International Journal of Power Electronics and Drive System (IJPEDS)
Vol. 8, No. 3, September 2017, pp. 1408~1415
ISSN: 2088-8694, DOI: 10.11591/ijpeds.v8i3.pp1408-1415

Design and Performance of a PV-STATCOM for Enhancement of Power Quality in Micro Grid Applications

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Article Info

Article history:

Received May 29, 2017
Revised Aug 5, 2017
Accepted Aug 11, 2017

Keyword:

Current harmonics
Power quality (PQ)
PV-stacom
Power factor correction
Reactive power management
Voltage source converter (VSC)
Wind-PV system

ABSTRACT

The Green Energy sources (solar, wind) are performing a vigorous role to reach the electrical power demand. Due to the presence of non-linear loads, reactive loads in the distribution system and the injection of wind power into the grid integrated system results power quality issues like current harmonics, voltage fluctuations, reactive power demand etc. This paper mainly investigates the designing and satisfactory performance evaluation of solar farm as PV-STATCOM (Static Synchronous Compensator) for enhancement of power quality in grid tie system by using MATLAB environment (Simulink). The proportional and integral (PI) Controller and Hysteresis Current Controller (HCC) were effectively utilized to inject the desired current from voltage source converter (VSC) based PV-STATCOM at PCC for the mitigation of quality related problems in the proposed test system.

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1. INTRODUCTION

From the last few decades the major activities (Industrial, Commercial, Domestic, Traction activities) in the nature are interrelated to an electrical energy. Hence the electrical power demand is always more than that of generation. It is also a major research issue for power Engineers. To meet the capital power demand Green energy source (wind, solar) are actively participating in the Grid integrated system [5]. The presence of non-linear or sensitive loads in the power system and injection of renewable energy into already existing Grid system rises the power quality related technical challenges (low PF, current harmonics, voltage variations, etc.). The poor quality electrical power may leads to heavy power losses and also effects on the nation's economy, customer services, productivity, system efficiency and etc. Most of the power quality related technical issues are nullified by Custom power devices (CPD) because ofdue to the fast and active forward steps in their research works of power Engineers on Custom Power Devices (FACTS devices). Among all the Custom power devices the shunt active filter (Statcom) will solve all the current related power quality problems [2], [3]. It is very essential to generate the reference or gate signals for shunt active power filter (PV-Statcom) for its active contribution towards the mitigation of power quality issues in the proposed system [21]. The Statcom is supplied by the Photovoltaic system for the enhancement of the power quality and active power into grid system. The PI Controller and Hysteresis Current Controller (HCC) were effectively utilized to inject the desired current from PV-STATCOM at PCC for the mitigation of quality related problems in the proposed test system. Organization of this article is as follows section-II represents Design Aspects of a Voltage Source Converter based STATCOM and sections III, IV, V demonstrates generation of reference signal, result analysis and conclusions respectively.

2. DESIGN ASPECTS OF A STATCOM FOR POWER QUALITY

This fragment mainly demonstrates the designing of shunt connected active power filter (Statcom) for mitigation of above mentioned power quality related technical challenges and for reactive power management in the grid assimilated proposed system. The Figure 1 represents the schematic arrangement of grid assimilated proposed system for enhancement of power quality. Three phase non-linear loads were fed by 3-phase AC mains and wind-PV systems.

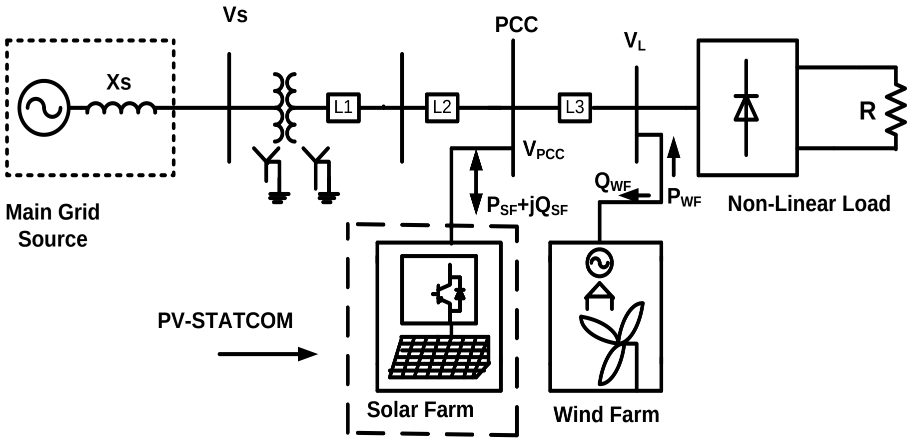

Figure 1. Representation of proposed system for power Quality Enhancement in Micro grid applications

Shunt connected PV-Statcom consists several components like interfacing inductor (L_f), DC bus capacitor ($\boldsymbol{C_{dc}}$), ripple filter components and etc. [2], [7] as shown in Figure 2.(a). The selection and fixation of ratings for these components are very much important for control and design of shunt connected Statcom to give a satisfactory performance in a grid tie system. The ratings fixation or designing specifications of various components of shunt connected Statcom are as follows.

2.1. DC Bus Voltage

The DC bus voltage ($\boldsymbol{V_{dc}}$) is calculated with the help of following expression

$$V_{dc} = \frac{2\sqrt{2}.V_{LL}}{\sqrt{3}.m} \tag{1}$$

Where V_{LL} is AC line output voltage, "m" is modulation index and it is treated as '1'. $\boldsymbol{V_{dc}}$ must be greater than AC mains voltage for successful PWM control of Shunt Active Power Filter (SAPF) [2]. By using Equation 1 for $V_{LL}$of 415V, $\boldsymbol{V_{dc}}$ is 677.69V and is fixed as 750V.

2.2. DC Bus Capacitor

The designing of $\boldsymbol{C_{dc}}$ depends on the nominal DC voltage ($\boldsymbol{V_{dc}}$), minimum voltage level of dc bus (V_{dc1}), Over Loading Factor (a), the phase voltage (V_{ph}), phase currents (I_{ph}) and on time (t) for which DC bus voltage is recovered [2]. DC bus capacitor is designed based on depression in its voltage due to application of loads and rise in dc bus voltage by removal of loads by using law of conservation of energy. The $\boldsymbol{C_{dc}}$ is calculated as

$$\frac{1}{2}C_{dc}\{(V_{dc}^2 - V_{dc1}^2\} = K\{3V_{ph}(aI_{ph})t\} \tag{2}$$

Where "K" is constant varying from 0.05 to 0.15 as [2] for $\boldsymbol{V_{dc}}$ =750V, V_{dc1}=677.69V, V_{ph}=239.60V, I_{ph}=38.95A, t=0.04*sec*, a =1.2 the value of $\boldsymbol{C_{dc}}$ is calculated as $\boldsymbol{C_{dc}}$ =3.905222*mF* and is selected as 5 *mF*.

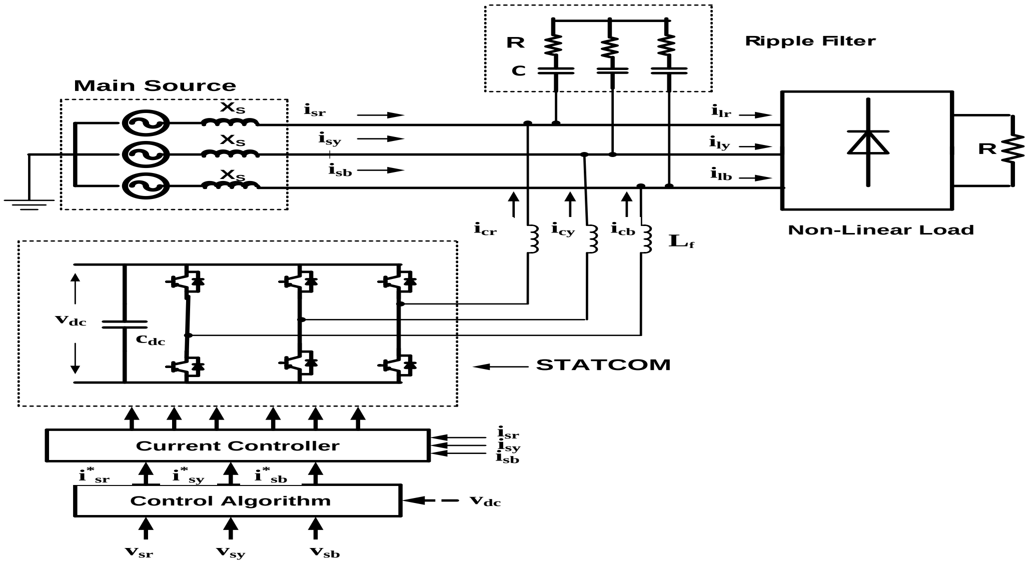

Figure 2 (a). Control of PV-Statcom for Enhancement of Power Quality in Micro Grid System.

2.3. Interfacing Inductor (L_f)

The designing of L_f depends on switching frequency f_s and ripple current i_{crpp}. The interfacing inductor is calculated as

$$L_f = \frac{\sqrt{3}.m.V_{dc}}{12.m.a.f_s.i_{crpp}} \quad (3)$$

For f_s of 5 *kHz*, m=1, V_{dc} =750V, a =1.2,i_{crpp} =8.39*A*. By the Equation (3) the value of interfacing inductance is calculated as 2.15*mH* and is selected value of L_f is 2.25mH.

2.4. Ripple Filter

The series connected capacitors 5*µF* and resistance 5*m*Ω are acting as a ripple filter. It is a first order high pass filter which filters the high frequency noise from the voltage at PCC. It is turned at half of the switching frequency [2]. It offers 636.64 Ohms as impedance at high frequency and 8.09 Ohms at fundamental frequency for considered switching frequency 5 *kHz*.

3. GENERATION OF GATE SIGNALS FOR A PV-STATCOM

It is very essential to generate switching signals for activation of PV-Statcom operation for power quality enhancement. There are several control strategies like *P-Q* control theory (Instantaneous Reactive power theory), I_d-I_q control theory (Synchronous reference frame theory), hysteresis current control strategy, perfect harmonic cancellation (PHC), Fuzzy logic controller and unity PF (UPF) methods are there to generate switching signals for PV-Statcom. In this paper hysteresis current controlled strategy is implemented with assist of unit vector template model as discussed in [1], [3], [9]. The unit vector voltage templates for each phase are calculated as

$$u_{sr} = \frac{V_{sr}}{V_{sm}}, u_{sy} = \frac{V_{sy}}{V_{sm}}, u_{sb} = \frac{V_{sb}}{V_{sm}}. \quad (4)$$

The sampled peak voltage (V_{sm}) is computed with help sinusoidal phase voltages V_{sr} , V_{sy} , V_{sb} as follows

$$V_{sm}=\{\frac{2}{3}(V_{sr}^2+V_{sy}^2+V_{sb}^2)\}^{\frac{1}{2}} \quad (5)$$

Where

$$V_{sr}=V_m\sin(wt)\ V_{sy}=V_m\sin(wt-120)\ V_{sb}=V_m\sin(wt-240) \quad (6)$$

The reference current signals for Statcom are computed with help of the unit vector templates and active current component for each phase as shown Equation 7.

$$i_{sr}^*=I_m.u_{sr}, i_{sy}^*=I_m.u_{sy}, i_{sb}^*=I_m.u_{sb} \quad (7)$$

The active current component (I_m) is computed as

$$I_{m(k)}=I_{m(k-1)}+K_PV_{dc(k)}(V_{err(k)}-V_{err(k-1)})+K_IV_{dc(k)}V_{err(k)} \quad (8)$$

Where "*k*" is sampling instant and V_{err} is dc-link error voltage. K_P is proportional gain and K_I is Integral gain. The Dc-Link error voltage $V_{err(k)}$ at k^{th} sampling instant is computed as

$$V_{err(k)}=V_{dcref(k)}-V_{dc(k)} \quad (9)$$

The reference signals for activation of PV-STATCOM operation are generated with help of the control algorithm and proposed current controller. The reference currents ($i_{sr}^*, i_{sy}^*, i_{sb}^*$) are developed with help of actual and reference voltages [13] [17] in the controlled algorithm as shown in Figure 2.(a). The proportional and integral (PI) Controller and Hysteresis Current Controller (HCC) were generates the reference signals for PV-Statcom by proper utilization of current error from reference currents ($i_{sr}^*, i_{sy}^*, i_{sb}^*$) and actual currents [20]. The given Block diagramin the Figure 2 (b) represents generation of reference or gate signals for activation of PV- Statcom operation for the enhancement of the power quality in micro grid.

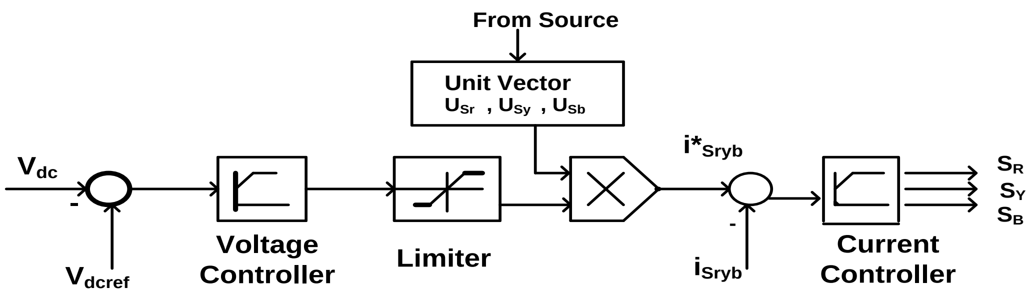

Figure 2 (b). Block diagram representation for reference current signals generation

The switching functions (S_r, S_y, S_b) of Voltage Source Converter (VSC) in PV-Statcom using the proposed current control strategy can be understand clearly from the Figure 3 where HB is hysteresis band. The given Table 1 indicates the required parameters and their specifications for the activeoperation and for enhancement of power quality in the Micro Grid system.

Table 1. Proposed system parameters and their specification

S.No.	Parameter	Specifications
1	Source Voltage	415 V, 50 Hz
2	IGBT Ratings	Collector Voltage=1200 V, I=50 A, Gate Voltage=20 V
3	Solar plant	3.75 kVA
4	Wind Generator	3.35 kVA,415V,50Hz,N=1500 rpm ,P=4,Rr=20 Ω, Lr=0.06 H
5	DC Bus Capacitor	V_{dc}=750 V, V_{dc1}=677.69 *V*, V_{ph}=239.60 *V*,I_{ph}=38.95 *A*, C_{dc} =5*mF*.
6	Interfacing inductor (L_f)	For f_s=5 *kHz*, m=1, V_{dc} =750 V, *a* =1.2, i_{crpp} =8.39*A*. L_f =2.25mH.
7	Ripple filter	C=5*μF* ,R= 5Ω,f_s=5 *kHz*
8	Distorting Load	25kW

SWITCHES

S_R can take either of two values

1	$i_{sr} > (i_{sr}^* - HB) \rightarrow S_R$
0	$i_{sr} < (i_{sr}^* - HB) \rightarrow S_R$

S_y can take either of two values

1	$i_{sy} > (i_{sy}^* - HB) \rightarrow S_y$
0	$i_{sy} < (i_{sy}^* - HB) \rightarrow S_y$

S_b can take either of two values

1	$i_{sb} > (i_{sb}^* - HB) \rightarrow S_b$
0	$i_{sb} < (i_{sb}^* - HB) \rightarrow S_b$

Where 1 = ON ; 0 = OFF

Figure 3. Switching Status for IGBT of PV-Statcom

4. RESULT ANALYSIS

The active performance of a solar farm as static synchronous compensator (PV-STATCOM) in the proposed test system is studied based on the MATLAB/Simulated results as follows. For the better analysis the PV-Statcom is inserted in shunt with the grid system. Similarly the wind energy source and diode rectifier 3 phase non-linear load are also introduced into the system. The proportional (k_p) and integral (k_i) gain values are taken as 2.5 and 1.25 respectively for the generation of reference current signals to activate the operation of PV-Statcom. The PV-Statcom is allowed to operate from 0.1s to 0.2s. The total Matlab simulation time is 0.25s.

The proposed micro grid system is supplied with the balanced 3-phase pure sinusoidal voltage source as indicated in the Figure 4 (a). From Figure 4 it can be observed that from 0.1s to 0.2s the PV-STATCOM is switched ON and the current harmonics due to presence of non-linear loads connected to the grid system are mitigated. Except the time period 0.1s to 0.2s (PV-Statcom is in ON condition) the PV-Statcom is in switched OFF condition so that the current harmonics were polluted the source current from its original nature as shown in Figure 4 (b). For this compensation action Voltage source converter (VSC) based PV-STATCOM injects the require amount of current in the grid system with desired magnitude and phase angle as shown in Figure 4 (d). The wind generator is supplying current of 8.1A in to the grid system without any fluctuations as presented in the Figure 4 (f). The Figure 4 (e) is indicating that the DC bus Capacitor average voltage is maintained as constant voltage as [16] from 0.1s to 0.2s (PV-Statcom ON), which indicates the proper active operation of VSC based shunt active power filter to regulate the voltage at point of common coupling (PCC).

In this paper the proposed micro grid system consists the reactive, nonlinear loads and induction generator. So that the system has reactive power demand nearly 4 kVAr before 0.1 sec and after 0.2 sec (PV-Statcom OFF) and that reactive power is compensated by PV-Statcom in the time period from 0.1sec to 0.2 sec (PV-Statcom ON) as shown in Figure 5 (a). From the Figure 5 (a) it is clearly observed that the main grid source is supplying less than 15 kW real Power to the load and to make the load power constant the PV-Statcom injecting the required amount of real power (nearly 1kW) in the grid system as shown in Figure 5 (b).

The power factor is improved from lagging PF to unity PF in the time period 0.1s to 0.2s (PV-STATCOM is in ON condition) i.e. the reactive power nearly 4 kVAr is successfully compensated by the PV-Statcom. Whereas for uncompensated time periods before 0.1s and after the 0.2s (PV-STATCOM OFF) the power factor is not corrected (Reactive power is not compensated) as shown in Figure 6.

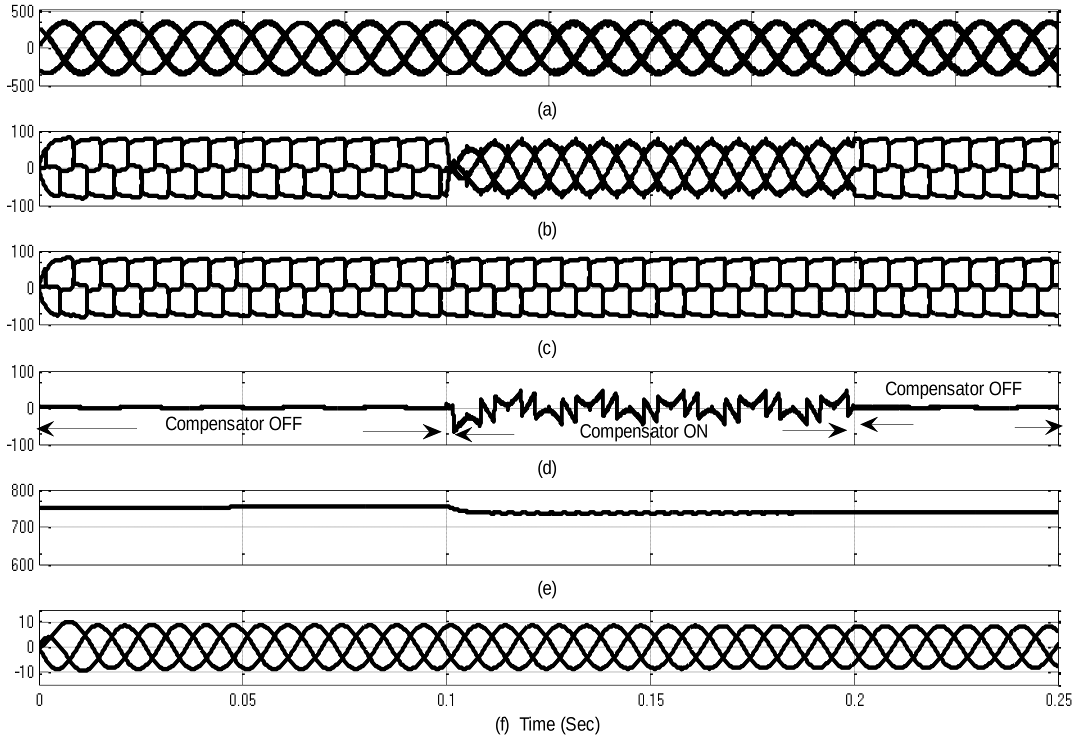

Figure 4. PV-Statcom performance Representation (a) Source Voltage, (b) Source Current, (c) Load Current, (d) PV-Statcom injected Current, (e) DC Bus Capacitor Voltage, (f) Wind Generator Current

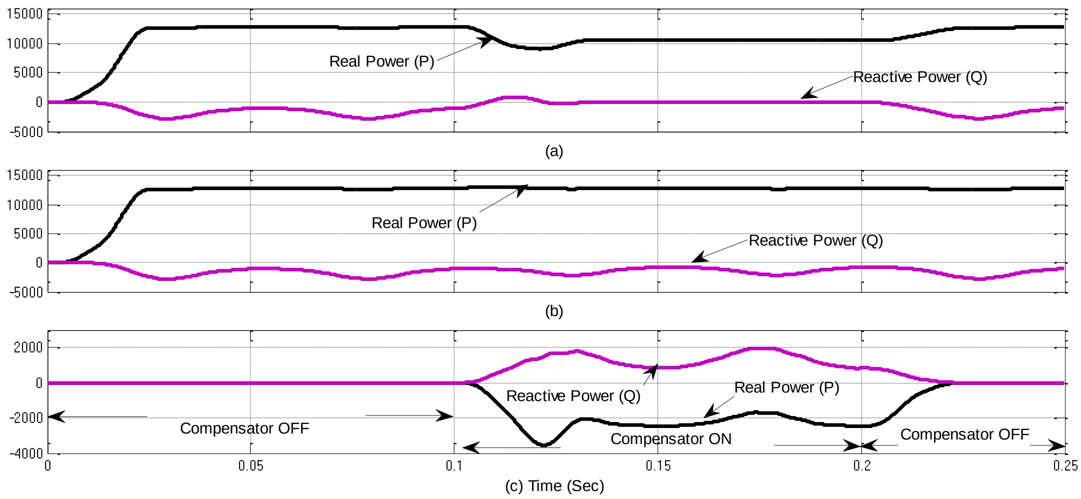

Figure 5. Representation of Active and Reactive power for (a) Source powers (P&Q), (b) Load Powers (P&Q), (c) PV-Statcom Powers (P&Q)

The active current component in Equation 8 is playing an important role in the micro Grid system for the generation of the reference currents (for all phases) with the assist of unit vector voltage templates for the efficient performance of the PV-STATCOM.

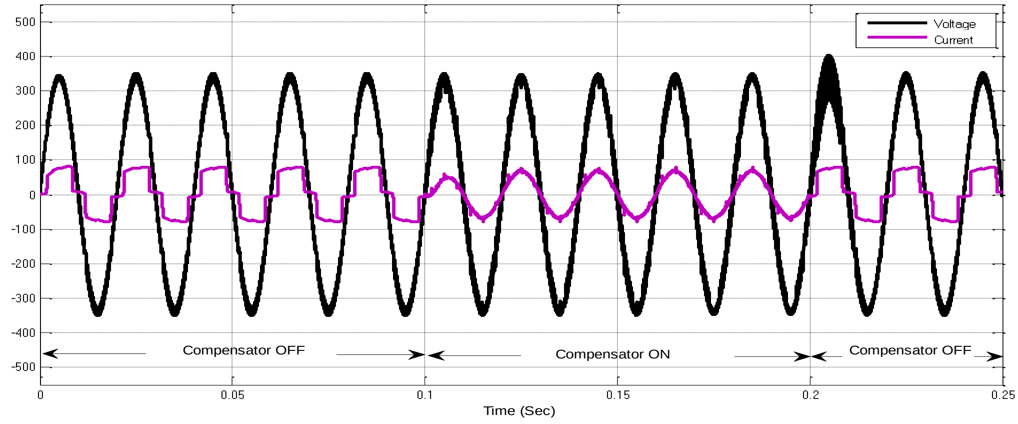

Figure 6. Representation of phage angle relationship between current & Voltage (Unity PF)

The source current and harmonic spectrum of the distorted wave is represented in the Figure 7 and Figure 8. The FFT analyses for this proposed work before compensation action and after the compensation action by PV-Statcom are shown as follows. It is clearly observed that the THD (total Harmonic Distartion) value is reduced from 26.97% to 2.93% (> 5%) which is in IEEE 519 accepted limit.

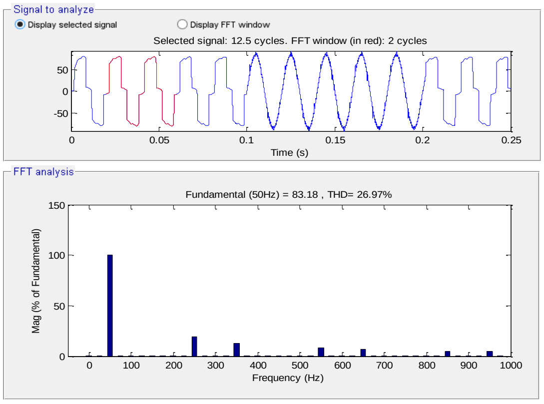

Figure 7. (a) Source Current, (b) FFT analysis without PV- Statcom

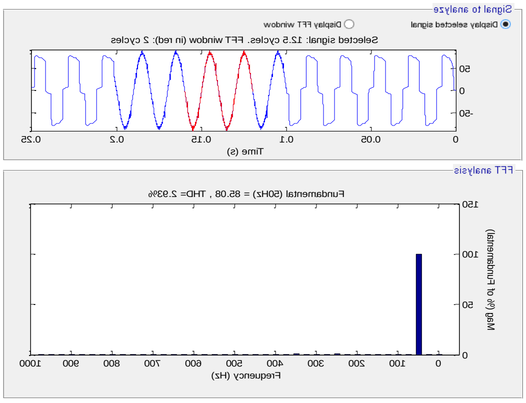

Figure 8. (a) Source Current, (b) FFT analysis with PV-Statcom

5. CONCLUSION

This paper recaps the efficient and effective performance of a Solar Farm as static compensator (PV-STATCOM) for mitigation of power quality issues due to non-linear loads in the grid-tie system. It also reminds the designing aspects of a PV-STATCOM and generation of switching signals with the assist of current control algorithm for active participation of Voltage Source Converter based shunt active filter for power quality magnification in MATLAB/Simulink platform. With active operation of PV-Statcom the harmonics were mitigated in the source current and the reactive power is also compensated.TheVoltage at the PCC is regulated by keeping the capacitor voltage constant, the power factor and Total Harmonic Distortions were improved with help of the proposed compensator.The advanced control strategy gave the best prospect to magnify the utilization factor of the present proposed grid integrated system.

REFERENCES

[1] Sharad W. Mohod, and Mohan V. Aware, “A statcom control scheme for grid connected wind energy system for power quality improvement”, IEEE systems journal, vol. 4, no. 3, SEPTEMBER 2010.

[2] Bhim Singh, Sabha Raj Arya*, “Design and control of a DSTATCOM for power quality improvement using cross correlation function approach”, International Journal of Engineering, Science and Technology Vol. 4, No. 1, 2012, pp. 74-86 .

[3] LakshmanNaikPopavath, K. Palanisamy and D.P. Kothari, “Research and Topology of Shunt Active Filters for Quality of Power”, Information Systems Design and Intelligent Applications, Advances in Intelligent Systems and Computing 433, Springer India 2016.

[4] Munoz Antonio Moreno. Power Quality: Mitigation Technologies in a Distributed Environment, Springer-Verlag, London, 2007.

[5] Lakshman.Naik and K.Palanisamy, “A Dual Operation of PV-Statcom as Active Power Filter and Active Power Injector in Grid Tie Wind-PV System”, International Journal of Renewable Energy Research, Vol.5, No.4, 2015.

[6] Fuchs Ewald F. and Mausoum Mohammad A. S. Power Quality in Power Systems and Electrical Machines, Elsevier Academic Press, London. 2008

[7] Bhim Singh, S. S. Murthy, and Sushma Gupta, Analysis and Design of STATCOM-Based Voltage Regulator for Self-Excited Induction Generators, IEEE transactions on energy conversion, vol. 19, no. 4, December 2004.

[8] Harbin, China.Guizhen Tian, Shengtie Wang, Guangchen Liu Design and Realization of STATCOM for Power Quality Improvement of Wind Turbine with Squirrelcage Induction Generator, 2012 IEEE 7th International Power Electronics and Motion Control Conference - ECCE Asia June 2-5, 2012,

[9] N M. I. Milands, E. R. Cadavai, and F. B. Gonzalez, “Comparison of control strategies forshunt active power filters In three phase four wire system”, IEEE Trans.P ower Electron.,vol. 22, no. 1, pp. 236, Jan. 2007.

[10] Singh Bhim, Jayaprakash P and Kothari D. P. A three-phase four-wire DSTATCOM for power quality improvement, Journal of Power Electronics, vol .8, no. 3, pp. 259-26. 2008.

[11] Ghosh Arindam and Ledwich Gerard, Power Quality Enhancement using Custom Power Devices, Springer International Edition, Delhi, 2009.

[12] Salim Chennai, “Efficient Control Scheme for Fivelevel (NPC) Shunt Active Power Filters Based on Fuzzy Control Approaches”, Periodica Polytechnica Electrical Engineering and Computer Science- DOI: 10.3311/PPee.9015, 60(2), pp. 135-142, 2016.

[13] Z. Chelli, et.al Hysteresis Control for Shunt Active Power Filter under Unbalanced Three-Phase Load ConditionsHindawi Publishing Corporation “Journal of Electrical and Computer Engineering Volume 2015”, Article ID 391040, 9 pages.

[14] Yeison Alberto Garcés Gomez, New Application’s Approach to Unified Power Quality Conditioners for Mitigation of Surge Voltages, “Journal of Electrical and Computer Engineering”, Volume 2016 (2016), Article ID 6384390, 8 pages.

[15] S. Parthasarathy, S. Rahini, “Performance Evaluation of Shunt Active Harmonic Filter Under Different Control Techniques”, International Conference on Circuit, Power and Computing Technologies [ICCPCT], 2015. 978-1-4799-7075-9/15/$31.00 ©2015 IEEE.

[16] R. Balamurugan, R. Nithya, “FC/PV Fed SAF with Fuzzy Logic Control for Power Quality Enhancement”, International Journal of Power Electronics and Drive System (IJPEDS), ISSN: 2088-8694, Vol. 5, No. 4, pp. 470~476April 2015.

[17] Jarupula Somlal, Venu Gopala Rao. Mannam, Narsimha Rao. Vutlapalli, “Power Quality Improvement in Distribution System using ANN Based Shunt Active Power Filter”, International Journal of Power Electronics and Drive System (IJPEDS), ISSN: 2088-8694, Vol. 5, No. 4, pp. 568~575, April 2015.

[18] Mutharasan A, Rajesh R, Rameshkumar T, Dharmaraj M, Chandrasekar P, “Improvement of Wind farm with PMSG using Statcom”, International Journal of Power Electronics and Drive System (IJPEDS), ISSN: 2088-8694, Vol. 7, No. 3pp. 996~1003, September 2016.

[19] A. Naderipour, A. Asuhaimi Mohd Zin, M. H. Habibuddin, M. Mortadi, M. Miveh, H. N. Afrouzi, “A New Compensation Control Strategy for Grid-Connected Wind Turbine and Fuel Cell Inverters in a Microgrid”, International Journal of Power Electronics and Drive System (IJPEDS), ISSN: 2088-8694Vol. 8, No. 1, pp. 272~278, March 2017.

[20] V S Prasadarao K, K V Krishna Rao, “Power Quality Enhancement in Grid Connected PV Systems using High Step up DC-DC Converter”, *Journal homepage: http://iaesjournal.com/online/index.php/IJECE,* International Journal of Electrical and Computer Engineering (IJECE) Vol. 7, No. 2, pp. 720~728 ISSN: 2088-8708, DOI:10.11591/ijece.v7i2.pp720-728. April 2017.

[21] Nabil Elhaj , M. Brahim Sedra, “DFPI-based Control of the DC-bus Voltage and the ACside Current of a Shunt Active Power Filter”, Bulletin of Electrical Engineering and Informatics (BEEI), ISSN: 2302-9285 DOI: 10.11591/eei.v5i4.572 ν 430, pp. 430~441, Vol. 5, No. 4, December 2016.