Implementation of P&O method for smart inverter PV STATCOM to Control power in Distribution System

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Abstract: - In this paper, the design and implementing of P&O method for smart inverter PVSTATCOM to control voltage in distribution system, in which a PV smart inverter can be controlled as a reactive power compensator. The distinguished feature of implementing of P&O method for smart inverter PVSTATCOM, to provide DC link voltage control faster during critical system needs and improve transient performance of the system. In the day time, during disturbance on critical system, the PV smart inverter discontinues temporarily its active power generation function and freeing its entire inverter capacity for STATCOM operation. Once the disturbance is cleared and the need for grid voltage control is fulfilled, the solar farm returns to its pre-disturbance real power production. In the night time, the entire inverter capacity is utilized for STATCOM operation. A MATLAB 2019a Simulink-based study is presented in day time and night conditions under different loads to validate the proposed distribution system.

Key Words— P&O method, PV STATCOM, Smart Inverter

I. INTRODUCTION

Distributed Generators bring more advantages to distribution networks (DN). However, these advantages along with recent challenges [1-2]. These challenges include unbalanced voltage, steady state overvoltage, power quality issues such as harmonics, operation of voltage regulators in transmission system such as capacitor delta banks and load tap changers. changes in PF (power factor), etc [1-5]. In recent days, huge penetration of photo voltaic (PV) solar farms are known to cause active power flows reverses resulting in peak over voltages which limit further DG installations [6]. Flexible AC Transmission Systems (FACTS) devices such as STATCOM (Stationary Compensator) and Static Var Compensator (SVC) are utilized for voltage regulation purposes in distribution and transmission systems [8]. These STATCOM and SVC devices can provide voltage control support to the point of common coupling (PCC) with a fast response time of 1-3 cycles in system frequency with STATCOM much faster than SVC [7]. In present scenario, the utility decided to install a FATCS device such as STATCOM for regulating the system voltage to within acceptable limits (according to standards). It is noted that the symmetrical grid voltage control provided by FACTS devices such as STATCOMs worsen the problem of temporary (3 to 4 cycles) Over voltages in an actual distribution and transmission system [8-9].

Recently, Smart based inverters have been proposed in distribution system for PV (Photo Voltaic) solar systems to effectively counteract voltage support issues [7-9]. Smart PV inverter functions such as V/Q(volts/VAR), v/w(volts/Watt), grid power factor, Low/High Voltage Ride Through, Low/High Frequency Ride through and Dynamic Reactive

Current Injection, etc. But from smart PV inverter system, it is very difficult to track maximum power and provide temporary voltage support. To overcome these drawbacks MPPT (Maximum Power Point Tracking) implemented to smart PV inverter. The distinguished feature of implementing of P&O method (MPPT method) **for smart** inverter PVSTATCOM, to provide DC link voltage control faster during critical system needs and improve transient performance of the system**. 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 [23-24]. The proposed control, termed PV-STATCOM, was utilized for increasing the connectivity of wind farms [25] and for improving the power transmission capacity [26].

II. METHODOLOGY

Figure. 1 illustrates the control system of the proposed smart PV inverter control

A. Controller design

(i) PLL

The *q*-component of PCC voltage in *dq*-frame is given as:

$$V_{pcc-q} = \hat{V} \sin(\omega_o t + \theta_o - \varphi) \qquad (1)$$

Where $\hat{V}$ is the magnitude of PCC phase voltage, θ_0 is initial phase angle and f_0 is the system frequency of the proposed system. For decoupling reactive and active power controls,

V_{pcc-q} is regulated to zero. The open loop transfer function of PLL with PI controller is:

$$H_{PLL}(s) = \frac{\hat{V} \times k_{PLL,gain}}{T_f}\left(\frac{s+z_{PLL}}{s+T_f^{-1}}\right)\frac{1}{s^2} \qquad (2)$$

Where $k_{PLL,gain}$ and z_{PLL} are PLL controller parameters. The Symmetrical Optimum technique [26] is used to design the PI controller with phase margin $\delta m = 60°$ at cross over frequency $\omega c = 268\ rad/s$.

(ii)   Current Control

The inverter currents in dq-frame are [18], [23]

$$L_f\frac{di_{id}}{dt} = L_f\omega(t)i_{iq} - R_f i_{id} + V_{id} - V_{pcc-d} \qquad (3)$$

$$L_f\frac{di_{iq}}{dt} = -L_f\omega(t)i_{id} - R_f i_{iq} + V_{iq} - V_{pcc-q} \qquad (4)$$

Where $V_{pcc,dq}$ is PCC voltages, $i_{i,dq}$, is inverter current $v_{i,dq}$ is the voltage at AC side of the inverter in dq-frame, respectively. A PI controller is used for each current component [23].
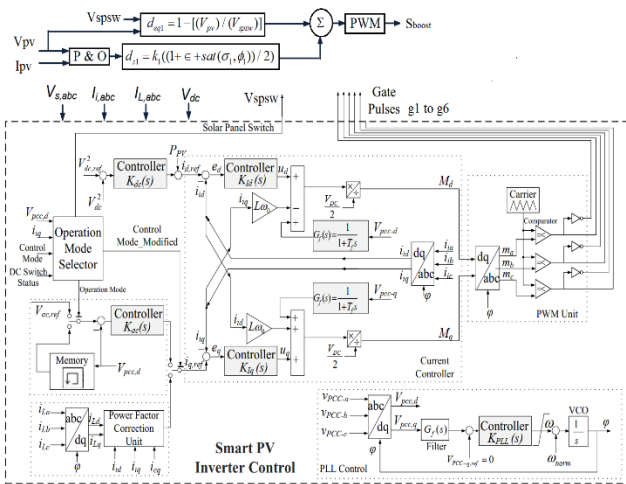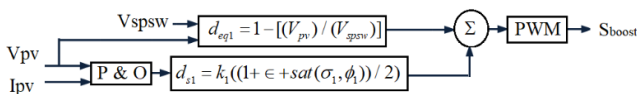

Fig. 1. Proposed smart inverter controls with P & O MPPT technique

B. P&O method

model of efficient operation on Human Resource Management in the Internet Age.

III.   PROPOSED SYSTEM AND RESULTS

This section presents the MATLAB software- Simulink based simulation studies of the proposed power system with the proposed smart inverter controls with P & O MPPT technique in a distribution system as depicted in Figure 2. System studies for the following smart PV inverter operation modes with P&O MPPT technique are described for different system operating conditions:

- Full STATCOM mode for voltage control conditions during day
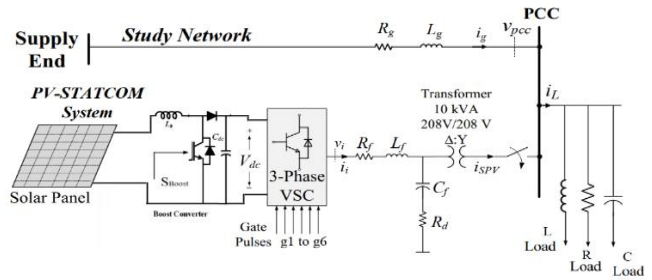- Full STATCOM mode for voltage control during night

Figure.2. Proposed Power System

In MATLAB Simulink results, the PCC voltage is denoted by v_{pcc}. Grid current and load current are represented by i_{grid} and i_{load}, respectively. The PV system currents before and after harmonics filter are represented by $i_{inverter}$ and i_{spv}, respectively. The reactive power generates by harmonics filter while the interface transformer absorbs reactive power. These reactive power components are included with the smart inverter reactive power in the variable Q_{spv}. Hence, the reactive power of the grid Q_{grid} together with the reactive power of the smart PV system Q_{spv} balance the reactive power of the load Q_{load} at all times.

A. Full STATCOM mode for voltage control conditions during day

Figure.3 (a)-(f) demonstrate the voltage in per-unit value of the utility grid voltage ($v_{pcc,pu}$), the utility grid voltage (v_{pcc}) in volts, utility grid current (i_{grid}) in amps, proposed smart PV STATCOM distribution system current (i_{spv}), PV STATCOM inverter current ($i_{inverter}$) in amps, load current (i_{load}) in amps.

During t < 1 second: The proposed smart PV system is not connected, and hence the active power and reactive power of load and grid are respectively, equal.

At t=1 second: Full PV Mode enabled: The PV system is connected to the grid when it generates 6 kW active power. Initially, 2 kW active and 2 kvar reactive loads are connected to the grid. Active power injection (P_{spv}) by the PV system

International Journal of Progressive Research in Science and Engineering
Volume-1, Issue-4, July-2020
www.ijprse.com

increases the PCC voltage ($v_{pcc,pu}$) to 0.97 pu. The PV system supplies active power of the load (P_{load}) and the surplus power flows into the grid in reverse direction. Therefore, the active power of the grid (P_{grid}) becomes negative. The reactive power output of the inverter is kept zero by the controller in this Full PV mode. However, some reactive power is generated by the filter capacitor. In this mode, the 2 kvar reactive load (Q_{load}) is supplied by the grid (Q_{grid}) and the small amount of reactive power generated by the harmonics filter of the PV-STATCOM(Q_{spv}).

At t=1.04 sec: Full STATCOM operation enabled: A reactive load of 1.5 kW and 5.5 kVAR is connected to the power grid. This load reduces the voltage from 1.0 pu to 0.905 pu, which is below the acceptable voltage range of the utility. The total load becomes 3.5 kW active and 7.5 kVAR reactive. In this case, the proposed controller disconnects the solar PV panel and controls the utility PCC voltage to its pre-fault value with reactive power generation. The PCC voltage is successfully regulated to its pre-fault value of 0.96 pu within one cycle.

At t=1.10 sec: Full PV operation enabled: The large load is removed and the controller returns to Full PV operation mode. In other words, the controller connects the solar panel to the inverter and generates only active power. The voltage control mode is deactivated as the PCC voltage is within acceptable range.
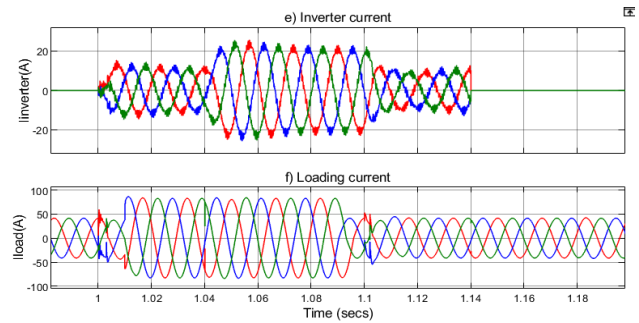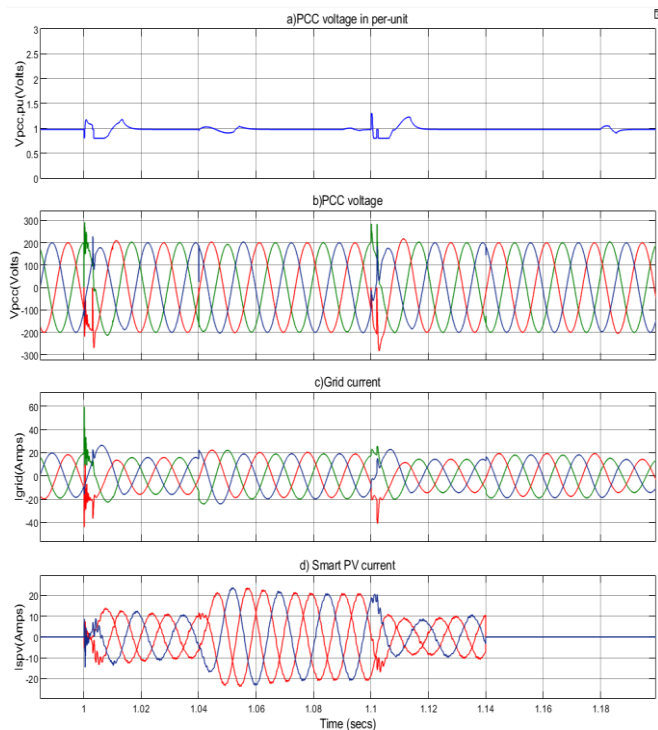

Figure.3. Simulation results for full STATCOM mode with voltage control during daytime a) Utility PCC voltage in per-unit b) Utility PCC voltage c) Utility Grid current d) Smart PV current e) Inverter current f) Load current

At t=1.14 sec: Solar PV system disconnected from system: The disconnection of solar PV-STATCOM causes the utility PCC voltage to drop slightly.

B. Full STATCOM mode for voltage control during night

Nighttime During the nighttime, the inverter is used fully as STATCOM. The control objective is selected as PCC voltage control. The load power is kept 3 kW for this test. Figure: 4 (a)-(d) demonstrate the per-unit value of the PCC voltage ($V_{pcc,pu}$), the PCC voltage ($v_{pcc,pu}$), the PCC voltage (v_{pcc}), grid current (i_{grid}).

t=1 sec: Full STATCOM operation enabled: The PV system is connected to the PCC in Full STATCOM. The initial reference voltage is kept at 1.06 pu. The smart inverter control follows the reference value and increases the PCC voltage from 1 pu to 1.06 pu within less than a cycle. Due to additional STATCOM current, the grid current is increased. The STATCOM absorbs some active power to keep the DC link capacitor charged. At the instant of connection of the PV-STATCOM system to the grid, the inrush current for charging capacitor creates a transient in inverter active power.

t=1.04 sec: Operation mode changed from capacitive to inductive: The reference value of the voltage controller is changed from 1.06 pu to 0.94 pu. The proposed smart inverter control reduces the bus voltage and regulates it to 0.94 pu in less than one cycle. The STATCOM changes its operation mode from capacitive to inductive, with the phase of STATCOM current changing from 90∘ leading to 90∘ lag to reduce PCC voltage.

t=1.08 sec: Operation mode changed from inductive to capacitive: The voltage reference is changed in reverse from 0.94 pu to 1.06 pu. The STATCOM control changes the PCC voltage (v_{pcc}) to 1.06 pu within one cycle. This test verifies the rapid performance of the control system.

t=1.12 sec: STATCOM system disconnected: The STATCOM current (is) goes to zero instantaneously. Since the previous operation mode of the STATCOM was capacitive, the disconnection of the STATCOM reduces the PCC voltage (v_{pcc}) correspondingly.
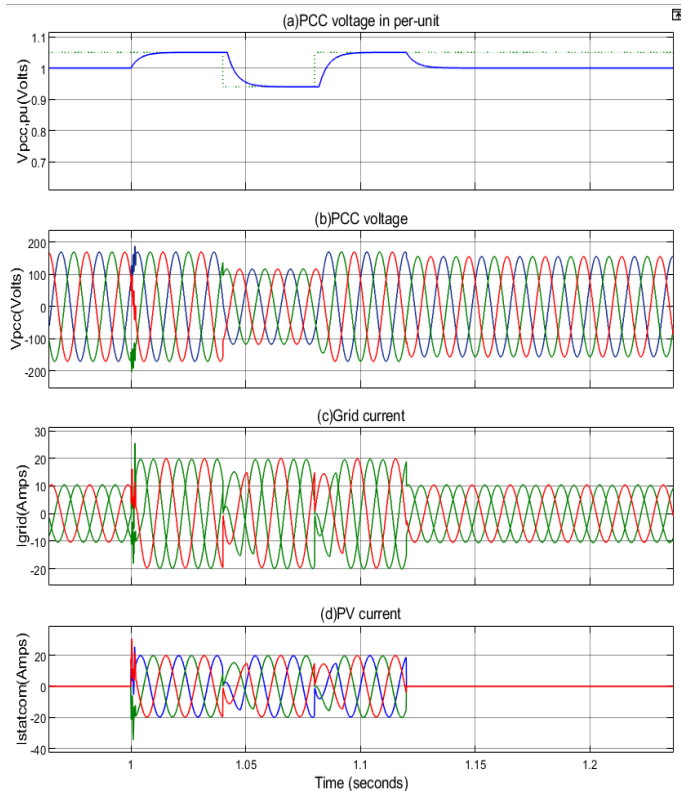

Figure.4. MATLAB Simulation results for full STATCOM operation with voltage control during nighttime a) utility PCC voltage in per-unit b) utility PCC voltage c) power Grid current d) PV current.

IV. CONCLUSION

PV solar systems employ inverters to transform dc power from solar panels into real ac power for injecting into the power transmission and distribution grids. Inverters that perform multiple functions in addition to real power production are known as "smart inverters". This paper presents a control of PV inverter as a dynamic reactive power compensator – STATCOM. This "smart PV inverter" control enables a PV solar inverter to operate in two modes**.** In the day time, during disturbance on critical system, the PV smart inverter discontinues temporarily its active power generation function and freeing its entire inverter capacity for STATCOM operation. Once the abnormal condition is cleared on the grid and the need for utility grid voltage control is fulfilled by controller, the PV solar farm returns back to its normal real power generation. During night time, the entire power inverter capacity is utilized for PV-STATCOM operation.

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