

# **An Integrated Hybrid inductive and capacitive with Multi-Axis Power Distribution System Based on Wireless Power Transmission**

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**ABSTRACT:** Photovoltaic solar farms generate power only during daytime and remain completely idle during the nights. This paper presents a novel technology of utilizing Photovoltaic (PV) Solar Farms in the night time. New controls are developed for the solar farm inverters to operate as STATCOM – a Flexible AC Transmission System (FACTS) Controller, using the entire inverter capacity in the night for accomplishing various power system objectives, such as voltage regulation, improvement of power transfer capacity, load compensation, etc. During the daytime, the same objectives can be achieved to a substantial degree with the inverter capacity remaining after real power generation. This technology is termed PV-STATCOM. Two novel applications of solar farms operating as PV- STATCOM in realistic transmission and distribution systems are presented in this paper for improving power transfer capacity of transmission lines.

**KEYWORDS:** Photovoltaic (PV) solar power systems, inverter, voltage control, reactive power control, damping control, Flexible AC Transmission System (FACTS), static synchronous compensator (STATCOM), transmission capacity, wind power system, renewable energy, power factor correction, wind power.

## **I. INTRODUCTION**

Photovoltaic (PV) technology, although expensive, is receiving strong encouragement through various incentive programs globally [1], [2]. As a result, large-scale solar farms are being connected to the grid. However, transmission grids worldwide are presently facing challenges in integrating such large-scale renewable systems (wind farms and solar farms) due to their limited power transmission capacity [3]. To increase the available power transfer limits/capacity (ATC) of existing transmission lines, series compensation and various FACTS devices are being considered [4]-[8]. In an extreme situation new lines may need to be constructed at a very high expense [9].

This paper proposes a novel voltage control together with auxiliary damping control for a grid connected PV solar farm inverter to act as a STATCOM both during night and day for increasing transient stability and consequently the power transmission limit; as well as provide voltage regulation to increase wind connectivity. This technology of utilizing a PV solar farm as a STATCOM is termed “PV-STATCOM”. It utilizes the entire solar farm inverter capacity in the night and the remainder inverter capacity after real power generation during the day, both of which remain unused in conventional solar farm operation. Similar STATCOM control functionality can also be implemented in inverter based wind turbine generators during no-wind or partial wind scenarios for improving the transient stability of the system. C.Nagarajan et al [2,5,10] has studies are performed for a Single Machine Infinite Bus (SMIB) system. which uses a single PV solar farm as PV-STATCOM connected at the midpoint. Three-phase fault studies are conducted using MATHLAB SIMULINK, and the improvement in stable power transmission limit is investigated for different combinations of STATCOM controller on the solar farm inverters, both during night and day.

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Section II describes the case study for enhancing power transmission capacity; Section III presents the simulation and results. The implications of this new PV-STATCOM technology and the conclusions are presented in Section IV.

## II. ENHANCEMENT OF STABLE POWER TRANSFER CAPACITY

A Single Machine Infinite Bus (SMIB) system is adopted for this study system and is presented as a single line diagram in Fig. 1. This system is comprised of a large equivalent synchronous generator (1110 MVA) which supplies power to the infinite bus over a typical transmission line length of 200 km connected in a 400 kV transmission network. A 100 MW PV solar farm (DG) as STATCOM (PV-STATCOM) is connected at the midpoint of the transmission line. All the system parameters are given in [10].

### A. System Model

The synchronous generator is represented by a detailed sixth order model and a DC1A type exciter [20]. The line segments are represented by lumped pi-circuits. The PV solar DG is modelled as an equivalent controlled DC current source feeding a voltage sourced inverter in its DC bus, as shown in Fig. 2. The controlled DC current source gives the output according to the I-V characteristics of Photovoltaic (PV) panels [11]. A maximum power point tracking (MPPT) algorithm based on incremental conductance algorithm [12] is also integrated with the inverter controller [13] to operate the solar DGs at its maximum power point.

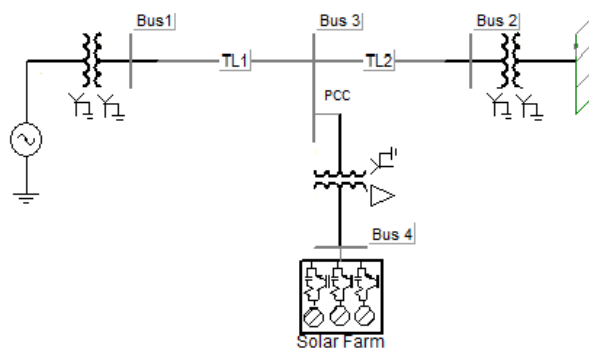


Fig. 1. Single line diagram of the study system with single solar farm (DG).

The amount of real power injection from the DGs to the grid depends upon the level of solar insulation, temperature etc. For PV-STATCOM operation during night time, the solar panels are disconnected from the DC bus of the inverter and a small amount of real power is drawn from the grid to charge the DC capacitor. The voltage source inverter is composed of six IGBTs with its associated snubber. The size of DC capacitor is selected according to [14] to reduce the DC side ripple. A pair of IGBT devices corresponds to each phase converts the DC voltage into AC voltages, using the sinusoidal pulse width modulation (SPWM) technique [15]. To maintain the power quality an L-C-L filter [20] is connected at the AC side of the inverter which includes the coupling transformer reactance.

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### B. Control System

#### B.1 Conventional Unity Power Factor (UPF) Control

The conventional UPF control only controls the reactive power output of the inverter to maintain unity power factor operation along with the DC link voltage control [21]. The switching signals for the inverter switching are generated through two current control loops in d-q-0 co-ordinate system [22]. The output of these two current control loops generates the IGBT switching signals in accordance with a high frequency carrier signal.

#### B.2 PCC Voltage Control

In the mode of PCC voltage control, the PV inverter exchanges reactive power with the grid. In this control mode of operation, the conventional UPF control channel is replaced by the PCC voltage controller simply by switching the ‘Switch-1’ to the position ‘A’. Hence, the measured signal,  $V_{PCC}$ , at the PCC is compared with the preset reference value  $V_{PCC\ ref}$  and is passed through the PI regulator, PI-4, to generate  $I_{d\_ref}$ . The rest of the controller remains same as before. Hence, in this controller the upper current control loop is used to regulate the PCC voltage whereas the lower current control loop is used for DC voltage control and supply the PV power to the grid at the same time.

#### B.3 Damping Control

To integrate the proposed novel auxiliary damping controller to the PV control system a washout stage, a  $p^{\text{th}}$  order lead-lag block, gain and low pass filters are added with the upper channel of  $I_{d\_ref}$ . This damping controller can be expressed with the following general equation

This controller is activated by toggling ‘Switch-2’ to the ‘ON’ position and used to damp down the rotor mode oscillations. This damping controller can operate with either the conventional UPF control mode or with the PCC voltage control mode by toggling the ‘Switch-1’ to position ‘B’ or ‘A’, respectively. In this controller, likewise the local line current magnitude signal as used here as a control signal, a verities of other local or remote signals which reflect mostly the rotor mode oscillations of the generator.

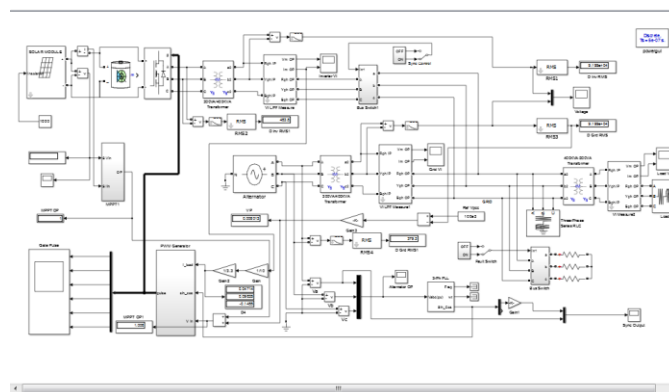


Fig. 2. Complete PV system model with damping controller and PCC voltage control system.

To study the transient stability, MATHLAB SIMULINK software is used, by applying a 3-Line to Ground (3LG) fault at bus 1 for 5 cycles during both night and day. For this study, the maximum stable power transfer limit from the generator is defined as the power for which the post-fault clearance settling time of the rotor mode oscillations is

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within 10 seconds and the peak overshoot of PCC voltage is within 1.1 pu of nominal voltage. This results in an acceptable damping ratio of better than 5% [23].

### III. SIMULATION AND RESULTS

#### A. Increase of Power Transfer Limits with Conventional Reactive Power Control and the Novel Damping Control

For the simulation in this paper, MATLAB software was used, In this study the solar DG is assumed to operate with its conventional reactive power controller through which the reactive power output from the solar DG is maintained zero in steady state and the DG operates at near unity power factor. The stable power transmission limits obtained from transient studies and the corresponding load flow results are presented in Table 1.

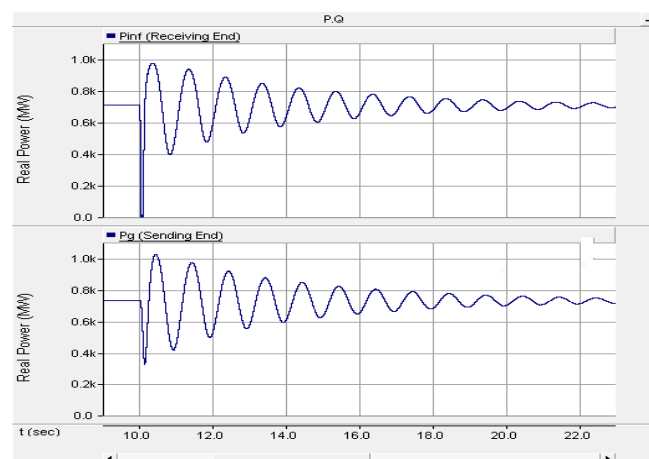


Fig. 3. Maximum night time power transfer (731 MW) from generator when solar DG remains idle

During night the conventional DG with damping controller increases the generator power transfer limit,  $P_g$ , by 119 MW as compared to the case when it is sitting idle as conventional PV. The real power from generator  $P_g$  and that entering into the infinite bus  $P_{inf}$  are shown in Fig. 3 when the conventional solar farm is sitting idle during night time and in Fig. 4 when the conventional solar farm is operating with proposed damping controller. It is noted; while the PV DG is operating with the proposed damping controller it is utilizing the whole inverter capacity during night time to perform the proposed operation.

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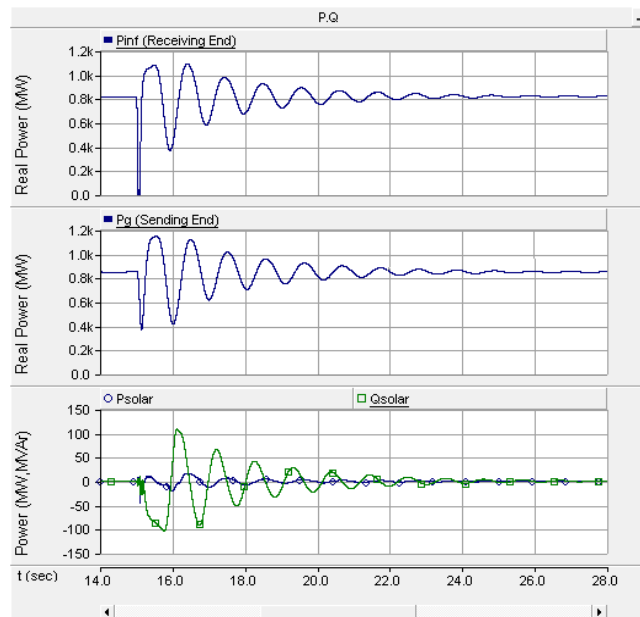


Fig. 4. Maximum night time power transfer (850 MW) from generator with solar DG using damping controller

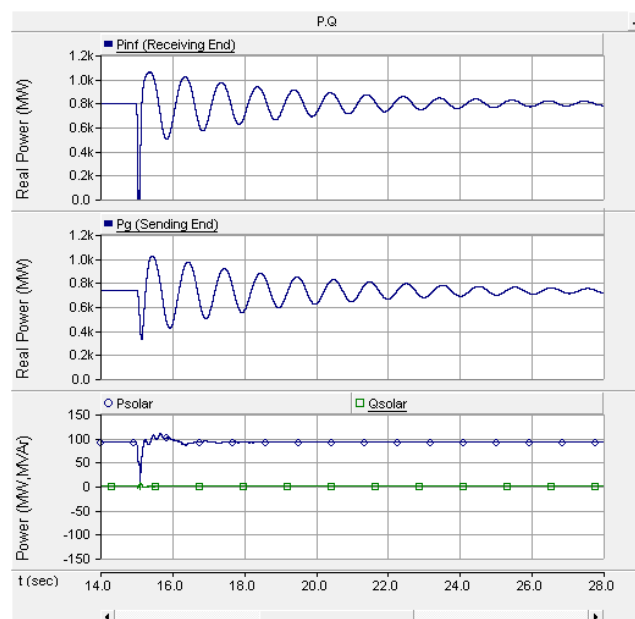


Fig. 5. Maximum daytime power transfer (719 MW) from generator with solar DG generating 91 MW real power.

During day time the solar inverter is utilizing the available inverter capacity after real power generation to perform this proposed damping control operation and increases the active power transmission limit by 121 MW while

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the PV is generating low level power typically around 19MW and by 142 MW when PV is generating a high level power typically around 91 MW. The quantities  $P_g$ ,  $P_{inf}$ ,  $P_{solar}$ , and  $Q_{solar}$  are shown for the cases without damping controller and with damping controller in Figs. 5 and 6, respectively.

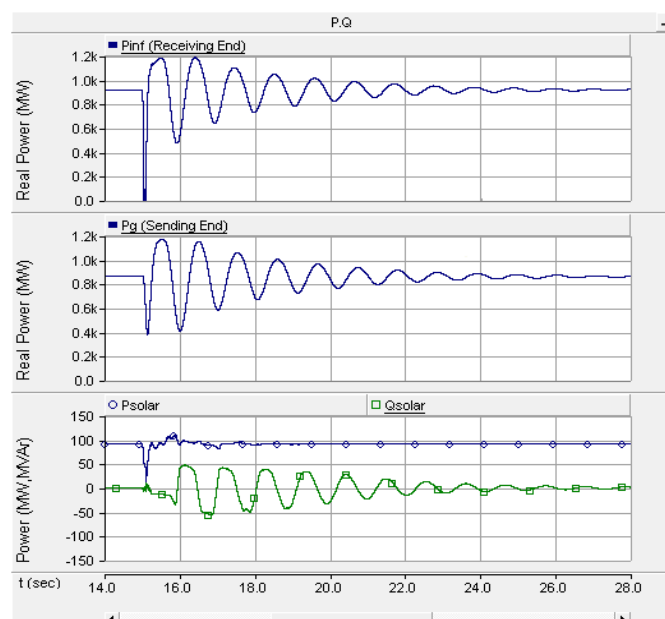


Fig.6. Maximum daytime power transfer (861 MW) from generator with solar DG generating 91 MW real power and using the damping controller

### B. Increase of Power Transfer Limits with PCC Voltage and the Novel Damping Control

Transient stability studies are now carried out for PCC voltage control together with damping control. During night with voltage controller the increase in power transfer limit is dependent upon the choice of reference values for PCC voltage  $V_{pcc}$ . In the best scenario when  $V_{pcc}$  is regulated to 1.01 pu, the maximum power output from the generator increases to 833 MW, as compared to 731 MW when the solar DG operates with conventional reactive power control. But the use of damping controller with voltage control increases the power transfer further to 899 MW. The generator and infinite bus power are depicted in Fig. 7.

For Study System 1, the net increase in power transfer capability as achieved with different PV-STATCOM controls in comparison with that obtained conventional reactive power control of the solar DG, is summarized in Table 2. The maximum increase in power transfer limit during night time is achieved with a combination of voltage control and damping control, whereas the same during daytime is accomplished with damping control alone. This is because in the night the entire MVA rating of the solar DG inverter is available for reactive power exchange, which can be utilized for achieving the appropriate voltage profile at PCC conducive for increasing the power transfer, as well as for increasing the damping of oscillations.

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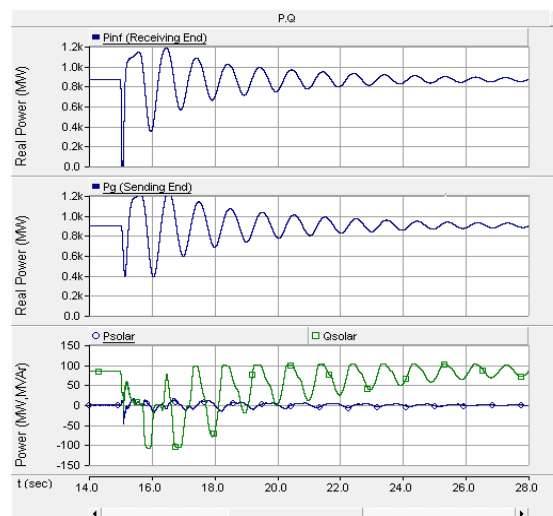


Fig.7. Maximum nighttime power transfer (899 MW) from generator while the solar DG uses damping controller with voltage control

### V. CONCLUSION

This paper proposes a new application of PV solar DG as STATCOM utilizing a novel voltage and damping control for improving the transient stability and consequently the stable power transfer limit in a transmission system. However, the economic benefits to the transmission system in form of increased stability limit. This study thus makes a strong case for relaxing the present grid codes to allow selected inverter based renewable generators (solar and wind) to exercise voltage regulation and damping control, thereby increasing much needed power transmission capability. Such novel controls on PV solar DGs (and inverter based wind DGs) will potentially reduce the need for investments in additional expensive devices such as series/ shunt capacitors and FACTS. The PV- STATCOM operation opens up a new opportunity for PV solar DGs to earn revenues in the night time and also daytime in addition to that from the sale of real power during the day.

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