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Improvement of Grid Power Transmission Limits during Night And Day For PV Solar Farm as Statcom (Pv-Statcom)

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ABSTRACT—This paper presents a novel concept of utilizing a photovoltaic (PV) solar farm inverter as STATCOM, called PV-STATCOM, for improving stable power transfer limits of the interconnected transmission system. The entire inverter rating of the PV solar farm, which remains dormant during nighttime, 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 EMTDC/PSCAD 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 in the same power system for: 1) two solar farms operating as PV-STATCOMs and 2) a solar farm as PV-STATCOM and an inverter-based wind farm with similar STATCOM controls. This novel utilization of a PV solar farm asset can thus improve power transmission limits which would have otherwise required expensive additional equipment, such as series/shunt capacitors or separate flexible ac transmission system controllers.

Index Terms**—***Damping control, flexible ac transmission systems (FACTS), inverter, photovoltaic solar power systems, reactive power control, STATCOM, transmission capacity, voltage control, wind power system.*

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 [7]. 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 ridethrough capabilities [10]. 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 EMTDC/PSCAD, 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.

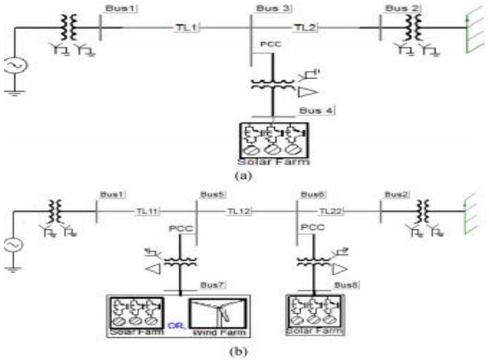


Fig. 1. Single-line diagram of (a) study system I with a single solar farm (DG) and (b) study system II with a solar farm (DG) and a solar/wind farm (DG).

2. LITERATURE SURVEY

Two control plans are actualized in the created lattice associated wind turbine model: speed control and pitch control. The pace control plan is made by two vectorcontrol plans composed individually for the rotor-side and network side PWM voltage source converters. Course control is utilized as a part of the vector-control plans. Two outline techniques, poleplacement and inside model control, are connected for planning the PI-controllers in the vector-control plans. The pitch control plan is utilized to direct the streamlined force from the turbine. The exhibitions of the control plans, individually current control circles, power control circles, DC-join voltage control circle and pitch control circle, are represented, which meet the configuration necessities. Reproduction results demonstrate that the wind turbine is equipped for giving tasteful consistent state and element exhibitions, which makes it conceivable that the wind turbine model can be connected to concentrate on the force quality issues of such sort of lattice associated wind turbines and their collaboration with the framework.

PHOTOVOLTAIC INVERTER

2.1 Introduction to PV system

The basic block diagram of grid connected PV power generation system is shown in Fig. 2.1. The PV power generation system consists of following major blocks:

1. PV unit
2. Inverter
3. Grid
4. MPPT

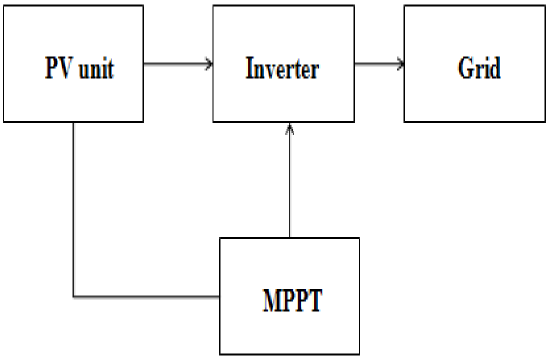


Fig. 2.1 Schematic diagram of PV system

1. PV unit : A PV unit consists of number of PV cells that converts the energy of light directly into electricity (DC) using photovoltaic effect.
2. Inverter : Inverter is used to convert DC output of PV unit to AC power.
3. Grid : The output power of inverter is given to the nearby electrical grid for the power generation.
4. MPPT : In order to utilize the maximum power produced by the PV modules, the power conversion equipment has to be equipped with a maximum power point tracker (MPPT). It is a device which tracks the voltage at where the maximum power is utilized at all times.

For the design of PV generation system, the specifications of considered PV system are shown in below Table 2.1

2.1.1 Photovoltaic Cell and Array Modeling

A PV cell is a simple p-n junction diode that converts the irradiation into electricity. Fig.3.1 illustrates a simple equivalent circuit diagram of a PV cell. This model consists of a current source which represents the generated current from PV cell, a diode in parallel with the current source, a shunt resistance, and a series resistance.

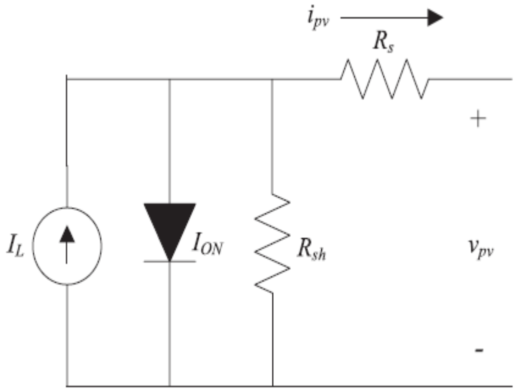


Fig.2.2 Equivalent circuit diagram of the PV cell

2.2.2 Light Generated Current

The generation of current in a solar cell, known as the "light-generated current", involves two key processes.

The first process is the absorption of incident photons to create electron-hole pairs. Electron-hole pairs will be generated in the solar cell provided that the incident photon has an energy greater than that of the band gap. However, electrons (in the *p*-type material), and holes (in the *n*-type material) are meta-stable and will only exist, on average, for a length of time equal to the minority carrier lifetime before they recombine. If the carrier recombines, then the light-generated electron-hole pair is lost and no current or power can be generated.

A second process, the collection of these carriers by the *p-n* junction, prevents this recombination by using a *p-n* junction to spatially separate the electron and the hole. The carriers are separated by the action of th electric field existing at the *p-n* junction. If the light-generated minority carrier reaches the *p-n* junction, it is swept across the junction by the electric field at the junction, where it is now a majority carrier. If the emitter and base of the solar cell are connected together (i.e., if the solar cell is short-circuited), the light-generated carriers flow through the external circuit.

3.DC-DC Converter Basics

A DC-to-DC converter is a gadget that acknowledges a DC info voltage and produces a DC yield voltage. Normally the yield delivered is at an alternate voltage level than the info. Also, DC-to-DC converters are utilized to give clamor confinement, force transport regulation, and so on. This is a synopsis of a portion of the prevalent DC-to-DC converter topologies.

3.1 BUCK CONVERTER

In this circuit the transistor turning ON will put voltage Vin toward one side of the inductor. This voltage will tend to bring about the inductor current to rise. At the point when the transistor is OFF, the present will keep coursing through the inductor however now moving through the diode.

We at first accept that the current through the inductor does not achieve zero, in this way the voltage at Vx will now be just the voltage over the leading diode amid the full OFF time. The normal voltage at Vx will rely on upon the normal ON time of the transistor gave the inductor current is persistent.

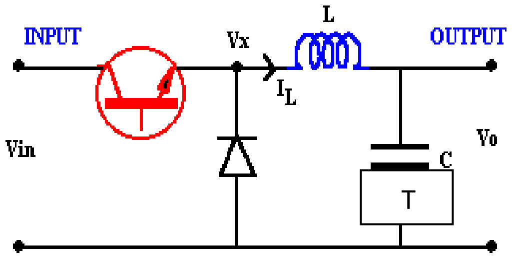


Fig 3.1 Buck Converter

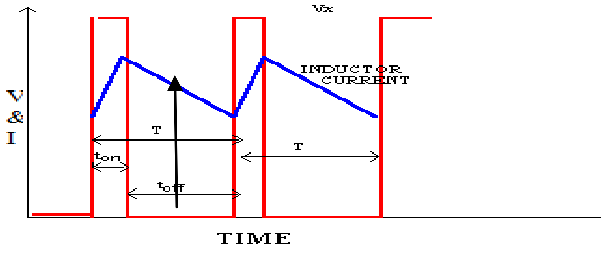


Fig 3.2 Voltage and current changes

4.WIND POWER

Offshore wind power refers to the construction of wind farms in bodies of water to generate electricity from wind. Unlike the typical usage of the term "offshore" in the marine industry, offshore wind power includes inshore water areas such as lakes, fjords and sheltered coastal areas, utilizing traditional fixed-bottom wind turbine technologies, as well as deep-water areas utilizing floating wind turbines. A subcategory within offshore wind power can be near shore wind power.

Fig.4.1 Wind turbines and electrical substation of Alpha Ventus in the North Sea

Offshore wind power refers to the construction of wind farms in bodies of water to generate electricity from wind. Stronger wind speeds are available offshore compared to on land, so offshore wind power's contribution in terms of electricity supplied is higher and NIMBY opposition to construction is usually much weaker. However, offshore wind farms are relatively expensive at the end of 2012, 1,662 turbines at 55 offshore wind farms across 10 European countries were generating electricity enough to power almost five million households

5.PROJECT DISCRIPTION

The single-line diagrams of two study systems: Study System 1 and Study System 2 are depicted in Fig. 1(a) and (b), respectively. Both systems are single-machine infinite bus (SMIB) systems where a large equivalent synchronous generator (1110 MVA) supplies power to the infinite bus over a 200-km, 400-kV transmission line. This line length is typical of a long line carrying bulk power in Ontario. In Study System 1, a 100-MW PV solar farm (DG) as STATCOM (PV-STATCOM) is connected at the midpoint of the transmission line. In Study System 2, two 100-MVA inverter-based distributed generators (DGs) are connected at 1/3 (bus 5) and 2/3 (bus 6) of the line length from the synchronous generator. The DG connected at bus 6 is a PV-STATCOM and the other DG at bus 5 is either a PV-STATCOM or a wind farm with STATCOM functionality. In this case, the wind farm employs permanent-magnet synchronous generator (PMSG)-based wind turbine generators with a full ac-dc-ac converter. It is understood that the solar DG and wind DG employ several inverters. However, for this analysis, each DG is considered to have a single equivalent inverter with the rating equal to the total rating of solar DG or wind DG, respectively. The wind DG and solar DG are considered to be of the same rating, hence, they can be interchanged in terms of location depending upon the studies being performed. Fig. 2 presents the block diagrams of various subsystems of two equivalent DGs. All of the system parameters are given in [1]. A. System Model The synchronous generator is represented by a detailed sixthorder model and a DC1A-type exciter [1]. The transmission-line segments TL1, TL2, TL11, TL12, and TL22, shown in Fig. 1.1, 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. 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. 2. 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 pulsewidth modulation (SPWM) technique [14]. An L-C-L filter [13] is also connected at the inverter ac side.

5.1 Control System

1) Conventional 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 setpoint 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.

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 . 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 setpoint 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) Damping Control: A novel auxiliary damping controller is added to the PV control system and shown in Fig. 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 as in [19] (1) The transfer function is comprised of a gain, a washout stage, and a first-order lead-lag compensator block. This controller is utilized to damp the rotor-mode oscillations of the synchronous generator and thereby improve system transient stability. The damping controller is activated by toggling “Switch-2” to the “ON” position.

This damping controller can operate in conjunction with either the conventional reactive power control mode or with the PCC voltage-control mode by toggling “Switch-1” to position “B” or “A,” respectively. 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 PSCAD/EMTDC 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. In this controller, although the line current magnitude signal is used, other local or remote signals, which reflect the generator rotor-mode oscillations [1], may also be utilized.

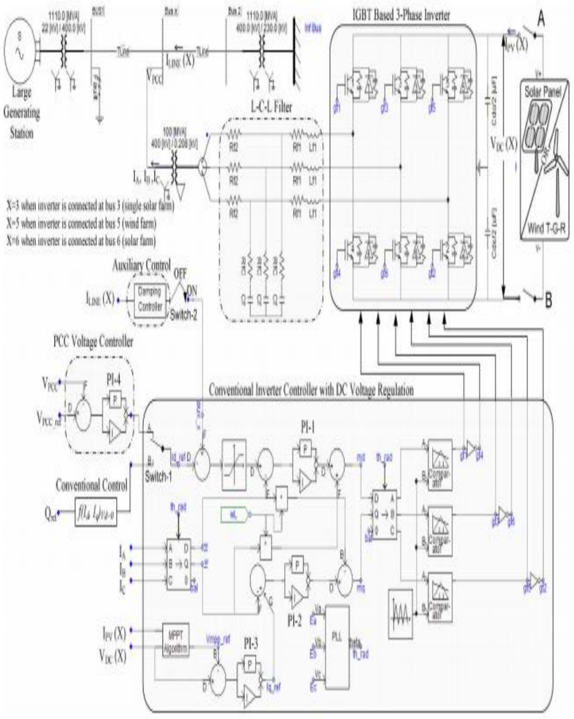


Fig :5.1 Complete DG (solar/wind) system model with a damping controller and PCC voltage-control system.

6.Simulation Results:

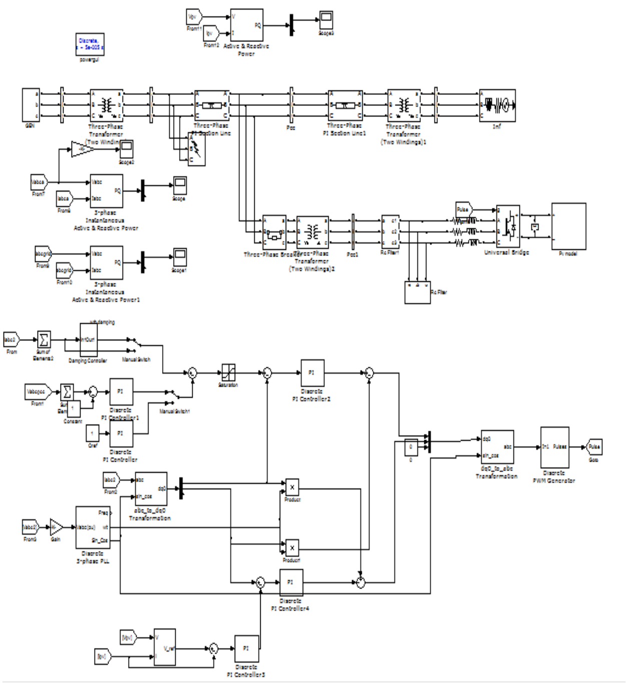
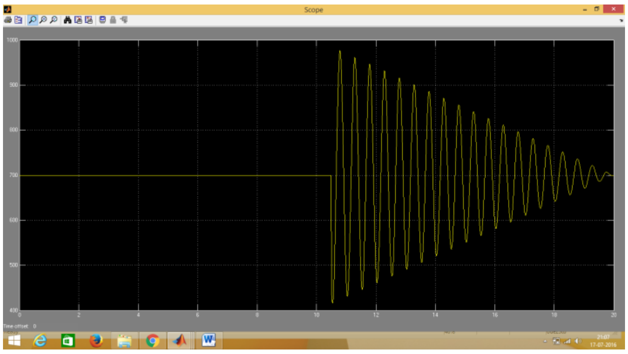
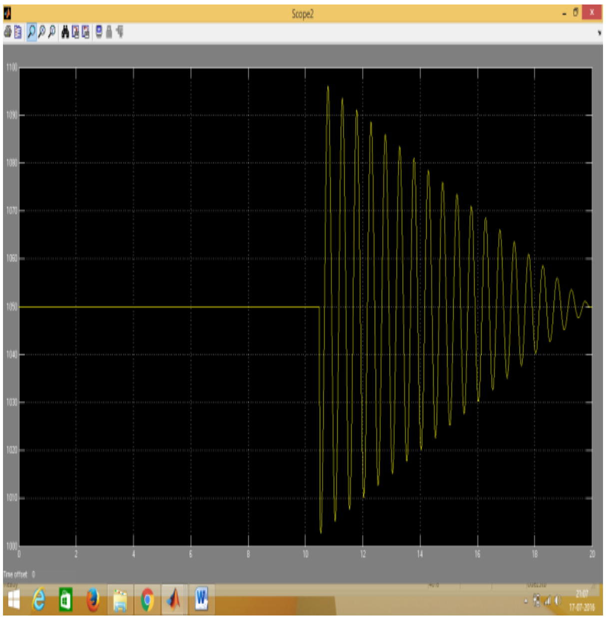


Fig:6.1 Proposed simulation diagram of PV-STATCOM





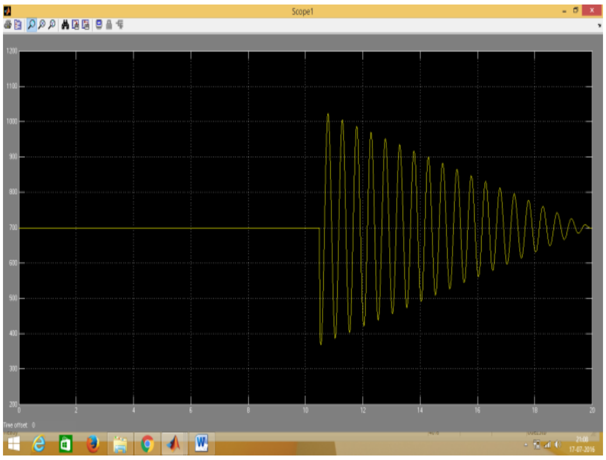
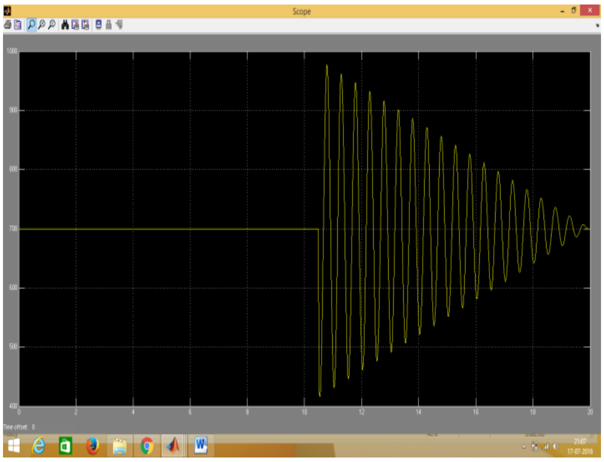


Fig:6.2 Maximum nighttime power transfer (850 MW) from the generator with solar DG using the damping controller.



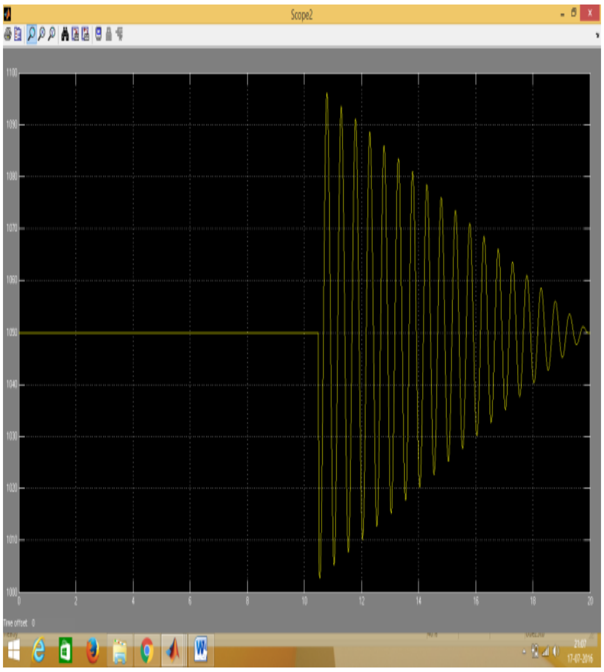
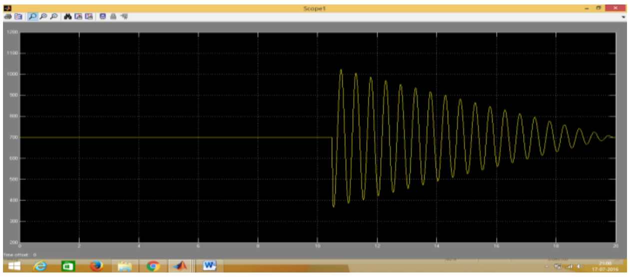


Fig :6.3 Maximum nighttime power transfer (899 MW) from the generator while the solar DG uses a damping controller with voltage control



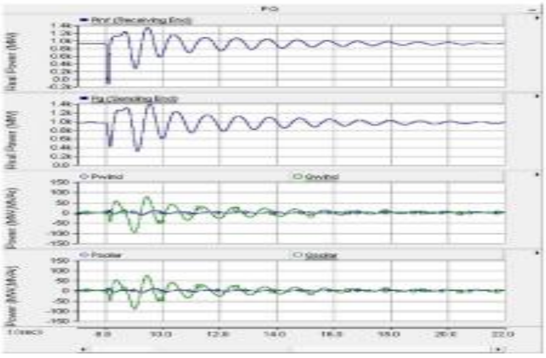


FIG:6.4 Maximum nighttime power transfer from the generator with both DGs using the damping controller but with no real power generation

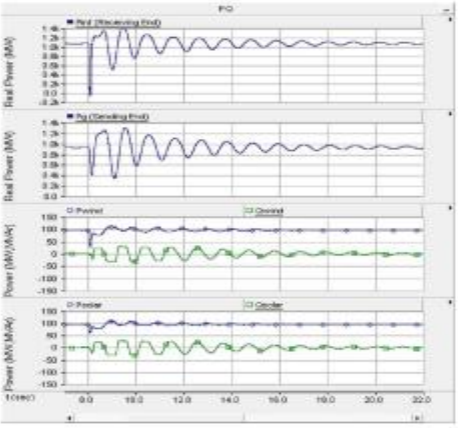


Fig:6.5 Maximum daytime power transfer from the generator while both DGs generate 95 MW, each using a damping controller.

VI. CONCLUSION

Solar farms are idle during nights. A novel patent-pending control paradigm of PV solar farms 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 [31], [32]. This new control of PV solar system as STATCOM is called PV-STATCOM. The effectiveness of the proposed controls is demonstrated on two study SMIB systems: System I has one 100-MW PV-STATCOM and System II has one 100-MW PV-STATCOM and another 100-MW PV-STATCOM or 100-MW wind farm controlled as STATCOM. Three different types of STATCOM controls are proposed for the PV solar DG and inverter-based wind DG. These are pure voltage control, pure damping control, and a combination of voltage control and damping control. The following conclusions are made: 1) In study system I, the power transfer can be increased by 168 MW during nighttime and by 142 MW in daytime even when the solar DG is generating a high amount of real power. 2) In Study System II, the transmission capacity in the night can be increased substantially by 229 MW if no DG is producing real power. During nighttime and daytime, the power transfer can be increased substantially by 200 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 (solar and wind) to exercise 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 nighttime and daytime in addition to that from the sale of real power during the day. This will, of course, require appropriate agreements between the regulators, network utilities, solar farm developers, and inverter manufacturers.

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