Smart Inverter PV-STATCOM for Effective Application of Solar Photovoltaic Technology

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Abstract- *The incorporation of solar photovoltaic (PV) systems into electrical grids has extraordinarily increased in the recent years, mainly due to the attractive installation cost, driven policies and the relevance of the environmental issues in some countries.*

This paper presents an innovative smart PV inverter control as STATCOM, named PV-STATCOM, for controlling the steady state overvoltage and more importantly, mitigation of Temporary over-voltages. The system will consider a single equivalent inverter for an entire PV solar farm to demonstrate a new control concept, whereas an actual solar farm may have multiple inverters involving plant controls and communication delays.

Keywords- *Solar PV, VAR Compensation, STATCOM, System faults*

I. INTRODUCTION

SMART Inverters (also previously known as Advanced Inverters) represent a paradigm shift in the integration of Distributed Energy Resources (DER). These inverters can perform multiple functions involving both reactive and real power control in addition to their main task of converting DC power to AC power. These functions include voltage regulation, power factor control, active power controls, ramp-rate controls, fault ride through, and frequency control, etc. Various grid support functions offered by smart inverters are presently being demonstrated on real distribution and transmission systems in different counties, to motivate their rapid deployment.

Grid interconnection standards are currently being revised to facilitate the adoption of smart inverter functions. The voltage control related smart inverter functions e.g., Volt/VAR are mainly a set of operating points which are implemented in open-loop with time constants of a few seconds. The ongoing IEEE P1547 Standard Full Revision is contemplating that DERs shall be capable of injecting a finite amount of reactive power (typically 44%) even at 100% of nameplate active power rating (kW). This implies that DER inverters will have to be oversized. The LVRT function requires that the DER shall stay connected even if the voltage goes below a specified limit. However, if the voltage continues to be at a low level for more than a pre-specified period of time, the DER must disconnect.

A unique concept of utilizing PV solar farms as STATCOM during night time for providing different grid support functions as well as for providing the same benefits during daytime with inverter capacity remaining after real power generation was studied earlier. STATCOM is a Voltage Source Converter (VSC) based Flexible AC Transmission System (FACTS) device. It can provide dynamic reactive power compensation with a response time of 1-2 cycles, and can provide rated reactive current for voltages as low as 0.2 pu. The utilization of PV solar farm as STATCOM, termed PV-STATCOM, was demonstrated for increasing the connectivity of neighbouring wind farms and enhancing the power transmission capacity during night and day.

II. SYSTEM OF PV-STATCOM

A static synchronous compensator (STATCOM), also known as a static synchronous condenser (STATCON), is a regulating device used on alternating current electricity transmission networks. It is based on a power electronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. If connected to a source of power it can also provide active AC power. It is a member of the FACTS family of devices. It is inherently modular and electable. Usually, a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. There are however, other uses, the most common use is for voltage stability.

A STATCOM is a voltage source converter (VSC)-based device, with the voltage source behind a reactor. The voltage source is created from a DC capacitor and therefore a STATCOM has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor. The reactive power at the terminals of the STATCOM depends on the amplitude of the voltage source. For example, if the terminal voltage of the VSC is higher than the AC

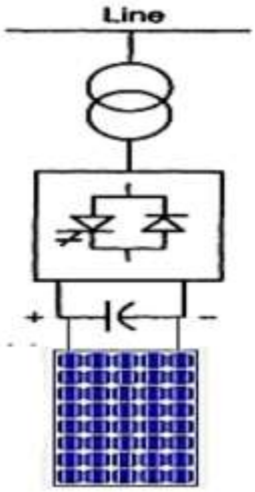

Fig 1– Smart Inverter Capacitive Mode

Voltage at the point of connection, the STATCOM generates reactive current, when the amplitude of the voltage source is lower than the AC voltage, it absorbs reactive power. The response time of a STATCOM is shorter than that of a static VAR compensator (SVC), mainly due to the fast switching times provided by the IGBTs of the voltage source converter.

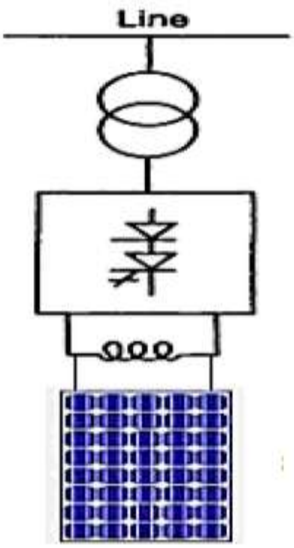

Fig 2 – Smart Inverter Inductive Mode

The STATCOM also provides better reactive power support at low AC voltages than an SVC, since the reactive power from a STATCOM decreases linearly with the AC voltage (as the current can be maintained at the rated value even down to low AC voltage).

III. SMART INVERTER METHODOLOGY

Smart inverters have been studied for PV solar systems to effectively counteract voltage issues. Smart inverter functions such Volt/VAR, Volt/Watt, off-unity power factor, Low/High Voltage Ride Through, Low/High Frequency Ride Through and Dynamic Reactive Current Injection, etc. have been demonstrated in field applications. Grid Codes such as IEEE 1547 have been revised in the interim. The newly proposed smart inverter functions as described in the revised IEEE 1547 (2018) although provide ride through capability but not Temporary Overvoltage mitigation explicitly. A unique control of PV solar farms as STATCOM during night time for providing various grid support functions with full inverter capacity and for delivering the same benefits during daytime with PV inverter capacity remaining after real power generation was introduced in 2009. The control of PV-STATCOM was utilized for increasing the connectivity of wind farms and for improving the power transmission capacity. The above control however has a limitation of available reactive power capacity especially during noontime when the inverter is completely utilized for real power generation.

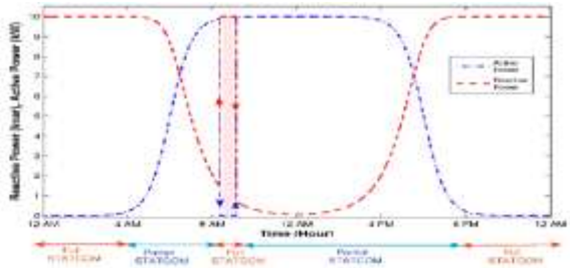

Fig 3 - Concept of smart PV inverter control as STATCOM

The real power generation from a solar farm on a sunny day and the remaining unutilized inverter capacity over a 24 hour period is depicted above. The operating modes of the proposed PV-STATCOM are described below:

- Full PV mode: The PV solar farm operates at unity power factor with no reactive power control.
- Partial STATCOM Mode: The inverter capacity remaining after active power

production is utilized for dynamic reactive power control as STATCOM.

- Full STATCOM mode: During a power system disturbance or fault in the day, when the need for reactive power support is high, the solar farm temporarily (for typically less than a minute) reduces its real power output to zero by varying the voltage across
  - the solar panels. It further makes its entire inverter capacity available for dynamic reactive power control as STATCOM.
  - After the grid support need is fulfilled, the solar farm returns to its pre-disturbance power output. The Full STATCOM mode can be activated at any time during the day depending upon system need. As an example, this Full-STATCOM mode is depicted by the thin rectangle around 8 am. The width of the rectangle is less than a minute but is shown over an exaggerated time period of an hour, just for ease of understanding. This mode is also fully available during night.

IV. CONTROLLER DESIGN AND SIMULATION

In this design, the system states that an additional PV system be equipped with the existing smart PV inverter PV-STATCOM control. The other two PV systems use only conventional controllers to generate real power at unity power factor. The controller is designed in d-q frame and includes abc/dq transformation block, PLL, DC controller, current controllers, AC voltage controller, TOV detector unit and PWM unit. The PLL unit extracts the phase angle of PCC voltage for transforming currents and voltages from abc-frame to dq-frame or vice versa. The DC controller, in order to regulate DC link voltage at the reference value, generates the reference current for d-component of inverter current which represents the active current component. Consequently, the current controller in d-axis regulates the active current component to its reference value.

During daytime, the smart PV control operates as a conventional PV system i.e., in Full PV mode. If steady state voltage control is required in all three phases, together with real power generation, Partial STATCOM mode is activated. The Full STATCOM mode is activated when a temporary overvoltage TOV occurs due to unsymmetrical faults. MPPT based on incremental conductance method is utilized during Full PV mode and Partial STATCOM mode.

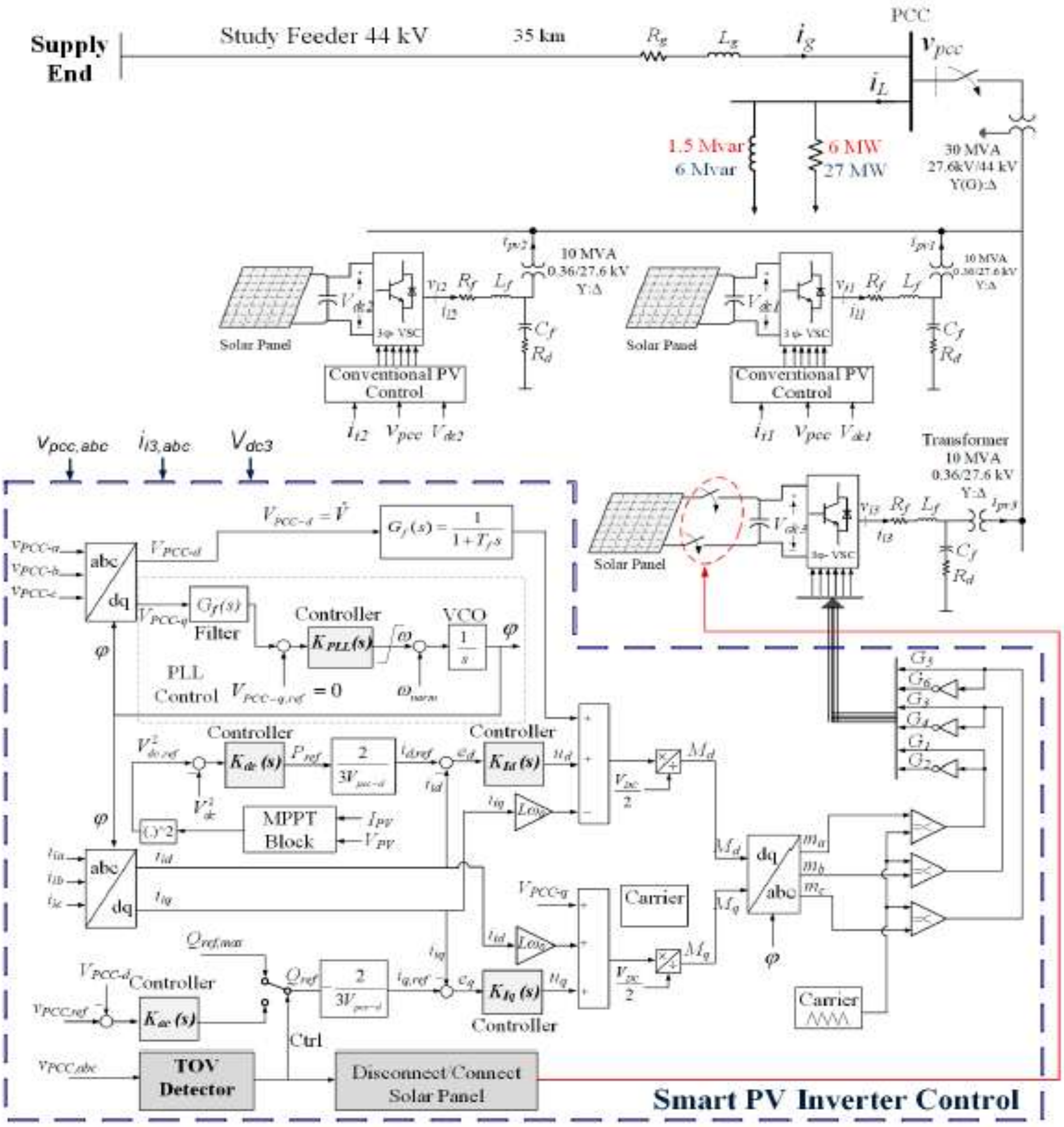

Fig 4- System modelling diagram

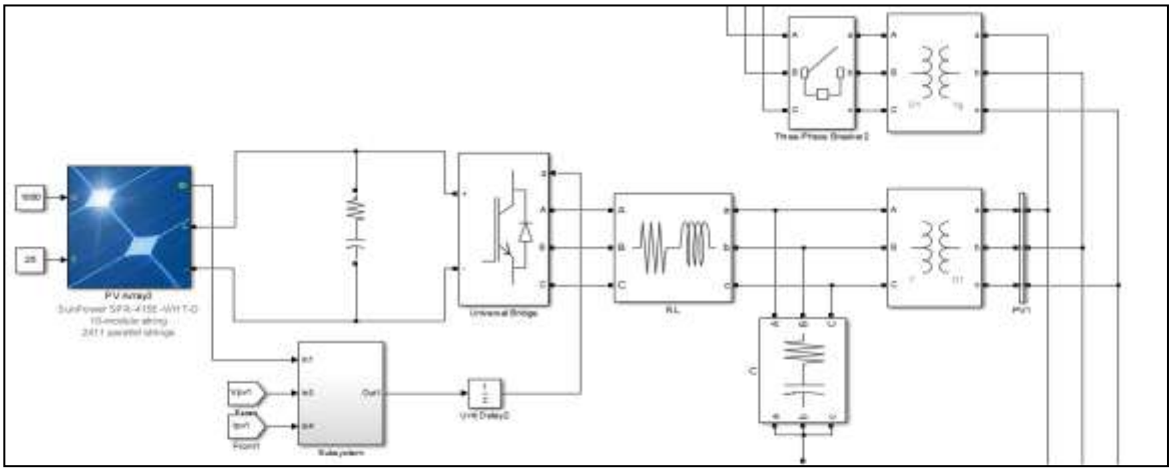

Fig 5– system implementation in MATLAB

The entire inverter capacity is then utilized to absorb reactive power in order to reduce the phase voltage. After the TOV is mitigated, power production from the solar panels is enabled and control mode is switched to Partial STATCOM mode.

In this study, instead of using an external STATCOM, the incoming third PV system is equipped with the proposed smart PV inverter PV-STATCOM controller, while the other two PV systems operate as conventional PV systems. The proposed smart inverter controller regulates the PCC voltage in steady-state with the remaining capacity of the inverter and also converts the PV system to Full STATCOM mode during a TOV event. Two different faults, single line-to-ground (SLG) fault and line-to-line-ground (LLG) fault, are considered to demonstrate the performance of the proposed controller.

V. RESULT AND DISCUSSION

The smart inverter PV-STATCOM under study provides TOV mitigation using the full inverter capacity both during night and anytime during the day as needed by the grid. It provides steady state voltage control throughout the night. During daytime, it is assumed in this study that light load conditions do not arise during full noon hours i.e., when the solar system is producing its rated power. Hence there is some remaining inverter capacity available for steady state voltage regulation in Partial STATCOM mode. Under the revised IEEE Standard 1547 - 2018, the PV inverters are also expected to provide reactive power injection and absorption capability of 44% and 25% of nameplate apparent power rating, respectively.

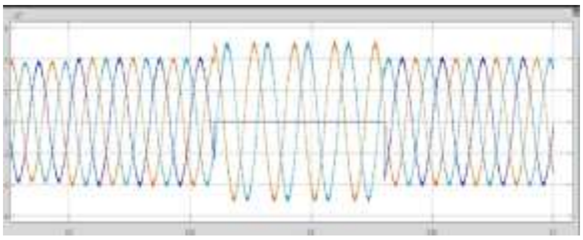
Fig 6-System voltage recovery

This over sizing will further leave room for adequate steady state voltage control in the Partial PV-STATCOM mode. In the worst case, if light load conditions do arise due to a disturbance during noon hours, the solar farm can switch to Full PV-STATCOM mode for voltage control as long as the disturbance lasts. In other words, the proposed control offers the full functionality of a STATCOM for voltage control during day or night.

This smart inverter control can therefore potentially eliminate the need for the physical STATCOM, thereby saving an enormous expense for utilities. It is only with the TOV control strategy proposed in this paper, the PV solar farm as PV-STATCOM can suppress TOV effectively. In Table I, the acceptable steady state voltage range is between 0.94 pu and 1.05 pu whereas the TOV limit is 1.25 pu Table I also presents a comparison of the different options. The PV-STATCOM is 50-100 times cheaper than an equivalent STATCOM for accomplishing the same voltage control functions. This is because only the additional PV-STATCOM control with its associated control and measurement circuitry, and protection needs to be installed on the existing inverters of the PV solar farm. The entire existing electrical (and civil) substation infrastructure of the PV solar farm including the transformers, bus-work, circuit breakers, lines and cables, etc. is utilized for implementing the overall PV-STATCOM. If a new SVC or STATCOM needs to be commissioned, the complete substation needs to be built all over, and new inverter needs to be procured. These costs are clearly avoided with PV-STATCOM.

Table 1 – Comparative values of different designs

Features \ Devices	*Conven – tional PV System*	*STATCOM with Voltage Control*	*STATCOM with Voltage and TOV Controls*	***PV-STATCOM with Voltage and TOV Controls***
Capacity	30 MW 0 Mvar	3.5 Mvar	10 Mvar	**10 MW/ 10 Mvar**
TOV Magnitude	1.35 pu	1.43 pu	1.24 pu	**1.22 pu**
Steady State Voltage	1.10 pu	1.02 pu	1.02 pu	**1.02 pu**
Response Time	----	Half Cycle	Half Cycle	**Half Cycle**
Steady-State Voltage Test	Fail	Pass	Pass	**Pass**
TOV Test	Fail	Fail	Pass	**Pass**

VI. CONCLUSION

In this study, an advanced concept of utilizing a PV solar farm as a STATCOM on a 24/7 basis, for supporting the grid. Such applications will of course require grid code approvals and appropriate agreements amongst the different stakeholders, i.e., the solar farm owner, inverter manufacturer, the interconnecting utility and system operator. This PV-STATCOM function also opens up a potential revenue making opportunity for the PV solar farm by providing similar grid support. It is also suitable for controlling the steady state overvoltage and more importantly, mitigation of Temporary Overvoltages. This novel control in Partial STATCOM mode regulates the steady state over voltage to the desired reference value within one and half cycle. Further, this smart inverter control in Full STATCOM mode successfully reduces the TOV caused during both single line to ground fault and line to line to ground fault to within utility acceptable values within one cycle.

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