

MARCO ANTONIO MARIN

GERAÇÃO DISTRIBUÍDA: VANTAGENS E DESVANTAGENS

Monografia apresentada como requisito parcial à obtenção do grau de Especialista. Curso de Pós-Graduação em Planejamento, Operação e Comercialização na Indústria de Energia Elétrica, Universidade Federal do Paraná. Orientador: Prof. Fabio Ramos.

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Dedico este trabalho a minha esposa, Maria Cristina pelo constante incentivo e compreensão em todos os momentos.

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Resumo

A tarefa de planejar a expansão de sistemas elétricos na área de distribuição tem sofrido grandes modificações com o aumento do uso de pequenas fontes de geração de energia conectadas diretamente aos alimentadores de distribuição. A geração distribuída tem mostrado ser uma excelente alternativa, tanto no aspecto de suprir cargas novas, quanto reduzir investimentos na expansão de sistemas de distribuição. Existem vários tipos de geração distribuída, que naturalmente utiliza os recursos disponíveis na região onde se quer implantá-la. O presente trabalho visa definir o conceito de geração distribuída, caracterizar os tipos existentes e verificar a melhora introduzida aos alimentadores, além de discutir os problemas e conseqüências na utilização de geradores conectados à rede de distribuição. Nas simulações efetuadas observou-se uma significativa redução das perdas elétricas no alimentador após a inserção de um gerador na extremidade oposta a subestação, além de uma sensível melhora nos perfis de tensão nos pontos monitorados.

Capítulo 1

Introdução

A utilização de fontes de energia de pequeno porte conectadas diretamente à rede de distribuição tem se tornado uma prática muito difundida no mundo inteiro. Isto se deve principalmente ao fato de que a construção de grandes centrais geradoras, na maioria das vezes, acarretam enormes impactos ambientais, além dos riscos e custos envolvidos serem muito maiores para as centrais de grande porte.

Segundo Ackermann (2001), um estudo do Electric Power Research Institute (EPRI) indica que em 2010, 25% da nova geração de energia será distribuída, já um

estudo da Natural Gas Fundation concluiu que este cenário poderá ser ainda maior, em torno de 30%.

O fator determinante para a difusão da Geração Distribuída (GD) é sem dúvida, o avanço tecnológico que vem sendo alcançado na produção de energia elétrica a partir de combustíveis renováveis como, energia solar, energia eólica, biomassa, células combustíveis e pequenas centrais hidrelétricas.

O aumento do uso de geração distribuída tem levado as concessionárias de energia a desenvolver estudos para determinar os impactos que esta geração traz para a rede de distribuição.

Os impactos presentes na utilização de GD podem ser tanto benéficos, como o melhoramento dos perfis de tensão na rede de distribuição, a redução das perdas elétricas no sistema, quanto provocar problemas sérios como a perda de coordenação da proteção, aumento de níveis de curto circuito, entre outros.

Este trabalho procura, além de definir o conceito de geração distribuída, caracterizar os tipos possíveis de geração, verificar a melhora nos níveis de tensão de alimentadores de distribuição, e analisar os ganhos com relação às perdas elétricas, em redes de distribuição que utilize geração distribuída.

Capítulo 2

Geração Distribuída: Definições

O uso de geração distribuída em vários países do mundo traz uma nova questão relevante, não existe consenso nas definições encontradas na literatura especializada.

O termo Geração Distribuída também pode ser chamado de geração dispersa (América do Norte), geração descentralizada (Europa), ou ainda no caso de países anglos americanos muitas vezes utiliza-se o termo '*embedded generation*', ou seja, geração embutida.

Apesar de várias designações, a maior controvérsia se encontra na qualificação da geração distribuída pela sua capacidade.

O Electric Power Research Institute (EPRI) define geração distribuída como geradores com poucos kW até 50 MW; de acordo com a Natural Gas Foundation geração distribuída são geradores tipicamente de 25 kW até 25 MW; Preston e Rastler definem o tamanho de geração distribuída como geradores com poucos kW até 100 MW; Cardell atribui geração distribuída como centrais elétricas com 500 kW até 1 MW; o International Conference on Large High Voltage Electric Systems (CIGRÉ) define como geração distribuída geradores menores que 100MW.

As diferenças também ocorrem nos órgãos de regulação governamentais, no mercado inglês e galês, plantas com menos de 100 MW com despacho não centralizado, ou com capacidade inferior a 50 MW, não precisam necessariamente negociar sua energia no mercado atacadista. A legislação sueca tem um tratamento especial para pequenos geradores com capacidade máxima de 1500 kW, mas fazendas eólicas com mais de cem turbinas de 1500kW também são consideradas geração distribuída, pois é considerado o valor de cada turbina e não do total da fazenda eólica.

Segundo Ackermann (2001), devido às variações de definições usadas, duas questões devem ser analisadas para definir geração distribuída mais precisamente, os objetivos e a localização da central.

O objetivo da central de geração distribuída deve ser prover potência ativa para a rede de distribuição. De acordo com Ackermann (2001), não existe a

necessidade de geradores com características de geração distribuída, prover potência reativa para a rede.

Centrais ligadas diretamente à rede de distribuição, ou ligadas à rede através do medidor do consumidor, segundo Ackermann (2001), é requisito essencial para a caracterização de geração distribuída.

Capítulo 3

Geração Distribuída X Usinas de Grande Porte

Grande parte da energia elétrica consumida no mundo é produzida em centrais de grande porte. Estas centrais se caracterizam por possuir potência instalada entre 150MW e 800 MW, e baixa eficiência, isto é, somente 28 a 35% do combustível utilizado nestas centrais são efetivamente convertidos em energia elétrica.

As pequenas centrais, como células combustíveis, micro turbinas com ciclo combinado, entre outras, podem atingir índices de eficiência de até 55%. Esta vantagem sobre as grandes centrais tradicionais se dá em função da geração distribuída ser relativamente nova, utilizando tecnologia de ponta.

Apesar das vantagens citadas das pequenas centrais, os grandes geradores têm a seu favor a economia de escala. O simples fato da construção das grandes centrais se dar com a mesma tecnologia e tipo de projeto da geração distribuída proporcionará maior eficiência.

Existem duas maneiras de analisar este aspecto, o primeiro é quanto à eficiência térmica, que será maior quanto maior for o tamanho da caldeira. O segundo aspecto é que sempre se pode dobrar o número de unidades, com isso abaixar os custos.

Destaca-se também que, equipamentos utilizados por uma única unidade para geração de energia, poderão ser utilizados por outras unidades próximas. Entre os equipamentos que podem ser utilizados citam-se os conversores DC-AC, equipamentos de proteção e transformadores. Estes equipamentos auxiliares acarretam uma diminuição de custos da instalação de centrais geradoras de grande porte, devido ao benefício de ganho de escala.

As vantagens de ganho de escala de grandes geradores não diminuem o interesse em geração distribuída, pois o uso de geração diretamente conectada à rede de distribuição, evita os gastos com transmissão, que muitas vezes pode até inviabilizar a construção de grandes centrais geradoras.

Um caso que pode ser citado é a futura Usina de Belo Monte, com potência instalada de 11.182 MW, situada o rio Xingu, no estado do Pará, com aproximadamente 1800 km de linhas de transmissão. Os custos de construção das linhas de transmissão para transferir a energia produzida na usina para os centros de carga, serão praticamente o mesmo da construção da usina.

Além de não precisar de investimentos em transmissão, as instalações de distribuição são beneficiadas com a inserção da geração distribuída.

Com a inserção de geradores distribuídos nas redes de distribuição, os níveis de tensão normalmente sofrem uma melhora, além de reduzir as perdas elétricas do sistema como um todo, devido às cargas serem providas pela geração local.

Apesar de exigir equipamentos de proteção, que em muitos casos necessitam serem adequados para comportar geradores conectados à rede de distribuição, os investimentos na atualização de instalações, devido ao aumento de carga nas redes de distribuição, com a inserção de geração distribuída, podem ser postergados e muitas vezes evitados.

Esta característica faz da geração distribuída uma alternativa muito boa, quando se comparado com a construção de grandes centrais, que terá toda uma infra-estrutura que segue junto com ela.

Apesar de todos os benefícios que a geração distribuída pode oferecer, alguns pontos negativos devem ser destacados. Entre eles têm-se o aumento nos custos de instalação de geração distribuída devido à dificuldade do transporte de combustível para estas centrais.

Outro aspecto relevante é que apesar da maioria das vezes as plantas de geração distribuída serem construídas com tecnologia de última geração, o conhecimento sobre esta tecnologia muitas vezes não é suficiente, trazendo alguns riscos ao bom desempenho da planta, logo tendo reflexos na sua confiabilidade e segurança.

Capítulo 4

Tipos de Geração Distribuída

A geração distribuída através de pequenos geradores conectados à rede de distribuição pode utilizar vários tipos de geração, turbinas a gás, células combustível, turbinas eólicas, painéis fotovoltaicos, pequena centrais hidrelétricas, etc.

Neste capítulo será feito uma caracterização de vários tipos de geração distribuída, mostrando seus custos, tamanho, combustível utilizado, eficiência, entre outros aspectos.

4.1 Turbinas a Gás

A geração de energia através de micros e pequenas centrais de geração através de turbinas a gás possuem deficiências com relação aos demais tipos de geração. Isto se dá em virtude dos baixos índices de eficiência que estas plantas possuem.

A baixa eficiência se deve ao fato que, originalmente, os equipamentos utilizados nestas centrais foram projetados para serem utilizados em pequenas aeronaves, navios militares, helicópteros ou tanques de guerra.

Outro fator que prejudica a difusão deste tipo de geração é a emissão de poluentes, que apesar de ser pequena, torna estas centrais menos atraentes que as centrais com energias renováveis, com emissão de poluentes praticamente nula, como é o caso das centrais eólicas e células a combustíveis.

Um aspecto que pode tornar estas centrais viáveis é o pequeno tempo de instalação, como são construídas em módulos, existindo disponibilidade de combustível no local, estas centrais podem ser instaladas em pouca semanas.

A tabela 1 mostra a comparação qualitativa das micro e pequenas centrais de geração que utilizam turbina a gás.

Característica	Micro	Mini
Potência (kVA)	20-500	650-10000
Tamanho aproximado	refrigerador	caminhão grande
Destino original	ônibus, caminhão	aeronave
Combustível típico	gás natural	gás natural
Eficiência	32%	30%
Tempo de instalação	1 semana	2 meses
Custo típico	US\$700/kW	US\$450/kW

Tabela 1 – Comparação quantitativa de categorias de geradores a gás natural – Fonte [1]

4.2 Células a Combustível

As células a combustível geram energia elétrica através de um processo químico. Um dos aspectos importantes deste tipo de geração é que no processo não há partes móveis, fazendo com que a geração de energia se dê de forma muito silenciosa, em comparação com as outras formas de geração de energia.

Outros fatores a favor da célula combustível é que ela tem emissão de poluentes quase que insignificante, possui também uma alta taxa de disponibilidade, produzindo energia continuamente sem interrupção por vários meses.

A agilidade para a instalação destas centrais, devido sua construção ser feita em módulos, é um atrativo para o seu desenvolvimento. Entretanto fatores negativos fazem com que esta alternativa para a geração distribuída, ainda seja uma promessa.

Entre os principais fatores negativos destacam-se a pouca difusão da tecnologia a nível mundial e o alto custo dos equipamentos, cerca de US\$ 2.000/kW instalado, dificultando seu uso em larga escala.

A tabela 2 mostra as características das tecnologias existentes de células a combustível.

	PEMFC	AFC	PAFC	MCFC	SOFC
Eletrólise	membrana polimera	ácido fosfórico- KOH e H ₂ O	Carbono lítium - H ₃ PO ₄	Zirconia - LiKaCo ₃	Estabilizada
Oxidante	ar	O ₂ puro	ar	ar	ar
Temperatura interna	85 °C	120 °C	190 °C	650 °C	1000 °C
Eficiência	30%	32%	40%	42%	45%
Aplicação Típica	carros	carros	GD	GD	GD
Custo típico	US\$1400/kW	US\$2700/kW	US\$2100/kW	US\$2600/kW	US\$3000/kW

Tabela 2 - Características das Células a Combustível – Fonte [1]

4.3 Energia Solar

É uma das mais flexíveis fontes de energia renovável, seu combustível não tem custo, mas a produção de energia fica condicionada a disponibilidade de luz solar, o que inviabiliza a produção desta fonte durante a noite.

Existem duas possibilidades para a geração de energia elétrica através da energia solar. A primeira consiste na conversão de calor coletado através de espelhos coletores, o calor gerado é usado para gerar vapor, que movimenta uma turbina.

A outra forma de gerar eletricidade através dos raios solares, é a utilização de painéis fotovoltaicos, que convertem a luz solar diretamente em energia elétrica.

Além da inconveniência da disponibilidade de luz solar para a produção de energia, outro problema enfrentado para o aumento da difusão deste tipo de fonte na matriz energética, é o alto custo inicial das instalações, que podem chegar a US\$ 4.000/kW instalado.

Apesar dos aspectos negativos relativos ao uso da energia solar, muitos estudos e tecnologias têm sido desenvolvidos para o aproveitamento deste recurso. Um deles é a utilização de baterias que aumentam o fator de capacidade, mas isto encarece ainda mais o sistema de geração.

4.4 Energia Eólica

A força do vento foi uma das primeiras fontes de energia utilizada pelo homem. Grandes moinhos, bombas d'água e navios utilizaram e ainda utilizam a energia eólica como sua fonte de energia.

A não utilização de combustíveis fósseis, característica não poluente, possibilidade de geração durante as 24 horas do dia, são as vantagens da geração eólica.

Em contrapartida, o alto custo da instalação das turbinas eólicas, e a impossibilidade de previsão real da geração de energia, caracterizam suas desvantagens.

A figura (1) mostra um infográfico com a evolução dos tamanhos e potências dos aerogeradores.

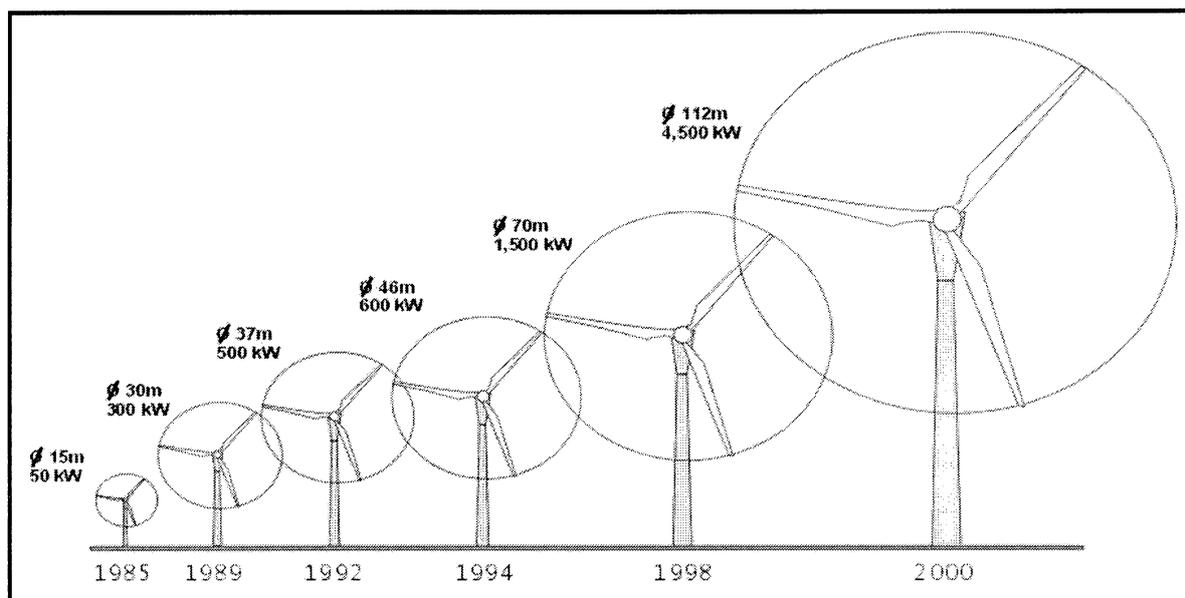


Figura 1 – Evolução da potência e tamanhos das turbinas eólicas – fonte MME.

4.5 Pequenas Centras Hidrelétricas (PCHs)

As tecnologias para a geração de energia elétrica aproveitando as diferenças de níveis d'água, isto é, da energia potencial existente nos desníveis dos rios, tem se aprimorado ano após ano.

O início da utilização da energia hidrelétrica se deu através de centrais de poucos kilowatts. Com o passar dos anos as usinas foram se tornando maiores e as pequenas centrais foram cedendo espaço às grandes usinas, com reservatórios que ocupam áreas faraônicas. Os reservatórios das usinas servem para regularizar a vazão do aproveitamento, ou seja, tornar constante a vazão do rio, tornando a geração praticamente constante.

A implementação de grandes usinas hidrelétricas ao longo das últimas décadas proporcionou um avanço nas condições tecnológicas, possibilitando

atualmente a viabilização de PCHs através da otimização de seu aproveitamento energético.

Uma das características importantes das PCHs é que normalmente estas centrais possuem pequenos reservatórios, e muitas vezes nem o possuem, deixando de ter maiores problemas com relação aos impactos ambientais decorrentes do alagamento de grandes áreas.

O pequeno porte dos reservatórios das PCHs, apesar de causarem pouco impacto ambiental, torna a potência disponível nestas centrais pouco firme, caracterizando uma desvantagem para as PCHs.

No Brasil, apesar de esforços dos governos federal e estadual e empresas de energia, não acarretaram o aumento da construção de pequenas centrais hidrelétricas no país.

4.6 Biomassa

A utilização da queima de rejeitos de processos industriais e até mesmo lixo para a produção de energia elétrica, tem se tornado uma alternativa interessante de geração de energia.

Normalmente a eficiência destas centrais é baixa, mas como o combustível utilizado é praticamente gratuito, esta característica não restringe a atratividade destas centrais.

No Brasil o setor sucroalcooleiro tem demonstrado grande interesse na produção de energia elétrica através da queima do bagaço da cana. Dados do Ministério de Minas e Energia (MME), da Agência Nacional de Energia Elétrica (ANEEL) e do Banco Nacional de Desenvolvimento Econômico e Social (BNDES) mostram que o potencial técnico do setor sucroalcooleiro pode chegar a 4.000 MW de potência, já existindo um total de 1.150 MW em projetos no BNDES.

Um dos problemas enfrentados pelos produtores independentes do setor é que, na maioria das vezes, a produção de energia destas usinas se restringe à época da safra, de 7 a 9 meses do ano, fazendo com que o mesmo não consiga assinar contratos de venda de energia de longo prazo. E quando consegue, os valores praticados ficam muito abaixo do valor que viabilize novos investimentos para expansão e modernização dos equipamentos existentes.

O custo de instalação do kW instalado para o setor sucroalcooleiro fica entre US\$700 e US\$1.000, considerado um dos mais baixos.

Capítulo 5

Confiabilidade do sistema de geração de energia elétrica

A confiabilidade de sistema de geração de energia elétrica é a probabilidade de um componente (aparelho, sistema, equipamento) cumprir suas funções prefixadas, dentro de um período de tempo desejado sob certas condições operativas, ou seja, é a probabilidade do equipamento estar em condições de atender à carga.

Com o aumento do uso de pequenas fontes conectadas à rede de distribuição, o fator confiabilidade destas fontes, tornou-se extremamente importante. Anteriormente, quando o número de fontes espalhadas pela rede era ínfimo, este fator era pouco relevante.

Para verificar a importância da geração distribuída existe um indicador que reflete o grau de penetração da mesma em um dado sistema. O grau de penetração em % (GP) é dado pela equação (1).

$$GP(\%) = \frac{PG}{P + PG} * 100 \quad (1)$$

onde: P= carga suprida por geração externa;

PG = nova carga suprida por geração local.

Este índice quantifica a importância das fontes de geração distribuída existentes no referido alimentador.

Uma análise detalhada da confiabilidade da geração distribuída é necessária para quantificar os benefícios da mesma nos sistemas de distribuição.

Capítulo 6

Simulações de Fluxo de Potência em Redes de Distribuição

As simulações de fluxo de potência em redes de distribuição, apresentadas neste capítulo, tem por objetivo quantificar os benefícios da geração distribuída em relação à melhora de níveis de perfil de tensão e redução de perdas elétricas em alimentadores.

A avaliação dos benefícios será feita com a utilização do programa computacional SPDIST[15], desenvolvido no Laboratório de Sistemas de Potência da UFSC e o Sistema de Distribuição (DPSD) da Diretoria de Distribuição da CELESC.

Os benefícios serão avaliados através de uma rede de distribuição hipotética, que comparará o desempenho da rede de distribuição, com relação a níveis de perfil de tensão e perdas elétricas, sem o uso de geração distribuída e com vários níveis de penetração da mesma.

O Programa SPDIST efetua os cálculos das tensões nas barras do alimentador, as correntes, o carregamento das linhas, as perdas elétricas do alimentador, além de outras variáveis. A metodologia de cálculo do programa é específica para sistemas com características radiais, que é o caso de alimentadores de distribuição. Estes alimentadores podem ser representados através de uma árvore orientada, onde a raiz corresponde à subestação, o tronco ao ramal principal e os ramos estão associados aos ramais secundários que partem do tronco. Este programa utiliza o método iterativo de Soma das Potências que explora a radialidade dos sistemas de distribuição tornando o processo de cálculo bastante rápido e eficiente.

6.1 Dados para simulação

O sistema utilizado nas simulações é o apresentado na figura 2 abaixo.

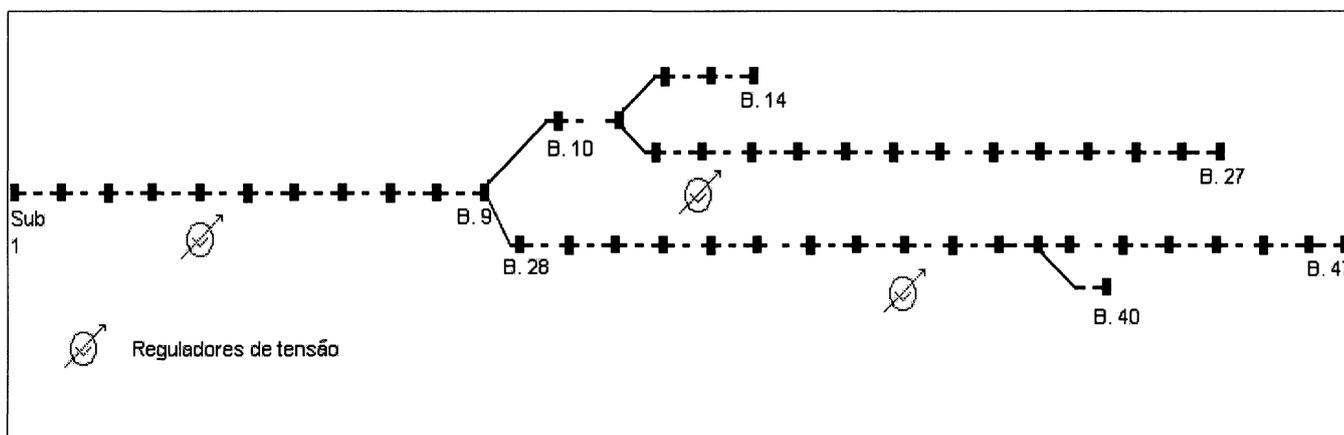


Figura 2 – Esquema do alimentador utilizado para as simulações.

O sistema utilizado possui 47 barras, 48 linhas e 3 reguladores de tensão. O ponto mais distante da rede, barra 47 foi a escolhida para a inserção do gerador. Primeiramente foi simulado o alimentador sem a presença do gerador, após isto se variou a penetração do gerador em 10, 20, 30, 40 e 50%.

Os relatórios de saída dos fluxos são apresentados no anexo 1.

6.2 Análise dos resultados obtidos

O gráfico 1 ilustra o perfil de tensão nas barras do alimentador com os diversos níveis de penetração de geração distribuída. O gráfico 2 mostra as perdas de potência acumuladas no alimentador sem e com a inserção da geração distribuída na rede de distribuição.

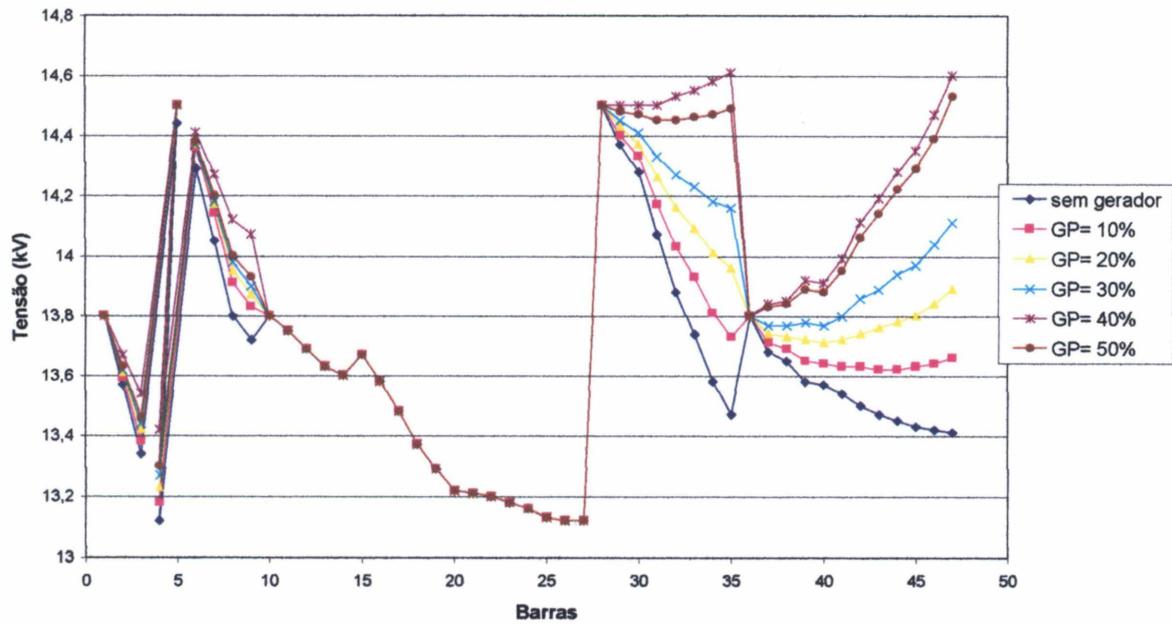


Gráfico 1 – Perfil de tensão das barras do alimentador

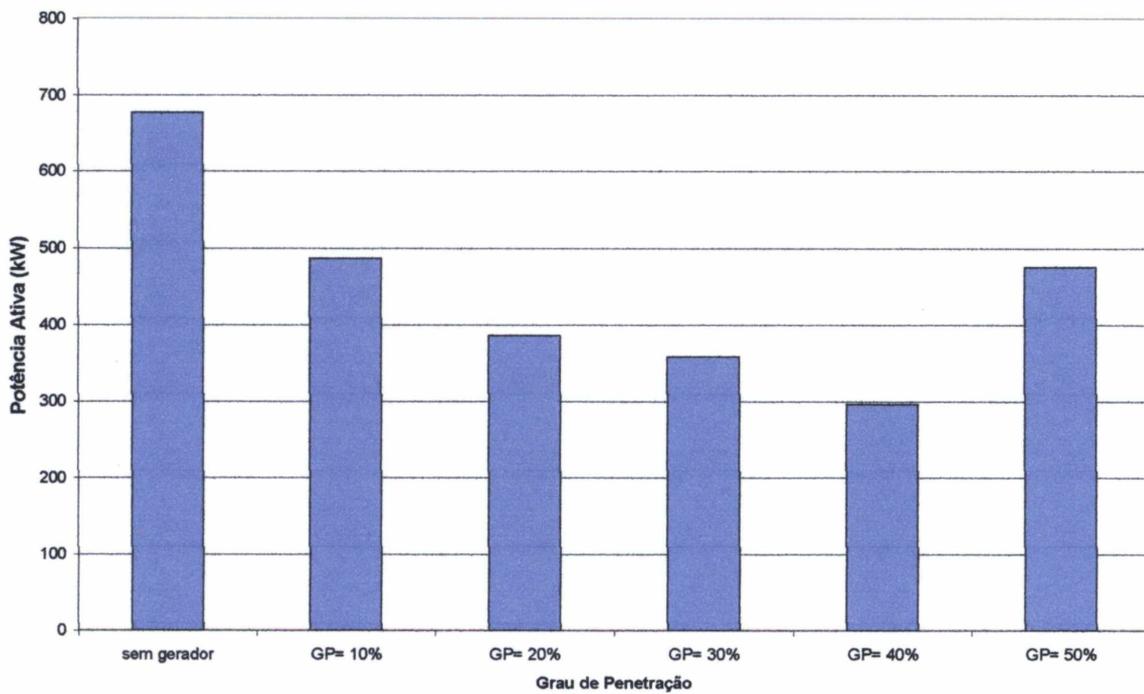


Gráfico 2 – Perdas ativas acumuladas no alimentador

Como se pode observar, no gráfico 1, com a inserção do gerador na barra 47 do sistema teste, as tensões nas barras próximas ao gerador, tiveram um sensível aumento, evidenciando a melhora já mencionada neste trabalho.

O ponto onde as tensões se igualam identifica a posição de um regulador de tensão, que como o nome já identifica, corrige as tensões para a tensão padrão.

O gráfico 2 mostra os ganhos na diminuição das perdas elétricas no alimentador, esta melhora se deve exclusivamente à mudança de fluxo da potência com a presença do gerador na extremidade do alimentador.

A tabela 3 mostra as percentagens de perda de potência com relação ao total consumido no alimentador.

Perdas de Potência Ativas Percentuais	
sem gerador	12%
GP= 10%	9%
GP= 20%	7%
GP= 30%	6%
GP= 40%	5%
GP= 50%	8%

Tabela 3 – Perdas elétricas relativas no alimentador

Como se pode observar, a perda mínima ocorre com um grau de penetração de 40%. Com 50% de penetração as perdas começam a aumentar, isto se deve ao fato de que após um certo grau de penetração, o fluxo de potência acaba mudando de sentido, acarretando um aumento nas perdas.

A redução das perdas elétricas, além de acarretar uma economia da energia, provoca um alívio no alimentador, retardando investimentos na rede para suprir entradas de novas cargas.

Capítulo 7

Conclusões

A geração distribuída tem sido objeto de inúmeros estudos em diversos países, inclusive no Brasil.

As políticas do setor elétrico brasileiro têm procurado incentivar o uso de recursos existentes em cada região, buscando o suprimento da demanda nos sistemas de energia elétrica.

Apesar destes incentivos, com a insolvência do mercado de energia elétrica no Brasil, o que se tem visto é um grande número de bons projetos, que na maioria das vezes, não se concretizam.

Além dos problemas regulatórios, a cultura existente no setor é que, somente grandes centrais de geração possuem a confiabilidade requerida pelos consumidores, e que as pequenas centrais somente trazem grandes 'dores de cabeça' para os planejadores e operadores.

Esta cultura tem que ser mudada, pois com o esgotamento dos grandes aproveitamentos hidrelétricos, e com a crescente preocupação com os impactos ambientais causados pela produção em grande escala da energia elétrica, a utilização de pequenas centrais espalhadas na rede de distribuição, têm se mostrado uma alternativa bastante razoável.

Capítulo 8

Recomendações

Apesar do grande número de estudos existentes na área de geração distribuída, a maioria destes estudos contempla somente um tipo de recurso energético. Para locais onde existe uma abundância de um certo insumo para geração de energia elétrica, este enfoque é realmente válido. Mas para locais onde existe uma grande diversidade de recursos, este enfoque se torna inadequado.

Um estudo que contemple uma diversificação das fontes de recursos existentes em uma dada região, com o compartilhamento dos benefícios que cada tipo de insumo pode representar no suprimento da carga, e também dos riscos que cada tipo de geração representa, formaria uma excelente ajuda para o desenvolvimento da geração distribuída.

Além disso, uma avaliação mais profunda nas restrições de caráter elétrico, como níveis de curto circuito, coordenação da proteção, confiabilidade e disponibilidade de várias fontes conectadas à mesma rede de distribuição, seria de grande valia.

ANEXO – Resultado das simulações de Fluxo de Potência

CELESC/UFSC (LABSPOT)

pag. 1

SPDST - Fluxo de Potencia - Soma de Potencias

Alimentador sem gerador

Tensao Nominal (kV) = 13.80 F. Potencia = .96

Tensao de Operacao (kV) = 13.80 F. Demanda = .51

Iteracoes p/ convergencia = 9

C A L C U L O											
TRECHO	TENSAO	QUEDA(%)	CORRENTE(A)	DEM.	PERDAS	REGULACAO					
PT PA	(kV)	OP. NOM.	I I/IN(%)	(kVA)	(KW)	Eq kV/kvar (%)					
2 1	13.57	-1.7	-1.7	266.9	52. 5384.6	60.3	0	.00	.0		
3 2	13.34	-3.4	-3.4	266.9	52. 5384.6	61.9	0	.00	.0		
5 4	14.44	4.7	4.7	266.9	52. 5384.6	44.4	1	15.39	11.5		
4 3	13.12	-4.9	-4.9	266.9	52. 5384.6	59.2	0	.00	.0		
6 5	14.29	3.5	3.5	239.4	47. 5384.6	39.2	0	.00	.0		
7 6	14.05	1.8	1.8	239.4	47. 5384.6	58.5	0	.00	.0		
8 7	13.80	.0	.0	239.5	47. 5384.6	64.3	0	.00	.0		
9 8	13.72	-.6	-.6	236.4	46. 5311.9	22.3	0	.00	.0		
10 9	13.80	.0	.0	114.1	53. 2629.6	15.9	1	13.98	1.3		
11 10	13.75	-.4	-.4	110.9	33. 2589.3	7.3	0	.00	.0		
12 11	13.69	-.8	-.8	41.0	19. 967.7	3.6	0	.00	.0		
13 12	13.63	-1.3	-1.3	37.1	17. 875.9	3.5	0	.00	.0		
14 13	13.60	-1.4	-1.4	11.7	5. 275.4	.4	0	.00	.0		
15 11	13.67	-1.0	-1.0	60.2	28. 1389.7	7.2	0	.00	.0		
16 15	13.58	-1.6	-1.6	57.7	27. 1328.6	7.2	0	.00	.0		
17 16	13.48	-2.3	-2.3	52.8	25. 1213.8	8.1	0	.00	.0		
18 17	13.37	-3.1	-3.1	47.4	22. 1087.6	7.6	0	.00	.0		
19 18	13.29	-3.7	-3.7	39.8	19. 911.6	4.5	0	.00	.0		
20 19	13.22	-4.2	-4.2	32.7	15. 747.1	3.6	0	.00	.0		
21 20	13.21	-4.3	-4.3	6.2	3. 141.5	.1	0	.00	.0		
22 21	13.20	-4.3	-4.3	3.6	2. 82.9	.0	0	.00	.0		
23 20	13.18	-4.5	-4.5	21.7	10. 496.0	1.2	0	.00	.0		
24 23	13.16	-4.7	-4.7	18.8	9. 429.7	.7	0	.00	.0		
25 24	13.13	-4.9	-4.9	13.7	6. 312.4	.6	0	.00	.0		
26 25	13.12	-4.9	-4.9	4.9	2. 110.9	.1	0	.00	.0		
27 26	13.12	-4.9	-4.9	1.3	1. 30.6	.0	0	.00	.0		
28 9	14.50	5.1	5.1	104.0	48. 2246.5	32.4	1	14.82	7.4		
29 28	14.37	4.1	4.1	92.4	43. 2133.1	17.4	0	.00	.0		
30 29	14.28	3.5	3.5	91.7	43. 2116.5	12.6	0	.00	.0		
31 30	14.07	2.0	2.0	91.4	43. 2108.8	27.5	0	.00	.0		
32 31	13.88	.6	.6	81.9	38. 1875.3	23.3	0	.00	.0		
33 32	13.74	-.4	-.4	79.9	37. 1826.8	16.6	0	.00	.0		
34 33	13.58	-1.6	-1.6	76.1	35. 1737.6	17.9	0	.00	.0		
35 34	13.47	-2.4	-2.4	71.7	33. 1633.0	11.6	0	.00	.0		
36 35	13.80	.0	.0	70.6	33. 1606.2	10.8	1	14.25	3.3		
37 36	13.68	-.9	-.9	66.7	31. 1566.7	12.1	0	.00	.0		
38 37	13.65	-1.1	-1.1	65.1	30. 1528.5	2.5	0	.00	.0		
39 38	13.58	-1.6	-1.6	46.4	22. 1086.8	4.8	0	.00	.0		
40 39	13.57	-1.7	-1.7	6.2	3. 146.6	.1	0	.00	.0		
41 39	13.54	-1.9	-1.9	34.5	16. 806.3	2.3	0	.00	.0		
42 41	13.50	-2.2	-2.2	22.7	11. 528.4	1.3	0	.00	.0		
43 42	13.47	-2.4	-2.4	20.7	10. 481.2	.7	0	.00	.0		
44 43	13.45	-2.5	-2.5	19.2	9. 446.8	.7	0	.00	.0		
45 44	13.43	-2.6	-2.6	15.5	7. 360.8	.3	0	.00	.0		
46 45	13.42	-2.8	-2.8	10.4	5. 241.5	.2	0	.00	.0		
47 46	13.41	-2.8	-2.8	7.7	4. 177.7	.1	0	.00	.0		

Potencia acumulada na Subestacao = 5846.1 kW - 2551.9 kvar (6378.9 kVA)

Perdas Totais no Alimentador = 676.9 kW - 1044.3 kvar (1244.5 kVA)

Fator de Demanda Corrigido = .604

----- Reguladores de Tensao -----						*----- LDC -----*				
Pto	Regulador	Tensao (kV)		Reg.	Fx Reg.	Pto	R	X	In	TP
		(entr)	(said)	(%)	(%)	Ctrl	(V)	(V)	(A)	
5	Regulador	12.95	14.44	11.50	11.5	5	.0	.0	.0	.0
10	Regulador	13.62	13.80	1.31	8.5	10	.0	.0	.0	.0
28	Regulador	13.50	14.50	7.38	11.5	28	.0	.0	.0	.0
36	Regulador	13.37	13.80	3.25	8.5	36	.0	.0	.0	.0

--- Tensoes Acima de : 5.00 % ---				
Pto	Nome	Tensao	Queda(%)	
		(kV)	Oper.	Nomin
28		14.50	5.1	5.1

CELESC/UFSC (LABSPOT)
SPDST - Fluxo de Potencia - Soma de Potencias

pag. 1

Alimentador com gerador - grau de penetração - GP=10%

Tensao Nominal (kV) = 13.80 F. Potencia = .96

Tensao de Operacao (kV) = 13.80 F. Demanda = .51

Iteracoes p/ convergencia = 12

C A L C U L O											
TRECHO	TENSAO	QUEDA(%)	CORRENTE(A)	DEM.	PERDAS	REGULACAO					
PT PA	(kV)	OP. NOM.	I I/IN(%)	(kVA)	(KW)	Eq kV/kvar (%)					
2 1	13.59	-1.5	-1.5	234.3	46. 4857.9	46.5	0	.00	.0		
3 2	13.38	-3.0	-3.0	234.3	46. 4857.9	47.7	0	.00	.0		
5 4	14.50	5.1	5.1	234.4	46. 4857.9	34.2	1	15.35	11.2		
4 3	13.18	-4.5	-4.5	234.4	46. 4857.9	45.6	0	.00	.0		
6 5	14.36	4.0	4.0	210.7	41. 4857.9	30.4	0	.00	.0		
7 6	14.14	2.5	2.5	210.8	41. 4857.9	45.3	0	.00	.0		
8 7	13.91	.8	.8	210.8	41. 4857.9	49.8	0	.00	.0		
9 8	13.83	.2	.2	207.8	41. 4785.4	17.2	0	.00	.0		
10 9	13.80	.0	.0	113.1	53. 2629.6	15.6	1	13.86	.4		
11 10	13.75	-.4	-.4	110.9	33. 2589.3	7.3	0	.00	.0		
12 11	13.69	-.8	-.8	41.0	19. 967.7	3.6	0	.00	.0		
13 12	13.63	-1.3	-1.3	37.1	17. 875.9	3.5	0	.00	.0		
14 13	13.60	-1.4	-1.4	11.7	5. 275.4	.4	0	.00	.0		
15 11	13.67	-1.0	-1.0	60.2	28. 1389.7	7.2	0	.00	.0		
16 15	13.58	-1.6	-1.6	57.7	27. 1328.6	7.2	0	.00	.0		
17 16	13.48	-2.3	-2.3	52.8	25. 1213.8	8.1	0	.00	.0		
18 17	13.37	-3.1	-3.1	47.4	22. 1087.6	7.6	0	.00	.0		
19 18	13.29	-3.7	-3.7	39.8	19. 911.6	4.5	0	.00	.0		
20 19	13.22	-4.2	-4.2	32.7	15. 747.1	3.6	0	.00	.0		
21 20	13.21	-4.3	-4.3	6.2	3. 141.5	.1	0	.00	.0		
22 21	13.20	-4.3	-4.3	3.6	2. 82.9	.0	0	.00	.0		
23 20	13.18	-4.5	-4.5	21.7	10. 496.0	1.2	0	.00	.0		
24 23	13.16	-4.7	-4.7	18.8	9. 429.7	.7	0	.00	.0		
25 24	13.13	-4.9	-4.9	13.7	6. 312.4	.6	0	.00	.0		
26 25	13.12	-4.9	-4.9	4.9	2. 110.9	.1	0	.00	.0		
27 26	13.12	-4.9	-4.9	1.3	1. 30.6	.0	0	.00	.0		
28 9	14.50	5.1	5.1	77.0	36. 1732.5	17.7	1	14.64	6.1		
29 28	14.40	4.4	4.4	68.2	32. 1620.4	9.5	0	.00	.0		
30 29	14.33	3.8	3.8	67.5	31. 1604.1	6.8	0	.00	.0		
31 30	14.17	2.7	2.7	67.3	31. 1596.5	14.9	0	.00	.0		
32 31	14.03	1.7	1.7	57.9	27. 1366.6	11.7	0	.00	.0		
33 32	13.93	.9	.9	56.0	26. 1319.1	8.2	0	.00	.0		
34 33	13.81	.1	.1	52.4	24. 1231.7	8.5	0	.00	.0		
35 34	13.73	-.5	-.5	48.1	22. 1129.7	5.2	0	.00	.0		
36 35	13.80	.0	.0	47.1	22. 1103.7	4.8	1	13.94	1.0		
37 36	13.71	-.6	-.6	45.0	21. 1065.3	5.5	0	.00	.0		
38 37	13.69	-.8	-.8	43.4	20. 1028.2	1.1	0	.00	.0		
39 38	13.65	-1.1	-1.1	25.8	12. 611.2	1.5	0	.00	.0		
40 39	13.64	-1.2	-1.2	6.2	3. 146.6	.1	0	.00	.0		
41 39	13.63	-1.2	-1.2	15.9	7. 376.7	.5	0	.00	.0		
42 41	13.63	-1.3	-1.3	10.9	5. 259.9	.3	0	.00	.0		
43 42	13.62	-1.3	-1.3	11.1	5. 265.0	.2	0	.00	.0		
44 43	13.62	-1.3	-1.3	11.5	5. 273.9	.2	0	.00	.0		
45 44	13.63	-1.3	-1.3	13.2	6. 312.0	.2	0	.00	.0		
46 45	13.64	-1.2	-1.2	16.5	8. 390.9	.6	0	.00	.0		
47 46	13.66	-1.0	-1.0	18.6	9. 440.6	.9	0	.00	.0		

Potencia acumulada na Subestacao = 5070.7 kW - 2377.6 kvar (5600.4 kVA)
Perdas Totais no Alimentador = 486.5 kW - 769.9 kvar (910.7 kVA)
Fator de Demanda Corrigido = .530

----- Reguladores de Tensao -----						*----- LDC -----*				
Pto	Regulador	Tensao(kV)		Reg.	Fx Reg.	Pto	R	X	In	TP
		(entr)	(said)	(%)	(%)	Ctrl	(V)	(V)	(A)	
5	Regulador	13.04	14.50	11.23	11.5	5	.0	.0	.0	.0
10	Regulador	13.74	13.80	.45	8.5	10	.0	.0	.0	.0
28	Regulador	13.67	14.50	6.08	11.5	28	.0	.0	.0	.0
36	Regulador	13.66	13.80	1.04	8.5	36	.0	.0	.0	.0

Relatorio Do Gerador : 47

Pto	Tens. Anagl	Pgerad	Qgerad	Qmin	Qmax
47	13.66-5.75	585.	-100.	-100.	100.

--- Tensoes Acima de : 5.00 % ---				
Pto	Nome	Tensao	Queda(%)	
		(kV)	Oper.	Nomin
5		14.50	5.1	5.1
28		14.50	5.1	5.1

CELESC/UFSC (LABSPOT)
SPDST - Fluxo de Potencia - Soma de Potencias

pag. 1

Alimentador com gerador - grau de penetração GP=20%

Tensao Nominal (kV) = 13.80 F. Potencia = .96
Tensao de Operacao (kV) = 13.80 F. Demanda = .51
Iteracoes p/ convergencia = 12

C A L C U L O											
TRECHO	TENSAO	QUEDA(%)	CORRENTE(A)	DEM.	PERDAS	REGULACAO					
PT	PA	(kV)	OP. NOM.	I	I/IN(%)	(kVA)	(KW)	Eq	kV/kvar	(%)	
2	1	13.61	-1.4	-1.4	207.3	41.	4348.5	36.4	0	.00	.0
3	2	13.42	-2.8	-2.8	207.4	41.	4348.5	37.4	0	.00	.0
5	4	14.50	5.1	5.1	207.4	41.	4348.5	26.8	1	15.28	10.7
4	3	13.23	-4.1	-4.1	207.4	41.	4348.5	35.7	0	.00	.0
6	5	14.37	4.1	4.1	187.3	37.	4348.5	24.0	0	.00	.0
7	6	14.17	2.7	2.7	187.3	37.	4348.5	35.8	0	.00	.0
8	7	13.95	1.1	1.1	187.4	37.	4348.5	39.4	0	.00	.0
9	8	13.87	.5	.5	184.4	36.	4276.4	13.5	0	.00	.0
10	9	13.80	.0	.0	112.8	52.	2629.6	15.5	1	13.82	.1
11	10	13.75	-.4	-.4	110.9	33.	2589.3	7.3	0	.00	.0
12	11	13.69	-.8	-.8	41.0	19.	967.7	3.6	0	.00	.0
13	12	13.63	-1.3	-1.3	37.1	17.	875.9	3.5	0	.00	.0
14	13	13.60	-1.4	-1.4	11.7	5.	275.4	.4	0	.00	.0
15	11	13.67	-1.0	-1.0	60.2	28.	1389.7	7.2	0	.00	.0
16	15	13.58	-1.6	-1.6	57.7	27.	1328.6	7.2	0	.00	.0
17	16	13.48	-2.3	-2.3	52.8	25.	1213.8	8.1	0	.00	.0
18	17	13.37	-3.1	-3.1	47.4	22.	1087.6	7.6	0	.00	.0
19	18	13.29	-3.7	-3.7	39.8	19.	911.6	4.5	0	.00	.0
20	19	13.22	-4.2	-4.2	32.7	15.	747.1	3.6	0	.00	.0
21	20	13.21	-4.3	-4.3	6.2	3.	141.5	.1	0	.00	.0
22	21	13.20	-4.3	-4.3	3.6	2.	82.9	.0	0	.00	.0
23	20	13.18	-4.5	-4.5	21.7	10.	496.0	1.2	0	.00	.0
24	23	13.16	-4.7	-4.7	18.8	9.	429.7	.7	0	.00	.0
25	24	13.13	-4.9	-4.9	13.7	6.	312.4	.6	0	.00	.0
26	25	13.12	-4.9	-4.9	4.9	2.	110.9	.1	0	.00	.0
27	26	13.12	-4.9	-4.9	1.3	1.	30.6	.0	0	.00	.0
28	9	14.50	5.1	5.1	56.6	26.	1288.7	9.6	1	14.55	5.4
29	28	14.43	4.5	4.5	49.6	23.	1185.8	5.0	0	.00	.0
30	29	14.37	4.2	4.2	49.0	23.	1170.9	3.6	0	.00	.0
31	30	14.26	3.3	3.3	48.8	23.	1164.1	7.8	0	.00	.0
32	31	14.16	2.6	2.6	40.5	19.	960.7	5.7	0	.00	.0
33	32	14.09	2.1	2.1	38.9	18.	920.3	3.9	0	.00	.0
34	33	14.01	1.5	1.5	35.9	17.	848.2	4.0	0	.00	.0
35	34	13.96	1.2	1.2	32.6	15.	768.2	2.4	0	.00	.0
36	35	13.80	.0	.0	31.8	15.	748.7	2.2	1	13.69	.8
37	36	13.74	-.4	-.4	30.9	14.	720.8	2.6	0	.00	.0
38	37	13.73	-.5	-.5	29.8	14.	694.8	.5	0	.00	.0
39	38	13.72	-.6	-.6	22.0	10.	520.0	1.1	0	.00	.0
40	39	13.71	-.7	-.7	6.2	3.	146.6	.1	0	.00	.0
41	39	13.72	-.6	-.6	24.2	11.	581.4	1.1	0	.00	.0
42	41	13.74	-.4	-.4	31.1	14.	748.6	2.5	0	.00	.0
43	42	13.76	-.3	-.3	32.5	15.	783.2	1.8	0	.00	.0
44	43	13.78	-.1	-.1	33.6	16.	809.3	2.1	0	.00	.0
45	44	13.80	.0	.0	36.4	17.	876.9	1.9	0	.00	.0
46	45	13.84	.3	.3	40.5	19.	975.6	3.5	0	.00	.0
47	46	13.89	.7	.7	42.8	20.	1030.1	4.6	0	.00	.0

Potencia acumulada na Subestacao = 4385.4 kW - 2307.0 kvar (4955.2 kVA)
Perdas Totais no Alimentador = 386.2 kW - 599.3 kvar (713.0 kVA)
Fator de Demanda Corrigido = .469

----- Reguladores de Tensao -----						*----- LDC -----*				
Pto	Regulador	Tensao(kV)		Reg.	Fx Reg.	Pto	R	X	In	TP
		(entr)	(said)	(%)	(%)	Ctrl	(V)	(V)	(A)	
5	Regulador	13.10	14.50	10.72	11.5	5	.0	.0	.0	.0
10	Regulador	13.78	13.80	.14	8.5	10	.0	.0	.0	.0
28	Regulador	13.75	14.50	5.44	11.5	28	.0	.0	.0	.0
36	Regulador	13.91	13.80	.82	8.5	36	.0	.0	.0	.0

Relatorio Do Gerador : 47

Pto	Tens. Anagl	Pgerad	Qgerad	Qmin	Qmax
47	13.89-2.55	1170.	-200.	-200.	200.

--- Tensoes Acima de : 5.00 % ---				
Pto	Nome	Tensao	Queda(%)	
		(kV)	Oper.	Nomin
5		14.50	5.1	5.1
28		14.50	5.1	5.1

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Alimentador com gerador - grau de penetração GP=30%

Tensao Nominal (kV) = 13.80 F. Potencia = .96
Tensao de Operacao (kV) = 13.80 F. Demanda = .51
Iteracoes p/ convergencia = 12

C A L C U L O											
TRECHO	TENSAO	QUEDA(%)	CORRENTE(A)	DEM.	PERDAS	REGULACAO					
PT	PA	(kV)	OP. NOM.	I	I/IN(%)	(kVA)	(KW)	Eq	kV/kvar	(%)	
2	1	13.62	-1.3	-1.3	185.3	36.	3864.1	29.1	0	.00	.0
3	2	13.44	-2.6	-2.6	185.3	36.	3864.1	29.8	0	.00	.0
5	4	14.50	5.1	5.1	185.3	36.	3864.1	21.4	1	15.23	10.4
4	3	13.27	-3.9	-3.9	185.3	36.	3864.1	28.5	0	.00	.0
6	5	14.37	4.1	4.1	167.9	33.	3864.1	19.3	0	.00	.0
7	6	14.18	2.8	2.8	167.9	33.	3864.1	28.8	0	.00	.0
8	7	13.98	1.3	1.3	168.0	33.	3864.1	31.7	0	.00	.0
9	8	13.90	.7	.7	165.1	32.	3792.9	10.9	0	.00	.0
10	9	13.80	.0	.0	112.5	52.	2629.6	15.5	1	13.79	.1
11	10	13.75	-.4	-.4	110.9	33.	2589.3	7.3	0	.00	.0
12	11	13.69	-.8	-.8	41.0	19.	967.7	3.6	0	.00	.0
13	12	13.63	-1.3	-1.3	37.1	17.	875.9	3.5	0	.00	.0
14	13	13.60	-1.4	-1.4	11.7	5.	275.4	.4	0	.00	.0
15	11	13.67	-1.0	-1.0	60.2	28.	1389.7	7.2	0	.00	.0
16	15	13.58	-1.6	-1.6	57.7	27.	1328.6	7.2	0	.00	.0
17	16	13.48	-2.3	-2.3	52.8	25.	1213.8	8.1	0	.00	.0
18	17	13.37	-3.1	-3.1	47.4	22.	1087.6	7.6	0	.00	.0
19	18	13.29	-3.7	-3.7	39.8	19.	911.6	4.5	0	.00	.0
20	19	13.22	-4.2	-4.2	32.7	15.	747.1	3.6	0	.00	.0
21	20	13.21	-4.3	-4.3	6.2	3.	141.5	.1	0	.00	.0
22	21	13.20	-4.3	-4.3	3.6	2.	82.9	.0	0	.00	.0
23	20	13.18	-4.5	-4.5	21.7	10.	496.0	1.2	0	.00	.0
24	23	13.16	-4.7	-4.7	18.8	9.	429.7	.7	0	.00	.0
25	24	13.13	-4.9	-4.9	13.7	6.	312.4	.6	0	.00	.0
26	25	13.12	-4.9	-4.9	4.9	2.	110.9	.1	0	.00	.0
27	26	13.12	-4.9	-4.9	1.3	1.	30.6	.0	0	.00	.0
28	9	14.50	5.1	5.1	45.4	21.	1012.6	6.2	1	14.48	5.0
29	28	14.45	4.7	4.7	40.4	19.	944.1	3.3	0	.00	.0
30	29	14.41	4.4	4.4	40.0	19.	934.9	2.4	0	.00	.0
31	30	14.33	3.9	3.9	39.9	19.	930.7	5.2	0	.00	.0
32	31	14.27	3.4	3.4	35.2	16.	826.4	4.3	0	.00	.0
33	32	14.23	3.1	3.1	34.5	16.	811.5	3.1	0	.00	.0
34	33	14.18	2.8	2.8	33.4	16.	791.2	3.4	0	.00	.0
35	34	14.16	2.6	2.6	32.7	15.	779.8	2.4	0	.00	.0
36	35	13.80	.0	.0	32.6	15.	779.1	2.3	1	13.47	2.4
37	36	13.77	-.2	-.2	33.3	15.	779.8	3.0	0	.00	.0
38	37	13.77	-.2	-.2	33.3	15.	782.4	.7	0	.00	.0
39	38	13.78	-.1	-.1	38.4	18.	932.9	3.3	0	.00	.0
40	39	13.77	-.2	-.2	6.1	3.	146.6	.1	0	.00	.0
41	39	13.80	.0	.0	45.5	21.	1112.1	4.0	0	.00	.0
42	41	13.86	.4	.4	54.1	25.	1324.8	7.6	0	.00	.0
43	42	13.89	.7	.7	55.7	26.	1363.2	5.3	0	.00	.0
44	43	13.94	1.0	1.0	56.9	26.	1391.6	6.1	0	.00	.0
45	44	13.97	1.3	1.3	59.8	28.	1463.6	5.1	0	.00	.0
46	45	14.04	1.7	1.7	64.0	30.	1565.9	8.7	0	.00	.0
47	46	14.11	2.3	2.3	66.3	31.	1621.5	11.0	0	.00	.0

Potencia acumulada na Subestacao = 3773.1 kW - 2316.2 kvar (4427.3 kVA)
Perdas Totais no Alimentador = 357.9 kW - 508.5 kvar (621.8 kVA)
Fator de Demanda Corrigido = .419

```

*----- Reguladores de Tensao -----* *----- LDC -----*
Pto Regulador      Tensao(kV)      Reg.  Fx Reg.  Pto  R    X    In    TP
      (entr)  (said)  ( % )  ( % )  Ctrl  (V)  (V)  (A)
-----
  5  Regulador  13.14  14.50  10.37  11.5    5  .0  .0  .0  .0
 10  Regulador  13.81  13.80   .07   8.5   10  .0  .0  .0  .0
 28  Regulador  13.82  14.50  4.96  11.5   28  .0  .0  .0  .0
 36  Regulador  14.14  13.80  2.39   8.5   36  .0  .0  .0  .0
-----

```

Relatorio Do Gerador : 47

```

-----
Pto  Tens. Angl Pgerad Qgerad  Qmin  Qmax
-----
 47  14.11  .53  1754.  -300.  -300.  300.
-----

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```

*--- Tensoes Acima de : 5.00 % ---*
Pto  Nome      Tensao      Queda(%)
      ( kV )  Oper.  Nomin
-----
  5      14.50    5.1    5.1
 28      14.50    5.1    5.1
-----

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Alimentador com gerador - grau de penetração GP=40%

Tensao Nominal (kV) = 13.80 F. Potencia = .96

Tensao de Operacao (kV) = 13.80 F. Demanda = .51

Iteracoes p/ convergencia = 11

C A L C U L O											
TRECHO	TENSAO	QUEDA(%)	CORRENTE(A)	DEM.	PERDAS	REGULACAO					
PT	PA	(kV)	OP. NOM.	I	I/IN(%)	(kVA)	(KW)	Eq	kV/kvar	(%)	
2	1	13.67	-0.9	-0.9	144.4	28.3040.2	17.7	0	.00	.0	
3	2	13.54	-1.9	-1.9	144.5	28.3040.2	18.1	0	.00	.0	
5	4	14.50	5.1	5.1	144.5	28.3040.2	13.0	1	15.02	8.8	
4	3	13.42	-2.8	-2.8	144.5	28.3040.2	17.3	0	.00	.0	
6	5	14.41	4.4	4.4	132.8	26.3040.2	12.1	0	.00	.0	
7	6	14.27	3.4	3.4	132.8	26.3040.2	18.0	0	.00	.0	
8	7	14.12	2.3	2.3	132.9	26.3040.2	19.8	0	.00	.0	
9	8	14.07	1.9	1.9	129.9	25.2967.8	6.7	0	.00	.0	
10	9	13.80	.0	.0	111.2	52.2629.6	15.1	1	13.63	1.3	
11	10	13.75	-.4	-.4	110.9	33.2589.3	7.3	0	.00	.0	
12	11	13.69	-.8	-.8	41.0	19.967.7	3.6	0	.00	.0	
13	12	13.63	-1.3	-1.3	37.1	17.875.9	3.5	0	.00	.0	
14	13	13.60	-1.4	-1.4	11.7	5.275.4	.4	0	.00	.0	
15	11	13.67	-1.0	-1.0	60.2	28.1389.7	7.2	0	.00	.0	
16	15	13.58	-1.6	-1.6	57.7	27.1328.6	7.2	0	.00	.0	
17	16	13.48	-2.3	-2.3	52.8	25.1213.8	8.1	0	.00	.0	
18	17	13.37	-3.1	-3.1	47.4	22.1087.6	7.6	0	.00	.0	
19	18	13.29	-3.7	-3.7	39.8	19.911.6	4.5	0	.00	.0	
20	19	13.22	-4.2	-4.2	32.7	15.747.1	3.6	0	.00	.0	
21	20	13.21	-4.3	-4.3	6.2	3.141.5	.1	0	.00	.0	
22	21	13.20	-4.3	-4.3	3.6	2.82.9	.0	0	.00	.0	
23	20	13.18	-4.5	-4.5	21.7	10.496.0	1.2	0	.00	.0	
24	23	13.16	-4.7	-4.7	18.8	9.429.7	.7	0	.00	.0	
25	24	13.13	-4.9	-4.9	13.7	6.312.4	.6	0	.00	.0	
26	25	13.12	-4.9	-4.9	4.9	2.110.9	.1	0	.00	.0	
27	26	13.12	-4.9	-4.9	1.3	1.30.6	.0	0	.00	.0	
28	9	14.50	5.1	5.1	12.3	6.292.1	.4	1	14.23	3.1	
29	28	14.50	5.1	5.1	12.7	6.350.9	.3	0	.00	.0	
30	29	14.50	5.1	5.1	12.9	6.361.7	.3	0	.00	.0	
31	30	14.50	5.1	5.1	13.1	6.366.8	.6	0	.00	.0	
32	31	14.53	5.3	5.3	18.9	9.552.1	1.2	0	.00	.0	
33	32	14.55	5.4	5.4	20.5	10.594.8	1.1	0	.00	.0	
34	33	14.58	5.6	5.6	23.4	11.675.5	1.7	0	.00	.0	
35	34	14.61	5.9	5.9	27.1	13.772.4	1.7	0	.00	.0	
36	35	13.80	.0	.0	28.1	13.797.6	1.7	1	13.01	5.7	
37	36	13.84	.3	.3	31.3	15.834.8	2.7	0	.00	.0	
38	37	13.85	.4	.4	32.7	15.871.1	.6	0	.00	.0	
39	38	13.92	.9	.9	50.2	23.1298.2	5.6	0	.00	.0	
40	39	13.91	.8	.8	6.1	3.146.6	.1	0	.00	.0	
41	39	13.99	1.4	1.4	61.6	29.1573.6	7.3	0	.00	.0	
42	41	14.11	2.2	2.2	72.8	34.1848.0	13.7	0	.00	.0	
43	42	14.19	2.8	2.8	74.7	35.1894.7	9.6	0	.00	.0	
44	43	14.28	3.5	3.5	76.1	35.1928.8	10.9	0	.00	.0	
45	44	14.35	4.0	4.0	79.5	37.2013.9	9.0	0	.00	.0	
46	45	14.47	4.8	4.8	84.3	39.2132.2	15.1	0	.00	.0	
47	46	14.60	5.8	5.8	86.8	40.2195.5	18.8	0	.00	.0	

Potencia acumulada na Subestacao = 3127.0 kW - 1461.7 kvar (3451.8 kVA)
Perdas Totais no Alimentador = 295.8 kW - 354.0 kvar (461.3 kVA)
Fator de Demanda Corrigido = .327

----- Reguladores de Tensao -----						*----- LDC -----*				
Pto	Regulador	Tensao(kV)		Reg.	Fx Reg.	Pto	R	X	In	TP
		(entr)	(said)	(%)	(%)	Ctrl	(V)	(V)	(A)	
5	Regulador	13.33	14.50	8.81	11.5	5	.0	.0	.0	.0
10	Regulador	13.98	13.80	1.26	8.5	10	.0	.0	.0	.0
28	Regulador	14.06	14.50	3.14	11.5	28	.0	.0	.0	.0
36	Regulador	14.64	13.80	5.74	8.5	36	.0	.0	.0	.0

Relatorio Do Gerador : 47

Pto	Tens.	Angr	Pgerad	Qgerad	Qmin	Qmax
47	14.60	-.28	2338.	400.	-400.	400.

--- Tensoes Acima de : 5.00 % ---				
Pto	Nome	Tensao	Queda(%)	
		(kV)	Oper.	Nomin
5		14.50	5.1	5.1
28		14.50	5.1	5.1
29		14.50	5.1	5.1
30		14.50	5.1	5.1
31		14.50	5.1	5.1
32		14.53	5.3	5.3
33		14.55	5.4	5.4
34		14.58	5.6	5.6
35		14.61	5.9	5.9
47		14.60	5.8	5.8

CELESC/UFSC (LABSPOT)
SPDST - Fluxo de Potencia - Soma de Potencias

pag. 1

Alimentador com gerador - grau de penetração - GP=50%

Tensao Nominal (kV) = 13.80 F. Potencia = .96
Tensao de Operacao (kV) = 13.80 F. Demanda = .51
Iteracoes p/ convergencia = 13

C A L C U L O											
TRECHO	TENSAO	QUEDA(%)	CORRENTE(A)	DEM.	PERDAS	REGULACAO					
PT PA	(kV)	OP. NOM.	I I/IN(%)	(kVA)	(KW)	Eq kV/kvar (%)					
2 1	13.63	-1.2	-1.2	155.3	30.	3013.4	20.4	0	.00	.0	
3 2	13.46	-2.4	-2.4	155.3	30.	3013.4	21.0	0	.00	.0	
5 4	14.50	5.1	5.1	155.4	30.	3013.4	15.0	1	15.18	10.0	
4 3	13.30	-3.6	-3.6	155.4	30.	3013.4	20.0	0	.00	.0	
6 5	14.38	4.2	4.2	141.3	28.	3013.4	13.7	0	.00	.0	
7 6	14.20	2.9	2.9	141.3	28.	3013.4	20.4	0	.00	.0	
8 7	14.00	1.4	1.4	141.3	28.	3013.4	22.4	0	.00	.0	
9 8	13.93	.9	.9	138.6	27.	2948.0	7.7	0	.00	.0	
10 9	13.80	.0	.0	112.3	52.	2629.6	15.4	1	13.76	.3	
11 10	13.75	-.4	-.4	110.9	33.	2589.3	7.3	0	.00	.0	
12 11	13.69	-.8	-.8	41.0	19.	967.7	3.6	0	.00	.0	
13 12	13.63	-1.3	-1.3	37.1	17.	875.9	3.5	0	.00	.0	
14 13	13.60	-1.4	-1.4	11.7	5.	275.4	.4	0	.00	.0	
15 11	13.67	-1.0	-1.0	60.2	28.	1389.7	7.2	0	.00	.0	
16 15	13.58	-1.6	-1.6	57.7	27.	1328.6	7.2	0	.00	.0	
17 16	13.48	-2.3	-2.3	52.8	25.	1213.8	8.1	0	.00	.0	
18 17	13.37	-3.1	-3.1	47.4	22.	1087.6	7.6	0	.00	.0	
19 18	13.29	-3.7	-3.7	39.8	19.	911.6	4.5	0	.00	.0	
20 19	13.22	-4.2	-4.2	32.7	15.	747.1	3.6	0	.00	.0	
21 20	13.21	-4.3	-4.3	6.2	3.	141.5	.1	0	.00	.0	
22 21	13.20	-4.3	-4.3	3.6	2.	82.9	.0	0	.00	.0	
23 20	13.18	-4.5	-4.5	21.7	10.	496.0	1.2	0	.00	.0	
24 23	13.16	-4.7	-4.7	18.8	9.	429.7	.7	0	.00	.0	
25 24	13.13	-4.9	-4.9	13.7	6.	312.4	.6	0	.00	.0	
26 25	13.12	-4.9	-4.9	4.9	2.	110.9	.1	0	.00	.0	
27 26	13.12	-4.9	-4.9	1.3	1.	30.6	.0	0	.00	.0	
28 9	14.50	5.1	5.1	58.1	27.	1364.0	10.1	1	14.40	4.3	
29 28	14.48	5.0	5.0	56.3	26.	1403.0	6.5	0	.00	.0	
30 29	14.47	4.9	4.9	56.5	26.	1409.3	4.8	0	.00	.0	
31 30	14.45	4.7	4.7	56.6	26.	1412.3	10.5	0	.00	.0	
32 31	14.45	4.7	4.7	59.3	28.	1519.6	12.2	0	.00	.0	
33 32	14.46	4.8	4.8	60.0	28.	1545.3	9.4	0	.00	.0	
34 33	14.47	4.9	4.9	61.6	29.	1595.5	11.7	0	.00	.0	
35 34	14.49	5.0	5.0	63.6	30.	1658.4	9.1	0	.00	.0	
36 35	13.80	.0	.0	64.2	30.	1675.2	9.0	1	13.13	4.9	
37 36	13.83	.2	.2	68.4	32.	1700.5	12.7	0	.00	.0	
38 37	13.84	.3	.3	69.3	32.	1725.5	2.8	0	.00	.0	
39 38	13.89	.7	.7	81.2	38.	2043.6	14.6	0	.00	.0	
40 39	13.88	.6	.6	6.1	3.	146.6	.1	0	.00	.0	
41 39	13.95	1.1	1.1	90.0	42.	2267.2	15.6	0	.00	.0	
42 41	14.06	1.9	1.9	99.3	46.	2500.2	25.5	0	.00	.0	
43 42	14.14	2.4	2.4	100.9	47.	2540.6	17.4	0	.00	.0	
44 43	14.22	3.0	3.0	102.1	47.	2570.3	19.5	0	.00	.0	
45 44	14.29	3.5	3.5	105.1	49.	2644.8	15.8	0	.00	.0	
46 45	14.39	4.3	4.3	109.2	51.	2749.4	25.4	0	.00	.0	
47 46	14.53	5.3	5.3	111.5	52.	2805.8	31.0	0	.00	.0	

Potencia acumulada na Subestacao = 2722.4 kW - 2522.4 kvar (3711.3 kVA)
Perdas Totais no Alimentador = 475.2 kW - 514.7 kvar (700.5 kVA)
Fator de Demanda Corrigido = .352

----- Reguladores de Tensao -----						*----- LDC -----*				
Pto	Regulador	Tensao (kV)		Reg.	Fx Reg.	Pto	R	X	In	TP
		(entr)	(said)	(%)	(%)	Ctrl	(V)	(V)	(A)	
5	Regulador	13.18	14.50	10.03	11.5	5	.0	.0	.0	.0
10	Regulador	13.84	13.80	.27	8.5	10	.0	.0	.0	.0
28	Regulador	13.90	14.50	4.35	11.5	28	.0	.0	.0	.0
36	Regulador	14.51	13.80	4.87	8.5	36	.0	.0	.0	.0

Relatorio Do Gerador : 47

Pto	Tens.	Angl	Pgerad	Qgerad	Qmin	Qmax
47	14.53	6.37	2922.	-500.	-500.	500.

--- Tensoes Acima de : 5.00 % ---				
Pto	Nome	Tensao	Queda(%)	
		(kV)	Oper.	Nomin
5		14.50	5.1	5.1
28		14.50	5.1	5.1
47		14.53	5.3	5.3

ANEXO 2 – Artigo – Distributed Generation: a definition

Distributed generation: a definition

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Abstract

Distributed generation (DG) is expected to become more important in the future generation system. The current literature, however, does not use a consistent definition of DG. This paper discusses the relevant issues and aims at providing a general definition for distributed power generation in competitive electricity markets. In general, DG can be defined as electric power generation within distribution networks or on the customer side of the network. In addition, the terms distributed resources, distributed capacity and distributed utility are discussed. Network and connection issues of distributed generation are presented, too. © 2001 Elsevier Science S.A. All rights reserved.

Keywords: Dispersed generation; Embedded generation; Distributed generation; Distributed resources; Distributed utility; Power distribution

1. Introduction

A study by the *Electric Power Research Institute* (EPRI) indicates that by 2010, 25% of the new generation will be distributed, a study by the *Natural Gas Foundation* concluded that this figure could be as high as 30% [1]. The *European Renewable Energy Study* (TERES), commissioned by the *European Union* (EU) to examine the feasibility of EU CO₂-reduction goals and the EU renewable energy targets, found that around 60% of the renewable energy potential that can be utilised until 2010 can be categorised as decentralised power sources [2].

The definitions for distributed generation (DG) used in the literature, however, are not consistent. This paper presents a discussion of the relevant aspects of DG and provides the required definitions.

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¹ In addition to this paper, a working paper entitled 'Distributed power generation in a deregulated market environment' is available. The aim of this working paper is to start a discussion regarding different aspects of distributed generation. This working paper can be obtained from one of the authors, Thomas Ackermann.

2. Background of definition

Distributed generation is a new approach in the electricity industry and as the analysis of the relevant literature has shown there is no generally accepted definition of distributed generation yet (see particular [35]).

In the literature, a large number of terms and definitions is used in relation to distributed generation.

For example, Anglo-American countries often use the term 'embedded generation', North American countries the term 'dispersed generation', and in Europe and parts of Asia, the term 'decentralised generation' is applied for the same type of generation.

In addition, in regards to the rating of distributed generation power units, the following different definitions are currently used:

1. The *Electric Power Research Institute* defines distributed generation as generation from 'a few kilowatts up to 50 MW' [4];
2. According to the *Gas Research Institute*, distributed generation is 'typically [between] 25 and 25 MW' [5];
3. Preston and Rastler define the size as 'ranging from a few kilowatts to over 100 MW' [3];
4. Cardell defines distributed generation as generation 'between 500 kW and 1 MW' [6];

5. The *International Conference on Large High Voltage Electric Systems* (CIGRÉ) defines DG as ‘smaller than 50–100 MW’ [36];

And because of different government regulations, the definition of the rating of each distributed power station also varies between countries, for example (also [35]):

1. In the English and Welsh market, DG plants with a capacity of less than 100 MW are not centrally dispatched and if the capacity is less than 50 MW, the power output does not have to be traded via the wholesale market [7]. The term distributed generation is, therefore, predominantly used for power units with less than 100 MW capacity;
2. Swedish legislation gives special treatment to small generation with a maximum generation capacity of up to 1500 kW, [8,9,37]. Hence, DG in Sweden is often defined as generation with up to 1500 kW. But under Swedish law, a wind farm with one hundred 1500 kW wind turbines is still considered DG, as the rating of each wind energy unit, and not the total wind farm rating, is relevant for the Swedish law. For hydro units, in comparison, it is the total rating of the power station that is relevant. Some of the proposed offshore wind farms for Sweden have a maximum capacity of up to 1000 MW. This would still be considered DG as they plan to use 1500 kW wind turbines [10].

Due to the large variations in the definitions used in the literature, the following different issues have to be discussed to define distributed generation more precisely:

- A. the purpose;
- B. the location;
- C. the rating of distributed generation;
- D. the power delivery area;
- E. the technology;
- F. the environmental impact;
- G. the mode of operation;
- H. the ownership, and
- I. the penetration of distributed generation.

2.1. Purpose

There is an agreement among different authors and organisations regarding the definition of the purpose of DG.

Definition A1. *The purpose of distributed generation is to provide a source of active electric power.*

According to this definition, distributed generation does not need to be able to provide reactive power.

2.2. Location

The definition of the location of the distributed generation plants varies among different authors. Most authors define the location of DG at the distribution side of the network, some authors also include the customers side, and some even include the transmission side of the network [3]. We think that the following definition is appropriate:

Definition B1. *The location of distributed generation is defined as the installation and operation of electric power generation units connected directly to the distribution network or connected to the network on the customer site of the meter.*

The motivation for using this definition is that the connection of generation units to the transmission network is done traditionally by the industry. The central idea of distributed generation, however, is to locate generation close to the load, hence on the distribution network or on the customer side of the meter.

Having defined distributed generation now as electric power generation at distribution level or below, the definition requires a more detailed distinction between a transmission and a distribution system.

A distinction based on voltage levels, e.g. 220 kV and higher is considered as transmission and below as distribution, is not very useful as distribution companies sometimes own and operate 220 kV lines and transmission companies operate 110 kV lines.

As the voltage level does not provide any internationally useful distinction between distribution and transmission, another approach is needed. The approach suggested in this paper is based on the legal definition.

Definition B2. *In the context of competitive electricity market regulations, only the legal definition for transmission and distribution systems provides a clear distinction between the two systems [11].*

In a competitive electricity system, the legal regulations define the transmission system, which is usually operated by an independent company that is not involved in power generation, distribution or retail service. In countries without a clear legal definition, however, further discussions will be required.

In some countries, e.g. Sweden, also regional networks are included in the legal definitions. These regional networks are located between the nation-wide

transmission network and the local distribution networks. However, usually they are considered to be part of the distribution network system.

Based on the above definition, another question arises: What is a small generation unit, e.g. a wind farm or a CHP system, connected to the transmission network? Theoretically, the two following situations can occur:

1. a CHP system is located on a large industrial site and the industrial customer is directly connected to the transmission network. In this case, the CHP system can be described as distributed generation as it is connected on the customer side of the meter;
2. a medium-sized wind farm is directly connected to the transmission system, due to the capacity limit of the local distribution network. In this case, the wind farm cannot be described as distributed generation.

2.3. Rating of distributed generation

The maximum possible rating of the distributed generation source is often used within the definition of distributed generation in the literature (see beginning of Section 2). Our definition, however, does not include any information regarding the rating of the distributed generation source.

Definition C1. *The rating of the DG power source is not relevant for our proposed definition.*

The motivation for this approach is that:

1. the rating is 'not critical to the definition of what constitutes distributed generation' [3];
2. the maximum rating that can be connected to a distribution system depends on the capacity of the distribution system, which is correlated to the voltage level within the distribution system. The technical design of each distribution system is unique, therefore, no general definition of the maximum generation capacity that can be connected to a distribution system can be given.

Taking into account these initial remarks, general data can be provided, of course. According to Klopfer et al. power units with more than 100–150 MW cannot be connected to 110 kV voltage levels, due to technical constraints [11]. As this is in most cases the maximum voltage level owned and operated by distribution companies, the maximum capacity for distributed power stations seems to be in the 100–150 MW range.

In Berlin, however, the local utility *BEWAG* built a CCGT power station in the centre of the city. The power plant produces both electricity (capacity 300 MW) as well as district heat (capacity 300 MW). The power station actually feeds into various 110 and 33 kV distribution lines, owned and operated by *BEWAG*.

The power as well as the heat is predominantly used locally. Hence, this power station can be considered distributed generation, according to definition Definition B1. This case, however, is certainly very special. The above discussion shows that DG can vary between a couple of kilowatts to up to ~300 MW.

The technical issues related to distributed generation, however, can vary significantly with the rating. Therefore, it is appropriate to introduce categories of distributed generation. We suggest the following distinction for these categories:

Micro	distributed generation: ~1 Watt < 5 kW;
Small	distributed generation: 5 kW < 5 MW;
Medium	distributed generation: 5 MW < 50 MW;
Large	distributed generation: 50 MW < ~300 MW.

Some authors define generation between 1 kW and 1 MW as dispersed generation. However, this definition is not used consistently in the literature and should therefore not be applied in this way.

2.4. Power delivery area

Some authors also define the power delivery area, e.g. all power generated by DG is used within the distribution network. In certain circumstances, defining the power delivery area is not very helpful, as the following example illustrates:

The New Zealand utility *Wairarapa Electricity* operated a 3.5 MW wind farm within its 11/33 kV southern distribution network (the wind farm is now owned by the *Electricity Cooperation of New Zealand*). The produced energy is almost totally used within its own network, however, during nights with very low demand and high wind speeds the wind farm actually exports energy back into the transmission system [12].

A definition of the area of power delivery restricted to the distribution network would disqualify this project as distributed generation, despite the fact that it is a very typical DG project. Furthermore, any restriction of the power delivery areas in the definition of DG would result in complex analyses of the power flow in the distribution network. Therefore:

Definition D1. *The area of the power delivery is not relevant for our proposed definition of DG.*

The term *embedded distributed generations* seems to be more appropriate to describe that the power output of the distributed generation source is only used locally. Unfortunately, the term *embedded* is not used consistently in the literature.

2.5. Technology

Often the term distributed generation is used in combination with a certain generation technology category, e.g. renewable energy technology. According to our definition, however, the technology that can be used is not limited.

Definition E1. *The technology used for DG is not relevant for the here proposed definition.*

Current praxis also shows that available technology for distributed generation varies widely (seen in Table 1). A detailed technical description and analysis of the current status for each of the technologies presented in Table 1 is beyond the scope of this paper. The paper will limit itself to discussing typical features of some of these technologies, which can be used to further categorise them.

First, many of the technologies utilise renewable energy resources. According to the *International Energy Agency* (IEA), renewable energy resources are defined as resources that are generally not subject to depletion, such as the heat and light from the sun, the force of wind, organic matter (biomass), falling water, ocean energy and geothermal heat [13]. As about 1000 times more energy reaches the earth as fossil fuel is currently consumed, renewable energy resources can be described as abundant. However, availability of the different resources varies significantly between areas and countries,

Table 1
Technologies for distributed generation^a

Technology	Typical available size per modul
Combined cycle gas T.	35–400 MW
Internal combustion engines	5 kW–10 MW
Combustion turbine	1–250 MW
Micro-Turbines	35 kW–1 MW
<i>Renewable</i>	
Small hydro	1–100 MW
Micro hydro	25 kW–1 MW
Wind turbine	200 Watt–3 MW
Photovoltaic arrays	20 Watt–100 kW
Solar thermal, central receiver	1–10 MW
Solar thermal, Lutz system	10–80 MW
Biomass, e.g. based on gasification	100 kW–20 MW
Fuel cells, phosacid	200 kW–2 MW
Fuel cells, molten carbonate	250 kW–2 MW
Fuel cells, proton exchange	1 kW–250 kW
Fuel cells, solid oxide	250 kW–5 MW
Geothermal	5–100 MW
Ocean energy	100 kW–1 MW
Stirling engine	2–10 kW
Battery storage	500 kW–5 MW

^a Source: Linden et al. [19], IEA [20], p. 64, Duffie et al. [21], pp. 638 and author.

as well as technology efficiency to harvest the renewable energy resources.

Secondly, technologies such as micro-hydro units, PV arrays, wind turbines, diesel engines, solar thermal systems, fuel cells and battery storage consist of a number of small modules, which are assembled in factories. These modules can be installed in a very short time at the final power station location. Manufacturing and construction on site requires significantly less time than for large centralised power stations.

Furthermore, each modular unit can start to operate as soon as it is installed on site, independent of the status of the other modules. In case a module fails, the other modules are not affected by it. As each module is small compared to the unit size of large centralised power stations, the effect of module failures on the total available power output is considerably smaller. And finally, these technologies allow for adding on modules later or move modules to another site, if required [14–16].

Another important aspect is the combined production of heat and power (CHP). Combined cycle gas turbines, internal combustion engines, combustion turbines, biomass gasification, geothermal, sterling engines as well as fuel cells are suitable for a combined production of heat and power. The combined local production of heat and power has the advantage of a high efficiency, if the heat is used locally. In most cases, heat and power output have an almost (positive) fixed correlation, as the heat production utilises the heat losses of the power production. The heat demand usually defines the operation process, unless there is a back-up system for the heat production. The technology of combined heat and power production is already widely used with combined cycle gas turbines, internal combustion engines, combustion turbines and biomass gasification. A commercial version of a 1 kW fuel cell for the combined production of heat and power for houses is expected to be available by 2001 [18].

For the discussion of the technical and economic issues related to distributed generation technologies, technology categories seems useful. We suggest the following categories, others are also possible, though:

Renewable	distributed generation;
Modular	distributed generation;
CHP	distributed generation.

2.6. Environmental impact

Often DG technologies are described as more environmentally friendly than centralised generation. According to our definition, however, the environmental impact of the DG technology is not relevant.

Table 2
Comparison of energy amortisation time and emissions of various energy technologies

Technology	Energy pay back time in months ^a	SO ₂ in kg/GWh ^a	NO _x in kg/GWh ^a	CO ₂ in t/GWh ^a	CO ₂ and CO ₂ equivalent for methane in t/GWh ^b
Coal fired (pit)	1.0–1.1	630–1370	630–1560	830–920	1240
Nuclear	N.A.	N.A.	N.A.	N.A.	28–54
Gas (CCGT)	0.4	45–140	650–810	370–420	450
Large hydro	5–6	18–21	34–40	7–8	5
<i>Renewable distributed generation technologies</i>					
Micohydro	9–11	38–46	71–86	16–20	N.A.
Smallhydro	8–9	24–29	46–56	10–12	2
Windturbine					
4.5 m/s	6–20	18–32	26–43	19–34	N.A.
5.5 m/s	4–13	13–20	18–27	13–22	N.A.
6.5 m/s	2–8	10–16	14–22	10–17	11
Photovoltaic					
Mono-cystalline	72–93	230–295	270–340	200–260	N.A.
Multi-cystalline	58–74	260–330	250–310	190–250	228
Amorphous	51–66	135–175	160–200	170–220	N.A.
Geothermal	N.A.	N.A.	N.A.	N.A.	50–70
Tidal	N.A.	N.A.	N.A.	N.A.	2

^a Source: Kaltschmitt et al. [22].

^b Source: Lewin [23], Fritsch et al. [24], also Ackermann [25]; All figures include direct and indirect emissions based on average German energy mix, technology efficiency, solar radiation and typical lifetime.

Definition F1. *The environmental impact of DG is not relevant for the here proposed definition.*

The motivation for this approach is that the analysis of the environment impact is too complex, to be included in the here proposed definition.

Table 2, for example, provides an overview of the most important emissions related to electricity production based on different technologies. The data comprises direct emissions and indirect emissions. Indirect emissions are emissions that occur during the manufacturing of the power unit and the exploration and transport of the energy resources. The calculation is based on the average German energy mix and on typical German technology efficiency, [24,25].

Table 2 shows that the emissions from typical DG technologies are significantly lower than that from coal power stations. *Combined cycle gas turbines (CCGT)* and large hydro units, too, have significantly lower SO₂ and CO₂ emissions than coal power stations.

Biomass is not included in the figure, as it is considered CO₂ neutral, as the amount of CO₂ emitted into the atmosphere when biomass is burned is equal to the amount of CO₂ absorbed during its growth. NO_x emissions of combustion of bio-fuels is reported to be

20–40% lower than that of fossil fuel plants, and SO₂ emissions are reported to be insignificant [26].

Battery storage as well as fuel cells have no direct emissions. Beside the emissions occurring during the manufacturing process, however, the fuel mix used for the production of the electricity stored in the batteries must be considered in the calculations of the indirect emissions of battery storage. In the case of fuel cells, the indirect emissions also depend on the energy mix that is required to produce hydrogen, as hydrogen cannot be exploited.

Additional environmental benefits, resulting from e.g. the reduction of transmission line losses, achieved by proper siting in terms of location and unit size, could further improve the environmental balance of DG. Apart from that, some argued that a large amount of DG might force the large units to operate below their optimum efficiency, which will lead to an increase in emissions per produced kWh [27]. Other aspects, which make an environmental comparison very difficult are different perceptions regarding the risk of nuclear power stations or regarding the visual impact, noise impact and land requirements of wind turbines, for example.

Therefore, the technologies that can be used for distributed generation cannot be described in general as environmentally friendly. But regarding the main current environmental issue, the increased greenhouse effect, all DG technologies lead to significantly lower emissions than coal-based technologies.

2.7. Mode of operation

The issue of the mode of operation is based on the wide-spread view that DG is 'relatively unencumbered by the rules of operation of central systems (scheduling, pool pricing, dispatch, etc.)' [3].

According to our definition, however, the mode of operation is not relevant.

Definition G1. *The mode of operation of distributed power generation is not relevant for the here proposed definition.*

The motivation for this approach is based on large variations in the international regulations regarding the operation of electricity network.

Taking the English and Welsh regulations as an example, a power unit connected to the distribution system with a capacity of more than 100 MW would be treated by the market regulations as a centralised power unit, but a unit with less than 100 MW would be less encumbered in the rules of operation [7].

Therefore, it cannot be assumed in general that distributed generation is relatively unencumbered by the rules of operation.

In situations, however, where distributed generation receives a special treatment by the regulations, this can be specially mentioned, for example: *not centrally dispatched distributed generation*.

2.8. Ownership

It is frequently argued that DG has to be owned by independent power producers or by the customers themselves, to qualify as DG. According to our definition, however, the ownership is not relevant.

Definition H1. *The ownership of DG is not relevant for the here proposed definition.*

The motivation for this approach is based on different international experiences regarding the ownership of distributed generation. In Sweden, for example independent generators as well as traditional generators are involved in DG.

However, the current experience in many countries shows that large power generation companies are often too inflexible to develop small DG systems. Furthermore, there is strong evidence that projects developed

by local companies and partly financed with regional involvement have more public support than projects of other organisations [2]. Large power generation companies, however, become more and more interested in the topic and there is no obvious reason why distributed generation should be limited to independent ownership.

Nevertheless, it is important to emphasise that ownership issues of DG can be of importance for the development of distributed generation. Therefore, the ownership of DG could be mentioned, for example, *independently-owned distributed generation*.

2.9. Penetration of distributed generation

Regarding the total amount of DG within a distribution network, some authors assume that DG stands for completely decentralised power generation, that does not require any transmission lines or large centralised power plants [17]. Other authors assume that distributed generation will be able to provide only a fraction of the local energy demand.

According to our definition, however, the penetration level of DG is not relevant.

Definition I1. *The penetration level of DG is not relevant for the here proposed definition.*

The motivation for this approach is based on the fact that the definition of the penetration level itself is problematic. This amount of DG must be put into relation to an area, e.g. local distribution system or nation-wide power network. The definition of this area, however, could significantly influence the penetration level.

It is, however, important to emphasise that if the predictions of the *Electric Power Research Institute (EPRI)* and the *Natural Gas Foundation*, which predict that by the year 2010, 25–30% of new generation will be distributed, will become reality, it will be likely that DG satisfies the majority of the energy needs within certain distribution networks. Therefore, the analysis of DG should always take into consideration that the penetration of DG could reach a significant level.

3. Proposed definition for distributed generation

Different definitions regarding *Distributed Generation (DG)* are used in the literature and in practice. These variations in the definition can cause confusion. Therefore, this paper suggests an approach towards a general definition of distributed generation.

The general definition for distributed generation suggested here is:

Definition 1. *Distributed generation is an electric power source connected directly to the distribution network or on the customer site of the meter.*

The distinction between distribution and transmission networks is based on the legal definition. In most competitive markets, the legal definition for transmission networks is usually part of the electricity market regulation. Anything that is not defined as transmission network in the legislation, can be regarded as distribution network.

The definition of distributed generation does not define the rating of the generation source, as the maximum rating depends on the local distribution network conditions, e.g. voltage level. It is, however, useful to introduce categories of different ratings of distributed generation. The following categories are suggested:

Micro	distributed generation: $\sim 1 \text{ Watt} < 5 \text{ kW}$;
Small	distributed generation: $5 \text{ kW} < 5 \text{ MW}$;
Medium	distributed generation: $5 \text{ MW} < 50 \text{ MW}$;
Large	distributed generation: $50 \text{ MW} < 300 \text{ MW}$

Furthermore, the definition of distributed generation does neither define the area of the power delivery, the penetration, the ownership nor the treatment within the network operation. It cannot be assumed, as it is often done, that distributed generation stands for local power delivery, low system penetration, independent ownership and special treatment within the network operation in general.

If these aspects are of interest, they should be mentioned additionally.

For example, if the power output of distributed generation is used only within the local distribution network, we suggest the term *embedded distributed generation*. And if the distributed generation source is not centrally dispatched, it should be called: *not centrally dispatched distributed generation*.

Also, the definition of distributed generation does not define the technologies, as the technologies that can be used vary widely. However, a categorisation of different technology groups of distributed generation seems possible. We suggest the following categories, but others are also possible:

Renewable	distributed generation;
Modular	distributed generation;
CHP	distributed generation.

4. What are distributed resources?

According to Moskowitz, distributed resources are

“demand- and supply-side resources that can be deployed throughout an electric distribution system (as distinguished from the transmission system) to meet the energy and reliability needs of the customers served by that system. Distributed resources can be installed on either the customer side or the utility side of the meter”. [28].

Distributed resources consist of two aspects:

1. distributed generation, located within the distribution system or on the customer side of the meter, and
2. demand-side resources, such as load management systems, to move electricity use from peak to off peak periods, and energy efficiency options, e.g. to reduce peak electricity demand, to increase the efficiency of buildings or drives for industrial applications or to reduce the overall electricity demand. An important aspect of the concept of distributed resources is that the demand-side resources are not only based on local generation within the electrical system on the customer’s side of the meter, but also on means that reduce customer demand. That will influence the electricity supply from the distribution network.

5. What is distributed capacity?

The term distributed capacity is less known than the terms distributed generation or distributed resources, probably because it is even more difficult to clearly define that term.

Distributed capacity includes all aspects of distributed resources, plus the requirements for transmission/distribution capacity. For a better distinction between distributed capacity and distributed generation, the following example can be used: one aim of installing distributed generation is to reduce the peak demand. However, distributed generation does not include any reserve capacity, hence the transmission/distribution network usually has to be able to cover at least some of the generation usually supplied by distributed generation. Hence, transmission/distribution lines will be overdimensioned and the load factor will be worse than without distributed generation. As transmission/distribution systems are regarded as monopolies, the transmission/distribution operator will usually be able to recover the costs for the overdimensioned system and the poor load factor via higher transmission tariffs.

Distributed capacity now includes all aspects of distributed generation and distributed resources plus reserve capacity, e.g. stand-by generators or load management, to minimize the requirements for overdimensioning of transmission/distribution system.

6. What is a distributed utility

The term distributed utility stands for a future network and utility architecture, based on distributed generation, distributed resources and distributed capacity. The concept for distributed utilities was developed in the US, see [29], where the term is commonly used. A thorough discussion of the concept is not within the scope of this paper. We refer to [41] and [30] for a working definition of distributed utilities.

7. Distribution network issues

The above definitions of distributed generation, resources, capacity and utility do not include a discussion of network or connection issues. These issues, however, are very important from the technical aspects, as there are significant differences in the design of distribution and transmission networks.

Firstly, distribution networks are often designed for a different purpose than transmission networks. The main difference is that distribution systems are usually not designed for the connection of power generation devices, e.g. the connection of distributed generation leads to a change in the fault-current, hence a redesign of local fault protection system might be required.

Furthermore, distribution networks have usually a radial or loop design, and not a meshed design like transmission networks. Therefore, the power flow in distribution networks usually is one-directional and no or little redundancy exists [6].

Secondly, high voltage lines, e.g. transmission lines or urban distribution lines, have a low resistance compared to low voltage lines in distribution networks. In transmission lines or urban distribution networks, the effect of line or cable resistance (R) on voltage drop is small, since its specific magnitude is generally much less than the reactance (X), i.e. $X/R > 5$. Hence, the reactance is the most important parameter in regards to voltage drop and line losses. In rural distribution systems, however, the resistance in the distribution lines is often larger than, or at least similar to, the inductance. Hence, the distribution line resistance causes a significant proportion of the voltage drop along the distribution lines as well as of the line losses [31]. The connection of distributed generation can therefore have a significant influence on the local voltage level.

Thirdly, the low voltage ends of distribution systems are usually not connected to *Supervisory Control and Data Acquisition* (SCADA) systems. The data gathering required for the control of the distribution system as well as the DG units is therefore difficult. The complexity of data gathering for system control in competitive markets increases due to the fact that independent power generators operate their DG units according to

the market price signals, which do not necessarily correspond to the system's control requirements in local distribution areas.

8. Connection issues

The electricity generation technology and grid connection of DG technologies can be significantly different from traditional centralised power generation technologies. Large power units use synchronous generators. These are capable of controlling the reactive power output, for example. Large DG units, utilising natural gas for instance, use synchronous generators, too.

Medium-sized and especially small DG technologies often use asynchronous generators (also known as induction generators), as they are significantly cheaper than synchronous generators. Asynchronous generators, however, have different operational characteristics than synchronous generators. For example, a directly grid-connected asynchronous generator is not capable of providing reactive power. It actually requires reactive power from the grid during the start-up process and at operation. Different technical options exist to overcome the disadvantages of grid-connected asynchronous generators. Manufactures of DG technologies have used a large range of options, such as capacitors and power electronic converters [32].

And finally, micro systems such as photovoltaic modules, batteries, fuel cells and micro hydro turbines have to be connected via an interface (converter) to the grid, as these micro-systems produce direct current. Modern power electronic interfaces offer different solutions to convert D.C. current to an A.C. voltage and active/reactive current with the required frequency. Power electronic converters introduce also 'new control issues and new possibilities' to grid integration [1]. Power converters could be used for voltage control in the distribution network, for instance [31]. In some cases, a control problem might emerge if dispersed converters somehow interact via the distribution network. This may lead to power fluctuations or oscillations in the distribution networks. However, such cases seem to be very rare [32].

This large variety of options for grid connection of distributed generation makes the analysis of grid integration issues very complex. Furthermore, local network conditions have an important influence on the relevant integration issues. Hence, each network will require a detailed analysis.

For an overview of the technical issues involved in the analysis of the connection of power generation to distribution networks, see IEE [40] as well as Hadjsaid [39]. For results of a case study, see Stieb [38].

The development of industry standards for the interface design of distributed generation, covering external as well as internal control issues of the interface, will be an important step towards reducing this complexity [33]. Currently, most distribution network operators rely on commonly used interconnection standards regarding the connection of DG resources to achieve a secure network operation. Many of those standards are based on recommendations by ANSI and IEEE. However, most of these standards do not distinguish between medium-sized CCGT power stations and micro PV systems [34]. Owners of the DG unit (s) and the distribution network operator often disagree regarding the appropriate interconnection standards.

9. Conclusion and future work

This paper discusses the relevant issues and aims at providing a general definition for distributed power generation in competitive electricity markets. In general, DG can be defined as electric power generation within distribution networks or on the customer side of the network.

In addition, the terms distributed resources, distributed capacity and distributed utility are discussed. Network and connection issues of distributed generation are presented, too.

Based on the above suggested definition for distributed generation, the next step will be to discuss this definition with all interested parties and to come up with a commonly accepted definition.

Furthermore, the network integration of distributed generation is a very complex issue, which can be significantly different from traditional network integration of power generation into transmission networks. Therefore, further research is required regarding the analysis of the impact of distributed generation on the reliable and economic operation of distribution systems.

Thereby it is important to consider the benefits of distributed generation, e.g. reduction of network losses, as well as additional costs, e.g. the redesign of the protection system.

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