Technical and Economic Impacts of Distributed Generation on Distribution System

N. Rugthaicharoencheep, S. Auchariyamet

Abstract**—**Distributed Generation (DG) in the form of renewable power generation systems is currently preferred for clean power generation. It has a significant impact on the distribution systems. This impact may be either positively or negatively depending on the distribution system, distributed generator and load characteristics. In this works, an overview of DG is briefly introduced. The technology of DG is also listed while the technical impacts and economic impacts are explained.

Keywords**—**Distributed Generation, Technical Impacts, Economic Impacts.

I. Introduction

DISTRIBUTED generation (DG) has much potential to improve distribution system performance. Because distribution system designs and operating practices are normally based on radial power flows, therefore, this creates a special challenge for introduction of distributed generation [1].

DG has an important role in power distribution system planning because of its modularity, small size and low investment cost as well as environmental concerns. In addition, DG also causes considerable reduction in required investment cost for supplying increased load in future years [1]-[3]. Unlike large central power plants, DG can be installed at or near the load. DG ratings range from 5 kW up to 100 MW.

The introduction of DG to distribution system can significantly impact the flow of power and voltage conditions at customers and utility equipment. These impacts may be either positively or negatively depending on the distribution system operating characteristics and the DG characteristics [4], [5].

Positive impacts are generally called "system support benefits," and include [5]-[7]:

- Loss reduction
- Improved utility system reliability
- Voltage support and improved power quality
- Transmission and distribution capacity release
- Deferments of new or upgraded transmission and distribution infrastructure.
- Easy and quicker installation on account of prefabricated standardized components.
- Lowering of cost by avoiding long distance high voltage transmission.
- Environment friendly where renewable sources are used.
- Running cost more or less constant over the period of time with the use of renewable sources.
- Possibility of user-operator participation due to lesser complexity.
- More dependability with simple construction, and consequent easy operation and maintenance.

Many studies [8], [9] have been done for assessing different system characteristics after DG implementation in electrical distribution system. On the other hand the parallel operation of DGs with existing system causes different conflicts in power system operation criteria such as protection coordination.

Developments in the assessment of DG from a strategic viewpoint have been described in [10]-[12]. A method of integrated market, engineering and financial evaluation of the impact of DG on distribution companies is proposed to address the key issues outlined in the introduction.

II. Technology of DG

Distributed generation is defined as a generation with a limited size (roughly 10MW or less), which is interconnected at the substation, distribution feeder or customer load levels. DG technologies include wind turbines (WT), photovoltaics (PV), gas turbines (GT), micro turbines (MT) and internal combustion (IC) engine, and so on. It is predicted that distributed generation may account for up to 25% of all new generation by the year 2010 [12], [13].

A. Wind Turbines

Grid connected wind turbines (WT) as an effective DG source has developed noticeably in the recent past. WT can be operated at nearly constant or variable speed and coupled to induction generators to produce power. Induction generators are widely used in WT, and variable speed technology is preferred in almost all newer installations. A squirrel cage induction generator could be connected to the power system through a power electronic interface as shown in Figure 1 [14].

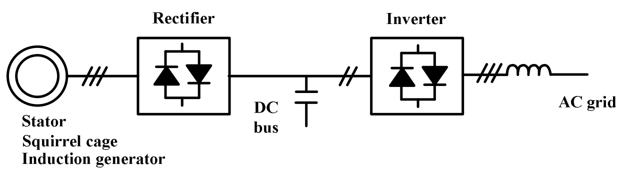

Fig 1 Variable speed induction generator

B. Photovoltaic Systems

The photovoltaic (PV) module or array is an unregulated dc power source, which has to be treated and conditioned before being connected to the power system. A dc/dc converter (chopper) is used at the PV array output for maximum power tracking (MPPT) as shown in Figure 2. It can extract maximum available power at a given insulation level, which

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means maintaining the voltage as close as possible to the maximum power point [14].

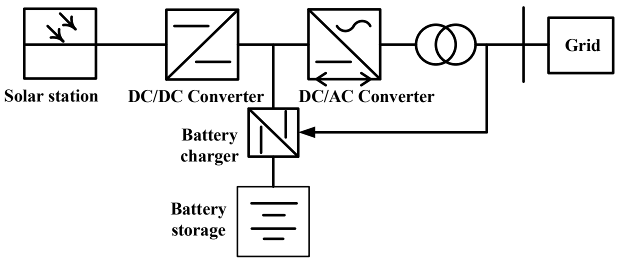

Fig. 2 Grid connection of PV system

Numerous benefits are expected for both the utility company and the consumer by integration of photovoltaic (PV) energy resource into the utility's conventional resources. This form of energy, beside being renewable, also possesses other advantages, such as its ability to improve service reliability by reducing the number of system outages and by avoiding line extensions to remote areas. Such systems can also relieve thermal overloads in selected utility distribution systems. Other important benefits also exist, such as loss reduction on both distribution and transmission lines and voltage support. There are many such applications that have proven to be cost effective [15].

C. Fuel Cell

A fuel cell is a device that generates electricity by a chemical reaction. Every fuel cell has two electrodes, one positive and one negative, called, respectively, the anode and cathode. The reactions that produce electricity take place at the electrodes. Every fuel cell also has an electrolyte, which carries electrically charged particles from one electrode to the other, and a catalyst, which speeds the reactions at the electrodes [16].

Hydrogen is the basic fuel, but fuel cells also require oxygen. One great appeal of fuel cells is that they generate electricity with very little pollution—much of the hydrogen and oxygen used in generating electricity ultimately combine to form a harmless byproduct, namely water.

A fuel cell is an electrochemical energy conversion device, where chemical energy in the fuel is directly and isothermally converted to electrical energy. The dc power produced by the fuel cell is converted into ac using a dc/ac inverter. The output DC power of fuel cell is converted via an inverter to grid compatible AC power as shown in Figure 3 [17].

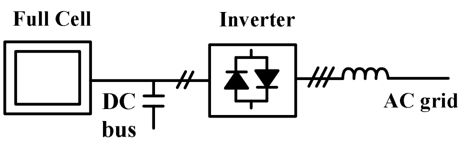

Fig. 3 Fuel cell electrical conversion system

D. Micro-Turbines

Gas fired micro-turbines in the range of 25kW to 1MW can be used to generate electricity. These micro turbines run at high speeds (50,000-90,000 rpm) with air foil bearings. The ac generator is a high frequency generator that cannot be directly connected to the power system, and hence a power electronic interface is used [14]. Generated voltage is first rectified by a diode rectifier. Dc/ac voltage source type inverter is employed to obtain utility-grade ac for injection into the grid as shown in Figure 4 [15].

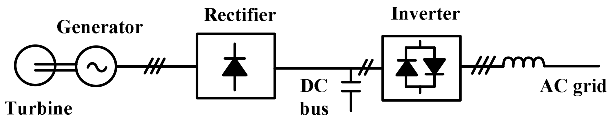

Fig. 4 Micro-turbine electrical system

III. Technical Impacts on Distribution System

With the improvement of DG technology and costs reduced, the ratio of the DG installed is increasing year by year, which bring a lot of technical issues to the power system [18]-[20]. The technical impacts are mainly in the following ways.

A. Distribution System Planning

The distribution network has a lot of nodes, the system increases a large number of DG nodes, so that it more difficult to find the best network layout program from all possible structure of the network. The inputs of DG gradually reduce the dependence of distribution network on the large scale power plants and transmission, and the feed power flow characteristics of the original unidirectional power also change.

The types of DG units and the diversification of energy used make it an urgent need to address how to make sure a reasonable power structure in distribution network and how to coordinate and effective use various types of power. In addition, national energy policy and energy planning have a direct impact on the decision-making of process power system planning.

As the penetration level of distributed generation is increasing in distribution network, it is no more passive in nature and its characteristics is becoming similar to an active transmission network. Therefore, it is relevant to consider the applicability of some pricing mechanism in distribution network that are finding applications in transmission networks [21].

B. Power Flow

Power flow is the most important and most basic tool to study operations, planning and safety analysis of power system. Power flow in the traditional radial distribution network is unidirectional from the source to the user. However, the introduction of DG to distribution system makes the structure of the network change and power flow not unidirectional from the substation bus to loads [22]-[24]. There may be reflux and complex voltage changes.

C. Reliability

Reliability is one of the important characteristics of power system that consists of security and adequacy assessment. Both of them are affected by implementation of distributed generation in electrical distribution system [25].

The traditional reliability indices covered only sustained interruptions. The time necessary to start-up the DG should be taken into account for the reliability evaluation of the distribution system including DG. If this time is sufficiently short, the customers suffer a momentary interruption, while, if not, they suffer a sustained interruption. Various resources recovering loads have an influence on the reliability indices, such as duration and frequency of sustained or momentary interruption, depending on the operation mode of DG.

Due to the complexity of all situations, the reliability has been evaluated by each researcher under different assumptions. In [26], the explicit equations, using the newly defined impact factor, are proposed for any cases with versatile system states, where the parameters are expressed as a function of time. Utilities employ a variety of standard indices to measure distribution system reliability and most utilities have to report these indices to regulatory bodies. In order to claim reliability as a benefit of DG**,** there should be a quantifiable improvement in these indices. Otherwise, the utility gets no credit for any supposed improvement [27].

D.Islanding

DG has the ability to reduce both temporary and permanent outages on distribution systems, but this generally requires what is called intentional islanding, although it is possible to switch a section with DG onto a separate feeder without creating an island. Islanding usually occurs when a section of the distribution system supported by DG is disconnected from the main substation during a transient.

Islands are not inherently harmful to distribution systems, although most utilities utilize some form of anti-islanding protection due to problems associated with islanding. One of the major problems with islanding is that it is often caused by faults that occur between the DG and the substation, which often results in relays opening at different times to remove fault current and results in a loss of phase and voltage synchronization. The loss of synchronization can result in large transients when a recloser operates to reconnect the island and can then result in false tripping [8], [28].

E. Power Quality

Many generators are designed to provide backup power to the load in case of power interruption. However, DG has the potential to increase the number of interruptions in some cases. In addition, there are harmonics concerns with both rotating machines and inverters, although concern with inverters is less with modern technologies [29].

With the extending of grid-connected DG, the power quality disturbances brought by them are increasing. These problems deserve our full attention. The main power quality disturbances are introduced simply in this part [30].

Short duration voltage variations will happen when there are faults or switching of large transformer or capacitor in the power system connected with DG.

F. Power Loss

DG can normally, but not necessarily, help reduce current flow in the feeders and hence contributes to power loss reduction, Electrical line loss occurs when current flows through distribution systems. The magnitude loss depends on amount current flow and the line resistance. Therefore, line loss can be decreased by reducing either line current or resistance or both. When DG is used to provide energy locally to the load, line loss can be reduced because of the decrease in current flow in some part of the network. However, DG may increase or reduce losses, depending on the location, capacity of DG and the relative size of load quantity, as well as the network topology and other factors [18].

The impact of DG units on energy losses [18], [19] , [21] will depend on the specific characteristics of the network, such as demand distribution and behavior, topology, as well as the relative location of the generators and whether their output is firm or variable. Incorporating these complexities into an optimization framework for energy loss minimization is a challenge that has only been (partially) addressed by a few studies.

G.Voltage Regulation

Power injections from DG can modify the usual direction of power flows in radial distribution networks and lead to voltage rise effect. The impact of voltage rise effect on the maximum DG capacity that can be connected to a distribution system is illustrated using a simple network as shown in Figure 5 [31], [32]. The network is composed of two feeders, one with DG and load and the other one with a single load lumped at the end. The network is supplied from substation on load tap changing transformers (OLTC). The voltage at bus 2 (V_2) can be approximately calculated as follows:

$$V_2 \approx V_1 + R(P_n - P_L) + (\pm Q_n - Q_L \pm Q_C)X \qquad (1)$$

where V_1, V_2 is voltage of bus 1and 2
$R,\ X$ is resistance and admittance
P_n, Q_n is active and reactive power of generation
P_L, Q_L is active and reactive power of load
Q_C is reactive power of capacitor

This simple equation in (1) can be used to analyze qualitatively the relationship between the voltage at bus 2 and the amount of generation that can be connected to the distribution network, as well as the impact of alternative control actions.

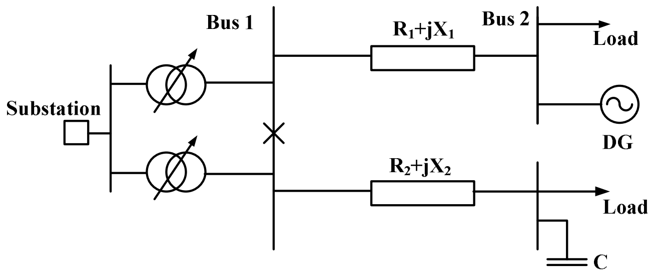

Fig. 5 Simple system for voltage rise

IV. Economic Impacts on Distribution System

The economic impacts of DG integration are mainly in the following ways.

A. Efficiency of support schemes

Several goals of promoting DG installations may include

• Reduction of greenhouse gas emissions

• Independence from imported fuels, i.e., higher security of supply

• Promotion of development of certain technologies

• Establishment of new industries with additional employment.

The instruments to reach such goals are chiefly measured by two criteria: effectiveness and efficiency. These imply that a certain combination of DG installed capacity or electricity production with a certain amount of expenses is aimed at. Efficiency can further be subdivided into static and dynamic efficiency: static efficiency focuses on a certain point in time, e.g., if a technological development is currently being supported with as little resources as possible to reach a desired level. Dynamic efficiency measures the technological development a support mechanism induces, i.e., if the costs of the energy decrease [33].

B. Financial Value Analysis

Distributed generation financial implications for distribution businesses are assessed using a linear value function incorporating each of the components of distributed generation impact on distribution businesses. The inputs to the value function are the costed effects of the impact of distributed generation on the distribution network.

The costed impacts of distributed generation are calculated using a set of unit costs and details of the regulatory policy. The set of unit costs are based on standard plant costs e.g. $/km cable and line costs and $/unit switchgear costs and the relevant aspects of regulatory policy e.g. efficiency driver in price control formula to value losses [34].

C. Regulating Power Markets

The purpose of the regulating power market is the same everywhere: the correction of deviations from the schedule, i.e., the provision of additional electricity if frequency decreases, and reduction of electricity generation if the frequency increases. It depends on national market design when actors have the last possibility to correct their schedules on other markets – day ahead or as close as 15 minutes ahead. In general, it is assumed that variable supply sources as most DG increase the demand for regulating power due to meteorological forecast errors.

Regulating power markets are nowadays characterized by a single buyer and large power plant operators, which have a considerable market shares in some countries. In Germany, the regulator concludes that these were “sharing the market peacefully” for a partial market. The participation of DG could therefore be positive to overcome assertions of non-competitive markets [33], [35].

V. Conclusion

To obtain more and more benefits from DG, It is necessary to know both positive and negative impacts of DG on distribution system. Many studies have been done to reveal DG impact on technical and economic issues as summarized in this paper.

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References

[1] T. Ackermann, G. Andersson, and L. Söder, “Distributed generation : A definition,” *Electric Power Systems Research*, vol. 57, no. 3, pp.195 -204, Apr. 2001.

[2] G. Pepermans, J. Driesen, D. Haeseldonckx, R. Belmans, and W. D’haeseleer, “Distributed generation : Definition, benefits and issues,” *Energy Policy*, vol. 33, no. 6, pp.787 -798, Apr. 2005.

[3] R. C. Dugan, T. E. McDermott, and G. J. Ball, “Planning for distributed generation,” *IEEE Industry Application Magazine*, vol. 7, no. 2, pp. 80-88, Mar./Apr. 2001.

[4] L. F. Ochoa, A. Padilha-Feltrin, and G. P. Harrison, “Evaluating distributed generation impacts with a multiobjective index,” *IEEE Trans. Power Delivery*, vol. 21, no. 3, pp. 1452-1458, July 2006.

[5] H. A. Gil and G. Joos, “Models for quantifying the economic benefits of distributed generation,” *IEEE Trans. Power Systems*, vol. 23, no. 2, pp. 327-335, May 2008.

[6] M. Yiming and, K.N. Miu, “Switch placement to improve system reliability for radial distribution systems with distributed generation,” *IEEE Trans. Power Systems*, vol. 18, no. 4, pp. 1346-1352, Nov. 2003.

[7] B. Delfino, “Modeling of the integration of distributed generation into the electrical system,” in *Proc. IEEE Conf. Power Engineering Society Summer Meeting*, USA, 2002, pp. 170-175.

[8] G. W. Jones, and B. H. Chowdhury, “Distribution system operation and planning in the presence of distributed generation technology,” in *Proc. IEEE Conf. and Exposition Transmission and Distribution*, 2008, USA, pp.1-8.

[9] N. S. Rau, and Y. H. Wan, “Optimum location of resources in distributed planning,” *IEEE Trans. Power Systems*, vol. 9, no. 4 pp. 2014-2020, Nov. 1994.

[10] S. Kotamarty, S. Khushalani, and N. Schulz, “Impact of distributed generation on distribution contingency analysis,” *Electric Power Systems Research*, vol. 78, no. 9, pp. 1537-1545, Apr. 2008.

[11] A. Soroudi, M. Ehsan, R. Caire, and N. Hadjsaid, “Possibilistic evaluation of distributed generations impacts on distribution Networks,” *IEEE Trans. Power Systems*, vol. 26, no. 4, pp. 2293-2301, Nov. 2011.

[12] J. Zhang, H. Cheng, and C. Wang, “Technical and economic impacts of active management on distribution network,” *Int. Journal of Electrical Power and Energy Systems*, vol. 31, no. 2-3, pp. 130-138, Feb./Mar. 2009.

[13] A. Zangeneh, S. Jadid, and A. Rahimi-Kian, “A fuzzy environmental-technical-economic model for distributed generation planning,” *Energy*, vol. 36, no. 5, pp. 3437-3445, May 2011.

[14] V. P. Mahadanaarachchi, R. Ramakuma, “Impact of distributed generation on distance protection performance - A review,” in *Proc. IEEE Conf. Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy*, USA, 2008, pp. 1-7.

[15] B. H. Chowdhury, and A. W. Sawab, "Evaluating the value of distributed photovoltaic generations in radial distribution systems," *IEEE Trans. Energy Conversion*, vol. 11, no. 3, pp. 595-600, Sep. 1996.
[16] P. Gomatom, and W. Jewell, "Fuel parameter and quality constraints for fuel cell distributed generators," in *Proc. IEEE Conf. and Exposition. Transmission and Distribution*, 2003, pp. 409–412.
[17] G. Joos, B. T. Ooi, D. McGillis, F. D. Galiana, and R. Marceau, "The potential of distributed generation to provide ancillary services," in *Proc. IEEE Conf. Power Engineering Society Summer Meeting*, 2000, pp. 1762 – 1767.
[18] L. F. Ochoa, and G. P. Harrison, "Minimizing energy losses: Optimal accommodation and smart operation of renewable distributed generation," *IEEE Trans. Power Systems*, vol. 26, no. 1, pp. 198-205, Feb. 2011.
[19] V. H. M. Quezada, J. R. Abbad, and T. G. S. Roman, "Assessment of energy distribution losses for increasing penetration of distributed generation," *IEEE Trans. Power Systems*, vol. 21, no. 2, pp. 533-540, May 2006.
[20] E. Carpaneto, G. Chicco, and J. S. Akilimali, "Branch current decomposition method for loss allocation in radial distribution systems with distributed generation," *IEEE Trans. Power Systems*, vol. 21, no. 3, pp. 1170-1179, Aug. 2006.
[21] R. K. Singh, and S. K. Goswami, "Optimum allocation of distributed generations based on nodal pricing for profit, loss reduction, and voltage improvement including voltage rise issue," *Int. Journal of Electrical Power and Energy Systems*, vol.32, no. 6, pp. 637-644, July 2010.
[22] G. P. Harrison, and A. R. Wallace, "Optimal power flow evaluation of distribution network capacity for the connection of distributed generation," *IEE Gener. Transm. Distrib.*, vol. 152, no. 1, pp. 115-122, Jan. 2005.
[23] F. Li, and R. P. Broadwater, "Distributed algorithms with theoretic scalability analysis of radial and looped load flows for power distribution systems," *Electric Power Systems Research*, vol. 65, no. 2, pp. 169-177, May 2003.
[24] S. M. Moghaddas-Tafreshi, and E. Mashhour, "Distributed generation modeling for power flow studies and a three-phase unbalanced power flow solution for radial distribution systems considering distributed generation," *Electric Power Systems Research*, vol. 79, no. 4, pp. 680-686, Apr. 2009.
[25] Y. M. Atwa, and E. F. El-Saadany, "Reliability evaluation for distribution system with renewable distributed generation during islanded mode of operation," *IEEE Trans. Power Systems*, vol. 24, no. 2, pp. 572-581, May 2009.
[26] In-Su Bae, and Jim-O Kim, "Reliability evaluation of distributed generation based on operation mode," *IEEE Trans. Power Systems*, vol. 22, no. 2, pp. 785-790, May 2007.
[27] T. E. McDermott, and R. C. Dugan, "Distributed generation impact on reliability and power quality indices," in *Proc. IEEE Conf. Rural Electric Power*, Colorado, 2002, pp. D3-D3-7.
[28] N. Perera, A. D. Rajapakse, and T. E. Buchholzer "Isolation of faults in distribution networks with distributed generators," *IEEE Trans. Power Delivery*, vol. 23, no. 4, pp. 2347-2355, Oct. 2008.
[29] R. Majumder, A. Ghosh, G. Ledwich, and F. Zare, "Load sharing and power quality enhanced operation of a distributed microgrid," *IET. Renew. Power Gener.*, vol. 3, no. 2, pp. 109-119, Jan. 2009.
[30] X. Luo, S. Su, G. Liu, P. Peng, and L. Fan, "Power Quality Auto-monitoring for distributed generation based on virtual instrument," in *Proc. IEEE Conf. Intelligent Computation Technology and Automation*, 2008, pp. 1106-1110.
[31] S. Grenard, D. Pudjianto, and G. Strbac, "Benefits of active management of distribution network in the UK," in *Proc. IEEE Conf. Electricity Distribution*, 2005, pp. 1-5.
[32] M. Joorabian, M. Ajodani, M. Baghdadi, "A method for voltage regulation in distribution network equipped with OLTC transformers and DG units," in *Proc. IEEE Conf. Power and Energy Engineering*, China, 2010. pp. 1-5.
[33] S. Ropenus, and el at., "Assessment of interactions between the economics of distributed generators, distribution system operators and markets," *Report of the project: Improvement of the Social Optimal of Market Integration of DG/RES in European Electricity Markets*, Feb. 2009.
[34] G. W. Ault, J. R. McDonald and G. M. Burt, "Strategic analysis framework for evaluating distributed generation and utility strategies," *IEE Gener. Transm. Distrib.*, vol. 150, no. 4, pp. 475-481, July 2003.
[35] D. Trebolle , T. Gómez, R. Cossent, and P. Frías, "Distribution planning with reliability options for distributed generation," *Electric Power Systems Research*, vol. 80, no. 2, pp. 222-229, Feb. 2010.

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