# Simulation Design and Harmonics Analysis of SPV-Wind Energy-based Hybrid Energy System under Different Nonlinear Load Condition

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**Abstract:** In this paper, a solar PV (SPV) and wind energy-based hybrid power system is design using MATLAB simulation and its harmonics level is analysis by integrating a shunt active power filter (SAPF). The SAPF is designed by using a synchronous reference frame technique for reference current generation, hysteresis current controller technique for switching pulse generation and conventional proportional and integral based DC-link voltage controller. The foremost objective of the proposed research is to design a SPV and wind energy-based hybrid power system using simulation and its power quality, mainly harmonics level is analysis. The analysis is carried out on the simulated results by connecting nonlinear load in the proposed hybrid system.

**Keywords:** Hybrid system, harmonics, MPPT, power quality, SPV

## 1. Introduction

The power crisis is the terribly massive drawback within the present world. The conventional energy sources are restricted and the price is increasing day by day. Also, it is polluting the globe [1]. The present world requires clean, uncontaminated and plentiful accessibility to the energy sources with freed from price. So, the world is moving towards renewable energy sources due to their unavoidable merits. The renewable energy sources are clean, extravagantly available in nature with freed from price [2]. There are different types are renewable sources are available. Some of the renewable energy sources are solar, wind, fuel cell etc [3]. The solar energy is extremely clean, available all over the world with freed from value. It also lowers the carbon footprint and does not emit the greenhouse gases. Nowadays, the solar power system is a great deal to development the effectiveness of the system and it cuts down the price of the materials [4]. New innovative techniques are produced to upgrade the execution and effectiveness of the system and the establishment cost is attenuated. The solar system has to be connected with the power electronic tools to improve again its efficiency. The power electronic tools are used to convert one type of energy into other types of energy with high efficiency. To take out the utmost power from photovoltaic panel, maximum power point tracking (MPPT) system is also used [5].

Among different types of renewable sources of energy, wind energy is the cleanest and the efficient source of energy. The major advantages of wind energy are wind-generated electricity doesn't pollute the water, air or soil. It doesn't contribute towards global warming. It doesn't consume large amount of water needed by other energy sources [6]. It is caused by every day solar radiation. Its supply is abundant unlike solar power during bad weather condition and night time. The price of electricity generation by wind power plant is comparatively lesser than other modes of generation [7]. One of the most efficient wind energy conversion systems is permanent magnet-based wind energy conversion system with fixed pitch angle [8]. First the power generated from the WES and is converter to dc power through diode rectifier which is feed to a boost converter. The boost converter implemented with a MPPT controller optimizes the power of the system. In order to deliver the optimized power to three phase consumers load an inverter can be used at the terminals of boost converter [9]. In case the consumer load increases or wind speed decreases over time, the deficient energy can be delivered by using a battery energy storage system [10].

Active power filter technology is emerged mainly for the need of reducing the harmonics in the power system. In addition to this, the filters are used to compensate the reactive power consumed by the nonlinear loads, load balancing, improving stability of the power system, reducing voltage flickering and neutral current compensation etc [11]. Earlier, passive filters were used and they were the main cause of resonance problem, frequency variations and instability of the system. Active filters overcome the problems of passive filters due to the usage of power electronic components [12]. The shunt active power filter (SAPF) may be connected at Point of Common Coupling (PCC) for the compensation of harmonic currents and voltage sag and swell. Moreover, SAPFs are application is more for compensations of reactive power, and current harmonics both in voltage and current waveform. Many control strategies for generating reference currents were proposed such as instantaneous p-q theory, synchronous detection, active and reactive current, synchronous reference frame (SRF) and sine multiplication are presented in the literature. However, SRF based control strategies for generating reference is simple and easy to implement. Hence, the author has used this scheme in this paper [13]. The authors in [14], have suggested that hysteresis current control (HCC) technique is simple and easy to implement. Hence, this switching scheme has been taken in this paper.

The main objectives of this research are given as follows

- To develop a SPV and wind energy-based hybrid power system in MATLAB/SIMULINK$^R$ environment.
- To develop a proper MPPT and boost converter for the proposed hybrid system.
- To analysis the power quality issues under nonlinear load condition by integrating a SAPF.

The rest of paper is organized as follows. Section 2, modelling of proposed hybrid system with MPPT and boost converter are presented. Section 3, discusses the configurations of the SAPF with its control scheme. In Section 4, harmonics analysis of the proposed hybrid system is presented under nonlinear load condition using a SAPF. The paper ends with a brief conclusion in Section 5.

## 2. Design of hybrid power system

### 2.1 Solar PV system

Sun oriented energy is a decent elective source, in light of its contamination free and plentiful nature for electric force creation. The solar energy is extremely clean, available all over the world with freed from value. It also lowers the carbon footprint and does not emit the greenhouse gases. Nowadays, the solar power system is a great deal to development the effectiveness of the system and it cuts down the price of the materials. The detail design of SPV system is explain in the subsequent sub-section.

#### 2.1.1 Modelling of solar panel

The PV array used in this new system, which is simulated by a model on the basis as given in the literatures [15]. This model represents the PV cell as a current source with a parallel diode and a resistance connected in series as demonstrated in Fig.1. The scientific model of a solar array is represented as in equation (1) which specifies the nonlinear output characteristics of the solar cell.

$$I_{PV} = N_P \times I_{Ph} - N_P \times I_0 \left[\exp\left\{\frac{q \times V_{PV} + I_{PV} R_{se}}{N_S \times AkT}\right\} - 1\right]$$

$$I_{PV} = N_P \times I_{Ph} - N_P \times I_0 \left[\exp\left\{\frac{q \times V_{PV} + I_{PV} R_{se}}{N_S \times AkT}\right\} - 1\right] \quad (1)$$

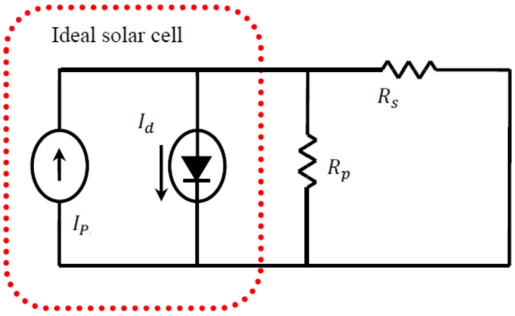



**Figure. 1** SPV equivalent model

#### 2.1.2 MPPT for SPV

The main issue in the PV generation system is that the value of power generated by the solar array is always varying with weather conditions, i.e., the intensity related to the solar radiation. MPPT algorithm having a quick response characteristic is capable of generating electric power at its maximum, in any weather condition is employed to solve the aforementioned problems [16]. Several MPPT algorithms have been reviewed in the literatures. Among them Perturb and Observe (Pe & Ob) technique is frequently used to achieve the maximum power point tracking. (Pe & Ob) assures an easy and fast response to the frequently varying solar irradiance. Hence, (Pe & Ob) is used here as an effective MPPT algorithm to produce maximum energy irrespective of the irradiation level. The flowchart of (Pe & Ob) MPPT is given in Fig.2. In Table.1 the parameters of SPV system are given [17].

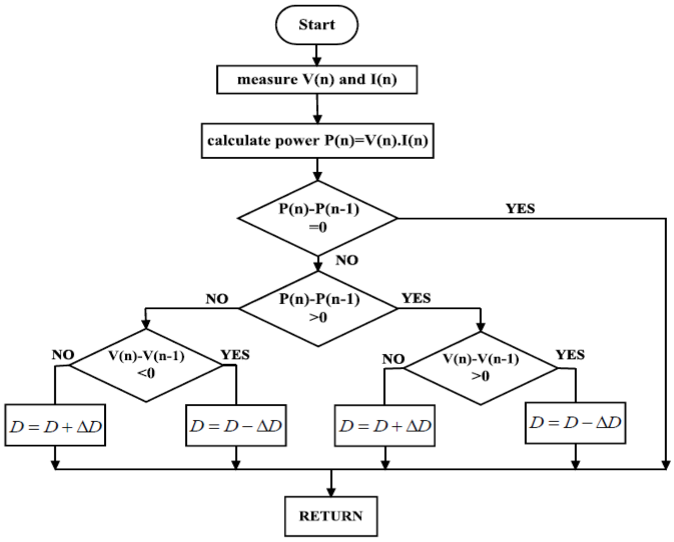



**Figure. 2** Flowchart of Pe & Ob MPPT

**Table .1**

| Different Parameters | Ratings |
|---|---|
| Cells in series ( $N_P$ ) | 72 |
| Cells in parallel ( $N_s$ ) | 01 |
| Short circuit current ($I_{sc}$) | 10.2A |
| Open circuit voltage ($V_{oc}$) | 90.5V |
| Voltage at maximum power ($V_{mp}$) | 81.5V |
| Current at maximum power ($I_{mp}$) | 8.6A |
| Output voltage | 230 V |

**2.1.3 Design of BC**

This is otherwise called as voltage step up converter and used for stepping up the solar array output and thus making the output voltage of level of DC-link capacitor operation. This is shown in the Fig. 3. In addition, boost converter (BC) is useful in tracking maximum power point also. The design of BC (voltage and current calculation) is achieved based on the following parameters [18]. Using the duty ratio *D*, then the output DC voltage is calculated. Fig. 4 shows the detail SPV system with BC and MPPT and its output is presented in Fig.5.

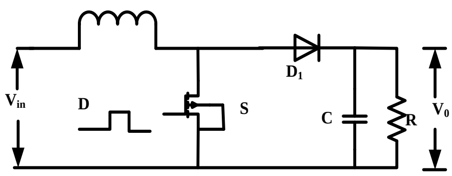



**Figure.** 3 Boost converter

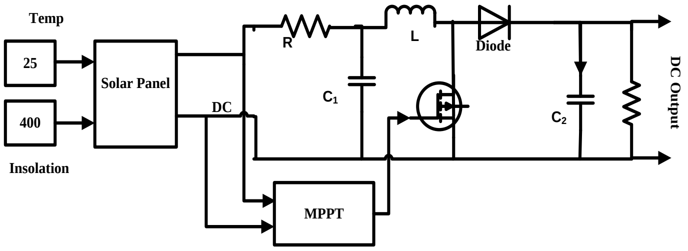



**Figure.** 4 Block diagram of overall SPV system

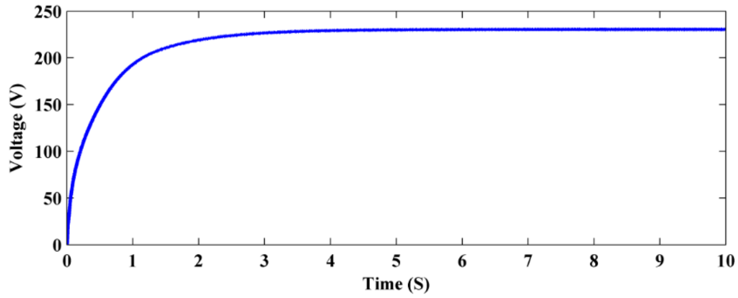



**Figure.** 5 Output voltage of SPV system

**2.2 Modeling of WES**

The wind generator is the second energy source in the construction of the hybrid source. A permanent magnet synchronous generator (PMSG) based wind system is used for generation of wind power. The basic equation foe wind power is given by (2) [19].

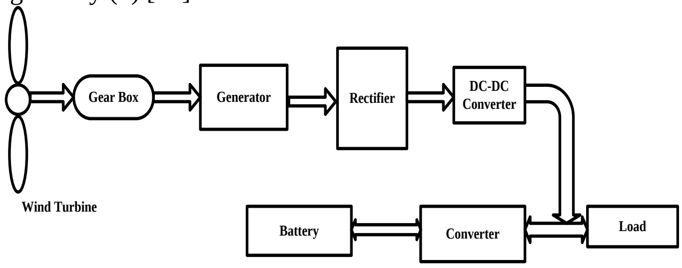



**Fig.6** Wind energy system

$$P_0 = \frac{1}{2}\pi\rho C_P(\lambda,\beta)R^2V^3 \quad (2)$$

Where $P_0$ represents the turbine mechanical power, $\rho$ is the air density, $\lambda$ is the tip-speed ratio, given by $\lambda = \Omega R / V$, $\beta$ is the pitch angle, R is the blade radius-speed of the wind. The wind energy conversion (WEC) system is modelled and developed by using these parameters . The Fig.6 shows the basic wind energy conversion system. The overall Simulink model of the WEC system and its output voltage waveform is presented in Fig.7 and Fig.8 respectively.

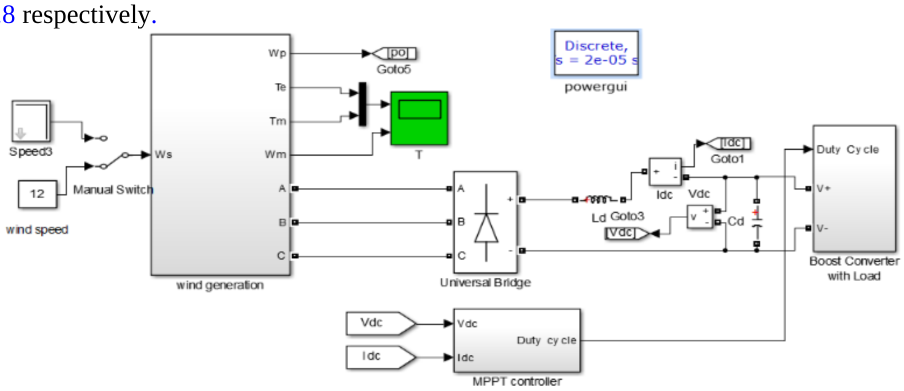



**Fig.7.** Simulink model WES with BC and MPPT

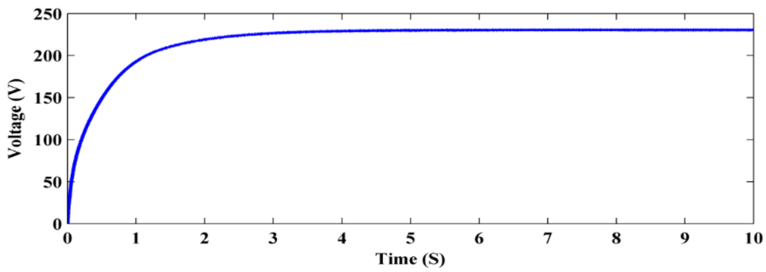



**Fig.8.** DC output voltage of WES

**3. Design of SAPF**

The control action of this SAPF is made to supply/draw a harmonic current to/from the utility, in order to cancel the harmonic currents produced by the nonlinear load along with the reactive power compensation. By doing this, the resulting current drawn from the utility grid is made as sinusoidal, which is free from harmonics. It comprises of three principal components called three phase Voltage source inverter (VSI), DC link capacitor, and an output filter inductor. The block diagram of SAPF is shown in the Fig. 9."

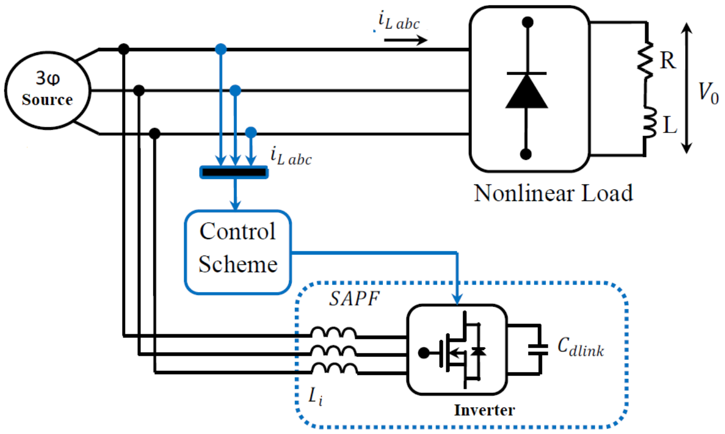



**Figure. 9** Basic structure of SAF

**f.2.2 Voltage Source Inverter**

Six IGBTs are employed with the desired rating. It will control the charging and discharging of DC- link capacitor in such a way to produce the required compensating current( $i_C$ ).Switching operation of this converter is completely depends on the design of control block.

**f.2.2 DC -Link Capacitor**

The reactive power requirement of the load is fulfilled by this capacitor. In general, to maintain constant DC voltage, large size capacitors are selected.

**f.2.2 Output Filter Inductor**

It acts a significant role in connecting the SAPFs to the grid at PCC. It also provides isolation for high frequency components. If the leakage reactance of the coupling transformer is quite high enough, then the filter inductance is provided by the transformer itself. Output filter inductor is otherwise called as smoothing inductor, coupling inductor, and interfacing inductor.

**f.2.2 Control Block**

The control block decides the overall performance of SAPF. It is based on the reference current and the $(V_{DC})$, the control signals for the power switches are produced. The current harmonics are injected into the line depending on the switching operation of the VSI.

To eliminate the harmonics from the source current $(i_S)$, an equal amount of compensating current ( $i_C$ ) is injected by SAPF in opposite phase to that of harmonic current. The equation shows below are the basic equation for understanding SAPF operation.

$$i_s(t) = i_l(t) - i_c(t) \tag{3}$$

$$v_s(t) = V_s \sin \omega t \tag{4}$$

For diode based nonlinear load

$$i_l(t) = i_1 \sin(\omega t + \varphi_1) + \sum_{n=2}^{\infty} i_n \sin(n\omega t + \varphi_n) \tag{5}$$

The compensation current due the filter.

$$i_c(t) = i_l(t) - i_s(t) \tag{6}$$

Hence, for the exact compensation of reactive power and harmonics current, it is essential to determine $i_S(t)$. Where, $i_s(t)$, $i_l(t)$, $i_c(t)$ are the values of source, load and compensating current respectively. Where, $i_1$ and $\varphi_1$ are the amplitude of the fundamental current and its angle with respect to fundamental voltage, $i_n$ and $\varphi_n$ are the amplitude of the n^th current and its angle.

**3.2 Control strategies for SAPF**

**3.2.1 Generation of reference current**

The compensation task has been carried out by implementing different reference current generation techniques, proposed in the literatures in, which includes an instantaneous power theory i.e., (p-q) method, an instantaneous current theory i.e., (d-q) method, direct testing and calculating method, Fourier transform method, sine multiplication theorem, synchronous reference frame (SRF) method. The scheme implemented in this research work is the SRF method [20]. The main reason for selecting this method is that it is very simple and easy to implement.

**SRF method**

Here, the three phase currents in $abc$ coordinates are transformed to $d$ - $q$ coordinate system. The transformed vectors in $d$ - $q$ are given as input to the LPF. The filtered elements are transformed back again to the stationary frame represented in terms of three phase equivalents is shown in the Fig. 10."

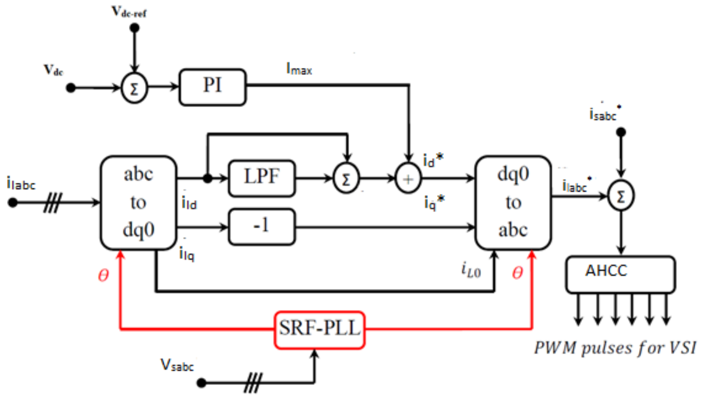



**Figure.10** SRF based control scheme

$$\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix}\begin{bmatrix} i_0 \\ i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \cos(\theta) & \cos(\theta-120) & \cos(\theta+120) \\ \sin(\theta) & \cos(\theta-120) & \cos(\theta+120) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_{lc} \\ i_{lb} \\ i_{la} \end{bmatrix}$$

$$\begin{bmatrix} \cos(\theta) & \cos(\theta-120) & \cos(\theta+120) \\ \sin(\theta) & \cos(\theta-120) & \cos(\theta+120) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_{lc} \\ i_{lb} \\ i_{la} \end{bmatrix} \quad (7)$$

First, the circuit senses the ( $i_{la}$ , $i_{lb}$ and $i_{lc}$ ) and converting into rotating components $i_d$ - $i_q$ as given in equation (11). The components $i_d$ - $i_q$ are representing the rotating reference frame of the $abc$ reference frame. The $i_d$ - $i_q$ currents are passed through an LPF for filtering the harmonic components of the load current, which allow only the fundamental component. Finally, this $i_d$ - $i_q$ current is transformed to three-phase stationary frame using inverse park-transformation technique.

**f.2.2 Generation of switching pulses**

A variety of approaches, are reported in the literature but a hysteresis current controller (HCC) technique has more beneficial for SAPF. The HCC is simple and easy to implement. Hence, the author has implemented this technique.

The detail control method of the HCC is demonstrated in Fig. 11. The switching pattern is derived from the falling and rising current inside the band. The HCC generates the $(i_{sa}^*)$ of preferred magnitude and frequency, which will then be compared with the $(i_{sa})$.

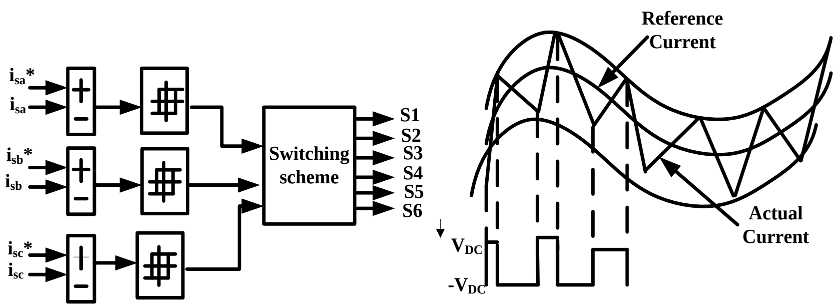


**Figure. 11** HCC switching scheme

**f.2 Voltage regulation**

The main purpose of connecting the SAPF is to inject the $(i_C)$ at PCC, thereby reducing the harmonic content and required reactive power. This paper proposes solar PV based $V_{DC}$ regulation under nonlinear load condition and for a proper comparison, conventional control scheme employing the PI controller is also projected.

**PI controller**

The control of $V_{DC}$ in the SAPF is normally done by the traditional PI controller. Maintaining $V_{DC}$ at a constant level it is important for obtaining the desired compensation performance of the SAPF. This voltage is maintained constant until the active power absorption by the converter is quite good for maintaining its losses. If the magnitude of this active power is decreased to the level of inability of the converter to compensate its losses, $V_{DC}$ will not remain as a constant magnitude. According to Fig.12, the measured $V_{DC}$ is compared with the $(V_{DC.ref})$. The error $(e_n)$ generated is managed by the PI controller with the help of PI gain $K_p$ and $K_i$ respectively.

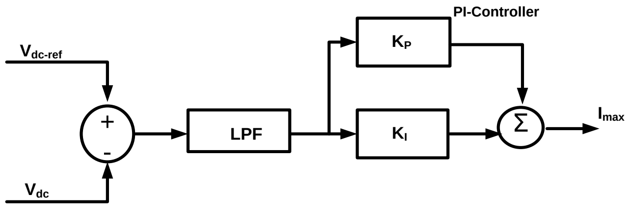



**Figure. 12** PI controller scheme

**f. Result analysis**

The proposed hybrid system with a SAPF is connected at the PCC through filter inductor as displayed in Fig. 13. The modeling of the proposed system is carried out using MATLAB/SIMULINK$^{R}$.

The performance analysis of the considered model is investigated in different cases are explain below.

a) Case 1: Performance analysis under different nonlinear load condition without SAPF
b) Case 2: Performance analysis under different nonlinear load condition with SAPF.

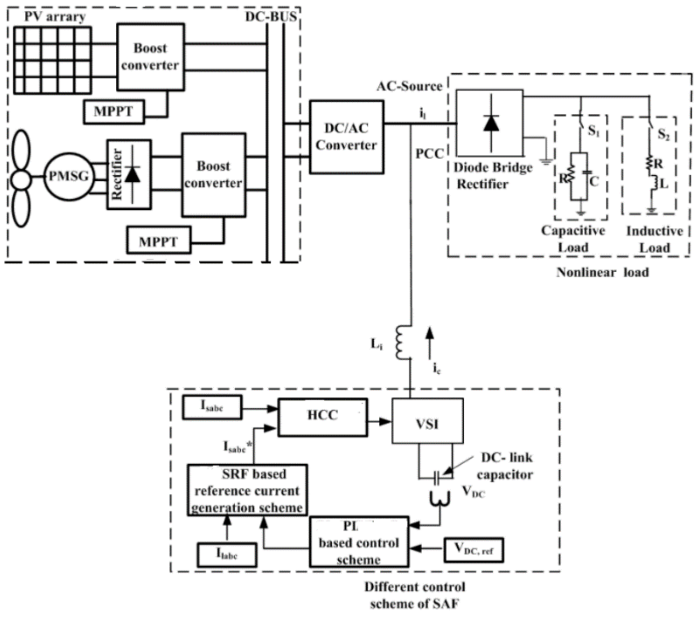
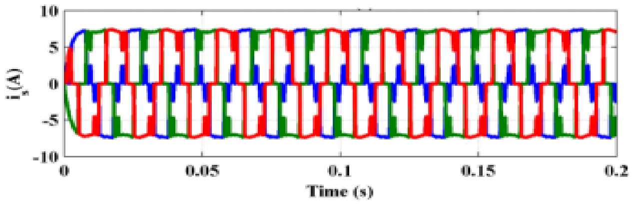


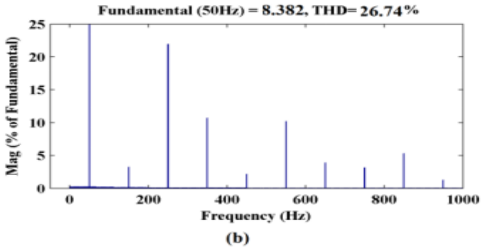

**Figure.13** Block diagram of the Proposed UPQC

**4.1 Performance analysis considering Case 1**

In this case, the hybrid system performance is analyses in the presence of the different nonlinear load (inductive and capacitive type). The different profiles obtain under inductive load are presented in Fig. 14, while in Fig. 15, the profiles under capacitive load are displayed. The profile of $i_S$ shown in Fig. 14(a) and its harmonics content (without SAPF) is revealed in Fig. 14(b). It is viewed from Figs. 14(a) and (b) that the $i_S$ waveform is non-sinusoidal and has very high THD value of 26.74% for inductive load. Similarly, for capacitive load, $i_s$ is also non-sinusoidal and the THD of 20.25% is observed as revealed in Figs. 15(a) and (b), respectively.

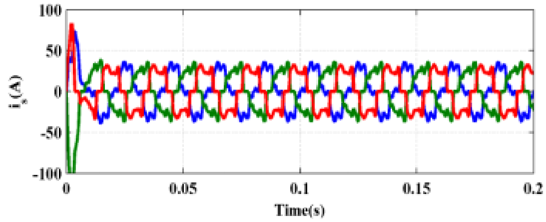



(a)

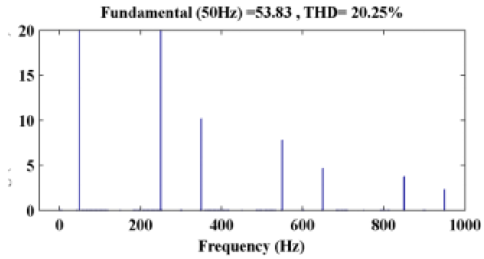



(b)

Fig.14 Harmonics level under inductive load (a) $i_s$ without SAPF (b) THD of $i_s$




(a)



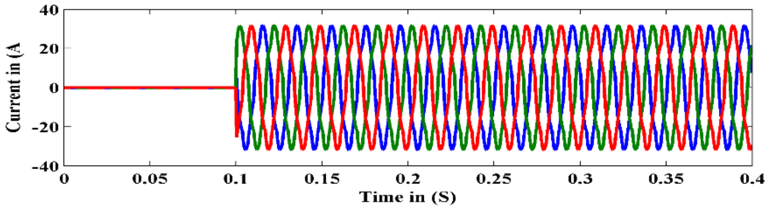

(b)

Fig.15 Harmonics level under capacitive load (a) $i_s$ without SAPF (b) THD of $i_s$

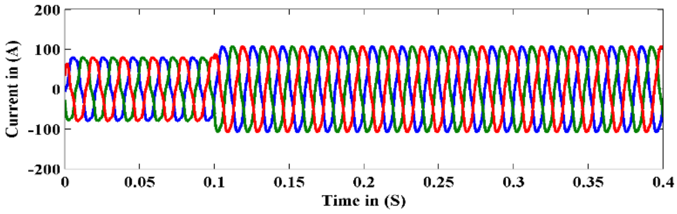
**4.2 Performance analysis considering Case 2**

In order to make source current to be sinusoidal the SAPF (employing SRF scheme with PI controller) is turned on, at t= 0.1s it injects compensating current at the PCC as displayed in Fig.16(a). As a result, THD level comes down to 2.63% as shown in Fig. 16(c) and the source current waveform is nearly sinusoidal after 0.1s as shown in Fig. 16 (b)."

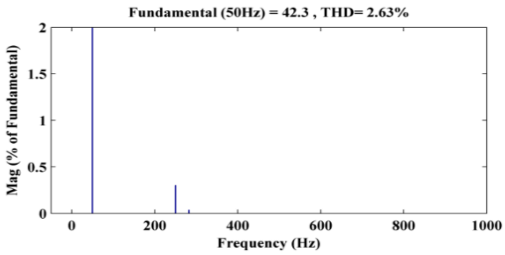
Similarly, for the case of capacitive laod, the corresponding waveforms are shown in Fig.16(d) to Fig. 16(f). In Fig.16(d) the compensating current generated by using the SAPF is shown, which reduces the THD level to 1.8% as displayed in Fig. 16(f). The source current after compensation is shown in Fig. 16 I


Current in (A
Time in (S)

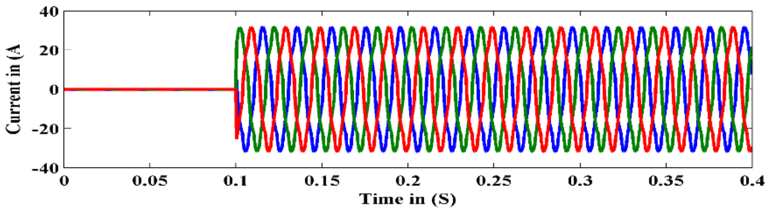
(a)


Current in (A)
Time in (S)

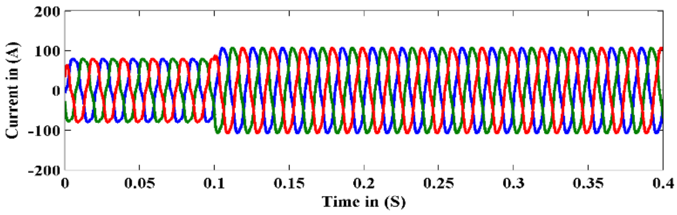
(b)


Fundamental (50Hz) = 42.3 , THD= 2.63%
Mag (% of Fundamental)
Frequency (Hz)

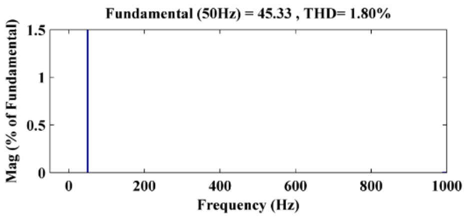
I


Current in (A
Time in (S)

(d)


Current in (A)
Time in (S)

I


Fundamental (50Hz) = 45.33 , THD= 1.80%
Mag (% of Fundamental)
Frequency (Hz)

(f)

Fig.16 Harmonics mitigation (a) $i_c$ injected by SAPF (b) $i_s$ with SAPF (c) THD level after compensation (for inductive case), (d) $i_c$ injected by SAPF I $i_s$ with SAPF (f) THD level after compensation (for capacitive case),

**5. Conclusion**

In this work, harmonics problems of a hybrid power system is investigated by ingratiating a SAPF under different loading condition. It is observed from the results obtained from series of simulation-based experiments that the proposed SAPF performs exceptionally well in mitigating the harmonics under load different loading condition. From the numerical comparison of results, it is evidently noticeable that the SAPF can able to reduce the source current harmonics about 2.63% and1.80% under inductive and capacitive load respectively. Investigations may be made to use the hybrid filter and to design its control loop in order to improve the power quality of the system in various aspects.

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