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A Comprehensive Review and Analysis on Voltage Stability Enhancement Using Distributed Generation

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The present-day scenario of electrical power system engineering mainly comprises issues like power paucity, blackout, load shedding, and ineptness in meeting the necessary demand for power. Therefore, new power plants are built and old ones are expanded and upgraded. Although these developments play a key role in today's scenario, there remains a field where the scope of development persists. This review article focuses on incorporating load models in traditional (OPF) studies and comparing the results of the above with those obtained from OPF analysis with the incorporation of (DG). The study of stability analysis and its behavior is a very important aspect of power system planning and its design for reliable operation. The determination of the transient stability of an electric power system is a crucial step in power system analysis. It has become imperative for power engineers to look out for improvement in the voltage stability of a power system. For this purpose, the IEEE 9 bus system is considered. The main objective is the analysis of the transient stability of an IEEE 9 bus system consisting of three generators and nine buses. Further, transient analysis of the power system network will facilitate the design of a better DG network. Here, MATLAB software is used to analyze the stability of the power system.

Keywords: Smart Grids; Power System Stability; Load Flow Control; Photovoltaic Systems; Microgrids.

Optimal Power Flow	OPF
Distributed Generation	DG
Transient Stability Analysis	TSA
Single-Machine Infinite Bus	SMIB

Introduction:

Current power setups/systems are huge, wide, and multifaceted. Because of the growing demand for power transfer, the transmission lines are becoming overloaded. As the load on the transmission lines rises, the voltage stability of the system is affected due to which the system becomes unstable. Some of the parameters involved are the rotor speed, bus voltage, power flow, and other system variables. Voltage stability is a significant aspect designing of a power system. Power system stability is the capability of the system, for a given initial operating state, to preserve a normal state of equilibrium after being exposed to a disturbance [1].

Stability means the conservation of synchronism and the stability limit is the amount of power that can flow through the system or a portion of it while it is still stable. The capacity of a power system to maintain equilibrium under normal operating conditions and to regain equilibrium after being exposed to disturbances is known as power system stability [2]. Electric power system stability analysis has been accepted as a vital and challenging issue for safe system processing. When large disturbances happen in interconnected power systems, the security of these power systems must be observed. Security of these power networks rests on the examiner of the stability of systems in detail and to ensure security.

Power network steadiness is the property owned by a power system that empowers it to stay in a condition of balance under typical working circumstances and to recapture harmony after being exposed to unsettling influences. Power network steadiness may be comprehensively gathered in consistent state stability, after transient stability, and finally in dynamic stability as shown in Figure 1. Dynamic stability is the capability of an electrical network to stay in synchronism after the underlying swipe till the time system gets stabilized to the new steady state balance state [3].

Figure 1. Power system stability and its types.

It has turned into a need to keep up with synchronism because the demand for electrical energy is increasing day by day, due to which the electrical power system is expanding, and this results in the installation of the larger size of electrical generation machines nowadays [4] Due to the increase in electricity demand and the requirement of expansion in generation and resultantly, the requirement of electrical power transmission lines and power systems has become more complex and expensive. It is also to be highlighted that due to the increase in electricity demand, the load over the transmission line network is also increasing and the lines are becoming more and more overloaded [5]. Moreover, under the unusual functioning of the power networks, the voltage at each line is decreased and electrical power generators are becoming incapable of supplying active power (kW) and reactive power (kVAR) into the system operating under unusual functioning of the power networks. This state identifies a likelihood of functioning and operational staff taking serious actions to reestablish the secure functioning of the system.

For the resolution of such issues of heavily loaded lines of the transmission system and managing the high energy requirement, two arrangements may be used. One of these is by enhancing the generation capacity of electrical power and the second is by adding a new transmission line [6]. The rising expenses of modification and changes have made it necessary that plain choice should be selected wisely along with performing point-by-point investigations of the impact on the arrangement of every choice in the light of various presumptions such as:

- Regular and irregular functioning states
- Top most and bottom most loadings
- Current and upcoming time of functioning

(TSA) is a portion of dynamic safety evaluation of electrical networks which grows the development of the capability of electrical networks to stay in steadiness when exposed to disturbances. The reaction of networks to such disturbances includes a huge disparity of rotor angles, electricity circulation, bus voltages along additional network parameters [7]. TSA depends on the condition and the disorder. It results in the complexity of TSA subjected to the fact that variables of the network may not be overlooked [8]. Minor disruptions such as demand alteration occur repeatedly in the network resulting the network alterations to all these minor variations by preserving a suitable voltage and frequency magnitude for acceptable conditions of electrical networks [9][10]. Alteration in the network reactance occurs when a load variation has carried out on a substantial scale since most of the electrical loads are inductive in nature. Large disruptions such as tripping of generator set and error in transmission lines, take to a huge change in constraints of the networks (V, f) and are able to activate the production units that will further attempt to take the network back to its original or satisfactory working condition. Transient stability is affected by the impacts of accidental blackouts, shortcoming occurrences, or the use of abrupt load shedding [11].

TSA tends to the impacts of unplanned blackouts like abrupt blackouts, the frequency of issue or deliberation, or the use of unexpected load [12]. Transient stability investigation is performed to check the capacity of the network to endure the transients and to work on the general execution of the electrical network. Detail of transient stability analysis by utilizing MATLAB software is talked about further. The standard IEEE 9 Bus system with PV module-based distributed generation system is used for this analysis and to work on the transient stability of the electrical network. The main concern of the electrical network utility is to make sure the arrangement of dependable and secure power to its users to satisfy their energy needs.

Steady-state stability is the ability of a system to keep up the equilibrium among equipment when minor disruption happens [10]. Dynamic stability is the capability of a network to stay in equilibrium subsequently after the underlying swipe till the power network establishes the new steadiness state. The principal accentuation goes to the transient stability of the network. Transient stability examination requires information on the appropriate upsides of voltages, power, and RMS values of voltages. The majority of the nations all over the globe have unified power networks, in which electric utilities introduce enormous generators and long transmission lines to generate and transmission of electrical power [13][14]. As part of the green revolution, protective devices are used throughout the entire power system up to the distribution level to more composite power generator devices. These devices serve as tools to illustrate and study the highly complex and constantly expanding power network, ensuring reliable operation at the consumer end [15].

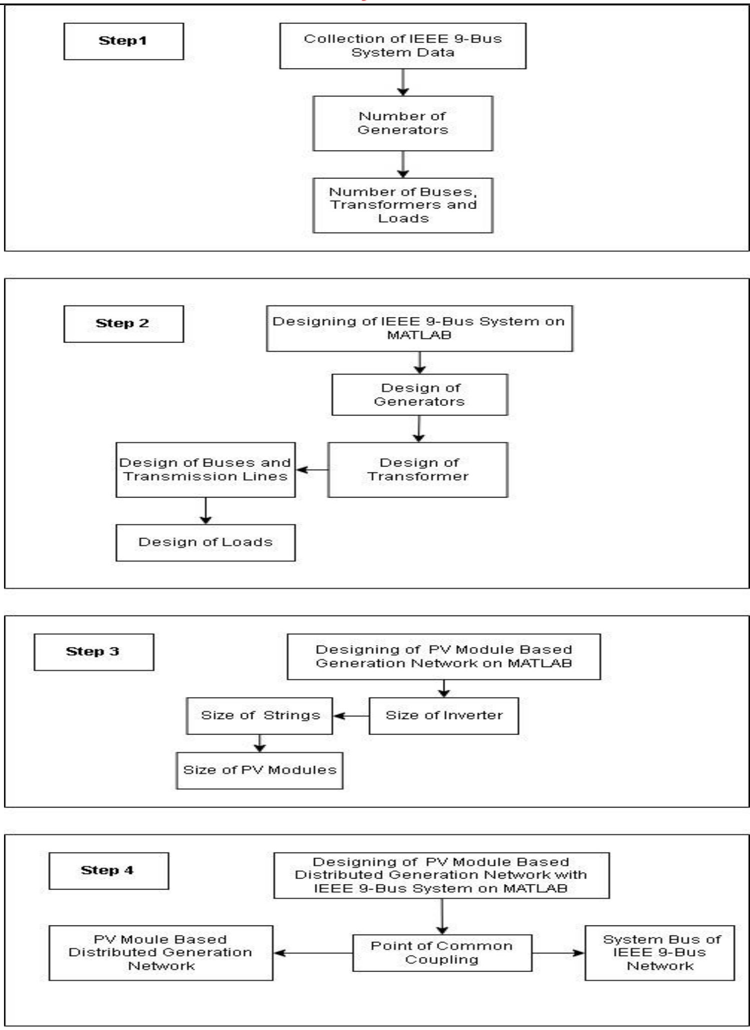

Figure 2. Proposed research methodology.

The methodology of the research is outlined in Figure 2 in which step 1 is collection of data of IEEE 9 Bus system which includes data of generators, transformers, transmission lines and loads. In step 2, IEEE 9 Bus system is designed which includes modeling of generators, transformers and designing of transmission lines and loads. In step 3, PV plant is designed after the characterization of series strings, parallel strings, inverter specifications and PV selection. In final step 4, the optimum bus for PV installation also termed as point of common coupling is evaluated by plotting the results of voltage and power factor before PV installation. After the PV integration, both results are re-evaluated for a one-to-one comparison.

Research Objectives:

This research work is aimed at improvising voltage stability of IEEE 9 Bus system by the use of distributed generation at a single bus of the IEEE 9 Bus system. As a distributed generator, photovoltaic (PV) plant is considered. The voltage and power factors at all 9 buses are evaluated initially without PV plant to examine the weakest bus or the bus having the poorest power factor and voltage plots. It is obvious that the integration of PV at this bus will give the best performance at this bus and the results will be improved at other buses also. Subsequently, a PV plant is installed at this bus and the simulation is run again to get the new set of results. A close comparison between the voltage profiles before and after the DG integration will give the voltage stability improvement.

Novelty:

There exists a considerable vacuum in the investigation of voltage and transient stability in a multi-bus system as a result of distributed generation especially when PV plant is used. One obvious reason is that a PV system initially undergoes transient oscillations when embedded with a feedback loop for current and voltage control. During this control action, output fluctuates before being settled to the final steady value. If the system is efficiently designed, the voltage profile at all the nine buses improves after the PV integration which is an aspect not reported in the published works so far.

Materials and Methods:

Concept of Power System Stability:

With the use of a (SMIB) system and two transmission lines, the idea of transient stability is explained and illustrated in Figure 3.

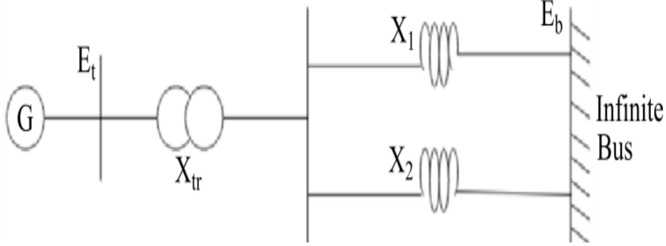

Figure 3. Two transmission lines with SMIB network.

Undescended order corresponding circuit of the SMIB network is depicted in Figure 4 ignoring the resistance of the stator, the P_e is the air gap power equal to the power at the terminal and is given in Eq. (1) [16]:

$$P_e = \frac{E' E_b}{X_T} \sin\delta = P_{max} \sin\delta \quad (1)$$

$$P_{max} = \frac{E' E_b}{X_T} \quad (2)$$

Where P_{max} is the maximum power and δ = Angle between transient voltages E' and E_b.

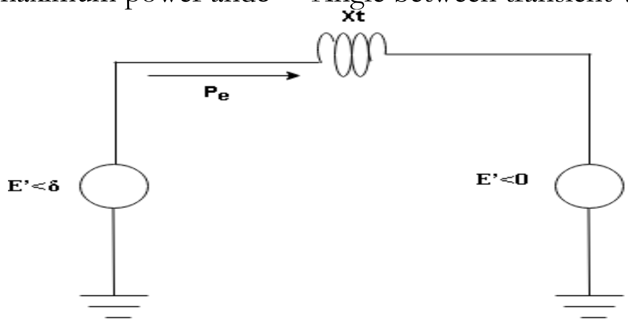

Figure 4. Reduced circuit of SMIB network.

Factors Influencing Transient Stability:

From the key lessons achieved in the previous discussion, it is obvious that the generator's transient stability rests on the subsequent factors [17]:

- Load at the generator end.
- The generator output during a fault depends on the nature and location of the fault.
- Clearing time of fault.
- Alteration in network reactance among production units and consumer hubs.
- Inertia related to the generator.
- The interior voltage level related to the generator that is related to the field.
- Excitation.

IEEE 9 Bus System:

IEEE Bus systems are mostly used by scientists to apply new concepts and theories. IEEE 9 Bus network/system is a broadly used test network model for various stability states and advanced simulation research by investigators and scientists for the simulation of new procedures or thoughts, particularly related to power network stability analysis. IEEE 9 Bus system consists of nine buses, three two-winding power transformers, three generator sets, three loads, and six lines as shown in Figure 5. IEEE 9 Bus system contains generators, loads, and transformers which are specified. Generator set 1 *i.e.* G_1 is linked with a slack bus named Bus 1, while generator set 2 *i.e.* G_2 and generator set 3 *i.e.* G_3 are linked with PV-bus. Loads *i.e.* A, B, and C are linked with bus bars 5, 6, and 8 respectively [18].

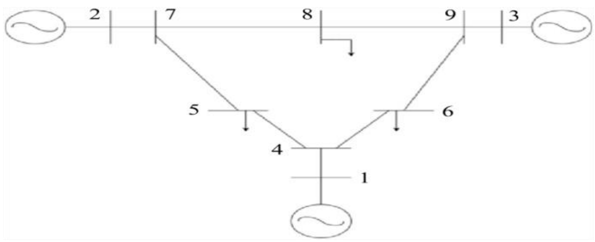

Figure 5. IEEE 9 bus network.

Buses in Power System:

A hub where one or more line or one or more than one load and generator sets are joined or linked is described as the bus. Every such hub or bus comprises four parameters which include a level of voltage, voltage angle, real power, and reactive power in the system. Buses are categorized into three types, subjected to the parameters which are described in Figure 6.

The load voltage, phase angle, real, and reactive power are the four parameters that make up a system node. We take into account three different bus types while specifying the system nodes. Buses and variables are connected. The buses have the names Load, Generator, and Slack. The load buses are those without generators (P-Q bus). While the reactive and real powers are known in this case, V and are unknown. Q and in the Generator bus (P-V bus) are unknown. The intensity of the voltage is maintained at this bus, and the generator's prime mover supplies the actual power. Reference bus is another name for slack bus. The magnitude and phase of the voltage are fixed. Types of buses are as described in the upcoming discussion [19]:

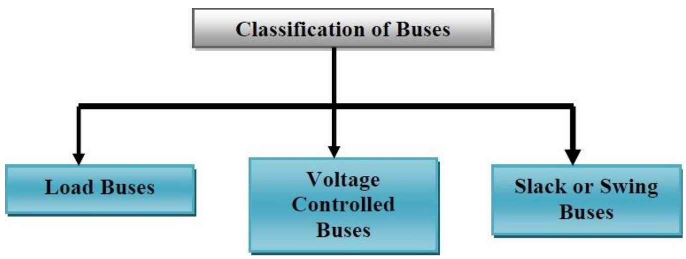

Figure 6. Type of busses.

Load Bus (P-Q Bus):

In a P-Q bus, real and reactive powers are already identified. However, voltages along with angles are the parameters that are desired to be found. In a typical power network, almost 80% of buses are P-Q buses [20].

Voltage Controlled Bus/ Generator Bus (P-V Bus):

In a P-V bus real power and voltages are already identified. However, reactive power along with angle is the parameter that is desired to be found. Generator sets are normally linked with these buses. Reactive power Q and voltage phase angle δ must be found in these types of buses [21]. In principle, the buses which are directly connected to the voltage source are called voltage controlled or P-V buses.

Slack or Swing Bus:

The injected powers at generator buses are taken as positive and as negative at load buses. Before finding the system parameters, the network failures or losses are not identified. Hence, a generator bus, usually called a reference or slack bus provides the required active and reactive powers to supply for these losses [22].

Distributed Generation:

To overcome the load demand and electrical power generation gap, the electrical power is generated at the load or local ends of a distribution network. Distributed power generation equipment comprises an integrated generator set and offers many potential advantages. In many cases, Distributed generators can deliver electricity at low expense with higher reliability of power along with safety with a smaller number of climatic concerns as compared to conventional electrical generators in contrast to the utilization of generating stations of large size situated far away from load centers. This technique is utilized for conventional electrical power plants. Schemes of distributed generators work for several but minor sizes of plants and power can be delivered on site with slight dependence on the distribution and transmission grid. Distributed generators are the latest, at load end, small size of grids, as compared to the conventional, central electricity grid. By connecting to the power appliance's bottom voltage distribution wire, distributed generators can be of great favor for the provision of neat consistent electricity for the surplus users and can decrease power failure in the whole power system or network.

Microgrids can be isolated from central power systems and function unconventionally, built-up system flexibility, and support alleviated system instabilities. These can be normally small voltages AC power stations which frequently can be in the form of diesel generator sets and are mounted by the communal they provide. Distributed generators progressively serve as a combination of diverse, disseminated energy assets like solar power networks which considerably decrease the quantity of released carbon dioxide. (DGs) comprises two stages which are the limited stage and the final stage DGs [17]. Local power production grids normally consist of re-useable power procedures that are identified with the location of the generation plan like wind turbines, geothermal energy generation, PV networks, and many other hydroelectric and heat-based stations as presented in Figure 7.

DG, dispersed assets and distributed sources deliver the distributed production of the power. Electricity may be produced near its location of usage. The following are the benefits of using DG:

- Helpful neighborhood situating away from the transmission and dispersion failures.
- Production nearby users permits appropriate usage of thermal power (mutual thermal and electrical energy).
- Helpful neighborhood installation empowers accessible wellsprings of power to be utilized, *e.g.* byproducts or inexhaustible assets might be handily used to preserve petroleum products.
- Helpful neighborhood installation permits the utilization of accessible 1-phase or 3-phase power production.

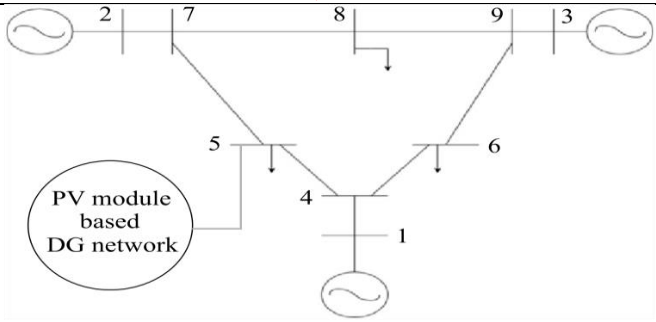

Figure 7. IEEE 9 Bus network with PV module-based distributed generation system.

Results and Discussion:

Load Flow Study:

Per unit symbolization and single-line diagrams are frequently used in load flow studies. When the power sources and loads are predefined, the main goal of load flow is to calculate the voltage level of every bus and its angle. The concurrent nonlinear algebraic power equations for the two unknown variables ($|V|$ and δ) at each node in a system are explained by load flow. Fast, efficient, and precise mathematical procedures are essential for solving nonlinear algebraic equations. Buses serve as the connecting points between two or more lines.

The most popular and important study for power networks is called load flow analysis, and it examines the sinusoidal stable level of system voltage, active and reactive power, and power dissipation. Power flow analysis, commonly referred to as load flow, is a crucial method for analyzing problems in the grid or network of power systems. Using load flow analysis, it is possible to determine the condition of the network's equipment and to check that it is operating within predetermined limits. In this review, the power system's stable operation state is reported using reference voltage and branch power flow. Another of the most important aspects of designing and operating a power system is the load flow analysis.

Transient stability analysis cannot be carried out without the awareness of pre-fault system load flow information. Numerous procedures are being introduced to resolve the nonlinear load flow issue. The following three methods are the most common for carrying out the load flow analysis.

- Gauss-Seidel Method
- Newton Raphson Method
- Fast Decoupled Method

Gauss Siedel and Newton Raphson's techniques are one of the frequently used methods which are considered for the load flow and they appear to be present in all significant software programs for power system analysis. The choice of which method to use rests on the kind of research required and the complication of modeling used. To efficiently resolve the power flow problem for huge and complex networks, additional knowledge is essential in terms of suitable selection and use of parameters. Many times, researchers go for Newton Raphson's method reason being that the surety of complete convergence is likely. The system is then configured for dynamic simulation by adding the dynamic modeling of the system to the static load flow model after determining the load flow. Finally, the fast decoupled method is preferred for fast convergence and less memory requirements however, the accuracy of this method is traded off. The performance comparison of all three methods is highlighted in Table 1.

Table 1. Methods of load flow study.

	Gauss -Seidel	**Newton- Raphson**	**Fast Decoupled**
Complexity	Easy	Complex	Less Complex
Sensitivity	Not Available	Available	Available
System Size	Can be Challenging in large systems	Suitable for all sizes	Suitable for all sizes
Accuracy	Good	Best	Average
	Gauss -Seidel	**Newton- Raphson**	**Fast Decoupled**
Complexity	Easy	Complex	Less Complex
Sensitivity	Not Available	Available	Available
System Size	Can be Challenging in large systems	Suitable for all sizes	Suitable for all sizes
Accuracy	Good	Best	Average

The current part is going to offer a mathematical representation of the equations that are of great use to resolve constraints to design a power system. Out of three described power flow algorithms, Newton Raphson method is assumed to be the most efficient in terms of fast and successful convergence, low computational cost and less memory requirements. Newton-Raphson method works on the electrical quantities in phasor form and similar to the other algorithms, it also uses three classifications of buses namely; slack bus, P-Q bus and P-V bus. As we have already basic knowledge about the analysis of AC circuits. Therefore solution of current (*i*), voltage (*v*), and impedance (*z*) in phasor form yields expressions shown in Eqs. (3)(5):

$$\nu = |V| \measuredangle \delta_v (3)$$
$$i = |I| \measuredangle \delta i (4)$$
$$z = |V| \measuredangle \delta v \; |I| \measuredangle \delta i (5)$$

Remembering that apparent power, S, in the 3-phase network is according to Eq. (6)

$$S_{3\varphi} = 3 * V_\varphi * I_\varphi = \sqrt{3} V_L - L I_L (6)$$

The apparent, active and reactive powers can be defined in polar form as shown in Eqs. (7)(9).

$$S_{3\varphi} = P_{3\varphi} + jQ_{3\varphi} (7)$$
$$P_{3\varphi} = \sqrt{3} V_L - L I_L \cos\theta (8)$$
$$Q_{3\varphi} = \sqrt{3} V_L - L I_L \sin\theta (9)$$

The system parameters acquired from the load flow study are calculated using the aforementioned formulas. One way to incorporate these expressions is the equation-based modeling which requires intensive coding exercises and is prone to errors and mistakes owing to the inclusion of several variables. The alternative approach deals with the GUI framework of a power flow solver which requires electrical components to be joined together to form a single line diagram (SLD) and run the simulation after selecting one of the three power flow programs. This approach is more user-friendly, time-saving, and error-free and gives the same result as the coding-based approach therefore; this technique is utilized in this paper.

System/Network Data:

The values of transmission lines attached with all busses are based on Table 2 which includes transmission line resistance, reactance, and susceptance according to their length.

Table 2. Transmission line data.

Tr Line	**R (pu)**	**X (pu)**	**B (pu)**
1-4	0	0.0576	0
2-7	0	0.0625	0

3-9	0	0.0586	0
4-5	0.010	0.085	0.176
4-6	0.017	0.092	0.158
7-5	0.032	0.161	0.306
7-8	0.0085	0.072	0.149
9-8	0.0119	0.1008	0.209
9-6	0.0390	0.17	0.358

π Model Equivalent Data of Transmission Line:

The transmission line is technically represented by either an equivalent T model or π model. In the π model equivalent circuit of the transmission line, the length along with 0 sequence and +ve sequence impedance is considered. Table 3 shows the length and sequence resistances of transmission lines between buses 4-5, 4-6, 7-5, 8-9, and 6-9. Notably, the 0-sequence resistance is 3 times greater than the +ve-sequence resistance from the values in Table 3.

Table 3. π model length and resistance

Tr L	Length	R_1	R_0
1-4	-	-	-
2-7	-	-	-
3-9	-	-	-
4-5	97.38	0.054	0.162
4-6	95.99	0.093	0.281
7-5	176.71	0.095	0.287
9-8	115.56	0.054	0.163
9-6	196.41	0.105	0.315

Table 4 outlines the 0 sequence and +ve sequence resistance inductances and capacitances of the transmission line's π model equivalent circuit. Here again, the 0 sequence inductances and capacitances are 3 times greater than the +ve sequence inductances and capacitances respectively. There are only five transmission lines between buses 4-5, 4-6, 7-5, 8-9, and 6-9 so the other data is absent from the first three rows in Table 4.

Table 4. π model inductance and capacitance

Tr L	L_1	L_0	C_1	C_0
1-4	-	-	-	-
2-7	-	-	-	-
3-9	-	-	-	-
4-5	0.0012	0.0036	9.06×10^{-9}	2.720×10^{-8}
4-6	0.0013	0.0040	8.257×10^{-9}	2.477×10^{-8}
7-5	0.0012	0.0038	8.687×10^{-9}	2.606×10^{-8}
9-8	0.0012	0.0036	9.073×10^{-9}	2.721×10^{-8}
9-6	0.0012	0.0036	9.144×10^{-9}	2.743×10^{-8}

The data of all nine buses including base voltages, their per unit values, and initial voltage angles is tabulated in Table 5. The first three buses have generators connected to them which are operating at 16.5 kV, 18 kV, and 13.8 kV respectively. The internal buses are connected with these P-V buses after the transformer which steps up the voltage to the same level of 230 kV.

Table 5. Bus data.

Bus #	Bus Type	Bus voltage kV	Set voltage pu	Angle Degree
1	Slack	16.5	1.04	0
2	Voltage	18	1.025	0
3	Voltage	13.8	1.025	0
4	Load	230	1	0
5	Load	230	1	0
6	Load	230	1	0
7	Load	230	1	0
8	Load	230	1	0
9	Load	230	1	0

The data on power generation and consumption through load is provided in Table 6. All load units deal with both active and reactive powers so generators are forced to supply reactive powers in addition to the active powers. The reactive powers of load units are implied by the presence of inductive loads.

Table 6. Generation and load data.

Bus#	Generator		Load	
	P(MW)	Q(MVAR)	P(MW)	Q(MVAR)
1	0	0	0	0
2	163	0	0	0
3	85	0	0	0
4	0	0	0	0
5	0	0	125	50
6	0	0	90	30
7	0	0	0	0
8	0	0	100	35
9	0	0	0	0

Simulation Results:

After modeling the required system, the desired simulation results are carried out which are stepwise discussed in detail as follows.

Without Distributed Generation:

IEEE 9 Bus networks without a proposed distributed generation system are discussed in terms of their voltage profile and their power factor profiles.

Voltage Profile:

MATLAB simulation results of case 1 are based on the IEEE 9 Bus system without an embedded PV module system. The results describe the behavior of all network bus voltages without a PV module-based distributed generation system. Due to the transmission line, a significant voltage drop occurs and due to these voltage drops, the voltage profile of the system is very poor at the load end side. The proposed system is designed on the load bus or Bus 5 since, among all the buses, Bus 5 has a relatively smaller voltage and power factor before the distributed generation. The normalized voltage of nine buses in IEEE 9 Bus system is defined as the ratio of the sum of actual bus voltages to the sum of base voltages. Here, we observed that the voltage profile at Bus 5 is very poor. Graphical representation of the IEEE 9 Bus network voltage profile is illustrated in Figure 8 which shows clearly the drop of voltage at load bus is very high. Before the installation of distributed generation, the normalized voltage is calculated to be 0.95 Due to this voltage drop, the overall voltage profile of the system declines.

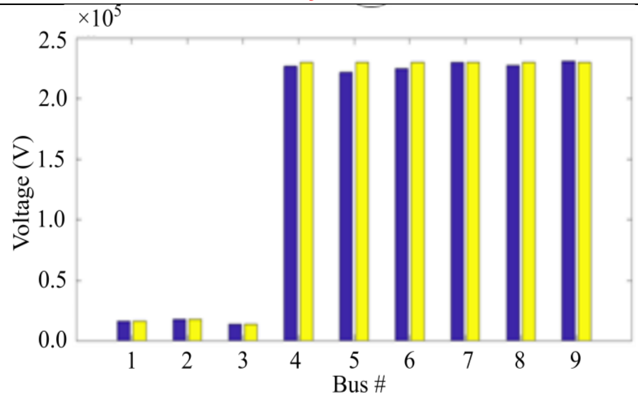

Figure 8. IEEE 9 Bus network voltage profile without DG.

Power Factor:

The simulation result of case 1 is based on the IEEE 9 Bus network without an embedded PV module system. The results describe the behavior of the all-network bus power factor without a PV module-based distributed generation system. Due to the transmission line, a voltage drop occurs which results in poor power factor profiles. Due to this lower power factor profile, the system power factor is very poor at the load end side. Here again, the normalized power factor is defined as the ratio of sum of power factors at all nine buses to the sum of maximum/ideal power factor *i.e.* 9. The proposed system is designed for the load bus or Bus 5. Here, we observed that the power factor profiles at Bus 5 and Bus 6 are very poor. A graphical representation of the IEEE 9 Bus network's power factor profile is illustrated in Figure 9 which shows that the power factor at Buses 5 and 6 are very poor. The normalized power factor at IEEE 9 Bus system before PV installation is calculated to be 0.93. Due to the poor power factor, the overall power factor profile of the system is not satisfactory.

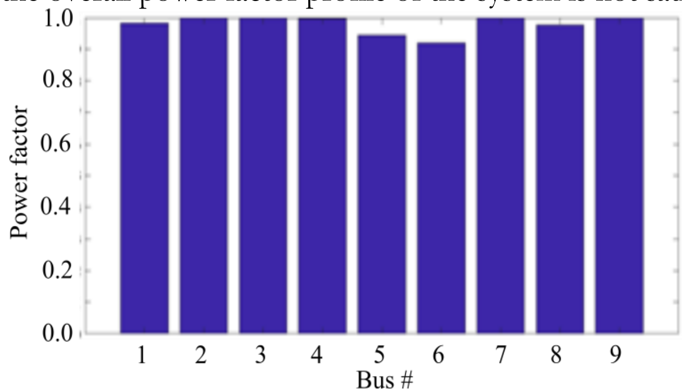

Figure 9. IEEE 9 Bus network power factor profile without DG.

With Distributed Generation:

Voltage Profile:

A detailed graphical comparison of the voltage profile of the IEEE 9 Bus network embedded with the PV module-based generation network has been depicted in Figure 10. It depicts clearly that the voltage profile of all of the IEEE 9 Bus networks after being embedded with solar-based renewable energy sources has been improved significantly. It can also be observed that the voltage profile has been improved at Bus 5 and as well as in the overall system *i.e.* with PV module in comparison with the previous system *i.e.* without PV module-based IEEE 9 Bus network. The normalized voltage after PV installation as distributed generation in IEEE 9 Bus system is calculated to be 0.98 which is improved from previous value of 0.95.

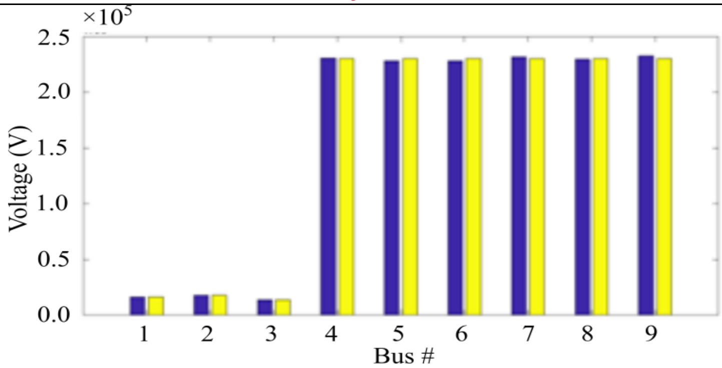

Figure 10. IEEE 9 Bus network voltage profile with DG.

Power Factor:

A detailed graphical comparison of the power factor profile of the IEEE 9 Bus network embedded with PV module-based generation has been illustrated in Figure 11. It demonstrates clearly that the power factor profile has been improved significantly in all of the IEEE 9 Bus networks after being embedded with solar-based renewable energy sources. It can also be observed that the power factor profile has been improved at Buses 5 and 6 especially and as well as overall in the system *i.e.* with PV module in comparison with the previous system *i.e.* without PV module-based IEEE 9 Bus.

Therefore, it is clear now that after connecting the PV module, the voltage profile of the entire IEEE 9 Bus network is improved. Moreover, it is also observed that by improving the voltage profile of the IEEE 9 Bus network embedded with a PV module-based distributed generation network, the power factor of such a system is also improved as illustrated in Figure 11. The normalized power factor which is a measure of the overall power factor of all the nine buses is evaluated to be 0.99 which is improved from 0.93 before PV integration.

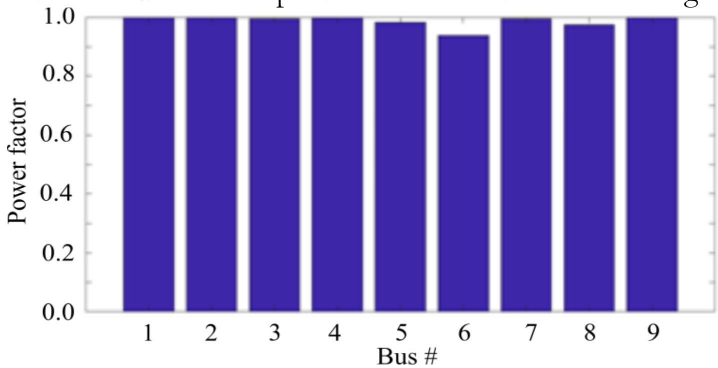

Figure 11. IEEE 9 Bus network power factor profile with DG.

The obtained results are in good agreement with the ones with our recent publication [23]. That methodology involved global search algorithm namely particle swarm optimization (PSO) to find the position of the DG bus which was evaluated as Bus 5 similar to this research. The objective function in that work was constituted by the normalized summation of voltage and power factor terms and was improved from 1.95 to 1.99. In this work, the target variables are also improved from 0.95 to 0.98 for voltage profile and 0.93 to 0.99 for power factor. This technique is rather simpler since it eliminates the need to execute global search algorithm and provided results of comparable quality. Hence, this approach is time saving, less computationally and memory wise expensive and accurate.

Conclusion:

Advanced electrical power networks have developed as more complicated because of interlinkage, the deployment of huge production plants and additionally huge voltage links, and other factors. Because of amplified processes that can lead the power network toward an extremely tense state, the requirement for dynamic stability of the network is growing. Transient stability analysis is related to the dynamic security assessment of the power network which grows the development of the capacity of a power system to stay balanced when it is encountered with a disturbance.

Analysis of transient stability is a component of the electrical network's dynamic security evaluation. This comprehensive review analyzed the transient stability of an IEEE 9 Bus system that was simulated using the MATLAB/SIMULINK program. One of the main stability issues with electric power stations is transient stability. To determine the level of stability that a grid possesses, the examination of transient stability is a key test method. It is broadly acknowledged that transient stability analysis is a significant feature and has key importance in designing and upgrading electric power systems/networks and grid stations. The objective of this review is to examine the transient stability analysis of one of the basic case IEEE 9 Bus systems with and without PV module-based distributed generation and then comparison of the outcomes for finding an appropriate conclusion by using with and without PV module-based distributed generation network. The load flow examination and transient stability analysis for the standard IEEE 9 Bus system have been accomplished. The standard IEEE 9 Bus system consists of 9 buses, 3 generators, 3 loads, and 3 transformers. The whole system is absolutely stable before and after the installation of DG. After the DG integration, the system could run into unstable oscillations due to the presence of feedback loop to control the inverter current and voltage. If this would be the case, the bus voltages would have undergone overshoot excessively higher than the base voltages. But since the bus voltages are observed close to the base voltages, the overall system is declared as stable also after the DG integration. The following text has been added to the conclusion section of the manuscript.

Using the MATLAB simulator, the goal was to examine and comprehend the stability of power network simulation and transient stability analysis of the IEEE 9 bus network. Load flow analysis was carried out to find out the transient stability of the network. With the help of a PV module-based distributed power generation system, the variations in voltage and power factor of the network were examined. Voltage is a feasible indicator of whether the power networks are deficient or not. For a distributed power generation system, transient stability was analyzed to restore the system to its stable condition. Moreover, with and without PV modules, performance was compared based on distributed power network for better results taking towards the transient stability of the network. As a result, to get the system to a stable condition, the influence of load switching was also calculated.

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REFERENCES:

[1] R. Kaur and D. Kumar, "Transient Stability Improvement of IEEE 9 Bus System Using Power World Simulator," *MATEC Web Conf.*, vol. 57, p. 01026, May 2016, doi: 10.1051/MATECCONF/20165701026.

[2] and B. V. R. S, Naghizadeh, Jazebi, "Modeling hydropower plants and tuning hydro governors as an educational guideline," *Int. Rev. Model. Simulations*, vol. 5, no. 4, pp.

1780–1790, 2012, [Online]. Available: https://www.semanticscholar.org/paper/Modeling-Hydro-Power-Plants-and-Tuning-Hydro-as-an/225781c45ad2ef7dc27ca0c4b6e4fc6e7a168e13

[3] J. Ansari, A. R. Abbasi, M. H. Heydari, and Z. Avazzadeh, "Simultaneous design of fuzzy PSS and fuzzy STATCOM controllers for power system stability enhancement," *Alexandria Eng. J.*, vol. 61, no. 4, pp. 2841–2850, Apr. 2022, doi: 10.1016/J.AEJ.2021.08.007.

[4] L. Kong, "Stability analysis and design of grid-interactive power electronic converters," *PhD Diss. Univ. Tennessee*, 2022, [Online]. Available: https://trace.tennessee.edu/utk_graddiss/7280/

[5] and J. R. X. Liang, H. Chai, "Analytical methods of voltage stability in renewable dominated power systems: a review," *Electricity*, vol. 3, no. 1, pp. 75–107, 2022, doi: https://doi.org/10.3390/electricity3010006.

[6] B. J. and S. M. P. M. Anderson, C. F. Henville, R. Rifaat, "Power system protection," *John Wiley Sons*, 2022, doi: 10.1002/9781119513100.

[7] M. Al-Muhaini and G. T. Heydt, "Evaluating future power distribution system reliability including distributed generation," *IEEE Trans. Power Deliv.*, vol. 28, no. 4, pp. 2264–2272, 2013, doi: 10.1109/TPWRD.2013.2253808.

[8] W. El-Khattam, Y. G. Hegazy, and M. M. A. Salama, "An integrated distributed generation optimization model for distribution system planning," *IEEE Trans. Power Syst.*, vol. 20, no. 2, pp. 1158–1165, May 2005, doi: 10.1109/TPWRS.2005.846114.

[9] A. Kumar, Prashant, D. Kumar, F. Danish, M. Sarwar, and R. Singh, "Reliability Assessment of Distribution System with Distributed Generation: A Case Study," *2023 Int. Conf. Power, Instrumentation, Energy Control. PIECON 2023*, 2023, doi: 10.1109/PIECON56912.2023.10085774.

[10] M. R. Nayak, "Optimal feeder reconfiguration of distribution system with distributed generation units using HC-ACO," *Int. J. Electr. Eng. Informatics*, vol. 6, no. 1, pp. 107-128, 2014, [Online]. Available: https://ijeei.org/docs-199989948533152c19aa86.pdf

[11] J. E. Kim and J. S. Hwang, "Islanding detection method of distributed generation units connected to power distribution system," *PowerCon 2000 - 2000 Int. Conf. Power Syst. Technol. Proc.*, vol. 2, pp. 643–647, 2000, doi: 10.1109/ICPST.2000.897098.

[12] and M. A. R. Syahputra, I. Robandi, "Performance analysis of wind turbine as a distributed generation unit in distribution system," *Int. J. Comput. Sci. Inf. Technol.*, vol. 6, no. 3, pp. 39–56, 2014, [Online]. Available: https://www.airccse.org/journal/jcsit/6314ijcsit03.pdf

[13] S. F. Alwash, V. K. Ramachandaramurthy, and N. Mithulananthan, "Fault-location scheme for power distribution system with distributed generation," *IEEE Trans. Power Deliv.*, vol. 30, no. 3, pp. 1187–1195, Jun. 2015, doi: 10.1109/TPWRD.2014.2372045.

[14] "https://www.electricaltechnology.org/2021/10/electric-power-distribution-network.html.".

[15] S. K. and S. K. N. Panwar, "Role of renewable energy sources in environmental protection: A review," *Renew. Sustain. Energy Rev.*, vol. 15, no. 3, pp. 1513–1524, 2011, doi: https://doi.org/10.1016/j.rser.2010.11.037.

[16] A. A. Jhumka, A. K. Ah, A. Khoodaruth, and C. Ramasawmy, "Comparative Performance Analysis of Solar Energy and Wind Energy Systems using Rotor Angle Stability," *ENERGYCON 2022 - 2022 IEEE 7th Int. Energy Conf. Proc.*, 2022, doi: 10.1109/ENERGYCON53164.2022.9830452.

[17] R. P. and K. N. H. R. F. Mochamad, "Probabilistic multi-stability operational

boundaries in power systems with high penetration of power electronics," *Int. J. Electr. Power Energy Syst.*, vol. 13, p. 107382, 2022, doi: https://doi.org/10.1016/j.ijepes.2021.107382.

[18] J. W. B. and J. R. B. J. Machowski, Z. Lubosny, "Power system dynamics: stability and control," *John Wiley Sons*, 2020, [Online]. Available: https://www.researchgate.net/publication/41231911_Power_System_Dynamics_Stability_and_Control

[19] R. Patel, T. S. Bhatti, and D. P. Kothari, "MATLAB/Simulink-Based Transient Stability Analysis of a Multimachine Power System," *http://dx.doi.org/10.7227/IJEEE.39.4.3*, vol. 39, no. 4, pp. 320–336, Oct. 2002, doi: 10.7227/IJEEE.39.4.3.

[20] and N. M. M. K. Saini, N. K. Yadav, "Transient stability analysis of multi-machine power system with FACT devices using MATLAB/SIMULINK environment," *Int. J. Comput. Eng. Manag.*, vol. 16, no. 1, pp. 46–50, 2013, [Online]. Available: https://www.semanticscholar.org/paper/Transient-Stability-Analysis-of-Multimachine-Power-Saini-Yadav/dcc2eb1582f020ac80532d33537f9ba01678c758

[21] F. Milano and K. Srivastava, "Dynamic REI equivalents for short circuit and transient stability analyses," *Electr. Power Syst. Res.*, vol. 79, no. 6, pp. 878–887, 2009, doi: https://doi.org/10.1016/j.epsr.2008.11.007.

[22] G. G. Karady, A. A. Daoud, and M. A. Mohamed, "On-line transient stability enhancement using multi-agent technique," *Proc. IEEE Power Eng. Soc. Transm. Distrib. Conf.*, vol. 2, pp. 893–899, 2002, doi: 10.1109/PESW.2002.985135.

[23] H. R. S. Haneef, Z. Rashid, S. A. Haider, Z. A. Arfeen, N. Husain, A. Yahya, M. Amjad, "Stochastic optimal PV placement and command based power control for voltage and power factor correction using MOPSO algorithm," *Ain Shams Eng. J.*, vol. 15, no. 11, p. 102990, 2024, doi: https://doi.org/10.1016/j.asej.2024.102990.