A FLC Based Control Scheme for PV System in Multimachine to Improve the System Stability

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Abstract - As photovoltaic (PV) systems are becoming more common on current power grids, new challenges in preserving the stability and dependability of the system as its entirety have developed. Even while PV systems have a lot to offer for both the environment and the economy, their variable and intermittent nature can lead to power production fluctuations, which can create voltage instability and frequency deviations in multimachine power systems. Particularly when load levels vary and there are unexpected grid disruptions, traditional control techniques frequently come short in successfully controlling these disturbances.

This thesis suggests a control technique for PV systems integrated into multimachine power networks based on fuzzy logic controllers (FLCs) in order to overcome these difficulties. By dynamically modifying the control parameters in response to current grid conditions, the main goal is to increase the system's stability. In comparison to traditional approaches, the suggested control system aims to offer a more resilient and adaptive solution by integrating fuzzy logic, which would ultimately guarantee a more steady and dependable power supply.

Keywords: Fuzzy logic controllers (FLC); Photo voltaic system (PV system)

I. INTRODUCTION

Photovoltaic (PV) systems are one of the renewable energy sources that have gained widespread popularity to combat climate change and reduce reliance on fossil fuels. However, integrating PV systems into existing power grids, especially in multimachine configurations, presents several challenges, particularly in maintaining system stability and reliability. The inherent variability and intermittency of solar power can result in voltage fluctuations, frequency deviations, and other power quality issues that are difficult for traditional control methods to effectively address.

The use of renewable energy sources (RES) to generate electricity has gained attention due to the detrimental environmental effects of burning fossil fuels for energy conversion. This process emits massive volumes of carbon dioxide and other greenhouse gases into the atmosphere. Conventional fossil fuels are often non-renewable, which raises the possibility of resource depletion. Photovoltaic solar energy is one of the most essential and promising renewable energy sources (RES). It is the most advanced RES extensively integrated with electrical grids and represents a trend in contemporary energy systems. Photovoltaic (PV) Power Plants are becoming more and more integrated into electrical networks, which raises the possibility of stability and dependability issues when they are separated from the network during severe faults.

Several nations and significant international organizations, including the International Electrotechnical Commission (IEC) in Switzerland and the IEEE in the United States, have imposed and updated various standards, requirements, and regulations for the operation of Renewable Energy Systems (RES), particularly photovoltaic (PV) systems, to address these issues. We refer to these as grid code (GC). A wide range of technical specifications are included in GCs that outline significant guidelines and limitations about integrating renewable energy generating units into the electrical grid and maintaining stable, error-free system operation.

Additionally, GCs guarantee that PV plants maintain their grid connection during a grid failure, a feature known as fault ride-through (FRT). When a PV inverter has FRT capability, it guarantees that it will function similarly to a traditional synchronous generator, which means it will be able to withstand voltage drops brought on by grid faults or disturbances, stay connected to the grid, and either supply or absorb the reactive power specified by the GC during the disturbance.

II. LITERATURE REVIEW

Optimizing the insertion of renewable energy in the off-grid regions of Colombia”- J. P. Viteri, F. Henao, J. Cherni, and I. Dyner

The welfare of impoverished communities and the expansion of their economies depend on electricity. However, 15% of people on the planet do not have access to it. Because of its remote location and challenging access from the country's major cities, 52% of Colombia's land is not connected to the national energy grid. There are about 2 million vulnerable and extremely poor individuals residing there. Off-grid communities can obtain some electricity through fossil fuel-based technology, but this is an expensive and harmful service. These off-grid locations may benefit from the development of renewable energy, but in order to assure sustainability, cost-effective solutions must be found. An optimization model is created for off-grid settlements to plan suitable stand-alone renewable electricity systems.

In order to identify the most beneficial aspects, it makes it easier to evaluate various technological configurations of renewable energy sources, fossil fuels, and batteries, as well as the unpredictability of demand and meteorological factors. A case study at the remote town of Playa Potes in Colombia's Choco Department was conducted to evaluate this methodology. The findings point to an electricity system based on solar power (22 and 29 kWp) and battery storage (74 and 93 kWh) as the optimum option for meeting present and future needs at a reasonable cost (35–38 ¢/kWh). These findings highlight the significant potential for adopting renewable energy technology rather than relying on fossil fuels to provide electricity to Colombia's off-grid villages.

“A sizing approach for stand-alone hybrid photovoltaic-wind-battery systems: A Sicilian case study”- A. Giallanza, M. Porretto, G. L. Puma, and G. Marannano

Solar and wind power are the two most readily available renewable energy sources globally. This research presents the results of a high-resolution analysis that enables the sizing of hybrid photovoltaic wind turbine-battery banks. The analysis aims to reduce the systems' yearly cost while meeting two reliability limitations. The numerical solution was obtained through an iterative process.

The solar area, wind turbine radius, and battery capacity are the variables that need to be considered. A fuzzy logic inference system-based high-resolution model has been created to assess the number of residents actively living in a home and the amount of power consumed there. A new reliability parameter called seasonal loss of load probability ratio that accounts for data seasonality has been created to enable more precise system sizing. In addition to the most popular loss of load probability, the seasonal loss of load probability ratio has also been applied in the iterative process. The collected results show that, compared to traditional methods, adding a new parameter to an iterative process improves the system's reliability significantly and somewhat increases its cost. Three locations in Sicily have been chosen for the simulation, which was run in the MATLAB® environment to supply power for a domestic home. When utilizing the new size process, reliability values derived from the previous procedure are compared to the acquired results, which demonstrate a 75% improvement in dependability.

Consequently, by enabling more efficient design of renewable facilities, the suggested methodology represents a significant advancement over the state of the art. Global power usage in 2014 was estimated at 19.8 TWh. These days, this value is unduly dependent on fossil fuels, which harms the environment. The energy industry relies heavily on fossil fuels since they are inexpensive, exacerbating the greenhouse effect and global warming phenomena. Therefore, it is essential to identify alternative energy sources to meet the ever-increasing need for energy while reducing the adverse effects on the environment In order to achieve an electricity target of net zero energy (Net Zero Energy Buildings), Cellura et al. analyze several scenarios of a building redesign problem; Esen et al. introduce performance experiments and economic analysis of several heat pump systems by proving the economic advantages over the traditional heating methods. These days, scientific research into the renewable energy sector is primarily concerned with decentralized energy production systems; in fact, the noble goal to reach is a self-sufficient and completely renewable supplied home.

The availability and topological advantages of solar and wind energy systems for local power generation make them attractive options for power generation. These days, these plants' strong points are their cost- and efficiency-effectiveness. The goal of Brazilian et al.'s [7] informational piece is to apprise photovoltaic players of the true costs of their products and the related technological and market changes that have occurred in the sector.

III. MATERIALS AND METHODOLOGY

Becquerel originally discovered the photoelectric effect: how solar radiation is converted. When a little glow is delivered to a stable or liquid instrument, it is commonly defined as the appearance of electrical capacitance between electrodes linked to this device. Solar cells are energy conversion apparatuses that use voltage shock imaging to transform sunlight into force. A solar cell, more widely called a photovoltaic cell, is a mobile device with just one inverter.

For this reason, they are referred to as "arrays"; the collection of these cells intended to boost power output is known as a solar module, solar array, or solar energy system. Large clusters of solar cells are referred to as arrays. With the ability to transform light into electrical power for distribution to contemporary, industrial, and residential consumers, these arrays—composed of several hundred individual cells—can function as significant electrical power plants. Solar boards or panels are typically solar cells with fewer configurations. The semi-performer in almost every PV device has a PN connection, which is how the photoelectric voltage is developed. Particularly, semiconductor fabric is used to make solar panels, with silicon being the most widely utilized material.

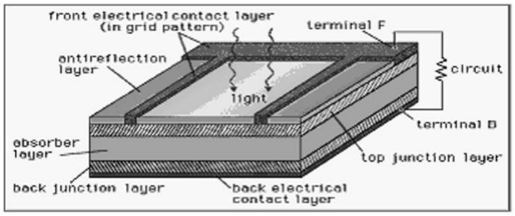


Fig. Solar cell

The materials used to build the vast majority of solar panels range from paperless (amorphous) registers to polycrystalline and crystalline (mono-crystalline) silicone, which has twice the energy and is inexpensive. Unlike solar cell collections, fuel cells today do not use analytical results or require electricity to provide energy. In contrast to electrical grinders, they currently lack motor elements.

- Types of controllers

The types of controllers are as follows:

1. Proportional Controller(P-controller)
2. Derivative Controller(D-controller)
3. Integral Controller(I-controller)
4. Fuzzy logic Controller

1. Proportional Controller(P-Controller)

The difference between the intended setpoint and the actual process variable is the error signal, and the proportional controller modifies the control output in direct proportion to this signal.

An output proportionate to the error signal is produced by the proportional controller.

The formula for calculating the control output (u(t)) is $u(t) = KP * e(t)$

where KP is the proportional constant.

Reducing errors and bringing the system closer to the setpoint are the two main goals of the proportional controller.

Although it is good at lowering steady-state error, it can cause oscillations and response overshoot.

2. Derivative Controller (D-Controller)

The derivative controller responds to the error signal's rate of change. It predicts future patterns in errors and offers management measures to offset them. An output that is the derivative of the error signal concerning time is produced by the derivative controller. The formula for the control output is $u(t) = KD * (de(t)/dt)$. Where KD is the derivative constant.

Enhancing system stability and reducing oscillations are two goals of the derivative controller. Based on the rate of mistake change, it predicts upcoming errors.

3. Integral Controller(I-Controller)

The integral controller reacts to all of the previous mistakes. It eliminates any steady-state inaccuracy by continuously adjusting the control output. The integral of the error signal concerning time is the output the integral controller generates.

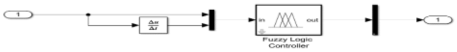
The formula for the control output is $u(t) = KI * \int e(t)dt$. Where KI is the integral controller.

The Integral Controller continuously integrates previous errors to aid in eliminating steady-state errors. It guarantees that the system eventually reaches and stays at the set point.

4. FUZZY LOGIC CONTROLLER

The transmission line parameters flow continuously from the transmitting end to the receiving end under stable operation conditions. The Proposed Fuzzy Logistic Controller receives data from the Measurements block, which constantly monitors the transmission parameters. Normal voltage and current measurements should be translated into phases that the fuzzy logic system can understand before being sent into the fuzzy block. The Fuzzification block in this FUZZY block transforms the raw values of the transmission line parameters into linguistic values.

If the data sent by the measurement block differs from the predetermined nominal values stored in the FUZZY LOGIC Controller, an error is created during this procedure to signal the fault situation.



The FUZZY LOGIC controller block permits the settings block to emit a pulse under this fault situation, which is then sent to Converters 1 and 2, which handle shunt and series compensation. The fuzzy logic controller permits pulses from the settings block until the measurement block parameters and the nominal rated values of the fuzzy logic controller are added together. The FUZZY LOGIC controller stops the pulse from the settings block to the corresponding controllers for turning off both Series and Shunt compensation after these values have been collected.

The current study aims to evaluate the effectiveness of the control method in a meshed power system, as suggested in reference. The outcomes are contrasted with those attained when the German GC's conditions are satisfied. During a significant disruption in the transmission network, both approaches are employed to regulate the inverters of a photovoltaic system in a modified Western System Coordinating Council (WSCC) 9-bus power system. The study focuses on modifying the control scheme as suggested. It demonstrates that the scheme can be modified to be used in a meshed power system during the stresses of a severe fault and significantly enhance the power system's transient and voltage stability.

In order to enable the control method to function in a meshed electrical system running with multiple SMs, loads, and transmission lines, the FRT control scheme published for a single SM and single PV system connected to a power system was modified in this research. The main goal of the FRT control strategy is to maintain the SM's active power output at the pre-fault value in the event of a significant transmission system disturbance. This is accomplished by the kinetic energy in the SM's rotating mass absorbed by the PV system's DC-link capacitors during the failure. The maximum direct current (dc) bus voltage of the inverter limits the amount of energy that can be absorbed.

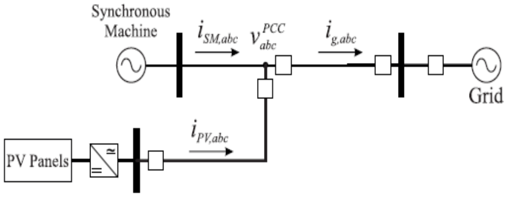


Fig. Radial power system used to design the control scheme

This cap sets a maximum active power that the DC-link capacitors can absorb, releasing some reactive power, which some GCs need. The control method has two main benefits: it enhances voltage stability during a significant disturbance and supports electrical system functioning. On the other hand, the majority of GCs just need support for voltage stability. But as illustrated in Fig. the control strategy was designed with a radial power system in mind, where a single SM is linked to an infinite bus via a transmission network, and the PV system is connected to the grid in parallel to the SM. This power system configuration is not realistic; rather, it is unique. A real power system often consists of multiple SMs, loads, and transmission lines meshing together.

IV. RESULTS & DISCUSSIONS:

A three-phase fault is located 50km from bus-6 on the transmission line between buses 6 and 9

Simulation results for the fault, located between buses 6 and 9, when the PV inverters act according to the German GC and when the proposed control scheme is used.

The simulation results in Figure.2 present a comparison of the active power flow in the transmission line between buses 7 and 8, based on simulation findings, between the usage of the suggested control scheme and PV inverters acting by the German GC. Both control techniques respond somewhat similarly, practically simultaneously achieving an operating point comparable to the one before the fault. The active power flow in the transmission line between buses 8 and 9 is depicted in Fig.3 While the outcomes for the two control schemes are comparable, the suggested control scheme's active power is marginally higher during the fault, indicating that the inverter's absorption of active power into the dc-link capacitors has an impact.

Fig.4 displays the active power output of every generator. It would be assumed from the preceding research that all of the generators' curves would behave similarly both during and after the incident.

Following the fault, both control techniques raise the active power output at the German GC-established Active Power Recovery Ramp Rate (APRRR) of 20%/s. The consequences of the control action based on the specifications given in the German GC are illustrated by the reactive power output.

When the control strategy based on the German GC is applied, the voltage is maintained during the fault at almost the same value with brief transients, according to the analysis of the dc-link voltage graphs in Fig.5 On the other hand, when the suggested control approach is used during the fault, the dc-link voltage increases.

This rise, albeit limited by the maximum inverter DC input voltage of 1500 V (1.36 p.u.), suggests energy is being stored in the DC-link capacitors of the inverter.

The rotor angles of every SM in the power system depicted in Fig.5.9 show comparable behaviour for both control schemes, as expected from the preceding plots. The analysis of case 1 shows that the performance of both control schemes in providing voltage stability and power system transients is nearly equal. It would appear that the suggested control technique has not produced any discernible improvements. Nevertheless, there is not a situation where the fault site can cause a voltage collapse in the power system.

The first scenario (case 1) is a three-phase fault located halfway along the transmission line between buses 6 and 9;

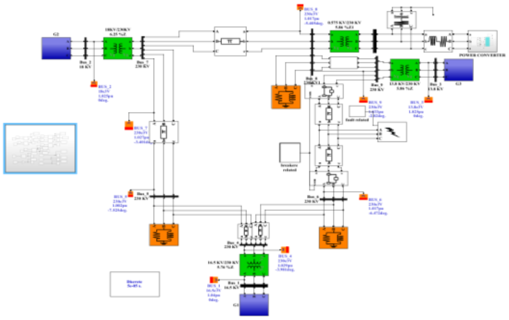


Fig.1: Schematic diagram when a fault is in between buses 6 and 9

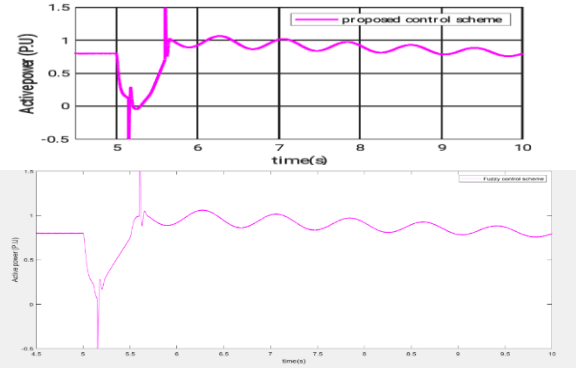


Fig.2: Active power flow in the transmission line between buses 7 and 8 in p.u. - case 1.

The power flow is stable at first, but after a few disruptions, there is a noticeable decrease in power flow, which is followed by oscillations that eventually subsid.

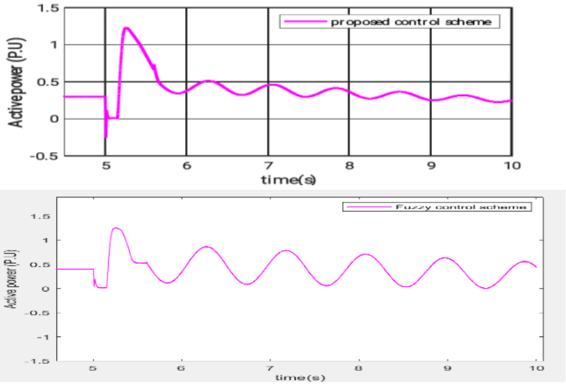
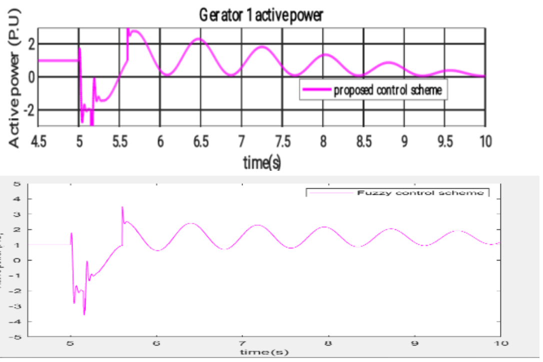
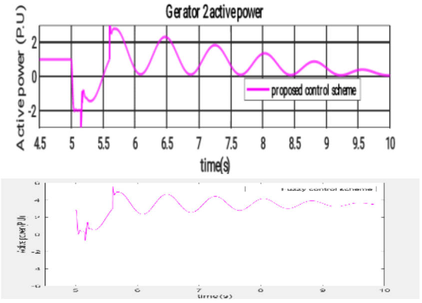


Fig.3: Active power flow in the transmission line between buses 8 and 9 in p.u. - case 1.

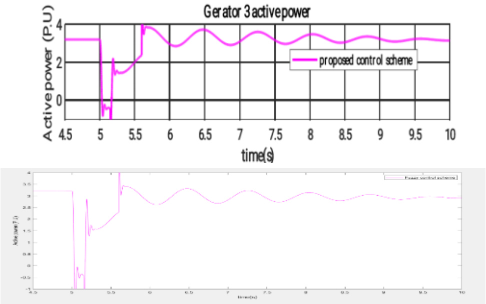
Like in figure 5.2, the power flow spikes sharply at about 5.5 seconds due to a disturbance. After then, there are oscillations that progressively change over time.



At first, the active power is constant, but at the 5-seconds point there is a disruption that causes the power output to oscillate.



Like generator 1, this plot displays a steady output Power before a disturbance that causes oscillations just after the 5 second's mark.



This generator receives a disturbance around 5 seconds, just like the first two generators, but it responds quickly to the disturbance and the oscillations are not as noticeable as those of generators 1 and 2.

Out of the three generators, the fuzzy logic control system is utilized to regulate the active power of the system following disruptions, demonstrating its ability to reduce oscillations and bring stability back.

Fig.4: The active power output of the test system generators in p.u- case1.

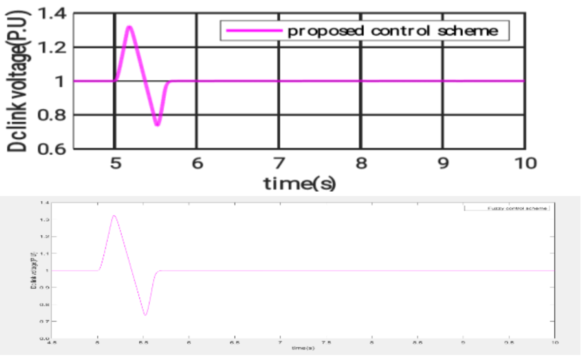


Fig. 5: Inverter dc-link voltage in p.u. - case 1.

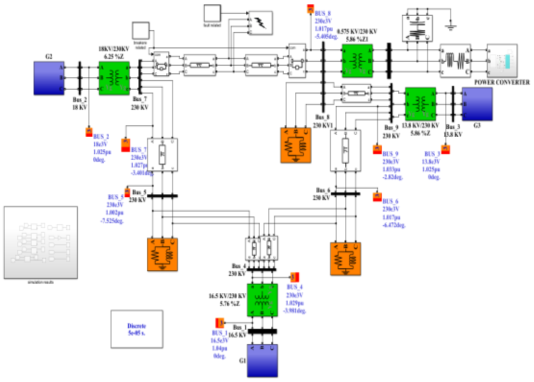
A disturbance in the inverter DC link voltage occurs roughly 5.5 seconds later, resulting in a DC-link voltage spike that peaks at approximately 1.35 p.u. The voltage then falls below the value that is intended before stabilizing and staying constant for the remainder of the duration.

A three-phase fault is located 30km from bus-7 on the transmission line between buses 7 and 8

Simulation results for the fault, located between buses 7 and 8, when the PV inverters act according to the German GC and when the proposed control scheme is used.

The control response mandated by the German GC, which involves transferring reactive power from the PV system to the transmission network, has already been demonstrated in subsection III-A to accelerate the loss of power system stability. This illustrates how requirements set by most GCs are not always appropriate for all scenarios. A comparison of the active power flow in the transmission line between busses 8 and 9 is displayed.

The second scenario (case 2) also involves a three-phase fault located three-tenths of the way along the transmission line between buses 7 and 8.



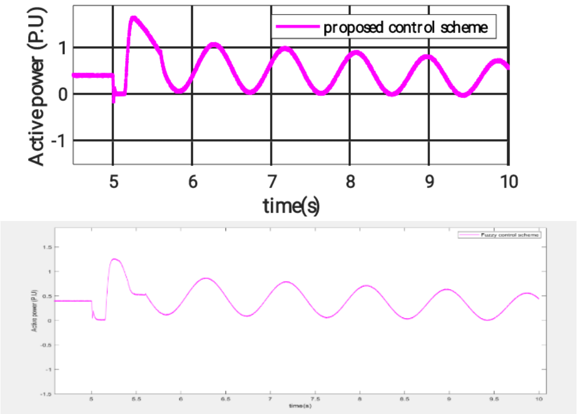
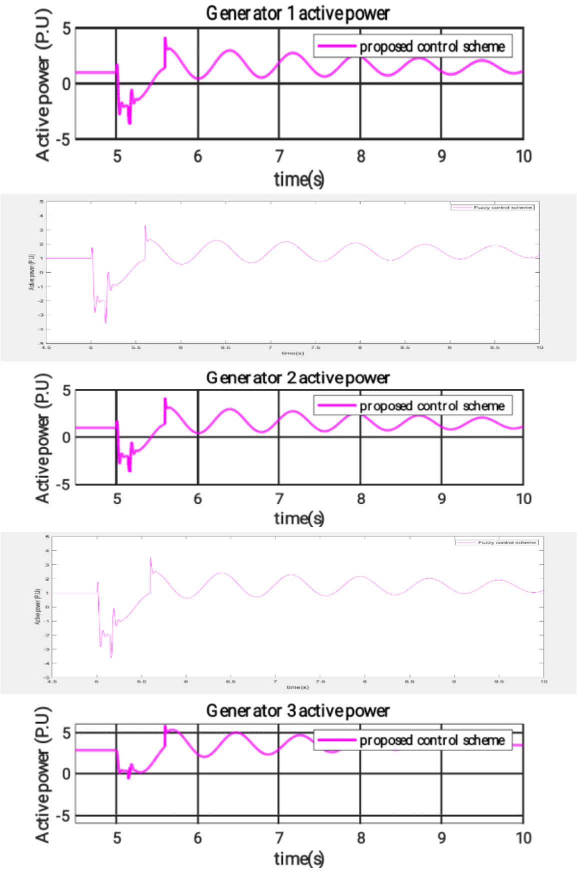


Fig. Active power flow in the transmission line between buses 8 and 9 in p.u. - case 2.

The oscillations seen in the plot of this graph demonstrate how the system temporarily reacts to the failure occurrence, which first interrupts the power flow.

Oscillations indicate that the system is modifying itself to stabilize power flow, most likely as a result of the fuzzy control technique intended to improve stability. As the oscillations lessen over time, the system approaches a steady state system.



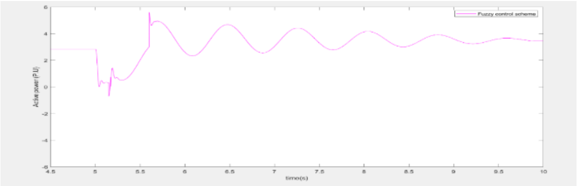


Fig. Active power output of the test system generators in p.u. - case 2.

An initially disturbance occurs in Generator 3, as evidenced by the abrupt changes in active power. These oscillations gradually become damped when the fuzzy control technique works, indicating that the generator is approaching a stable pattern of oscillations.

This behavior is consistent with Generators 1 and 2's responses, demonstrating how well the control method stabilizes the system's several generators.

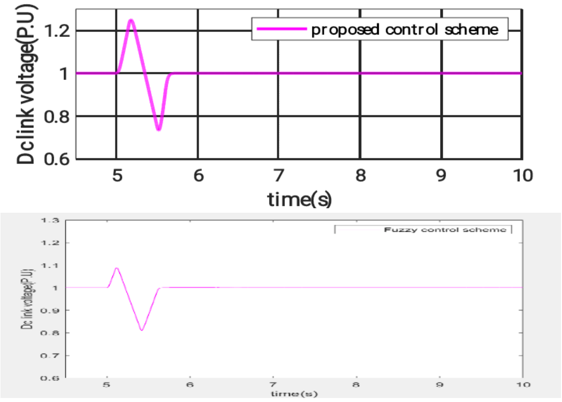


Fig. Inverter dc-link voltage in p.u. - case 2.

The DC-link voltage fluctuates initially due to a disturbance, seeing a notable decrease and then a peak. However, by reducing the oscillations, the fuzzy control system rapidly stabilizes the voltage at about 1p.u. This illustrates how well the fuzzy controller maintains a steady DC-link voltage, which is essential for the steady operation of the inverter and the steady flow of power from the PV system.

V. CONCLUSION

The FLC-based control method for PV inverters described in this thesis has been modified for usage in severe transmission network disruptions in a meshed power system with several SMs. In power systems with a voltage condition that could lead to voltage collapse, the FLC control scheme's priority of enhancing transient stability rather than voltage stability produced higher performance than the control action needed by the German GC and with other GCs.

The fuzzy logic controller was investigated as a possible improvement for increased system performance and flexibility, whereas the PI controller was used as the baseline because of its widespread use and proven dependability in similar applications.

Reactive power support in this situation can potentially hasten the voltage decline. The simulation results using the suggested control scheme demonstrate that the voltages on all of the power system's buses return to their pre-fault values even in the absence of reactive power and that the rotor angles of the SMs also return to their pre-fault operating values. Based on the study presented here, a multimachine power system's transient and voltage stability can be enhanced using the suggested control strategy in the PV system's inverters.

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