# Placement of D-FACTS in Distribution Network with the Accommodation of Distributed Sources

*Kamalesh Sharma*, Pushpendra Singh**, Nagendra Kumar Swarnkar***, Sunil Agrawal*****

## Abstract

This article proposes the placement of D-facts in distribution network at optimal location in the presence of distributed energy resources. With increasing capacity of DGs in power system, at present concerns on increasing capacity of distributed energy resources in the power system leads to monitor the voltage profile all the time. An increasing implementation of environmentally friendly power-generation technologies in power system operation imposes problems in its operation. In particular, the power does not only flow “vertically,” i.e., from the higher to the lower voltage levels of the system, but also “horizontally,” i.e., from one distribution system to another or from a generator to a load within the same distribution system. The operation of the power system in such a horizontally manner is an important issue for the inclusion of D-FACTs devices along the distribution networks.

The main objective of the proposed research work is to increase the penetration level of distributed generators in the distribution networks with improved power quality and reliability, as the power quality mainly voltage profile is disturbed with the penetration of distributed generators in distribution networks, because of bidirectional flow of power. In order to maintain the voltage profile within the permissible limit, there is need to place D-FACTs devices at optimal locations. In order to have increased DGs capacity and to maintain the voltage profile in permissible limits D-FACTs devices have been placed optimally, according to the ranking of the nodes depending upon the voltage profile.

The problem has been formulated and simulated in MATLAB environment. The 33-node generic distribution network with the injection of various DERs capacity has been considered.

## Introduction

Electrical power has become very essential for the development of any country. With the increase in population of a country and changing life style, going toward comfort, energy demand is

*M. Tech Scholar (Power System), Dept. of Electrical Engineering, AIET, Sitapura Jaipur.

**Associate Professor at JKLU, Jaipur.

***Professor & Head, Dept. of Electrical Engineering, AIET, Sitapura Jaipur.

****Associate Professor, Dept. of Electrical Engineering, AIET, Sitapura Jaipur.

***Correspondence to***: Mr. Kamlesh Sharma, Dept. of Electrical Engineering, AIET, Sitapura Jaipur.

***E-mail Id:*** kamlesh.sharma22@gmail.com

continuously growing. It is necessary to meet the increased energy demand without affecting the reliability and quality of supply at less cost. In the present decade, the demand-supply gap is widening. For minimizing the energy demand and supply gap, the power generation capacity has to be increased, with the consideration of environmental constraints, i.e., green energy sources, renewable energy sources or reducing the energy demand considerably at consumer end by using solar-powered lighting equipment and solar energy-operated home appliances. The energy demand during the peak load hours can be met by altered load pattern also. In order to meet the increased energy demand, new generating plants and additional power system infrastructure may not be required if load at the consumer end is managed properly or more solar panels and small wind turbines are installed on their premises to fulfill the energy demand. The additional generated power may be transferred to the grid directly or generated energy may be stored (during off-peak load hours) and transferred to the grid (during peak load hours). The existing power system is based on large and centralized power stations connected to high and extra-high voltage networks, which transfer power to medium and then low-voltage distribution systems (i.e., vertically integrated manner). However, demand for more and higher-quality power, along with the increasing concern about problems related to our environment, such as global warming, are giving new challenges to the power system. The electric grid having more constrained, it is expected to perform better and also greener. That can be achieved only with accommodation of new technological advances, such as distributed generation (DG). DG applications in the distribution network show great operational and power-quality advantages [1, 2], in addition to transmission and distribution network losses reduction. DGs are very suitable for site-specific applications, as they have short period of construction and low investment. When DGs are penetrated into the distribution network, the power-flow pattern gets affected [3]. This article proposes the placement of D-Facts at optimal location. In this article, a scheme is proposed to relax the restriction on the location and capacity of DGs by the optimal placement of D-FACTs devices.

## Distributed Generation

Distributed generators are small-capacity generation units connected to the distribution network or connected directly to the costumer site The aiming of distribution generation is to increase the uses of renewable energy, i.e., wind energy, solar energy, etc. It brought attention from the power sector that sometime location and capacity of distributed generators (DGs) has adverse impact on distribution system. With the increasing electricity generation from renewable energy sources, the incursion capacity of DGs is increasing, which affects power flow in the distribution networks. D-FACTs [1, 2] devices with capability of power-flow control and maintaining the voltage profile in permissible limit may be a possible solution to this issue. Distributed generation (DG) produces electricity at or near the place where it is used. Distributed generation technologies may be renewable and non-renewable. Government public policies and regulations have played a major role in the rapidly growing rate at which distributed generation is penetrating. Distributed generation technologies can be further categorized as renewable and non-renewable. Renewable technologies are:

- Solar, photovoltaic or thermal
- Wind
- Geothermal
- Ocean

Nonrenewable technologies are:

- Internal combustion engine (IC engine)


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- Combined cycle
- Combustion turbine
- Micro-turbine
- Fuel cell

## Distribution Network

Generating plants, transmission lines and the distribution systems are the main components of an electric power system. Generating stations and a distribution system are connected through transmission lines, which also connect one power system to another. A distribution system connects all the loads in a particular area to the transmission lines. Electric power is generated at a voltage of 11 to 33 kV which then is stepped up to the transmission levels. The first step-down of voltage from transmission level is at the bulk power sub-station. This step-down is from the transmission and grid level to sub-transmission level. The next step-down in voltage is at the distribution substation. The distribution system fed from the distribution transformer stations supplies power to the large number of domestic or industrial and commercial consumers.

## Distribution Network and Impacts of DGs

The main function of distribution networks is to transfer electricity to consumers after receiving electric energy from interconnected high-voltage transmission networks.

The electric energy is being transported from remotely located centralized power plants to the consumers. The transmission system of an area is known as a grid.

Distribution networks are designed to supply power to meet out the load demands at a specified voltage level, if load increased on distribution line the voltage at the node may not be in the specified limit as in shown Fig. 2. The existing distribution network having distributed generators as in Fig. 1, the voltage rise problem has been observed as in Fig. 4.

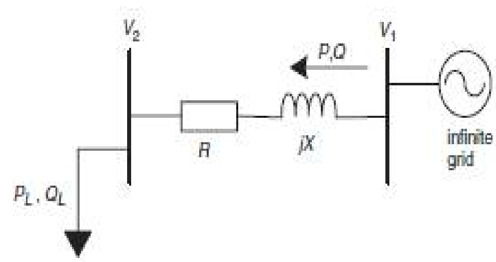


Figure 1.Basic Two Bus-Bar (Radial) Network

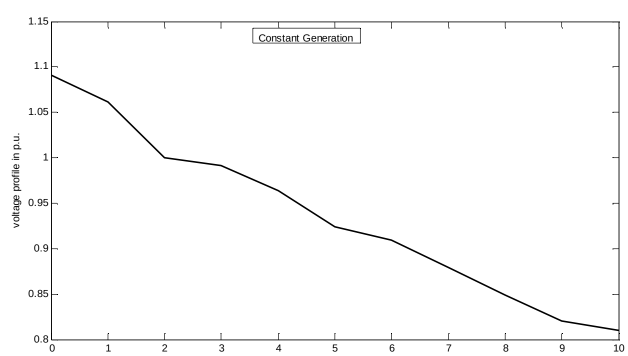


Figure 2.Voltage Profile at Load Bus of the Radial Network for Constant Generation

Distribution feeders are typically operated in a radial fashion. Feeders consist of a tree-like topology rooted at the secondary of a transformer, typically with on-load tap-changing for voltage regulation. The voltage at bus-bar 2 is calculated as:

$$V_2 \approx V_1 + R(P_G - P_L) + X(Q_G - Q_L)$$

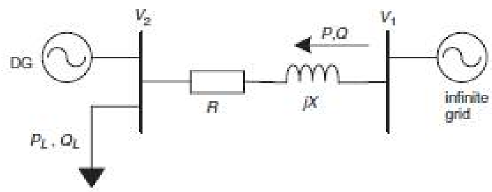


Figure 3.Voltage Profile of the Radial Network with Distributed Generators

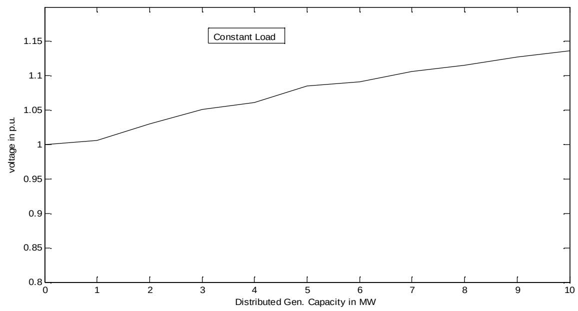


Figure 4.Load Bus Voltage Profile of the Radial Network with Injected Generator Power and Constant Load

The voltage profile at bus 2 varying with the capacity of distributed generators at the end of radial feeders is shown in Fig. 3. When DG capacity is higher than the connected load at that particular node, the direction of power flow is in opposite direction. The distributed generators inject power into the distribution networks but the power quality of supply gets affected as shown in Fig. 4. The benefits which we can get from distributed generators in relation to T&D networks could include reduction in additional power system infrastructure; T&D network losses, improved reliability and quality, improved voltage regulation, and T&D system congestion. The integration of distributed generators with distribution network could worsen the performance of the power system. For example, the reliability of the power system may be degraded if the distributed generators are not properly coordinated with the electric power system protection. The integration of distributed generators can have a serious impact on the operation and integrity of electric power [4, 7].

## D-FACTs

The FACTs devices are used for maintaining, i.e., either supporting or preventing from rising the voltage, which means supplying or absorbing the reactive power but not exclusively for the improvement of quality of the supply [9, 10]. The D-FACTs devices are exclusively for improvement of the quality of supply [1, 4]. Widespread use of conventional FACTs controllers has not extensively occurred due in part to size, expense, and installation effort. The use of distributed flexible AC transmission system (D-FACTs) devices may facilitate the realization of a comprehensively controllable power system [6]. Large-scale power-flow control may finally be achievable. A D-FACTs device changes the effective line impedance actively by producing a voltage drop across the line which is in quadrature with the line current [4]. Thus, a D-FACTs device provides either purely reactive or purely capacitive compensation. D-FACTs devices do not change the line's resistance at all since doing so would imply the ability of the device to create real power. Hereafter, when it is referred to the ability of D-FACTs devices to change line impedances, it is only referring to the reactive line impedance, as line impedance-changing devices D-FACTs devices have an impact on states, power flows, losses, and more [6]. The impact on the system caused by D-FACTs devices on different lines working together can be coordinated to achieve some desired control objective. D-FACTs devices may be configured to operate autonomously in certain situations such as during transients, faults, etc. Recently-Introduced [4, 5] Distributed FACTs devices [4, 7]:

- Capacitive or inductive
- Distributed static series compensator (DSSC)
- Distributed series reactor (DSR) (inductive only) [11]
- Synchronous voltage source improved operation of distribution networks with the use of D-FACTs devices.
- Determine the best location, then D-Facts settings potential applications for D-FACTs include minimization DN losses and ultimately cost minimization.

## Integration of DGs with Distribution Networks

The electricity is being generated primarily from fossil fuel (coal, gas, oil, etc.) based centralized power plants. The fossil fuel sources are finite natural resources, and depleting at a faster rate. The fossil fuel reserves are needed to be preserved for longer periods. For energy security and climate change abatement, renewable energy sources are only the way. In the present scenario, there is need to generate more electricity from renewable energy sources, i.e., small combustion turbines and micro-turbines, small steam turbines, fuel cells, mini/micro hydroelectric power, photovoltaic, solar energy, wind turbines, energy storage technologies, etc. Electricity produced from renewable energy sources need to be injected into the electric grid. Existing power system faces many problems when distributed generation is added with the distribution networks; this is because the power system was designed for electricity generation from centralized electricity generation. The addition of generation possibly will influence power-quality problems, reduced system reliability due to electricity generation variability, reduction in the efficiency and over-voltages issues. Modern electric power system configurations interconnect centralized power plants through high-voltage transmission networks and provide electricity to the consumers through radial feeders. With the increasing efforts toward electricity generation from green energy sources, there is need to integrate the distributed energy resources with the power system, which may be integrated with the placement of DGs and D-Facts devices at suitable locations [10].

## Problem Formulation

The objective of placement of D-Facts in the distribution system is to maintain the voltage profile in the permissible limit and reduction of distribution network losses, subjected to certain operating constraints and load pattern. For simplicity, the operation and maintenance cost of the D-Facts placement in the distribution system is not taken into consideration [4]. The three-phase system is considered as balanced and loads are assumed as time invariant.

Thus, objective function is considering the following constraints:

- Branch current constraint
- Node voltage constraint
- Load connectivity
- Radial network structure

In order to maintain the voltage profile and to reduce the distribution network power losses, D-Facts devices are placed in the distribution systems.

- It has line-drop compensation to maintain constant voltage at its location.
- It causes sudden voltage rise in discrete steps at its location leading to better voltage profile and reduction in losses.

The variation in voltage profile has two sub-problems-optimal placement and optimal parameters of D-Facts components. To obtain the optimal location for D-Facts devices that maintain the voltages within the permissible limits of the distribution system, the grading of nodes has been done. The system is a 33-bus, 12.66-kV, radial distribution system. The initial power loss of 33-node distribution network system is 201.588 kW. The node voltage is considered as 1 pu. The algorithm was developed in MATLAB, and the simulations were done on a computer.

## Result

$P_L$=3715 Kw, $Q_L$=2300kVAR

**Table 1.Before and After D-Facts Voltage Profile**

| S. N. | % Penetration of DGs | $P_G$ kW | $Q_G$ kVAR | $P_{loss}$ kW | $Q_{loss}$ kVAR | $P_{DG}$ kW | $Q_{DG}$ kVAR | Before D-Facts voltage profile | After D-Facts voltage profile |
|---|---|---|---|---|---|---|---|---|---|
| 1 | No DGs | 3916 | 2470 | 201 | 170 | 0 | 0 | $V_{min}$: .90509 at node-18<br>$V_{max}$:1.094 at node-1 | $V_{min}$: .90509 at node-18<br>$V_{max}$: 1 at node-1 |
| 2 | 10 | 3527 | 2274 | 182 | 158 | 370 | 167 | $V_{min}$: .94201 at node-18<br>$V_{max}$: 1.0103 at node-1 | $V_{min}$: .94021 at node-18<br>$V_{max}$: 1.0107 at node-1 |
| 3 | 20 | 3139 | 2081 | 167 | 149 | 743 | 322 | $V_{min}$:.96053 at node-10<br>$V_{max}$:1.0712 at node-26 | $V_{min}$: .98206 at node-14<br>$V_{max}$: 1.05361 at node-25 |
| 4 | 30 | 2810 | 1844 | 187 | 142 | 1092 | 697 | $V_{min}$: .99130 at node-31<br>$V_{max}$: 1.04360 at node-22 | $V_{min}$: .99703 at node-17<br>$V_{max}$: 1.05361 at node-33 |
| 5 | 40 | 2493 | 1593 | 212 | 121 | 1434 | 848 | $V_{min}$: 1.04360 at node-14<br>$V_{max}$:1.12059at node-25 | $V_{min}$: 1.0215 at node-17<br>$V_{max}$: 1.05531 at node-03 |

## Conclusion

In radial distribution systems, it is necessary to maintain voltage levels within limits at various buses. This article aims at discussing for maintaining the voltage levels by using voltage regulators in order to improve the voltage profile. The proposed method deals with initial selection of VR by using power-loss indices (PLIs) and grading of node voltage has been used for optimal location and number along with setting of the D-FACTs to maintain voltage profile within the desired limits and reduce the network losses. The proposed algorithm is tested with 33-bus. From the simulation results, it has been observed that with placement of D-Facts in the distribution network, the increased capacity of DGs may be accommodated.

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