RESEARCH ARTICLE

Improve the Stability of the Meshed Power System Network with a Fuzzy-based PV System

P. Sarala[1]* and J. Mano Chandra[2]

[1]Associate Professor, Department of Electrical and Electronics Engineering, Malla Reddy Engineering College (Autonomous), Secunderabad, (Affiliated to Jawaharlal Nehru Technological University Hyderabad), Telangana, India.
[2]PG Scholar, Department of Electrical and Electronics Engineering, Malla Reddy Engineering College (Autonomous), Secunderabad, (Affiliated to Jawaharlal Nehru Technological University Hyderabad), Telangana, India.

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***Address for Correspondence**
P. Sarala
Associate Professor,
Department of Electrical and Electronics Engineering,
Malla Reddy Engineering College (Autonomous),Secunderabad,
(Affiliated to Jawaharlal Nehru Technological University Hyderabad),
Telangana, India.
E.Mail:

ABSTRACT

Achieving stability in a multi-machine power system network can be challenging due to the complexity of the interconnected generators, loads, transmission lines, and control systems. The interactions between various components can lead to dynamic behavior that requires careful coordination and control. Transient stability refers to a system's ability to maintain synchronism after a disturbance, such as a fault or sudden load change. Coordinating the operation of multiple generators to maintain synchronization is difficult, especially during transient events. Voltage stability is essential for the proper functioning of power systems. Challenges include maintaining acceptable voltage levels across the network and avoiding voltage collapse during disturbances. With integration and operation, the PV inverter with intelligent fuzzy rules both transient stability and voltage stability can be attained.

Keywords: Fuzzy Logic Controller, power system network, transient stability.

INTRODUCTION

Grid-integrated renewable energy stability refers to the ability of a power grid to maintain its reliability, security, and performance while incorporating a significant amount of renewable energy sources (such as solar, wind, and hydroelectric power) and fault conditions also [1-2]. Integrating these variable and often intermittent sources of energy into the grid presents several challenges related to stability, and addressing these challenges is crucial for ensuring a reliable and resilient power system. As the share of renewable energy in the energy mix continues to grow, maintaining grid-integrated renewable energy stability becomes increasingly important. Balancing the benefits of clean energy with the need for a stable and resilient power supply requires a combination of technological advancements, regulatory support, and strategic planning [3-4]. Fault ride-through (FRT) capability is a critical feature for grid-connected power generation systems, particularly renewable energy sources like wind turbines and solar photovoltaic (PV) systems. It refers to the ability of these generation systems to remain connected to the grid and continue operating during and after a fault or disturbance in the grid, such as a short-circuit fault. Here's why fault ride-through capability is significant [5-6]. Faults in the power grid, such as short circuits or sudden drops in voltage, can disrupt the stable operation of the grid. Without proper FRT capability, large-scale disconnections of generation systems during faults could exacerbate grid instability and lead to voltage collapses or even blackouts. FRT helps maintain grid stability by preventing unnecessary disconnections. When a fault occurs in the grid, traditional power generation sources with synchronous generators (like coal or gas power plants) contribute inertia and help stabilize the system [7]. Renewable energy sources, however, lack the same level of inertia. Without FRT capability, these sources might immediately disconnect during a fault, leading to sudden drops in power output and destabilizing the grid. Many grid codes and regulations require power generation systems to have FRT capability [8-10]. Compliance with these codes is essential for ensuring that the integration of renewable energy sources doesn't compromise grid stability and reliability. Interrupting energy generation during a fault can lead to energy loss and potential revenue loss for renewable energy system owners. FRT capability allows these systems to continue operating, minimizing energy production disruptions and financial impacts.

Multi Machine Power System Network

Radial power system

Fig.1 represents the photovoltaic (PV) system integrated into a grid radial power system network. In these configurations solar photovoltaic installations to a power distribution network that follows a radial topology. A radial power system network is a common distribution configuration where power flows from a single source (such as a substation) outward through a series of interconnected feeders in a tree-like structure. Each feeder serves various load points along its path. The system is "radial" because there is a single primary path for power to flow, and if a fault occurs, the affected portion of the system might experience an outage. The voltage stability of the radial network easily improved because single PV and grid were integrated.

Meshed power system

A meshed multi-machine power system network is a complex electrical grid configuration in which multiple synchronous generators (machines) are interconnected in a meshed or interconnected manner, forming a dense network topology. This type of network is characterized by having multiple paths for power flow between various generators and load points. In contrast to a radial network, where power flows primarily along a single path, a meshed network provides multiple routes for power to travel, enhancing system robustness, redundancy, and flexibility. The same concept which is applied to the radial network is extended for the meshed multi-machine in this paper to improve the stability of the meshed power system network. For the fault identification and detection between the buses used phase measuring units (PMU). To suppress the voltage drops and maintain the voltage stability used PV generation. The structure of the fault data detection and inverter power levels computation block are depicted in Fig.2.

Fuzzy-based PV System

The significance of the grid-interfaced PV system is discussed in this section.

PV systems

Solar panels or photovoltaic (PV) modules capture sunlight and convert it into electrical energy in the form of DC. The amount of power generated depends on factors such as sunlight intensity, angle of sunlight, and the efficiency of the panels. The DC power output from the solar panels is not directly compatible with the electrical grid, which operates on AC power. The inverter is a crucial component that converts the DC power into AC power with the appropriate voltage and frequency that matches the grid's requirements. In addition to converting the power, modern inverters often include advanced features such as maximum power point tracking (MPPT) to optimize energy production and safety mechanisms like anti-islanding protection. A grid interfaced PV system through an inverter is a setup (depicted in Fig.3a) where solar panels are connected to an inverter, which in turn is connected to the electrical grid. This configuration allows the generated solar power to be converted from direct current (DC) produced by the solar panels into alternating current (AC) that is compatible with the grid's AC voltage and frequency.

SIMULATION RESULTS

The MATLAB circuit diagram of the 9-busmeshed power system network is configured in Fig.4 below.
In these three grid generators with respective ratings of 192 MVA, 247.5 MVA, and 128 MVA are connected in a messed network. A 50 MVA rating of PV inverter generation is connected to these grids at bus bar 8 to enhance the transient stability and voltage stability of the overall power system network. Two fault locations are considered one is between bus 6 and bus 9 and the other fault at bus 7 and bus 8. The duration of these faults is 150 ms and after the fault clears (break the fault location by isolating the fault network from the healthy power system network) the nominal reclosing time is 600ms.the effectiveness of the proposed fuzzy-based PV system is tested for two scenarios.

Scenario-1
In this case the 3-phase fault considered in the TL between bus 6 and bus 9. At 5 secs simulation fault is detected by PMU. Fig.5 and Fig. 6 are simulation outputs of active power between buses 7 and 8 and buses 8 and 9 respectively. From simulation responses, it is observed that from 5 sec to 5.5 sec there is distortion (due to fault) in active power. After 5.5secs the PS network is restored (the fault is cleared) and active power (P_{act}) between the transmission line (TL) is balanced. To stabilize the PS network against these transients, at this fault duration, PV inverter absorbs the active power to the DC capacitors. The negative active power (see Fig.7) in PV indicates that PV consuming the power. To enhance the voltage profile of the synchronous motors (SM) have to maintain the rotor angles in a steady state. For this purpose, reactive power compensation is required. That reactive power is delivered by the PV inverter (See fig.8) into the TL. A fig.9 simulation represents the rotor angles of each generator within the less time (<0.5secs) SM rotor angles are restoring to their nominal values.

CONCLUSION

The proposed fuzzy-based PV inverter introduces new dynamics that need to be managed to ensure stability. Well-designed fuzzy rules in the proposed approach support the power system stability. From the simulation in both cases, it is ensured that generators remain synchronized and that power system components respond appropriately to disturbances. During the fault period PV inverter absorbs or delivers the power to the transmission line so both transient and voltage stability of the overall meshed power system network is improved.

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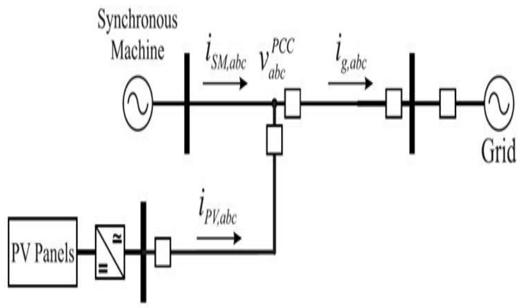

Figure.1 Radial power system topology

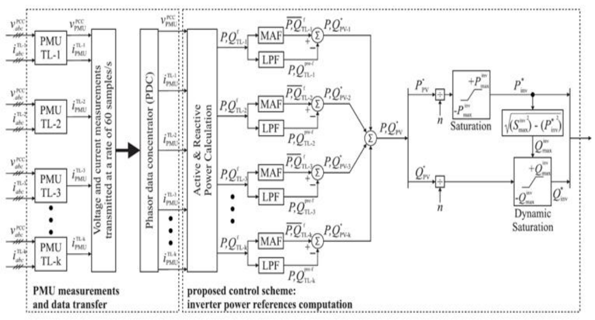

Figure.2 Fault data detection and inverter power levels computation block

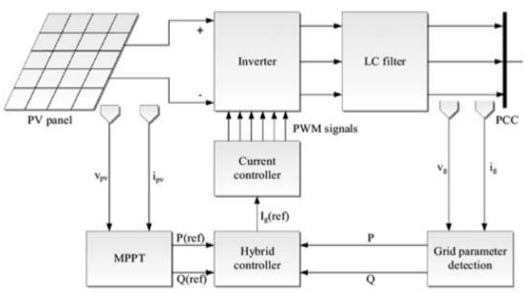

Figure.3a Schematic structure of the PV system

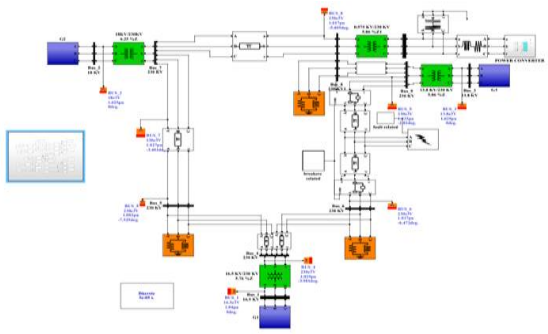

Figure.4 MATLAB circuit diagram of the meshed power system (Case-1)

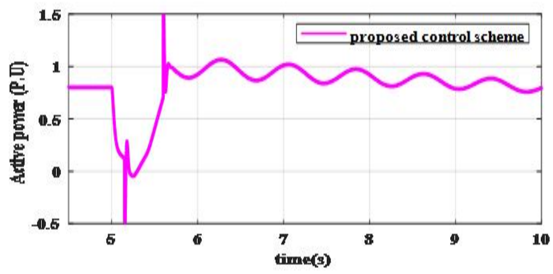

Figure.5. P_{act} **in the TL between bus 7 and bus 8**

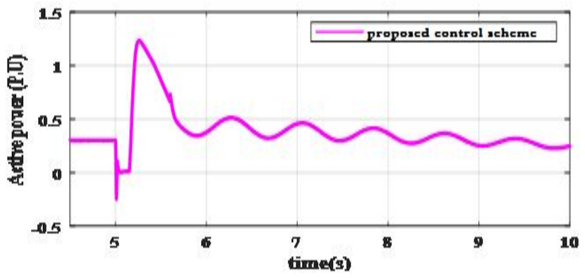

Figure.6. P_{act} **in the TL between bus 8 and bus 9**

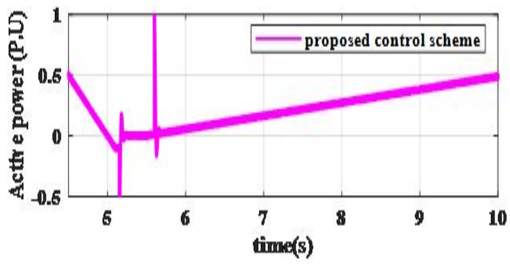

Figure.7. P_{act} **of PV system**

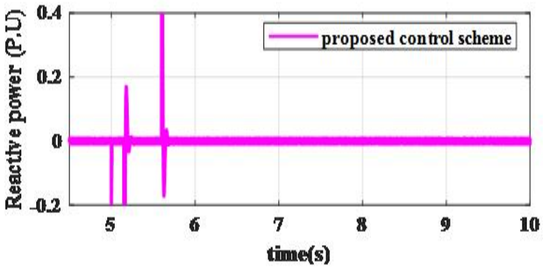

Figure.8. Q_{rec} **of PV system**