International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 22 (2017) pp. 12214-12218

Series Active Power Filter for Power Quality Improvement Based on Distributed Generation

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Abstract

This paper deals with the performance of Series Active Power Filter (SAPF) for the power quality improvement based on the distributed generation. The SAPF has the ability to mitigate the voltage related problems in the distribution system. The real power supply is given by the PV system (Distributed Generation) for the compensation of the voltage related problems. The control strategy is achieved through the Synchronous Reference Frame Theory for the generation of the reference voltage which is compared with constant voltage for pulse generation using hysteresis band PWM. The SAPF has the better performance in the elimination of the voltage related problems in the distribution side. The performance of SAPF is modeled and simulated using MATLAB / SIMULINK.

Keywords: Series Active Power Filter (SAPF), VSC-Voltage Source Converter, PV-Photo Voltaic, SRF-Synchronous Reference Frame.Distributed Generation.

INTRODUCTION

One of the main responsibilities of a utility system is to supply electric power in the form of sinusoidal and currents with appropriate magnitudes and frequency for the customers at the points of common coupling (PCC) .Although the generated voltage of synchronous machines in power plants are nearly sinusoidal ,some undesired conditions such as lightning and short circuit faults and nonlinear loads cause steady state error or transient voltages and current disturbances. For example, electric arc furnaces cause voltage fluctuations, power electronic converters generate current harmonics and distort voltage waveforms, and short circuits faults result in voltage sags and swells [1-4]. On the other hand most customer loads such as computers, microcontrollers and hospital equipment are sensitive and unprotected to power quality disturbances and their proper operation depends on the quality of the voltage that is delivered to them. This is possible only by ensuring an uninterrupted flow of power at proper voltage and frequency levels. Custom power is a strategy, which is designed primarily to meet the requirements of industrial and commercial customer.

Power distribution systems should provide their customers with an uninterrupted flow of energy at smooth sinusoidal voltage at the contracted magnitude level and frequency [8-10]. Power systems, have many nonlinear loads, which significantly affect the quality of power supplies [11], [12].Power quality can be classified into three categories that is, voltage stability, continuity of supplying power, and voltage. Comprehensive review of compensating type custom power devices, issues of power quality[13-16], [21], survey of power quality problems, standards and indices proposed by different agencies and different approaches to improve power quality from time to time.

SERIES ACTIVE POWER FILTER

SAPF [17-18] injects a voltage component which is connected in series with the supply voltage, thus compensating the voltage sags and swells on the load side. Control response is of the order of 3msec, ensuring a secure voltage supply under transient conditions. The main function of a SAPF is the protection of sensitive loads from voltage sags/swells coming from the network. The SAPF is located on the basis of sensitive loads. If a fault occurs on other lines, DVR inserts series voltage and compensates load voltage to pre fault value. The momentary amplitudes of the three injected phase voltages are controlled in such a way to eliminate any detrimental effects of a bus fault to the load voltage.

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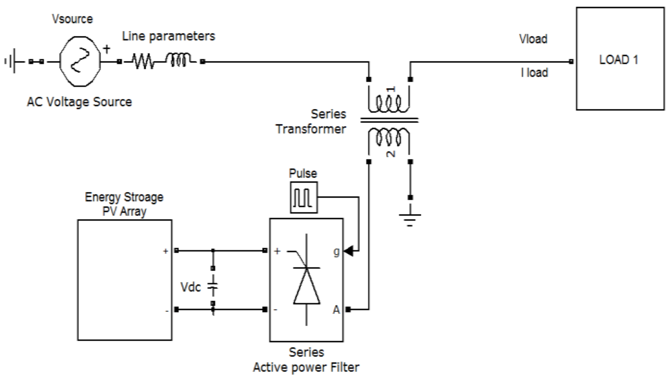

Figure 1: Series Active Power Filter (SAPF) configuration

Synchronous Reference Frame (SRF) Theory

The control strategy for the SAPF [19-20] is based on the Synchronous Reference Frame (SRF) (Metin Kesler et al. 2011) Theory. The supply voltage Vsabc is transformed as d-q-0 by using the Transformation matrix T given by

$$\begin{bmatrix} V_{S0} \\ V_{Sd} \\ V_{Sq} \end{bmatrix} = T \begin{bmatrix} V_{Sa} \\ V_{Sb} \\ V_{Sc} \end{bmatrix} \qquad (1)$$

$$T = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ \sin(wt) & \sin(wt - 2\pi/3) & \sin(wt + 2\pi/3) \\ \cos(wt) & \cos(wt - 2\pi/3) & \cos(wt + 2\pi/3) \end{bmatrix} \qquad (2)$$

The inverse transformation matrix T^{-1} is used for producing the reference load voltage by the average component of source voltage and ωt produced by PLL.

$$T^{-1} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \sin(\omega t) & \cos(\omega t) \\ \frac{1}{\sqrt{2}} & \sin(\omega t - 2\pi/3) & \cos(\omega t - 2\pi/3) \\ \frac{1}{\sqrt{2}} & \sin(\omega t + 2\pi/3) & \cos(\omega t + 2\pi/3) \end{bmatrix} \qquad (3)$$

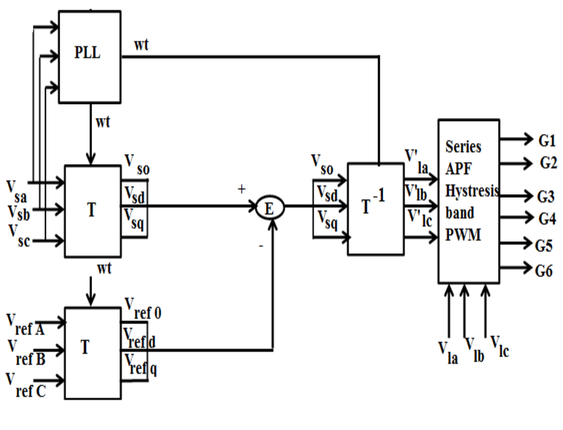

Figure 2: Series Active Power Filter (SAPF) configuration

The control strategy is for series converter along with the DC link control. The DC voltage for the compensation is supplied by the PV array. The control block diagram is shown in Figure.2.

Series Controller

The Series converter has the function of compensating the Voltage Problems like Sag. The series controllers have the PLL which supplies the sine and cosine value to the abc to dq0 and dq0 to abc transformation. In series control the reference signal is generated by the use of abc to dq0 and dq0 to abc. The reference signal generated is compared with the PCC point voltage and using the hysteresis band Pulse signals is generated. The generated signals are given as the gate pulse to the converter. The simulation diagram for series controller is shown in Fig.3.

The control strategy of the system is to control the converter for the injections of the negative harmonics for the compensation of the system. The converter output is controlled by the gate pulse given to the IGBT's. This is achieved by the Synchronous Reference Frame (SRF) Theory. The SRF theory is based on the synchronous machine in which for the analysis of 3phase system is made easy. The 3phase system abc is converted to the direct and quadrature axis quantities dq0. For the series APF is considered for the reference signal calculation and pulse is generated. The equation (3), (4), (5) represents the current for the three phases which is converted to dq0 for the balanced state.

$$i_a = I_m sin\omega_s t \qquad (3)$$

$$i_b = I_m \sin\left(\omega_s t - \frac{2\pi}{3}\right) \qquad (4)$$

$$i_a = I_m \sin\left(\omega_s t + \frac{2\pi}{3}\right) \qquad (5)$$

The transformation matrix for the i_a, i_b i_c is given by equation (6),

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} cos\theta & -sin\theta & 1 \\ cos\left(\theta - \frac{2\pi}{3}\right) & -sin\theta\left(\theta - \frac{2\pi}{3}\right) & 1 \\ cos\left(\theta + \frac{2\pi}{3}\right) & -sin\theta\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \qquad (6)$$

The transformation of abc to dq0 and inverse transform of dq0 to abc is simultaneously performed to calculate the reference signal for the pulse generation. The equation (7), (8), (9) shows the transformation of dq0 under the balanced state. The i_d, i_q, i_0 are the currents of direct, quadrature and zero axis of the system which is obtained from the inverse transformation.

$$i_d = k_d \frac{3}{2} I_m \sin(\omega_s t - \theta) \qquad (7)$$

$$i_q = -k_q \frac{3}{2} I_m \sin(\omega_s t - \theta) \qquad (8)$$

$$i_0 = \frac{1}{3}(i_a + i_b + i_c) \quad (9)$$

The transformation matrix for the dq0 transform is given by (10)

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3}\begin{bmatrix} cos\theta & cos\left(\theta - \frac{2\pi}{3}\right) & cos\left(\theta + \frac{2\pi}{3}\right) \\ -sin\theta & -sin\theta\left(\theta - \frac{2\pi}{3}\right) & -sin\theta\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix}\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} (10)$$

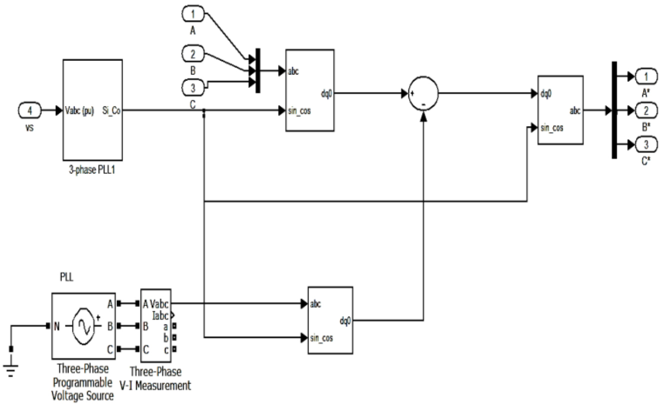

Figure 3: Simulation of Series Controller

Simulation of Series Active Power Filter

The MATLAB/Simulink is used for the simulation of the SAPF based on the control strategy SRF theory is shown in the Figure.4.

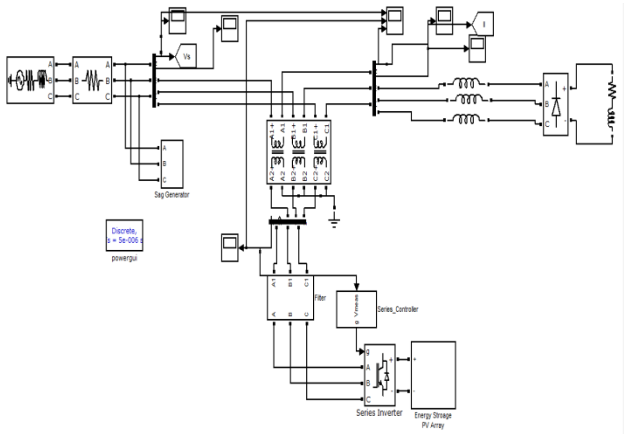

Figure 4: Simulation of Series Active Power Filter

System Parameters

Source Voltage : 415V, 50Hz

Load Parameters Rectifier Fed

Resistive Load : 10KΩ

Inductive Load : 20mH

Shunt Inverter side

LC filter : 3.5mH, 5Ω, 10μF

Series Inverter Side

LC filter : 12μH, 5Ω, 10μF

DC Link Capacitor

For UPQC-VSC : 500mF

PV array voltage : 250V

The Figure.3 shows the Simulink model of the SRF theory which is used for reference signal calculation. The reference signal calculated and the measured signal is compared by using the hysteresis band for the PWM pulse for the IGBT operation. The Figure.5 shows the simulation of the Hysteresis band for the PWM pulse generation.

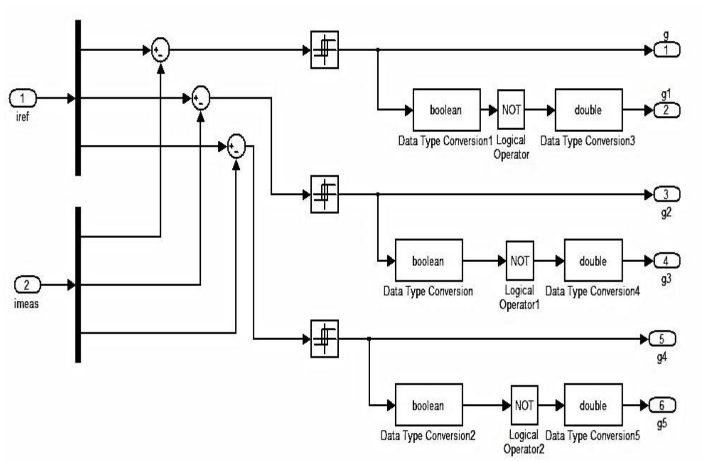

Figure 5: Simulink model of Hysteresis Controller

Simulation Results and Discussion

The performance analysis of SAPF is simulated MATLAB / SIMULINK. The simulation output of the SAPF with disturbance in source voltage and the compensated voltage is shown in the figure.6. The compensation given for the system is supplied by the SAPF. The voltage with disturbance has the drop in the voltage of about 0.2 P.U. In order to maintain the system voltage at 1 P.U, the compensation is required to increase the efficiency of the system.

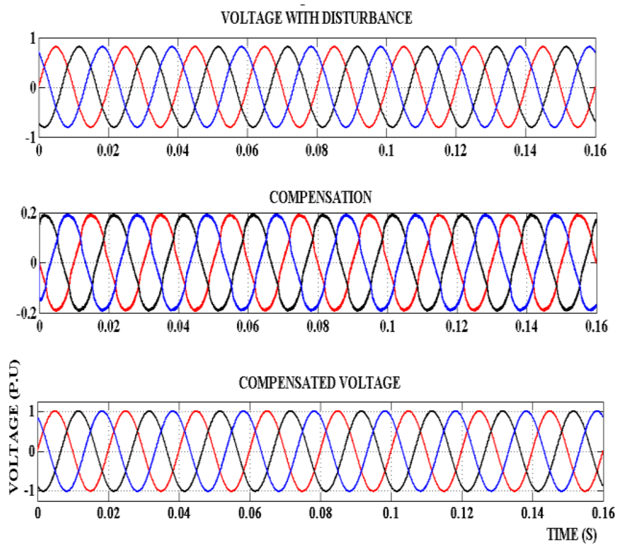

Figure 6: Output for SAPF with disturbance in source voltage

Sag Compensation

The sag is created manually by additional of loads in the PCC for the time period of 0.03 to 0.08 seconds. The uncompensated voltage (sag) is mitigated by the injection of compensating voltage to make the system voltage at 1 P.U is shown in the figure.7.

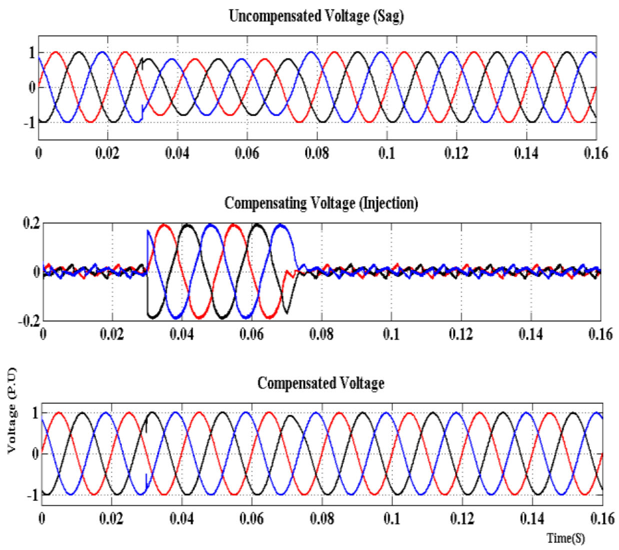

Figure.7: Output for SAPF with disturbance in source voltage

SWELL COMPENSATION

The swell is created by the sudden removing of loads for the time period of 0.03 to 0.07 seconds and there is decrease in the voltage profile in the remaining time periods to compensate the swell and drop in the voltage is injected by the SAPF is shown in the figure.8.

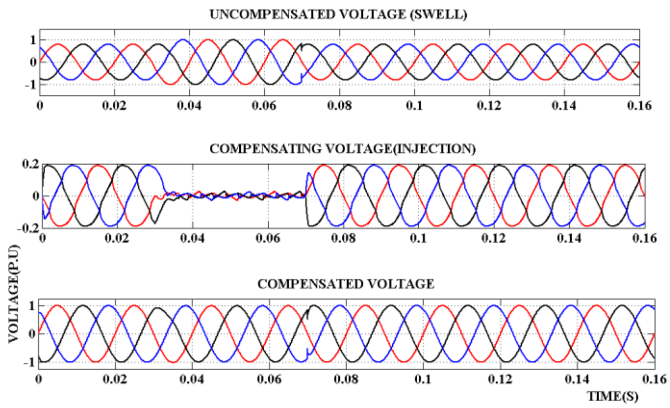

Figure 7: Output for SAPF with disturbance in source voltage

CONCLUSION

In this paper, the Series Active Power Filter (SAPF) using Synchronous Reference Frame (SRF) Theory is implemented to control the SAPF for the sag and swell mitigation. The simulation results show that the device is capable of mitigating the sag, swell and the drop in voltage to maintain the voltage at 1 P.U. The Distributed Generation is used for the mitigation of power quality problems has the superior performance.

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