An Improved Controller for Shunt Active Filter Interfacing PV System and Grid

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***Abstract*— The global warming concerns, diminishing fossil fuels have made it necessary to move towards Renewable Energy Sources (RES) as a future energy solution. As a result of this, Renewable energy resources (RES) connected with distribution systems increases gradually. This paper presents a narrative control strategy for the implementation of a three-phase four wire current-controlled Voltage Source Inverter (CC-VSI) as both power quality improvement and wind energy extraction. For power quality improvement, the inverter works as a shunt active power filter. The output of wind energy source is a DC voltage that determines the DC-bus voltage and the dc-side voltage is controlled by a fuzzy PI controller. The new approach has been illustrated in order to find the best way to reduce network harmonic currents of the connected load. All of the studies have been carried out through dynamic simulation using the MATLAB/Simulink Power System Toolbox.**

***Keywords*— Power Quality, Active Power Filter, Fuzzy PI controller, harmonics compensation .**

I. INTRODUCTION

Increase in demand for power, depletion of conventional energy sources and their effects on environment are making power engineers to look for alternatives for power generation. Power generation through solar [1],[2] is highly popular across the world due to advancement of technology and low installation costs when compared to other sources of renewable energy. Now-a-days, these sources are interconnected with the distribution system. The utilization of these sources indirectly reduces the line losses in the transmission because these sources are installed closely to the utilization point.

With the increase in solar power interconnection with the grid, the power quality becomes a vital issue for power engineers. In order to overcome this power quality issue, voltage source inverters are used to interface the intermittent RES. In [3] an inverter operates as active inductor at a certain frequency to absorb the harmonic current. But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in [4]. In [5], a control strategy for renewable interfacing inverter based on p-q theory is proposed. In this strategy both load and inverter current sensing is required to compensate the load current harmonics. Thus, the Shunt Active filter [6] drains the distorted components of the load currents from the grid in a way that the system current is in phase with the system voltages.

Hence, to improve dynamic behaviour of a SAF and its robustness under range of load variations, the proposed method uses instantaneous p-q theory for reference current generation and fuzzy logic controller for DC voltage control.

II. BASIC CONFIGURATION OF ACTIVE FILTER

Shunt active power filter compensate current harmonics by injecting equal-but-opposite compensating current. In this case the shunt active power filter operates as a current source injecting the harmonic components generated by the load but phase shifted by 180^o. With a suitable control scheme, the active power filter can also compensate the load power factor. The compensation characteristic of the shunt active power filter is shown in Fig. 1.

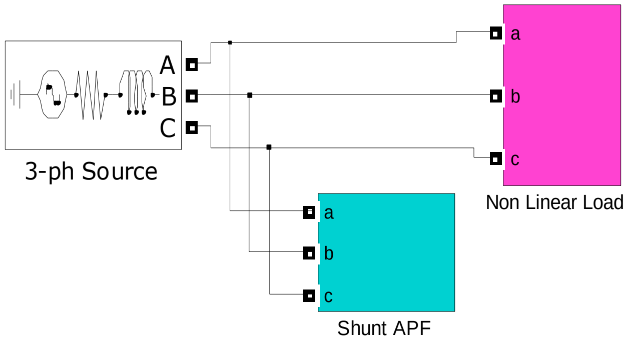

Fig.1. Compensation characteristics of a shunt active power filter

The shunt APF based on Voltage Source Inverter (VSI) is an efficient method to harmonic problems. The performance of an active filter [7],[8] depends mainly on the technique used to compute the reference current and the control method used to inject the desired compensation current into the line.

III.SOLAR INTERFACED SHUNT ACTIVE FILTER CONFIGURATION

The most important objective of the SAF[9] is to compensate harmonic currents. The voltage source inverter is a key element of a DG system as it interfaces the renewable energy source to the grid and delivers the generated power. The power generated from these renewable sources needs power conditioning before connecting on dc-link.

IV.CONTROL OF GRID INTERFACING INVERTER

The regulation of dc-link voltage carries the information regarding the exchange of active power in between renewable source and grid [10]-[13]. The actual dc-link voltage is sensed and passed through a first-order *low pass filter* (LPF) to eliminate the presence of switching ripples on the dc-link voltage. The difference of this filtered dc-link voltage and reference dc-link voltage is given to a fuzzy controller to maintain a constant dc-link voltage under varying generation. Thus the output of dc-link voltage regulator results in an active current. The multiplication of active current component with unity grid voltage vector templates generates the reference grid currents. These reference grid currents are compared with actual grid currents to compute the current errors. These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses for the gate drives of grid-interfacing inverter.

V.REFERENCE CURRENT GENERATION

The reference current has great impact on steady state performance of the SAF. In this scheme, synchronous reference frame theory [SRFT] is used to calculate the reference current. SRFT transforms the three phase voltage and current into stationary reference frame using Park's transformation.

The d-q transformation output depends upon the load currents and the PLL circuit. The PLL provides sinθ and cosθ for synchronization. If AC source currents are I_{sa}, I_{sb}, I_{sc} , load currents are I_{La}, I_{Lb}, I_{Lc} and the filter compensating currents are I_{fa}, I_{fb}, I_{fc} then the load currents are converted into d-q reference frame is shown in the equation (1)

$$\begin{bmatrix} I_d \\ I_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & -\sin\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} I_{La} \\ I_{Lb} \\ I_{Lc} \end{bmatrix} \quad (1)$$

These currents composed of DC component and harmonic component. These d-q currents are passed through LPF which allows only the fundamental frequency component thereby eliminating harmonic component of the load current. Thus the harmonic component obtained using LPF is shown in equation (2).

I_{dh}=I_L-LPF (I_d) I_{qh}=I_L-LPF (I_q)
(2)

The LPF is designed using second order Butterworth filter with a cut off frequency of 75 Hz. The output of the fuzzy controller is subtracted from harmonic component of direct axis in order to eliminate the steady state error. The inverse transformation from d-q to a-b-c is achieved through equation (3).

$$\begin{bmatrix} I^*_{fa} \\ I^*_{fb} \\ I^*_{fc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \sin\theta \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) \end{bmatrix} \begin{bmatrix} I_{dh} \\ I_{qh} \end{bmatrix} \quad (3)$$

Thus, the AC components of d axis and q axis are used for harmonics elimination and reactive power compensation.

VI.IMPLEMENTATION OF FUZZY CONTROLLER

Fuzzy logic controllers (FLCs) [14], [15] are intelligent control systems characterized by a set of linguistic statements based on expert knowledge or experience. Fuzzy logic was first proposed by Lotfi A. Zadeh of the University of California.

A simple FLC consists of four major elements: a fuzzifier, rule base, inference engine and a defuzzifier. The fuzzifier converts real system variables into fuzzy variables. The inference unit provides the necessary connection between the controller input and output fuzzy sets. The rule base expressed in the form of IF-THEN rules is used by the inference unit. The defuzzifier takes the results of fuzzy reasoning and produces a new real control action.

VII. SIMULATION RESULTS AND DISCUSSION

The proposed system not only supplies extracted solar power to the power system, but it also mitigates harmonic currents which are drawn by non-linear loads. In order to demonstrate the validity of the proposed system a simulation is carried out using MATLAB/SIMULINK environment

In this fuzzy controller, Mamdani's Fuzzy Inference Method is adopted. Figure 3 indicates the membership functions are triangle ones having linguistic labels of NB (Negative Large), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium) and PB (Positive Large) because of its simplicity.

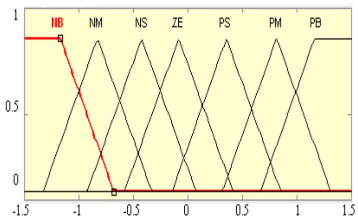

Fig. 3a. Membership Functions for *e*.

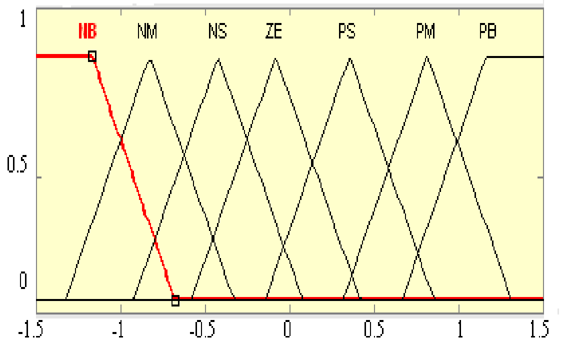

Fig. 3b. Membership Functions for Δ*e*.

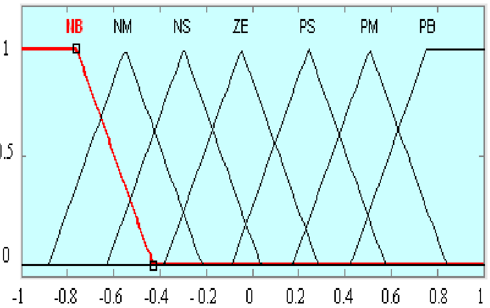

Fig. 3c. Membership Functions for Δu.

Rules form the basis for the fuzzy logic to obtain the fuzzy output. The rule-based form uses linguistic variables as its antecedents and consequents. The antecedents express an inference or the inequality, which should be satisfied. The consequents are those, which we can infer the output.

Table 1 shows the rule base of fuzzy controller with "Vdc" and "Vdc-ref" as inputs. Output variable is change in current. The rule base consists of 49 IF-THEN rules.

TABLE I. RULE BASE OF FUZZY PI CONTROLLER.

Δe/e	**NB**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PB**
NB	NB	NB	NB	NM	NM	NS	ZE
NM	NB	NB	NM	NS	NS	ZE	PS
NS	NB	NM	NS	NS	ZE	PS	PM
ZE	NM	NS	NS	ZE	PS	PS	PM
PS	NM	NS	ZE	PS	PS	PM	PB
PM	NS	ZE	PS	PS	PM	PB	PB
PB	ZE	PS	PM	PM	PB	PB	PB

Before compensation

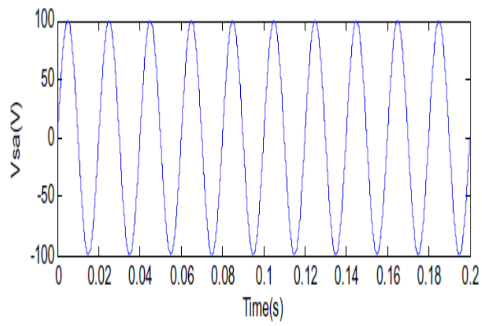

Fig. 4. Source voltage for nonlinear load

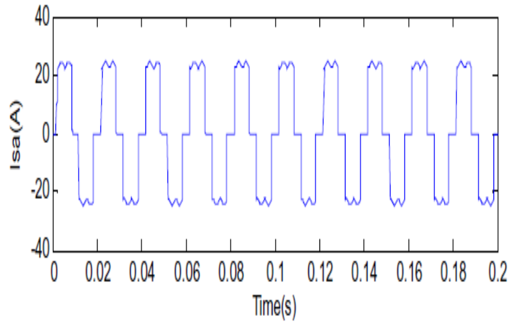

Fig. 5. Source current for nonlinear load

After compensation

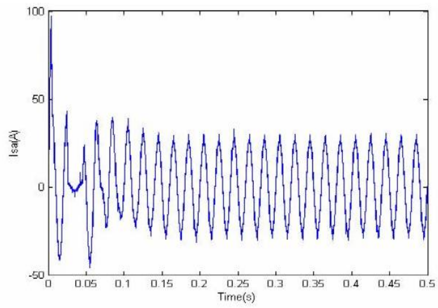

Fig. 6. Source current for nonlinear load

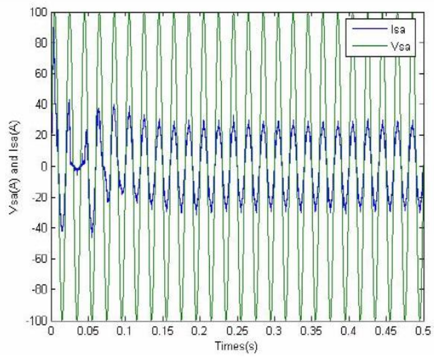

Fig. 7. Voltage and current of Source

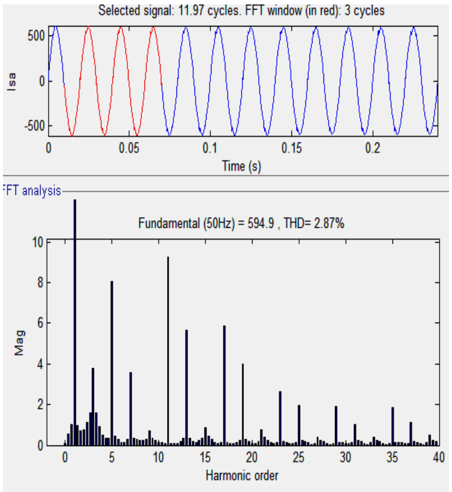

Fig. 8. Harmonic Spectrum of Source Current of SAF with controller

Fig. 4 shows the simulated responses of source voltage and Fig.5 shows the source current waveform before compensation whereas Fig. 6 represents source current after compensation using FLC controller.Fig. 7 shows both source voltage and current are in phase with each other after compensation which indirectly indicates that the harmonics are eliminated and reactive power is compensated to make power factor close to unity. As the source current is becoming sinusoidal after compensation, the power quality is improved. The simulation results show the spectral analysis, performed on the source current after active filtering represented in Fig. 8.

The ASF filter reduces considerably the total harmonic distortion of current, from 27.88% to 2.87% incase of fuzzy controller which is below IEEE standard.

VIII. CONCLUSION

The proposed system couples a solar with shunt active power filter (SAPF). From the results obtained, it is proven that the proposed system, injects surplus power into the mains with harmonic mitigation capability. Thus, the proposed system is an effective tool for bringing green energy for future generations.

References

[1] GWEC, “Global Wind Power Continues Expansion,” Global Wind Energy Council Release, march 4th, 2005.

[2] Z. Chen, E. Spooner, “Wind Turbine Power Converters – A comparative study,” IEE Conference on Power Electronics and Variable Speed Drives, 21-23 September 1998.

[3] U. Borup, F. Blaabjerg, and P. N. Enjeti, “Sharing of nonlinear load in parallel-connected three-phase converters,” *IEEE Trans. Ind. Appl.*,vol. 37, no. 6, pp. 1817–1823, Nov./Dec. 2001.

[4] P. Jintakosonwit, H. Fujita, H. Akagi, and S. Ogasawara, “Implementation and performance of cooperative control of shunt active filters for harmonic damping throughout a power distribution system,” *IEEE Trans. Ind. Appl.*, vol. 39, no. 2, pp. 556–564, Mar./Apr. 2003.

[5] J. P. Pinto, R. Pregitzer, L. F. C. Monteiro, and J. L. Afonso, “3-phase 4-wire shunt active power filter with renewable energy interface,” presented at the Conf. IEEE Rnewable Energy & Power Quality, Seville, Spain, 2007.

[6] Anil Kumar and Jatinder singh “Harmonic Mitigation and Power Quality Improvement using Shunt Active Power Filter,” International Journal of Electrical, Electronics and Mechanical control, Volume 2, Issue 2,.2013.

[7]] Shyamsundar Jena, Rahul Kumar Gupta and Chitti Babu B. “Comparative Study between Different Control Strategies for Shunt Active Power Filter,” 1st National Conference on Power Electronics Systems & Applications, PESA 2013.

[8]] Shilpy Agrawal and Vijay Bhuria “Shunt Active Power Filter for Harmonic Mitigation by using Fuzzy Logic Controller,” International Journal of Advanced Research in Computer Engineering & Technology (IJARCET),Volume 2, Issue 6,2013.

[9] J. Khazaie, D. Nazarpour, M. Farsadi ,M. Khalilian and S. Badkubi, “Shunt hybrid active power filter to alleviate the harmonics of VSC-HVDC in off-shore wind farms,” International Journal on Technical and Physical Problems of Engineering (IJTPE), Iss. 11, Vol. 4, No. 2, Jun. 2012.

[10] Mukhtiar Singh, Vinod Khadkikar, Ambrish Chandra and Rajiv K. Varma , “Grid Interconnection of Renewable Energy Sources at the Distribution Level With Power-Quality Improvement Features,” IEEE TRANSACTIONS ON POWER DELIVERY, VOL. 26, NO. 1, JANUARY 2011

[11] N.Mohana Priyaa and J.Jayashree, “Mitigation of Power Quality Features With the Renewable Energy Sources at the Distribution Level,” INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH & DEVELOPMENT, Vol 2 Issue 2, Ferbruary, *2013*

[12] Saeed nateghi jahromi and Reza Ghandehari, “A Novel and Fast Technique for Harmonic Reduction Based on Wavelet Analysis and Active Filter in Wind Farms,” IRACST – Engineering Science and Technology: An International Journal (ESTIJ), Vol.2, No. 4, August 2012

[13] Hassan Abniki, Mahdi Bashooki and Mohammad Ehsan Kargahi, “A Wavelet Based Technique for DFIG Harmonic Reduction in Frequency Domain Based Model of Power System Using Active Filter,” International Journal of Energy Engineering 2013, 3(4): 209-216.

[14] Dusan Krokavec and Anna Filasovsa “Stabilizing Fuzzy Output Control for a Class of Nonlinear Systems,” Advances in Fuzzy Systems, 2013.

[15] Seyed Mohammad Attaran , Datin Dr. Rubiyah Yusof1 and Dr.Hazlina binti selamat, “Application of the Fuzzy-logic Controller to the New Full Mathematic Dynamic Model of HVAC System,” International Journal of Engineering and Innovative Technology (IJEIT),Volume 2, Issue 11.