Impacts of Distributed Generation in Restructured Power System: A `Review

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***Abstract*—This is the review work to unite the conclusions resulting from previous work in finding the impacts of DG in Restructured Power System with different aspects. Firstly authors endow with different definitions of DG furnished by institutional authorities or industrial organizations. Then stepped separately into overview and impact of DG on transmission pricing, system reliability and interconnected system. At last under the heading of sizing and siting of DG authors reviewed adequacy assessment of placement of DG, network investment deferral on DG, impact of distributed generation on distribution contingency. And finally conclusion of this review is given.**

***Index Terms*—Transmission pricing, System reliability, Interconnected System, Sizing and Siting.**

I. Introduction

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. These units are of limited size (100 MVA or less) and can be connected directly to the distribution network or on the customer site. Recent studies have predicted that by year 2010, DG will account for up to 25% of all new generation. The main reasons behind the expected widespread of DG's are [2]

- Deregulation in the power market, which encourages public investment to sustain the development in the power demand. This development has led to the breaking up of investments (small generating units);
- Emergence of new generation techniques with small ratings, ecological benefits, increased profitability, and further this can be combined with heat generation;
- Saturation of existing networks and the continuous growth of the demand.

Hence based over these rationales the DG devices can be strategically placed in power systems to achieve well known technical benefits like grid reinforcement, reduction in power loss and on-peak operating costs, improvement in voltage profiles and load factors, deferment or elimination of system upgrades, improvement of system integrity, reliability and efficiency [1].

In this paper authors established fuse information about DG, starts with section II, preliminary definitions set by different institutional authorities or industrial organizations. Section III furnished overview and information on impact of DG's on transmission pricing. Further section IV gives impact of DG on system reliability and interconnected systems. While section V reviewed those publications which sets views in sizing and sitting of DG. Finally section VI gives conclusion.

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II. Definitions

This section furnished different definitions agreed for Distributed Generation a bibliography review [4] on the concepts of distributed generation

A. *Def by Distributed Power Coalition of America (DPCA)*

Distributed power generation is any small-scale power generation technology that provides electric power at a site closer to customers than central station generation. A distributed power unit can be connected directly to the consumer or to a utility's transmission or distribution system [5].

B. *Def by International Conference on High Voltage Electric Systems (CIGRE)*

Distributed generation is :
• Not centrally planned.
• Today not centrally dispatched.
• Usually connected to the distribution network.
• Smaller than 50 or 100 MW [6].

C. *Def by International Energy Agency (IEA)*

Distributed generation is generating plant serves a customer on-site, or provides support to a distribution network, and connected to the grid at distribution level voltages. The technologies generally include engines, small (including micro) turbines, fuel cells and photovoltaic. It does not generally include wind power, since most wind power is produced in wind farms built specifically for that purpose rather than for meeting an on-site power requirement [7].

D. *Def by US Department of Energy (US. DOE)*

Distributed generation - small, modular electricity generators sited close to the customer load - can enable utilities to defer or eliminate costly investments in transmission and distribution (T&D) system upgrades, and provides customers with better quality, more reliable energy supplies and a cleaner environment [8].

Another definition of US DOE establishes that Distributed energy resources (DER) refers to a variety of small, modular power-generating technologies. DER systems range in size and capacity from a few kilowatts up to 50 MW [9].

E. Def by Electric Power Research Institute (EPRI)

EPRI's DG definition roundabout integrating distributed energy resources. It establishes that the new system would also be able to flawlessly integrate an array of locally installed, distributed power generation as power system assets. Distributed power sources under 20 MW per unit could be installed on both the supply and consumer side of the energy/information gateway as essential assets dispatching reliability, capacity and efficiency [10]. On other hand, another EPRI definition of distributed resources includes small generation (1kW to 50MW) and/or energy storage devices typically sited near customer loads or distribution and sub-transmission substations**.**

F. Def by Institute of Electrical and Electronic Engineers (IEEE)

Defines distributed resources as sources of electric power that are not directly connected to a bulk power transmission system. And the Distributed Resources includes generator and energy storage technologies [11].

G. Def by American Gas Association (AGA)

Distributed generation (DG) is the strategic placement of small power generating units (5 kW to 25 MW) at or near customer loads. Situated at a customer's site, distributed generation can be used to manage energy service needs or help meet increasingly rigorous requirements for power quality and reliability. Located at utility sites such as substations, distributed generation can provide transmission and distribution (T&D) grid support and expand the utility's ability to deliver power to customers in constrained areas. Distributed generation technologies include such resources as industrial gas turbines, reciprocating engines, fuel cells, micro turbines, windpower, and photovoltaic [20].

III. Overview and Impact of DG on Transmission Pricing

Transmission and distribution (T&D) pricing has been one of the keystones of the ongoing deregulation and privatization process in the power industry. The presence of dispersed generation or DG further complicates the problem of pricing because it introduces additional supplying nodes and changes power flows [15]. Eventually affects the transmission pricing / wheeling charges which are different from previous existing power network (without DG). Reasons being distribution system with DG becomes active network (unlike passive distribution networks without DG) due to counter flows. Hence, it is necessary to develop methods, which allow the shared use of the transmission system by different users and another reason is reactive power. Because flow of reactive power with DG may vary, as in case of wind generators, it injects real power and withdraws reactive power.

J. Mutale et.al in 2007 [14], proposed a network pricing methodology that explicitly models the impact of DG on networks investments and has argued that it is through identifying the strong link of network cost drivers and pricing that supports technical and economic integration of DG into the power systems which can be realized in consistent way. X. Zhong and K.L. Lo [17] in 2007 researched to focus on the mathematical formulation and case studies of a proposed charging methodology for optimal use and expansion of a distribution network, especially when the network contains Distributed Generation (DG). The aim of this charging methodology is developed by providing the correct economic signal, reflecting the true cost and promoting the uncertainties of network users, especially the DG resources. In this authors suggested the impact of the level of DG penetration by the proposed method in generation output and installed capacity. It is a fair, strong and transparent calculation methodology because it could avoid adverse market conditions and protect consumers. Recently in 2008, Furong Li et.al [15] suggested a method for distribution pricing known as MW+MVAr-Miles which is better than MVA-Miles methodology, pricing a network based on real and reactive power [16]. The MVA-Miles approach, however, only reflects the apparent power flow along circuits; it does not recognize the leading or lagging condition of the circuits. As in case of wind generators the MVA-Miles method fails to distinguish the difference in the direction of the same network user, resulting in misleading network charges. Because it injects real power and withdraws reactive power. Whereas the new MW+MVAr-Mile charging methodology not only takes care of the power factor of network users but also the leading or lagging nature of power factor. Firstly it separates the MW and MVAr power flows, and then acknowledges the full cost-benefit of network users, especially embedded generators or DG. Authors also gave the comparison with the MW-Miles and MVA-Miles methodologies [16]. Thus proposed charging methodology MW+MVAr-Miles methodology is able to provide forward looking economic signals to encourage network users to behave in a manner leading to a better network condition. The introduction of this method allows further commercial separation between generation and transmission companies, offering better transparency to market operation and regulation.

IV. Impact of DG on System Reliability and in an Interconnected System

With distributed generation (DG), to improve system reliability for radial distribution systems under fault conditions, switch placement schemes are proposed in [3] to form self-supported areas after fault isolation. Authors considered customer priority in this problem. They formulated switch placement problem as a nondifferentiable, multiobjective optimization problem. And to locate switches Graph-based algorithms, are developed which incorporates direct load control. Their results enable DG to support customers continuously in the event of fault. The proposed algorithms can also be applied to unbalanced distribution networks with single or multiple distributed generators. Graph-based search algorithms have been developed which incorporate direct load control if available. Results provide the following critical information: 1) Where to install new sectionalizing switches; 2) Which existing switch must be opened or closed; 3) Which loads should be on and off? The algorithms are flexible and accommodate changes in the treatment of priority loads. The proposed algorithms can be used in planning and/or online application problems for radial distribution systems with DG.

In [12] authors did a study to explore the applicability and cost-effectiveness of DG in a transmission-constrained two-area system whose tie lines transfer capability is severely limited using PV, fuel cell and micro turbine resources. For that authors effectively extended the single area production costing model to a two-area system production costing problem where the real power transfer between the areas is explicitly accounted. This is a novel attempt to model the generation from PV as DG-based resource planning methods. Economic attractiveness of DG resources in transmission-constrained load pockets of an interconnected system resides in higher insolation availability and higher PV penetration. Moreover, present electric system networks are experiencing the difficulty of constrained transmission lines with limited transfer capability. Increased competition, constrained transmission lines with limited transfer capability, technological advances of newly emerging generation resources, and strong environmental movement in all sectors of the economy are important factors for electricity enterprises to consider in their planning activities. In the path of solution authors suggested one new important development is the application of dispersed generation (DG) resources to meet forecasted load growth, particularly the application of photovoltaic (PV) generation.

V. Sizing And Siting of DG

As given in **[13]** it is well known fact that if DG is properly planned and operated it may provide benefits to distribution networks (e.g., reduction of power losses and/or deferment of investments for network enforcing, etc.), otherwise it can cause degradation of power quality, reliability, and control of the power system. DGS are not widely used because of imperfect technologies, the immature power retail market, the lack of appropriate control measures for the influence of DGS on the grid and other factors. Therefore, they have been a hot topic for research in recent years. Nowadays, a number of impediments and barriers still inhibit an increased market penetration of DG. The examples of the most common barriers to the DG development are

- The high costs and uncertain performances of many DG technologies,
- The lack of uniform standards and communication protocols,
- The architecture of the distribution system

The need for more flexible electric systems, the changing in the regulatory and economic scenarios, the importance of harnessing energy savings and minimizing environmental impacts have been providing the impetus for the development of distributed generation (DG). Anyway, in the distribution system of the future DG is intended to play vital role hence distribution engineers need new planning tools to maximize benefits in the new uncertain scenario. In [13] an algorithm is proposed based on these assumptions, for the optimal allocation of DG in a given network. It is based on the application of GA and MO, and allows the schemer to force the solution toward his particular requirements. In the context of a liberalized energy market, it can be used to find the most valuable sites to exploit and evaluate any additional credits DISCO might offer if the DG is placed in the appropriate location to have real benefits for the network. In addition, the consideration of the power quality aspects in the planning of DG siting and sizing is compulsory.

A. Adequacy assessment of placement of DG

The work given in [2] presents a method to assess the adequacy of distributed generation systems by Monte Carlo-based method. Adequacy assessment implies the determination of the actual distribution system power capacity and the ability of this capacity to meet the total system demand. The term “distribution system power capacity” is introduced in this paper to account for the generating power from the available DG plus the received power from the transmission system. In this state duration sampling approach is employed to model the operating histories of the installed distributed generators. This proposed concept is implemented in a typical case study where several distributed generation units are running in parallel within a sample distribution system and the system margins and the average amount of unsupplied loads are estimated using Monte Carlo simulation. The results obtained are presented and a new perspective to the power management of distribution systems is discussed. In this authors consider the stochastic nature of the distribution system operation when customer-controlled DG units are running in parallel within the system. Consequently, the overall system power capacity will vary randomly and the determination of this capacity requires proper modeling of the random operation state of the system.

B. The Impact of Network Investment Deferral on DG

In publication [19] DNOs preference for the siting and sizing of DG installation are analyzed, using a multiyear multiperiod optimal power flow. Actually an appropriate framework is required to foster the integration of DG within grid network planning, consequently avoiding potential inefficiencies in electricity supply infrastructure. As DG may provide many benefits for DNO and can choose where to place it, as well as DNO can control DGs operating pattern through peak load operation, the recognition of DG deferment benefits may influence the optimal connection of new generation within existing networks.

C. Impact of distributed generation on distribution contingency analysis

The size and site of DGs will have an effect on the voltages and operations of the distribution power system in the future.

The work [18] focuses on looking at the system voltages in the presence of a DG with the system configured after the removal of the faulty part of the system and before the restoration of the system. It spotlights on the assessment of the size and the location impact of the DG with a change in the loading conditions due to a contingency on unbalanced distribution systems. The optimal location and the size of the DG are selected from the results obtained from the unbalanced distribution power flow. A contingency analysis was done taking three contingencies, three different sizes and four different locations for the DG on each of the feeders with the power flow run taking. In this research both types of models taken into consideration for the DG, i.e PQ, and PV. Through analysis the best location and size of the DGs are justified. In previous works DGs were modeled as a PQ node only with negative injections into the network for simplicity. But in this research, the DG was modeled also as a PV node, and a comparison of the models was also made to see the effect of the DG model on the system before and after the fault. However, authors set a view that this kind of work is not feasible on large systems, as it is difficult to handle the different cases and the different inputs.

VI. Conclusion

DGS are new energy systems that are based on the optimization of resources, environment and efficiency by identifying optimum operational methods and capacity. The main economic benefits from distributed generation are its potential to relieve network congestion, enhance reliability, defer T&D upgrades, increase utilization of the T&D network and stimulate competition. This work is the review work to unite the conclusions resulting from previous work in finding the impacts of DG in Restructured Power System with different aspects. This work carries definitions for DG furnished by institutional authorities or industrial organizations, overview and impact of DG on transmission pricing, system reliability and interconnected system. And lastly under the heading of sizing and siting of DG authors reviewed adequacy assessment of placement of DG, network investment deferral on DG, impact of distributed generation on distribution contingency.

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