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DISTRIBUTED GENERATION- A NEW APPROACH

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Abstract— **Indian power sector and power distribution utilities are going through a reformation process to cope up with the regulatory change for reduction in AT & C Loss, improvement in Power Quality, Reliability of Power Supply, Improvement in Customer Satisfaction and rationalization of electricity tariff. Apart from restructuring and unbundling of the power sector there is a need for introduction of Distribution Generation to bridge the gap between Demand and supply. Distributed Generation (DG) has become an important part of electrical generation in many countries and its importance is continuing to increase. Distributed Generation becomes an important part in total generation in India. Nowadays due to increasing demand and increased gap between supply and demand, Distributed Generation plays an important role in bridging that gap. Various DG technologies are depicted in this paper. As the power flows also affected due to the presence of DG at distribution end, so methods of load flow analysis are required to be reviewed. Different methods of Load Flow in presence of DGs are reviewed. Also different proposed models of DGs are discussed. Distributed Generation also gets discussed with conjunction of conventional resources.**

Index Terms— Distributed Generation, Load Flow studies, DG Technologies.

I. Introduction

The electric power systems at present are mostly based on central generation. In these system, large generators feed power through transformers to high voltage transmission network to transport it over considerable distances. This power is then extracted through distribution transformers for delivery to the end users. However around the world, the shortage of transmission system capacities along with the need for reliable power supply is causing an increased interest in Distributed Generation. Generation (DG) can be defined as the integrated use of small generation units directly connected to a distribution system or inside the facilities of a customer [3]. The potential development of DG is sustained in the following areas increasing power quality requirements, avoiding or shifting investment in transmission lines and/or transformers, ohmic losses minimization, environmental protection, and existence of high energy prices at retail level [3][7].Traditionally, a distribution company purchases energy from wholesale market, at a high voltage level, and then transfers this energy to final customers. Nevertheless, the restructuring process of the energy sector has stimulated the introduction of new agents and products, and the unbundling of traditional distribution company to technical and commercial tasks, including ancillary services. These units are of limited size and can be connected directly to the distribution network or on the customer site. Generally, the term Dispersed or Distributed Generation refers to any electric power production technology that is integrated within distribution systems, close to the point of use. Distributed generators are connected to the medium or low voltage grid. In case of Distributed Generators, they are not centrally planned and they are only used less than 30 MW. Distributed Generation (DG) includes the application of small generators, scattered throughout a power system, to provide the electric power needed by electrical customers. Distributed power is a concept that covers a wide spectrum of schemes used for local electric power generation from renewable and non-renewable sources of energy in an environmentally responsible way. Main schemes are mainly based on solar energy, wind energy, fuel cells, and micro turbine engines.

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II. Present Power Production Situation

Since the beginning of the twentieth century, the backbone of the electric power industry structure has been large utilities operating within well-defined geographical territories and with in local market monopolies under the scrutiny of various regulatory bodies. Traditionally, these utilities own the generation, transmission and distribution facilities within their assigned service territories; they finance the construction of these facilities and then incorporate the related capital costs in their rate structure which is subsequently approved by the relevant regulatory bodies. Given their friendly environmental impact, hydro power plants are most often the preferred generation technology wherever and whenever feasible. However, the identification of feasible new sites in highly industrialized countries is becoming increasingly difficult. In developed countries, where cost-attractive traditional hydro facility sites have been almost entirely built, some power plants could be, and are, reconfigured to become pumped-storage facilities. Even though several pollution-abatement technologies are being successfully implemented, often at significant capital and operational costs, fossil fuel power plants bring operating pollution problems that are becoming increasingly difficult to ignore. The emergence of a broad array of "green power" marketing initiatives provides yet another indication of the growing concern regarding air pollution. Except for a few economically emerging regions of the world, it is safe to observe that nuclear power production, using existing technologies, will decrease during the coming decades as old plants are retired and are not being replaced. As the technologies evolved, ever larger power production units were constructed allowing their operators to take full advantage of construction-cost economies of scale to provide a more cost-attractive generation mix to their customers. As the industry enters the competitive arena, fewer and fewer corporations are capable of taking on the financing of the construction of large electric power plants at costs far exceeding a billion dollars. Under the present economic and investment climate, with its almost exclusive focus on short-term results, the justification of a multibillion dollar investment with a pay-back period measured in decades has become virtually impossible. In several industrialized countries, aggressive public policies backed by strict regulatory mandates are such that electric power production within the confines of vertically integrated utilities has most probably been relegated to the past, while a true highly diversified electric power production industry is the future.

After a century with power stations getting bigger and transmission grids needed to transmit wider, the idea of local generation for local consumption is back. There are several reasons behind the motivation and the interest developed for Distributed Generation. One is market liberalization. Small, local power plants offer a cheap way into market and cause only low investments. They do not suffer huge transmission losses. The surplus heat they generate can be employed for useful purposes. Therefore local power becomes economically competitive. Another reason is the demand for reliable, uninterrupted power. The situation in India is the best motivation for distributed power generation. The distributed generation (DG) framework is moving away from traditional large-scale power generation plants (100 MW's to GW's) located near the natural resource converted to electricity, to small power generators (kW to MW's) sited directly at the loads. Enabling this concept is more of a regulatory than a technological issue. The gradual shift from centralized to distributed generation means changes not only in the kinds of power plants used, but in the way electricity is transported from the point of production to the point of consumption. DG allows us to place power generation facilities much closer to end-users, reducing transmission losses. If DG-units are rare, the system operator can accompany them and make maximum use of them depending upon the demand and cost effectiveness. If their number is growing they need to be coordinated with the system's control centre. The aggregation of several DG-units to a micro grid opens up a large field of customer oriented and optimized operation. In India apart from conventional resources other resources like non conventional resources also paid contribution for bridging a wider existing gap.

It may be observed that renewable grid capacity has increased more than 5 times, from 2% to around 11% in only 8 years, and is contributing about 4.13% to the electricity generation mix. The high level of penetration of renewable power in India compares favorably with that of the EU and far exceeds that of the US.

Table I. Source-wise Contribution to Installed Power Generation Capacity (in MW)

Year	Thermal %	Hydro (<25 MW) %	Nuclear %	Renewable Sources %
2002	59 %	26%	2%	2%
2007	65%	26%	3%	6%
2010	64%	22.4%	2.7%	10.90%

III. DISTRIBUTED GENERATION TECHNOLOGIES

The exact definition of distributed generation (DG) varies somewhat between sources and capacities; however, it is generally and summarily defined as any source of electric power of limited capacity, directly connected to the power system distribution network where it is consumed by the end users. Distributed generation should not to be confused with renewable generation. Distributed generation technologies may be renewable or not; in fact, some distributed generation technologies could, if fully deployed, significantly contribute to present air pollution problems [2]. The increased market penetration of distributed generation has also been the advent of an electric power production industry.These resources have lower energy density than fossil fuels and so the generation plants are smaller and geographically widely spread. The distributed generation may be based on fuel cells, photovoltaic system, wind turbines, mini/micro hydro turbines, gas turbines and micro turbines [1].

Table II. Distributed generation capabilities and system interfaces

Technology	**Capability Ranges**	**Utility Interface**
Fuel cells	A few tens of kW to a few tens of MW	dc to ac converter
Micro turbines	A few tens of kW to a few MW	ac to ac converter
Combustion turbine	A few MW to hundreds of MW	Synchronous generator
Combined cycle	A few tens of MW to several hundred MW	Synchronous generator
Internal Combustion Engine	A few hundred kW to tens of MW	Synchronous. generator or ac to ac converter
Ocean	A few hundred kW to a few MW	Four-quadrant. synchronous machine
Geothermal	A few hundred kW to a few MW	Synchronous generator
Wind	A few hundred W to a few MW	Asynchronous generator
Solar, photovoltaic	Solar, photovoltaic	dc to ac converter

A. Fuel Cells (FCs)

Fuel Cells (FC) are electrochemical devices converting the chemical energy content of a fuel directly to electrical energy. Fuel cells are generally characterized by the material of electrolyte used. Their output is a dc voltage that can be converted to an ac voltage by using power conditioning equipment and used locally or fed to the network. This is also one kind of Distributed Generation which uses the effect of power conditioning equipment and ensures the power quality and reliability of supply. This application is of special interest as the production is as close as possible to the demand. A couple of activities from several big companies are ongoing for immobile as well as mobile use. Different technologies in the power ranges up to 5 kW [3], up to 250 kW [5] or as backup power [3] are available as pilot installations.

B. Photovoltaic Systems (PVs)

Photovoltaic (PV) cells are devices that convert sunlight to electricity, bypassing thermodynamic cycles and mechanical generators, sunlight photons free electrons from common silicon generating emf at the PV terminals. These systems are commonly known as solar panels. PV solar panels consist of discrete multiple cells, connected together either in series or parallel, that convert light radiation into electricity. Photo voltaic systems provide supply for intermittent type of load. The power of a single module varies between 50 and 100W and its efficiency is near about 15%. Usually PVs are built in arrays with series and parallel connections, and coupled to the network thorough an inverter. PV systems show high investment and very low maintenance costs [2], [4], [5].

C. Wind Energy

Wind energy is another DG source, which can be converted to electrical energy. The speed of the wind can be quite variable. Besides, some areas are not windy enough to extract considerable amount of energy from the wind. The renewable energy sources such as wind, solar, etc., play a major role as electrical and mechanical energy supplies, not by replacing the conventional energy sources but supplementing them. Wind energy uses various types of wind turbines and for convert ting mechanical energy to electrical energy using induction generators like SEIG and DFIG. Normally there are two recent trends concerning wind power. The first one is the introduction of permanent magnetized direct driven machines and the second one is wind farm with DC interconnections. In case of permanent magnet direct driven machines the construction gets simplified while reducing rotor losses. This reduces the vulnerability, operation and maintenance costs. The nowadays power electronic converters are allowing to fulfil all guidelines for the grid connection in a very flexible way. An additional trend is a higher output voltage up to 4 kV, which reduces the energy transmission losses and allows simplified setups of wind farms. The second trend concerns wind farm configurations with low cost profile and high efficiency. There are several solutions existing in AC and/or DC technology. Due to the existing power electronic converters within the today's windmills, there are several opportunities of combining AC and DC parts within a farm setup. In general this is an ongoing research topic on power system, control as well as material side.

D. Small Hydro-Turbines

The terms small hydro defines installations for the production of hydroelectricity at low power levels. Usually, the power from such installations can be in the range of 5–100 kW for ‘‘micro hydroelectric’’ power stations, and between 500 kW and 10MW for mini hydro-power stations. Small hydro turbines employ mini hydro generation with small capacity and used for peak power plants.

E. Micro turbine Based Energy

There are some distributed power schemes based on the micro turbines as the prime mover for the generator. In these schemes the generator connected to the micro turbine is a synchronous machine whose output voltage has a frequency directly proportional to the angular speed of the micro turbines shaft. Micro turbines are one of the most promising DG products currently on the market. The key technical features are high efficiency (as high as 85%), low emission (< 15ppm No_X and CO). It also provide fuel flexibility means oil, diesel, natural gas, biogas, methanol, hydrogen, etc any kind of fuel can be used. It has low maintenance cost (high speed single shaft engine and static power electronics converter). While using micro turbine technology the remote control of power production is available. Typical applications for micro turbines are industrial, commercial and public buildings, large residential buildings, fun parks etc. They always require a power electronics interface to connect them to the distribution grid. Most attractive applications for micro turbines make use of the thermal energy as well for heating or cooling.

F. Reciprocating Engines

This DG technology was developed more than a century ago, and is still widely utilized in a broad array of applications. The engines range in size from less than 5 to over 5,000 kW, and use diesel, natural gas, or waste gas as their fuel source. Development efforts remain focused on improving efficiency and on reducing emission levels. Reciprocating engines are being used primarily for backup power, peaking power, and in cogeneration applications.

G. Industrial Combustion Turbines

A mature technology, combustion turbines range from 1 MW to over 5 MW. They have low capital cost, low emission levels, but also usually low electric efficiency ratings. Development efforts are focused on increasing efficiency levels for this widely available technology. Industrial combustion turbines are being used primarily for peaking power and in cogeneration applications.

According to some authors, in the future a substantial share of electricity will be produced by technologies associated with DG [2]. These technologies encompass a wide range of subcategories characterized by fuel type, generation capacity, environmental impact, and operation flexibility. Irrespective of the specific DG technology, when interconnected to a power grid either they use a synchronous generator or a power electronic inverter [4]. Consequently, from a steady state point of view, these different technologies can be represented by standard load flow equations with minimum and maximum power limits (active and reactive), complex power limit, and voltage limits at the connection bus bar.

IV. Network Considerations

Distributed generation technologies are overwhelmingly connected to existing electric power delivery systems at the distribution level. One of their significant benefits is that they are modular enough to be conveniently integrated within electric distribution systems, thereby relieving some of the necessitate investment in transmission system expansion. However, significant penetration within existing electric distribution systems is not without a new set of problems. The following are among the key issues that need to be addressed.

A. Power Quality

Several of the distributed generation technologies rely on some form of power electronic device in conjunction with the distribution network interface, be it ac to ac or dc to ac converters. All of these devices inject currents that are not perfectly sinusoidal. The resulting harmonic distortion, if not properly contained and filtered, can bring serious operational difficulties to the loads connected on the same distribution system [3]. Existing standards have been enacted to limit the harmonic content acceptable in conjunction with various power electronic loads; similar standards are required for distributed generation systems and are under various stages of preparedness.

B. Reactive Power Coordination

Distributed generation, implemented at the distribution level, i.e., close to the load, can bring significant relief to the reactive coordination by providing close proximity reactive power support at the distribution level, provided the proper network interface technology is used and that proper system configuration has taken place. However, wind generation actually contributes to worsen the reactive coordination problem.

C. Reliability and Reserve Margin

Traditionally, the vertically integrated utility was also responsible for the availability of sufficient reserve margins to ensure adequate system reliability. But in case of distributed generation technologies their production levels depend on nature (wind and solar) or are such that their availability is subject to the operational priorities of their owners. The requirement to use sophisticated power electronic network interfaces may affect the plant's availability. As a result, the issue of reliability comes to the forefront along with the necessity to maintain sufficient generation reserve margins. The ownership of distributed generation increases the reserve margin maintenance which leads to loss of reliability and effect the capability reserve of individual.

D. Reliability and Network Redundancy

Most electric distribution systems feature a radial network configuration as opposed to the meshed structure adopted at transmission levels. As a result, network redundancy becomes an issue when significant distributed generation is connected directly to distribution system, since single line outages could completely curtail the availability of generation facilities. This also leads to loss of reliability and complete collapse of the integrated system.

E. Safe and Secure System

Distribution system protection schemes typically are designed to rapidly isolate faults occurring either at load locations or on the line itself. The assumption is that, if the distribution line is disconnected somewhere between the fault and the feeding substation, then repair work can safely proceed. Clearly, if distributed generation is connected on the same distribution feeder, then significantly more sophisticated protective relaying schemes must be designed and implemented to properly protect not only the personnel working on the lines but also the loads connected to them. Some specifying relays and secured protection is required to ensure the system secure and safe and also reliable.

When DGs were installed in distribution feeders and participated in system operations, the problems including power flow, power quality, Ferro resonance, voltage control, loss reduction, protection device coordination, voltage flicker and so on, needed to be carefully re-analyzed. Since voltage profiles are directly related to power quality and customer satisfaction, an efficient and robust three phase load flow method taking the mathematical models of DGs into account should be developed first.

V. MATHEMATICAL MODELS OF DGS FOR LOAD FLOW ANALYSIS

As the connection of DG units strongly affects the operation of distribution systems and for load flow analysis of distribution system with DGs it is required to model the DGs. The energy sources of DGs can be categorized into stable energy sources, such as fuel cell and micro-gas turbine, and unstable energy sources, such as wind and solar. Different energy sources combining with different energy converters will result in special output characteristics. For example, if the induction generator is used to convert wind energy to power grids, it will act like a constant real power and variable reactive power generator. However, if the static electronic converter is used to convert wind energy to power grids, it will mostly act like a generator with a constant power factor in normal operation condition. Therefore according to the output power characteristics, DGs can be specified as constant power factor model, constant voltage model or variable reactive power model in the load flow analysis.

Various researchers had developed the mathematical models of Distributed generators. Mathematical models of distributed generations was developed by Teng [10] utilizing the output power characteristics for load flow analysis. The models can be specified as constant power factor model, constant voltage model or variable reactive power model. Khushalani et al. [11] discussed various models of the Distributed Generation depending upon the control of output. The nodes with small DG are modeled as PQ nodes and large output DG are modeled as constant PV nodes. Various mathematical relations are derived by Losi and Russo [12] to model asynchronous DGs, synchronous DGs and DGs connected to distribution system by power converter. Chen et al. [13] modeled the DGs based on the control of excitation. They modeled synchronous DGs as PV nodes, PQ nodes as well as static voltage characteristic model. Divya and Rao [14] developed mathematical models of wind turbine generating systems and modeled wind DGs as PQ nodes for use in load flow studies. Fejoo and Cidras [15] modeled the wind farms in two forms namely PQ and RX models for load flow analysis of the system. The models are based on steady state behavior of induction generators. Various DG models were presented by Tafreshi and Mashhour [16] with respect to DG and its connection to grid. The DGs with generators directly connected to grid are modeled as PV nodes, PQ nodes or SVCM nodes while DGs connected through power electronic interfaces are modeled as either PV node or PQ node depending upon the control.

VI. LOAD FLOW ANALYSIS

The connection of DG units strongly affects the operation of distribution systems which are usually designed for unidirectional power flows and presence of DG units may lead to reverse or bidirectional power flows. Therefore methods used to obtain the load flow of conventional distribution system may not be suited.

Shrimohammadi and Chang [17] presented a three phase power flow solution of distribution system based on compensation method. The voltage mismatches of PV nodes are eliminated to handle dispersed generation also. An adaptive compensation based method was proposed by Zhu and Tomsovic [18] to obtain load flow of distribution systems with dispersed generations. The method is suitable for slow dynamics on the distribution system. Teng [10] integrated the mathematical models of DGs in three phase load flow algorithm which fully utilizes the special topological characteristics of distribution networks. An unbalanced three phase load flow algorithm based on ladder iterative method capable of handling multiple sources was presented by Khushalani et al. [3]. The distributed generation modeled as PV or PQ model can be incorporated. Tafreshi and Mashhour [8] presented the power flow of distribution systems including DGs operating in various nodes and observed the improvement in voltage profile and reduction in system losses.

VII. CONCLUSION

The paper has reviewed about Distributed Generation and its associated technologies. It is also reviewed about the impacts of DG on various critical issues which are responsible for normal operation and also for maintaining reliability and cost effective. It is concluded that the integration of DGs changes the power flows significantly so it is required to revise load flow analysis due to change of network from passive to active network. As the conventional methods of load flow are not applicable, various revised methods are reviewed which are based on forward and backward sweep. Also it is concluded that DGs are generally modeled as PQ and PV nodes in load flow calculations.

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