ANALYSIS OF ROTOR ANGLE STABILITY OF PV INTEGRATED GRID

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Abstract
In the last decade, energy demand is increased rapidly and it is increasing day by day so along with renewable sources energy generation, people shifted their focus on nonrenewable sources as well. In energy generation, from renewable sources such as solar and wind played a key role. Therefore, it is necessary to connect the existing grid to the solar PV generating system. While doing this interconnection several issues may occur such as Instability imbalance, harmonics, etc. In the same regard, this paper presents a review and analysis of one of the key challenges of maintaining stability i.e. Rotor angle stability using IEEE 5 bus system.
Keywords: PV System, Grid Integration, and stability.

INTRODUCTION
As more green energy sources like solar and wind power have been used, the way the power system works has changed a lot in the last few years. Because of the current overuse of fossil fuels, Because of development, nonrenewable energy sources are running out every day. This is why people are now focusing on green sources. Renewable energy must be used to meet the world's energy needs and make up for the loss of fossil fuels. In India, the two most important types of clean energy are wind and solar power[1]. The cost of green energy has gone down over the past few years as it has gotten better. Grid supply isn't always there, and the cost of energy is going up, so we should add sources like solar to the grid. This study looks at how solar PV generation affects the stability of the rotor angle. There are six parts to this story. Part 1 is an introduction, and Part 2 is about the solar PV system. Rotor angle stability is talked about in Section 3. Part 4 talks about the modelling and outcomes of the standard IEEE 5-bus system. The concluding part of this paper is shown in Section 5.

SOLAR PV SYSTEM
The solar panel is the most important part of a solar PV (photovoltaic) system because it directly turns the energy from the sun into electricity. DC is the form of energy that comes from the sun. Inverters are used to convert solar energy into AC. Most of the time, semiconductor materials, especially silicon (Si), are used to make solar panels. Materials with better conversion qualities, like gallium (Ga) and aluminium (Al), are being used more and more these days. The electrical parts that connect the PV output to AC or DC loads are in the system's components. Improving cell efficiency and getting the most energy out of solar cells is one of the biggest challenges to getting the most power out of them. At a certain operating point, the solar cell can make the most power [2]-[6]. However, this operating point changes based on the weather. Utilities find it challenging to forecast the power output at any given time in that location, which complicates their planning for power generation. You can use the I-V (current-to-voltage) characteristic to determine the optimal working point of the cell, maximizing its power output. There is a p-n junction in the solar cell, which is made of a small layer of semiconductor. The power that is generated by the solar cell is based on how much sunlight energy (photons) the semiconductor material can receive. Fig. 1 illustrates how the I-V property of the semiconductor material dictates the power output of the solar cell. You can also use the I-V curve to determine the solar cell's maximum power point (MPP), or the point at which it produces the most power [7] one can find the power at the highest possible level by multiplying the voltage by the output current. Usually, we run the solar cell at or very close to its highest power point to obtain the maximum

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power. The voltage-current curve nears the "knee" or "bend" at point A in Fig. 1.
There are two different areas in a solar cell's voltage-current curve:
The current source region
The voltage source region.
The area with the electricity source.
In the first part of the I-V curve, the solar cell has a high internal impedance, and the output current stays the same as the voltage goes up. In the later part, the terminal voltage stays the same across an extensive range of output current, and the internal impedance is low.

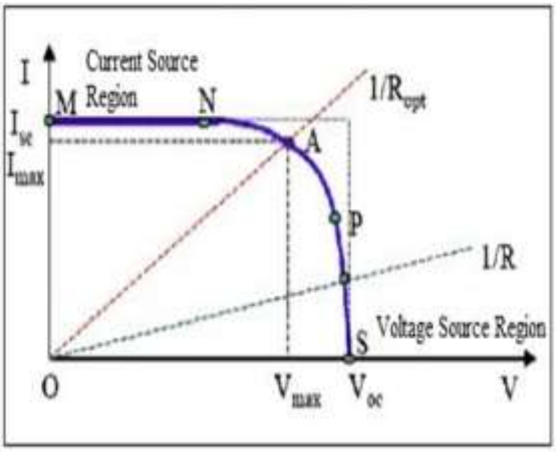

Fig 1. IV Characteristics Of Solar Cell.

The idea of maximum power transfer says that the load gets the most power when the source's internal resistance and the load's impedance are equal. We then set the solar cell's output impedance to match the level of the load's input impedance. This lets the solar cell work at or near its highest power point. The internal resistance of the solar cell is controlled by the voltage at the terminals and the current going out of them. This means that either the voltage or the current can be changed to keep the maximum power working. Environmental factors like temperature and irradiance can change the maximum operating point [8]-[12]. This makes it hard to keep the point of maximum operation at the optimum point (MPP), which causes the total power to change. To complete the job, a maximum power point tracker (MPPT) is used. A buck converter (step-down), a boost converter (step-up), or a buck boost converter is what most MPPT controllers are built on.
To understand the stability constraints of the PV integrated system, see Figure 2. The block diagram illustrates how a power electronics interface connects PV to the grid. Which includes a DC-DC converter, a DC-AC converter, MPPT IPSO, and an additional control shown at the bottom. Mainly, stability is of three different types: voltage, frequency, and, most importantly, rotor angle stability. This paper explores the effect of rotor angle stability on an integrated system.

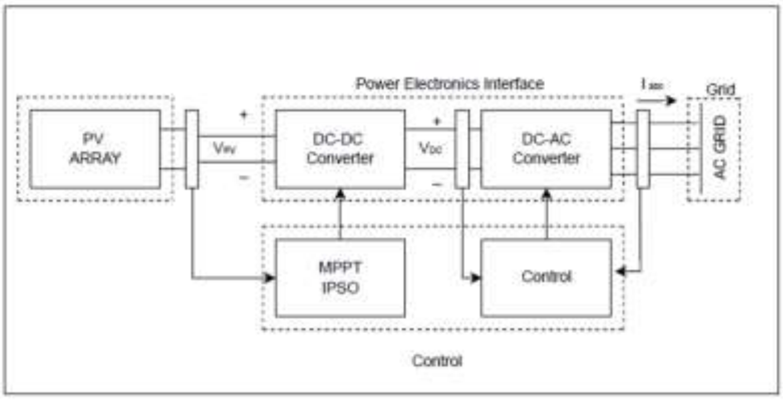

Fig 2. Solar PV System Connected to Grid.

ROTOR ANGLE STABILITY

The synchronous machines' ability to maintain synchrony following a disturbance in a power system is known as rotor angle stability. When there is instability, some generators speed up or slow down and lose sync with other generators. The stability of the rotor angle relies on how well each synchronous machine can keep both the electromagnetic and mechanical torque in balance. In steady state, the input mechanical power and output electrical torque of each generator are equal, and the speed of each generator stays the same. A disturbance upsets this equilibrium, causing the generators to accelerate or decelerate based on the spinning body's operation. There are several types of rotor angle stability.

i. Small-signal or small disturbance rotor angle stability.

ii. Large-signal OR transient stability rotor angle stability.

The stability of the rotor angle in the presence of small signals or disturbances is known as small signal stability. This is the power system's ability to stay in sync when there are small interruptions. The system equation can then be linearized around the original operating point, and stability is only affected by the operating point and not the disturbance. Instability can cause (i) a rotor angle that doesn't change or that changes every so often; (ii) in a literature study, rotor oscillations get louder because there isn't enough damping. Modern voltage controllers that work quickly have mostly gotten rid of the first type of instability. The second type of instability is more common. Once there is a disturbance, a small signal is stable for about 10 to 20 seconds. Stability of the large-signal rotor angle, or transient stability: This refers to how well the power system can stay in sync when there are big problems, like line outages, short circuits, etc. The system reaction includes big changes in the angle of the generator rotor. Transient stability depends on both the starting place and the disturbance parameters, such as where it is, what kind of disturbance it is, how big it is, etc. Most of the time, instability looks like a regular angular split. The time range that matters is between 3 and 5 seconds after the disturbance. In the past, the word "dynamic stability" meant steady-state stability when automatic controls (mostly excitation controls) were present instead of manual controls. All generators today feature automatic controls, rendering dynamic stability obsolete, and the Task Force has recommended against its use.

IEEE 5-BUS TEST SYSTEM

Using the physical properties of a system to do calculations regarding the way the entire system acts is of the utmost importance not only to the design of such a system but also to the maintenance and management of such a system. Power system analysis is an essential component of any gearbox or distribution system. These calculations are performed on a 5-bus system using the data that is supplied in this report. In addition, fault analysis is carried out for two distinct types of faults: having a 3-phase symmetrical bus fault to ground and having a symmetrical failure on a line connecting two buses that causes the line to be put out of service. Both of these types of faults are considered to be symmetrical faults. What would happen to the system's stability, as well as the overall influence on load flow to each surviving line, is determined by the latter fault, which is highly crucial and is used to figure out how it is going to occur.

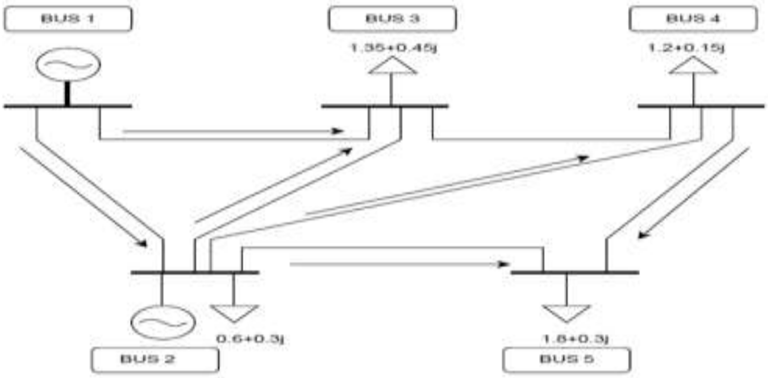

Fig 3. IEEE 5 Bus System.

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Figure 3 is a schematic of a system that uses the IEEE 5 bus. There are five buses in the line diagram: Out of the five buses, three are PVs, four are PQs, and bus one is considered slack. Transmission lines enable the buses to be linked. The power flow in the transmission line is analyzed through the use of MATLAB software, which is used to simulate the IEEE 5 bus system. The various bus types utilized in the project are detailed in this section. Each bus type has its own unique set of uses and known values. Real power (P), reactive power (Q), voltage angle (del), and voltage magnitude (|V|) are these numbers. A load bus, sometimes known as a PQ bus, does not produce its own electricity but does carry current for both active and reactive loads. Real and reactive power are the only variables that a load bus can report; however, the magnitude and angle of the voltage are not. Modifying the generator excitation on a generator bus, also known as a voltage-controlled bus, can control the output voltage. Under typical conditions, its output voltage does not fluctuate. The magnitude of the voltage and the real power are the established parameters of a generator bus. The reactive power and voltage angle are the unknown variables. In the event that the generating bus is unable to manage the system's load, a slack bus, also known as a swing bus, can step in and produce additional electricity. The amount and angle of the extra power's generation are constant, but the bus's active and reactive power are mysteries. The fact that the magnitude and angle of a slack bus's voltage remain constant regardless of the state of the system makes it similar to a reference bus.

Table 1. IEEE 5 Bus System Simulation Results Without Adding Solar PV.

Line	Real Power Flow (kW)	Reactive Power Flow (kVAR)	Current Flow (A)	Real Power Losses (kW)	Reactive Power Losses (kVAR)
1-2	2.442	0.228	3.54	0.021	0.064
1-3	1.137	0.237	1.677	0.019	0.058
2-3	0.701	0.22	1.072	0.006	0.018
2-4	0.791	0.214	1.195	0.007	0.022
2-5	1.542	0.336	2.303	0.018	0.054
3-4	0.531	0.046	0.789	0.002	0.002
4-5	0.175	0.003	0.26	0.002	0.001

When connecting the photovoltaic array to bus 4, Figure 3 illustrates the power flow across the various transmission lines. Table 2 presents the characteristics of the reactive power flow, the current flow, the real power, and the losses.

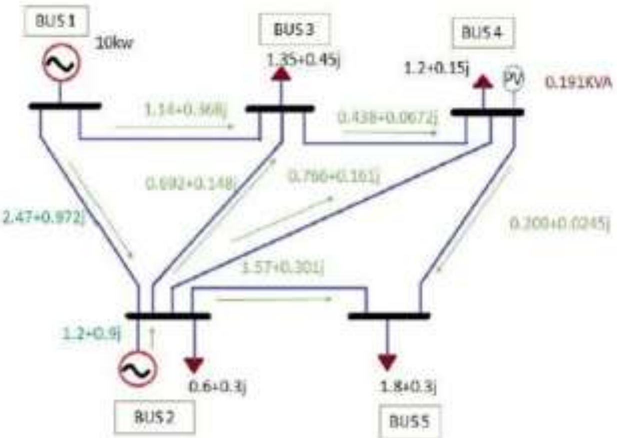

Fig 4. Simulation of IEEE 5 Bus System With Addition Of Solar PV at Bus 4.

According to table 2, we can deduce that the transmission line 3–4 experiences the least amount of reactive power loss, while the transmission line 4-5 experiences the least amount of real power loss. Connecting the PV panel to Bus 4 confirms this.

Table 2 .Simulation results of IEEE-5 bus with addition of PV at bus 4

Line	Real Power Flow (kW)	Reactive Power Flow (kVAR)	Current Flow (A)	Real Power Losses (kW)	Reactive Power Losses (kVAR)
1-2	2.237	0.209	3.243	0.018	0.054
1-3	1.037	0.228	1.532	0.016	0.048
2-3	0.636	0.217	0.979	0.005	0.015
2-4	0.697	0.211	1.062	0.006	0.017
2-5	1.498	0.333	2.237	0.017	0.051
3-4	0.365	0.046	0.543	0.005	0.001
4-5	0.223	0.004	0.33	0.001	0.002

RESULT AND DISCUSSION

In order to provide transient stability, a three-phase fault is initiated at bus 2 at 20 s and cleared at 20.1 sec. The system's transient response is examined in various scenarios. At first, we examine the grid's behavior and do a transient stability analysis on the fault that does not have PV penetration. Figure 3 is a time-series visualization of the relative rotor angle of generator 2 over 100 s. The oscillation's amplitude was large when the fault was present, but it settled into a steady state of 3.89 degrees once the fault was removed.

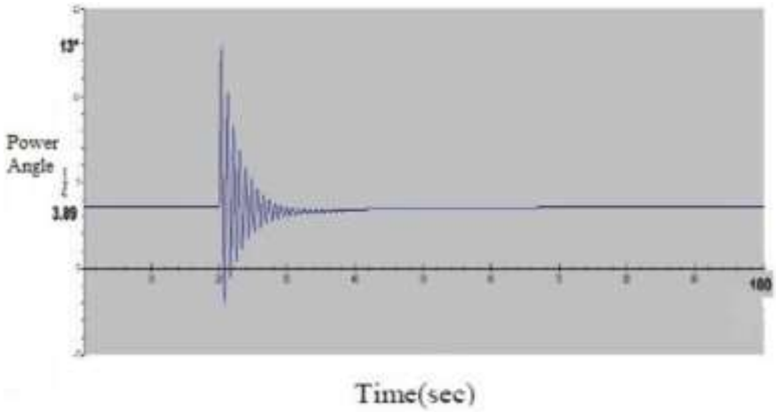

Fig. 5.Generator 2 power angle Vs time without Adding PV penetration

Basically Researchers do a transient stability analysis for the fault and analyses the grid's behavior with 10% PV penetration. Figure 5 displays the load angle of generator 2 as a function of time over a 100-second interval.

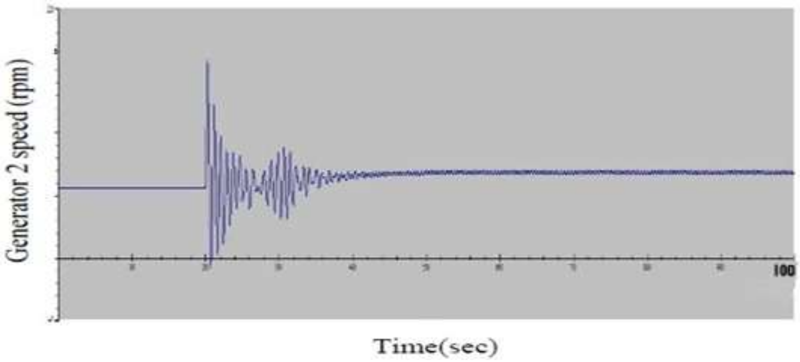

Fig 6.Generator 2 load angle Vs time for 10% of PV penetration.

CONCLUSION

This paper uses MATLAB to simulate an IEEE 5-bus system with and without photovoltaic penetration. Before introducing a PV array, a transient stability analysis is run to see how the system reacts under fault conditions. After installing the array, the stability is tested again under transient disturbances. The system becomes unstable at higher levels of PV penetration. A 5-bus system model with and without PV penetration is used to implement hardware in a controlled environment. In order to determine the best spot for the PV array, the 5-bus system looks at the power flow analysis.

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