Application of Model Predictive Control in PV-STATCOM for Achieving Faster Response

Sanooja Jaleel[1], Dr. K.N Pavithran[2]

[1]*Student, Department of Electrical and Electronics Engineering, Government Engineering College, Trivandrum, Kerala, India*
[2]*Professor, Department of Electrical and Electronics Engineering, Government Engineering College, Trivandrum, Kerala, India*

Abstract:- *This paper presents the concept of application of Model Predictive Control (MPC) in PV-STATCOM. In this the inverter capacity remaining after real power generation during day time is utilized for improving the power quality of the associated grid by modifying the conventional solar inverter controller so that it can function as a STATCOM and the entire set up is called as PV-STATCOM. This can be used for improving voltage regulation, power factor correction and reduction in Total Harmonic Distortion during day time in the corresponding grid. The conventional MPPT using perturb and observe method is replaced with an algorithm used for Model Predictive Control (MPC) in order to improve the response during fast changing atmospheric conditions. For further improvement in performance, the PI controllers are replaced with the Artificial Neural Network controllers so that the response time is improved. The proposed method is simulated using MATLAB/SIMULINK.*

Key Words: **STATCOM, MPPT method, Model Predictive Control (MPC), Perturb and Observe (P&O), Voltage Source Converter (VSC).**

1. INTRODUCTION

Renewable energy resources are gaining more importance and concern due to the fast depletion of fossil fuels all over the world. Solar energy which is abundant in nature is one of the important renewable energy which is utilized more and more in order to have a sustainable development. Even though the PV- technology is expensive it is getting strong encouragements through various incentive programs globally. As a result of this large scale solar farms are being connected to grid.

The conventional PV-solar inverter systems are facing many challenges. The PV-solar system generates rated real power only during middle hours of day time and sits idle at night, and thus its inverter capacity is underutilized [1].Modification of PV solar inverter as PV-STATCOM is done for voltage compensation, power factor correction and for reducing Total Harmonic Distortion at the point of common coupling in the grid. In this, conventional solar inverter controller is replaced with a STATCOM controller [2].This allows maximum utilization of the expensive PV solar inverter asset. This can also bring additional financial benefits and can also avoid the use of FACTS (Flexible AC Transmission System) devices.

Another major concern in the PV-solar technology is its operating point. The power output from a PV is changing with fast changing atmospheric conditions. Therefore MPPT (Maximum Power Point Tracking) is necessary. The commonly used Perturb and Observe (P&O) method cannot always converge to the true maximum power point. The P&O method is relatively slow, which limits its ability to track transient insolation conditions. To overcome this, the P&O method will be replaced with the Model Predictive Control technique. It reduces the time to achieve maximum power point [3]. For further improvement in performance, the PI controllers are replaced with the Artificial Neural Network controllers so that the response time is improved. The proposed method is simulated using MATLAB/SIMULINK.

2. SYSTEM MODEL

The proposed integrated system is shown in Fig. 1. It consists of a MPPT powered PV module with DC-DC converter, which is directly connected to the inverter. The inverter with its DC side connected to the output from PV module can now act as a STATCOM. In this part each of the components is considered in brief.

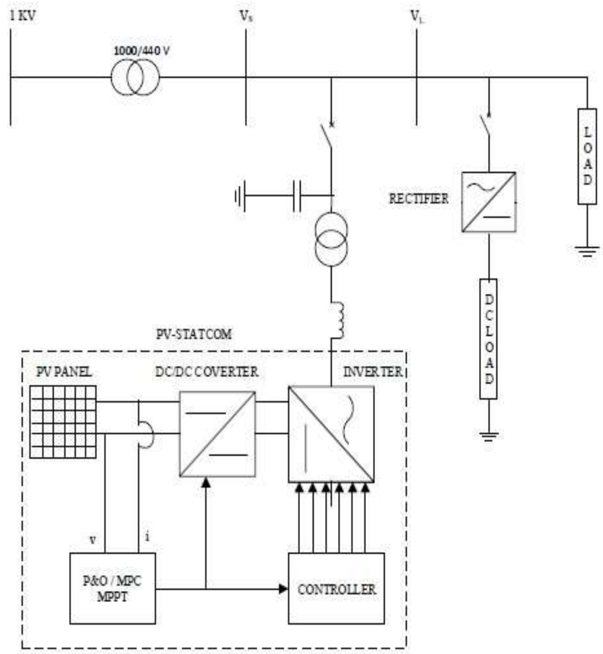

Fig – 1: Integrated system of PV-STATCOM.
Where V_t is the thermal voltage.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 05 Issue: 10 | Oct-2018 www.irjet.net p-ISSN: 2395-0072

2.1 PV Module

Fig.2 shows the equivalent circuit of the ideal photovoltaic cell. The basic equation that describes the I-V characteristic of the ideal photovoltaic cell is:

$$I = I_{pv,cell} - \underbrace{I_{o,cell}\left[exp\left(\frac{qV}{akT}\right) - 1\right]}_{I_d} \qquad (1)$$

where $I_{pv,\,cell}$ is the current generated by the incident light, I_d is the Shockley diode equation, $I_{o,\ cell}$ is the reverse saturation or leakage current of the diode, q is the electron charge [1.60217646 $\cdot 10^{-19}$C], k is the Boltzmann constant whose value is [1.3806503$\cdot 10^{-23}$J/K], T is the temperature of the *p-n* junction, in Kelvin and a is the diode ideality constant [4].

By neglecting the parallel resistance and by knowing the diode current I_d, the output current equation becomes in the form of (2).

$$I = I_{ph} - I_d = I_{ph} - I_o\left(exp\left(\frac{V + IR_s}{V_t}\right) - 1\right) \qquad (2)$$

The PV model is developed and well defined in [4] and finally equation (3) evolves as the main equation of the PV module.

$$I^M = I^M_{SC}\left[1 - exp\left(\frac{V^M - V^M_{OC} + R^M_S \cdot I^M}{V^M_t}\right)\right] \qquad (3)$$

Where I^M_{SC} is the current of short circuited module ($V^{M=0}$) and V^M_{OC} is the voltage of the open circuited module (I^M=0) [2].

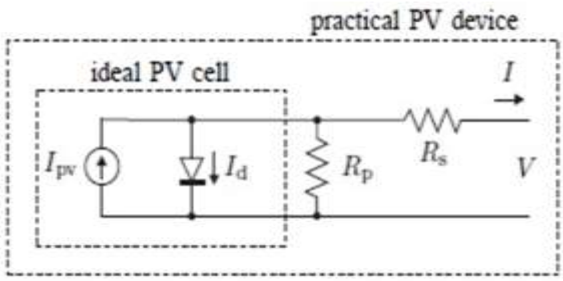

Fig -2: Equivalent circuit of a PV cell

2.2 STATCOM

STATCOM (Static Synchronous Compensator) is a shunt connected FACTS device. It consists of a capacitor at the DC side and a Voltage Source Converter (VSC) and it is connected to the AC side through a shunt transformer as shown in Fig. 3. It is used for voltage compensation, reactive power compensation and power factor correction. It is done by suitably controlling the switches of the VSC to produce an output voltage to be injected into the grid.

Here the PV solar inverter system is modified as STATCOM because of the structural similarity between a STATCOM and the conventional PV solar inverter system. The modified system also has the capabilities of a conventional STATCOM.

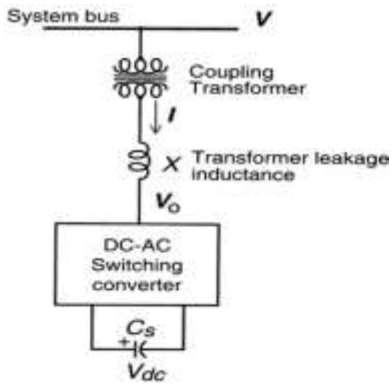

Fig- 3 : Schematic of STATCOM.

3. CONTROL METHODS

3.1 MPPT using Perturb and Observe method.

There are various methods available for Maximum Power Point Tracking. Among them Perturb and Observe (P&O) is the most commonly used method.

Fig. 4 shows the algorithm used for Perturb and Observe method. The algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power ΔP is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If ΔP is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed [5].

The Perturb and Observe method cannot always converge to true maximum power point during fast changing insolation conditions. This is one of the drawback of P&O method and it is relatively slow [3].

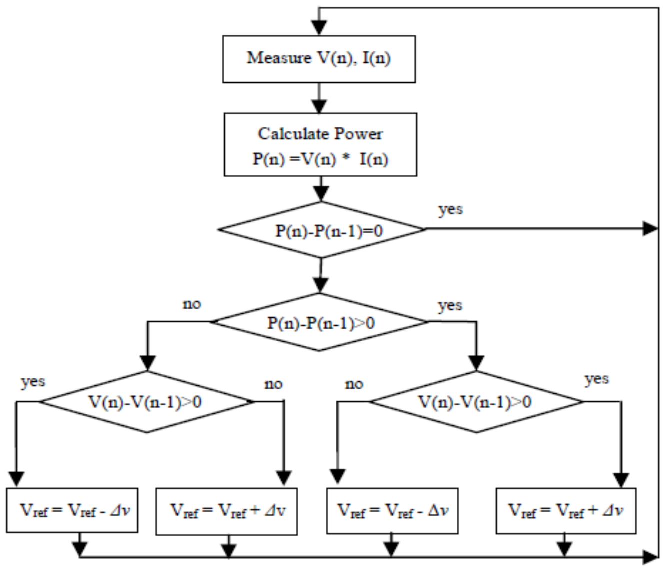

Fig- 4: MPPT using P&O method.

3.2MPPT using Model Predictive Control (MPC)

The Model Predictive Control Technique is used for Maximum Power Point Tracking in this paper to overcome the drawbacks of P&O method. This technique will improve the performance by predicting the error one step ahead in horizon, by using the algorithm given in Fig. 5. This method has faster response than the conventional Perturb and Observe Method [3].

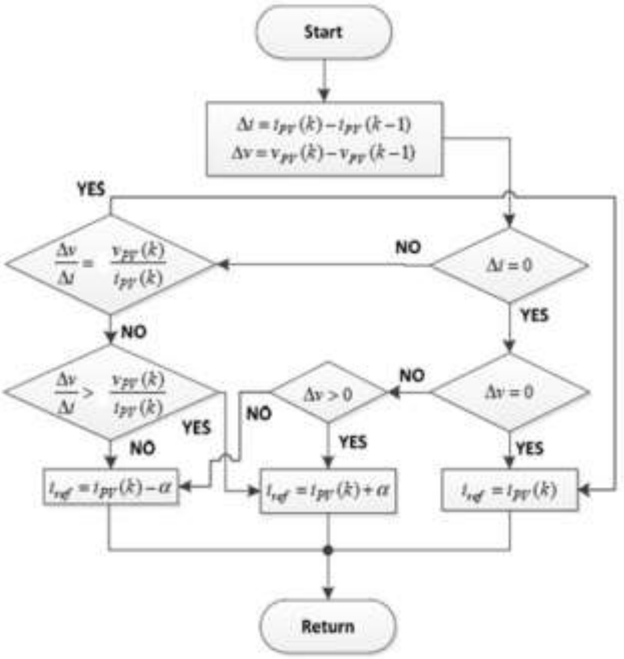

Fig- 5: MPPT using Model Predictive Control.

3.3 Control of PV solar inverter system as PV-STATCOM

The objectives of this controller are voltage compensation, power factor correction and reduction in Total Harmonic Distortion (THD). The controller is developed by using dqo coordinate system. Using abc to dqo transformation given in equation(4) the load current, source voltage and the STATCOM output current are converted into dqo coordinates [2].

$$T_{abc\rightarrow dq} = \frac{2}{3}\begin{bmatrix} sin(\theta) & sin\left(\theta - \frac{2\pi}{3}\right) & sin\left(\theta + \frac{2\pi}{3}\right) \\ cos(\theta) & cos\left(\theta - \frac{2\pi}{3}\right) & cos\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \quad (4)$$

The controller is shown in Fig. 6. Here Θ is extracted by Phase Locked Loop (PLL) from the source voltage and hence voltage has only d component. Current will have both d and q components by considering the phase angle between voltage and current. The in-phase d component is dedicated for regulating DC voltage which is done by active power control. For this the difference between the actual and the reference voltage of the DC side of the inverter is passed through PI controller and the d axis reference current is thus obtained.

The q axis component is perpendicular to the voltage, so it is used for ac voltage and reactive power compensation, but the two controls cannot be done simultaneously.

In reactive power compensation mode, q axis component of load itself represents the reactive power requirement, and injection of this current by STATCOM leads to reactive power compensation. In AC voltage control mode, difference between the voltage at PCC and the reference voltage is passed through the PI controller and the output forms the q axis reference current. Both the reference currents are compared with actual currents of STATCOM and are passed through PI controller. Output in voltage forms are returned to abc coordinates. This will feed a PWM generator to generate the gate signals for the inverter [2].

The conventional PI controller does not work well for nonlinear systems and time varying systems. So in order to improve the performance of the overall system the PI controllers are replaced with Artificial Neural Network Controllers (ANN) at the final stage. This improves the transient response of the overall system.

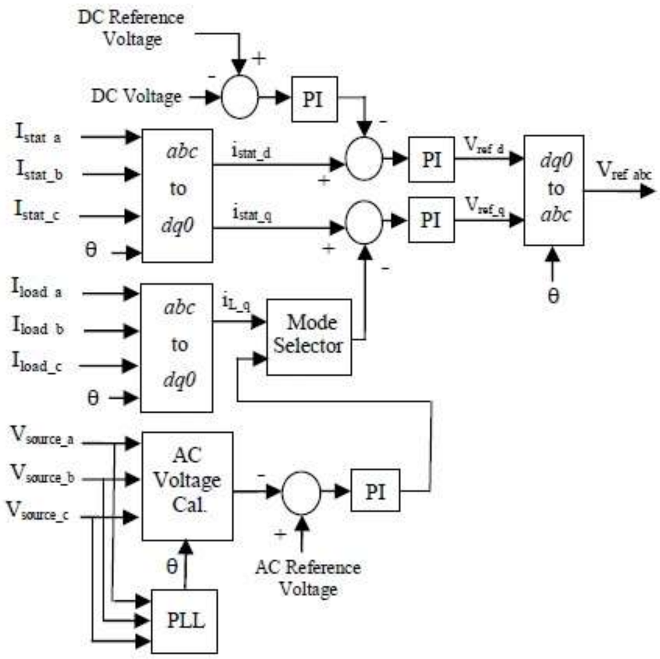

Fig- 6: Control System of PV-STATCOM.

4. SIMULATION RESULTS

To analyze the capacities of the proposed system, a sample system is developed by using the circuit given in Fig. 1 using MATLAB/SIMULINK.

The studies are conducted by keeping the temperature at 25°C and by varying irradiation. A DC rectifier load is connected to the point of common coupling during the time interval of 0.1 to 0.3 seconds. Due to this rectifier load the power quality of the point of common coupling get distorted. In order to analyze the results, the PV-STATCOM module is also connected to the point of common coupling from 0.1 to 0.3 seconds.

4.1 Waveform at the point of common coupling.

Fig. 7 shows the voltage waveform at the point of common coupling during the interval of 0.2 to 0.3 seconds with only rectifier load connected. Here we can see that the voltage at PCC is very much distorted.

Fig. 8 shows the variation of PCC voltage when rectifier and PV-STATCOM module are connected. Here it is seen that the distortion caused by the rectifier load at the PCC voltage is corrected by connecting PV-STATCOM module during the same time.

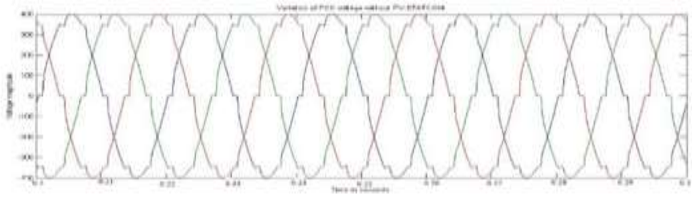

Fig- 7: Variation of PCC voltage when rectifier load is connected.

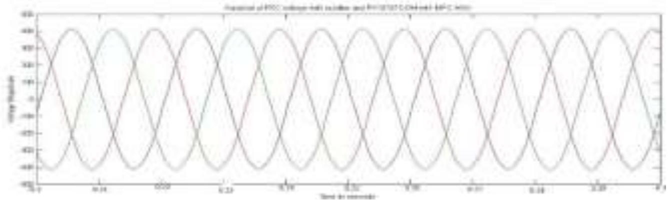

Fig-8: Variation of PCC voltage when rectifier load and PV-STATCOM module are connected.

Similarly Fig. 9 shows the variation of PCC current by connecting the rectifier load during the interval of 0.2 to 0.3 seconds. Fig. 10 shows the corrected waveform of PCC current during the same interval when the PV-STATCOM module is also connected to the PCC.

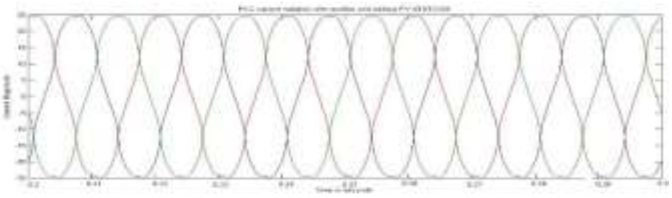

Fig-9: Variation of PCC current when rectifier load is connected

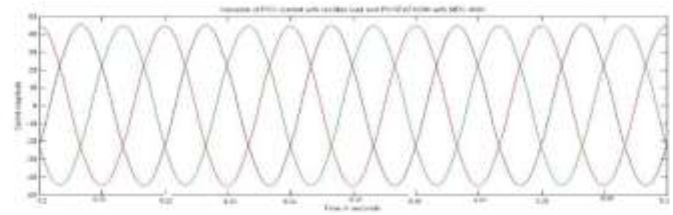

Fig-10: Variation of PCC current when rectifier load and PV-STATCOM module are connected.

4.2 Total Harmonic Distortion

Fig. 11 shows the THD of the current at PCC when the rectifier load is connected and the PV-STATCOM module is not connected. It is seen that the THD of current is around 7.32% and there are considerable amount of 5th, 7th, 11th, 13th order harmonics etc.

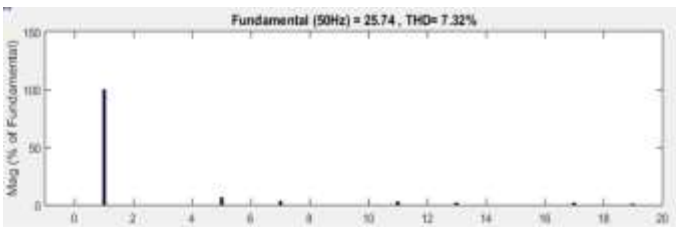

Fig-11: THD of current at PCC when rectifier load is connected.

Fig. 12 shows the THD of current at PCC with rectifier load and also PV-STATCOM. In this case MPPT using conventional P&O method is used. It is seen that the THD of current is reduced to 3.12% and higher order harmonics are eliminated. But here, several inter harmonics are seen. Fig. 13 shows the variation in the THD of current when PV-STATCOM with MPPT using MPC-ANN is used. In this case the THD is further reduced and inter harmonics are not as dominant as in the previous case.

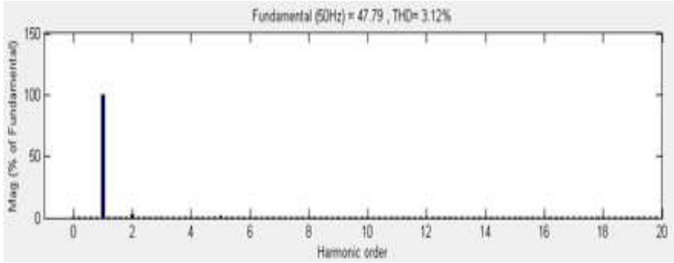

Fig-12: THD of current with rectifier load and PV-STATCOM using P&O are connected.

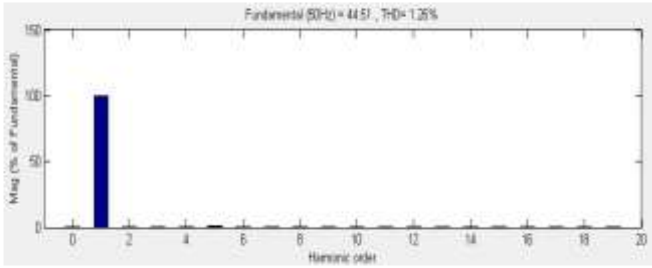

Fig-13: THD of current with rectifier load and PV-STATCOM using MPC with ANN are connected.

Now, THD of voltage at PCC is studied. Fig. 14 shows the THD of voltage at PCC with rectifier load connected and without PV-STATCOM. It is seen that the THD of voltage at PCC is 5.73% with considerable amount of 5th, 7th, 11th and 13th order harmonics.

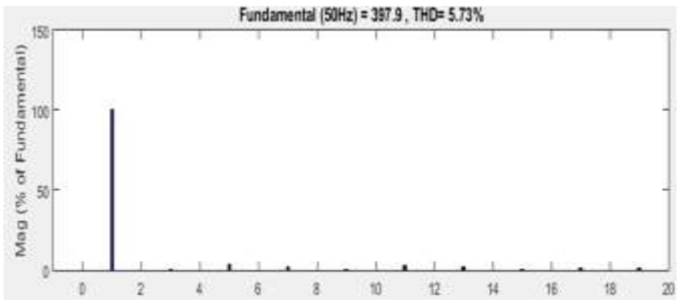

Fig- 14: THD of voltage at PCC when rectifier load is connected.

Fig. 15 shows the THD of voltage with rectifier load and also PV-STATCOM employing P&O is connected. Even though the THD is reduced several inter harmonics are seen. The THD of voltage at PCC is further reduced and inter harmonics are not as pronounced with the use of PV-STATCOM with MPC –ANN as shown in Fig. 16.

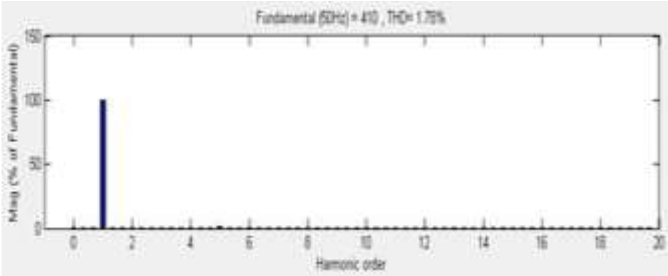

Fig- 15: THD of voltage with rectifier load and PV-STATCOM using P&O are connected.

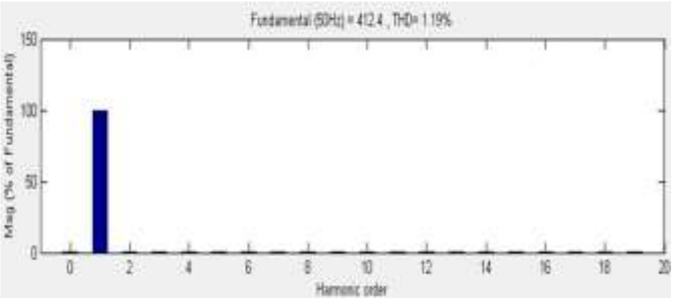

Fig- 16: THD of voltage with rectifier load and PV-STATCOM using MPC with ANN are connected

4.3 Power Factor

Here power factor at the PCC is considered. Fig. 17 shows the power factor at the PCC when rectifier load is only connected from 0.1 to 0.3 seconds. Fig. 18 shows the improvement in power factor when the PV-STATCOM with P&O is connected along with the rectifier load. From Fig. 19 it is clear that the power factor at PCC is further improved by connecting PV-STATCOM using MPC ANN along with the rectifier load.

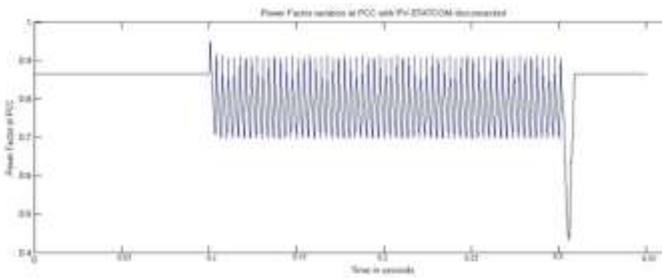

Fig- 17: Power factor at PCC when rectifier load connected and without PV-STATCOM.

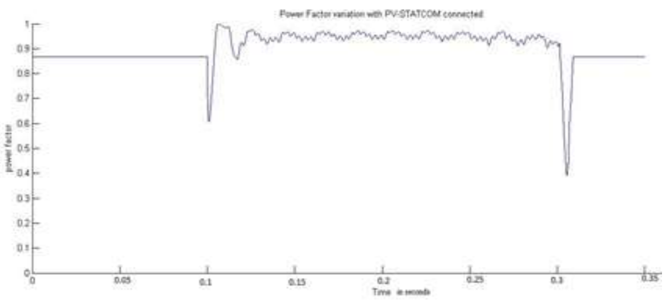

Fig- 18: Power factor at PCC when rectifier load and PV-STATCOM with P&O are connected.

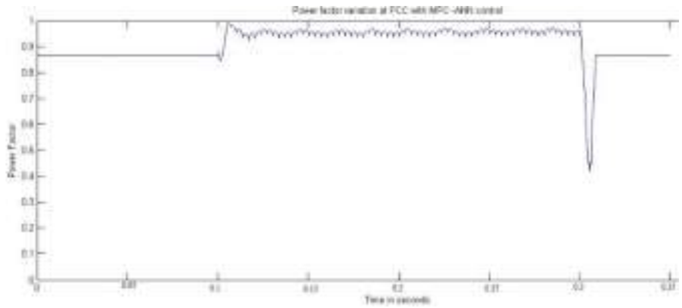

Fig- 19: Power factor at PCC when rectifier load and PV-STATCOM with MPC -ANN are connected.

4.4 Transient Response

Fig. 20 shows the waveform of the current at PCC when rectifier load and PV-STATCOM with P&O are connected from 0.1 to 0.3 seconds. The waveform of the current at PCC when rectifier load and PV-STATCOM with MPC- ANN are connected is shown in Fig. 21.

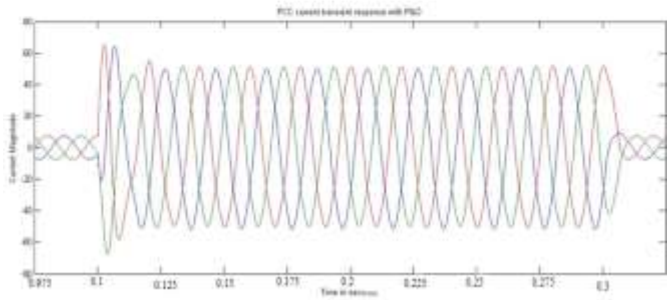

Fig-20: Transient response of current at PCC when rectifier load and PV-STATCOM with P&O are connected.

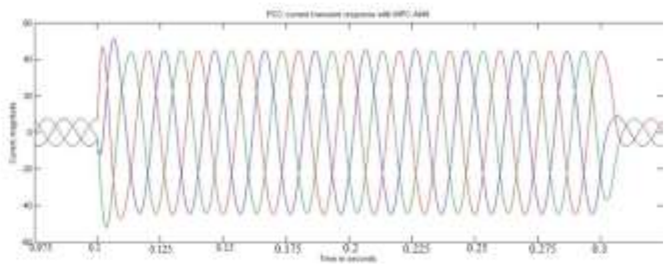

Fig- 21: Transient response of current at PCC when rectifier load and PV-STATCOM with MPC-ANN are connected.

Comparing both it is seen that, when PV-STATCOM using MPC with ANN is connected, the steady state is achieved at a faster rate than PV-STATCOM using P&O.

5. CONCLUSIONS

In this paper the modification of conventional solar inverter as STATCOM was introduced for ensuring maximum utilization of the PV solar inverter asset. By this proposed method the conventional PV solar inverter is able to act as STATCOM. This arrangement provides voltage regulation, reactive power compensation and in turn power factor correction and reduction in Total Harmonic Distortion. Comparison results of P&O and MPC with ANN shows that the latter gives better results in power quality and transient response.

Since the existing inverter itself can act as STATCOM when modified, it brings additional financial benefits to the owners. There is no need of additional FACTS devices. The results of simulation done in MATLAB/SIMULINK verify the above conclusion.

REFERENCES

[1] Rajiv K. Varma, Iurine Axente and Tim Vanderheide, "Optimal utilization of a PV Solar System as STATCOM (PV-STATCOM)in a distribution network". IEEE Power and Energy Society General meeting 2011.

[2] H. Toodeji, N. Farokhnia and G.H. Riahy, "Integration of PV Module and STATCOM to Extract Maximum Power from PV", IEEE Electric Power and Energy Conversion Systems Conference 2009.

[3] Mohammad Shadmand, Robert S. Balog, and Haitham Abu Rub, "Maximum Power Point Tracking using Model Predictive Control of a Flyback Converter for Photovoltaic Applications", IEEE Power and Energy Conference 2014.

[4] M. G. Villalva, J. R. Gazoli, E. Ruppert F, "Modeling And Circuit-Based Simulation Of Photovoltaic Arrays", Brazilian journal of Power Electronics. Vol.14, No.1,2009.

[5] Jaya Shukla, Jyothi Shrivastava, "Analysis of PV Array System with Buck-Boost Converter Using Perturb & Observe Method", International Journal Of Innovative Research In Electrical, Electronics, Instrumentation And Control Engineering Vol. 3, Issue 3, March 2015