Application of Photovoltaic Power System through PV-STATCOM

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ABSTRACT- Solar Farms are absolutely idle in the night and even during daytime operate below capacity in early mornings and late afternoons. Thus, the entire expensive asset of solar farms remains highly unutilized. This paper presents novel technologies for utilization of PV solar farm inverter in night time for providing multiple benefits to power systems, as well as accomplishing the same objectives during the daytime from the inverter capacity left after production of real power. The new technology transforms a solar farm inverter functionally into a dynamic reactive power compensator known as STATCOM, and termed PVSTATCOM. Novel PV-STATCOM control is employed to significantly enhance the power transfer limit of a long transmission line both in the night time and also during daytime even when the solar farm is producing a large amount of real power. This technology can open up new avenues for solar farms to earn revenues apart from the sale of real power.

Keywords- Photovoltaic (PV) Solar Farms, Inverter Modelling, STATCOM, PV-STATCOM, Reactive Power Compensation, Voltage Control, Damping Control, Power factor correction.

I. INTRODUCTION

A new application of a grid connected PV solar farm inverter as a PV-STATCOM, during both night and day for increasing transient stability and consequently, the power transmission limit of long transmission line. It utilizes the entire solar farm inverter capacity during 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 second system uses a combination of a PV-STATCOM and another PV-STATCOM or an inverter based wind Distributed Generator (DG) with similar STATCOM functionality.

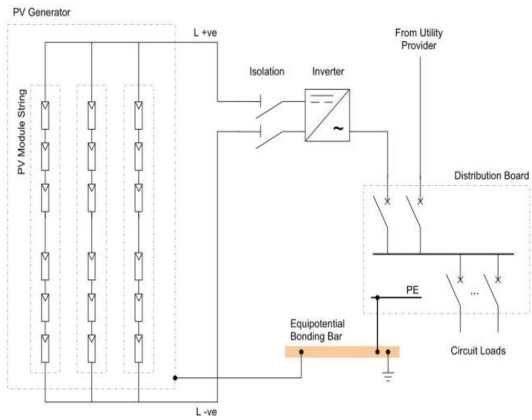

Fig.1- Solar Farm interface with Grid

A conventional grid connected Photovoltaic PV solar farm utilizes an inverter for converting the DC power output from PV arrays into AC power to be supplied to the grid. The STATCOM (a FACTS device) is also based on a voltage sourced converter which functions both as an inverter and rectifier. A novel control technology was proposed 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. This technology can open up new avenues for solar farms to earn revenues apart from the sale of real power. The control of PV solar farms as a smart inverter PV-STATCOM was proposed in few earlier research. The control presented in this paper provided only steady state voltage control in the grid by three-phase symmetrical real power generation by PV systems. However, the control strategy cannot provide mitigation of Temporary Overvoltage (TOV) during unsymmetrical faults which is a major issue in the integration of PV solar farms. For suppressing TOV, an entirely different control is required. This study is based on a patent-pending technology for modulation of real and reactive power of PV solar farms. Implementation of this control on a PV solar farm allows the solar farm to provide a 24/7 functionality as a STATCOM with rated inverter capacity both during night-time and any time during the day as needed by the grid, including full-noon.

II. SYSTEM COMPONENTS

The system under study is supposed to perform the task of regulating the power flow in the grid. The important components needed on the system are as discussed below:

a) FACTS devices: Here STATCOM, these are power electronic based equipment's, which are used for the dynamic control of voltage, impedance and phase of high voltage AC transmission lines. These have a characteristic 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, 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. Thus, the attainable reactive compensating voltage is a function of the prevailing line current.

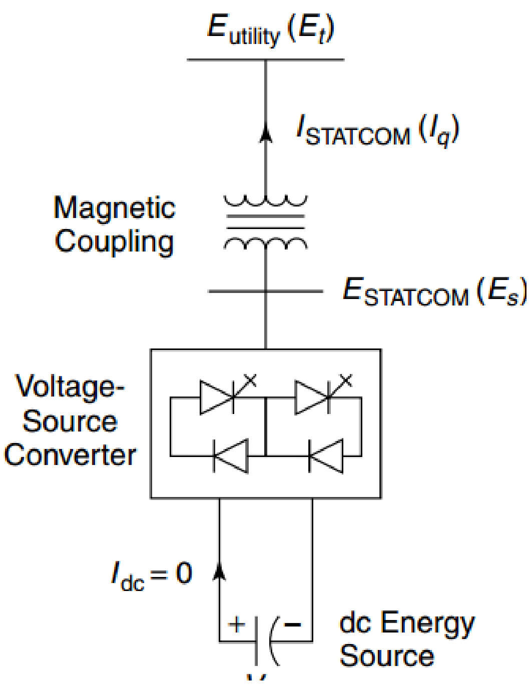

Fig.2- STATCOM

b) Solar PV Unit: 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. 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

III. PV – STATCOM AS SMART PV INVERTER

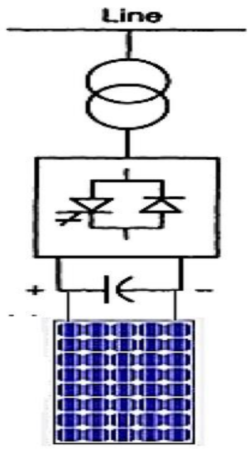

Fig.3– Smart Inverter Capacitive Mode

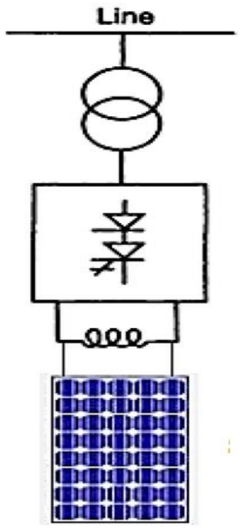

Fig.4 – Smart Inverter Inductive Mode

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 in graph below. The operating modes of the PV-STATCOM under study 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.

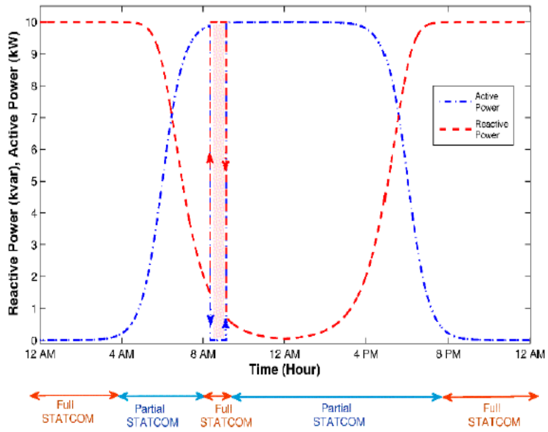

Fig.5- Concept of smart PV inverter control as STATCOM (PV-STATCOM)

IV. INVERTOR CONTROL METHODOLOGY

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

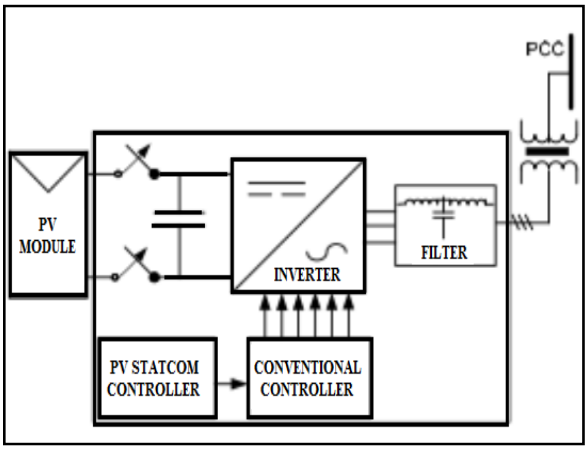

Fig.6 – System Control block diagram

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 [30] is utilized during Full PV mode and Partial STATCOM mode. In Full-STATCOM mode, the MPPT mode is disabled and the real power generation is made zero by making the voltage across PV panel equal to its open circuit voltage. 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.

The PCC voltage is controlled by the AC voltage controller. Therefore, either maximum reactive current or output of the AC voltage controller defines the reference value of reactive current control loop. The current controller in q-axis regulates the reactive current to its reference value. It is noted that the TOV Detector unit switches between voltage control mode and TOV mitigation mode. Also, this unit generates the command to enable or disable the power production from PV solar panels. The modulation indices in abc-frame are compared with carrier signal to generate gate pulses for the VSC switches

During daytime, the voltages in three phases are measured. If any phase voltage exceeds the TOV limit while the voltages in other phase/phases decrease substantially, the output of TOV Detector unit is trigged "ON", and Full STATCOM mode is activated. The controller keeps the inverter current lagging the inverter voltage by 90 degrees (i.e. keeps absorbing reactive power) to reduce TOV until the phase voltages reach an acceptable value. After the fault is cleared all the phase voltages will rise to their normal values. The controller thus recognizes that TOV is mitigated. It therefore enables power generation from the solar panels and switches to Partial STATCOM mode for steady-state voltage control. In partial STATCOM mode, the controller regulates the PCC voltage with Qrem, which is the inverter capacity remaining after real power generation. During night time, the PV solar system operates in Full STATCOM mode to control either the steady-state voltage or TOV. The smart PV inverter control thus autonomously determines its operation mode and prioritizes between active power generation and reactive power exchange based on the system requirements, nature of transient/disturbance, time of the day and remaining inverter capacity.

V. SIMULATION OF SYSTEM

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. 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, is only proportional to which sets the reference for the upper control loop involving PID1.

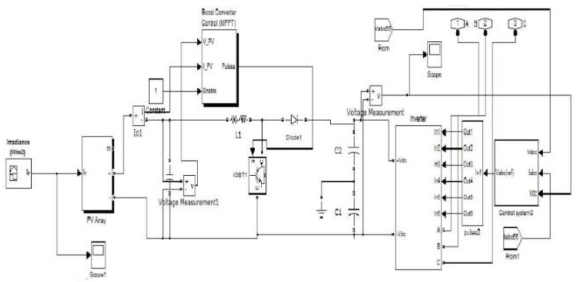

Fig.7 – Simulation in MATLAB

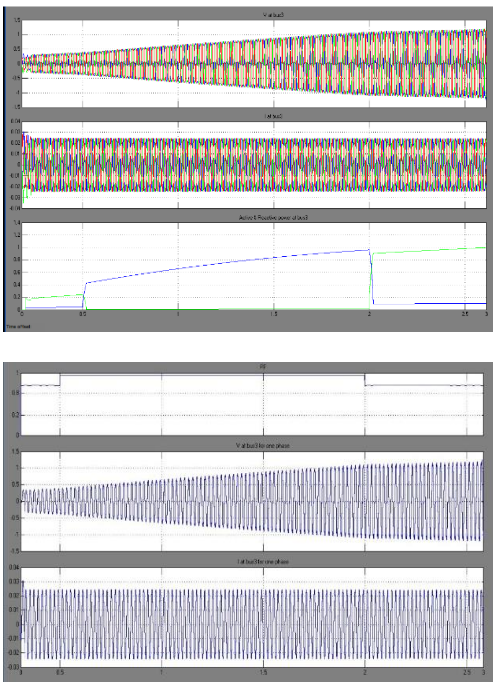

Fig.8 – Results of bus parameters

Meanwhile, the quadrature axis component is used for dc-link voltage control through two PID controllers (PI-2 and PID-3) according to the set point voltage provided by the MPPT and and injects all available real power to the network. To generate the proper IGBT switching signals (gt1, gt2, gt3, gt4, gt5, gt6), the d –q 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.

VI. CONCLUSION

PV solar farms remain absolutely unutilized during the night and are only partially utilized during the day. It presents the concepts of a new use of a PV solar inverter as PV-STATCOM, which can potentially lead to complete utilization of the PV solar farm inverter asset both during night and day. PV-STATCOM technologies are designed based on the unused capacity of the solar inverter and other based on used capacity of the solar inverter. These new applications of PV solar farms can help to improve the performance of power systems. The smart PV inverter control is used for controlling steady state overvoltage and more importantly, mitigation of Temporary Over-voltages (TOV).

VII. REFERENCES

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