branch 8	3.27	2.69	1.80	4.59	6.03	4.52	9.53	31.27	11.27	3.32	7.88	2.76
Branch 9	4.91	6.83	12.80	3.38	12.41	72.34	130.34	288.97	130.62	197.99	13.49	13.08
Branch 10	0.73	1.02	1.92	0.51	1.86	10.90	19.71	43.98	19.75	30.04	2.02	1.96
Branch 11	1.07	1.49	2.81	0.74	2.72	16.07	29.15	65.56	29.22	44.62	2.96	2.87
Branch 12	3.10	4.32	8.13	2.13	7.88	46.84	85.37	193.69	85.58	131.27	8.57	8.31
Branch 13	0.80	1.11	2.09	0.55	2.02	12.09	22.09	50.41	22.15	34.07	2.20	2.13
Branch 14	0.56	0.78	1.46	0.38	1.42	8.50	15.57	35.72	15.61	24.08	1.54	1.49
Branch 15	0.40	0.55	1.04	0.27	1.01	6.07	11.16	25.73	11.19	17.30	1.10	1.06
Branch 16	0.30	0.42	0.80	0.21	0.78	4.69	8.64	20.03	8.66	13.44	0.85	0.82
Branch 17	0.04	0.06	0.11	0.03	0.11	0.67	1.23	2.86	1.23	1.92	0.12	0.12
Branch 18	0.06	0.09	0.14	0.01	0.22	1.02	2.02	3.04	2.51	2.12	0.20	0.21
Branch 19	0.90	1.17	1.75	0.42	2.66	10.70	20.61	30.12	24.84	21.19	2.64	2.41
Branch 20	0.37	0.45	0.63	0.26	0.95	3.34	6.36	8.97	7.38	6.35	1.01	0.81
Branch 21	0.93	1.06	1.43	0.83	2.12	6.66	12.57	17.09	14.03	12.18	2.40	1.72
Branch 22	2.67	2.53	2.13	2.99	2.83	1.01	8.62	8.05	4.28	2.34	4.68	3.06
Branch 23	6.46	6.47	6.49	6.95	9.12	9.74	35.43	37.00	25.28	17.68	13.22	8.56
Branch 24	1.62	1.62	1.62	1.74	2.28	2.44	8.91	9.31	6.35	4.44	3.31	2.14

Branch 25	0.95	0.87	0.82	1.13	3.28	6.43	5.46	0.91	10.44	1.29	3.20	1.18
Branch 26	0.82	0.74	0.67	1.00	2.98	5.70	4.40	0.24	9.11	0.81	2.86	1.00
Branch 27	10.29	10.33	11.44	11.30	30.12	71.81	90.53	59.98	129.66	47.81	31.86	14.92
Branch 28	5.45	5.47	6.06	5.98	15.99	38.27	48.32	31.94	69.39	25.43	16.92	7.91
Branch 29	2.21	2.21	2.45	2.42	6.49	15.58	19.69	12.99	28.32	10.33	6.87	3.20
Branch 30	2.39	2.40	2.66	2.62	7.04	16.95	21.45	14.12	30.92	11.23	7.45	3.47
Branch 31	0.34	0.34	0.38	0.37	1.00	2.41	3.05	2.00	4.39	1.59	1.06	0.49
Branch 32	0.09	0.09	0.10	0.10	0.27	0.66	0.84	0.55	1.21	0.44	0.29	0.14

Voltage Magnitude (pu) for Scenario B

Time	1	2	3	4	5	6	7	8	9	10	11	12
Bus1	1.0931	1.095307908	1.094418135	1.095916415	1.094013398	1.095481048	1.096634528	1.095291928	1.095162324	1.090965805	1.096481326	1.09370604
Bus2	1.0918	1.093639803	1.092896789	1.094376287	1.092761595	1.093948995	1.095743593	1.094456342	1.094479743	1.090321512	1.095632057	1.092141884
Bus3	1.0838	1.084396588	1.084326564	1.085937801	1.085629509	1.085600655	1.09085023	1.089792361	1.09057967	1.087168395	1.090976915	1.083487815
Bus4	1.0793	1.078378098	1.078888961	1.080245166	1.081144856	1.080341854	1.089235972	1.088394454	1.089953102	1.086877389	1.089735807	1.07900089
Bus5	1.0755	1.073176328	1.074198323	1.075375528	1.077275201	1.075882056	1.087746774	1.087084072	1.089442246	1.086658073	1.088658006	1.075118109
Bus6	1.0685	1.063857835	1.065854275	1.066756563	1.070441283	1.068095506	1.084915887	1.084608309	1.088662048	1.086383559	1.086764634	1.068239317
Bus7	1.0678	1.06267002	1.064659498	1.065310423	1.069304565	1.066754355	1.085713326	1.085314875	1.089180018	1.087103516	1.087368462	1.067774527
Bus8	1.0642	1.053325696	1.055901752	1.05362861	1.061742087	1.056391024	1.094184476	1.094209093	1.095674681	1.094995133	1.094220642	1.066382826
Bus9	1.0643	1.050847492	1.053491662	1.049747374	1.059535567	1.053162465	1.099843557	1.099999778	1.099999825	1.099999989	1.098966385	1.067823813
Bus10	1.0433	1.02027932	1.025866764	1.019283641	1.037153562	1.024086971	1.094859565	1.096225157	1.096311083	1.097831082	1.093362677	1.046001628
Bus11	1.0401	1.015666051	1.021697566	1.014686129	1.033775432	1.019698909	1.094107131	1.09565529	1.095754181	1.097503626	1.092516693	1.042707963
Bus12	1.0348	1.007928794	1.014709819	1.006975428	1.028120225	1.012341942	1.092852114	1.094705006	1.094825532	1.096957744	1.09110547	1.037195023
Bus13	1.0144	0.977996922	0.987717118	0.977147352	1.006330626	0.983902908	1.088054211	1.091073889	1.091277207	1.094873239	1.085709012	1.01596078
Bus14	1.0072	0.967459432	0.97822072	0.966646575	0.998673492	0.973894459	1.086373762	1.089802359	1.090034686	1.094143487	1.083818722	1.00849992
Bus15	1.0015	0.959162635	0.970743504	0.958378681	0.99264423	0.966014138	1.085050329	1.088800954	1.089056127	1.093568754	1.082330042	1.002625171
Bus16	0.9964	0.951603282	0.963932988	0.950845719	0.987155455	0.958835397	1.08384739	1.087890809	1.088166751	1.093046461	1.080976833	0.997277426
Bus17	0.9895	0.941454407	0.954794423	0.940732409	0.979797249	0.949200232	1.082239101	1.086674177	1.086977896	1.09234844	1.079167485	0.990109152
Bus18	0.9878	0.938939007	0.952529077	0.938225814	0.977972747	0.946811963	1.08184	1.086372252	1.086682863	1.092175204	1.078718502	0.988331683
Bus19	1.0922	1.093975251	1.093277151	1.094676478	1.093136231	1.094238422	1.095819248	1.094566808	1.094611845	1.090238582	1.095720812	1.092444973

Bus20	1.0966	1.09777506	1.097375811	1.098092478	1.097107992	1.09769963	1.097573303	1.096625033	1.096573305	1.090730692	1.097540768	1.096385332
Bus21	1.0978	1.098617812	1.098351119	1.098825591	1.098145513	1.098529708	1.098284246	1.097474098	1.09731479	1.09120975	1.0982683	1.097573331
Bus22	1.1000	1.09999994	1.09999993	1.099999926	1.09999982	1.099999952	1.099999666	1.099488739	1.098989632	1.092690667	1.099999731	1.099999325
Bus23	1.0830	1.084751593	1.084455464	1.086615001	1.085671508	1.085769999	1.088621423	1.087445073	1.087973068	1.084757464	1.088533748	1.082134543
Bus24	1.0771	1.079644748	1.079479009	1.082436847	1.081489685	1.080799644	1.082217732	1.081034342	1.081565499	1.078859142	1.081865941	1.074696411
Bus25	1.0742	1.077099581	1.07699888	1.080354856	1.079405863	1.078322561	1.079025543	1.077838636	1.078371373	1.075919119	1.078541942	1.070987876
Bus26	1.0681	1.063993882	1.066024966	1.067338707	1.070606854	1.06866107	1.083432425	1.083081938	1.087843532	1.085462825	1.085727984	1.067641452
Bus27	1.0679	1.064534536	1.066574602	1.068386356	1.071089983	1.069685221	1.081834211	1.081423922	1.087002391	1.084486922	1.084658495	1.06727016
Bus28	1.0582	1.055723633	1.05877499	1.062571568	1.064800344	1.063877671	1.069710734	1.0692956	1.079354221	1.076625518	1.07503708	1.055477085
Bus29	1.0520	1.050158744	1.053849255	1.058899935	1.060828725	1.060210614	1.062051564	1.061633363	1.074524248	1.071660789	1.068959947	1.048026761
Bus30	1.0492	1.04760829	1.051591814	1.057217359	1.059008648	1.058530135	1.058540886	1.058121277	1.072310717	1.069385482	1.066174663	1.04461183
Bus31	1.0445	1.043433657	1.047897499	1.054464831	1.056030928	1.055781045	1.052791157	1.052369233	1.068688459	1.065661977	1.061615117	1.039019093
Bus32	1.0435	1.042507868	1.047078222	1.053854402	1.055370561	1.055171378	1.051516094	1.051093657	1.06788516	1.064836226	1.060603972	1.037778843
Bus33	1.0429	1.04195239	1.046586661	1.05348816	1.054974355	1.054805594	1.050751008	1.050328263	1.067403188	1.064340781	1.059997273	1.037034648

Voltage Magnitude (pu) for Scenario B

Time	13	14	15	16	17	18	19	20	21	22	23	24
Bus1	1.095949734	1.095409499	1.095711091	1.095692081	1.094690478	1.096293608	1.094927535	1.094541082	1.098248931	1.095153889	1.095020638	1.093902293
Bus2	1.095023183	1.094440681	1.094772766	1.094765523	1.093330666	1.094591125	1.092660317	1.092404675	1.095905825	1.093424436	1.093530458	1.092719727
Bus3	1.089882306	1.088987531	1.08948763	1.089862663	1.085673856	1.085216122	1.080247993	1.080652125	1.08309405	1.083987268	1.085370138	1.085844286
Bus4	1.088453728	1.087296489	1.087937092	1.088712302	1.082516726	1.080462618	1.076311354	1.077599659	1.077531125	1.080643068	1.082504096	1.08338501
Bus5	1.087219009	1.085832566	1.086577115	1.087724651	1.079629233	1.075951387	1.072734145	1.074965045	1.072291567	1.077624271	1.079937288	1.081231995
Bus6	1.085062399	1.083269988	1.084153212	1.086072715	1.07416967	1.066985651	1.065966881	1.070265323	1.061835305	1.071967908	1.075196339	1.077394404
Bus7	1.08563543	1.083721997	1.084744688	1.08664167	1.074928056	1.068259889	1.067602656	1.071775835	1.063812735	1.073132634	1.076106693	1.077764825
Bus8	1.092419505	1.089639978	1.091700211	1.094594429	1.084021318	1.082072474	1.086856931	1.088371112	1.084278754	1.086114051	1.086649254	1.083422612
Bus9	1.097233322	1.094056846	1.096622533	1.099999788	1.09064846	1.091659686	1.099999749	1.0999482	1.098221413	1.095272764	1.094202702	1.087999182
Bus10	1.090611414	1.086244585	1.089956083	1.09450833	1.080111067	1.080213843	1.086371318	1.0856631	1.083868106	1.083093203	1.083214184	1.077180566
Bus11	1.089611732	1.085065223	1.088949677	1.093679292	1.078520382	1.078486046	1.084314114	1.083506792	1.081701505	1.081254667	1.08155541	1.075547436
Bus12	1.087943783	1.083097016	1.087270495	1.092296366	1.075864277	1.075600475	1.08087697	1.079903592	1.07808104	1.078183727	1.078785381	1.072820291
Bus13	1.081562907	1.075563683	1.080846515	1.087008373	1.065686204	1.06453887	1.067689205	1.066074808	1.064185451	1.066408035	1.068168879	1.062368626

Bus14	1.079327405	1.072923876	1.078595892	1.085156114	1.062117917	1.060660207	1.063063286	1.061223457	1.059310583	1.06227847	1.064446609	1.058704221
Bus15	1.077566875	1.070844972	1.076823456	1.083697381	1.059307901	1.057605802	1.059420503	1.057403178	1.055471788	1.059026505	1.061515346	1.055818522
Bus16	1.075966427	1.068954916	1.075212178	1.082371407	1.056752575	1.054828031	1.056107064	1.053928099	1.05197984	1.056068896	1.05884967	1.053194306
Bus17	1.073826194	1.06642697	1.073057448	1.080598503	1.053333484	1.051110816	1.051671662	1.04927587	1.047304965	1.052110621	1.055282714	1.049682882
Bus18	1.073295127	1.065799729	1.072522784	1.080158562	1.052485228	1.050188633	1.050571407	1.048121862	1.046145344	1.051128665	1.05439779	1.048811731
Bus19	1.095148323	1.094612322	1.094924949	1.094816112	1.093534755	1.094686858	1.092759088	1.092547838	1.095904618	1.09353777	1.093663996	1.093015143
Bus20	1.097308741	1.097135771	1.097268543	1.096642068	1.096645222	1.097183611	1.095974987	1.095963281	1.097959258	1.096397639	1.096477354	1.096590166
Bus21	1.098123142	1.098027357	1.098111478	1.097515147	1.097695228	1.098025418	1.097149505	1.097167887	1.098542595	1.097460415	1.097528147	1.097711554
Bus22	1.099999735	1.099999778	1.099999729	1.099736227	1.099999746	1.099999936	1.099999946	1.09999975	1.099999902	1.099999708	1.099999764	1.099999909
Bus23	1.087276373	1.086476072	1.086902656	1.087076018	1.083096835	1.083100798	1.074487653	1.074427024	1.07902068	1.080109688	1.082001486	1.083125377
Bus24	1.080072385	1.079266681	1.079696146	1.079606193	1.074535279	1.074272883	1.057577931	1.057104526	1.064770845	1.068171216	1.071694444	1.074830256
Bus25	1.076480758	1.075672354	1.076103258	1.075881859	1.070265799	1.069870373	1.049132795	1.048452594	1.05765759	1.062214198	1.066552958	1.070693833
Bus26	1.084012532	1.082272136	1.083019332	1.084934925	1.072209029	1.063669262	1.062634859	1.067794233	1.057541876	1.069585121	1.073264866	1.076242274
Bus27	1.082944275	1.08127732	1.08185302	1.083762445	1.070141793	1.060043773	1.05910599	1.065268545	1.052871827	1.06708434	1.071257055	1.075110887
Bus28	1.072814502	1.071131239	1.071218485	1.073147515	1.052781672	1.033453737	1.029195732	1.040976814	1.017102944	1.045492012	1.053400842	1.06290751
Bus29	1.066415991	1.06472241	1.064500842	1.066442279	1.041808826	1.016631286	1.010266035	1.025612214	0.994450258	1.031838507	1.042113926	1.055197756
Bus30	1.06348336	1.061785046	1.061421887	1.063369014	1.036778279	1.008916038	1.001583097	1.018566288	0.984056768	1.025577953	1.036939297	1.051663872
Bus31	1.058682138	1.056976048	1.056380627	1.058337107	1.028530864	0.996243314	0.987311011	1.006998666	0.966951056	1.015305342	1.028454879	1.045875969
Bus32	1.057617401	1.055909588	1.055262663	1.057221216	1.026701977	0.993433265	0.984146379	1.004433625	0.963158227	1.013027423	1.026573442	1.044592441
Bus33	1.056978542	1.055269693	1.05459186	1.056551658	1.025604471	0.991746668	0.982246836	1.002894156	0.960881333	1.011660348	1.025444391	1.043822274

Lambda P (UM/MWh) for Scenario B

Time	1	2	3	4	5	6	7	8	9	10	11	12
Bus1	273.8056657	328.8511766	301.9717297	305.4257832	251.3565917	304.2644199	171.9343241	162.0864962	133.7183429	123.4477874	165.2800617	308.2120968
Bus2	274.4455849	329.7537801	302.7340163	306.1949304	251.8846893	305.0324513	172.2017078	162.3266575	133.8802435	123.5888678	165.5251764	309.0304357
Bus3	278.8068886	336.2980474	308.1764558	311.7864804	255.5181766	310.4481713	173.8162276	163.7032244	134.8287907	124.3014109	166.9856587	314.3943741
Bus4	281.2818936	340.5973027	311.6607489	315.5719215	257.8127305	313.8952109	174.359922	164.0961253	134.9644608	124.3550654	167.3799968	317.2217853
Bus5	283.5407541	344.5462497	314.8432754	319.0241572	259.8938265	317.0119742	174.8750928	164.4686121	135.0757093	124.3944695	167.7349242	319.7914861
Bus6	287.6997452	351.8711286	320.7039445	325.36543	263.691998	322.6702528	175.8725478	165.1903536	135.2500704	124.4437135	168.3774302	324.4949424

Bus7	288.2248702	353.2633459	321.8308186	326.8133063	264.4228843	323.9613183	175.6085522	164.8839056	135.0763519	124.2438849	168.1827025	324.9587244
Bus8	291.4357598	363.2840971	329.8863624	337.603577	269.5890525	333.4227914	172.9814924	161.9406985	133.3648775	122.3592977	166.1624437	327.3264857
Bus9	292.4006326	367.6387385	333.3473463	342.5774124	271.7669099	337.6658824	171.2821816	160.0944593	132.2656951	121.1954753	164.8098788	327.6196255
Bus10	302.3355066	386.6756204	348.7449059	360.2699626	281.7003143	354.1699037	172.5566687	160.9936387	132.9915222	121.5847892	166.1921156	339.1772532
Bus11	304.0512839	390.0073948	351.4287095	363.36615	283.4192208	357.0522635	172.7721638	161.1454452	133.1140485	121.6503882	166.4260113	341.1752766
Bus12	306.9558692	395.6928745	355.9971079	368.6492964	286.3325058	361.964517	173.1325158	161.3990784	133.3187485	121.7598707	166.8173055	344.5596686
Bus13	317.149817	416.0955221	372.2776928	387.6049591	296.5901845	379.529069	174.3552159	162.2576627	134.0115705	122.1293615	168.1466008	356.4570366
Bus14	320.4444448	422.8622584	377.6338543	393.8905556	299.9178942	385.3301483	174.7352778	162.5238269	134.2263068	122.2435018	168.5603725	360.3095137
Bus15	323.3412857	428.8368702	382.3566864	399.440168	302.8455392	390.4485653	175.0675529	162.7564395	134.4139693	122.3432074	168.9221883	363.6978525
Bus16	326.1160545	434.5954549	386.8997744	404.7888623	305.6523075	395.3768449	175.3830039	162.977143	134.5920165	122.4377357	169.2657902	366.9448643
Bus17	329.4391453	441.6348241	392.4177696	411.3261562	309.0237286	401.381194	175.7493691	163.2329282	134.7983341	122.5469869	169.6652865	370.8393652
Bus18	330.3745559	443.6088787	393.9669198	413.1594624	309.9721943	403.0659662	175.8531815	163.3054429	134.8568269	122.57798	169.7784579	371.9352987
Bus19	274.0069177	328.971749	302.1012048	305.5055237	251.4905069	304.4077749	172.1209893	162.2823824	133.8412354	123.5966166	165.453972	308.5561742
Bus20	269.8108277	321.6360302	296.1664657	299.0470217	247.7543817	298.4660225	171.1398725	161.643511	133.3459402	123.4530175	164.5797329	303.7954552
Bus21	268.6235142	319.5970713	294.5172557	297.2538391	246.7058282	296.793093	170.8079798	161.40685	133.1740319	123.3556218	164.2821971	302.3912832
Bus22	266.4889315	315.9936474	291.6022478	294.0882535	244.8349388	293.8011931	170.1222858	160.8894254	132.8126486	123.0866634	163.6649376	299.7751128
Bus23	279.3974644	336.4073406	308.3697271	311.6934933	255.669867	310.6312041	174.570977	164.4420232	135.4988417	124.8710625	167.7776233	315.4124145
Bus24	281.8438976	338.9457424	310.6372387	313.6111016	257.2455749	312.9097334	176.2207341	165.9994909	136.7809128	125.9608948	169.4295165	318.9023512
Bus25	283.0786128	340.2248334	311.7795394	314.5756028	258.0381216	314.0575572	177.0541275	166.7862848	137.4285752	126.5109129	170.2644226	320.6690756
Bus26	287.9831777	351.8799117	320.6854462	325.0951816	263.6701998	322.4108086	176.3787387	165.6822289	135.4656434	124.663991	168.7178056	324.9476556
Bus27	288.2008774	351.6936675	320.4993598	324.5960346	263.5335922	321.9280473	176.9558987	166.2473416	135.702859	124.9112933	169.0935646	325.3389516
Bus28	292.383767	356.2977868	324.1976714	327.3710697	265.9669523	324.6734268	180.1153573	169.217984	137.2084864	126.3398485	171.4694741	331.064232
Bus29	295.085328	359.2655301	326.5763964	329.1485044	267.527036	326.4318141	182.1653845	171.145535	138.176294	127.2585533	173.0029928	334.7777891
Bus30	296.461548	360.7760254	327.7859407	330.0506328	268.3191846	327.3242633	183.211844	172.1294837	138.6682741	127.7256709	173.7839703	336.6731192
Bus31	298.4725374	362.9800576	329.5480799	331.3609502	269.4705543	328.620494	184.7461358	173.5721446	139.3847	128.4061265	174.9246341	339.4512852
Bus32	298.9036258	363.4521097	329.9251244	331.6407971	269.7165592	328.8973287	185.0757207	173.8820489	139.537951	128.5517142	175.1690835	340.0479746
Bus33	299.1420007	363.7129583	330.1333184	331.7950996	269.8522464	329.0499687	185.2582593	174.0536886	139.6225542	128.6320999	175.3042245	340.3784069

Lambda P (UM/MWh) for Scenario B

Time	13	14	15	16	17	18	19	20	21	22	23	24
Bus1	180.5413537	189.5583118	182.755187	180.5402732	262.2038785	321.6739992	426.5009901	404.3881529	434.9006314	329.6448906	286.2309527	231.392277
Bus2	180.8332155	189.878349	183.0545352	180.8351241	262.8205903	322.6079896	428.1597186	405.8721183	436.612831	330.6257808	286.9680085	231.8677725
Bus3	182.6001769	191.8474707	184.8970506	182.4448615	266.7811112	328.8633532	439.0636998	415.6084873	448.7485973	336.9041779	291.5927323	234.9389927
Bus4	183.0972878	192.4634382	185.4449743	182.7927543	268.4536419	332.1372618	442.7439295	418.3439883	454.3939546	339.2340105	293.2725504	236.0525529
Bus5	183.5431878	193.0164924	185.9425866	183.0949962	270.0353449	335.3471676	446.2365531	420.8461362	459.9380764	341.4256834	294.8368673	237.0646601
Bus6	184.3464163	194.0139238	186.8543904	183.6149211	273.0895036	341.8248516	453.00734	425.4695853	471.1461807	345.6284248	297.7983975	238.9201146
Bus7	184.1430576	193.8424696	186.6422188	183.3229789	272.7107408	341.0490267	451.4314256	424.3258677	469.541866	344.9148653	297.3079237	238.7541199
Bus8	181.9702075	191.8788098	184.3828886	180.4059101	268.5112257	333.0148391	435.6805926	412.444543	453.4027824	337.3602033	292.0007867	236.5538427
Bus9	180.4829639	190.4676501	182.8405264	178.5125472	265.5673579	327.6744571	425.5428851	404.5484449	442.9668247	332.2524124	288.3479823	234.8321395
Bus10	182.2794659	192.7182301	184.6739957	179.9778779	269.8456051	333.4175276	434.4084594	413.3996516	452.722771	338.4406406	293.1819854	238.7290527
Bus11	182.5838542	193.1001373	184.9846663	180.2257979	270.5741329	334.3966137	435.9238869	414.9138877	454.3919775	339.4965516	294.0055866	239.392904
Bus12	183.093453	193.7400741	185.5048009	180.6405192	271.7973302	336.0415819	438.4738758	417.4631102	457.2022792	341.2715017	295.3888339	240.5077603
Bus13	184.8281276	195.9236168	187.2755067	182.0490787	275.9940002	341.6955197	447.2754914	426.2738158	466.9171177	347.3807622	300.1385887	244.3350878
Bus14	185.3693302	196.6067335	187.8280109	182.4874079	277.3152461	343.479275	450.0658409	429.0713447	470.0023779	349.3112845	301.6354048	245.5409122
Bus15	185.8427274	197.2044938	188.311301	182.8706837	278.4724371	345.0420146	452.5121787	431.5245305	472.7079626	351.0030012	302.9465471	246.5971208
Bus16	186.2925245	197.7728021	188.7705089	183.2346441	279.5741782	346.5305736	454.8449739	433.8646794	475.289006	352.6150068	304.1951345	247.6028804
Bus17	186.8164398	198.4361849	189.3054315	183.6577234	280.8666407	348.279682	457.596602	436.6283256	478.3376521	354.5115796	305.6609742	248.783408
Bus18	186.9647949	198.6239396	189.4569006	183.7775813	281.2320324	348.7739926	458.3735836	437.4084981	479.1982486	355.0474152	306.0753118	249.1171131
Bus19	180.7371884	189.7586432	182.946335	180.8014257	262.5408996	322.1162086	427.383112	405.1668124	435.518551	330.2013573	286.674275	231.6361747
Bus20	179.615216	188.425827	181.7272469	180.1535041	259.5712344	316.988469	419.0681263	397.6709243	424.509086	325.5614497	283.402454	229.2649255
Bus21	179.2449852	188.0000519	181.3345632	179.885674	258.6552427	315.4288644	416.4903731	395.3596485	421.2564258	324.0999269	282.357843	228.5537976
Bus22	178.4929031	187.1549324	180.5503963	179.2651933	256.8856032	312.451448	411.4989003	390.9014651	415.1998205	321.2330685	280.2872245	227.2097424
Bus23	183.5292894	192.7967164	185.8317138	183.4272984	268.1810098	330.3579435	444.2391942	420.8620163	452.6240248	339.55667	293.5717349	236.2228359
Bus24	185.4857981	194.8551179	187.8141605	185.4562548	271.6006138	334.7035718	455.6988356	431.9931302	462.3709862	345.6496592	298.0976713	239.1396795
Bus25	186.475723	195.896619	188.817219	186.4833761	273.3355631	336.9095069	461.6122723	437.7418661	467.3730321	348.7619839	300.4019383	240.6187698
Bus26	184.7271824	194.3990047	187.2709473	184.0281445	274.1690932	344.1625166	456.2077166	427.6643459	475.480348	347.3144793	298.9625672	239.4789402
Bus27	185.1440092	194.8152833	187.7305573	184.4856544	275.389202	346.8927252	459.8814902	430.1102452	480.5675694	349.22095	300.265952	240.0792446
Bus28	187.8905081	197.7145773	190.6606022	187.3544305	282.5985081	361.2712413	481.5322896	446.2164773	508.2371568	360.7453013	308.3520689	244.4225499
Bus29	189.6651512	199.5880731	192.5558744	189.2099233	287.3299834	370.9033938	496.1440927	456.9487739	527.1669221	368.3788828	313.6644223	247.2416409

Bus30	190.569362	200.542679	193.5220063	190.155744	289.757481	375.8905622	503.7346773	462.4923709	537.0608859	372.3114314	316.3911794	248.6808859
Bus31	191.8910596	201.9381072	194.9353172	191.5392619	293.3466048	383.3782658	515.1955317	470.7821454	552.1566902	378.1658683	320.4258183	250.7915733
Bus32	192.1744435	202.2373086	195.2384897	191.8360328	294.1215946	385.0104503	517.7024975	472.5846946	555.4801797	379.4353671	321.2974137	251.2450419
Bus33	192.3311677	202.4027843	195.4062199	192.0002169	294.5525189	385.9245363	519.1101638	473.5923086	557.3553349	380.1435318	321.7822268	251.4962211

Active Power Losses (I^2*R) (Watt) for Scenario B

Time	1	2	3	4	5	6	7	8	9	10	11	12
Branch 1	2.90	4.10	3.44	3.47	2.36	3.46	1.27	1.15	0.77	0.68	1.16	3.74
Branch 2	20.59	28.51	24.27	23.80	16.56	23.14	7.82	6.96	4.87	3.20	7.04	24.44
Branch 3	8.38	15.51	12.57	13.87	8.46	11.77	1.10	0.80	0.15	0.03	0.64	8.46
Branch 4	6.41	11.78	9.49	10.35	6.36	8.64	0.93	0.69	0.10	0.02	0.48	6.40
Branch 5	9.63	17.53	14.00	15.04	9.34	12.28	1.58	1.20	0.12	0.01	0.71	9.45
Branch 6	0.57	2.51	2.08	3.30	1.41	2.70	0.59	0.77	0.38	0.61	0.36	0.30
Branch 7	2.06	13.01	10.69	18.57	7.18	14.65	6.52	7.96	4.14	6.06	4.24	0.71
Branch 8	0.42	4.01	3.21	6.27	2.07	4.72	4.65	5.38	2.91	3.94	3.22	0.35
Branch 9	49.06	103.58	84.69	102.87	55.71	93.77	2.78	1.60	1.52	0.53	3.51	52.97
Branch 10	7.38	15.64	12.78	15.54	8.39	14.15	0.42	0.24	0.23	0.08	0.53	7.97
Branch 11	10.86	23.11	18.85	22.95	12.34	20.89	0.61	0.35	0.33	0.11	0.77	11.73
Branch 12	31.58	67.57	55.02	67.10	35.93	61.04	1.75	1.01	0.96	0.33	2.22	34.14
Branch 13	8.14	17.47	14.21	17.35	9.27	15.77	0.45	0.26	0.25	0.08	0.57	8.80
Branch 14	5.72	12.30	10.00	12.21	6.51	11.10	0.31	0.18	0.17	0.06	0.40	6.18
Branch 15	4.08	8.81	7.15	8.74	4.65	7.94	0.22	0.13	0.12	0.04	0.28	4.41
Branch 16	3.15	6.81	5.53	6.77	3.59	6.14	0.17	0.10	0.09	0.03	0.22	3.41
Branch 17	0.45	0.97	0.79	0.96	0.51	0.87	0.02	0.01	0.01	0.00	0.03	0.48
Branch 18	0.48	0.93	0.75	0.84	0.45	0.70	0.05	0.02	0.03	0.00	0.04	0.43
Branch 19	4.84	8.98	7.20	8.00	4.41	6.92	0.72	0.50	0.44	0.05	0.66	4.75
Branch 20	1.45	2.56	2.06	2.28	1.29	2.03	0.32	0.25	0.20	0.07	0.29	1.55
Branch 21	2.74	4.65	3.75	4.12	2.41	3.77	0.82	0.71	0.51	0.33	0.75	3.18
Branch 22	0.55	0.22	0.20	0.21	0.13	0.21	1.96	2.10	2.55	2.16	2.33	1.16

Branch 23	4.35	3.25	3.08	2.17	2.18	3.08	5.11	5.12	5.11	4.33	5.54	6.89
Branch 24	1.09	0.81	0.77	0.54	0.54	0.77	1.28	1.28	1.28	1.08	1.39	1.72
Branch 25	0.23	0.05	0.05	0.21	0.04	0.20	1.82	1.95	0.58	0.70	0.91	0.43
Branch 26	0.17	0.17	0.17	0.49	0.13	0.47	1.69	1.84	0.51	0.64	0.80	0.30
Branch 27	9.59	7.79	6.11	3.40	3.98	3.39	14.73	14.74	5.87	6.21	9.29	13.94
Branch 28	5.08	4.12	3.23	1.80	2.10	1.79	7.80	7.81	3.11	3.28	4.92	7.38
Branch 29	2.06	1.67	1.31	0.73	0.85	0.72	3.16	3.16	1.26	1.33	1.99	2.99
Branch 30	2.23	1.81	1.42	0.79	0.92	0.78	3.43	3.43	1.36	1.44	2.16	3.24
Branch 31	0.32	0.26	0.20	0.11	0.13	0.11	0.49	0.49	0.19	0.20	0.31	0.46
Branch 32	0.09	0.07	0.06	0.03	0.04	0.03	0.13	0.13	0.05	0.06	0.08	0.13

Active Power Losses (I^2*R) (Watt) for Scenario B

Time	13	14	15	16	17	18	19	20	21	22	23	24
Branch 1	1.37	1.50	1.41	1.40	2.91	4.47	7.98	7.10	8.31	4.67	3.49	2.21
Branch 2	8.58	9.63	9.07	7.67	19.22	29.43	51.38	45.97	56.14	29.48	21.88	15.34
Branch 3	0.84	1.18	1.00	0.52	4.23	9.84	6.66	3.98	13.77	4.78	3.48	2.52
Branch 4	0.63	0.89	0.77	0.38	3.52	8.77	5.50	3.01	12.16	3.90	2.79	1.93
Branch 5	0.92	1.30	1.16	0.53	5.90	15.93	9.12	4.45	21.88	6.37	4.46	2.92
Branch 6	0.33	0.22	0.35	0.57	0.53	1.40	3.00	1.99	3.18	1.18	0.75	0.15
Branch 7	4.12	3.09	4.33	6.33	7.22	16.76	34.25	24.17	36.58	14.74	9.73	2.71
Branch 8	3.27	2.69	3.42	4.59	6.03	12.81	25.14	18.61	27.00	11.60	7.88	2.76
Branch 9	4.91	6.83	4.97	3.38	12.41	14.63	20.73	22.77	22.99	16.56	13.49	13.08
Branch 10	0.73	1.02	0.74	0.51	1.86	2.19	3.11	3.42	3.45	2.48	2.02	1.96
Branch 11	1.07	1.49	1.09	0.74	2.72	3.21	4.56	5.01	5.06	3.64	2.96	2.87
Branch 12	3.10	4.32	3.14	2.13	7.88	9.30	13.21	14.53	14.67	10.54	8.57	8.31
Branch 13	0.80	1.11	0.81	0.55	2.02	2.39	3.40	3.74	3.77	2.71	2.20	2.13
Branch 14	0.56	0.78	0.56	0.38	1.42	1.67	2.38	2.62	2.64	1.90	1.54	1.49
Branch 15	0.40	0.55	0.40	0.27	1.01	1.19	1.70	1.87	1.88	1.35	1.10	1.06
Branch 16	0.30	0.42	0.31	0.21	0.78	0.92	1.31	1.44	1.45	1.04	0.85	0.82
Branch 17	0.04	0.06	0.04	0.03	0.11	0.13	0.19	0.20	0.21	0.15	0.12	0.12

Branch 18	0.06	0.09	0.08	0.01	0.22	0.41	0.60	0.55	1.09	0.31	0.20	0.21
Branch 19	0.90	1.17	1.04	0.42	2.66	4.65	7.06	6.47	11.31	3.81	2.64	2.41
Branch 20	0.37	0.45	0.41	0.26	0.95	1.58	2.50	2.28	3.55	1.41	1.01	0.81
Branch 21	0.93	1.06	0.98	0.83	2.12	3.40	5.60	5.07	7.12	3.26	2.40	1.72
Branch 22	2.67	2.53	2.64	2.99	2.83	2.16	13.65	15.67	7.53	6.26	4.68	3.06
Branch 23	6.46	6.47	6.47	6.95	9.12	9.70	35.53	37.29	25.25	17.73	13.22	8.56
Branch 24	1.62	1.62	1.62	1.74	2.28	2.43	8.93	9.38	6.34	4.45	3.31	2.14
Branch 25	0.95	0.87	1.10	1.13	3.28	9.26	9.61	5.30	15.70	4.85	3.20	1.18
Branch 26	0.82	0.74	0.96	1.00	2.98	8.84	8.87	4.65	14.97	4.39	2.86	1.00
Branch 27	10.29	10.33	11.34	11.30	30.12	70.34	88.86	58.78	126.71	46.50	31.86	14.92
Branch 28	5.45	5.47	6.01	5.98	15.99	37.49	47.42	31.29	67.78	24.73	16.92	7.91
Branch 29	2.21	2.21	2.43	2.42	6.49	15.25	19.32	12.72	27.66	10.05	6.87	3.20
Branch 30	2.39	2.40	2.63	2.62	7.04	16.60	21.04	13.84	30.19	10.92	7.45	3.47
Branch 31	0.34	0.34	0.37	0.37	1.00	2.36	2.99	1.96	4.29	1.55	1.06	0.49
Branch 32	0.09	0.09	0.10	0.10	0.27	0.65	0.82	0.54	1.18	0.43	0.29	0.14

Voltage Magnitude (pu) for Scenario C												
Time	1	2	3	4	5	6	7	8	9	10	11	12
Bus1	1.0931	1.0953	1.094418135	1.095916415	1.094013398	1.095416601	1.096230419	1.092057095	1.090076094	1.081498917	1.09120341	1.09369152
Bus2	1.0918	1.0936	1.092896789	1.094376287	1.092761595	1.093892335	1.095363507	1.091279039	1.08948429	1.080970253	1.090491716	1.092272584
Bus3	1.0838	1.0844	1.084326564	1.085937801	1.085629509	1.085577992	1.090559063	1.086965535	1.086138083	1.078529956	1.086574372	1.084359806
Bus4	1.0793	1.0784	1.078888961	1.080245166	1.081144856	1.080351142	1.089030663	1.085881987	1.086008314	1.078882221	1.086004469	1.080543977
Bus5	1.0755	1.0732	1.074198323	1.075375528	1.077275201	1.07591808	1.087611541	1.084841803	1.085926031	1.079217916	1.085498287	1.077229292
Bus6	1.0685	1.0639	1.065854275	1.066756563	1.070441283	1.068180361	1.084920582	1.08282969	1.085885601	1.079903269	1.084623962	1.071352713
Bus7	1.0678	1.0627	1.064659498	1.065310423	1.069304565	1.066844336	1.085674261	1.083701246	1.086660961	1.080950477	1.085420678	1.071112426
Bus8	1.0642	1.0533	1.055901752	1.05362861	1.061742087	1.056573013	1.094299353	1.093701656	1.094882869	1.09108755	1.094353164	1.071821139
Bus9	1.0643	1.0508	1.053491662	1.049747374	1.059535567	1.053379359	1.099999848	1.099999989	1.099999989	1.097126842	1.099999989	1.074141895
Bus10	1.0433	1.0203	1.025866764	1.019283641	1.037153562	1.024511687	1.095519315	1.097721003	1.098632147	1.097917585	1.097740043	1.056185032
Bus11	1.0401	1.0157	1.021697566	1.014686129	1.033775432	1.02015498	1.094842883	1.097376928	1.09842563	1.098036976	1.097398842	1.053474631

Bus12	1.0348	1.0079	1.014709819	1.006975428	1.028120225	1.012850933	1.093714742	1.096803329	1.098081411	1.098235893	1.096830038	1.048941775
Bus13	1.0144	0.9780	0.987717118	0.977147352	1.006330626	0.984619398	1.089402774	1.094612889	1.096767405	1.098994573	1.094657922	1.03151409
Bus14	1.0072	0.9675	0.97822072	0.966646575	0.998673492	0.974684442	1.087892648	1.093846037	1.096307452	1.099260049	1.093897489	1.025395531
Bus15	1.0015	0.9592	0.970743504	0.958378681	0.99264423	0.966861979	1.086703346	1.093242086	1.095945202	1.099469138	1.093298591	1.020577554
Bus16	0.9964	0.9516	0.963932988	0.950845719	0.987155455	0.959736099	1.085622368	1.092693236	1.095616024	1.099659107	1.092754335	1.016193383
Bus17	0.9895	0.9415	0.954794423	0.940732409	0.979797249	0.95017225	1.084177237	1.091959712	1.09517614	1.099912893	1.092026953	1.010320477
Bus18	0.9878	0.9389	0.952529077	0.938225814	0.977972747	0.947801632	1.083818616	1.091777666	1.095066966	1.099975885	1.091846431	1.008863939
Bus19	1.0922	1.0940	1.093277151	1.094676478	1.093136231	1.094184618	1.095458542	1.091350285	1.08955477	1.080805417	1.090549972	1.092563239
Bus20	1.0966	1.0978	1.097375811	1.098092478	1.097107992	1.097667649	1.097373495	1.093051533	1.090954087	1.080557499	1.09206426	1.096344628
Bus21	1.0978	1.0986	1.098351119	1.098825591	1.098145513	1.098507936	1.09814975	1.093803687	1.091542615	1.080837467	1.092746797	1.097532733
Bus22	1.1000	1.1000	1.09999993	1.099999926	1.09999982	1.099999953	1.099999375	1.095651372	1.092953303	1.081978622	1.09443859	1.099999849
Bus23	1.0830	1.0848	1.084455464	1.086615001	1.085671508	1.085730356	1.088280054	1.084478357	1.083312421	1.075831674	1.083814346	1.082686838
Bus24	1.0771	1.0796	1.079479009	1.082436847	1.081489685	1.080759817	1.081874322	1.078049805	1.076876837	1.069883678	1.077117014	1.075252572
Bus25	1.0742	1.0771	1.07699888	1.080354856	1.079405863	1.078282642	1.078681113	1.074845196	1.073668715	1.066918844	1.073778263	1.07154597
Bus26	1.0681	1.0640	1.066024966	1.067338707	1.070606854	1.068737439	1.083419265	1.081225114	1.08494892	1.078828797	1.083431084	1.07058562
Bus27	1.0679	1.0645	1.066574602	1.068386356	1.071089983	1.069749691	1.081796109	1.079458483	1.083943205	1.077639654	1.082143807	1.069976231
Bus28	1.0582	1.0557	1.05877499	1.062571568	1.064800344	1.0639425	1.069672182	1.067306896	1.076272738	1.06972659	1.072499097	1.058214543
Bus29	1.0520	1.0502	1.053849255	1.058899935	1.060828725	1.06027567	1.062012728	1.059629931	1.071428666	1.064729192	1.066407226	1.050784089
Bus30	1.0492	1.0476	1.051591814	1.057217359	1.059008648	1.058595295	1.058501919	1.056111089	1.06920867	1.062438906	1.063615184	1.047378273
Bus31	1.0445	1.0434	1.047897499	1.054464831	1.056030928	1.055846375	1.052751975	1.050347931	1.065575805	1.058690817	1.059044535	1.041800527
Bus32	1.0435	1.0425	1.047078222	1.053854402	1.055370561	1.055236746	1.051476864	1.04906989	1.064770154	1.057859614	1.058030927	1.040563601
Bus33	1.0429	1.0420	1.046586661	1.05348816	1.054974355	1.054870985	1.050711749	1.048303016	1.06428677	1.057360898	1.057422751	1.039821402

Voltage Magnitude (pu) for Scenario C

Time	13	14	15	16	17	18	19	20	21	22	23	24
Bus1	1.092945783	1.095976199	1.095740389	1.093395844	1.094855063	1.078219812	1.076534387	1.075393422	1.08637085	1.076522135	1.095020638	1.093902293
Bus2	1.092152821	1.09511846	1.094880693	1.092510052	1.093522803	1.077046282	1.074779259	1.073763221	1.08457802	1.075297019	1.093530458	1.092719727
Bus3	1.087705275	1.090290291	1.090004459	1.087855461	1.086021596	1.070199041	1.064628307	1.064323616	1.073750852	1.068396816	1.085370138	1.085844286
Bus4	1.086906454	1.089150911	1.088820209	1.086928961	1.083001939	1.067803954	1.06290184	1.063526794	1.070161838	1.067427325	1.082504096	1.08338501
Bus5	1.086206186	1.088158829	1.087771084	1.086133948	1.080231673	1.065249476	1.061134594	1.062757021	1.06648746	1.066398062	1.079937288	1.081231995

Bus6	1.085009322	1.086421946	1.085903952	1.084813461	1.074974403	1.059774894	1.057630501	1.061418407	1.058975203	1.06427093	1.075196339	1.077394404
Bus7	1.085727249	1.087093775	1.086583364	1.085498682	1.075794171	1.061339331	1.059213159	1.063014932	1.060172787	1.065915849	1.076106693	1.077764825
Bus8	1.094389696	1.09477964	1.094621254	1.094235345	1.085335891	1.082033121	1.084464498	1.085879566	1.084755633	1.086065237	1.086649254	1.083422612
Bus9	1.0999998	1.09997308	1.099999822	1.099999793	1.092160368	1.094468242	1.099999806	1.099999709	1.099999742	1.098269884	1.094202702	1.087999182
Bus10	1.096583464	1.094908295	1.095206902	1.095582014	1.082332435	1.096003994	1.099198266	1.098451278	1.098410059	1.098749924	1.083214184	1.077180566
Bus11	1.096067685	1.094143665	1.094483312	1.094915054	1.08084883	1.096235874	1.099077248	1.098217497	1.09817005	1.098822403	1.08155541	1.075547436
Bus12	1.095207656	1.092868285	1.09327645	1.093802727	1.078371884	1.096622154	1.09887556	1.097827822	1.09776999	1.098943166	1.078785381	1.072820291
Bus13	1.091921889	1.087992377	1.088663005	1.089551307	1.068883249	1.098095009	1.098105818	1.09634018	1.09624268	1.099403824	1.068168879	1.062368626
Bus14	1.09077136	1.086284583	1.087047213	1.088062403	1.065557094	1.098610324	1.097836403	1.095819433	1.095708043	1.099565024	1.064446609	1.058704221
Bus15	1.089865247	1.084939617	1.085774698	1.086889813	1.062937736	1.099016193	1.097624216	1.095409303	1.095286974	1.099691985	1.061515346	1.055818522
Bus16	1.089041732	1.083717096	1.084618058	1.085824029	1.060555929	1.099384926	1.097431409	1.095036613	1.094904342	1.099807339	1.05884967	1.053194306
Bus17	1.087940956	1.082082611	1.08307171	1.084399223	1.057369345	1.09987748	1.097173778	1.094538569	1.094393011	1.09996145	1.055282714	1.049682882
Bus18	1.087667778	1.08167701	1.082687977	1.084045646	1.056578748	1.09999974	1.097109835	1.094414961	1.094266105	1.099999702	1.05439779	1.048811731
Bus19	1.092262417	1.095247289	1.09502331	1.092533041	1.093715345	1.077187308	1.075016171	1.074000906	1.084994553	1.07537722	1.093663996	1.093015143
Bus20	1.094246532	1.097361927	1.097257991	1.094108283	1.096716051	1.079913508	1.079275729	1.078083912	1.090474941	1.077801289	1.096477354	1.096590166
Bus21	1.095057179	1.098158632	1.098095896	1.094913759	1.097739155	1.081050691	1.081012222	1.079721586	1.092427849	1.07892655	1.097528147	1.097711554
Bus22	1.096970853	1.099982221	1.09999925	1.097018996	1.099999732	1.083765523	1.085107711	1.083550042	1.096677837	1.081753723	1.099999764	1.099999909
Bus23	1.08480014	1.087538328	1.087250537	1.084968289	1.083384025	1.066839214	1.057571257	1.056804008	1.068408612	1.063286747	1.082001486	1.083125377
Bus24	1.077579407	1.080336107	1.080046375	1.077483677	1.074824788	1.057873641	1.040378764	1.039179167	1.054011931	1.051153441	1.071694444	1.074830256
Bus25	1.073979411	1.076745363	1.07645466	1.073751952	1.070556468	1.053402268	1.031791541	1.030375277	1.046825003	1.045098794	1.066552958	1.070693833
Bus26	1.083815035	1.085297006	1.084687494	1.083620699	1.072980841	1.055834221	1.053704438	1.05836487	1.054143506	1.061283964	1.073264866	1.076242274
Bus27	1.08254479	1.084123225	1.083405001	1.082371797	1.07086706	1.051344506	1.049356333	1.055033983	1.048728507	1.057945297	1.071257055	1.075110887
Bus28	1.072411114	1.074004953	1.072786406	1.071742596	1.053519624	1.024505952	1.019126901	1.030479106	1.012792531	1.036147411	1.053400842	1.06290751
Bus29	1.066010134	1.067613719	1.066078851	1.065028328	1.042554822	1.007525442	0.999993969	1.014947279	0.99003322	1.022363394	1.042113926	1.055197756
Bus30	1.06307637	1.064684426	1.063004523	1.061950921	1.037527967	0.999737549	0.991217579	1.00782452	0.979590659	1.016042896	1.036939297	1.051663872
Bus31	1.058273287	1.059888688	1.057970867	1.056912206	1.029286644	0.986944265	0.976790075	0.996129571	0.962403031	1.005671114	1.028454879	1.045875969
Bus32	1.057208138	1.058825168	1.056854589	1.055794806	1.027459108	0.98410749	0.973590992	0.993536305	0.958592044	1.003371211	1.026573442	1.044592441
Bus33	1.05656903	1.058187038	1.056184798	1.055124342	1.026362413	0.982404838	0.971670747	0.99197988	0.956304236	1.001990931	1.025444391	1.043822274

Lambda P (UM/MWh) for Scenario C												
Time	1	2	3	4	5	6	7	8	9	10	11	12
Bus1	273.8056657	328.8511766	301.9717297	305.4257832	251.3565917	302.8280639	167.7399246	149.2424557	113.6300277	97.67609301	136.7987962	279.7074766
Bus2	274.4455849	329.7537801	302.7340163	306.1949304	251.8846893	303.589104	167.9954345	149.4496221	113.7506205	97.76922428	136.9725534	280.3867148
Bus3	278.8068886	336.2980474	308.1764558	311.7864804	255.5181766	308.9475449	169.5078003	150.6275088	114.4479408	98.21244677	137.9536064	284.7519268
Bus4	281.2818936	340.5973027	311.6607489	315.5719215	257.8127305	312.3512879	169.9865674	150.9067904	114.4634149	98.14272126	138.0801465	286.8855489
Bus5	283.5407541	344.5462497	314.8432754	319.0241572	259.8938265	315.4280559	170.4402835	151.1771021	114.4699256	98.07500295	138.1929317	288.8223263
Bus6	287.6997452	351.8711286	320.7039445	325.36543	263.691998	321.0117473	171.31895	151.7140795	114.4632726	97.93999199	138.3944383	292.3632958
Bus7	288.2248702	353.2633459	321.8308186	326.8133063	264.4228843	322.2826547	171.0364825	151.3919122	114.2682634	97.72806887	138.1375965	292.5723016
Bus8	291.4357598	363.2840971	329.8863624	337.603577	269.5890525	331.5863208	168.2714299	148.3842446	112.4584908	95.83246294	135.7270929	293.0839292
Bus9	292.4006326	367.6387385	333.3473463	342.5774124	271.7669099	335.7512438	166.5076743	146.5462794	111.3576073	94.72089223	134.2460062	292.5532807
Bus10	302.3355066	386.6756204	348.7449059	360.2699626	281.7003143	352.0289493	167.6198413	147.0408223	111.5825673	94.56413909	134.6953549	300.8919944
Bus11	304.0512839	390.0073948	351.4287095	363.36615	283.4192208	354.870959	167.8077718	147.1241686	111.6204383	94.53685861	134.7710802	302.3260189
Bus12	306.9558692	395.6928745	355.9971079	368.6492964	286.3325058	359.713595	168.121917	147.2632893	111.6836138	94.489357	134.8974743	304.7475739
Bus13	317.149817	416.0955221	372.2776928	387.6049591	296.5901845	377.0207217	169.1867932	147.7329289	111.896515	94.32070835	135.324124	313.1876941
Bus14	320.4444448	422.8622584	377.6338543	393.8905556	299.9178942	382.7335147	169.517426	147.8780438	111.9621691	94.26498644	135.4559487	315.8937315
Bus15	323.3412857	428.8368702	382.3566864	399.440168	302.8455392	387.773558	169.8064425	148.0048128	112.019508	94.2111558	135.571106	318.2701284
Bus16	326.1160545	434.5954549	386.8997744	404.7888623	305.6523075	392.6256982	170.080757	148.1250068	112.0738495	94.15199904	135.680289	320.5421185
Bus17	329.4391453	441.6348241	392.4177696	411.3261562	309.0237286	398.5345999	170.3990658	148.2639487	112.1365692	94.06514216	135.8064976	323.2459147
Bus18	330.3745559	443.6088787	393.9669198	413.1594624	309.9721943	400.1927221	170.4892796	148.3033631	112.154368	94.0244603	135.8423001	324.0079679
Bus19	274.0069177	328.971749	302.1012048	305.5055237	251.4905069	302.9730633	167.9300283	149.4192291	113.729909	97.78992538	136.9485668	280.0321191
Bus20	269.8108277	321.6360302	296.1664657	299.0470217	247.7543817	297.1115331	167.095051	148.9245662	113.4216381	97.80697213	136.5432069	276.4043147
Bus21	268.6235142	319.5970713	294.5172557	297.2538391	246.7058282	295.4607015	166.804447	148.7316116	113.3057281	97.76451905	136.3827616	275.3173921
Bus22	266.4889315	315.9936474	291.6022478	294.0882535	244.8349388	292.5074586	166.1927439	148.297449	113.0500146	97.60977081	136.0189043	273.2654113
Bus23	279.3974644	336.4073406	308.3697271	311.6934933	255.669867	309.1370617	170.2559373	151.342669	115.0592511	98.71197543	138.6780718	285.8083989
Bus24	281.8438976	338.9457424	310.6372387	313.6111016	257.2455749	311.4047996	171.8659462	152.7840464	116.1574903	99.58812788	140.0556028	288.9675025
Bus25	283.0786128	340.2248334	311.7795394	314.5756028	258.0381216	312.547188	172.6792668	153.5122456	116.7123473	100.030392	140.7519203	290.5667226
Bus26	287.9831777	351.8799117	320.6854462	325.0951816	263.6701998	320.7585302	171.8191621	152.1861322	114.6681768	98.13927878	138.7130548	292.8553038
Bus27	288.2008774	351.6936675	320.4993598	324.5960346	263.5335922	320.2850966	172.3913904	152.7333665	114.9002046	98.36975618	139.0761681	293.3270932
Bus28	292.383767	356.2977868	324.1976714	327.3710697	265.9669523	323.0161276	175.4695818	155.4729705	116.182456	99.50961657	141.0397558	298.4615702
Bus29	295.085328	359.2655301	326.5763964	329.1485044	267.527036	324.7653222	177.466882	157.2507778	117.0067541	100.2428163	142.3072644	301.7914847

Bus30	296.461548	360.7760254	327.7859407	330.0506328	268.3191846	325.6531052	178.4864272	158.158326	117.4257987	100.6156482	142.9527978	303.4909128
Bus31	298.4725374	362.9800576	329.5480799	331.3609502	269.4705543	326.9425572	179.98126	159.4890613	118.0360555	101.1588398	143.8957025	305.9816902
Bus32	298.9036258	363.4521097	329.9251244	331.6407971	269.7165592	327.217944	180.3023689	159.7749345	118.1666011	101.2750699	144.0977799	306.5166235
Bus33	299.1420007	363.7129583	330.1333184	331.7950996	269.8522464	327.3697856	180.4802132	159.9332699	118.2386719	101.3392506	144.2094996	306.8128435

Lambda P (UM/MWh) for Scenario C												
Time	13	14	15	16	17	18	19	20	21	22	23	24
Bus1	153.5417332	166.719263	167.1234277	171.3991634	256.5401778	215.6526618	324.2556837	302.2805007	335.2806308	225.8623201	286.2309527	231.392277
Bus2	153.7583521	166.9703169	167.3764887	171.6678023	257.131873	216.1141484	325.2908297	303.1778274	336.3638792	226.3665118	286.9680085	231.8677725
Bus3	155.0050038	168.4856192	168.8963136	173.1228571	260.9258087	218.8634349	331.4376489	308.5103292	343.0692603	229.275011	291.5927323	234.9389927
Bus4	155.2069017	168.8424641	169.2578147	173.3852017	262.4922336	219.7876915	332.2853781	308.7684635	345.1449838	229.6156391	293.2725504	236.0525529
Bus5	155.3850863	169.1630369	169.5858641	173.6122049	263.9770354	220.7761554	333.1539741	309.0070649	347.2866425	229.9780355	294.8368673	237.0646601
Bus6	155.6989231	169.741874	170.1864866	174.0004182	266.8525393	222.9629711	334.9921851	309.4546567	351.8599255	230.7741875	297.7983975	238.9201146
Bus7	155.4210952	169.5057798	169.9274637	173.6904649	266.4500872	221.8133491	332.8292861	307.7251708	349.5146616	229.6732393	297.3079237	238.7541199
Bus8	152.7609503	167.1342724	167.3605078	170.6761248	262.1058972	211.6295631	313.5099489	292.1647331	328.4758234	219.8536358	292.0007867	236.5538427
Bus9	151.096542	165.5877538	165.7054806	168.7645027	259.118117	205.7402235	302.2744045	283.0421283	316.1878499	214.1358583	288.3479823	234.8321395
Bus10	151.8639117	166.8397998	166.8904492	169.8757838	262.9981771	204.458174	302.6262922	283.6874279	316.9298063	213.3327264	293.1819854	238.7290527
Bus11	151.993407	167.0515245	167.0907594	170.0635495	263.6582918	204.2259497	302.6856002	283.7961341	317.0547632	213.1841841	294.0055866	239.392904
Bus12	152.2097084	167.4055969	167.4256727	170.377405	264.7660369	203.8025926	302.7846785	283.9775763	317.2632727	212.9074797	295.3888339	240.5077603
Bus13	152.9414142	168.6071916	168.5616326	171.4411686	268.5610936	202.219696	303.1187625	284.589483	317.9663289	211.8474421	300.1385887	244.3350878
Bus14	153.1680658	168.9807614	168.9145813	171.7714097	269.7539032	201.6643815	303.2217146	284.7782795	318.1832498	211.4657047	301.6354048	245.5409122
Bus15	153.3661252	169.3073701	169.2231341	172.0600783	270.7983562	201.0872599	303.3116505	284.9431895	318.372715	211.0588976	302.9465471	246.5971208
Bus16	153.5540116	169.6174548	169.516036	172.334054	271.7923863	200.3952675	303.3968923	285.0995055	318.5522997	210.5577383	304.1951345	247.6028804
Bus17	153.771628	169.977639	169.8560986	172.6519348	272.9569602	199.2660686	303.4952115	285.27999	318.7596556	209.714903	305.6609742	248.783408
Bus18	153.833331	170.0796967	169.9524656	172.7420297	273.2862931	198.6628882	303.5231223	285.3312059	318.8184947	209.2518233	306.0753118	249.1171131
Bus19	153.7172952	166.8936535	167.3030093	171.6444401	256.8683709	216.0361196	325.102757	303.005526	336.0717076	226.3060039	286.674275	231.6361747
Bus20	153.1337315	165.9833277	166.421265	171.106885	254.0555224	214.8898191	322.4372056	300.6251173	332.6376926	225.216869	283.402454	229.2649255
Bus21	152.9190586	165.6798271	166.1253593	170.8731916	253.1843439	214.4620968	321.4608766	299.7636921	331.5033221	224.7766572	282.357843	228.5537976
Bus22	152.4515557	165.0588526	165.5171534	170.3187501	251.4959144	213.5236455	319.3439021	297.9086403	329.1987851	223.7687783	280.2872245	227.2097424
Bus23	155.8660544	169.3804656	169.7927221	174.0846982	262.3188053	220.2885676	336.0842827	313.1123833	346.6954289	231.5537334	293.5717349	236.2228359

Bus24	157.5354273	171.1852343	171.6028807	176.0179779	265.6618385	223.2778639	345.0495495	321.68861	354.3173446	235.8464816	298.0976713	239.1396795
Bus25	158.3801268	172.0983787	172.5187582	176.9967211	267.3579239	224.7961219	349.6810747	326.1232279	358.2311182	238.0409325	300.4019383	240.6187698
Bus26	156.0610505	170.1139726	170.5903292	174.4081559	267.9213217	224.7738081	337.7956139	311.4303084	355.5416307	232.1741079	298.9625672	239.4789402
Bus27	156.4700401	170.5282594	171.0436588	174.8641495	269.1335372	226.9550323	341.1207966	313.736934	359.9673476	233.8298088	300.265952	240.0792446
Bus28	158.7929714	173.052159	173.7052495	177.5906389	276.1687451	236.5404328	357.5289023	325.7431797	380.8903432	241.6947285	308.3520689	244.4225499
Bus29	160.2939512	174.6828959	175.4267627	179.3542047	280.7857183	242.9683623	368.6173091	333.7522458	395.2145845	246.908799	313.6644223	247.2416409
Bus30	161.0587313	175.5137674	176.3042943	180.2531895	283.1544151	246.2980508	374.3810007	337.891225	402.7037599	249.5959236	316.3911794	248.6808859
Bus31	162.1766338	176.7282232	177.5879349	181.5682529	286.6564651	251.3011624	383.0923619	344.0856735	414.1366595	253.5988363	320.4258183	250.7915733
Bus32	162.416324	176.988608	177.8632836	181.8503474	287.4126352	252.3922807	384.9991007	345.4332957	416.6545713	254.4671854	321.2974137	251.2450419
Bus33	162.5488843	177.1326104	178.0156168	182.006415	287.8330874	253.0035721	386.0702436	346.1868978	418.0755638	254.9517212	321.7822268	251.4962211

Active Power Losses (I^2*R) (Watt) for Scenario C												
Time	1	2	3	4	5	6	7	8	9	10	11	12
Branch 1	2.90	4.10	3.44	3.47	2.36	3.43	1.22	1.00	0.58	0.46	0.84	3.11
Branch 2	20.59	28.51	24.27	23.80	16.56	22.94	7.47	5.98	3.61	1.95	4.93	20.33
Branch 3	8.38	15.51	12.57	13.87	8.46	11.62	0.97	0.48	0.01	0.06	0.13	6.09
Branch 4	6.41	11.78	9.49	10.35	6.36	8.53	0.83	0.43	0.00	0.05	0.10	4.62
Branch 5	9.63	17.53	14.00	15.04	9.34	12.12	1.42	0.79	0.00	0.09	0.15	6.87
Branch 6	0.57	2.51	2.08	3.30	1.41	2.65	0.66	1.02	0.69	1.12	0.80	0.07
Branch 7	2.06	13.01	10.69	18.57	7.18	14.36	7.07	9.99	6.59	9.97	7.86	0.08
Branch 8	0.42	4.01	3.21	6.27	2.07	4.61	4.93	6.41	4.16	5.86	5.08	0.55
Branch 9	49.06	103.58	84.69	102.87	55.71	92.44	2.25	0.58	0.21	0.07	0.57	35.92
Branch 10	7.38	15.64	12.78	15.54	8.39	13.95	0.34	0.09	0.03	0.01	0.09	5.40
Branch 11	10.86	23.11	18.85	22.95	12.34	20.59	0.49	0.13	0.05	0.02	0.12	7.93
Branch 12	31.58	67.57	55.02	67.10	35.93	60.15	1.42	0.37	0.13	0.04	0.36	23.03
Branch 13	8.14	17.47	14.21	17.35	9.27	15.54	0.36	0.09	0.03	0.01	0.09	5.93
Branch 14	5.72	12.30	10.00	12.21	6.51	10.94	0.25	0.07	0.02	0.01	0.06	4.16
Branch 15	4.08	8.81	7.15	8.74	4.65	7.83	0.18	0.05	0.02	0.01	0.05	2.97
Branch 16	3.15	6.81	5.53	6.77	3.59	6.05	0.14	0.04	0.01	0.00	0.04	2.29

Branch 17	0.45	0.97	0.79	0.96	0.51	0.86	0.02	0.01	0.00	0.00	0.00	0.33
Branch 18	0.48	0.93	0.75	0.84	0.45	0.69	0.04	0.01	0.01	0.02	0.01	0.31
Branch 19	4.84	8.98	7.20	8.00	4.41	6.82	0.63	0.35	0.24	0.00	0.28	3.53
Branch 20	1.45	2.56	2.06	2.28	1.29	2.00	0.29	0.20	0.12	0.02	0.16	1.19
Branch 21	2.74	4.65	3.75	4.12	2.41	3.72	0.77	0.59	0.35	0.18	0.49	2.52
Branch 22	0.55	0.22	0.20	0.21	0.13	0.21	2.02	2.32	2.92	2.62	2.83	1.47
Branch 23	4.35	3.25	3.08	2.17	2.18	3.08	5.11	5.15	5.16	4.41	5.58	6.88
Branch 24	1.09	0.81	0.77	0.54	0.54	0.77	1.28	1.29	1.29	1.10	1.40	1.72
Branch 25	0.23	0.05	0.05	0.21	0.04	0.20	1.88	2.13	0.72	0.92	1.18	0.62
Branch 26	0.17	0.17	0.17	0.49	0.13	0.46	1.75	2.04	0.66	0.88	1.10	0.46
Branch 27	9.59	7.79	6.11	3.40	3.98	3.39	14.73	14.80	5.91	6.29	9.33	13.86
Branch 28	5.08	4.12	3.23	1.80	2.10	1.79	7.80	7.84	3.13	3.33	4.94	7.34
Branch 29	2.06	1.67	1.31	0.73	0.85	0.72	3.16	3.18	1.26	1.35	2.00	2.98
Branch 30	2.23	1.81	1.42	0.79	0.92	0.78	3.43	3.44	1.37	1.46	2.17	3.22
Branch 31	0.32	0.26	0.20	0.11	0.13	0.11	0.49	0.49	0.19	0.21	0.31	0.46
Branch 32	0.09	0.07	0.06	0.03	0.04	0.03	0.13	0.13	0.05	0.06	0.08	0.13

Active Power Losses (I^2*R) (Watt) for Scenario C												
Time	13	14	15	16	17	18	19	20	21	22	23	24
Branch 1	1.04	1.19	1.20	1.28	2.80	2.31	5.13	4.42	5.35	2.51	3.49	2.21
Branch 2	6.34	7.55	7.67	6.93	18.46	15.13	33.10	28.65	37.50	15.38	21.88	15.34
Branch 3	0.25	0.53	0.57	0.34	3.88	2.39	1.15	0.23	5.21	0.37	3.48	2.52
Branch 4	0.19	0.40	0.45	0.24	3.24	2.60	1.15	0.20	5.26	0.40	2.79	1.93
Branch 5	0.28	0.59	0.68	0.34	5.47	5.83	2.40	0.37	10.96	0.88	4.46	2.92
Branch 6	0.73	0.49	0.56	0.72	0.62	5.27	7.96	6.21	8.00	4.74	0.75	0.15
Branch 7	7.45	5.49	6.15	7.61	8.01	47.26	73.34	57.80	74.28	43.09	9.73	2.71
Branch 8	5.00	3.98	4.38	5.26	6.46	27.88	44.50	35.42	45.42	25.76	7.88	2.76
Branch 9	1.31	2.87	2.57	2.19	10.79	0.26	0.07	0.27	0.28	0.03	13.49	13.08
Branch 10	0.20	0.43	0.38	0.33	1.62	0.04	0.01	0.04	0.04	0.00	2.02	1.96
Branch 11	0.29	0.63	0.56	0.48	2.37	0.06	0.02	0.06	0.06	0.01	2.96	2.87

Branch 12	0.82	1.81	1.62	1.38	6.85	0.17	0.05	0.17	0.18	0.02	8.57	8.31
Branch 13	0.21	0.46	0.42	0.35	1.76	0.04	0.01	0.04	0.05	0.00	2.20	2.13
Branch 14	0.15	0.33	0.29	0.25	1.23	0.03	0.01	0.03	0.03	0.00	1.54	1.49
Branch 15	0.10	0.23	0.21	0.18	0.88	0.02	0.01	0.02	0.02	0.00	1.10	1.06
Branch 16	0.08	0.18	0.16	0.14	0.67	0.02	0.00	0.02	0.02	0.00	0.85	0.82
Branch 17	0.01	0.03	0.02	0.02	0.10	0.00	0.00	0.00	0.00	0.00	0.12	0.12
Branch 18	0.02	0.05	0.05	0.01	0.20	0.04	0.10	0.10	0.23	0.03	0.20	0.21
Branch 19	0.47	0.75	0.74	0.32	2.49	0.89	2.14	1.96	3.39	0.73	2.64	2.41
Branch 20	0.23	0.31	0.32	0.22	0.90	0.46	1.06	0.95	1.37	0.44	1.01	0.81
Branch 21	0.64	0.79	0.79	0.73	2.02	1.29	2.94	2.58	3.33	1.35	2.40	1.72
Branch 22	3.17	2.91	2.91	3.17	2.93	4.18	18.60	21.01	10.88	9.59	4.68	3.06
Branch 23	6.49	6.46	6.46	6.97	9.12	10.00	36.73	38.59	25.77	18.31	13.22	8.56
Branch 24	1.62	1.62	1.62	1.75	2.28	2.51	9.24	9.71	6.47	4.59	3.31	2.14
Branch 25	1.20	1.07	1.25	1.22	3.37	13.00	13.45	8.10	20.54	7.47	3.20	1.18
Branch 26	1.10	0.95	1.13	1.10	3.09	13.19	13.28	7.80	20.69	7.36	2.86	1.00
Branch 27	10.30	10.27	11.31	11.33	30.08	71.65	90.74	60.04	127.88	47.38	31.86	14.92
Branch 28	5.45	5.44	5.99	6.00	15.97	38.19	48.43	31.97	68.42	25.20	16.92	7.91
Branch 29	2.21	2.20	2.42	2.43	6.48	15.54	19.73	13.00	27.92	10.24	6.87	3.20
Branch 30	2.39	2.38	2.63	2.63	7.03	16.91	21.50	14.14	30.48	11.13	7.45	3.47
Branch 31	0.34	0.34	0.37	0.37	1.00	2.40	3.05	2.01	4.33	1.58	1.06	0.49
Branch 32	0.09	0.09	0.10	0.10	0.27	0.66	0.84	0.55	1.19	0.43	0.29	0.14