International Journal of Smart Electrical Engineering, Vol.6, No.2,Spring 2017
pp. 43:46

ISSN: 2251-9246
EISSN: 2345-6221

Improving the Voltage Profile of the Power System Using PV-STATCOM

Navid Ghardash khani *, Ali Mastan Abadi

Department of Electrical Engineering, Bandar Anzali Branch, Islamic Azad University, Bandar Anzali, Iran, navid_gh@aut.ac.ir
Department of Electrical Engineering, Lahijan Branch, Islamic Azad University, Lahijan, Iran, a.mastanabadi94@stumail.liau.ac.ir

Abstract

This paper presents a novel concept of utilizing the photo voltaic solar farm inverter as STATCOM(Static Compensator), named PV-STATCOM, in order to improve the voltage profile of the power system. The entire STATCOM is able to transmit either active or reactive power into the grid. This system is connected to a 14 BUS IEEE standard grid as a case study to simulate the performance of the system. By decoupling active and reactive power, the inner loop control algorithm is used to trace the active power and the reactive power current separately. Meanwhile, outer loop regulates DC link voltage and grid-connected voltage. The simulation results shows that the photo voltaic system with STATCOM can improve the active power stably, keep grid connected voltage stable, and improve power quality of output voltage and current. Moreover the mathematical modeling of the whole system is verified. The simulation process is validated in MATLAB/SIMLULINK environment.

Keywords: PV(Photo Voltaic), STATCOM(Static Compensator), Facts(Flexible AC Transmission System), VSC(Voltage Source Converter)
Article history: Received 08-NOV-2017; Revised 13-NOV-2017; Accepted 06-DEC-2017.

1. Introduction

Nowadays, Flexible AC Transmission System (FACTS) Controllers are being increasingly considered to increase the available power transfer limits/capacity (ATC) of existing transmission lines [1]-[4]. The FACTS devices have different applications in power system. One of the most useful FACTS devices is STATCOM which is able to inject reactive power to the grid, to improve voltage profile and power factor.[1]

The idea of using PV-STATCOM has been proposed for optimal utilization of the system in [5]. The PV inverter acts as active power provider when the solar energy is available and provides reactive power when the irradiation is low. The concept is validated through simulation studies. In [6], a PV-STATCOM which can operate as a STATCOM throughout the day is presented. Operation of a PV Inverter as STATCOM for 24-h for reactive power compensation and to control the DC link voltage in a distribution utility network is discussed in [7] and [8]. A PV-Active Filter -STATCOM for Harmonic compensation and for the regulation of reactive power for grid applications is proposed in [9]. Voltage flickering, transient voltages and harmonics are the main issues with the power quality of PV generation system. Operation of PV inverter as PV-STATCOM for short duration to improve the stability of voltage sensitive loads during grid faults is presented in [10], In [11], authors presented the PV-STATCOM testing in three stages. In the first stage of testing, RSCAD software is used to test the controller. In stage two, to test the controller and control algorithm, a hardware-in-loop simulation is carried out by interfacing the DSP based controller with Real time digital simulator. System operation is tested on the 10 kW laboratory model in stage three. Presented results explain that the system can be used for voltage control and for correcting the power factor. Steady state response and dynamic response of a PV-STATCOM controller are explained through the hardware-in-loop (HIL) simulation results in [12]. In [13], a PV-STATCOM without a DC-DC converter is proposed. DC link voltage is controlled through STATCOM operation in this system. Eliminating the DC-DC converter resulted in the reduction of cost and size of this system. The impact of Distributed generation systems on the grid and the technical challenges on power quality, protection and stability are discussed [14]. Negative impacts of PV systems on the grid network and a comprehensive review of the power quality improvement i.e. voltage regulation controls and static compensation techniques are presented in [15]. In [16], Authors presented the effects of power quality issues and the issues related to islanding are discussed and presented a brief review of anti-islanding techniques. A PV-STATCOM is simulated to understand the power flow through PV-STATCOM. A load equal to the capacity of PV-STATCOM is connected at the at the AC terminals of the inverter.

In [17], a Sliding mode control based on an extended state observer for the grid-connected converter is presented. DC-link capacitor voltage is regulated by the external control loop. It gives the current references to inner control loop based on the desired power factor. Inner current control loop maintains the actual currents equal to their reference currents. Concepts of extended state observer (ESO), Super-twisting algorithm (STA) are explained briefly. Instead of using a general PI Controller for outer voltage control loop, STA + ESO based control is adopted in this work to reject disturbances and uncertainties. Inner current control loop is based on Super twisting algorithm. From presented results, it is observed that this control is an alternative solution for grid connected inverter controls.

2. Modeling of PV-STATCOM

In this section, the modeling and control system of the VSC is presented. It is connected to PV to control the active and reactive power. Figure 3 illustrates this system [18], [19].

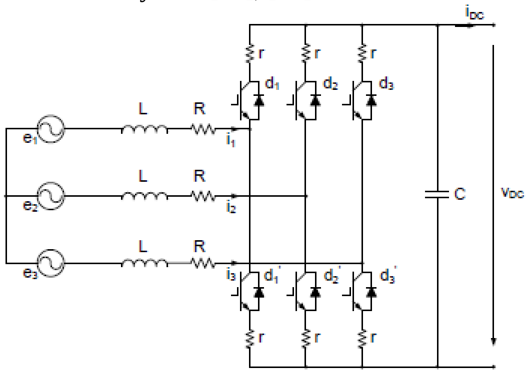

Fig. 1. Model of VSC.

In Figure 1, we have:

$$
\begin{aligned}
L\frac{di_a}{dt}+Ri_a &= V_{ta}-U_a\\
L\frac{di_b}{dt}+Ri_b &= V_{tb}-U_b\\
L\frac{di_c}{dt}+Ri_c &= V_{tc}-U_c
\end{aligned}
\tag{1}
$$

where, V_{ta}, V_{tb} and V_{tc} are the output voltages of the VSC. By using Fourier's series of these periodical voltages, the Equation (1) can be rewritten as follows:

$$
\begin{aligned}
L\frac{di_a}{dt}+Ri_a &= (-U_a+\frac{1}{T_s}\int_{t-T_s}^{T_s}V_{ta}(\tau)d\tau)+\sum_{h=1}^{\infty}\left[a_{ah}\cos(hw_s\tau)+b_{ah}\sin(hw_s\tau)\right]\\
L\frac{di_b}{dt}+Ri_b &= (-U_b+\frac{1}{T_s}\int_{t-T_s}^{T_s}V_{tb}(\tau)d\tau)+\sum_{h=1}^{\infty}\left[a_{bh}\cos(hw_s\tau)+b_{bh}\sin(hw_s\tau)\right]\\
L\frac{di_c}{dt}+Ri_c &= (-U_c+\frac{1}{T_s}\int_{t-T_s}^{T_s}V_{tc}(\tau)d\tau)+\sum_{h=1}^{\infty}\left[a_{ch}\cos(hw_s\tau)+b_{ch}\sin(hw_s\tau)\right]
\end{aligned}
\tag{2}
$$

where, we have:

$$
\begin{aligned}
a_{ih} &= \frac{2}{T_s}\int_{t-T_s}^{T_s}(V_{ti}(\tau)\cos(hw_s\tau)d\tau)\\
b_{ih} &= \frac{2}{T_s}\int_{t-T_s}^{T_s}(V_{ti}(\tau)\sin(hw_s\tau)d\tau)
\end{aligned}
\tag{3}
$$

The Equation (2) is a set of differential equations, has AC and DC responses. Although these two components can be separately analyzed using the superposition law, the AC component is negligible if the switching frequency is too larger than $\frac{R}{L}$. Therefore, Equation (2) can be rewritten as follows:

$$
\begin{aligned}
L\frac{di_a}{dt}+Ri_a &= (-U_a+\frac{1}{T_s}\int_{t-T_s}^{T_s}V_{ta}(\tau)d\tau)\\
L\frac{di_b}{dt}+Ri_b &= (-U_b+\frac{1}{T_s}\int_{t-T_s}^{T_s}V_{tb}(\tau)d\tau)\\
L\frac{di_c}{dt}+Ri_c &= (-U_c+\frac{1}{T_s}\int_{t-T_s}^{T_s}V_{tc}(\tau)d\tau)
\end{aligned}
\tag{4}
$$

For a Sinusoidal PWM, Equation (4) can be rewritten as bellow:

$$L\frac{di_a}{dt}+Ri_a=(-U_a+m_a\frac{V_{dc}}{2})$$
$$L\frac{di_b}{dt}+Ri_b=(-U_b+m_b\frac{V_{dc}}{2}) \quad (5)$$
$$L\frac{di_c}{dt}+Ri_c=(-U_c+m_c\frac{V_{dc}}{2})$$

These equations can be illustrated on Figure 4. In order to achieve appropriate I_d and I_q on the VSC system, a PI controller is used on the control block diagram of this system. Moreover this controller satisfies the zero steady state error in direct and quadrature currents of the VSC. The required direct and quadrature values of reference currents ($I_{q_{ref}}$ & $I_{d_{ref}}$) are calculated as bellow.[20]

$$i_{d_{ref}}(t)=\frac{2}{3}\frac{V_{sd}}{V_{sd}{}^2+V_{sq}{}^2}P_{ref}(t)+\frac{2}{3}\frac{V_{sq}}{V_{sd}{}^2+V_{sq}{}^2}Q_{ref}(t) \quad (6)$$

$$i_{q_{ref}}(t)=\frac{2}{3}\frac{V_{sq}}{V_{sd}{}^2+V_{sq}{}^2}P_{ref}(t)-\frac{2}{3}\frac{V_{sd}}{V_{sd}{}^2+V_{sq}{}^2}Q_{ref}(t) \quad (7)$$

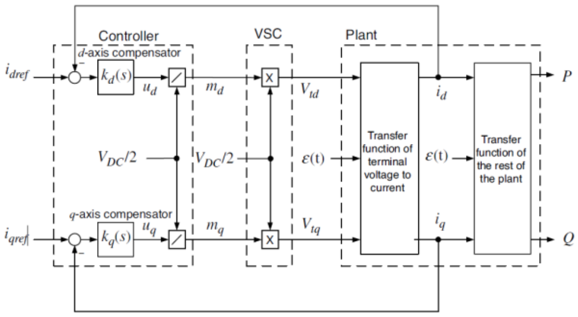

Fig. 2. Block diagram of VSC control system.

3. Simulation Results

In this section we are assumed to simulate the accurate performance of the PV-STATCOM, connected to the grid during the load and voltage variations. Figure 5, illustrates the case study of the simulation. The PV- STATCOM is connected to a 14 Bus standard system through a transformer. The simulation results are presented in the following.

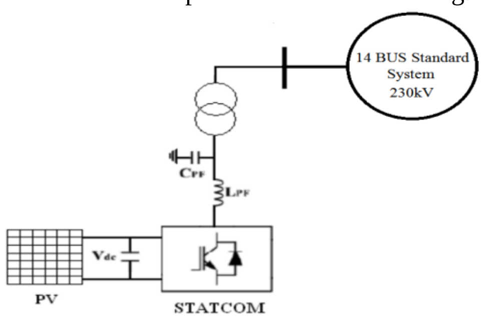

Fig. 3. Schematic of the PV-STATCOM connection to the grid.

Figure 3, illustrates the active power absorbed by the grid via PV-STATCOM. The active power is controlled by controlling of $I_{q_{ref}}$, as discussed before. In this simulation it is assumed at 1 p.u.

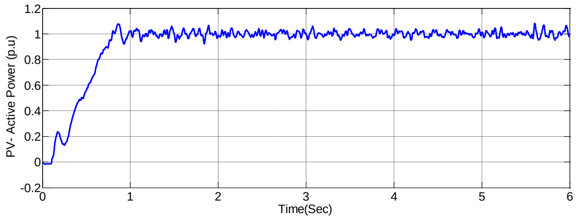

Fig. 4. Active power injected to the grid by PV.

Figures 5 and 6, illustrate the DC link voltage and reactive power delivered to the grid by the PV-STATCOM, respectively. In this simulation the load of the power system increases and decreases $\Delta P=0.52\,pu$ at $t=2\sec$ and $t=4\sec$ respectively. The simulation results show that the PV-STATCOM injected the reactive power to the grid to control the voltage profile of the power system.

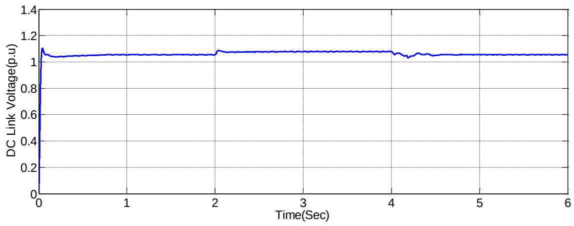

Fig. 5. DC Link Voltage of the PV-STATCOM

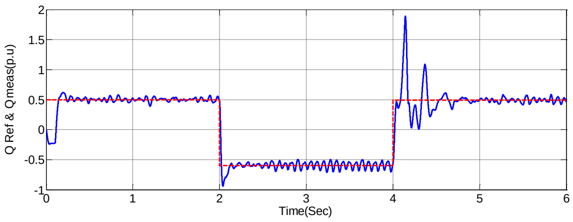

Fig. 6. Reactive power (measured & Ref) of the PV-STATCOM

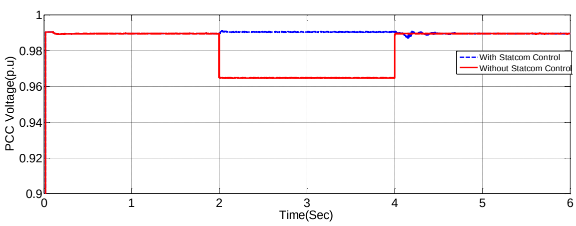

Fig. 7. Voltage of the PCC, with and without of the PV-STATCOM control

In the following, the Bode diagram of the PV-STATCOM is presented and analyzed below. As Figure 8 illustrates, the phase margin of the closed loop system, near 0dB magnitude, is +90 degree which is acceptable [21].

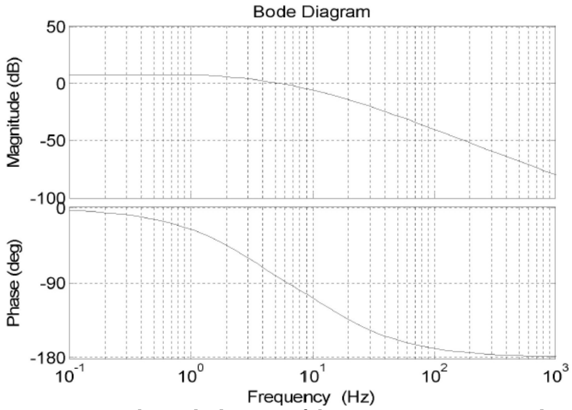

Fig. 8. The Bode diagram of the PV-STATCOM control system.[21]

4. Conclusion

In this paper, a PV-STATCOM control system is analyzed to control the injected active and reactive power to the power system grid. The proposed PV-STATCOM is connected to a 14 BUS, standard grid as the case study. The STATCOM is modeled on the *d-q* frame and the VSC average model is analyzed to apply on simulation process. The proposed system has been analyzed and modeled by MATLAB Simulink software. The simulation results validated that the control system is able to improve the voltage profile of the grid during heavy load changes. Moreover, this system is capable to inject desired active and reactive power to the grid during different conditions. The stability of the system is checked by bode plot phase margin. This application is so useful for large photo voltaic farms connected to the grid to improve power quality of the system.

References

[1] R. M. Mathur and R. K. Varma, "Thyristor-Based FACTS Controllers for Electrical Transmission Systems", New York: Wiley-IEEE Press, 2002.

[2] Shah Arifur Rahman, Rajiv K. Varma and Wayne Litzenberger, “Bibliography of FACTS Applications for Grid Integration of Wind and PV Solar Power Systems: 1995-2010, IEEE Working Group Report”, Paper 2011GM1483, Proc. IEEE PES GM, Detroit, USA, July 2011.

[3] Ying Xiao, Y.H. Song, Chen-Ching Liu, Y.Z. Sun, "Available transfer capability enhancement using FACTS devices," IEEE Transactions on Power Systems, vol.18, no.1, Feb 2003.

[4] Rajiv K. Varma, Shah Arifur Rahman, and Tim Vanderheide, "New Control of PV-Solar Farm as STATCOM(PV-STATCOM) for Increasing Power Transmission Limits During Night and Day", IEEE Transactions on Power Delivery, 2014.

[5] V.sirdhar, S.Umashankar, " A comprehensive review on CHB MLI based PV inverter and feasibility study of CHB MLI based PV-STATCOM ", Renewable and Sustainable Energy Reviews Vol 78, 2017.

[6] Varma RK, Rahman SA, Vanderheide T. , "New control of PV solar farm as STATCOM (PV-STATCOM) for increasing grid power transmission limits during night and day", IEEE Trans Power Delivery ,vol 30,no 2,2003.

[7] Varma RK, Das B, Axente I, Vanderheide T., "Optimal 24-hr utilization of a PV solar system as STATCOM (PV-STATCOM) in a distribution network", Proceedings of IEEE conference publications, 2011.

[8] Varma RK, Rangarajan SS, Axente I, Sharma V., " Novel application of a PV solar plant as STATCOM during night and day in a distribution utility network" , Proceedings of IEEE conference publications, 2011.

[9] Seo Hyo-Ryong, Kim Gyeong-Hun, Jang Seong-Jae, Kim Sang-Yong, Park Sangsoo, Park Minwon, Yu In-Keun. "Harmonics and reactive power compensation method by grid-connected Photovoltaic generation system", Proceedings of IEEE conference publications, 2009.

[10] Varma RK, Rahman SA, Sharma V, Vanderheide T. , "Novel control of a PV solar system as STATCOM (PV-STATCOM) for preventing instability of induction motor load" , Proceedings of IEEE conference publications, 2012.

[11] Varma RK, Siavashi EM, Das B, Sharma V., "Novel application of a PV solar plant as STATCOM (PV-STATCOM) during night and day in a distribution utility networ", Proceedings of IEEE conference publications, 2012.

[12] Varma RK, Siavashi EM, Das B, Sharma V. Real-Time Digital Simulation of a PV solar system as STATCOM (PV-STATCOM) for voltage regulation and power factor correction.", Proceedings of IEEE conference publications, 2011.

[13] Toodeji H, Farokhnia N,Riahy GH. "Integration of PV module and STATCOM to extract maximum power from PV", Proceedings of IEEE conference publications, 2009.

[14] Mahmud N, Zahedi A., "Review of control strategies for voltage regulation of the smart distribution network with high penetration of renewable distributed generation", Renew Sustain Energy Rev 64, 2016.

[15] Kow KW, Wong YW, Rajkumar RK, Rajkumar RK., "A review on performance of artificial intelligence and conventional method in mitigating PV grid-tied related power quality events" , Renew Sustain Energy Rev 46, 2016.

[16] Karimi M, Mokhlis H, Naidu K, Uddin S, Bakar AH. "Photovoltaic penetration issues and impacts in distribution network–A review", Renew Sustain Energy Rev 53, 2016.

[17] Liu J, Vazquez S, Wu L, Marquez A, Gao H, Franquelo LG. , "Extended State Observer-Based Sliding-Mode Control for Three-Phase Power Converters", IEEE Trans Industrial Electron ,vol 64, no 1,2016.

[18] Edward Wilson Kimbarak, "Direct Current Transmission", Volume 1. Wiley Inter science 1971.

[19] Jef Beerten, Ronnie Belmans , "Modeling and control of Multi-terminal VSC HVDC system", Energy Procedia 24 , 2012.

[20] A. Yazdani and R. Iravani, “Voltage-Sourced Converters in Power Systems,” IEEE Wiley, 2010.

[21] Guopeng Zhao, Minxiao Han, and Jinjun Liu, " Analysis and Design of the Interface Inductor and the DC Side Capacitor in a STATCOM with Phase and Amplitude Control Considering the Stability of the System", Journal of Power Electronics, Vol. 12, No. 1, January 2012.