Performance Evaluation of STATCOM for Three Phase Grid Connected Photovoltaic (PV) System

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Abstract: Solar Photovoltaic (PV) energy is the future source of energy to meet the power demand. In the world wide, the non-renewable energy sources are going to be exhausted, so that the photovoltaic technology has found immense applications to utilize the vast amount of solar energy. The main concern of power system is to enhance the performance of the system. In this project, the performance of the three phase grid connected PV system can be enhanced by inserting the STATCOM into the system to overcome the power quality problem is due to the change in the solar intensity and temperature. The unbalanced dip is produced due to fault occur in the system and it creates positive and negative sequence voltages. By inserting the STATCOM into the three phase grid connected PV system, the voltage dip power quality problem will be compensated and the THD of the load current can be reduced. The simulation has done by using the MATLAB SIMULINK.

Index: PV system, MPPT technique, Boost converter, Voltage Source Inverter (VSI), Linear and non-linear controller, STATCOM.

I. INTRODUCTION

In recent years, the energy crisis and environmental problems such as air pollution and global warming effect are driving research towards the development of the non-conventional energy. In order to protect the environment and face the power demand the people always find new green energies such as wind energy, water energy, solar energy etc. Among them, the solar energy is now widely used, and it is a clean, maintenance-free, safe, and pollution free, so it is one of good green energy sources. But, there are still some problems because the sunlight intensity and temperature level of solar cells change anytime [1].

A PV module (composed of many solar cells in series/parallel) has the unique current versus voltage (I-V) characteristics. From this characteristic, the power versus voltage (P-V) curve has a unique maximum power point (MPP) at a particular operating voltage and current. For any PV system, the output power can be increased by tracking the MPP by using a controller in a boost converter [2], [3]. However, the MPP changes with sunlight intensity and temperature level due to the nonlinear characteristic of solar cells. Each type of solar cell has its own specific characteristic, so it leads to make the tracking of MPP more complicated. To overcome this problem, many MPPT algorithms have been presented and one of well-known algorithms is perturbation and observation algorithm (P&O algorithm). The P&O algorithm has the advantages of low cost and simple circuit [4].

Inverters interfacing PV modules with the grid perform two major tasks—one is to ensure that PV modules are operated at maximum power point (MPP), and the other is to inject a sinusoidal current into the grid in [5]. In a grid-connected PV system, the control objectives are met by a strategy using a pulse width modulation (PWM) scheme based on two cascaded control loops. The two cascaded control loops have a outer voltage control loop to settle the PV array at the MPP, and an inner current control loop to establish the duty ratio for the generation of a sinusoidal output current is in phase with the grid voltage. Linear controllers such as proportional integral (PI), hysteresis, and model predictive controllers are presented in which provide satisfactory operation over a fixed operating points as the system is linearized at an equilibrium point. The PI current control scheme is used to keep the output current as sinusoidal and to have fast dynamic responses under rapidly changing atmospheric condition and to maintain the power factor at the unity.

To ensure the operation of a grid-connected PV system over a wide range of operating points, the design and implementation of a non-linear controller is important one. For a non-linear PV system, the linear controller affect the electrical characteristics of the PV source are time varying, so that the system is not linearizable around a unique operating point or trajectory to achieve a good performance over a wide variation in atmospheric conditions. Feedback linearization has been increasingly used for non-linear controller design. It transforms the non-linear system into fully or partly linear equivalent by cancelling the non-linearity in [6], [7].

To overcome the complexity, a simple and consistent inverter model is used and a feedback linearization technique is employed to operate the PV system at MPP in [8]. A feedback linearizing controller is designed by considering the dc-link voltage and quadrature-axis grid current as output functions. Power-balance relationships are considered to express the dynamics of the voltage across the dc-link capacitor. However, this relationship cannot capture non-linearities cannot capture the non-linear switching functions between inverter input and output; to accurately represent a grid-connected PV system but it is essential to consider these switching actions. However, this relationship does not capture non-linearities switching functions between inverter input and output; to accurately represent a grid-connected PV system but it is essential to consider these switching actions. The current relationship between the input and output of the inverter can be written in terms of switching functions rather than the power balance equation. Therefore the voltage dynamics of the dc-link capacitor include non-linearities due
The absolute−1 is the dark saturation current, \( I_{0r} \) is the error, which include parametric and modellers in [11]. The feedback linearization technique is widely used in the design of non-linear controllers for the three-phase grid connected PV system, this paper proposed the extension of the partial feedback linearizing scheme, that is by considering uncertainties within the PV system model.

\[ V_{pv} = \frac{N_{e}ATK}{q} \ln \left[ \frac{N_{p}I_{ph} - I_{s}I_{0}}{I_{0}} \right] - I_{ph}R_{S} \quad (3) \]

Where \( N_e \) and \( N_p \) are the number of cell in series and the number of panel in the parallel and if the the value of the \( N_e \) and \( N_p \) can be varied, then the PV voltage and current can be varied. \( R_{S} \) and \( R_{ph} \) is the series and shunt resistance of the PV cell. \( R_{S} \) is the resistance offered by the contacts and the bulk semiconductor material of the solar cell. The shunt resistance \( R_{SH} \) is related to the non-ideal nature of the p–n junction and the presence of imurities near the edges of the cell that provide a short-circuit path around the junction.

The output current of the PV cell can be written as,

\[ I_{pv}N_{ph}R_{S} \left[ \frac{N_{p}}{N_{e}} \right] \exp \left[ \frac{q \left( V_{pv} + I_{ph}R_{S} \right)}{nkT} \right] - 1 \quad (4) \]

III. MAXIMUM POWER POINT TRACKING (MPPT) TECHNIQUES

Maximum Power Point Tracking is the algorithm used for extracting maximum available power from PV unit under climatic changing conditions. The voltage at which PV module can produce maximum power is called ‘maximum power point’ (or peak power voltage). Maximum power of the PV unit can vary with respect to the solar irradiation, solar cell temperature.

In the PV system, there are many MPPT techniques used to extract maximum power under environmental changing condition. The some of them are, Constant Voltage (CV), short current (SC), open voltage (OV), and temperature methods (temperature gradient (TG), are perturbation and observation (P&O) and incremental conductance (IC). To
improve the efficiency of PV systems, MPPT must take into account:

- Main parameters, which are the solar irradiance and the temperature
- The other important parameters, which are the light intensity, the cells’ aging, and the irradiance spectrum in MPPT technique. But, they are mostly neglected in MPPT techniques

P&O algorithms are widely used in the MPPT techniques; because of their simple structure and the only few measured parameters are required. The P&O algorithms operate by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage or current and comparing the PV output power with that of the previous perturbation cycle. If the PV unit operating voltage change and power increases (ΔP/dVPV>0), the control system moves the PV array operating point in that direction; otherwise the operating point is moved in the opposite direction. In the other perturbation cycle the algorithm continues in the same way.

The P&O algorithm should operate with high sampling rates and the sample values of voltage and current can reflect the tendency of the output power when increasing or decreasing the reference signal for the MPPT power converter should be very fast while keeping the switching losses (frequency) low. This can be done by comparing instantaneous, instead of average values of VPV and peak current control that presents one-cycle speed of response for small variations in the reference current, to further improve the performance of the system. Fig.5 shows the flowchart of the P&O technique.

![Fig.3 Flowchart of P&O method](Image)

**IV CONTROLLER DESIGN**

As three-phase grid-connected PV system as represented by (10) has two control inputs (Kd and Kq) and two control outputs (Iq and VPV), the mathematical model can be represented by the following form of a nonlinear multiinputmultoutput (MIMO) system,

\[
\dot{x} = f(x) + g_1(x)u_1 + g_2(x)u_2
\]

\[
y_1 = h_1(x),
\]

\[
y_2 = h_2(x)
\]

Where,

\[
f(x) = \begin{bmatrix}
\frac{R}{L}i_d - \frac{E_d}{L} & 0 \\
0 & \frac{R}{L}i_q - \frac{E_q}{L}
\end{bmatrix} + \frac{1}{C}i_{pv}
\]

\[
g(x) = \begin{bmatrix}
\frac{v_{pv}}{L} \\
0
\end{bmatrix},
\]

\[
u = \begin{bmatrix} K_d \\ K_q \end{bmatrix} \quad \text{and} \quad y = \begin{bmatrix} I_d \\ V_{pv} \end{bmatrix}
\]

In this paper uncertainties are considered in the controller. The PV generation can be depend on solar intensity So that it can considered as a uncertainties and then other uncertainties is the system parameter. The uncertainty is added in the f(x) and the g(x). then the equation for the system is given as,

\[
x = [f(x) + \Delta f(x)] + [g_1(x) + \Delta g_1(x)]u_1 + [g_2(x) + \Delta g_2(x)]u_2
\]

\[
y_1 = h_1(x)
\]

\[
y_2 = h_2(x)
\]

\[
\Delta f(x) = \begin{bmatrix}
\Delta f_1(x) \\
\Delta f_2(x) \\
\Delta f_3(x)
\end{bmatrix}, \quad \Delta g(x) = \begin{bmatrix}
\Delta g_{11}(x) & 0 \\
0 & \Delta g_{22}(x) \\
\Delta g_{31}(x) & \Delta g_{32}(x)
\end{bmatrix}
\]

To match the uncertainties to the PV system model, the relative degree value of the uncertainty \(\Delta f(x)\) should be 2 as it needs to equal to the relative degree of the nominal system which is 2. The relative degree of the uncertainty \(\Delta f(x)\) can be calculated as,

\[
L_{\Delta f}L_{h_1}^{-1}h_1(x) = \Delta f_1
\]

\[
L_{\Delta f}L_{h_2}^{-1}h_2(x) = \Delta f_3
\]

(7)

To match the uncertainty \(\Delta g(x)\) to the normal PV system, the relative degree of \(\Delta g(x)\) should be equal to or greater than the relative degree of the nominal system and will be 2 if following conditions hold,

\[
L_{\Delta g}L_{h_1}^{-1}h_1(x) = \Delta g_{11} \neq 0
\]

\[
L_{\Delta g}L_{h_2}^{-1}h_2(x) = \Delta g_{31} + \Delta g_{32} \neq 0
\]

(8)

In this paper the maximum change in system parameter is considered as 40% and the changes in environmental condition is considered as 60%, then the \(\Delta f(x)\) can be written as,

\[
\Delta f(x) = \begin{bmatrix}
-0.00025 \frac{R}{L}i_d + 0.80 \omega L_i - 0.25 \frac{E_d}{L} \\
-0.38 \omega L_i - 0.048 \frac{R}{L}i_q - 0.25 \frac{E_q}{L} \\
0.15 \frac{1}{C}i_{pv}
\end{bmatrix}
\]
\[
\Delta g(x) = \begin{bmatrix}
0.20 \frac{V_{pv}}{L} & 0 \\
0 & 0.20 \frac{V_{pv}}{L} \\
-0.10 \frac{I_d}{C} & -0.16 \frac{I_q}{C}
\end{bmatrix}
\]

The uncertainty modelling is considered in the controller design, then the robust stabilization is achieved. The partial feedback linearization scheme for the system with uncertainty can be written as,
\[
\dot{Z}_1 = h_1(x) = I_q \\
\dot{Z}_2 = h_2(x) = V_{pv}
\]

The partial feedback linearization scheme for the PV system can be written as,
\[
\dot{Z}_1 = V_1 = 1.38 \alpha I_d - 1.044 \frac{R}{L} I_q = 1.25 \frac{E_q}{L} + 1.20 \frac{V_{pv}}{L} K_q \\
\dot{Z}_2 = V_2 = \frac{1.16}{C} I_{pv} - \frac{1.10}{C} I_d K_d - \frac{1.15}{C} I_q K_q
\]

The above equation (15) can be obtained by using linear control technique. In this paper two PI linear controller are used. Then the non-linear controller output control law equation is,
\[
K_d = 0.86 \frac{L}{V_{pv}} (V_1 + 1.38 \alpha I_d + 1.044 \frac{R}{L} I_q + 1.24 \frac{E_q}{L}) \\
K_q = -0.89 \frac{C}{I_q} (V_2 + 1.18 \frac{I_{pv}}{C} - 1.10 \frac{I_d K_d}{C})
\]

V . STATCOM IN PV SYSTEM

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 powerelectronics voltage-source converter and can act as either a source or sink of reactive AC power to an electricity network. It is a member of the FACTS family of devices. Usually a STATCOM is installed to support electricity networks that have a poor power factor and often poor voltage regulation. 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. 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 voltage at the point of connection, the STATCOM generates reactive current; on the other hand, 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 an SVC, mainly due to the fast switching times provided by the IGBTs of the voltage source converter.

The basic electronic block of the STATCOM is the voltage-source inverter that converts a input dc voltage to a three-phase output voltage at fundamental frequency. These voltages are in phase and coupled with the acsystem through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the STATCOM output voltages allow effective control of active and reactive power exchanges between the STATCOM and the acsystem. The firsttransformer is Y- Y connection and the second transformer is Y- connection. The first transformer is stepdown and the second one is stepup transformer. The IGBT of the proposed STATCOM is interfed to the reference frame and DSOGI-PLL which is used to separate the positivesequence and negativesequence voltages and currents.

Voltage regulation is a measure of change in the voltage magnitude between the sending and receiving end of a component, such as a transmission or distribution line. Voltage regulation describes the ability of a system to provide near constant voltage over a wide range of load conditions. The term may refer to a passive property those results in more or less voltage drop under various load conditions, or to the active intervention with devices for the specific purpose of adjusting voltage. In the modern power systems operate at some standard voltages. In many applications this voltage itself may not be good enough for obtaining the best operating condition for the loads. When the fault occurs then there is a variation in load voltage. The power quality problem such as voltage fluctuation (voltage sag) is take place. At that situation the STATCOM come into operation and compensate the power quality problem. The overall implementation block diagram of proposed system is shown in Figure 5.

Fig 4. Overall structure of STATCOM

Fig 5. Overall implementation block diagram proposed system
VI. SIMULATION RESULTS

The basic PV system is modelled based on the equations in equivalent circuit of the PV cell. In this paper, totally ten panel are made. Each single panel are in the ratings of 4.7A 25.04V 117.07W. It is done by using MATLAB Simulink.

Perturbation & Observation (P&O) MPPT technique are used in this project to extract the maximum power from PV unit under climatic changing condition. In MPPT technique the present value and previous value can be compared and depend upon the value, MPPT technique can increase or decrease the voltage and power.

Boost converter are used to boost up the PV output voltage to synchronize the inverter to the grid by using the MPPT technique, the boost converter output voltage can be made constant under climatic changing condition.

The output waveform of PV unit under normal condition is shown in Fig 9. In this irradiation is considered as 100W/m² and the temperature is 25K

The output waveform of PV unit under climatic changing condition is shown in Fig 10

The output voltage of boost converter after the tracking of the maximum power point using the maximum power point
A. WITHOUT STATCOM

The circuit performance without it is shown here. The circuit breaker used in RL load closes at 0.1s, opens at 0.2s and then closes at 0.3s. The output waveform of load is shown in Fig 12

B. WITH STATCOM

The circuit performance without it is shown here. The circuit breaker used in RL load closes at 0.1s, opens at 0.2s and then closes at 0.3s. The output waveform of load is shown in Fig 14

From the Fig 12, the load voltage and load current as per the CB operation. At the time of 0.1s voltage sag is observed as RL load is switched on. At 0.2s a voltage swell is observed as RL load is switched off. Again at 0.3s sag is observed as RL load is on. Accordingly load current changes

Fig.13 shows the spectrum analysis of the load current of system without the STATCOM. The THD is 11.08%.

The THD is the important factor in the grid connected system. If the THD is high in the system then there is a power quality problem.

Fig.14 shows the load voltage and Load current of the load in power system with the STATCOM. At the instant 0 to 0.1 and 0.2 to 0.3 seconds when the disturbances have occurred the load voltage is remains constant.

The power factor of the load is shown in Fig 15. The voltage and the current of the load is in phase. So that the system will in stable condition.

Fig.15 shows the improved power factor (source voltage and current are in phase) of the system with STATCOM

Fig.15 shows the spectrum analysis of the load current of system without the STATCOM. The THD is 0.48%.
APPENDIX

Table- Parameters of PV panel modelling

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( N_s )</td>
<td>36</td>
</tr>
<tr>
<td>( N_P )</td>
<td>10</td>
</tr>
<tr>
<td>Maximum power</td>
<td>117.7W</td>
</tr>
<tr>
<td>Maximum Voltage</td>
<td>25.04V</td>
</tr>
<tr>
<td>Maximum Current</td>
<td>4.7A</td>
</tr>
<tr>
<td>Short Circuit Current Isc</td>
<td>5A</td>
</tr>
<tr>
<td>Open circuit voltage Voc</td>
<td>29.7V</td>
</tr>
<tr>
<td>Reference Temperature</td>
<td>301.18</td>
</tr>
</tbody>
</table>

VII. CONCLUSION

The utilization of the power from the renewable energy is very important than the production of the power. In this project, stability enhancement of a three-phase grid-connected PV system is done by modelling the uncertainties to ensure the operation of the system at unity power factor. The partial feedback linearization approach is used, and with the designed scheme, only the upper bounds of the PV systems parameters and states need to be known rather than network parameters, system operating points. The resulting scheme enhances the overall stability of a three-phase grid connected PV system, considering admissible network uncertainties. Thus, this stabilization scheme has good stabilization against the PV system parameter variations, irrespective of the network parameters and configuration. Instability in voltage of grid connected PV system reduces efficiency of PV system and quality of voltage. To overcome this problem integration of grid connected PV system with the STATCOM is analysed in this paper. The performance of STATCOM is analysed with various parameters such as sag, swell by inserting the STATCOM into the system the effectively compensates the oscillations in voltage and maintains power quality. The application of STATCOM effectively increases the utilization of PV systems in grid. This control system may extend to other grid connected renewable power system.

REFERENCES