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Reactive power control strategy for integrated photovoltaic inverter

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ABSTRACT

Rising penetration of photovoltaic (PV) power also poses several threats to electrical system which demands proper inverter control schemes to be designed. One major issue is that as PV systems are inherently non-inertial in nature, they do not participate in regulating voltage or reactive power and hence become highly sensitive to external disturbances. Any perturbation in voltage or frequency may cause some serious consequences in terms of loss of transient stability and reliability. Thus controlling the PV inverter for smooth operation of system while interfacing with grid brings a challenging task of maintaining both voltage and frequency well within the acceptable limits. Another important aspect is intermittency in PV output which demands application of some advance tracking algorithms. Therefore, novel control strategies for PV interfacing have been presented in this paper. The proposed synchroconverter based inverter controller enables the system to inject both active and reactive powers and facilitates the integrated PV system to withstand voltage or frequency perturbation. Whereas an enhanced control algorithm is applied here that can estimate panel parameters precisely offering effective tracking for any conditional variance. Proposed synchroconverter based controllers have been analyzed through simulations for different spans of time according to voltage and frequency variations.

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1. INTRODUCTION

The recent advancements in photovoltaic (PV) technology like reduced panel costs, higher efficiency and improved tracking schemes have provided a driving thrust resulting in enormous PV penetration. However, with this growing trend there have been rising issues also like deterioration in system reliability, transient stability and power quality [1]-[4]. While integrating PV systems to grid the control strategy for inverter interface plays a very crucial role for optimized power extraction. There are various topologies available for PV inverter in the literature [5]-[9] which more or less performs well at small scale. However, in current scenario where centralized generation is rapidly shifting towards distributed generation with likes of PV power as primary resources [10], advance control schemes are required to counter the imminent challenges.

Research by Dietmannsberger *et al*. [11] first highlighted the significance of low voltage ride through (LVRT) feature of PV inverters with increasing grid connectivity. Authors have presented an inverter control strategy that also facilitates anti islanding features. But this methodology can be effectively adopted for low voltage level connections only. PV systems are inherently non-inertial in nature hence they hardly participate in regulating voltage or frequency. Thus for higher level penetrations the disturbances on grid side or some load variations result into considerable fluctuations in voltage and frequency causing serious impact on PV system reliability and stability [12]-[14]. Elrayyah *et al*. [15] presented a methodology for modeling and tuning of the PV systems connected to microgrid. In this control strategy droop control has been combined with maximum power point tracking MPPT so that designed system may regulate the voltage along with frequency. But the major drawback is that performance is heavily dependent on accurate tracking of reference voltage and hence inverter performance is affected by variation in the error. Yang *et al*. [16] presented the need for changes and modifications to be made in standards and norms for grid connectivity with rapidly increasing PV integration. Meyer *et al*. [17] analyzed the features of distributed system which are important for stabilizing grid performance. One of the important features required is the capability of riding through in faulty conditions. Inverters used by authors are for medium level voltages and having lower switching frequency which hardly possess this property. Another challenging aspect of PV interfacing is its non-linearity due to which output greatly varies with the ambient conditions [18]. There exist various MPPT schemes having their individual pros and cons [19]-[21]. Among these perturb & observe and incremental conductance are found to be simplest and commonly preferred approaches [22], [23]. However, on increasing the rate of perturbation it also leads to higher oscillations around maxima. There are also some new techniques applied on the basis of soft computing [24], [25] which have good accuracy and reduction in settling time. But the issues like increased system complexity, greater memory requirement and stochastic nature are some of their drawbacks.

Therefore, this paper presents development of control algorithm for inverter on the basis of synchroconverter which mimics the inherent properties of inertia and damping incorporated in a synchronous generator (SG). The proposed scheme enables the system to inject reactive power simultaneously which leads to the voltage and frequency regulation to be performed by the inverter. Thus it develops immunity in the system for any external disturbances and enhances ride through fault capability. Simultaneously, an enhanced control algorithm for model based (MB) technique is applied to ensure effective tracking even for rapid variations in conditions.

2. OVERVIEW OF PV SYSTEM WITH PROPOSED CONTROLLERS

The overview of PV model with incorporated controllers is shown in Figure 1. Here, Shaded area represents the part of the system which acts as a synchroconverter. It can be seen that MPPT controller is also in-built and plays a very important role for optimizing the system performance. Synchroconverter is an inverter whose behavior is made analogous to that of SG. By developing an algorithm to control the inverter operation, voltage and frequency regulation is made feasible. Thus it virtually introduces inertia and damping in electrical power system in similar manner to that of SG. Designing the controlling loops forms the core part of synchroconverter and hence for this purpose voltage and frequency droop control loops are implemented in the inverter that imparts virtual inertia to the system. Control loops generate the gate pulses as their output, through the pulse width modulation (PWM) scheme, which is then given as input to the inverter. The input to the inverter is DC-link voltage, V_{dc} and the output is an AC voltage at a specified magnitude and frequency determined by the controller. Utility grid has been modeled as three phase sinusoidal supply with rated values of 400 V and 50 Hz.

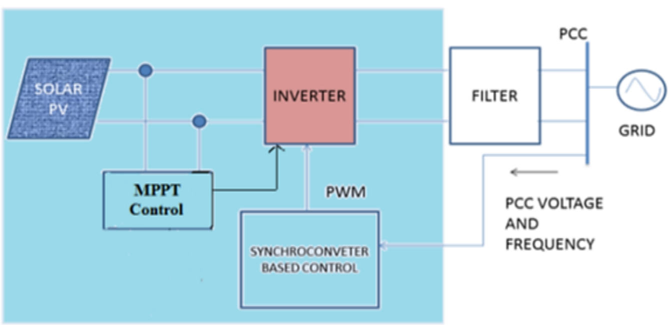

Figure 1. Integrated PV model with in-built controllers

2.1. Loop for controlling droop in voltage

Nested loop designed for controlling the amplitude of voltage and reactive power is shown in Figure 2. Whenever any disturbance in system voltage is found, it generates an error signal that indicates deviation from set reference. The amplitude of point of common coupling (PCC) voltage (V_m) is calculated as given in (1), where v_a, v_b, v_c are instantaneous magnitude of grid phase voltages.

$$v_a v_b + v_b v_c + v_c v_a = -\frac{3}{4} v_m^2 \quad (1)$$

After multiplying this voltage with coefficient of voltage droop (Dq) finally it enters into second loop on adding with the reference value of reactive power. This outer loop is responsible for making sure that output reactive power of inverter tracks its set point which is taken as 600 VAR here.

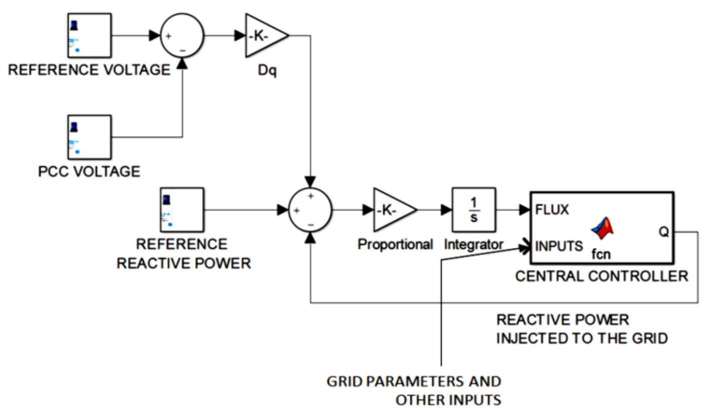

Figure 2. Voltage/reactive power control loop

2.2. Loop for controlling droop in frequency

Nested loop designed for controlling the frequency and active power is shown in Figure 3. The reference for active power is taken to be 800W and the corresponding reference for torque is taken to be 2.54 Ws/rad. As seen from the system perspective, this power is taken from the DC bus. When applied to a synchroconverter, P_m represents the mechanical power input by the imaginary prime mover which is taken as actual active power in below loop. Whenever disturbance in system frequency is found, it generates an error signal that indicates deviation from set reference. To obtain the rotor virtual angular position (θ), output of the summing block is divided by the virtual inertia constant (J) of the synchroconverter and then two integrators are put in series as described in (2). After multiplying this signal with coefficient of frequency droop (D_P) finally it enters into second loop and accordingly it is followed by output torque.

$$\theta = \iint \frac{1}{J} (T_m - T_e - D_p \Delta\theta) \quad (2)$$

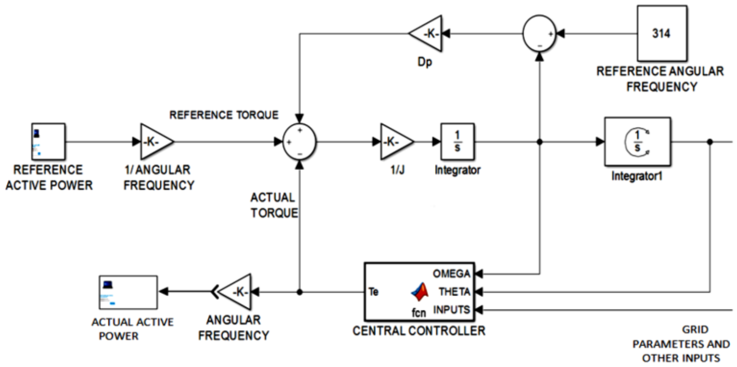

Figure 3. Frequency/active power control loop

2.3. MPPT controller

Under the influence of dynamic variations in operating conditions or due to non-uniform irradiance, PV modules exhibit multiple points of local maxima out of which only a single point is actually corresponding to the global maximum power point. Thus to design accurate and effective tracking controller here parameters are estimated precisely. For the detailed algorithm of applied model based MPPT scheme and its advantages, published work in [26] may be referred. Solar radiation is directly measured here through pyranometer and collected through portable data logger shown in Figure 4. Cell temperature (T_c) is defined in terms of temperature for a closest possible point to the cell (T_p). In (3) introduces a relationship for the cell temperature with the insolation (S) and (T_p), which is the temperature defined for rear surface. The coefficient $k_{\Delta T}$ relates the difference between cell temperature and that of environmental (T_e) for normal working condition (NWC) with respect to insolation (S) as given in (4).

$$T_c=T_p+k_{\Delta T}S \quad (3)$$

$$k_{\Delta T}=(T_{c,\,NWC}-T_{e,\,NWC})/S_{NWC} \quad (4)$$

Figure 4. Data logger

3. MODES OF OPERATION OF SYNCHROCONVERTER

The designed strategy enables the controlled operation in various modes according to frequency and voltage conditions. For disturbance in grid frequency, active power control plays the important role and hence this mode is named as frequency watt control. Similarly, for the disturbance in grid voltage, reactive power control plays the important role and hence this mode is named as volt var control.

3.1. Frequency watt control mode

During high frequency conditions on the system synchroconverter quickly acts to lower the flow of active power to maintain the stability. Whereas when the load increases it leads to lowering of grid frequency. In this case synchroconverter takes the control action by increasing the active power supply. Thus, the system supports low frequency ride-through and increases the flow of active power, similar to the manner of a conventional SG.

3.2. Voltage var control mode

During low voltage conditions on the system the control mechanism reacts quickly to inject reactive power depending on magnitude of voltage sag. Thus, synchroconverter is seen to possess the properties of a synchronous condenser in this case. Whereas when system voltage rises above nominal level it regulates the voltage by reducing the injected reactive power and hence normalizes the operation.

3.3. Simultaneous regulation of frequency and voltage

Here control mechanism is exposed to the condition where both frequency and voltage of the grid fluctuates simultaneously. The control mechanism is set to work in all the modes of operation in response to both frequency and voltage perturbations above and below the nominal value of system.

4. RESULTS AND DISCUSSIONS

The performance analysis of proposed controllers has been carried out in details. As discussed in above sections working of synchroconverter is examined for fluctuations in system frequency, system voltage and also for simultaneous perturbations in both. Also maximum power tracking has been effectively achieved through the incorporated MB algorithm. First the MATLAB model for PV inverter interfaced with grid is shown in Figure 5. Then the corresponding control model of synchroconverter is shown in Figure 6. Simulation is run for different spans of time according to the parameter whose variance is observed.

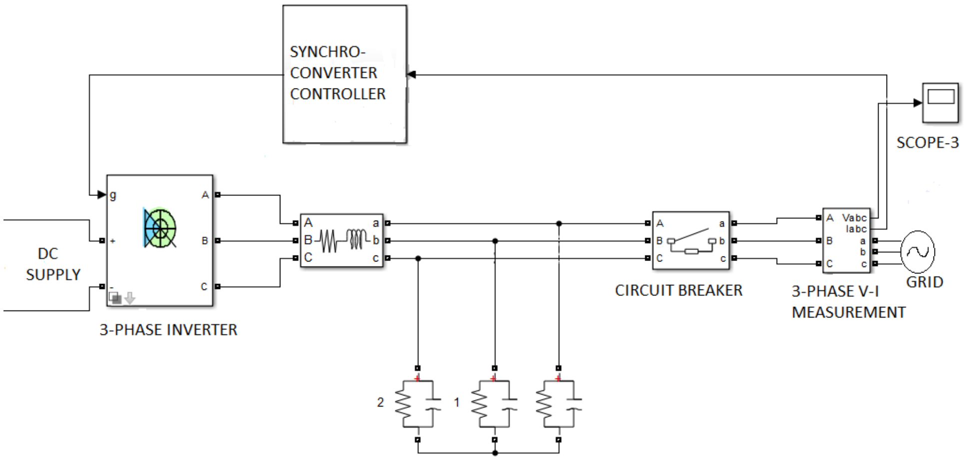

Figure 5. MATLAB model for a grid connected inverter working as a synchroconverter

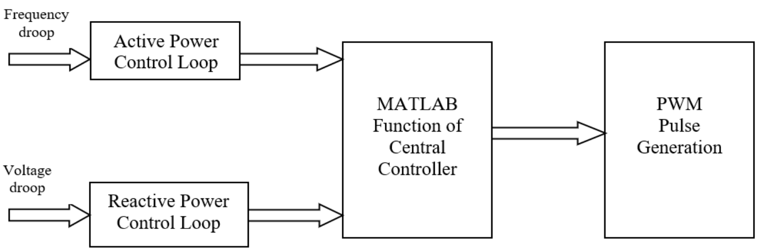

Figure 6. Block diagram for control mechanism of synchroconverter

This is followed by one by one presentation of various results obtained while system is subjected to all sorts of disturbances in conditions. Starting with fluctuations in frequency, the response of controller is shown in Figure 7. Then the response for voltage perturbations is shown in Figure 8. Similarly, response of synchroconverter while system is subjected to simultaneous fluctuations in frequency and voltage is shown in Figure 9. Finally the results achieved for effective tracking of maximum power is shown in Figure 10.

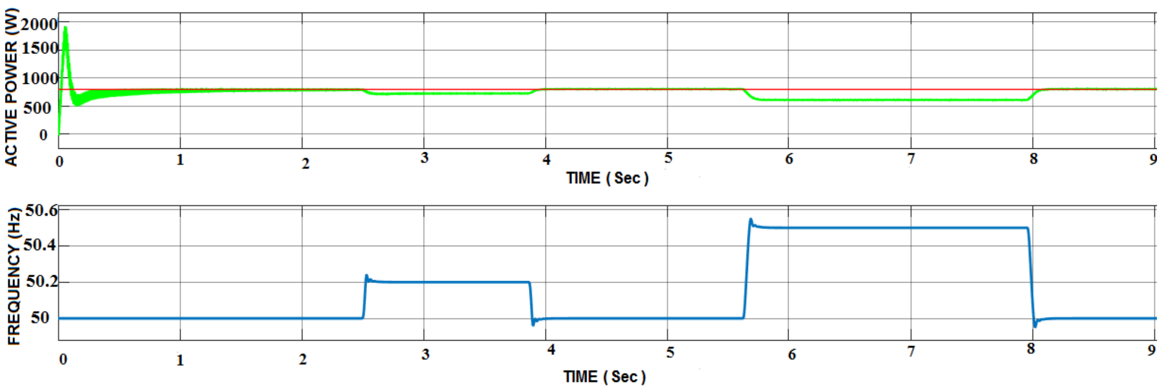

Figure 7. Injected active power with variation in system frequency

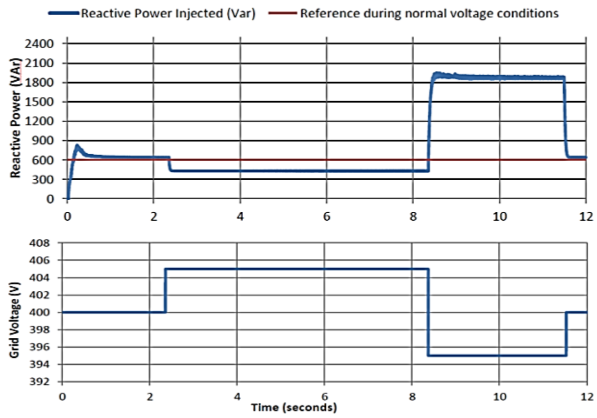

Figure 8. Injected reactive power with variation in system voltage

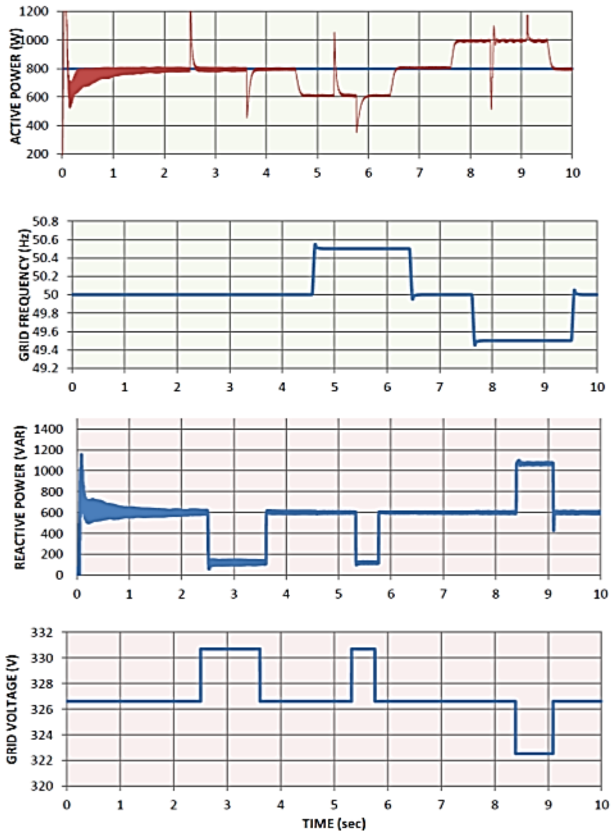

Figure 9. Synchroconverter responses for simultaneous variations in frequency & voltage

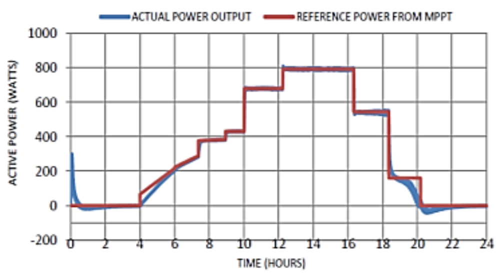

Figure 10. Tracking of active power for dynamic conditions

5. CONCLUSIONS

In this paper the challenges for large scale PV penetration into the grid system have been analyzed and remedies have been proposed to resolve the issues. It is found that while integrating the PV systems it is very important to develop and design proper control strategies for the inverter which interfaces PV with the grid. One of the biggest challenges arising with continuously increasing grid-integrated PV power is the system instability under slight load variations. Thus controllers based on synchroconverter have been developed that induces features of inertia and damping. The inverter performance has been evaluated in MATLAB for different modes of fluctuations along with tracking capability. Controller is found to respond well to the grid side fluctuations in terms of both real and imaginary power. Thus voltage and frequency have been tracked effectively to their reference value without much oscillation arising in system.

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