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Conservation of Power Quality in Micro Grid Using Photovoltaic Interfaced Shunt Active Power Filter

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Abstract: This paper leads a way to mitigate the harmonic distortion in micro grid system. In conventional system capacitors and voltage source inverter (VSI) are used to generate reactive power and to inject the compensation current into the grid [2],[3],[4]. The performance of SAPF is mainly depends on controllability of DC link voltage [6]. The main objective of this paper is to improve the exploit of the Shunt Active Power Filters (SAPF) by adding RE source in the DC link side. In proposed technique the capacitor banks are replaced by clean renewable energy donors from fuel cell, solar power, bio gas and wind mill generator etc. Among this we prefer PV panels for effective compensation due to its current controllability and the preferable output characteristics. Due to the addition of this Shunt Active Power Filters (SAPF) the power carrying capability of the grid lines must be improved and the efficiency of transmission can be extended. The additional real power demand in the micro grid has been meeting out with the help of this new topology. The output results are observed from MATLAB/Simulink environment.

Keywords: Photovoltaic (PV), Shunt Active Power Filter (SAPF), Maximum Power Point Tracking (MPPT), Total Harmonic Distortion (THD).

I. INTRODUCTION

On current situation power demand became vital role. In that occasion losing of power during transmission made some major issues. On referring ancient days the electrical power demand is meeting out by centralized power generation units which are located near to the energy resources. Then the generated power is transmitted to the load through the long transmission lines. As the population increases the above mentioned transmission lines became faulty. Due to evolution of Micro Grid Technology Renewable energy sources like Photo voltaic system, Wind energy, Bio mass generation etc. Major researches are going in the field of Micro Grid technology in order to manage the power demand. A micro grid is a localized power system comprised of distributed generation assets, energy storage devices, and smart distribution technologies that interoperates through controls and software-based intelligence systems. Clean Spark provides integration, installation, and operations and maintenance products and services that specifically address the global virtual power plant and micro grid markets [4]. The major concern in micro grid technology is harmonics ejection by the nonlinear load [5], [8]. Harmonics is nothing but a severe Power quality issue which is the effect of addition of more than one frequency with the fundamental frequency. A load is considered to be non-linear if the current drawn by load will be non-sinusoidal even if it is connected to a sinusoidal voltage. Now a day's industries prefer several nonlinear loads, among them we selected 3 phase controlled rectifier for our analysis. In considered load a severe power quality issue is caused when it is operated at RL Loaded condition. The only control variable in this system is triggering angle (α). Triggering angle is nothing but the instant at which gate is given to the switches the rectifier. Due to this delayed turn on/off of load the current consumed by the load is also nonlinear i.e., non-sinusoidal in nature it looks like almost square waveform. This will result in severe power quality issue in the Micro Grid System. These problems are pre-defined in IEEE 519 and EN50160. According to the IEEE standard Grid system operated less than 69kV should maintain Total Harmonic Distortion (THD) value less than 5% and individual voltage distortion must be less than 3% [1]. To satisfy those constraints compensation is done by various methods. In normal topology the Harmonic mitigation is encountered by using Active Power Filter. They are connecting series, parallel, series-shunt and hybrid configuration with the Grid lines [9]. In our topology current harmonic is compensated by coupling SAPF parallel with maintaining some external power supply (photovoltaic cell). The performance of proposed system is evaluated under two operation condition. One is under fixed triggering angle (Static performance) another one is under various triggering angle (Dynamic performance).

For evident these compensation, the performance of the proposed system is seen through MATLAB/SIMULINK environment and we conclude the results.

II. CONFIGURATION OF PV-SAPF

A. Operating principle of SAPF

Shunt Active Power Filter (SAPF) is a power electronic circuit which is used to meet out the power quality issues in a grid line. It is coupled with external DC source to maintain the input voltages called DC link voltage. In ancient days these can be achieved by coupling a capacitor

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of large values [7]. It consumes power from the grid to maintain the constant voltage with small deviation. The efficiency of compensation is mainly depending on controllability of DC link voltage. But the capacitor provides short range of controllability. Additional to that the magnitude of some intermediate frequency is dominant in nature. So, we proposed a system to replace the place of capacitor by renewable energy source. Here, we prefer photovoltaic system to provide finer controllability, which works under the principle of Photo-electric effect. In order to increase the power rating of PV Cell more than one cell is connected either in series/parallel depends on our requirement. Which is also be designed in MATLAB/SIMULINK environment.

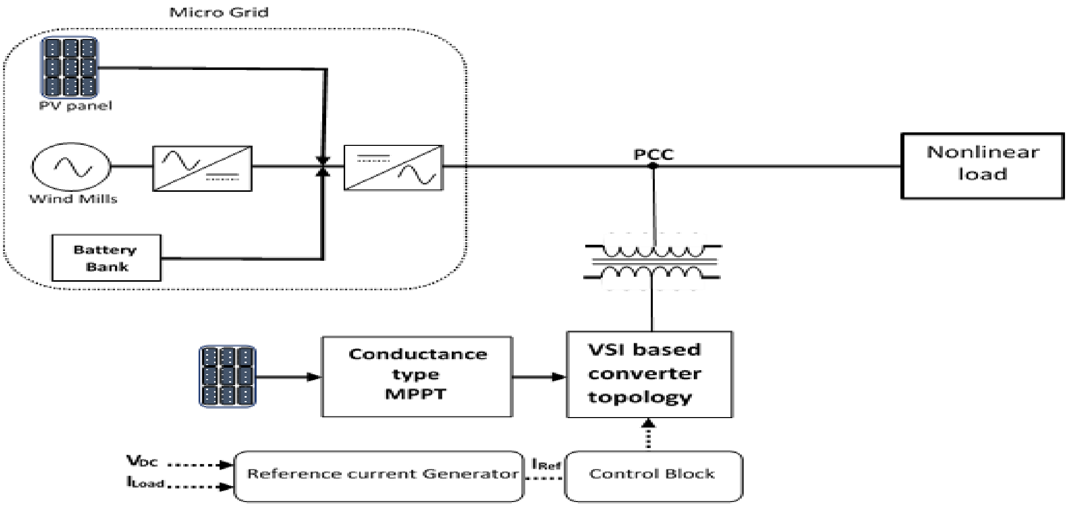

Fig.1 Block Diagram of PV-SAPF

As mentioned in the block diagram, non-linear load is directly connected to the Micro grid means there will be more power quality issues must be happened. To meet out these problems we have proposed a new topology called PV based Shunt Active power filter. In this system, compensation current is generated from Photovoltaic panel and injected through SAPF at 180^0 out of phase with Micro grid at the point of common couple (PCC) which is nearer to load. This compensation current mitigates the harmonics current and make the source or grid current as pure sinusoidal.

$$I_l = I_c + I_s \qquad \text{eq. (1)}$$

This compensation current can be controlled by Hysteresis current controller. The reference current for these controller is calculated by Fast Action Reference Current generator method. Here we preferred Instantaneous Power Theory method for reference current generation. The data for this calculation is obtained from current sensors attached in transmission line of Micro grid.

B. Designing of DC source

In these paper we are proposed a new topology to maintain a dc source generated from Photovoltaic panel (PV). The equivalent circuit of PV is shown in the figure. The design parameters that have been consider from IEEE Standards.

$$I = I_{pv} - I_o\left[e^{\left(V + R_s I\right)/V_{ta}} - 1\right] - \left[\left(V + R_s * I\right)/R_p\right] \quad eq.(2)$$

Where I_{pv} and I_0 are the photovoltaic (PV) and saturation currents, respectively with the array and $V_T = N_s kT/q$ is the thermal.

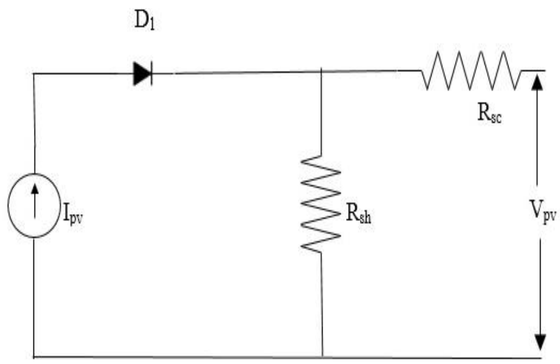

Fig.2 Equivalent circuit of PV panel

Parameters	Range
I_{mp}	76.1A
V_{mp}	26.3v
$P_{max, m}$	200.143W
I_{sc}	8.21A
V_{oc}	32.9V
$I_{o, n}$	$9.825*10^{-8}$ A
I_{pv}	8.214A
A	1.3
R_p	415.405Ω
R_s	0.221 Ω
N_{sc}	1
N_{pc}	1
P_0	1579.2W

Tab.1 Design parameters of PV panel

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The photovoltaic panel is connected to the SAPF is designed from the above mentioned parameters and equations. Voltage from the designed PV panel is feed into the DC link side of the SAPF. In order to maintain the coupled DC voltage as constant a PI controller is designed. The performance of designed PV panel at different environment condition is projected in Fig. 5(b&c).

III.CONTROL STRAGIES

A. Reference current generation by Clarke's transform method

There are different methods for generating a reference current for SAPF. Here, the reference current is generated by using Clarke transformation. During this conversion the revolving phase current i_{abc} into stationary reference frame $i_{\alpha\beta}$. For Clarke transform the formula is given in Equation (3) - (11).

$$\begin{bmatrix} i_\alpha \\ i_\beta \\ i_\gamma \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & 0.87 & -0.87 \\ 0.707 & 0.707 & 0.707 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad \text{eq. (3)}$$

$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} 1 & -0.5 & -0.5 \\ 0 & 0.87 & -0.87 \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad \text{eq. (4)}$$

$$P = v_\alpha i_\alpha + v_\beta i_\beta \quad \text{eq. (5)}$$

$$Q = v_\alpha i_\beta - v_\beta i_\alpha \quad \text{eq. (6)}$$

$$P_{osc} = P_{loss} - P \quad \text{eq. (7)}$$

$$i_{c1} = \left(\frac{-1}{\left(v_\alpha^2 + v_\beta^2\right)} \right) * \left(\left(P_{osc} * v_\alpha\right) + \left(Q * v_\beta\right) \right) \quad \text{eq. (8)}$$

$$i_{c2} = \left(\frac{-1}{\left(v_\alpha^2 + v_\beta^2\right)} \right) * \left(\left(P_{osc} * v_\beta\right) - \left(Q * v_\alpha\right) \right) \quad \text{eq. (9)}$$

$$i_{c3} = i_\gamma \quad \text{eq. (10)}$$

$$\begin{bmatrix} i_{ca} \\ i_{cb} \\ i_{cc} \end{bmatrix} = \sqrt{2}\Big/\sqrt{3} \begin{bmatrix} 1 & 0 & 0.707 \\ -0.5 & 0.87 & 0.707 \\ -0.5 & -0.87 & 0.707 \end{bmatrix} \begin{bmatrix} i_{c1} \\ i_{c2} \\ i_{c3} \end{bmatrix} \quad \text{eq. (11)}$$

From equation (3) & (4) we can easily convert the line current and voltage from revolving frame to stationary reference frame. Using these values, the instantaneous real and reactive power (P&Q) has been calculated from (5) & (6). Then reference current $i_{c1,\ c2,\ c3}$ has been calculated from (8) - (10) in stationary frame. From this finally the values are converted to revolving frame using (11). Then it is given to the Hysteresis controller in order to control the current injected by the PV-SAPF into the MG by controlling Gate pulse given to VSI in the SAPF.

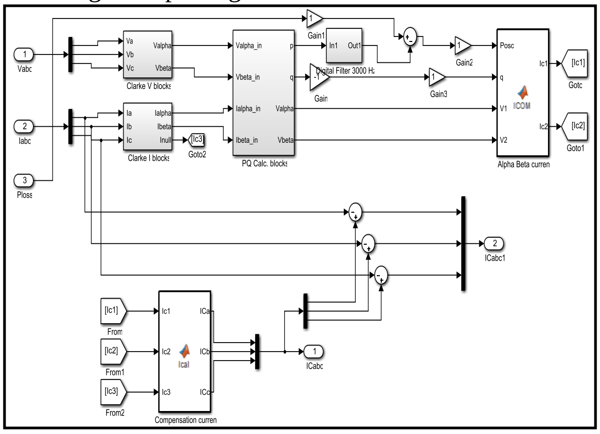


Fig.3a Reference current calculation by Clarke transform

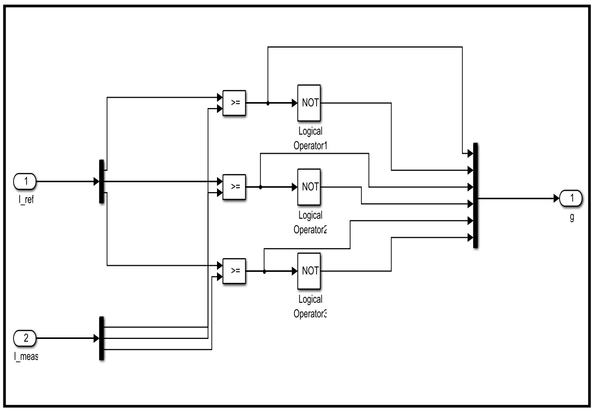
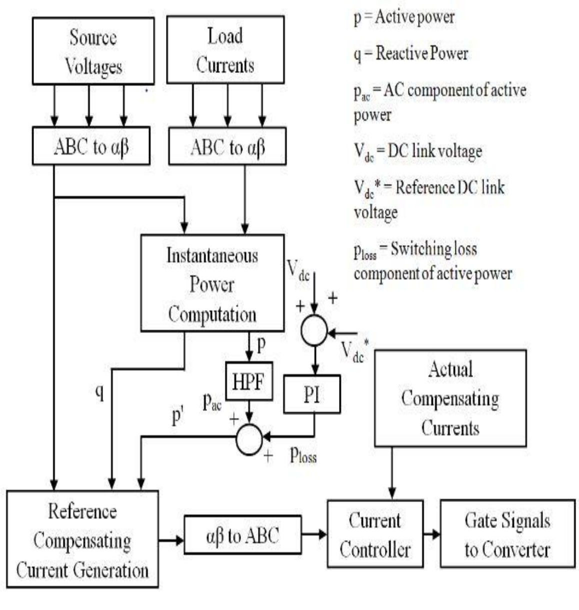


Fig.3b Block diagram of Hysteresis current controller

Fig 3a shows the sequence of reference current calculation Clarke transformation method. The estimated reference current is given to the hysteresis current controller to generate gating pulse for VSI.

Fig. 3b shows the gate pulse generation for VSI from Hysteresis current controller. This pulse is given to the



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switches in SAPF.

B. MPPT coding for proposed PV panel

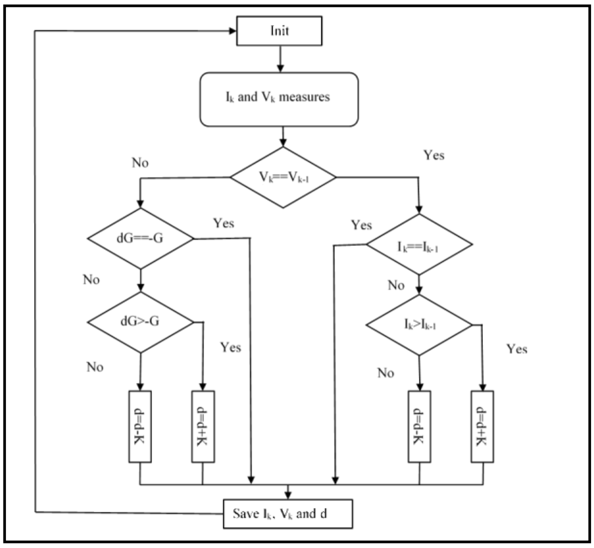

Fig.4Conductance type MPPT algorithm

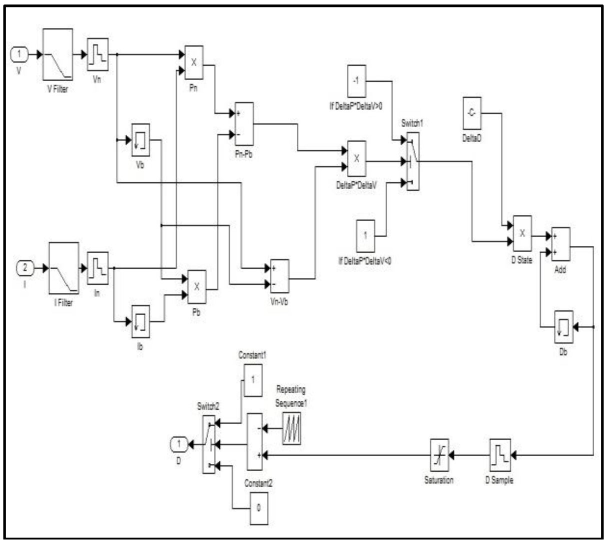

Fig.5 MPPT Algorithm

The Maximum power is obtained from the PV panel by using an algorithm called **Maximum Power Point Tracking (MPPT)**. There are many power point tracking techniques are proposed by conventional authors. Among them we are stepped to **Incremental Conductance** method. It based on the property of MPP: Where the change in power to change in voltage is Zero, i.e., (dP/dV) = 0. So, the IC method uses a repetitious algorithm based on the evolution of the derivative of conductance G, i.e., dG+G=0. The algorithm for this IC method is followed back.

C. DC link voltage regulation

The DC link voltage is maintained as constant with the help of DC-DC converter. Here we use two control loops one isto obtain maximum power from the PV panel. Another one is to maintain constant voltage from at the DC link side it is done by a normal PI controller. The output of Boost converter is shown in Fig. 6c.

Parameters	Values
K_{op}	0.5
K_i	10
C	1000µF
L	66mH

Tab. 2 Design parameter of Boost converter

IV. SIMULATION RESULTS

A. Results for PV panel with plots

The performance of the photovoltaic panel (PV) is simulated with the above parameters and shown in fig 6(b&c).As below fig shows that plot between Voltage and Power obtained from the PV panel. It indicates at constant temperature 25^{0}C. The PV exhibits non-linear P/V and I/V characteristics, there will be one unique point where the maximum power is obtained under particular environmental condition (fig6c&b). The P/V and V/I characteristics alters according to the temperature and irradiations. The fig (6d &6c) show the pv panel at the constant radiation and with different temperature.

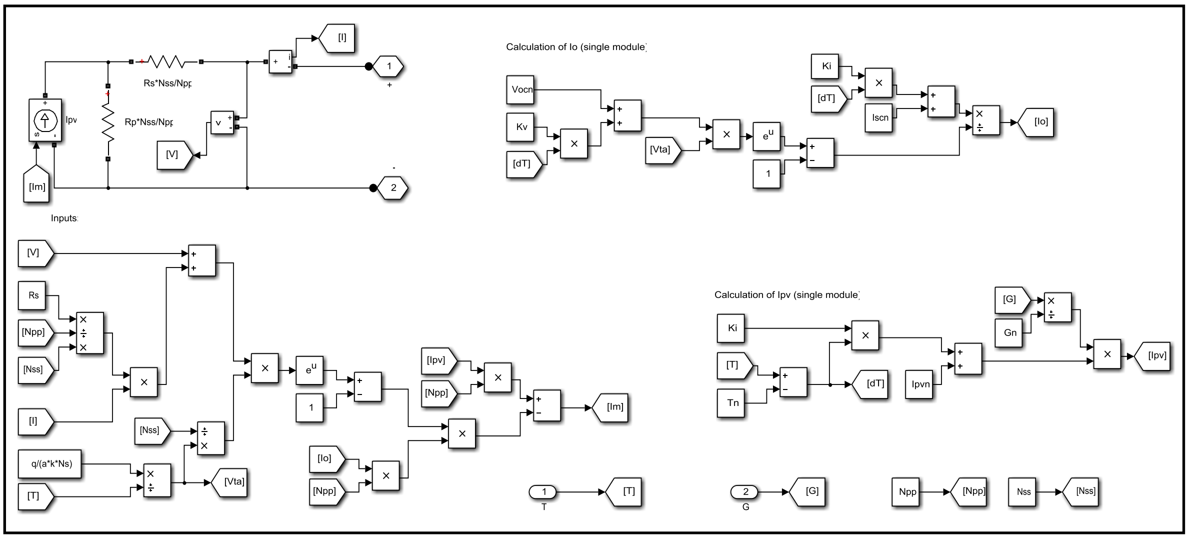

Fig.6a Designed PV system in Simulink environment

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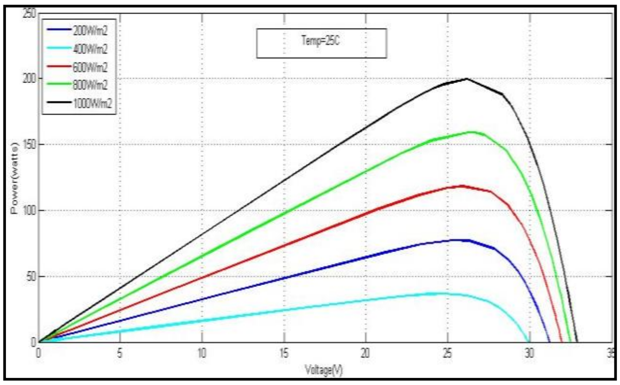

Fig.6b PV power vs voltage at constant temp

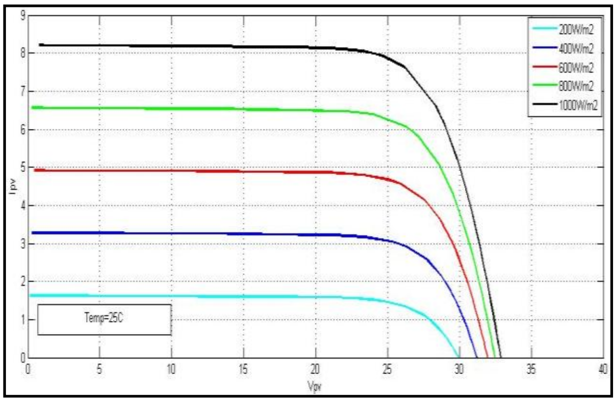

Fig.6c PV voltage vs. current at constant temp

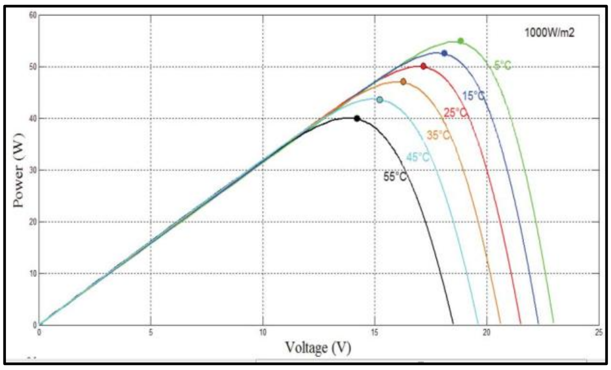

Fig.6d PV power vs voltage at variation temp & constant radiation

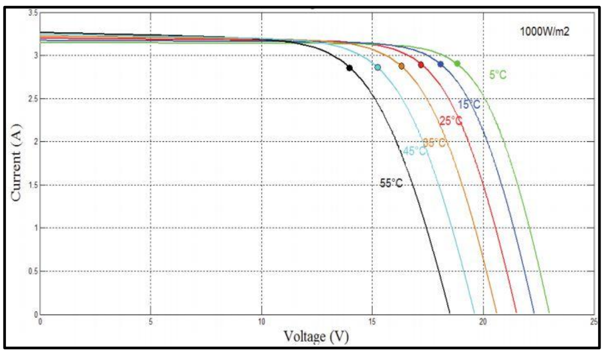

Fig.6e PV voltage vs. current at variation temp & constant radiation

B. DC Link side of PV-SAPF

The shows the constant DC Link voltage maintained at SAPF with the help of PI controller. From the plot is observed that the settling time of PV voltage is 0.1 sec up to which the SAPF is separated with the help of electromechanical relay which is permanently turned on after the settling down of PV panel.

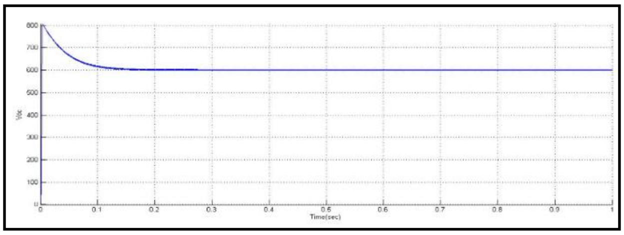

Fig.5d Constant PV voltage at DC Link side of PV-SAPF

C. Capacitor based SAPF vs. PV-SAPF

The result of proposed and conventional system is compared with their different operating condition are shown below. To obtain these results a non-linear load of 3phase control rectifier is designed with the following parameters.

Parameters	Values
V_{ab}	400V
f_g	50Hz
R_s	10µΩ
L_s	1µH
$L_{coupling}$	2mH
V_{dc}	1200V

Tab. 3 Design parameters of SAPF

Parameters	Range
R_l	100Ω
L_l	500 mH
V_{ab}	400V
α	$0\text{-}90^0$

Tab.4 Design parameters of Non-Linear load

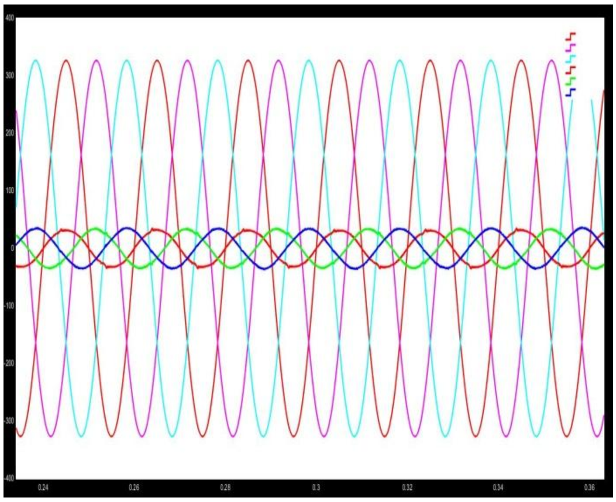

Fig.7 Load current at α=0°

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To obtain the dynamic performance of the proposed PV-SAPF the triggering angle α should vary from 0-90 degree when it is connected with RL load. Static performance is observed by fixing α as constant at 0 degree which is projected in following plots.

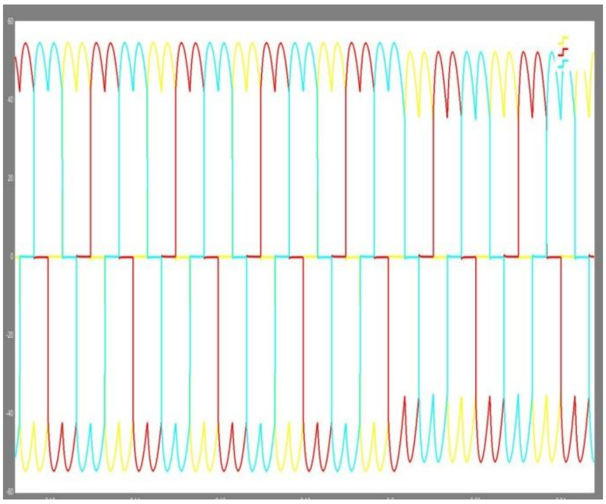

Fig.8 source current at α=0°

The output waveform of load current without filter is shown in fig.7. It consists of high harmonic content which affects the transmission efficiency of the Micro grid and loads connected in the same grid. The compensation current generated from proposed system is shown (fig.9). After the injection of these current into the Micro grid, the source current will become looking like sinusoidal as shown in (fig.9). The Harmonic content in the source current will be eliminated by injected compensation current is inferred from fig.9.

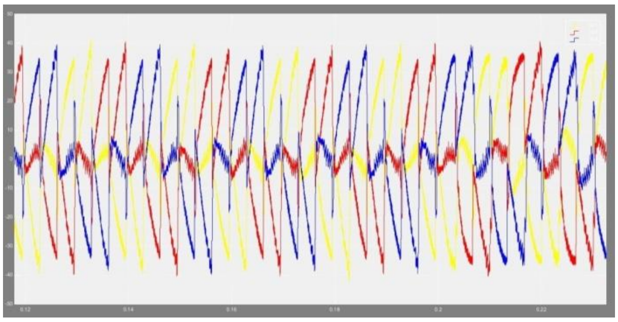

Fig.9Compensation current at α=0°

D. Comparison of Conventional with PV-SAPF System

The THD results of different systems such as

- Without any Filter.
- With Capacitor based SAPF.
- With PV based SAPF.

The below fig.10 implies the THD value of source current will be very high at absence of filter. In spite of this the performance of micro grid will be reduced and major issues have been observed in load connected in the MG system. On comparing with Fig. 10, even though the THD value is reduced the magnitude of intermediate frequencies are dominant in nature. It is due to partial participation of capacitor into the circuit and so the resonance frequency of LC component in the circuit will be permutated, which results in dominant nature of intermediate frequency. These PV-SAPF provides a satisfactory performance on the basis of THD reduction of **5.72%**and other problems in previous system. And the system is fully based on renewable energy sources.

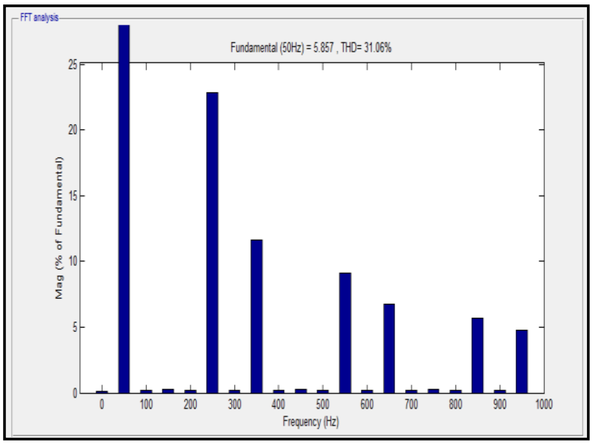

Fig.10 THD result of without Filter

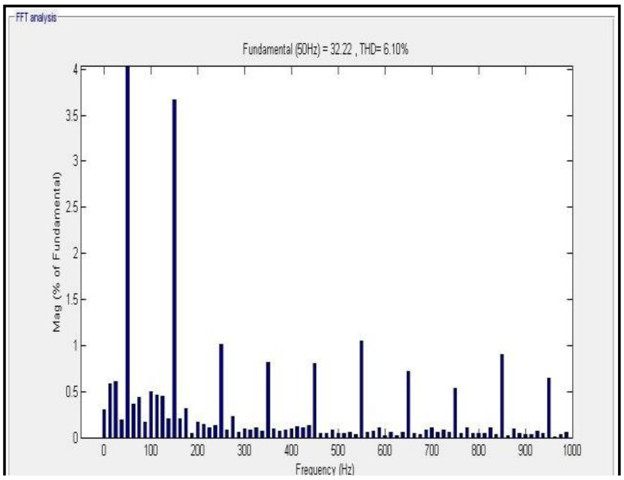

Fig.11 THD result of Capacitor-SAPF

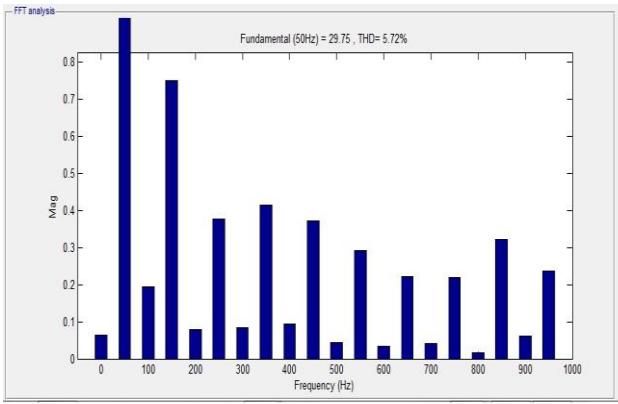

Fig.12 THD Result of PV-SAPF

E. Dynamic performance of PV-SAPF

The Dynamic performance of PV-SAPF is obtained by observing the source and load current for different

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triggering angle at the Non-linear load, which means dynamic characteristics of load and source current.

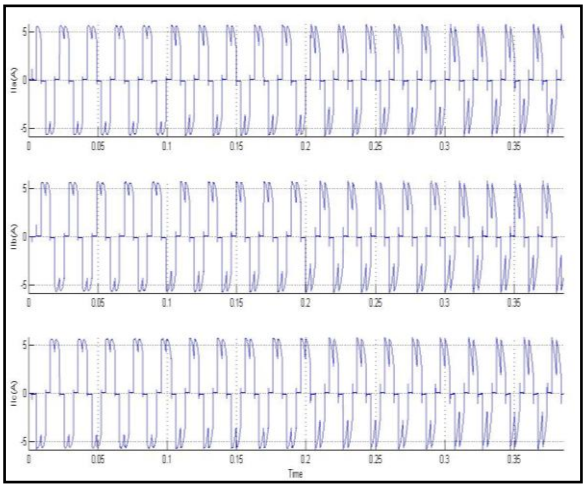


Fig.13 Dynamic characteristics of load current

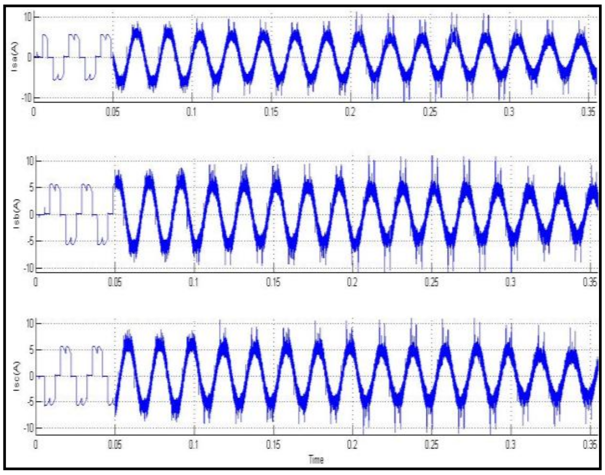
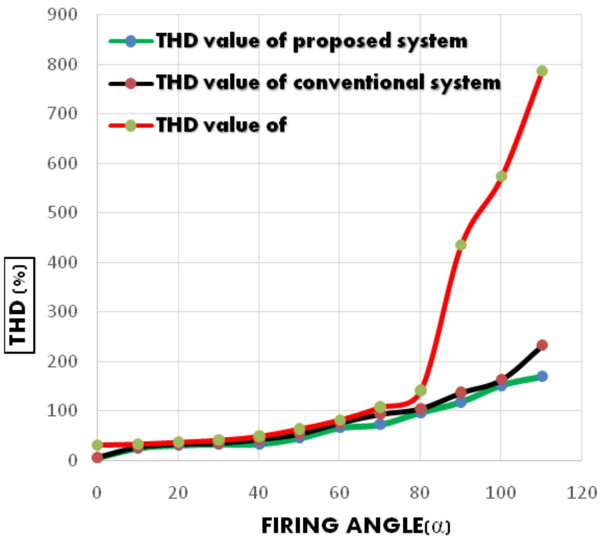


Fig.14 Dynamic characteristics of source current

The following plot shows that the relationship between THD in source current increases exponentially with increase in triggering angle (α) at the Non-Linear load considered in the system.

Tab. 5 Comparison between without filter, conventional Filter and proposed filter

Triggering angle(α)	THD value of proposed system	THD value conventional system	THD value of Without any filter
0	5.72	6.1	31.06
10	25.16	27.12	32.87
20	31.34	33.1	36.68
30	33.18	35.16	40.62
40	33.56	42.51	48.21
50	45.24	53.72	63.28
60	66.17	75.99	81.44
70	72.47	93.62	107.04
80	97.08	104.95	140.74
90	117.95	137.15	434.3
100	151.86	163.49	572.58
110	169.09	232.091	784.96



V. CONCLUSION

From this paper, the role of a PV-SAPF to meet out power quality issues on micro grid due to non-linear is analyzed. From these analyses it is concluded that PV-SAPF is superior to other Conventional topologies. The purpose of filter is to put off the harmonics imposed by the non-linear loads. To enhance the compensation PV panel with high performance is coupled at DC link side of SAPF. It beaten the resonance frequency effect arises in Conventional Capacitor coupled system. In addition to that compensation is also enhanced by absolute controllability of PV system which concluded at low **THD** value of **5.72%** at **$\alpha=0^0$**. Addition to that the effect of contrast in load side parameters like triggering angle is also analyzed. The exploit and analysis of both AC side and DC side are inquired and difference is shown before and after compensation by using **MATLAB/SIMULINK**. The results attached in the paper also provide an evident the same conclusion.

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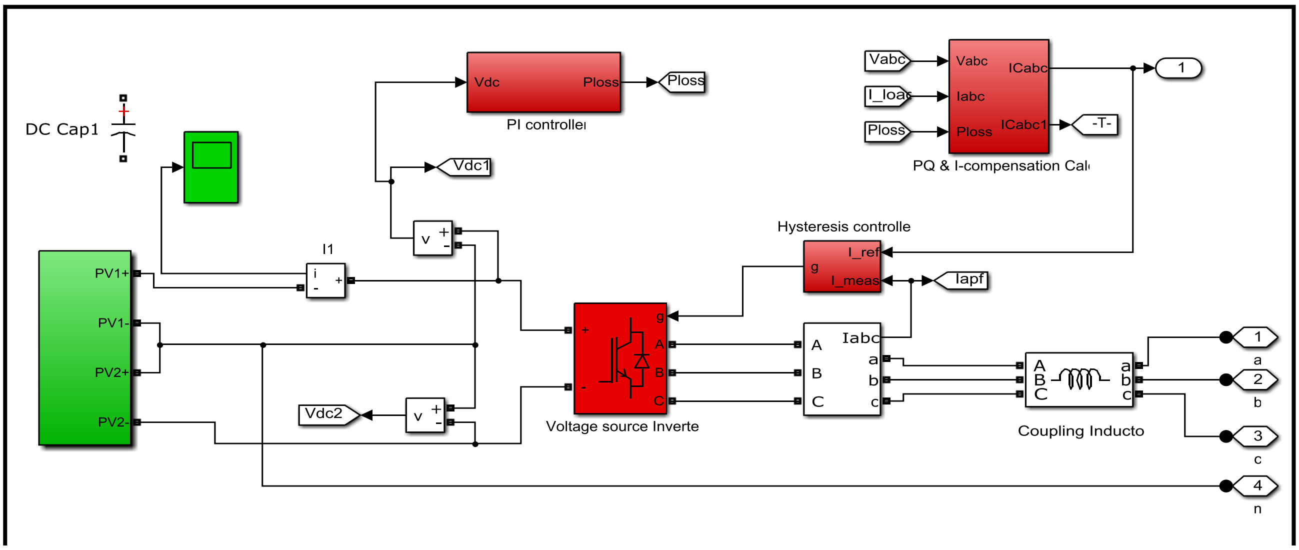

Fig.15 Simulation files of proposed PV-SAPF in MATLAB/Simulink environment