# Enhancing the Voltage Profile in Distribution System with 40 GW of Solar PV Rooftop in Indian Grid by 2022: A review


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***Abstract*— Distribution system comprises the residential, commercial and industrial system with different operating voltage. Maintaining the voltage profile is one of the major concerns in the distribution system. Injection and drawl of reactive power from the distribution grid resulting in poor voltage profile. During the peak hours the voltage in the distribution system is reduced due to drawl of reactive power from the distribution grid especially residential system (power factor maintenance is not mandatory). This affects the performance of the end user equipment's and increased the power losses. Distributed Generation (DG) is providing the solutions for these problems. DG mostly using the solar for distributed power generation. The power output from the solar PV is directly proportional to solar irradiance available at surface of the panel. However solar power is intermittent in nature. It affects the voltage profile in the distribution system. It is essential to maintain the voltage profile in the distribution system with solar. There are various methods are available to maintain the voltage profile in the distribution system. These methods are application of capacitors banks, load balancing amongst all three phases, re-conditioning of distribution lines, bifurcation of distribution lines, distribution energy storage, re-configuration of distribution lines and deployment of FACTs devices. When integrating the Solar Photovoltaic (SPV) rooftop based distributed generation in the existing distribution lines, the use of one or more of these methods are essential to improve the voltage profile. By deploying these methods, the voltage profile in the distribution system is improved marginally/significantly in both peak and non-peak hours. These methods have its own limitations and economic factors for deployment. This paper discusses the technical limitations and economics involved in these methods for deploying into distribution system with 40 GW of solar PV.**



**Keywords-solar; distribution system; voltage profile; distributed generation; FACTs**


## I. DISTRIBUTION SYSTEM IN INDIA

Distribution and utilization system comprise the residential, commercial and industrial power system. Various types of loads are connected in 3ϕ 4W, 3ϕ3W and 1ϕ 2W distribution system. A 3ϕ 4W distribution system operating at 415V, 50Hz frequency, 3ϕ 3W system operating at 415V, 50Hz frequency and 1ϕ 2W distribution system operating at 240V, 50Hz frequency. All the low voltage distribution loads are connected in any one of the above distribution. Low voltage commercial and industrial systems are connected in 3ϕ 3W or 3ϕ 4W system based on the requirements and residential systems are connected in 3ϕ 4W or 1ϕ 2W system. Normally low voltage distribution systems have 3ϕ 4W circuits along its distribution, can able to connect the 3ϕ 3W, 3ϕ 4W and 1ϕ 2W loads as shown in figure 1.

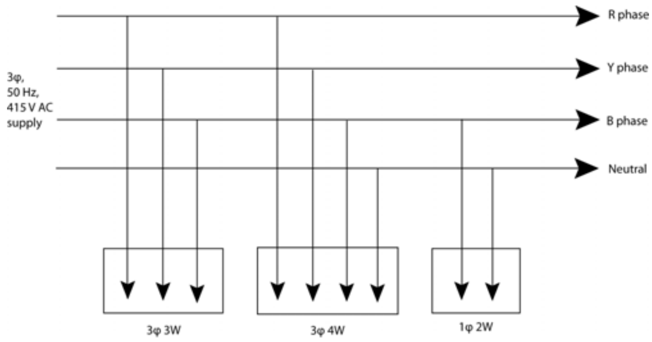


Figure 1: 3ϕ 4W distribution system

In many locations small scale commercial and industrial system like handloom, food processing, warehouse etc is located vicinity to residential system. These locations were sharing the same distribution feeders with residential systems. Most of the small scale commercial and industrial system loads are 3ϕ and connected in 3ϕ 4W system while in residential system most of the loads are 1ϕ connected in 1ϕ 2W. Maintaining the Power Factor (PF) is mandatory for commercial and industrial system while it is not mandatory for residential system. The drawl of reactive power by the loads in residential system is not significant in non peak hours but it is significant during peak hours.

## II. SOLAR ROOFTOP SYSTEM

Solar Photovoltaic (SPV) rooftop methods are now a day's widely used for renewable power generation in Distributed Generation (DG) [9]. This solar rooftop system is more suitable for the customers who have considerable power demand like academic institutions as school and colleges, government offices, small scale commercial and industrial system, etc. The power demand of the organization or system operating through SPV reduces the energy consumption from the grid or diesel generators. Based on the grid availability, SPV classified into two types namely OFF grid and ON grid system. SPV is the prime source of OFF grid system where Electricity Board (EB) supply is not available. In ON grid system SPV connected parallel to the EB supply have the capability of importing the power from grid when solar power is not available, load demand is higher than the solar power generation and exporting the power to the grid when solar power is highly available, higher than the load demand [11].

Based on the type of supply connection SPV classified into two types as 1ϕ and 3ϕ. Single phase SPV is used for lower power demand in residential system and commercial system for 1ϕ loads. Three phase SPV is used for medium power demand in commercial and industrial system.

## III. ENHANCING THE VOLTAGE PROFILE IN DISTRIBUTION SYSTEM

Maintaining the voltage profile is a major concern for distribution system. Due to various reasons like unbalanced loading amongst the phases, overloading, under sized cables or conductors, under sized transformer, improper PF compensation, etc resulting in poor voltage profile across the distribution system [2] – [4]. There are various techniques/methods used for enhancing the voltage profile in distribution systems are

1. Applications of capacitor banks
2. Load balancing amongst three phases
3. Re-conditioning of distribution lines
4. Bifurcation of distribution lines
5. Distribution energy storage
6. Re-configuration of distribution lines
7. Deployment of FACTs devices

### A. *Application of capacitor banks*

Now a day’s most of the loads employed in the modern power systems are RL type. These loads are drawing both real power and reactive power from the supply. Reactive power is directly proportional to voltage and drawl of more reactive power by these loads impacts the voltage profile in distribution system. By supplying the reactive power locally into the system can enhance the voltage profile in the distribution system. This can be achieved by installing the capacitor banks locally into the system. Capacitors supplying the reactive power to into the system and counteract the reactive power demand by the load. Supplying reactive power by capacitor bank enhancing the voltage profile, reduces the apparent power demand, reduces the overloading of cables & branch circuits, reduce the losses, enhancing the system voltage regulation and power factor improvement [2].

The reactive power compensation can be achieved by two ways one is fixed compensation and other one is variable compensation. The reactive power compensation by capacitor banks are fixed compensation and variable compensation by Automatic Power Factor Correction (APFC). Fixed compensation is supplying the fixed reactive power irrespective of the reactive power requirement or demand. Variable compensation is supplying the variable reactive power based on the reactive power requirement or demand. Application of capacitor bank is the economic solution for voltage profile enhancement in distribution system. The overall cost depends on type of compensation fixed or variable. Economics involved in fixed compensation is less compare to the same rating of the variable compensation. Cost of variable compensation is 15 – 25% higher than fixed compensation for the same rating. Solar inverters can able to operate 0.8 lag PF to 0.8 lead PF [15]. That means it can operate the capacitive or inductive reactive power. The various operation of distribution system with integration of SPV and APFC are listed in table 1.

TABLE I. VARIOUS OPERATING CONDITION

| Condition | Operation | Reactive power support | Voltage profile |
|---|---|---|---|
| 1 | Only Transformer | Only grid through transformer | Poor |
| 2 | Transformer and SPV | Transformer and SPV | Improved voltage profile |
| 3 | Transformer, SPV and APFC | Transformer, SPV and APFC | Better voltage profile |

Condition 1: When transformer alone is supplying both real and reactive power, losses increased and voltage profile is decreased.

Condition 2: Adding SPV in the distribution system reduce the power loss and improve the voltage profile by locally supplying real and reactive power. During night time, SPV cannot supply both real & reactive power and this is becomes like only transformer (condition 1) powering the load (both real and reactive power).

Condition 3: Adding APFC along with SPV and grid supply improves the voltage profile. During day time, both SPV and APFC responsible for supplying the localized reactive power while in the night, SPV don’t supply the reactive power and APFC supplying the reactive power.

Size and location of the APFC & SPV can be obtained from load flow studies.

### B. *Load balancing amongst three phases*

Most of the distribution systems are facing load balancing problem in amongst three phases in 3ϕ 4W distribution system. This problem majorly exists where the combination of residential, commercial and industrial system loads are sharing same distribution feeders. Unbalance is mainly due to residential system because most of the residential systems loads are single phase and connected in 3ϕ 4W distribution system. However these loads are not balanced amongst each other phases. Due to this, loading at all three phases are different and leading to higher voltage drop in highly loaded phase, lower voltage drop in lightly loaded phase [4]. On the other hand, 3ϕ loads connected in these feeders receives the unbalanced voltage magnitude amongst three phases leading to poor performance of the equipments.

Voltage drop of the conductor is multiplication of flow of current of the conductor and impedance. The expression for voltage drop across the conductor is in Eq. 1.

$V_{drop} = I \times Z$ (1)

Where

$V_{drop}$ is voltage drop across the conductor

I is current flowing in the conductor

Z is impedance of the conductor

This can be explained through an example of 11 kV / 433 V, 300 kVA distribution transformer supplying to domestic resident, small scale commercial systems through 3ϕ 4W distribution system. Connected load of the transformer is 90% of single phase loads and 10% 3ϕ loads. Impedance offered by the distribution line assumed as 0.1 Ω / kM between transformer secondary to end user equipments. The current drawn by the load is 310/30/300 A respectively in R, Y and B phase. Voltage drop in R phase is 31 V, Y phase is 3 V and B phase is 30 V. End user 3ϕ induction motor receives the terminal voltage 384/412/385 V.

At many locations utility company having the restrictions to providing the 3ϕ supply to agricultural usage as providing the 3ϕ supply over a defined time period & 2ϕ supply over a defined time period. When utility is providing 2ϕ supply, 3ϕ 4W distribution becomes to 2ϕ 3W system and load connected in the third phase will not receive the supply. Most of the villages comes under this category. There is no separate feeder used for agriculture and residential application. A common feeder is used for residential, commercial (small scale) and agriculture applications. So 1ϕ domestic resident loads are connected in any two phase R & Y phase or R & B phase or Y & B phase. Due to this, two phases are loaded and one phase is not loaded. This cause the higher voltage drop in loaded phase. A 3ϕ SPV connected parallel with the distribution grid cannot deliver the power in the absent phase. It reduces the installed capacity of the SPV to two by third (2/3) of its rating. So for this condition, 3ϕ SPV converted into three 1ϕ SPV. The 1ϕ SPV can connect that particular two (available) phase only and absent phase in this distribution grid becomes unused.

Unbalanced loading in the distribution feeder can be reduced by distribution company by continuously providing the 3ϕ power supply and balancing the single phase loads amongst each other. When a significant single phase loads going to add into the distribution system a load flow assessment needs to be carry out to find the feeder loadings. This method is economically feasible and able to accomplish in short duration by carryout the load flow analysis.

### *C. Re-conditioning of distribution lines*

Re-conditioning of the distribution conductors are one of the method to reduce the voltage drop across the distribution lines. In this method higher impedance conductors are replaced with lower impedance conductor. This method effectively increases the voltage profile of the system by reducing voltage drop while reduction of line impedance will have an impact in short circuit current. Replacement of entire distribution lines to new lines need higher capital investment and time consuming. Cost of this method can be reduced by changing only the specific higher conductor instead of entire distribution lines. A separate study (load flow assessment and short circuit study) should be carried out in order to find these lines in the distribution system.

### *D. Bifurcation of distribution lines*

From Eq. (1), voltage drop is directly proportional to current flow and impedance of the line. When the lines and circuits highly overloaded, voltage drop across the distribution line is high. Due to higher voltage drop, receiving end or end user receives reduced voltage. In this method existing single feeder or line is split into two or more feeders. Load assessment should be carried out to re-allocate the loads into new lines. This method requires construction of new lines/infrastructure. Economics involved in this method is high. Time requirement for this method is high due construction of new feeders. This method is recommended for permanent solution to voltage profile problem.

Optimal size and location of SPV & APFC can reduce the loading of the line up to certain extent. This will improve the voltage profile marginally. While splitting the existing line into two or more lines, impedance offered by the line is reduced and this will increase the system short circuit current. This also considered as one of the criteria to select the number of new lines.

### *E. Distribution energy storage*

Energy Storage System (ESS) utilize the excess amount of RE power (solar) when it is highly available time to non-available or less available time by storing the energy.
The advantages of energy storage systems are

- Short term supply backup
- Enable storing and supplying the energy
- Instantaneous support of both real power and reacti ve power
- Smoothing the power output from renewable energ y sources

There are various energy storage systems are exits like flywheel energy storage, Battery Energy Storage System (BESS), super capacitors, Super Magnetic Energy Storage (SMES) etc [1] & [6]. The objective of any storage system is same however storage medium involved in these storage are different. For selection of which storage device is based on specific application, rating and size, speed of operation (conversion) and finally economics involved. The cost of these storage system are quite different from each other. Flywheel energy storage and BESS are economically lower compare to super capacitors and SMES. BESS will give the ability to meet the challenges of Time Shift (TS) to meet the loads, Grid regulation (voltage & frequency) and Peak demand saving [12]. This energy storage reduces the voltage related power quality problems like voltage sag, voltage swell and interruption.

### F. Re-configuration of distribution lines

Network Reconfiguration is the process of operating switches to alternate the circuit topological structure by changing the status of sectionalizing switch position to open or close [2] – [3]. This method is modifying radial feeders from time to time by changing the switch position to open or close. By this method, load is transferring from heavily loaded circuit to lightly loaded circuit. This method improves the voltage profile by reducing the overload and reduces the losses. This method has complex Infrastructure and higher capital.

### G. Deployment of FACTs devices

FACTs devices are capable for supplying or absorbing the reactive power in dynamically varying condition. These FACTs devices are classified into two types as shunt compensation and series compensation. The shunt compensating devices are SVC and DSTATCOM while the series compensating devices are TCSC, DVR and SSSC. DSTATCOM is a shunt connected device and DVR is a series connected device which can supply or absorb both real & reactive power in the system [8]. Voltage profile in the system is maintained by supplying or absorbing the reactive power by these FACTs devices. UPQC is a combination of series and shunt connected device. Load flow assessment/study needs to be carryout in order to know the requirements of FACTs device like type, location and rating. Economics involved in this method is high. Compare to bifurcation and reconditioning methods, this method consumes lesser time.

## IV. Conclusion

Maintaining the voltage profile in the distribution system is a major concern for distribution company. Due to drawl and injection of reactive power resulting in poor voltage profile of the distribution system. SPV rooftop is providing the solutions to both power losses and voltage profile problems. However intermittent characteristics of solar affects the voltage profile in the distribution system. It is essential to maintain the voltage profile in the distribution system with integration of SPV. The technical and economics involved in various methods are discussed to/for improve the voltage profile with integration of SPV. Adopting these kind of approaches will help us to achieve the 40 GW of solar rooftop power in Indian power system within the year of 2022.

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