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# Integrating Hybrid Wind Solar Energy Source into Distribution Grid with Reduced Harmonics

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**ABSTRACT**
The ever-increasing energy consumption, fossil fuels costs and exhaustible nature and worsening of global environment have created a boom to renewable energy based generation system. Among the renewable energy sources, solar and wind energy are infinite and high potential sources. Thus the fusion of these two energy system is best suited for the reduction of fossil fuel in energy generation. When is connected to grid, it causes power quality problem because of its fluctuating nature. This proposed work describes the methodology for improving power quality of the grid system interfaced with hybrid wind-solar system. The proposed topology is validated through dynamic simulation using the MATLAB/Simulink Power System Toolbox.



## 1. Introduction

Increase in demand for power and depletion of conventional energy sources have made it necessary to move towards the renewable energy sources for power generation. The incursion of RES in distribution systems may entail a threat to network in terms of stability, voltage regulation and power quality issues. Apart from the RES interconnection, the usage of non-linear load may result in harmonics and can cause PQ problem in the power system network. Hence to improve PQ, Active power filters (APF) are used at distribution level.

In general, Voltage source inverters are used for transmitting power from RES to the distribution grid. Since the configuration of VSI used for transmitting power is similar to the active filtering configuration, it is probable to combine both functions in one VSI. In this way, the power converter would be able to improve the system power quality as well as to deliver energy from renewable energy sources.

Many researches have made a research on the control strategies of grid interfaced renewable energy with power quality improvement. Khazaie et al., [6] proposed a Shunt hybrid active power filter to alleviate the harmonics of VSC-HVDC in off-shore wind farms. In this, p-q theory is used for reference current generation. Mukhtiar Singh et al., [7] introduced a novel control strategy for achieving maximum benefits from these grid-interfacing inverters when installed in 3-phase 4-wire distribution systems. N.Mohana Priya et al., [8] proposed an assent controlled voltage source inverter for Mitigation of Power Quality Features with the Renewable Energy Sources at the Distribution Level. In [9], wavelet transform is used as a controller for shunt active filter. Hassan Abniki [10] proposed a wavelet based technique for DFIA harmonic reduction of power system using active filter. M.Archana et al., [11] proposed a Photo Voltaic (PV) system integration to a three phase distribution system. In this work, the existing PV inverter acts as Shunt Active Power Filter (SAPF) that is capable of simultaneously compensating problems like current unbalance, current harmonics and also of injecting the energy generated by renewable energy source.

This work proposed new topology for hybridization the wind and solar power sources along with the improved power quality. This work integrated the features of APF in interfacing renewable sources with grid. Thus, this work proposes and validates an enhanced control Strategy of shunt active filter for hybrid wind and solar system interfaced with the grid.

## 2. Proposed System Description

Figure 1 shows the topology of the proposed system. The AC output voltage from the wind turbine is converted into DC voltage using a rectifier and the output voltage from the Photovoltaic system is connected to a DC-DC converter. This DC-DC converter is used as switch mode regulators to convert unregulated dc voltage to a regulated dc output voltage. The output of the regulator is connected VSI which also operates as shunt active filter to reduce harmonics of the power system.

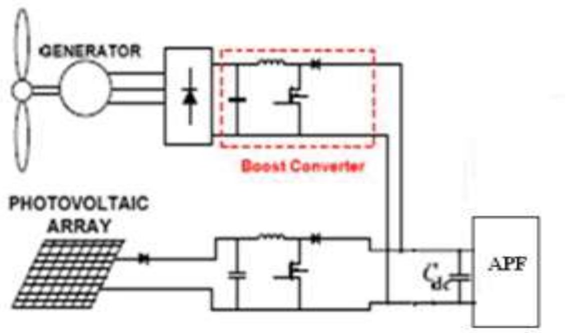


**Figure1. Configuration of proposed topology.**

### 2.1. PV Energy Conversion

The amount of power injected from PV panels is determined by the output voltage of the PV system. The MPPT controls the output voltage of the PV system and is independent on the current control loop and the voltage control loop of the inverter.

The photovoltaic energy source delivers power at variable low voltage. Hence, the generated power needs power conditioning before connected to dc-link. Hence, the output of the PV system is connected to the boost converter which is coupled to dc link capacitor is described in Figure 2.

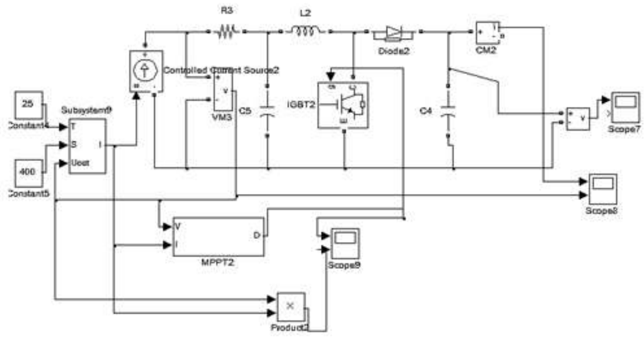


**Figure 2. PV Energy Conversion.**

### 2.2 Wind Energy Power Conversion

The turbine is that the foremost part of wind generation systems. Wind turbines convert it to a mechanical power. This mechanical power is delivered to the rotor of an electrical generator and is reborn to electricity. The induction generator or synchronous generator can be used as an Electrical generator. This wind energy conversion is represented in Figure 3.

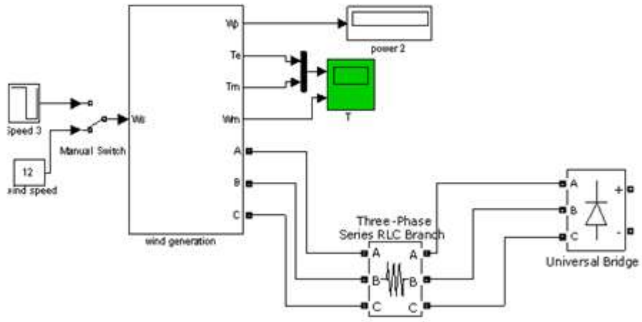


**Figure 3. Wind Energy Conversion**

### 2.3. Inverter Deign

The inverter is a key element of system as it interfaces a renewable energy source to the grid and delivers power [12, 13].

### 2.4. Control Structure

The control structure of the inverter structure, with current control as the inner control loop and the dc-link voltage control as the outer control loop as shown in Figure 4.

The output of the voltage regulator is adjusted to be in phase with the supply phase voltage using a phase locked loop .It is then added to the measured nonlinear load current to extract the reference for the SAF.

### 2.4.1 DC-Link Voltage Balancing

In the operation of APF, APF should correctly trace the reference so that the source current will be free from harmonic. This APF will draw small power from the source to compensate the switching loss and capacitor losses, so the DC voltage of each converter should be balanced. The control structure of the system incorporates fuzzy controllers, to regulate the dc link voltage.

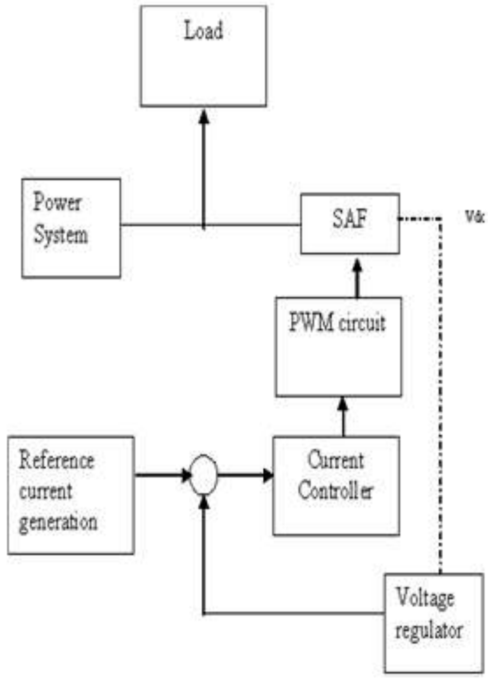


**Figure 4. Control structure of the Shunt Active Filter.**

Mamdani's Fuzzy Inference Method is the fuzzy methodology adopted here. It uses the minimum operator to compute the fuzzy AND for combining the two fuzzified inputs to obtain rule strength. Next process is to select a suitable membership in fuzzy model which gives minimum error and estimated output as per desire standard. Hence, both antecedents and consequent linguistic variables are represented by a triangular membership functions as shown in figure.5.1, 5.2 and 5.3, because of its simplicity.

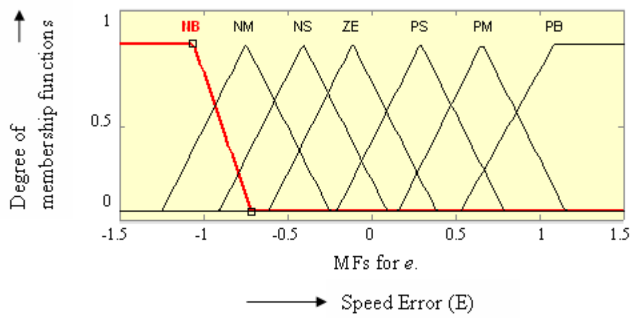


**Figure 5.1. voltage membership function.**

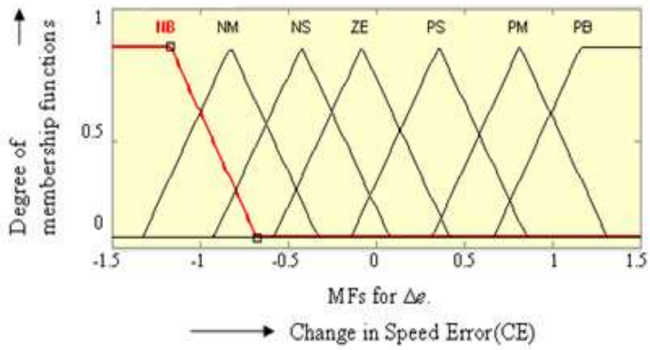


**Figure 5.2. Change in voltage error membership function.**

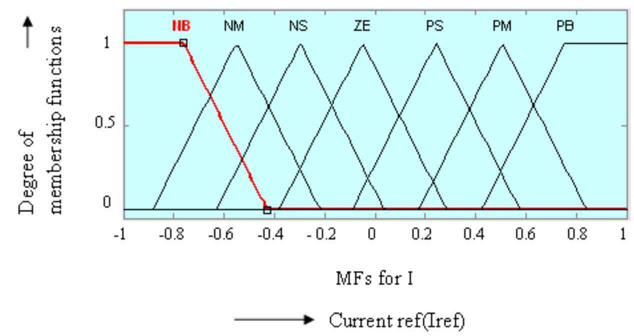


**Figure 5.3. Current reference membership function**

**Table 1. Rule data base.**

| □e/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 |

### 2.4.2 Reference Current Generation

The reference current has great impact on steady state performance of the SAF. In this scheme, 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 block diagram of synchronous reference frame theory is shown Figure 6.

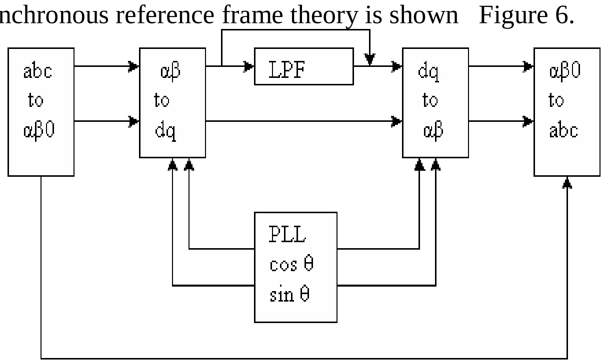


**Figure 6. Block diagram of synchronous reference frame theory**

The output of the d-q transformation 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 are shown in equation (2)

$$I_d = I_{ddc} + I_{dh}, \; I_q = I_{qdc} + I_{qh} \quad (2)$$

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 (3).

$$I_{dh} = I_L - LPF(I_d), \; I_{qh} = I_L - LPF(I_q) \quad (3)$$

The LPF is designed using second order Butterworth filter with a cut off frequency of 75 Hz. The output of the fuzzy PI 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(4).

$$\begin{bmatrix} I^*_{fa} \\ I^*_{fb} \\ I^*_{fc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos\theta & \sin\theta \\ \cos\left(\theta - \frac{2\Pi}{3}\right) & -\sin\left(\theta - \frac{2\Pi}{3}\right) \\ \cos\left(\theta + \frac{2\Pi}{3}\right) & -\sin\left(\theta + \frac{2\Pi}{3}\right) \end{bmatrix} \begin{bmatrix} I_{dh} \\ I_{qh} \end{bmatrix} \quad (4)$$

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

## 3. Simulation Result and Analysis

The test consists of a three phase AC source of voltage 360 V (peak) and 50 Hz frequency to a nonlinear diode rectifier load through a source and line combined reactance of 15mH/Phase. The R-L Load on the DC side of diode rectifier is about 20 ohm and 0.1 mH. The simulation results of the proposed method is shown below.

The Figure 7 shows the single phase voltage and current waveforms of hybrid system with SAF.

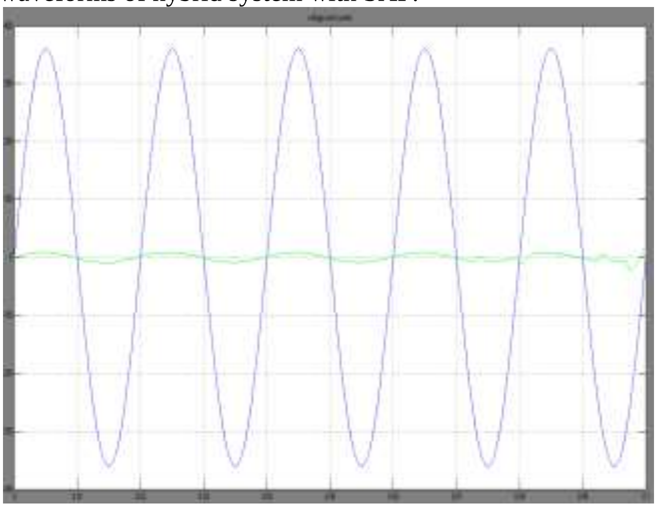

**Figure 7. voltage and current waveforms with SAF**

The THD in source current is about 2.28 as shown in Figure 8.

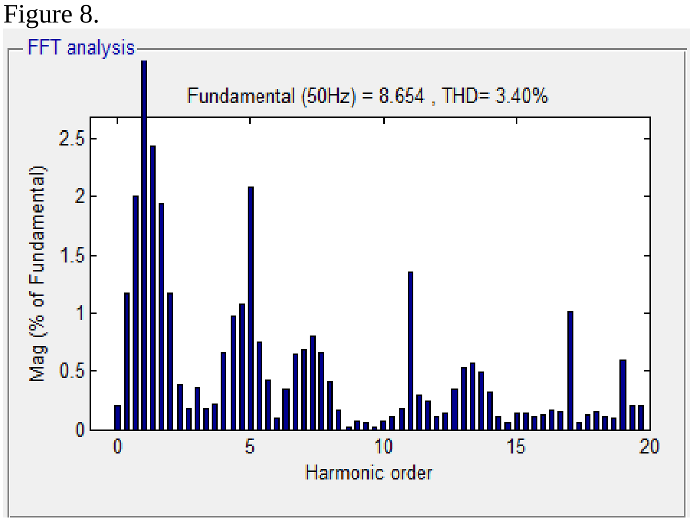


**Figure 8. Harmonic Spectrum of Source Current of SAF .**

Thus, the proposed SAPF successfully injected the power from hybrid system into the grid along with harmonic compensation.

**4. Conclusion**

This work suggested a novel controller for integrating hybrid solar and wind system with the electric grid. From the results obtained, it is proven that the proposed system, injects surplus power into the grid from hybrid system with harmonic mitigation. This approach eliminates the need of additional power conditioning equipment for the improvement of power quality. Thus, the proposed system is an effective tool for bringing green energy for future generations.

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