A CASE STUDY ON PV STATCOM WITH DIFFERENT CONTROLS FOR INCREASING GRID POWER TRANSMISSION LIMITS DURING NIGHT AND DAY

Anjali Surendran[1],Arya S Mohan[2]
[1]PG Scholar,Department of EEE,UKF College of Engineering and Technology,Paripally,Kollam.
[2]Assistant Professor,UKF College of Engineering and Technology,Parippally,Kollam.

Abstract PV solar farms produce power during the day and are completely idle in the nights. This paper presents utilization of a PV solar plant as STATCOM in the night for load reactive power compensation and voltage regulation. This STATCOM functionality will also be available to a substantial degree during the daytime with the inverter capacity remaining after real power production. In the night, when the solar farm is completely idle, this new control technique makes the solar farm inverter behave like a STATCOM – a Flexible AC Transmission System (FACTS) device. The solar farm inverter then provides voltage regulation at the point of common coupling and improves the stability and transfer limits far beyond minimal incremental benefits. During the day also, when solar farm is producing real power, new control strategy makes the solar farm inverter provide voltage control with the remaining inverter capacity (after meeting the requirements of real power generation) and thereby increases power transfer limits substantially.The result verify the validity of pv solar farm as statcom

Index Terms FACTS,Solar power system,STATCOM,Damping control,Voltage control

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1 INTRODUCTION

Recent studies suggest that in medium and long terms, photovoltaic (PV) generator will become commercially so attractive that large-scale implementation of this type can be seen in many parts of the world. A large-scale PV generation system includes photovoltaic array, DC/AC converter and the associated controllers. It is a multivariable and non-linear system, and its performance depends on environmental conditions. Recently, the increasing penetration levels of PV plants are raising concerns to utilities due to possible negative impacts on power system stability as speculated by a number of studies. Thus, the thorough investigation of power system stability with large-scale PV is an urgent task. PV technology is becoming more popular for connecting to the grid both on large and small scales. PV solar farms are inactive during night and only partially utilized during daytime.

Among stability issues, voltage instability has been a major concern for power system. Several major power interruptions have been linked to power system voltage instability in recent past. It has been proved that inadequate reactive power compensation during stressed operating condition can lead to voltage instability. Although large scale PV is capable of generating reactive power, however, the operation of PV in terminal voltage mode has the potential for adverse interaction with other voltage controllers . Therefore, grid code requires operation at power factors equal or greater than 0.95 for PV generators. Moreover, the size and position of large-scale PV generator can introduce detrimental effect on power system voltage stability as the level of PV penetration increased. PV technology is expensive. Such an expensive asset thus remains entirely unutilized in the night time and brings no revenue to the solar plant owner.

Furthermore, the technical regulations or specific standards are trying to shape the conventional control strategies to allow the flawless integration of renewable energy based distributed generation (DG) in main grid. According to technical regulations or standards the post fault voltage recovery time at DG bus is crucial as it requires DG to trip, if recovery time exceeds certain limits . With increased penetration of renewable energy DG, early tripping of DG due to local disturbance can further risk the stability of the system. Hence system operator becomes responsible to maintain the voltage profile under all operating conditions.

Nowadays solar energy using PV technology is becoming popular due to government subsidies. Obviously solar forms generate energy during sunny periods only. When sunlight is not bright enough they remain idle. To make the PV technology cost effective with higher utilization factor it is to be used throughout day and night. Efforts are being made in this direction.

Flexible AC Transmission System(FACTS) controllers are being increasingly considered to increase the available power transfer limits/capacity (ATC) of existing transmission lines globally[8]. 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 solar farm. Although, proposed voltage-control functionality with PV systems, none have utilized the PV system for power transfer limit improvement.

. A novel control technology was proposed in , by which a PV solar farm can be operated as a STATCOM in the night time as well as during day. During the night time the entire inverter capacity of the PV solar farm is utilized as STATCOM, whereas during the day, the inverter capacity remaining after real power generation is utilized for STATCOM operation. Since this STATCOM is based on a PV solar system, it has been given the name PV-STATCOM[1]. It utilizes the entire solar farm inverter capacity in the night and the remainder inverter capacity after real power generation during the day. Studies are performed in single machine infinite bus system(SMIB) .In SMIB system uses only a single PV solar farm as PV-STATCOM connected at the midpoint. The improvement in the stable power transmission limit is investigated for different combinations of STATCOM controllers on the solar.

2 PV SOLAR PANEL

A photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be grouped to form panels or arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and dc motors.

In a PV solar system, the PV modules, often called PV panels, are the power generating devices[3]. For a large scale PV system a number of PV modules are connected in series to form a 'String', and these strings connect in parallel to form an 'Array'. However, the PV modules, or panels, are comprised of a number of PV cells also connected in series and shunt configuration. These PV cells are a formation of p-n junctions from the doping of p-type and n-type substrates that are able to produce DC current and DC junction voltage upon the incidence of light due to the photovoltaic effect on semiconductors. As a result of the series and shunt combination of the cells in a module, the PV module can be equally characterized with an increased level of current **and** voltage.

3 PV INVERTER MODELING

Two types of inverter configuration are employed presently in solar farms. One is called string technology where several modules in string configuration feed in to a single large inverter. These large inverters are grouped together to feed the grid. The other is called the micro-inverter, also known as AC module technology where each individual module has its own inverter and the outputs of all micro-inverters are integrated together to feed the grid**.**

To construct inverter circuits, manufacturers use Metal-Oxide Semiconductor Field Effect Transistor (MOSFET) , Gate Turn Off (GTO) thyristor, and Insulated Gate Bipolar Transistor (IGBT) switches . The present trend is to use IGBT switches ,because of their low loss and ease of switching . The firing pulses to trigger the IGBT switches are generated from the inverter controller.

4 NEED OF FACTS DEVICES

The main advantages of using FACTS devices are

- Better utilization of existing transmission system assets
- Increased transmission system reliability and availability
- Increased dynamic and transient grid stability and reduction of loop flows
- Increased quality of supply for sensitive industries
- Environmental benefits

There is a better utilization of existing transmission system assets. Building new transmission lines to meet the increasing electricity demand is always limited economically and by environmental constraints and FACTS devices meet these requirements using the existing transmission systems. Increase in transmission system reliability and availability as FACTS devices mitigate the effects of faults and make supply of electricity more securely by reducing the number of trips. Increase in dynamic and transient grid stability and reduction of loop flows is achievable as FACTS devices can stabilize transmission systems with higher energy transfer capability and reduction in risks of line trips. There is an increased quality of supply for sensitive industries because FACTS devices can provide the required quality of supply to high quality electricity supply where loss of supply or voltage dips leading to interruptions in manufacturing processes resulting in high economic loss could be overcome. Furthermore FACTS provide in terms of environmental benefits as they do not contain harmful materials nor produce waste or pollutants. In fact FACTS devices help to distribute electricity more economically through better utilization of existing installations thereby reducing the need for additional transmission lines.

5 FACTS DEVICES

As previously mentioned FACTS devices are power electronic based equipments, which are used for the dynamic control of voltage, impedance and phase of high voltage AC transmission lines. There are basically two types of FACTS controllers; Thyristor-based controllers and converter-based controllers.

Thyristor-based FACTS Controllers (including Static Var Compensator or SVC, the Thyristor- Controlled Series Capacitor or TCSC, and the Thyristor-Controlled Phase Angle Regulator or TCPAR) employ conventional Thyristors (i.e., those having no intrinsic turn-off ability) to control one of the three parameters determining power transmission, voltage (SVC), transmission impedance (TCSC), and transmission angle (TCPAR). The major members of this group, the SVC and TCSC, have a common characteristic in that, the necessary reactive power required for the compensation is generated or absorbed by conventional capacitor or reactor banks, and the Thyristor switches are used only for the control of the combined reactive impedance these banks present to the AC system. The tap-changer-based regulators do not inherently need a capacitor or reactor; however, they may do so if the AC system is unable to supply the reactive power needed to support their operation. Consequently, conventional Thyristor-controlled compensators, the SVC and TCSC, present variable reactive impedance to, and thus act indirectly on, the transmission network. The SVC functions as a controlled shunt reactive admittance that produces the required reactive compensating current. Thus, the attainable reactive compensating current is a function of the prevailing line voltage. The TCSC is controlled reactive impedance in series with the line for the purpose of developing a compensating voltage. Thus, the attainable reactive compensating voltage is a function of the prevailing line current. Neither the SVC nor the TCSC exchanges real power with the ac system (except for losses).

6 STATCOM

6.1 Basic Operating Principle

It is well known that STATic synchronous COMpensator (STATCOM) is a FACTS device acts as a shunt compensating device. A key component of the PV solar plant is a voltage source inverter which is also acore element of STATCOM. Since the STATCOM controls reactive power flow through power electronics processing, it does not require any additional capacitor banks or reactors as a SVC that contributes to a compact design, and smaller footprint, as well as low noise and low magnetic impact. The only capacitor used is at the DC terminal of the STATCOM, which provides a constant voltage. As DC power does not have any reactive component and the voltage at the DC terminal is held constant, the DC link capacitor does not participate in any reactive power exchange. Since the STATCOM does not inject any real power to the grid, the DC link provides an instantaneous power-circulating path to satisfy the power balance relation and thus, the converter establishes a circulating reactive power exchange among the phases. However, in a practical STATCOM system there are real power losses that are compensated from the DC link capacitor, thereby reducing the DC link voltage. Thus, some real power must be absorbed from the AC system to keep the DC link capacitor voltage constant. This is accomplished by making the VSC terminal voltage lag the utility system voltage by an angle of θ. The magnitude of this angular difference depends on the amount of charge that needs to be replenished in the DC link capacitor.

6.2 Configuration

A STATCOM is comprised of a voltage sourced converter (VSC) with a DC link capacitor. The sole purpose of the DC link capacitor is to maintain the DC link voltage constant such that the voltage at the AC terminal can be controlled smoothly. The VSC can be based on either Gate Turn Off (GTO) thyristors or Insulated Gate Bipolar Transistors (IGBT). The IGBT based STATCOMs are becoming more popular due to being more cost effective. Along with the IGBT switches, snubber circuits are incorporated for smooth switching operation of the IGBT devices . The IGBT switches can be controlled through various control techniques among which the Pulse Width Modulation (PWM) technique is widely used in large size STATCOMs. A typical STATCOM is where the coupling transformer is used for transforming the STATCOM output voltage to the system bus voltage. While using the PWM technique, a filter is needed to eliminate harmonics and maintain the power quality at the AC side of the STATCOM.

7 SYSTEM MODEL

The single-line diagrams of study system are depicted in fig 2.1. In Study System, a 100 MW PV solar farm (DG) as a STATCOM (PV STATCOM) is connected at the midpoint of the transmission line.

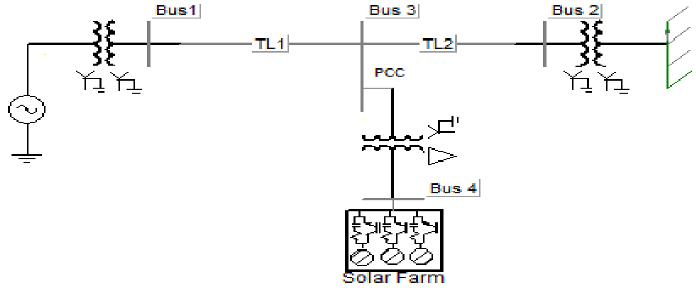

Figure 2.1 single line diagram of study system

A.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 operationalong with dc-link voltage control. The switching signals for the inverter switching are generated through two current control loops in d- q-0 coordinate system. In this simulation, the voltage vector is aligned with the quadrature axis, that is,V_d=0 hence, Q_{ref} is only proportional to I_d which sets the reference I_{d-ref} for the upper control loop involving PI1. Meanwhile, the quadrature axis component

I_q is used for dc-link voltage control through two PI controllers (PI-2 and PI-3) according to the setpoint voltage provided by the MPPT and and injects all available real power "P" to the network. To generate the proper IGBT switching signals (gt1, gt2, gt3, gt4, gt5, gt6), the – components(md and mq) 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[1]. The conventional control channel is replaced by the PCC voltage controller 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 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%.

3) Damping Control:

A novel auxiliary damping control mode is added to the PV control system. The output is compare with I_{q-ref} .This controller utilizes line current magnitude as the control signal. The principle of this damping controller is to modulate the voltage at the PCC with the auxiliary damping signal. This controller is utilized to damp the rotor mode oscillations of the synchronous generator and to thereby improve system transient stability.

8 CASE STUDY

8.1 Solar DG operation during night with a damping controller

The damping controller utilizes the full rating of the DG inverter at night to provide controlled reactive power Q_{solar} and effectively damps the generator rotor mode oscillations. A very small amount of negative power flow from the solar farm P_{solar} is observed during night time. This reflects the losses in the inverter IGBT switches, transformer, and filter resistances caused by the flow of real current from the grid into the solar farm inverter to charge the DC link capacitor and maintain its voltage constant while operating the PV inverter as STATCOM with the damping controller. The oscillation observed in the PV power is essentially due to the oscillation in the PCC voltage that is significantly low and continues as long as the voltage oscillation occurs at the PCC. In nighttime, during the negative half cycle of the oscillations, the active power is consumed by the DC link capacitor of the PV inverter resulting in the rise in DC link voltage.

8.2 Solar DG operation during day with a damping controller

The maximum power transfer during the night is actually less than the maximum power transfer during the day. This is because of an additional constraint that while increasing the power transfer, the overshoot in PCC voltage should not exceed 1.1pu. If the power transfer is allowed until its damping ratio limit of 5% is reached, regardless of voltage overshoot, the maximum nighttime power transfer is observed to be 731 MW; whereas, the maximum daytime power transfer is expectedly seen to be lower at 861MW shown in table 3.1.

Table 8.1 Power flows study system with solar DG with damping control during night and day

Simulation Description	Generator Bus (sending End)		PCC/Middle bus(3)		Infinite Bus (receiving end)	
	P_g (MW)	Q_g (MVAr)	P_{solar} (MW)	Q_{solar} (MVAr)	P_{inf} (MW)	Q_{inf} (MVAr)
Solar DG during night with damping control	731	139	0	0	-708	82
Solar DG during day with damping control	**861**	**216**	91	-0.20	-917	208

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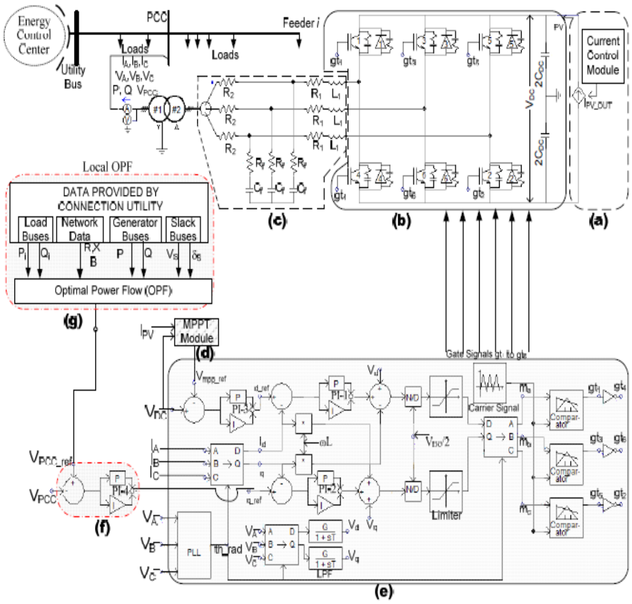

Figure 8.1 Detailed PV STATCOM configuration in the study system**(a)** PV array model **(b)** IGBT matrix of inverter **(c)** L-C-L filter **(d)** MPPT model **(e)** conventional inverter controller **(f)** PCC voltage regulator and **(g)** Optimal power flow unit

8.3 Solar DG operation night with voltage controller

The increase in power transfer limit is dependent upon the choice of reference values for PCC voltage *Vpcc*. In the best scenario, when *Vpcc* is regulated to 1.01pu, the maximum power output from the generator increases to 833 MW.

8.4 Solar DG operation during day with voltage controller

If the solar farm is operated with the proposed voltage control while producing a relatively high amount of real power . The maximum generator power output is shown in table 8.2.

Table 8.2 Power flows study system with solar DG with voltage control during night and day

Simulation Description	Generator Bus (sending End)		PCC/Middle bus(3)		Infinite Bus (receiving end)	
	P_g (MW)	Q_g (MVAr)	P_{solar} (MW)	Q_{solar} (MVAr)	P_{inf} (MW)	Q_{inf} (MVAr)
Solar DG during night with damping control	833	160	-0.3	-9.5	-801	146
Solar DG during day with damping control	815	188	19	-13.7	-804	147

8.5 Solar DG operation during the night with both voltage and damping controllers

The generator power and infinite bus power are shown in table 3.3. Although rotor mode oscillations settle faster, the power transfer cannot be improved beyond 899 MW due to high overshoot in voltages.

8.6 Solar DG operation during day with both voltage and damping controller.

A further increase in power transfer is observed when both voltage control and damping control are employed.The generator power and infinite power are shown in table 8.3.

Table 8.3 Power flows study system with solar DG with voltage control and damping control during night and day

Simulation Description	Generator Bus (sending End)		PCC/Middle bus(3)		Infinite Bus (receiving end)	
	P_g (MW)	Q_g (MVAr)	P_{solar} (MW)	Q_{solar} (MVAr)	P_{inf} (MW)	Q_{inf} (MVAr)
Solar DG during night with damping control and voltage control	899	174	-1.2	850	-866	133
Solar DG during day with damping control and voltage control	823	190	91	-41	-817	159

9.COMPARISON OF DIFFERENT PV STATCOM CONTROLS

The generation of real power from the solar DG tends to increase the voltage at PCC and secondly, the net reactive power availability is also 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 as well as to impart adequate damping to the oscillations. However, if only damping control is exercised during daytime, power transfer limits appear to improve with higher real power outputs from the solar DG. This is because real power generation increases the PCC voltage which can be potentially helpful in increasing the power transfer capacity.Comparison of different PV STATCOM controls shown in table 9.1.

Table 9.1 comparison of different PV STATCOM controls

PV-STATCOM Control	Nighttime solar power output (MW)	Daytime solar power output (MW)
Voltage control	102	85
Damping Control	119	**121**
Voltage control with damping control	**168**	93

10. CONCLUSION

A normal solar plant remains idle when sunlight is not good. Hence solar plant is used as STATCOM during dark periods to increase transmission power limits with different controls. This study thus makes a strong case for relaxing the present grid codes to allow selected inverter-based renewable generators to different control, thereby increasing much needed power transmission limits. Such novel controls on PV solar 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.

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