PV- STATCOM FOR POWER OSCILLATION DAMPING USING FUZZY LOGIC CONTROLLER

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Abstract- **Flexible AC Transmission System (FACTS) devices like Static-Synchronous Compensators (STATCOM) have been used to improve the quality and control of power systems. This paper presents a Photovoltaic (PV) system as a STATCOM, termed PV-STATCOM, which utilizes a Fuzzy Logic Controller. The primary purpose of the STATCOM is to achieve Power Oscillation Damping (POD).During the day, when the system experiences oscillations, the PV inverter in the PV-STATCOM temporarily suspends real power generation (for a few tens of seconds) to act as a STATCOM and dampen the oscillations. Once the damping is achieved, the PV inverter's real power generation is gradually restored to its pre-disturbance levels. This allows for faster grid power restoration compared to grid code requirements. At night, when there is no real power generation from the PV array, the PV inverters can use their full capacity to dampen power oscillations. MATLAB simulations indicate that the proposed PV-STATCOM significantly increases power transfer capacity under various oscillation modes. Furthermore, the PV-STATCOM is a more cost-effective solution for POD compared to equivalent STATCOM devices. This method has the potential to provide substantial savings for power generation and distribution companies.**

Index Terms--**Photovoltaic solar power systems, voltage control, reactive power control, power oscillation damping, FACTS, STATCOM, power transmission, PV ramp rate Fuzzy logic controller.**

I INTRODUCTION

Power oscillations (0.1 Hz to 2 Hz) are a major challenge in long transmission lines, hindering efficient power transfer [1-2]. These low-frequency oscillations, caused by electrical and mechanical factors, need to be dampened for effective power transmission. Conventional systems use Power System Stabilizers (PSS) along with synchronous generators to dampen these oscillations [1-2].

However, enhanced power transfer capability and improved damping of power fluctuations can be achieved through the effective utilization of power electronics-based Flexible AC Transmission System (FACTS) devices [3-5]. Various FACTS devices, such as Static-VAR-Compensators (SVC), STATCOM, Unified Power Flow Controller (UPFC), Unified Power Quality Controller (UPQC), Thyristor Controlled Series Compensator (TCSC), and Convertible Static Compensator (CSC), have been explored for power oscillation damping (POD) in previous works [6-10].

This paper analyzes the effectiveness of using PV inverters in solar farms as STATCOM, termed as PV-STATCOM, for power oscillation damping and enhanced power transfer capability. The PV-STATCOM achieves this by modulating reactive power, utilizing the full inverter capacity at night for POD, and briefly discontinuing real power generation during the day to divert the entire inverter capacity for POD. These functions are demonstrated on various test systems, including a Single-Machine Infinite-Bus (SMIB) system [23], a Two-Area Four-machine system [1-2], and a 12-bus system [28], using MATLAB/SIMULINK. The POD controller is designed using the simplex optimization method embedded in MATLAB [24], and the small-signal Residue Analysis technique [25-27] is used to determine the optimal positioning of the PV-STATCOM in the transmission system. The feasibility of using Fuzzy control for the PV-STATCOM controller has also been explored and demonstrated using MATLAB software.

II. PV-STATCOMCONCEPT

Typical active power generation of a PV inverter(**p**)when sun light is available in a day and the reactive power capability**(q)**in remaining period when sun light is not available is illustrated in Fig 5.1. This smart inverter which will act as Photovoltaic -STATCOM can function in two modes as shown in the figure: -

Partial mode. The capability of PV-inverter available after generating real power output is used for functioning as STATCOM in case of 'partial PV-STATCOM mode'. This mode is employed in daytime [1].

Full mode.In Full PV-STATCOM mode pf operation, full capability of PV inverter of the solar-farm is exploited to function as STATCOM. Full mode of operation is utilized in night time[1].

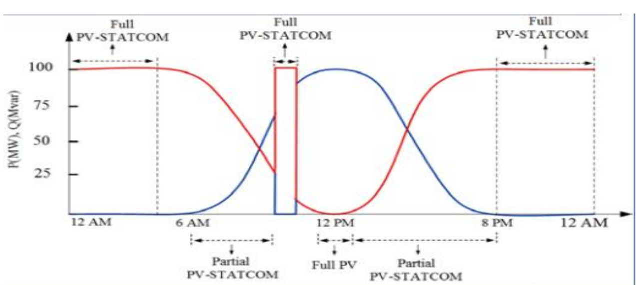


Fig-5.1. Active-reactive power output of PV inverter(24 hours ideal distribution on a sunny day)

During the daytime, the real power generation function is interrupted whenever undesirable low-frequency power oscillations are identified due to system interference. In response, the PV inverter will act as a PV-STATCOM, using its full inverter power capacity to modulate reactive power for damping the oscillations, as needed. Once the damping is achieved, the PV inverter will return to its normal mode to generate active power, ramping up its output to the previous level before the interference, while continuing partial PV-STATCOM operation for ongoing oscillation damping.

At night, when no sunlight is available, the PV inverter will operate in full PV-STATCOM mode, utilizing its full capacity for reactive power modulation and power oscillation damping.Besides these two modes, the inverter can also function in a "full-mode" where it generates active power at unity power factor, depending on the available solar irradiance, without any "smart functions" for reactive power control or oscillation damping.

III. Single Machine Infinite Bus (SMIB) System: FIG3.2 Diagram of ahuge alternator/synchronous generator feeding an Infinite-Bus using a long transmission line (600 km)[23]. In the figures, a PV solar farm (100 MW) acting as STACOM is positioned at Bus 2 ,which is mid-point of the line.

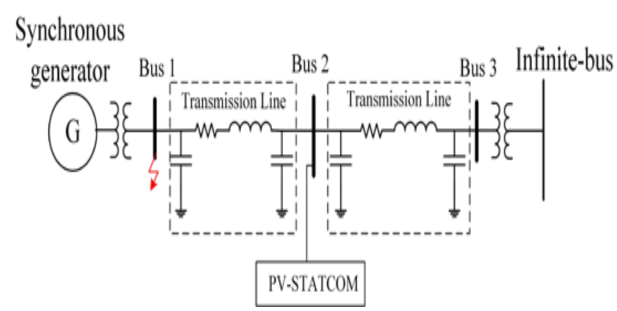


Fig. 3.2 SMIB system with PV-STATCOM at Mid Point

Two-Area Four-Machine system. A Two-Area (A and B) system with four Machines (G1-G4) connected through a long 220 km transmission line with a PV-STATCOM (100 MW) at the midpoint between bus 7 and 9 is illustrated in fig 5.3[1-2].In this two-area four machine system, the machines are not installed with Power System

Stabilizer (PSS). The parameters as given in [1-2] and [23] are considered in this paper for calculations. In case of Two-Area systems, oscillations due to local inertial fluctuations as well as inter-area fluctuations will be affecting the transfer of power [1-2].

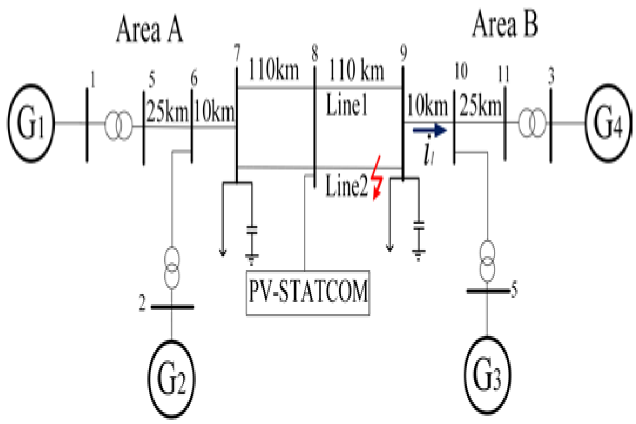


Fig 3.3: 12 Bus FACTS power system:

Impact of FACTS controls is studied widely using 12 bus FACTS power system. Efficiency of the controller has been demonstrated by performing damping of power oscillations with PV-STATCOM on 12 bus system with various oscillation modes. In this system no Power Stabilizer Systems are considered on machines.

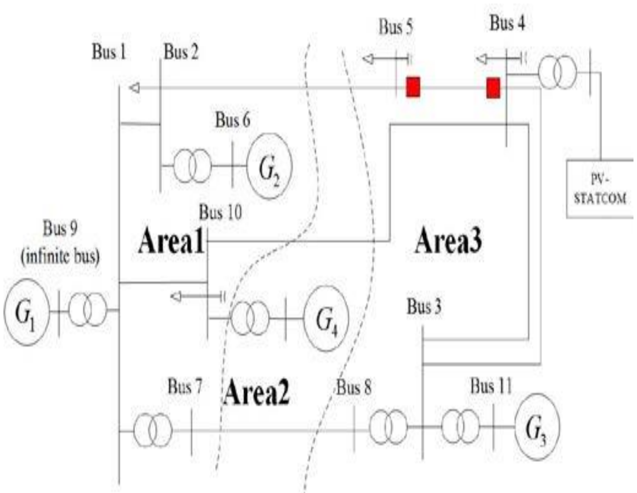


Fig. 3.4. 12 bus FACTS power system with 100 MW PV solar systems at bus 4

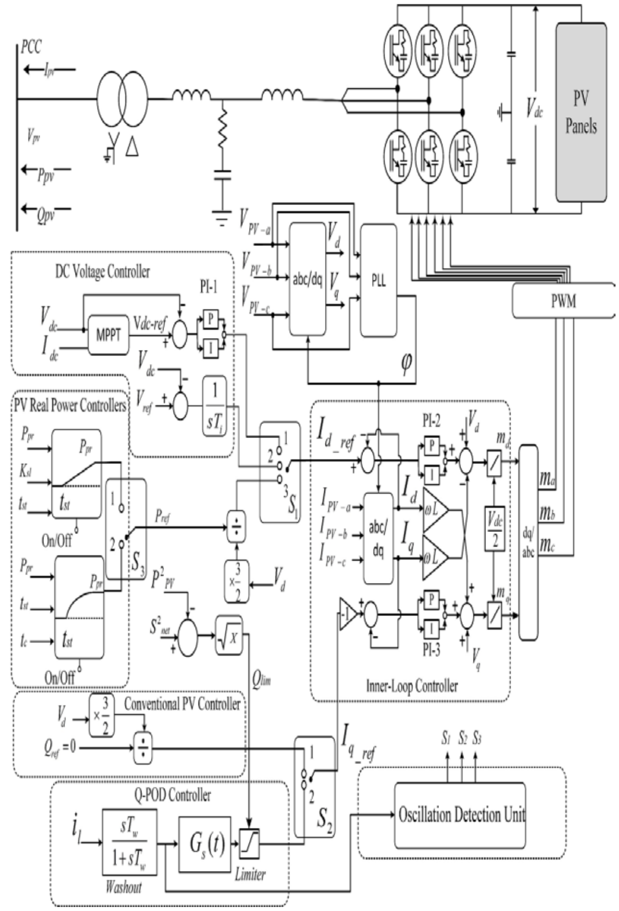


Fig. 3.5 PV-STATCOM controller

<u>PV-STATCOM</u><u>MODELING</u>. Varioussub-units of the PV-STATCOM controlleras illustrated in Fig. 3.5 are described below.

<u>PV Panels and Inverter</u>.An equivalent panel model in which dc current out of PV array based on its V-I characteristic is represented by ‘PV Panel’ [30]. The PV solar inverter is athree phase Voltage Controlled Inverter controlled by six pulseswith a DC link capacitor [31]. This VSI type photovoltaic inverter is inserted in to power transmission line via an Inductor-Capacitance-Inductor (LCL)-filter [32]. Various parameters at the PCC are represented with symbols Vpv, Ipv , Ppv and Qpv depictsvoltage, current, real power and reactive powerof the inverter.

Inner Loop Controller. The parameters for controllingactive and reactive power using decoupled 'd-q' components is provided by inner loop controller . The same is achieved using respective reference currents of direct (d) and quadrature(q) components Id-ref and Iq-ref respectively [31]. Further, the inner loop controller derives modulation index m_d and m_q. This phasor indices undergo transformation again with the help of inverse Park transformation (dq/abc) andgenerate three phase modulation index 'm_a', 'm_b' and 'm_c'. The indices (m_a,m_b and m_c) derived by inverse Park transformation are used for generating triggering pulses for IGBTs in the Voltage Source Inverter using suitable Pulse Width Modulation (PWM)method [29]. The Parks transformation ('abc' / 'dq)block and Phase Locked Loop (PLL) blockare designed as demonstrated in [31]. 'Vdc' in the fig 5.5 represents voltage of DC link in PV-STATCOM. 'Vd', 'Id','Vq' and 'Iq' represents d and q axis voltage (V) and current (I).

IV. FUZZY CONTROLLER:

The word Fuzzy means vagueness. Fuzziness occurs when the boundary of piece of information is not clear-cut. In 1965 Lotfi A. Zahed propounded the fuzzy set theory. Fuzzy set theory exhibits immense potential for effective solving of the uncertainty in the problem. Fuzzy set theory is an excellent mathematical tool to handle the uncertainty arising due to vagueness. Understanding human speech and recognizing handwritten characters are some common instances where fuzziness manifests.

Fuzzy set theory is an extension of classical set theory where elements have varying degrees of membership. Fuzzy logic uses the whole interval between 0 and 1 to describe human reasoning. In FLC the input variables are mapped by sets of membership functions and these are called as "FUZZY SETS".

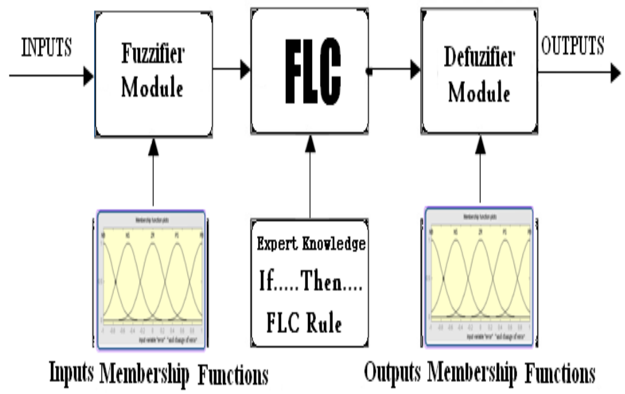


Fig 3.1: block diagram of fuzzy logic Controller

3.1 Fuzzy rules:

In the fuzzy control, input and output variables are the size of the form to describe in words, so to select special vocabulary to describe these variables, generally used in "big, medium and small" Three words to express the controller input and output variables state, plus the positive and negative directions, and zero, a total of seven words : { negative big, negative medium, negative small, zero, positive small, middle, CT } , the general terms used in the English abbreviation prefix : {NB , NM, NS , ZE, PS , PM, PB}.

IV.Simulink Model and Results

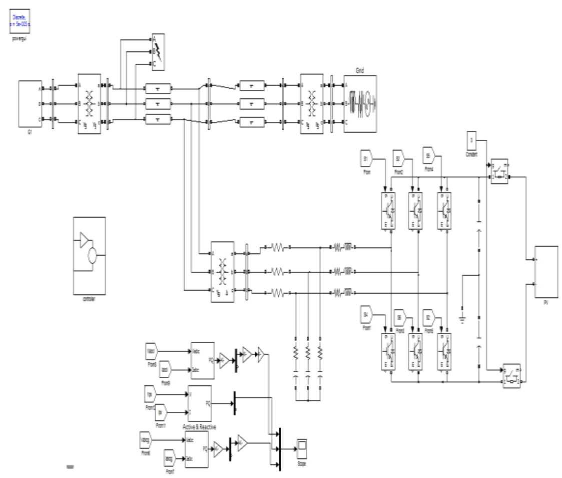


Fig4.1Simulink Block Diagram

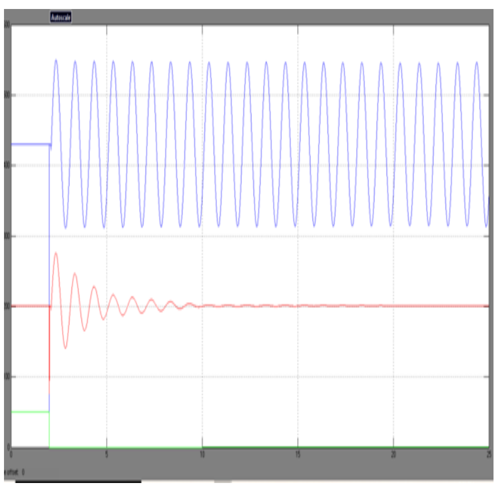


Fig. 4.2. Maximum power transfer capability of the SMIB system

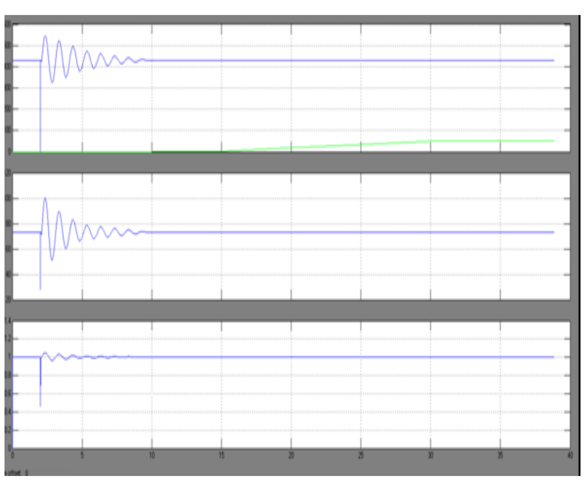
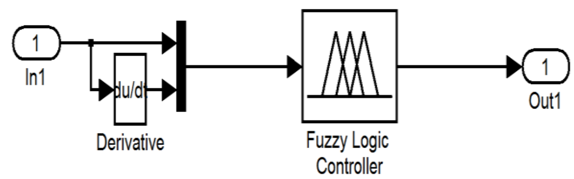


Fig. 4.3 (a) Midline and PV system real powers, (b) PV-STATCOM reactivepower, (c) Midline voltage during POD and normal ramped power restoration



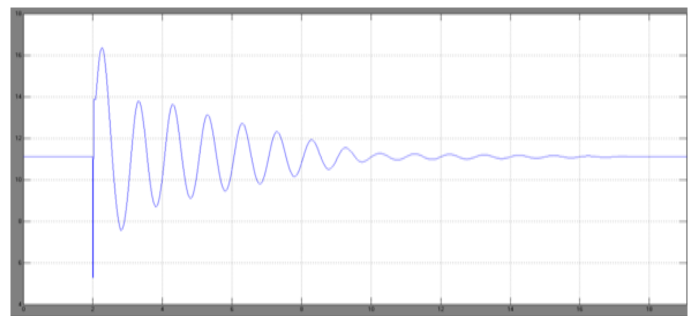


Fig. 4.4. Nighttime using fuzzy logic controller (a) Midline real power without POD with PV-STATCOM control, (b) Midline real power with Full PV-STATCOM POD Control, (c) PVSTATCOM reactive power

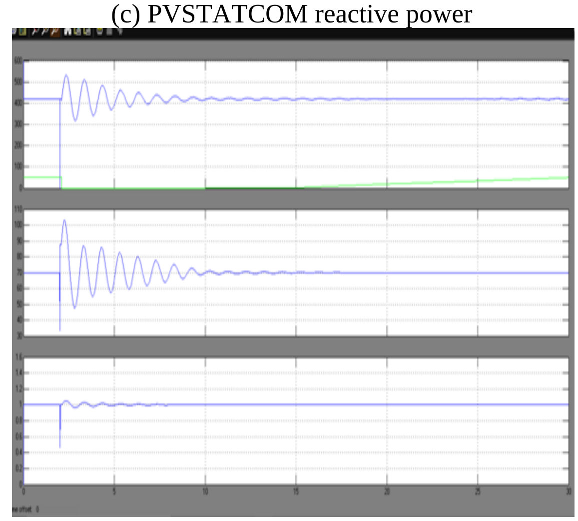


Fig. 4.5(a) Midline and PV real power, (b) PV reactive power, (c) Midlinevoltage during POD and power restoration in a fast ramped manner.

CONCLUSION

This paper presents a photovoltaic (PV) solar farm functioning as a STATCOM (static synchronous compensator), termed a PV-STATCOM, which utilizes a fuzzy logic controller. The proposed PV-STATCOM has been demonstrated to provide effective power oscillation damping (POD). When system oscillations are detected, the PV-STATCOM temporarily suspends real power generation (for around 15 seconds) and instead operates in STATCOM mode, using the full inverter capability to dampen the oscillations by modulating reactive power. Once the oscillations are mitigated, the PV system's real power generation is restored.

The effectiveness of the PV-STATCOM has been evaluated using a Single-Machine-Infinite-Bus (SMIB) system, a Two-Area Four-Machine system, and a 12-bus system, all simulated in MATLAB/Simulink. A simplex optimization method embedded in MATLAB was used to design the POD controller, and a fuzzy control approach was also explored.The results show that a 100 MW mid-point inserted PV-STATCOM can enhance the power transfer capability by 230 MW in the SMIB system and 200 MW in the Two-Area Four-Machine system. Importantly, the PV-STATCOM is able to reinstate the real power much faster (over 3 times faster) compared to restoration using grid codes alone. Additionally, the PV-STATCOM is a more cost-effective solution, costing less than 10% of an equivalent STATCOM, as it leverages the existing solar farm infrastructure. This presents an attractive opportunity for solar farms connected to the grid to provide valuable FACTS functionality in a cost-effective manner. However, implementing this technique would require agreements among various stakeholders, similar to other power generation and distribution regulations.

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