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A PV Solar Farm as PV-Statcom for Reactive Power Compensation and for Enhancement of Grid Power Transmission Limits

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ABSTRACT

Power system performance may be referred as the performance study of power system during normal operating condition, fault condition and after removal of fault. A novel concept of utilizing a photovoltaic (PV) solar farm inverter as STATCOM, called PV-STATCOM using dynamic controller is proposed in this paper, for improving stable power transfer limits of the interconnected transmission system. During daytime, the inverter capacity left after real power production is used. During different operating conditions system has different real and reactive power flow which is required to be controlled to enhance the system power transfer capability, transient stability and reduce the losses in the system. For this purpose, recent trend is the use of FACTS control devices. The PV-STATCOM improves the stable transmission limits substantially in the night and in the day even while generating large amounts of real power. The main function of the LCL filter is to reduce high-order harmonics on the output side; however poor design may cause a distortion increase. Here we are using the dynamic controller compared to other controllers i.e. the dynamic controller is the most suitable for the human decision-making mechanism, providing the operation of an electronic system with decisions of experts. Power transfer increases are also demonstrated in the same power system for- Two solar farms operating as PV-STATCOMs and, Single solar farm as PV-STATCOM and an inverter-based wind farm with similar STATCOM controls.

By using the dynamic controller for a nonlinear system allows for a reduction of uncertain effects in the system control and improves the efficiency. By using the simulation results we can analyze the proposed method.

KEYWORDS:*FACTS devices, inverter, photovoltaic solar power systems, wind power system, Dynamic controller, STATCOM, transmission capacity, reactive power control, voltage control, Damping control*

I. INTRODUCTION

Flexible AC Transmission Systems being increasingly considered to increase the avail-stem (FACTS) controller's able power transfer limits/capacity (ATC) of existing transmission lines globally. New research has been reported on the night time 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. New voltage control has also been proposed on a PV solar farm to act as a STATCOM for improving the power transmission capacity. Although, and 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 project 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"[3]. 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, 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[3].

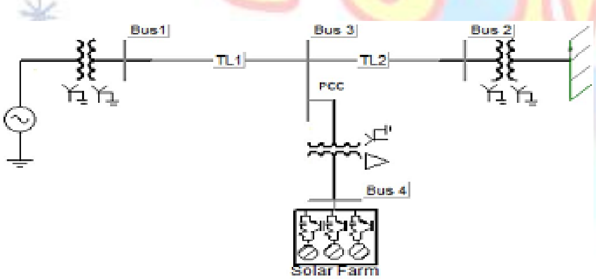
II. SYSTEM MODELS

The single-line diagrams of two study systems: Study System 1 and Study System 2 are portrayed in Fig. 1(a) and (b), individually. The two frameworks are single-machine vast transport (SMIB) frameworks where an expansive equal synchronous generator (1110 MVA) supplies energy to the limitless transport over a 200-km, 400-kV transmission line. This line length is common of a long queue conveying mass power in Ontario. In Study System 1, a 100-MW PV sun powered homestead (DG) as STATCOM (PV-STATCOM) is associated at the midpoint of the transmission line. In Study System 2, two 100-MVA inverter-based conveyed generators (DGs) are associated at 1/3 (transport 5) and 2/3 (transport 6) of the line length from the synchronous generator. The DG associated at transport 6 is a PV-STATCOM and the other DG at transport 5 is either a PV-STATCOM or a breeze cultivate with STATCOM usefulness. For this situation, the breeze cultivate utilizes changeless magnet synchronous generator (PMSG)- based breeze turbine generators with a full air conditioning dc-air conditioning converter [3]. It is comprehended that the sunlight based DG and wind DG utilize a few inverters. Notwithstanding, for this investigation, every DG is considered to have a solitary proportional inverter with the rating equivalent to the aggregate rating of sunlight based DG or wind DG, separately. The breeze DG and sun oriented DG are thought to be of a similar rating, henceforth, they can be traded as far as area relying on the examinations

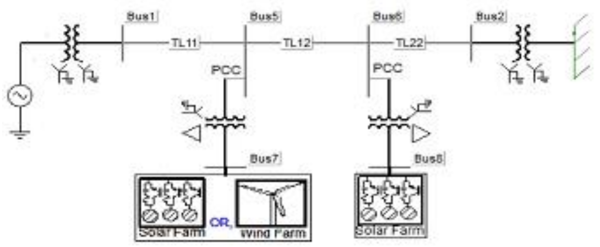
being performed. Displays the square graphs of different subsystems of two equal DGs. The greater part of the system parameters are given.

A .System Model

The synchronous generator is spoken to by a nitty gritty 6th request demonstrate and a DC1A-type exciter. The transmission-line sections TL1, TL2, TL11, TL12, and TL22, appeared in Fig. 1, are spoken to by lumped pi-circuits. The PV sun oriented DG, as appeared in Fig. 2, is displayed as a proportional voltage-source inverter alongside a controlled current source as the dc source which takes after the - attributes of PV boards. The breeze DG is similarly demonstrated as a comparable voltage-source inverter. In the sun based DG, dc control is given by the sun based boards, while in the full-converter-based breeze DG, dc control leaves a controlled ac– dc rectifier associated with the PMSG wind turbines, delineated as "wind Turbine-Generator-Rectifier (T-G-R)[3]." The dc control created by every DG is bolstered into the dc transport of the relating inverter, as showed in Fig. 2. A maximum power point following (MPPT) calculation in light of an incremental conductance calculation is utilized to work the sunlight based DGs at its greatest power point constantly and is coordinated with the inverter controller. The breeze DG is additionally accepted to work at its most extreme power point, since this proposed control uses just the inverter limit left after the greatest power point operation of the sunlight based DG and wind DG. For PV-STATCOM operation amid evening, the sunlight based boards are detached from the inverter and a little measure of genuine power is attracted from the network to charge the dc capacitor. The voltage-source inverter in every DG is made out of six protected entryway bipolar transistors (IGBTs) and related snubbed circuits as appeared in Fig. 2. A suitably expansive dc capacitor of size 200 Farad is chosen to diminish the dc side swell. Each stage has a couple of IGBT gadgets which changes over the dc voltage into a progression of variable-width throbbing voltages, utilizing the sinusoidal heartbeat width tweak (SPWM) strategy. An L-C-L channel is likewise associated at the inverter air conditioning side.



(a)



(b)

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)[3].

B. 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 presents the block diagrams of various subsystems of two equivalent DGs. The switching signals for the inverter switching are generated through two current control loops[3]. The inverter operates in a conventional controller mode only provided that "Switch-2" is in the "OFF" position.

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.3.Depends upon the set point voltage at the PCC the amount of reactive power flow from the inverter to the grid. To achieve the fastest step response, least settling time, the parameters of the PCC voltage controller is tuned by a systematic trial-and-error method and a maximum overshoot of 10%–15%[3].

3) Damping Control

A novel auxiliary damping controller is added to the PV control system and shown in Fig.3. 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

$$F_D = G.\frac{sT_w}{1+sT_w}.\left(\frac{1+sT_1}{1+sT_2}\right) \quad (1)$$

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,"

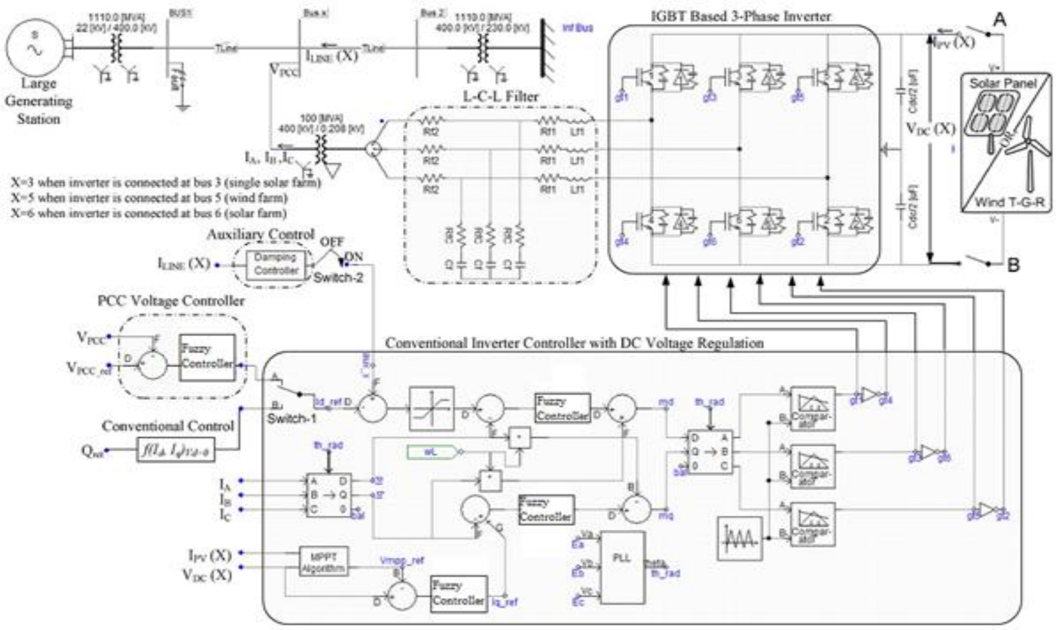


Fig. 2 Complete DG (solar/ wind) system model with a damping controller and PCC voltage-control system [3].

III. SYSTEM STUDIES

Transient strength contemplates are completed utilizing MATLAB recreation programming, for both the examination frameworks amid night and day, by applying a three-line-to-ground (3LG) blame at transport 1 for five cycles. The damping proportion is utilized to express the rate of rot of the sufficiency of wavering. For an oscillatory mode having an Eigen value of, the damping proportion is characterized [3]as

$$\xi = -\frac{\sigma}{\sqrt{\sigma^2 + \omega^2}}, \quad \text{and} \quad \sigma = \frac{1}{\tau}$$

Accordingly, for a 5% damping proportion of the rotor mode having a swaying recurrence of 0.95 Hz, as considered in this investigation, the post blame leeway settling time of the motions to draw near 5% (normally inside 3 times the time consistent) of its enduring state esteem is just about 10 s. The pinnacle overshoot of PCC voltage ought to likewise be restricted inside 1.1 p.u. of ostensible voltage. The greatest stable generator control confine for the framework is resolved through transient soundness ponders for various methods of operation of the sun based DG in think about framework 1, and those of the sun based DG and the sunlight based/twists DGs in contemplate system2[3].

A. Case I: Power Transfer Limits in Study System 1

Conventional Reactive Power Control with Novel Damping Control: In this study, the solar DG is assumed to operate with its conventional reactive power controller and the DG operates at near unity power factor. For the nighttime operation of solar DG, the dc sources (solar arrays) are disconnected, and the solar DG inverter is connected to the grid using appropriate controllers, as will be described. Power transmission limits are now determined for the following four cases[3]. The stable power transmission limits obtained from transient stability studies and the corresponding load-flow results are presented in Table II where represents the inductive power drawn 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.

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, may also be utilized[3].

Solar DG Operation during Night with Conventional Reactive Power Controllers:

The maximum stable power output from the generator is 731 MW when the solar DG is simply sitting idle during night and is disconnected from the network. This power-flow level is chosen to be the base value against which the improvements in power flow with different proposed controllers are compared and illustrated[3]. The real power from generator and that entering the infinite bus for this fault study.

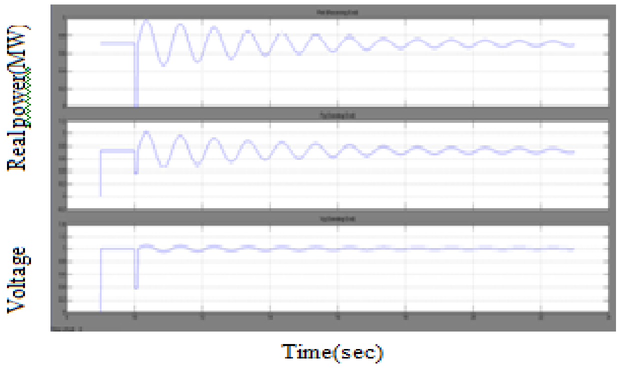
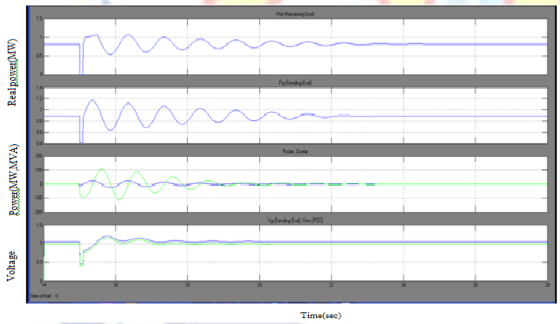


Fig. 3(a) Maximum nighttime power transfer (731 MW) from the generator when solar DG remains idle. (b) Voltage at the generator terminal.

The sending-end voltage at the generator is shown in **Fig.3** (b) which shows a voltage overshoot of 1.1 p.u.

Solar DG Operation during the Night with Damping Controllers:



(a)

Fig. 4(a) Maximum nighttime power transfer (850 MW) from the generator with solar DG using the damping controller.

(b) Voltages at the generator terminal and DG PCC.

The damping controller utilizes the full rating of the DG inverter at night to provide controlled reactive power and effectively damps the generator rotor-mode oscillations. The voltages at generator bus and at the PCC bus are depicted[3].

The oscillations in the solar PV power output during nighttime, as seen in Fig. 9, are due to the active power exchanged by the solar inverter both during the charge and discharge cycles in trying to maintain a constant voltage across the dc-link capacitor, thereby enabling the inverter to operate as a Statcom [3].

Solar DG Operation during the Day with a Conventional Reactive Power Controller:

The conventional control of a PV solar DG does not seem to alter the stable transmission limit in any appreciable manner.

Solar DG Operation during the Day with a Damping Controller:

The quantities $P_{g,}$, $P_{inf,}$ P_{solar} and $Q_{solar}$are shown for the cases without the damping controller and with the damping controller.

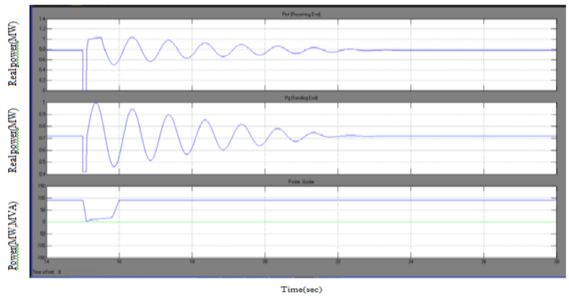


Fig. 5 Maximum daytime power transfer (719 MW) from the generator with solar DG generating 91-MW real power.

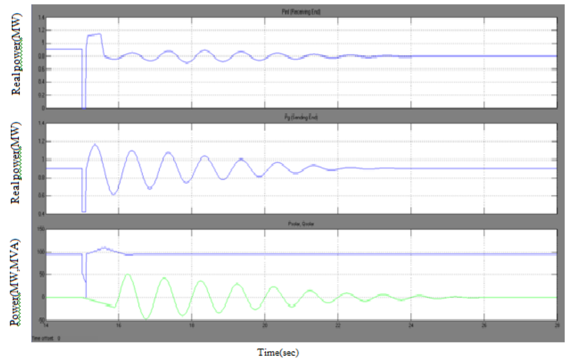


Fig. 6 Maximum daytime power transfer (861 MW) from the generator with solar DG generating 91-MW real power and using the damping controller.

The power transfer capacity increase in the daytime is expected to be lower than the nighttime, since only a part of the total inverter capacity is available for damping control during the day. However, it is noticed from Table II that the maximum power transfer during night time (850 MW) is actually less than the maximum power transfer value during the daytime (861 MW).

2) PCC Voltage Control with the Novel Damping Control:

Transient stability results for a new control strategy involving PCC voltage control, together with damping control, are shown in Table IV for the following four cases.

Solar DG Operation during the Night with a Voltage Controller:

The increase in the power transfer limit depends upon the choice of reference values for PCC voltage. In the best scenario when is regulated to 1.01 p.u., the maximum power output from the generator increases to 833 MW, compared to 731 MW when the solar DG operates with conventional reactive power control[3].

Solar DG Operation during the Day with the Voltage Controller:

The power transfer increases for both low (19 MW) and high (91 MW) power output from the solar farm are seen to be highly sensitive to the PCC bus voltage set point. It is also noted that with lower availability of reactive power capacity after real power production, the ability to change the bus voltage is limited, which leads to a lower increase in power transmission capacity[3].

Solar DG Operation during the Night with Both Voltage and Damping Controllers:

The generator and infinite bus power are depicted and corresponding voltages

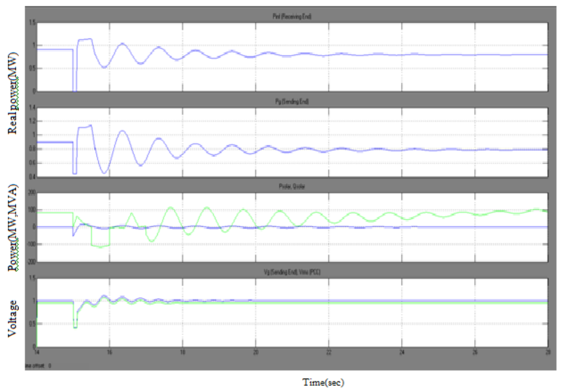


Fig. 7(a) Maximum nighttime power transfer (899 MW) from the generator while the solar DG uses a damping controller with voltage control and (b) voltages at the generator terminal and solar DG PCC (1.01 p.u.).

Although, the rotor-mode oscillations settle faster, the power transfer cannot be improved beyond 899 MW due to high overshoot in voltages.

Solar DG Operation during the Day With voltage and Damping Controllers:

A further increase in power transfer is observed when both voltage control and damping control are employed, compared to case 2) when only the voltage controller is utilized. For Study System 1, the net increase in power transfer capability as achieved with different PV-STATCOM controls in comparison with that obtained from conventional reactive power control of the solar DG is summarized. The maximum increase in the power transfer limit during nighttime is achieved with a combination of voltage control and damping control, whereas the same during daytime is accomplished with damping control alone[3].

This is because at night, the entire megavolt-ampere 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. During daytime, first, the generation of real power from the solar DG tends to increase the voltage at PCC [5] and second, the net reactive power availability also gets reduced especially with large solar real power outputs. Therefore, it becomes difficult with limited reactive power to accomplish the appropriate voltage profile at PCC for maximum power transfer and to impart adequate damping to the oscillations[3].

B. Case II: Power Transfer Limits in Study System II

In this study, the proposed damping control strategy is compared with the conventional reactive power control strategy for Study System II. A three-phase-to-ground fault of 5 cycles is applied to the generator bus at 8 s. The following eight cases are studied:

1) Night time:

Case1 – None of the DGs Generate Real Power:
The maximum power transfer limit is 731 MW.

Case2– Only Wind DG Generates Real Power. Both DGs Operate With Conventional Reactive Power Control:

The power transfer limit decreases slightly with increasing wind power output.

Case3 – None of the DGs Generate Real Power But Both DGs Operate With Damping Control :

The different variables, generator power , infinite bus power , real power of wind DG , reactive power of the wind DG , real power of the solar DG , and the reactive power of the solar DGare illustrated.

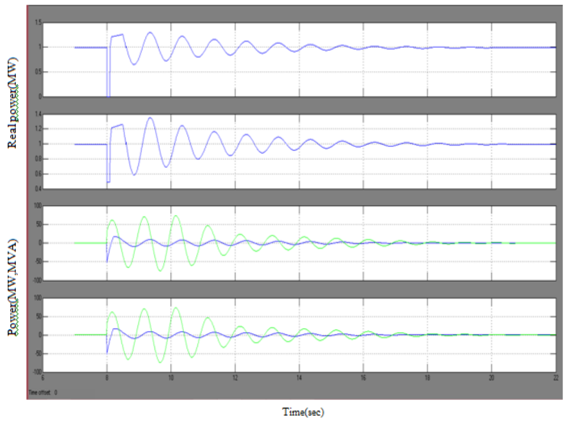


Fig.8 Maximum nighttime power transfer from the generator with both DGs using the damping controller but with no real power generation.

Even though the entire ratings (100 MVar) of the wind DG and solar DG inverters are not completely utilized for damping control, the power transfer limit increases significantly to 960 MW.

Case4 – Only Wind DG Generates Real Power But Both DGs Operate on Damping Control: There is only a marginal improvement in the power limit with decreasing power output from the wind DG.

Case5 – Both DGs Generate Real Power: The power transfer limit from the generator decreases as the power output from both DGs increase.

Case6 – Only Solar DG Generates Power: The power transfer limit from the generator decreases as the power output from the solar DG increases. However, no substantial changes in power limits are observed compared to the case when both DGs generate power (Case 5).

Case7– Both DGs Generate Real Power and Operate on Damping Control: This case is illustrated by different variables. The power limit does not change much with increasing power output from both DGs.

Case8 – Only Solar DG Generates Real Power But Both DGs Operate on Damping Control:

The power limit does not appear to change much with increasing power output from the solar DG.

For Study System II, the net increases in power transfer limits accomplished with the proposed novel damping control for different real power outputs from both DGs compared to those attained with the conventional operation of both DGs, are depicted.

The proposed damping control on the two DGs (of rating 100 MW each) in the night increases the power transfer limits substantially by about 220 MW. The improvement is slightly less when wind DG produces high power. During daytime, the proposed damping controlon both DGs also increases the power transfer limits substantially.

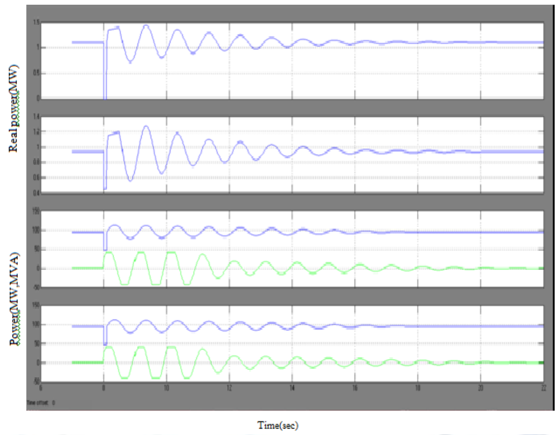


Fig. 9 Maximum daytime power transfer from the generator while both DGs generate 95 MW, each using a damping controller.

IV. IMPLEMENTATION OF PV-STATCOM ON LARGE-SCALE SOLAR SYSTEMS

For the first time in a utility network of a 10kW PV solar system the PV-STATCOM technology will be shown. The 10-kW solar system will be utilized for voltage regulation and power factor correction in addition to generating real power. The PV-STATCOM will be allowed to connect to the wires of the utility. These include: 1) PV-STATCOM controller testing with **MATLAB** simulation studies; 2) controller validation using real-time digital simulation (RTDS) and finally a full-scale 10-kW lab-scale demonstration of the PV-STATCOM.

V.CONCLUSION

Solar farms are idle throughout nights. A novel patent-pending manage paradigm of PV sun farms is presented where they can function for the duration of the night time as a STATCOM with full inverter capability and in the course of the day with inverter capability final after actual strength generation, for providing giant improvements inside the strength switch limits of transmission systems. This new manages of PV solar device as STATCOM is referred to as PV-STATCOM. The effectiveness of the proposed controls is proven on examine SMIB systems: System I has one a hundred-MW PV-STATCOM and System II has one 100-MW PV-STATCOM and another one hundred-MW PV-STATCOM or one hundred-MW wind farm managed as STATCOM. Three different sorts of STATCOM controls are proposed for the PV sun DG and inverter-based totally wind DG. These are natural voltage manipulate, natural damping manipulate, and a combination of voltage manage and damping control. The following conclusions are made: 1) In examine gadget I, the electricity switch can be increased by way of 168 MW during middle of the night and with the aid of 142 MW in daylight even if the solar DG is producing a high amount of real power. In Study System II, the transmission potential within the night time may be accelerated notably via 229 MW if no DG is producing actual power. During midnight and daylight, the power switch can be increased appreciably by two hundred MW, even when the DGs are producing high actual power. The PV-STATCOM operation opens up a new possibility for PV sun DGs to earn sales inside the middle of the night and sunlight hours further to that from the sale of real strength in the course of the day. This will, of route, require appropriate agreements among the regulators, community utilities, sun farm developers, and inverter manufacturers.

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