Dispersed Generation Enable Loss Reduction and Voltage Profile Improvement in Distribution Network—Case Study, Gujarat, India

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***Abstract*—Distribution system operators are often challenged by voltage regulation problems, energy losses, and network capacity problems. This paper analyses a real-life 3.9-MVA distribution network in Gujarat State, India. Distributed generation from renewable energy sources like wind and solar, at optimal locations on distribution feeders, may enable energy loss reduction and voltage profile improvement. A methodology is developed and presented for deciding the appropriate location of these embedded renewable generators. Simulations are performed to calculate different scenarios, and the final analysis reveals that the low voltage problem has totally been eliminated on all of the nodes of the distribution network. Complimentary, significant energy loss reductions are also achieved in the distribution, and the network reserve capacity has also increased.**

***Index Terms*—Distributed generation (DG), distribution network, embedded renewable generation (ERG), renewable energy sources (RESs).**

I. Introduction

THE emergence of intermittent local energy production, most likely by renewable energy sources (RESs) has presented new challenges to all, such as the electricity supply chain, transmission system operators (TSOs), distribution system operators (DSOs), and energy supply companies (ESCos). One of these challenges is possibly leading to problems in the networks that have not been planned in advance, as, originally, the electric power system is designed to have centralized generating plants facilitating unidirectional power flow through an extensive transmission and distribution network. The traditional system operation by ESCos was to plan for peak loads rather than net load. The peak load was very predictable, and, hence, control of the generation station could optimally be performed even manually. In contrary, consumers expect an absolute right to turn their loads on and off at will, as this have been the situation through most of the 20th century. With potential storage units such as batteries, electric vehicles (EVs), or heat pumps with heat storage, increasing shares of consumers tend to cover their electricity demand by their own local generation, such as photovoltaic (PV) for typical households and combined heat and power (CHP) units or micro wind turbines and in combination with renewable energy sources (RESs) generation for larger area networks, planning challenges are already existing in generation, transmission, and distribution systems. This situation will even more dramatically evolve when local generation will be significantly cheaper than supply provided by electric utilities. New strategies are required to guarantee a secure, reliable, and environmentally friendly electricity supply with affordable tariffs.

Conventional power generation is accompanied with some serious environmental problems including the associated green house gas (GHG) emissions. Nevertheless, the existing power system has several problems like over loaded lines, low voltage problems, high losses, and capacity/expansion problems.

Distributed generation (DG) can be defined as small capacity power generation integrated on the consumer side (that is, within the distribution system). If DG uses RESs for generation, it may be termed as embedded renewable generation (ERG).

Various factors can be considered for deciding the optimal capacity and location of the ERGs. Since a decade ago, due to the ongoing rapid changes in the electric utility infrastructure, there has been a keen interest for researchers and engineers on the ERG (DG integration) issues, its impact on the power system as a whole and distribution system in particular, and the benefits and issues associated with it. The performance of the distribution systems with ERG depend upon various factors like penetration levels of ERG, its location uncertainty, and varying output from ERGs.

Energy loss reduction is expected with introduction of ERG in the distribution system. Looking at the deregulation and the shortage of transmission capacities, researchers in [1]–[3] have presented analytical methods to determine the optimal location of ERG in a networked as well as radial system considering power loss reduction of the system, which can be helpful to

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system designers in proper selection of the ERGs. The energy loss reduction will be different for different locations and various capacities of the ERGs. However, Quezada *et al.* [4] computed the annual energy losses variations with different penetration and concentration levels of the ERG analyses that this is not always true, as the network power flows are modified to a significant extent by ERG. The authors also state that higher reduction in energy losses can be expected when distributed generators are more dispersed along the network feeders.

Analytical methods have also been developed for assessment of the prediction of the allowable DG penetration levels based upon the harmonic limit considerations [5]. If energy storage is used along with ERG, then the type and the capacity of storage will also have an impact on the penetration capacity of the ERG [6]. A set of indices to quantify the technical benefits of DG such as voltage profile improvement, energy loss reduction, environmental impact reduction, and DG benefit were proposed [7]–[10]. Evaluation and investigation of the performance of the distribution system with ERG is done in [11] using Monte Carlo simulations. In [12], particle swarm optimization is used as a tool to minimize the cost of the overall system by changing the location and capacity of the DGs. Various real-system case studies have also been conducted across the globe. Reference [13] evaluates the impact of ERG on a real-life 2.8-MVA distribution network of a particular area of Gujarat State, India. The improvement in voltage profile and reduction in line losses are analyzed for various locations and capacities of ERGs, and the results are quiet encouraging. An 89.22% reduction in line losses is achieved, and the minimum network voltage improves to 0.96 p.u. as compared with the original 0.91 p.u., under peak loading conditions. In [14], the impacts of DG on dispatch modes of power systems based on the Guangdong power grid in China are assessed. The paper provides suggestions for smooth integration of a large amount of distributed RES generation in the future.

The distribution networks in India and, particularly, in many areas of Gujarat State are operating at maximum capacity and may get overloaded under peak loading conditions. Gujarat is one of the leading states of India, where, currently, industrial development is peaking. Owing to the accelerated rate of urbanization and industrialization, the way-leave permission for laying of new lines for bifurcation of currently overloaded lines is also a problem faced by the utility. Furthermore, expansion of the distribution network is inevitable in this scenario, thereby putting in additional investment and burden for distribution infrastructure.

The government of Gujarat has announced a photovoltaic rooftop program across six cities of Gujarat state, wherein a total of 25-MW through about 2000 PV rooftop systems of various capacities on residential and commercial buildings would be added.[1] In a true sense, this can be considered as ERG at the distribution level, and hence a need has emerged to study the impact the ERG and the distribution network will have on each other.

The aim of this paper is to analyze a real-life 3.9-MVA distribution network in Gujarat State, India. DG from RESs wind and solar are considered to enable energy loss reduction and voltage profile improvement at optimal locations. The paper will provide guidelines for optimal allocation of ERGs and exhibit the impact of the addition of these ERGs to support grid infrastructure. The selected area, close to the sea-shore, has an average wind velocity of 5.6 to 6.0 m/s, which is feasible for wind power generation[2] and has a significant solar irradiance of four peak sun hours per day, which is suitable for PV generation.[3] There is no conventional centralized generating station in the vicinity of the area. The nearest generating station is approximately 200 km away from the selected area. One of the reasons to select this particular area is a high level of existing technical losses and the scope of loss reduction with ERGs.

This paper is structured as follows. In Section II, the distribution network is formulated with the existing grid infrastructure. Section III provides the load flow analysis modeling without ERG and highlights the below-standard voltage profiles exhibited on the grid system, while Section IV describes the developed methodology for optimal ERGs location. In Section V, the grid case scenario analysis with ERG integration is performed, and, in Section VI, the results of the study, in particular, the energy loss reduction and the voltage profile improvements, are highlighted. Finally, in Section VII, the main conclusions are presented.

TABLE I
DETAILS OF CONNECTED LOAD

Connected Transformer Capacity (kVA)	No. of Transformers connected	Load Connected to each Transformer (kVA)	Total Load (kVA)
25	12	21	252
63	43	53	2279
100	16	84	1349
Total	71	--	3875

II. Problem Formulation

The case study is based on a radial 3.9-MVA distribution network in Gujarat State, India, which has a total line length of 46 km with 115 buses, supplying power to single-phase and three-phase loads. The details of the connected load to the radial 3.9-MVA distribution network under study are given in Table I.

In engineering terms, power is the rate of energy delivered and is proportional to the product of the voltage and the current. The power supply system can only control the quality of voltage; it has no control over the currents that particular loads might draw. Therefore, the standards in power quality area are devoted to maintain the supply voltage within certain limits. Electric distribution networks expand with time on the demand. ERGs contribute to the improvement of power quality in the areas where voltage support by grid is difficult.

The study and analysis of existing power distribution network revels that the major problem faced by the consumers is supply at poor voltage and that faced by utility is a high level of distribution losses and limited or no reserve capacity. This paper, as a

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[2][Online]. Available: http://www.cwet.tn.nic.in/html/departments_wpdmap.html

[3][Online]. Available: www.mnre.gov.in