Control of Solar PV-Inverter Fed to Grid for Active and Reactive Power Control during Day And Night

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ABSTRACT

In this paper a simplified concept of utilizing a solar PV inverter as STATCOM, so called as PV-STATCOM, for improving power transfer capability of the interconnected transmission system during Night and Day. The inverter as part of the PV solar farm, which remains idle during night time, is utilized with voltage and damping controls to enhance stable power transmission limits. During daytime, the inverter capacity left after real power production is used to accomplish the aforementioned objective. Transient stability studies are conducted on a realistic single machine infinite bus power system having a midpoint located PV-STATCOM using MATLAB simulation software. The PV-STATCOM improves the stable transmission limits substantially in the night and in the day even while generating large amounts of real power. Power transfer increases are also demonstrated by comparing PI control and Wavelet Transformation control in the same power system for a solar farm as PV-STATCOM. This novel utilization of a PV solar farm asset can thus improve power transmission limits without making use of auxiliary filters.

Keyword: - *PV STATCOM, Reactive power compensator, Single machine Infinite bus.*

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1. INTRODUCTION

Flexible AC transmission system (FACTS) controllers are being increasingly considered to increase the available power transfer limits/capacity (ATC) of existing transmission lines [1]–[4], globally. New research has been reported on the nighttime usage of a photovoltaic (PV) solar farm (when it is normally dormant) where a PV solar farm is utilized as a STATCOM–a FACTS controller, for performing voltage control, thereby improving system performance and increasing grid connectivity of neighboring wind farms [5], [6]. New voltage control has also been proposed on a PV solar farm to act as a STATCOM for improving the power transmission capacity. Although, [8] and [9] have proposed voltage-control functionality with PV systems, none have utilized the PV system for power transfer limit improvement. A full converter-based wind turbine generator has recently been provided with FACTS capabilities for improved response during faults and fault ride through capabilities.

This paper proposes 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. This technology of utilizing a PV solar farm as a STATCOM is called "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. Studies are performed for two variants of a single-machine infinite bus (SMIB) system. One SMIB system uses only a single PV solar farm as PV-STATCOM connected at the midpoint whereas the other system uses a combination of a PV-STATCOM and another PV-STATCOM or an inverter-based wind distributed generator (DG) with similar STATCOM functionality. Three-phase fault studies are conducted using the electromagnetic transient software MATLAB, and the improvement in the stable power transmission limit is investigated for different combinations of STATCOM controllers on the solar and wind farm inverters, both during night and day.

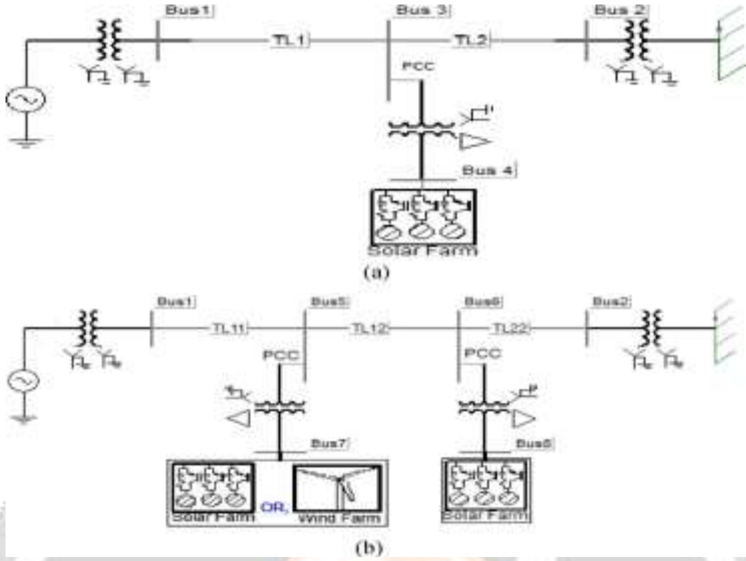

Fig-1: Single machine infinite bus system.

2. PV SYSTEM

The word "photovoltaic" combines two terms – "photo" means light and "voltaic" means voltage. A photovoltaic system in this discussion uses photovoltaic cells to directly convert sunlight into electricity.Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Materials presently used for photo voltaic include mono crystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium solenoid/sulfide. Due to the increased demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years. Solar photovoltaic is a sustainable energy source where 100 countries are utilizing it. Solar photovoltaic's is now, after hydro and wind power, the third most important renewable energy source in terms of globally installed capacity. Installations may be ground-mounted or built into the roof or walls of a building. (Either building-integrated photovoltaic or simply rooftop)

2.3.2 PV CELL

A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a 'photovoltaic module'. Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on the intensity of light reaching the module. Several modules can be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

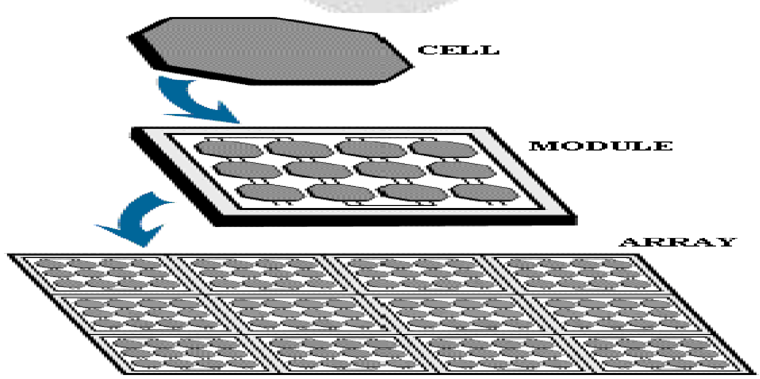

Fig-2:.PV module

2.1 Electrical Connections Of The Cell

The electrical output of a single cell is dependent on the design of the device and the Semi-conductor material(s) chosen, but is usually insufficient for most applications. In order to provide the appropriate quantity of electrical power, a number of cells must be electrically connected. There are two basic connection methods: series connection, in which the top contact of each cell is connected to the back contact of the next cell in the sequence, and parallel connection, in which all the top contacts are connected together, as are all the bottom contacts. In both cases, this results in just two electrical connection points for the group of cells.

1. Series Connection

Figure shows the series connection of three individual cells as an example and the resultant group of connected cells is commonly referred to as a series string. The current output of the string is equivalent to the current of a single cell, but the voltage output is increased, being an addition of the voltages from all the cells in the string (i.e. in this case, the voltage output is equal to 3Vcell).

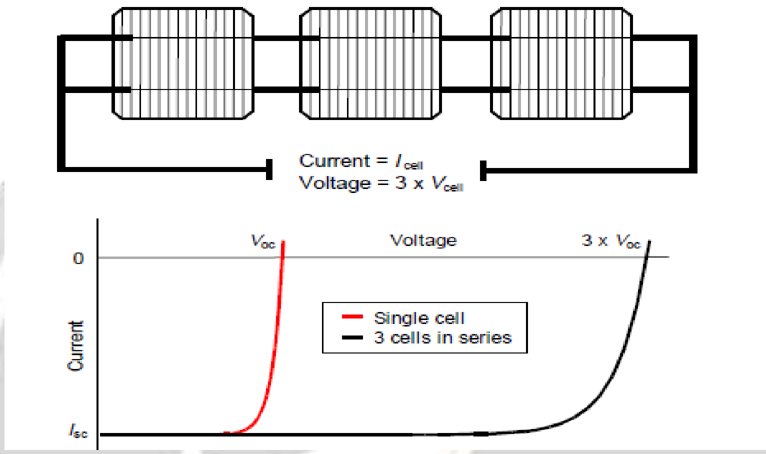

Fig-3:.Series connection of cells, with resulting current–voltage characteristic.

It is important to have well matched cells in the series string, particularly with respect to current. If one cell produces a significantly lower current than the other cells (under the same illumination conditions), then the string will operate at that lower current level and the remaining cells will not be operating at their maximum power points. From the above we can observe some the important points to be noted such as the graphs depicts the linearity of the system.

2. Parallel Connection

Figure shows the parallel connection of three individual cells as an example. In this case, the current from the cell group is equivalent to the addition of the current from each cell (in this case, 3 I cell), but the voltage remains equivalent to that of a single cell. As before, it is important to have the cells well matched in order to gain maximum output, but this time the voltage is the important parameter since all cells must be at the same operating voltage. If the voltage at the maximum power point is substantially different for one of the cells, then this will force all the cells to operate off their maximum power point, with the poorer cell being pushed towards its open-circuit voltage value and the better cells to voltages below the maximum power point voltage. In all cases, the power level will be reduced below the optimum.

2.2 The Photovoltaic Array

A PV array consists of a number of PV modules, mounted in the same plane and electrically connected to give the required electrical output for the application. The PV array can be of any size from a few hundred watts to hundreds of kilowatts, although the larger systems are often divided into several electrically independent sub arrays each feeding into their own power conditioning system.

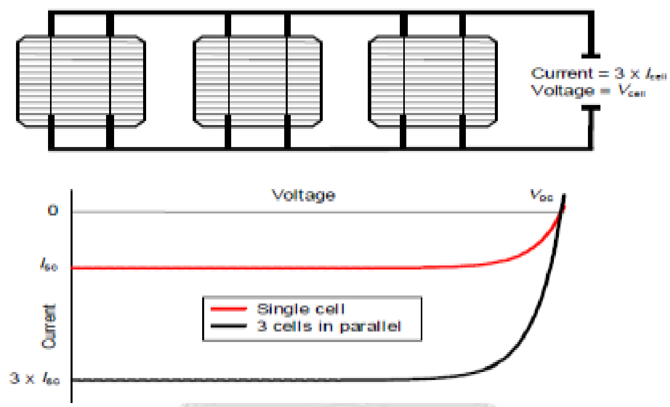

Fig-4:.Parallel connection of cells, with resulting current–voltage characteristic.

3. PROPOSED SYSTEM OF SIMB

The synchronous generator is represented by a detailed sixth order model and a DC1A-type exciter. The transmission-line segments TL1, TL2, TL11, TL12, and TL22, shown in Fig. 1,
are represented by lumped pi-circuits. The PV solar DG, as shown in Fig. 2, is modeled as an equivalent voltage-source inverter along with a controlled current source as the dc source which follows the - characteristics of PV panels [11]. The wind DG is likewise modeled as an equivalent voltage-source inverter. In the solar DG, dc power is provided by the solar panels, whereas in the full-converter-based wind DG, dc power comes out of a controlled ac–dc rectifier connected to the PMSG wind turbines, depicted as "wind Turbine-Generator-Rectifier (T-G-R)." The dc power produced by each DG is fed into the dc bus of the corresponding inverter, as illustrated in Fig. 7.2. A maximum power point tracking (MPPT) algorithm based on an incremental conductance algorithm [12] is used to operate the solar DGs at its maximum power point all of the time and is integrated with the inverter controller [11]. The wind DG is also assumed to operate at its maximum power point, since this proposed control utilizes only the inverter capacity left after the maximum power point operation of the solar DG and wind DG.
For PV-STATCOM operation during nighttime, the solar panels are disconnected from the inverter and a small amount of real power is drawn from the grid to charge the dc capacitor.
The voltage-source inverter in each DG is composed of six insulated- gate bipolar transistors (IGBTs) and associated snubber circuits as shown in Fig. 5. An appropriately large dc capacitor of size 200 Farad is selected to reduce the dc side ripple [13]. Each phase has a pair of IGBT devices which converts the dc voltage into a series of variable-width pulsating voltages, using the sinusoidal pulse width modulation (SPWM) technique [14]. An L-C-L filter [13] is also connected at the inverter ac side

3.1 Reactive Power Control

The conventional reactive power control only regulates the reactive power output of the inverter such that it can perform unity power factor operation along with dc-link voltage control [15]. The switching signals for the inverter switching are generated through two current control loops in - -0 coordinate system [15], [16]. The inverter operates in a conventional controller mode only provided that "Switch-2" is in the "OFF" position. In this simulation, the voltage vector is aligned with the quadrature axis, that is, 0 [15], [16], hence, is only proportional to which sets the reference for the upper control loop involving PI1. Meanwhile, the quadrature axis component is used for dc-link voltage control through two PI controllers (PI-2 and PI-3) [14], [16] shown in Fig. 2(b) according to the set point voltage provided by the MPPT and and injects all available real power "P" to the network [15]. To generate the proper IGBT switching signals (gt1, gt2, gt3, gt4, gt5, gt6), the – components
(and) of the modulating signal are converted into three-phase sinusoidal modulating signals and compared with a high-frequency (5-kHz) fixed magnitude triangular wave or carrier signal.

3.2 PCC Voltage Control

In the *PCC voltage control* mode of operation, the PCC voltage is controlled through reactive power exchange between the DG inverter and the grid. The conventional " " control channel is replaced by the PCC voltage controller in Fig. 2(b), simply by switching "Switch-1" to the position "A." Hence, the measured signal at the PCC is compared with the preset reference value and is passed through the PI regulator, PI-4, to generate .

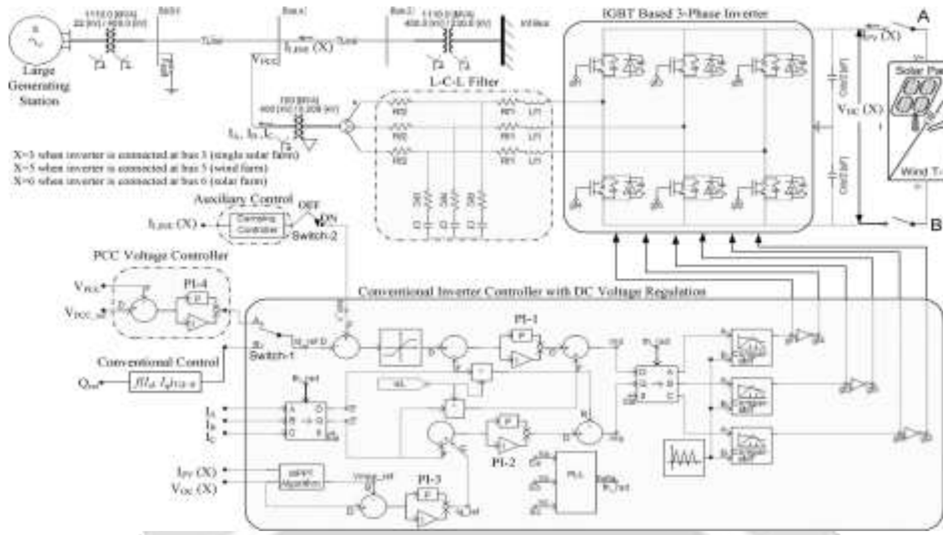

Fig-5: Complete DG (solar/wind) system model with a damping controller and PCC voltage-control system.

The rest of the controller remains unchanged. 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 as well as for the supply of DG power to the grid. The amount of reactive power flow from the inverter to the grid depends on set point voltage at the PCC. The parameters of the PCC voltage controller are tuned by a systematic trial-and-error method to achieve the fastest step response, least settling time, and a maximum overshoot of 10%–15%. The parameters of all controllers are given in the Appendix.

3.3. Damping Control

An auxiliary damping controller is added to the PV control system and shown in Fig. 7.2. (b). This controller utilizes line current magnitude as the control signal. The output of this controller is added with the signal. The transfer function of this damping controller is expressed.

At first, the base-case generator operating power level is selected for performing the damping control design studies. This power level is considered equal to the transient stability limit of the system with the solar farm being disconnected at night. At this operating power level, if a three-phase fault occurs at Bus 1, the generator power oscillations decay with a damping ratio of 5%. The solar farm is now connected and operated in the PV-STATCOM mode. The parameters of the damping controller are selected as follows. The washout time constant is chosen to allow the generator electromechanical oscillations in the frequency range up to 2 Hz to pass through [19]. The gain , time constants , and are sequentially tuned to obtain the fastest settling time of the electromechanical oscillations at the base-case generator power level through repetitive simulations. Thus, the best combination of the controller parameters is obtained with a systematic hit-and-trial technique, and the parameters are given in the Appendix. It is emphasized that these controller parameters are not optimal and better parameters could be obtained by following more rigorous control-design techniques [19], [20]. However, the objective of this paper is only to demonstrate a new concept of using a PV solar farm inverter as a STATCOM using these reasonably good controller parameters

4. Results and Analysis

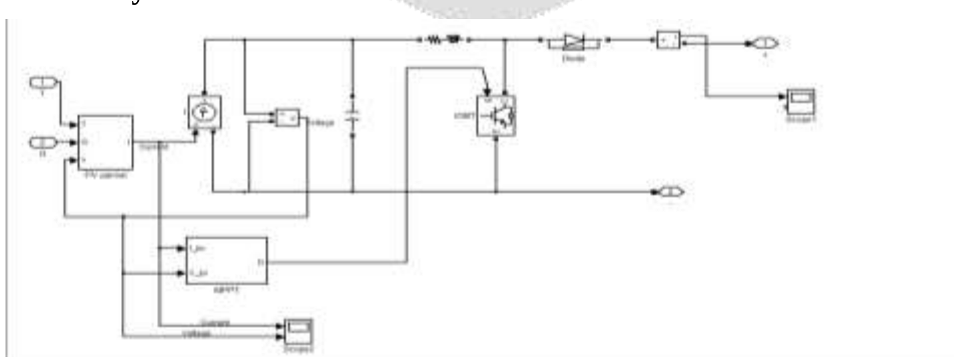

Fig-6: Solar PV system design

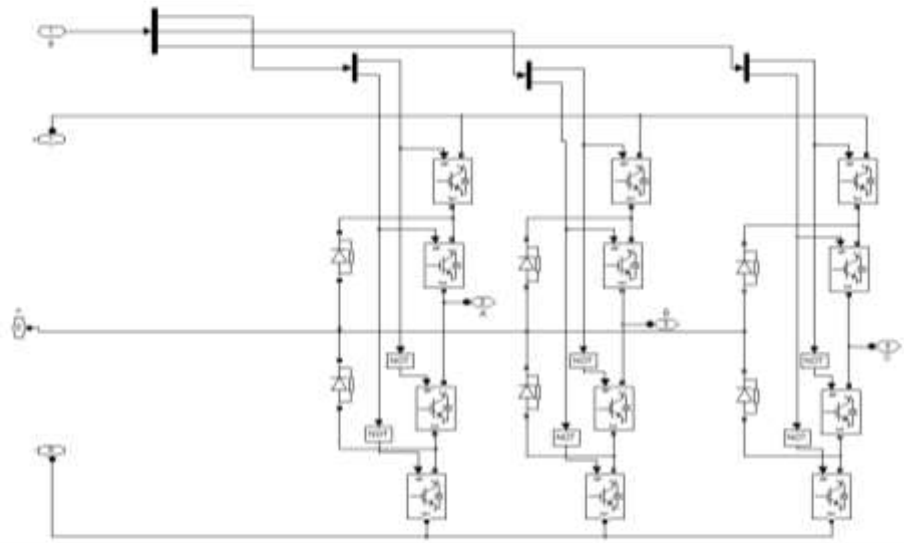

Fig.7 Inverter design

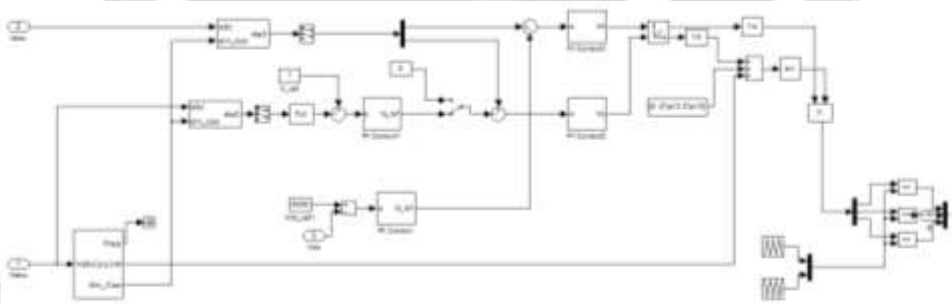

Fig-8: Inverter control strategy

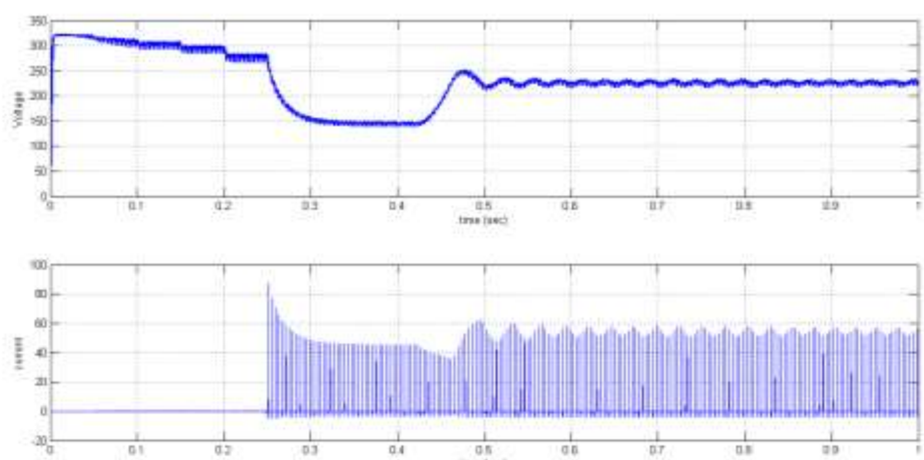

Fig-9: Output voltage and current of boost converter

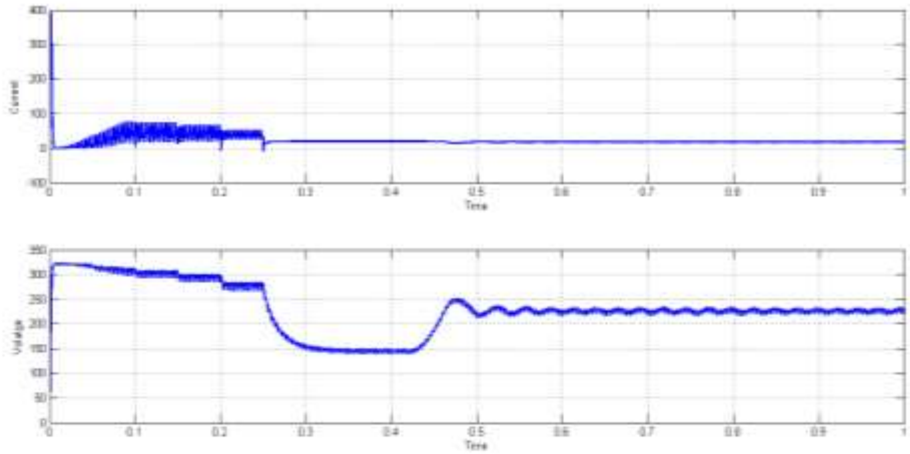

Fig-10: Output voltage and current of MPPT t converter

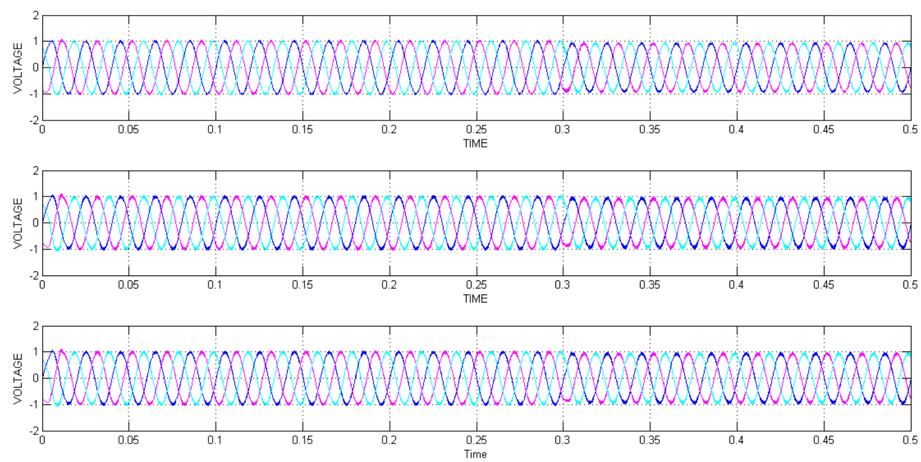

Fig-11: three phase per unit voltages at BUS1, BUS2 and BUS 3

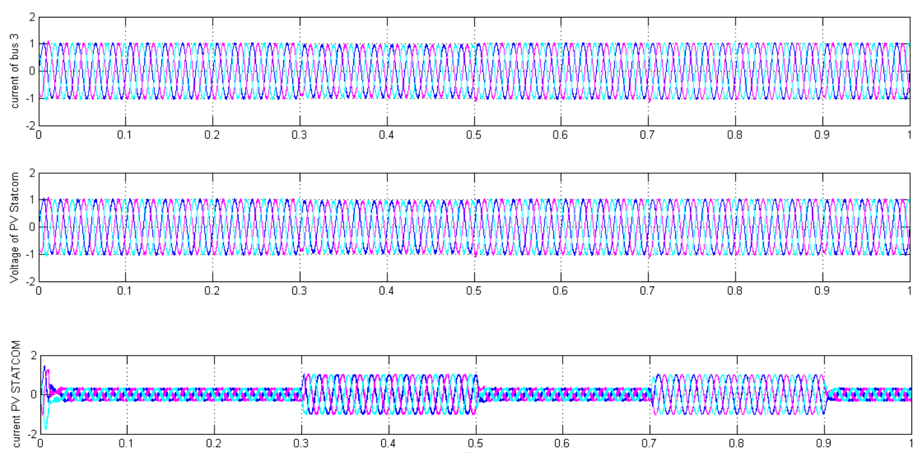

Fig-12: three phase per unit voltages at Bus 3 Currents, Statcom Voltage and Statcom Currents

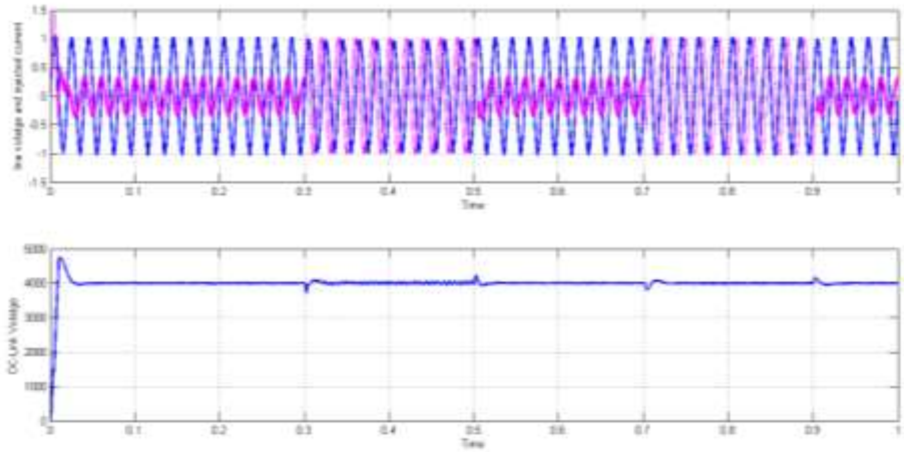

Fig-13: (a) Three phase per unit at PCC and current injected into PCC and (b)DC-LINK voltage

4. CONCLUSIONS

In this paper PV solar farm is presented where they can operate during the night as a STATCOM with full inverter capacity and during the day with inverter capacity remaining after real power generation, for providing significant improvements in the power transfer limits of transmission systems. This new control of PV solar system as STATCOM is called PV-STATCOM. The effectiveness of the proposed controls is demonstrated on pure voltage control, pure damping control, and a combination of voltage control and damping control using SMIB system. In Study System During nighttime and daytime, the power transfer can be increased substantially by additional MW, even when the DGs are generating high real power. This study thus makes a strong case for relaxing the present grid codes to allow selected inverter-based renewable generators to exercise damping control, thereby increasing much needed power transmission capability. The simplified control of PV solar DG 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 nighttime and daytime in addition to that from the sale of real power during the day. The analysis of proposed system has done by comparing the proposed control for both PI and Wavelet controllers. Finally it is found that Wavelet control is more robust to harmonics and it is effective in utilizing DC link of the Inverter.

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