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Integration of Solar Distributed Generation with Power Grid

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ABSTRACT: *Some technologies, including solar panels and combined heat and power plants, are referred to as "distributed generation" because they generate energy at or close to the area where it will be utilised. Distributed generation (DG) can be used to power a single structure, such as a home or a place of business, or it can be a part of a microgrid, which is a smaller grid connected to a larger electricity delivery system. Examples of such structures include sizable factories, military bases, and college campuses. When linked to the lower voltage distribution lines of the electric utility, distributed production can increase the amount of clean, dependable power delivered to consumers while reducing electricity losses along the routes of transmission and distribution. The main causes of the growing interest in distributed generation are discussed in this research study. The voltage fluctuation of the distribution system before and after the connection of photovoltaic (PV) generation to the distribution network is investigated from the perspective of voltage drop in the power network. And the conclusion is that adding PV generation to the distribution network causes the distribution network's line voltage arisen. The suggested method is used with conventional 34-bus radial distribution systems.*

KEYWORDS *- Distributed Generation, Photovoltaic, Voltagr Fluctutaions*

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I.OVERVIEW

The generating, transmission, and distribution systems are the primary components of the power system. The distribution systems link the network to the major loads, including commercial, industrial, and residential buildings. The challenge of keeping voltages within the acceptable limits is made more difficult by the fact that the power system receives power from several producing units and distributes it to a sizable number of loads. The expansion of photovoltaic distributed generation (PVDG) in recent years has been crucial in addressing the power quality problems that are unavoidable, such as power outages, voltage control, and increased power losses. In addition to offering clients greater backup services, these modest power plants situated at later stations help reduce pollution, greenhouse gas emissions, and global warming. DG, which can range in size from a few kW to MW, is currently a component of distributed energy resources, along with energy storage and responsive loads. With the necessary needs of massive power plants, it also lessens the demand for the growth of distribution and transmission. The most appealing objective for the installation of DG near to the consumer's side of the network is to reduce power losses and voltage dips.

A solar cell, also known as a photovoltaic cell, is a device that utilizes the photovoltaic effect to transform light into an electric current. Charles Fritts created the first solar cell in the 1880s. Ernst Werner von Siemens, a German manufacturer, was one among many who understood the significance of this finding. Although the original selenium cells only converted 1% of incoming light into energy, German engineer Bruno Lange created a photo cell in 1931 using silver selenide in place of copper oxide. Researchers Gerald Pearson, Calvin Fuller, and Daryl Chapin created the silicon solar cell in 1954 following the work of Russell Ohl in the 1940s.. These early solar cells had efficiencies of 4.5–6% and were priced at US$286/watt. At Bell Laboratories, Mohamed M. Atalla created the thermal oxidation method for silicon surface passivation in 1957. Since then, the efficiency of solar cells has depended heavily on the surface passivation process. Almost 90% of the market will be crystalline silicon by 2022. The arrangement of a photovoltaic system provides direct current (DC) electricity which changes with the sunlight's intensity. This often requires conversion to alternating current (AC) via inverters for practical usage. Within solar panels, several solar cells are linked. Inverters, which provide electricity at the desired voltage and, for AC, the desired frequency/phase, are connected to arrays of panels that have been hooked together.

Several solar cells with semiconductor properties are combined to form a solar panel, which is then protected from the elements by a covering. These features allow the cell to collect light, or more specifically, photons from the sun, and convert their energy into usable power through the photovoltaic effect. The produced electricity is "collected" on both sides of the semiconductor by a layer of conducting material. To reduce reflection-related losses, the panel's lit side also has an anti-reflection layer. The bulk of solar panels produced globally are made of crystalline silicon, which has an account of the potential limit of 33% for transforming solar radiation into electricity.

II.SOLAR PHOTOVOLTAIC POWER GENERATION

Solar photovoltaic (PV) power generation involves employing solar panels to transform solar energy into electrical current. In a PV system, solar panels, also known as PV panels, are assembled into arrays. PV systems can be set up either off-grid (stand-alone) or linked to the grid. Solar panels, combiner boxes, inverters, optimizers, and disconnects are the fundamental parts of PV system topologies. Battery disconnects, meters, batteries, charge controllers, and grid-connected PV systems are further potential components. Grid-connected PV systems are more popular because they are simpler to construct and often less expensive than off-grid PV systems, which depend on batteries. Grid-connected PV systems enable residential users to reduce their grid usage and send any extra or unused energy back to the utility grid. Off-grid (stand-alone) PV systems employ solar panel arrays to charge batteries during the day so they may be used at night when there is no sunlight. Reduced energy expenses and power outages, the generation of clean energy, and energy independence are just a few of the benefits of adopting an off-grid PV system. Battery banks, inverters, charge controllers, battery disconnects, and optional generators are components of off-grid PV systems. Solar energy operates by transforming sunlight into electrical energy. The energy contained in each photon that makes up sunlight varies with their wavelength. A p-n junction is formed by the joining of two different types of semiconductors (such as silicon, Si), n-type and p-type. As photons from the incident light strike a solar cell, they may be reflected, transmitted through the cell, or absorbed by the semiconductor material. The semiconductor substance absorbs photons, which aids in the production of electricity. This occurs because for each photon that the material absorbs, an electron with a negative charge is ejected from one of its atoms.

The front surface of the solar cells is made to be more sensitive to displaced or liberated electrons so that they migrate to the cell's surface during design and manufacturing. A difference in electrical charge between the front and rear surfaces is produced when these free electrons migrate in the direction of the front surface. The solar cell's voltage potential is created as a result of this difference.

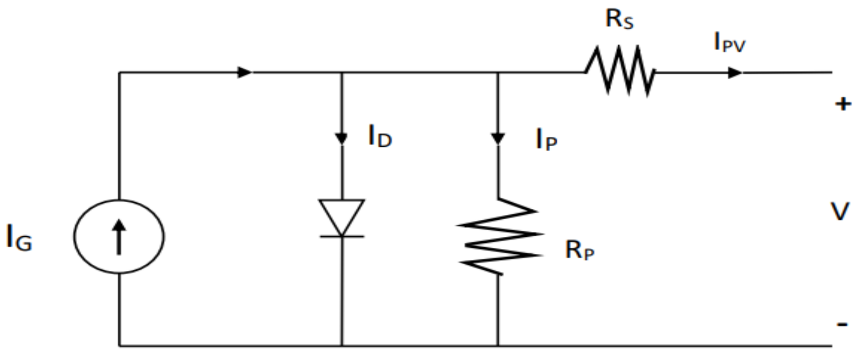

Fig. I Equivalent Circuit Model of a PV cell

In the above circuit, I_G represents the light-generated current in the cell, diode current is represented by $I_{D,}$ the current lost due to shunt branch resistance is denoted by $I_{P,}$ R_S and R_P are the seies and shut branch resistace respectively.

A Solar PV panel or module is created by electrically connecting solar cells. The solar panel's parameters and solar cell count determine its size and capacity. To create a solar PV array, solar PV modules are electrically linked. DC power is generated by a PV cell (direct current). This DC power may be utilised in devices that only use DC power or it can be transformed into AC power (alternating current) via an inverter. The majority of everyday objects are powered by AC energy.

III. SOLAR-GRID DISTRIBUTION SYSTEM

Your solar panel system is linked to the grid when it is grid-tied via a bi-directional electricity meter. When your solar panel system produces more energy than you use, it measures

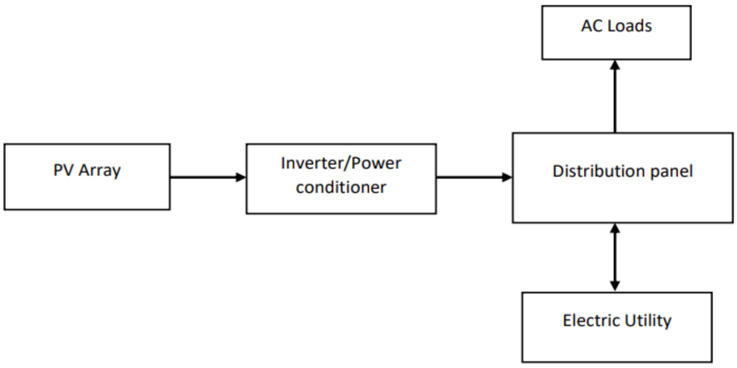

Fig. II Block diagram of Solar PV to Distribution System

the excess you send to the grid, and when it does not, it monitors the energy you draw from the grid. The technique known as solar-grid integration enables large-scale solar electricity generated by PV or CSP systems to enter the already-existing electrical grid. This technique needs considerable thought and study in all aspects, including the production, installation, and use of solar componentry. Effectively connecting the levels of solar energy penetration onto the transmission grid necessitates a thorough understanding of the impacts on the grid at various locations. The inverter is probably the most crucial component for integration in a photovoltaic plant that employs PV modules to input into the grid. Other components are also included. PV generators (solar modules), Generator Junction Boxes (GJB), Meters, Grid connections, and DC and AC cabling are other components. Each solar energy system depends on inverters, which are sometimes referred to as a project's brains. The primary purpose of an inverter is to convert direct current (DC) output into alternating current (AC), which is the industry standard for all appliances. Despite variable load circumstances, inverters must provide constant voltage and frequency, and in the event of reactive loads, they must either supply or absorb reactive power. Inverters do more than just invert; they also balance the systems with one another and feed solar energy into the grid as efficiently as feasible. Hence, the orientation, connections, and quality of the PV modules are just as crucial to the yield of a PV system as the inverter's dependability and efficiency.

IV. LOAD FLOW ANALYSIS

Forward sweep and BIBC martix were used for the load flow calculations. The BIBC matrix regulates the connections between bus current injected and branch currents. The KVL is implemented to upgrade the terminal voltages in a forward sweep starting from the branches in the first section and working towards those in the final. All of these are repeated until the voltage lies within allowable range.

These are the mathematical steps for the load flow solution:

Step 1: Initializing the variables

- Input network data.
- Input base voltage and base power.
- Determine base impedance.
- Determine p.u. values of line and load data.

Step 2: Numbering method for the radial distribution network

A number will be given to any section of the distribution system linking two buses according to the numbering method. A distribution system's total number of sections, N_s, may be estimated this way:

$$N_s = N_b - 1 \quad (1)$$

where, N_b represents the total number of buses. The number that each section carries must be one less than the bus number at the receiving end.

Step 3: Creation of BIBC matrix of order

$$(N_b - 1)\text{x}(N_s) \quad (2)$$

Step 4: Bus current

The injected bus current may be computed as:

$$I_k = \left(\frac{S_k}{V_k}\right)^* \quad (3)$$

where I_k is the current injection at k^{th} bus, S_k is the power injected at k^{th} bus, V_k denotess the voltage at k^{th} bus.
Step 5: Branch current
Branch current may be estimated by the product of BIBC matrix and bus current as:

$$I_B = [BIBC][I_{BUS}] \qquad (4)$$

where I_B denotes the current which is flowing in a branch.
Step 6: Forward sweep
By applying KVL in the branches, the bus voltages can be calculated. The receiving end voltage of a line linked to transmitting and receiving ends a and b may be computed as follows:

$$V_b = V_a - Z_B * I_B^n \qquad (5)$$

where V_b and V_a denotes the sending and receiving end voltages respectively.
Step 7: Stopping criterion
When the voltage at each bus come within permissible range the code will be stopped.
The following boundations has been applied to the objective function:
(a) Operating limitations

- Restriction on Bus voltage

The allowable minimum and maximum ranges for the voltage (V) for each bus are as follows.:

$$V_{min} \leq V \leq V_{max} \qquad (6)$$

- Total power factor restriction

The minimum power factor *(pf^{m})* should greater than the entire network power factor *(pf_{total})*, as:

$$| pf_{total} | \geq pf^{m} \qquad (7)$$

V.MODELING OF SOLAR IRRADIANCE

The power delivered by the Sun in the form of electromagnetic radiation in the measuring device's wavelength range per unit of surface area is known as solar irradiance. The SI unit for describing sun irradiance is Watts per square metre (W/m^2). The irradiance statistics typically show a bimodal distribution function for the same hour of the ordinary day for each season. The data are divided into two categories, each of which has a distribution function that is unimodal. Hence, a Beta pdf is used for each unimodal to depict the random behavior of the irradiance data, as seen in the following:

$$f_B(s) = \begin{cases} \frac{(a+b)!}{a!b!} * s^{(a-1)} * (1-s)^{(b-1)} \text{ for } 0 \leq s \leq 1, a \geq 0, b \geq 0 \end{cases} \qquad (8)$$

Where, *s* denotes the solar irradiance in KW/m^2. $f_b(s)$ denotes the Beta distribution factor of *s*. Parameters of the Beta distribution function are denotes by a and b.
The mean and standard deviation of the random variable are used to compute the parameters of the Beta distribution function as follows:

$$b = (1-\mu) * \left(\frac{\mu * (1+\mu)}{\sigma^2} - 1\right) \qquad (9)$$

$$a = \frac{\mu * b}{1-\mu} \qquad (10)$$

The probability of solar irradiance for every state at any given hour is determined by:

$$P_s\{G_y\} = \int_{s_{x1}}^{s_{x2}} f_B(v).dv \qquad (11)$$

where, $P_s\{G_y\}$ denotes the solar irradiance in a state *x*, s_{x1} and s_{x2} are the solar irradiance limits of sate *x*.

VI. DETERMINATION OF PHOTOVOLTAIC OUTPUT POWER

In addition to the parameters of the module itself, the solar irradiation and ambient temperature of the area affect the PV module's output power. The output power during the various states is therefore determined for this segment using the following formula once the Beta pdf has been created for a specified time interval as follows:

$$T_{C_x} = T_0 + s_{a_x}\left(\frac{N_t - 20}{0.8}\right) \qquad (12)$$

$$I_x = s_{a_x}[I + K_i(T_C - 25)] \qquad (13)$$

$$V_x = V - K_v * T_{C_x} \qquad (14)$$

$$P_{S_x}(s_{a_x}) = N * FF * V * I \qquad (15)$$

$$\text{FF} = \frac{V_m * I_m}{V * I} \qquad (16)$$

where, cell temperature in per degree celcius is denoted by T_{C_x}. T_0 represents the ambient temperature in per degree celcius. K_i and K_v represents the current and voltage temperature coefficient respectively. N_t denotes the nominal operating temperature of cell. FF represents the fill factor. Short circuit current and Open circuit voltage is denoted by I and V respectively. At maximum power site, voltage is denoted by V_m and at maximum power site, current is denoted by I_m.

VII.SELECTION OF OPTIMAL PV MODULE

The procedures for choosing the best PV module for a particular site are described in this section. The choice is made depending on the available PV modules capacity factors (CF). The proportion of average output power to rated power is known as a capacity factor. The total of the power generated in all feasible states for this hour multiplied by the associated probability of each state yields the hourly average output power of a PV module. Once the average output power for every time span has been determined, the yearly average output power may then be determined by calculating the average output power for a typical day throughout each season.

VIII.RESULTS AND DISCUSSION

In Fig.2, an IEEE-34 distribution bus system has been used for the study of this system. The range for voltage magnitude is set to be between 0.95 and 1.05 p.u. At bus number 18 and bus number 19, respectively the distribution system's minimum and maximum voltages were 0.89346 and 0.99285 before solar implantation.

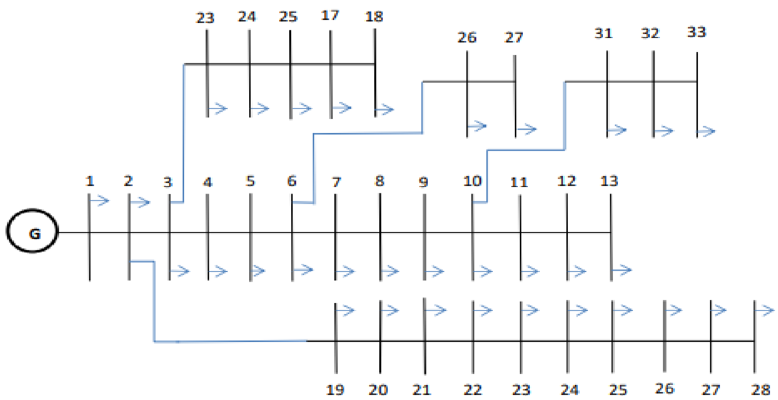

Fig. III IEEE-34 bus distribution system

When an active distribution system, like Solar's, is incorporated into the traditional passive distribution network, line losses are reduced and the voltage profile is improved, raising these figures to 0.95000 p.u. and 0.99564 p.u. Table I displays the voltages at each bus with and without solar panels.

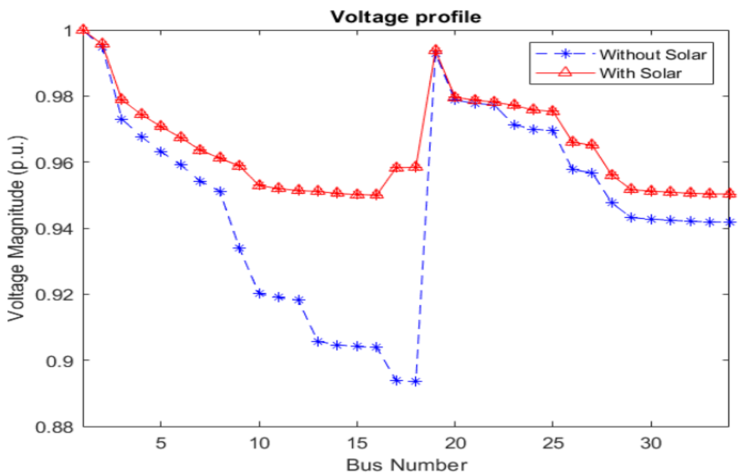

Fig. IV Voltage profile of the system

TABLE I

Voltage of the system with and without solar

Bus no.	Without Solar (p.u.)	With Solar (p.u.)
1	1.00000	1.00000
2	0.99473	0.99564
3	0.97302	0.97884
4	0.96768	0.97439
5	0.96320	0.97071
6	0.95909	0.96741
7	0.95429	0.96364
8	0.95110	0.96114
9	0.93390	0.95881
10	0.92016	0.95290
11	0.91897	0.95197
12	0.91817	0.95136
13	0.90569	0.95111
14	0.90466	0.95047
15	0.90414	0.95016
16	0.90389	0.95000
17	0.89387	0.95829
18	0.89346	0.95839
19	0.99285	0.99376
20	0.97870	0.97962
21	0.97782	0.97875
22	0.97725	0.97818
23	0.97131	0.97714
24	0.96995	0.97579
25	0.96950	0.97533
26	0.95767	0.96601
27	0.95677	0.96512
28	0.94761	0.95604
29	0.94317	0.95164
30	0.94274	0.95121
31	0.94240	0.95087
32	0.94206	0.95053
33	0.94189	0.95037
34	0.94184	0.95031

IX.CONCLUSION

When Distribution Generation is used in a distribution network such as solar, there are various advantages, including enhanced system voltage profile, lower line losses, and a reduction in the need for transmission and distribution capacity for both utilities and the end user. A 34-bus radial distributon system's simulation results uisng MATLAB are shown and evaluated in this paper.

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