Analysis of the Effect of Solar PV Penetration for Empowering the Grid

Shobhit Kureel[1], Lokesh Varshney[1,2*], Sheetla Prasad[1]

[1]Department of Electrical, Electronics & Communication Engineering, Galgotias University, Greater Noida, India
[2]Electrical and Electronics Engineering Department, Ajay Kumar Garg Engineering College, Ghaziabad, India
E-mail:lokesh.varshney@gmail.com

This research article aims to highlight the effects of distribution generation on the grid. An investigation was performed to analyze the roof-top solar PV system using real-time data from the electrical distribution network of district Shamli, Uttar Pradesh India. On the basis of information gathered from the utility on PV system, transformer, electrical lines, and running loads, simulation was carried out using the software ETAP (Electrical Transient Analyzer Program). By increasing penetration level of PV system on power distribution network the impact analysis was performed. According to the findings, the grid experienced a considerable variation in terms of line loss, power factor, and overall harmonic distortion. This research study discovered that utilities can create a constructive strategy to design for integrating PV system penetration to the grid, which aids in lowering line-loss, although considerations must be taken to keep power factor and THD within acceptable limits. The study also supported and reinforced the energy system's decarbonization and greater integration of renewable energy sources, making the move to smart grids a beneficial endeavor for many countries and utilities.

Keywords: Distributed generation, rooftop solar PV, penetration level, smart grid, ETAP.

1. Introduction

Distribution of electricity in remote and rural areas of many countries suffer from problems like high line loss, huge gap between the supply and demand, low power factor, voltage drop etc. [1]. To overcome these issues distribution generation like rooftop solar PV, wind-mill, small hydro biomass, distributed energy storage system, are initiatives for converting conventional grid to smart grid [2] .One of the world's top producers of power is India with approximate capacity of 410.3 GW as of October 31, 2022 wherein the thermal power is the major electricity source (Ministry of Power, GOI) [3]

Hydro, wind, solar, BM/Cogen, nuclear, and small hydropower make for 42.5% of the installed generating capacity. National Solar Mission (NSM) increased the Indian solar sector quickly from 2009–10. [4].

Multiple investors promote rooftop solar PV to help power providers reduce transmission and distribution losses by stabilizing household and industrial energy [5]. Distribution generation reduces network congestion, assures voltage stability, minimizes losses, and produces energy efficiently. DG's unexpected nature generates high transmission network demand, power flow in the other way, and optimization challenges employing multiple network-balancing approaches. Modern technology includes data measurement and machine learning for PQ forecasting. KNN, Bayesian networks, and DBSCAN may be utilized for historical data, PV output tracking, and random operating conditions. DRL functions, ELM NN creates datasets, and D2QL measures [6]. Distribution feeder losses are reduced by distributed PV roofs [7]. Studying load flow with a full feeder in Solar ON reveals feeding extra energy, decreasing grid dependence, enhancing voltage, cutting system losses, and helping the grid by exporting energy [8]. PV cannot supply reactive power, thus as PV levels rise, power factor declines, producing system losses. The ideal power factor is 0.95–1. Harmonic effects include improper circuit breaker opening, device corrosion, voltage drop, durability loss, and heat losses [9]. ETAP simplifies in-ring main distribution network load flow analysis, solar system analysis, and transformer sizing, according to another study. APFC voltage helps fulfill local reactive power needs, improve current profile, and raise node power factor, decreasing network losses [10]. The research study framework forecasts RPF intensity for each distribution system DER injection scenario. The framework's net load profile and penetration speed are recommended [11]. Store excess PV production during peak demands to avoid reverse power flow from substation transformer overloads due to PV penetration. Solar PV penetration depth and transformer operating loads were associated using a radical test LV network.

ETAP simulated AC-distributed LVDC at various voltages. In a moderate-sized house, 220V AC, 48V, and 380V DC were tested for efficiency. The DC gain in PV-connected buildings was deceiving. Losses may reduce with lower power conversion stages [12]. Once the DG is connected to the distribution network, fault current rises, affecting protection system reliability and security [13].

Inverters at nearby buses pollute the LV network, creating harmonic current and voltage waveform distortion, according to research. PV inverters are recommended because PCC nonlinear output waveforms create harmonics. Solar PV at another bus (PV penetration 50%) of the distribution network has the highest THDi and THDv values of 10.2 and 5.2%, compared to the IEEE norm of 8%. Losses dropped by 1.9 for active power, 2.6 for reactive power, and 3.3% for apparent power as the voltage profile improved [14].

PV inverters have excessive current THD when power was below rated. Harmonic current increased with harmonic voltage except for the third and ninth harmonics. The operating mood was optimal at unity and 0.95 power factor [15]. At 20% capacity, PV inverters inoculate harmonics. PV inverters may alter distribution transformer qualities.

A grid-connected PV system stimulation study using "RSCAD." Peak renewable power generation at 48 distorted current consumption 14.99% and TVE 4.98%. US study indicated that 15% PV penetration on MV feeders permits maximum load with connection impacts and is safe. MV distribution networks with installed capacity above 20% have problems regulating voltage because the transmission system responds slowly and power reversals generate gradual voltage violations [16].

Location, dispersion, DG technology, penetration, and DG output active and reactive fractions impact distribution system power losses during DG power insertion. Significant DG penetration changes power flow and transmission-system-produced energy. Power stability is affected by angle, frequency, and voltage [17]. Unbalanced voltage may restrict LV PV hosting. Overvoltage restricts three-phase LV systems quantitatively [18]. PV rating and location affect voltage imbalance. When an LV feeder starts, rooftop PV seldom effects voltage imbalance [19]. Stability exceeds high transient when PV plant is unplugged [20].

Network average daily power losses are minimal when PV's active power exceeds network loads [21]. There is moderate to high PV penetration with the PV system near the end of feeders, but less with feeders further away [22]. After PV deployment, penetration level does not effect significant eigenvalues, however grid level does affect voltage stability. Reactive power rises during peak solar irradiation (10 a.m.–3 p.m.) as PV penetration increases, cutting line losses [23]. PV lacks voltage stability; hence voltage control may induce overvoltage or collapse in regions with high PV usage. [24].

Due to phase shift, PV inverters must be larger to create reactive power without sacrificing active power. The grid manages reactive power but offers less actual power as PV penetration grows. PV inverters may inject or absorb reactive power to lower voltage sags or rises. [25-28]. Renewable power performance and reliability are studied [29–32]. The Solar Tracker Transcript provided an example of innovative shadowing arrangements [33–35]. Visual sun monitoring creates an effective energy-harvesting gadget. Also conducted was Modified Simulation (MS) study on PV system performance enhancement under partial shadowing [36–39].

2. System Description

A real time data is gathered from distribution network of district Shamli, Uttar Pradesh, India. The real time data of distribution network is made available by 'Uttar Pradesh Power Corporation Ltd.' India. Analysis took into account two 11 kV feeders recognized as "Sub-Station" and "Bus-Stand that are originating from 33/11 kV Substation UNN. A power transformer of 5 MVA is installed at sub-station UNN. One distribution transformer (DT) of 63 KVA is connected to sub-station feeder. At secondary side of this transformer a rooftop PV system, with capacity of 20kW is connected with it as shown in figure 1 Twelve distribution transformers with different capacities are connected to second 11kV "Bus-stand" feeder. Total 13 distribution transformers are connected to the sub-station. Real time data is collected from the modems of these transformers as shown in table 1. The 63KVA transformers at serial no.1 in the table 1 is connected with sub-station feeder and from serial no. 2 to 13 in table 1 are connected to bus stand feeder.

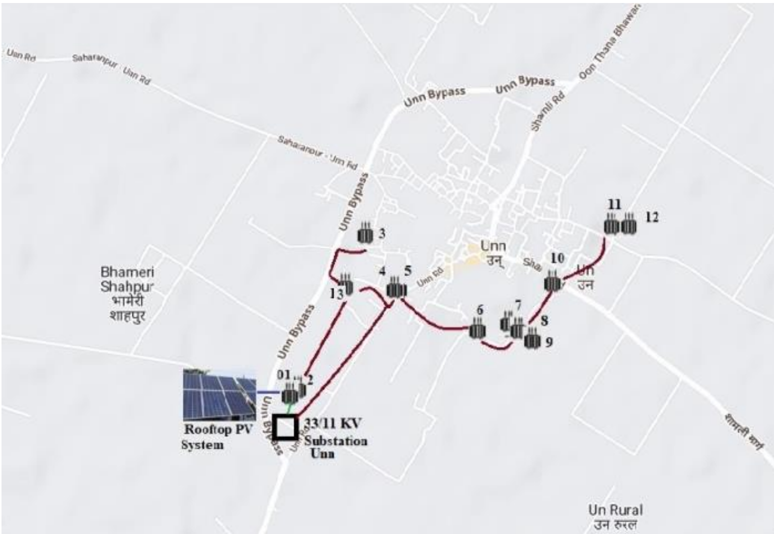

Fig. 1. Geographical location of distribution network

Table 2 lists the parameters of the substation's 20 KW rooftop solar system module. System has 8 PV structures. Every PV structure contains eight PV modules, totaling 64. (8x8 =64). Just one PV module may provide 315W. The maximum power output is 20 KW (315Wx64).

The photovoltaic inverter is described in table 3. There are 4 MPPTs for 20 KW PV [34-36]. This string inverter converts DC voltage to AC voltage using transformer-less topology and protects against DC Reverse Polarity, Output Over Current, Short Circuit, Insulation Resistance Monitoring, Temperature Protection, Resistance Current Detection, Surge Protection, Islanding Protection, and Grid Monitoring. Maximum efficiency for the 20 KW inverter is 98.6%.

Table 1. Details of Distribution Transformers

SN	Capacity (KVA)	DT Meter No	KVA	KW	KV AR	%PF	Load (Ampere)
1	63	20278241	6	6	0.26	99.9	7.9
2	100	20279047	22.6	20.7	9	91.6	29.7
3	63	20082322	15.3	15	3.31	97.6	20.1
4	400	20082113	46.2	46	4.1	99.6	60.6
5	250	20278233	65.7	64	15	97.3	86..2
6	63	20082111	22.6	20.7	9.04	91.6	29.7
7	25	21520527	7.76	7.74	0.6	99.7	10.18
8	250	17127425	126.2	124	23.5	98.2	165.6
9	400	17127381	83.68	70	45.8	83.6	109.8
10	25	20082302	27.3	16	22.1	58.6	35.8
11	250	17127388	69.2	67	17.6	96.7	90.9
12	400	20082102	60	59	10.6	98.4	78.7
13	400	17127319	74	73	12.6	98.5	97.2

3. Designing and Simulation in ETAP

For the investigation simulation of system was performed with load flow analysis. Real time data of the distribution transformer which were collected from different modems and the field details related with the electrical lines, sub-station power transformer, rooftop PV system was feed in ETAP software. To analyse the various parameters of radial distribution network like line-loss, power factor, total harmonic distortion (THD) simulation was conducted by varying penetration level of PV system [37-39]. Real power loss for a radial distribution system can be calculated as following equation [27].

$$P(loss) = \sum_{i=1}^{n\ br} |I_i|^2 \quad * R_i$$

Where is the real power loss, is the total no. branches, is the current flow magnitude, is the resistance of branch i.

4. Result and Discussion

To demonstrate efficacy of suggested method, the simulation under different scenarios were conducted. By connecting PV at different buses and varying the penetration level the result of line loss, power factor, total harmonic voltage distortion (THDv) of the grid were evaluated. The percentage of penetration level was increased by increasing the number and capacity of PV at each bus but keeping in limit of the maximum DT capacity.

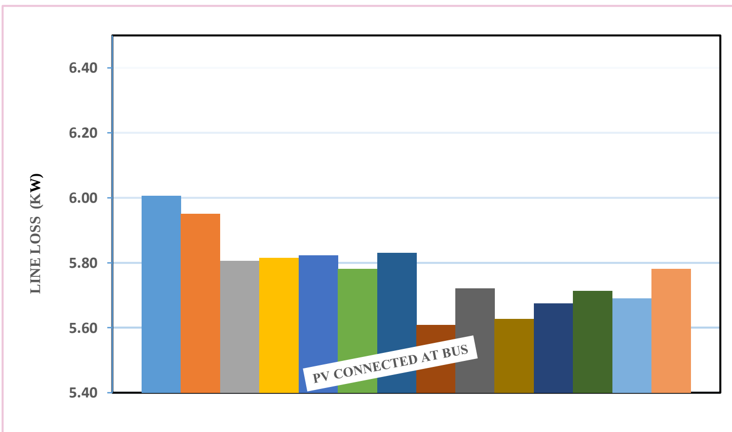

Fig 2. Line loss of network

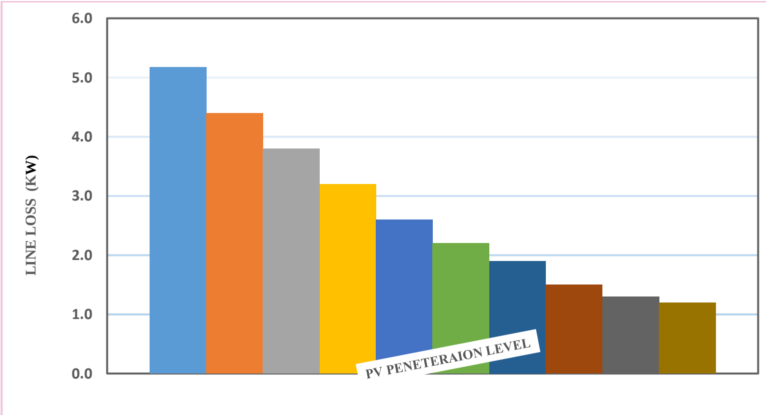

Fig 3. Line loss with PV Penetration

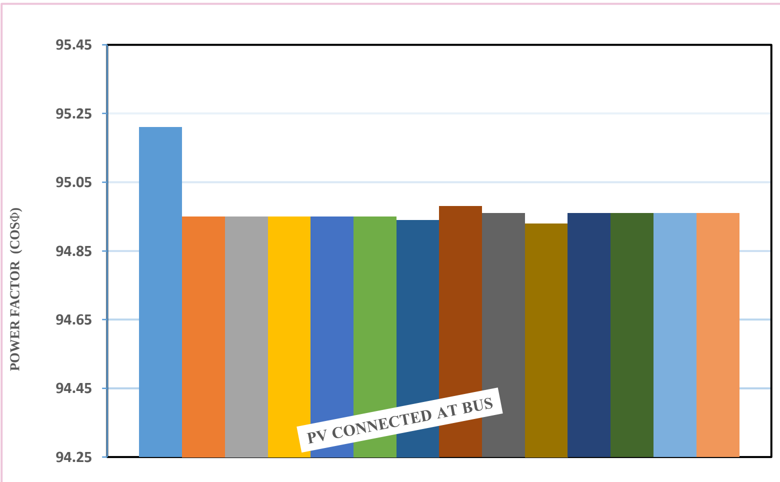

Fig. 4. Line loss with PV Penetration

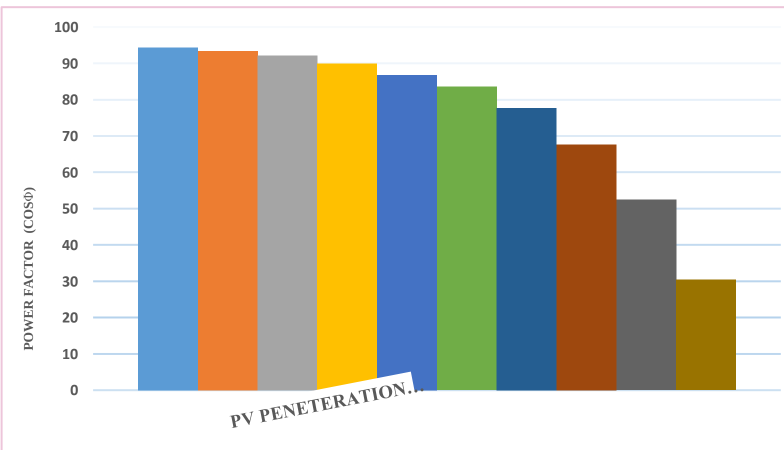

Fig. 5. Power factor with penetration level

5. Conclusion

This investigation was done in India's Shamli area. ETAP program simulated several models. Simulations using solar PV system and actual load data yielded more realistic findings for future study and planning. The line loss, power factor, and THD were acceptable since the 20KW rooftop PV system is linked to bus no. 2. Grid power factor and line loss were checked using load flow analysis. In harmonic analysis, the percentage of total voltage harmonic distortion limit was determined. PV systems linked at distribution network centers had the highest line loss and lowest grid power factor decrease. The impact evaluation showed that high PV system penetration reduced grid line loss and power factor. However, overall voltage harmonic distortion exceeded permitted limits above 30% penetration level.

Conflicts of Interest

The authors declare that they have no competing interests.

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