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Mitigation of Voltage Sag, Swell and Load Hamonics by the Combined Opertation of Series APF and Solar System

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Abstract – **To overcome the voltage related problems like voltage Sag, voltage swell and load harmonics in electrical power distribution system, Series APF is the most efficient and effective device. The series APF is controlled in various ways to mitigate power quality problems. This paper proposes a new configuration of series APF with solar system to reduce burden on dc link and reduce the complexity in controlling techniques which are used in conventional techniques. A detailed mathematical analysis, to develop series inverter with solar system, is presented in this paper. MATLAB/SIMULINK-based simulation results are discussed to support the developed configuration.**

Keywords – **Series APF, Voltage Sag, Voltage Swell, Harmonics, Unit Template Technique, PV Cell, PV Module, PV Array.**

I. INTRODUCTION

The various types power quality problems in present electrical power distribution system are voltage sag, voltage swell, harmonics, notch, noise, under voltage, over voltage, interruptions etc. are increases due to the increment uses of nonlinear loads, entering of distribution generations like solar/wind generation near load to meet load demand, faults like short circuits, loading effects etc… In order to reduce power quality problems and maintain power quality within limits the voltage magnitude, voltage waveform and its shape should be maintained as a desired level i.e. power quality=voltage quality. Under disturbance condition, Series active power filter (APF) is effectively and efficiently used to overcome voltage related problems.

II. SYSTEM CONFIGURATION OF SERIES ACTIVE POWER FILTER

The general block diagram of Series APF with dc link capacitor and series APF with solar generation are shown in figure 1 and 2. The voltage at PCC is distorted due sudden increment of loads and nonlinear loads.

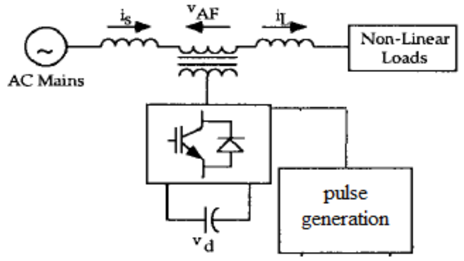

Fig. 1. Series active power filter with dc link capacitor

The series APF is a 3-leg voltage source inverter connected to a dc link capacitor in conventional configurations. In new configuration instead of dc link capacitor a solar generation is connected to series APF. In both conventional and new configurations the APF is connected to the system through series transformer. In both configurations the function of series APF is inject the voltage in phase to the system voltage under voltage sag condition and out phase to the system under voltage swell condition to main the voltage at a desired level as per the load requirement..

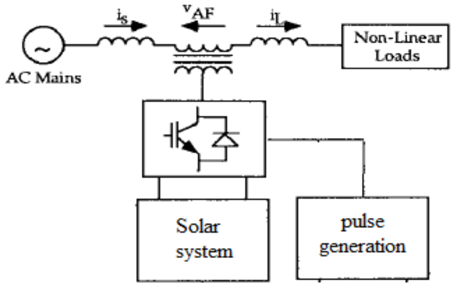

Fig. 2. Series active power filter with solar generation

III. STEADY STATE ANALYSIS OF SERIES ACTIVE POWER FILTER

The per phase equivalent circuit model of 3-phase series active power filter is shown in figure 3.

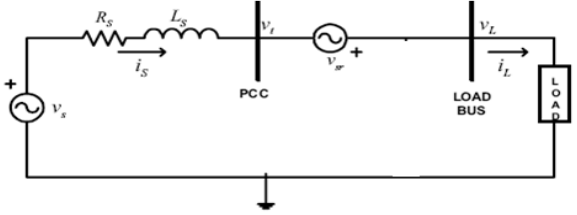

Fig. 3. Equivalent circuit of series APF

The source voltage, terminal voltage at PCC and load voltage are denoted by v_s, v_t and v_L respectively. The source and load currents are denoted by i_s and i_L respectively. The voltage injected by series APF is denoted by v_S. Taking the load voltage, v_L, as a reference phasor and suppose the lagging power factor of the load is $Cos_{\varphi L}$ then we can write

$$\overline{V_L} = V_L\angle 0^0 \qquad 3.1$$

$$\overline{I_L} = I_L\angle -\emptyset_L \qquad 3.2$$

$$\overline{V_t} = V_L(1+K)\angle 0^0 \qquad 3.3$$

Where factor k represents the fluctuation of source voltage, defined as,

$$k = \frac{V_t - V_L}{V_L} \qquad 3.4$$

The voltage injected by series APF must be equal to

$$\overline{V_{sr}} = \overline{V_L} - \overline{V_t} = -kV_L\angle 0^0 \qquad 3.5$$

The series APF is assumed to be lossless and therefore, the active power demanded by the load is equal to the active power input at PCC. The Series APF provides a nearly unity power factor source current, therefore, for a given load condition the input active power at PCC can be expressed by the following equations,

$$P_t = P_L \qquad 3.6$$

$$V_t i_s = V_L i_s \cos\emptyset_L \qquad 3.7$$

$$V_L(1+k)i_s = V_L i_s \cos\emptyset_L \qquad 3.8$$

$$i_s = \frac{i_L}{(1+k)}\cos\emptyset_L \qquad 3.9$$

The above equation suggests that the source current i_S depends on the factor k, since φ_L and i_L are load characteristics and are constant for a particular type of load.

The complex power absorbed by the series APF can be expressed as,

$$\overline{S_{sr}} = \overline{V_{sr}} i_s \qquad 3.10$$

$$P_{sr} = V_{sr} i_s \sin\emptyset_s = -kV_L i_s \cos\emptyset_s \qquad 3.11$$

$$Q_{sr} = V_{sr} i_s \sin\emptyset_s \qquad 3.12$$

$\emptyset_S = 0$, since UPQC is maintaining unity power factor

$$Q_{sr} = 0 \qquad 3.13$$

During voltage sag condition, the series APF injects the voltage in phase i.e.. 0 degrees phase with the source voltage and during voltage swell conditions the series APF injects the voltage out of phase i.e.. 180 degrees with the source voltage to maintain voltage as constant at pcc near the loads.

V. OPERATING PRINCIPLE AND CONTROLLING OF SERIES APF

The figure 4 shows the MATLAB based block diagram of the series active filter system with solar generation, which consists of three-phase VSI connected in series with three-phase supply through three single phase coupling transformers. Three-phase VSI with a solar system is used as an active filter. A small capacity rated RC filter is connected across secondary of each series transformer to eliminate high switching ripple content in the series active filter injected voltage. An unbalanced and distorted supply voltage source is considered. The system load includes voltage fed type load, like variable frequency ac motor drives, as balanced harmonic producing load and linear resistive-inductive load to represent unbalanced load with reactive power requirement.

If the supply voltage is unbalanced and/or distorted due to the non-linear load connected ahead of the system, then the series AF is controlled to inject a voltage so that the sum of supply voltage and injected voltage becomes sinusoidal and balanced. In this manner, the supply voltage impurities are alleviated from the load terminals.

A simple algorithm is implemented to control the series AF. The series active filter is controlled such that it injects a voltage (v_{ca}, v_{cb}, v_{cc}) which cancels out the distortions and/or unbalance present in the supply voltages (v_{sa}, v_{sb}, v_{sc}), thus making the load voltage (v_{la}, v_{lb}, v_{lc}) as perfectly balanced and sinusoidal with desired amplitude. The control strategy for series AF is shown in Fig.5. Since the supply voltage is unbalanced and or distorted, a phase locked loop (PLL) is used to get the synchronization with the supply. Three-phase distorted/unbalanced supply voltages (v_{sa}, v_{sb}, v_{sc}) are sensed and given to PLL which generates two quadrature unit vectors ($\sin\theta, \cos\theta$). The sensed supply voltage is multiplied with a suitable value of gain before giving as input to PLL. The in phase sine and cosine outputs from the PLL are used to compute the supply in phase, 120^0 displaced three unit vectors (u_a, u_b, u_c) using eqn. (5.1) as

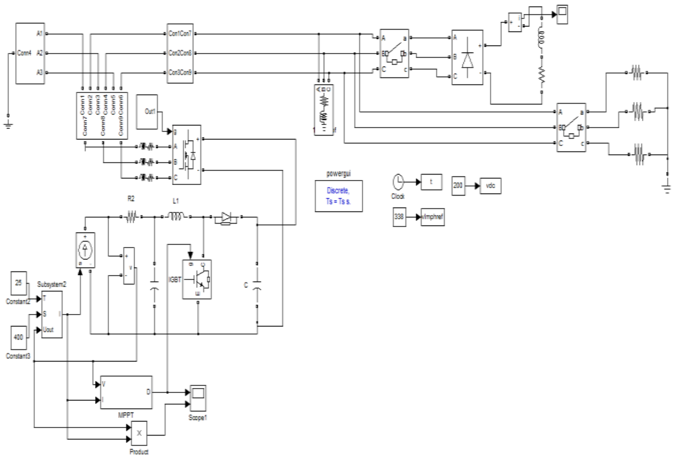

Fig. 4. MATLAB based block diagram of the series active filter system with solar generation.

$$\begin{pmatrix} u_a \\ u_b \\ u_c \end{pmatrix} = \begin{pmatrix} 1 & 0 \\ -1/2 & -\sqrt{3}/2 \\ -1/2 & \sqrt{3}/2 \end{pmatrix} \begin{pmatrix} \sin\theta \\ \cos\theta \end{pmatrix} \qquad 5.1$$

The computed three in phase unit vectors are then multiplied with the desired peak value of PCC phase voltage (V^*_{lm}), which become the three-phase reference PCC voltage ($v^*_{la}, v^*_{lb}, v^*_{lc}$) as

$$\begin{pmatrix} v^*_{la} \\ v^*_{lb} \\ v^*_{lc} \end{pmatrix} = V^*_{lm} \begin{pmatrix} u_a \\ u_b \\ u_c \end{pmatrix} \qquad 5.2$$

The desired peak value of PCC phase voltage is considered as 338V (415*√2/√3). The computed voltages from eqn. (5.2) are then given to hysteresis controller along with the sensed three-phase PCC voltages.

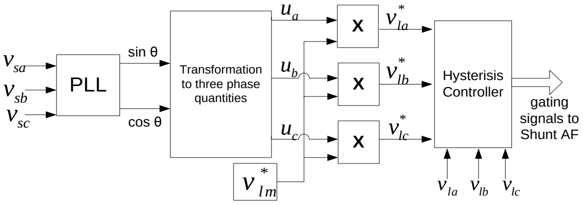

Fig. 5. Control Scheme of Series AF for voltage sag/swell and harmonic elimination

The hysteresis controller output is switching signals to the six switches of VSI of the series active filter. The hysteresis controller generates the switching signals such that the voltage at the PCC terminal becomes the desired sinusoidal reference voltage. Therefore, the injected voltage across the series transformer through the ripple filter cancels out the harmonics and unbalance present in the supply voltage.

VI. SIMULATION RESULTS

The performance of the proposed series APF with solar system in the power system has been evaluated by simulation. The simulation results of the proposed series active power filter with solar system is shown in figure 6.

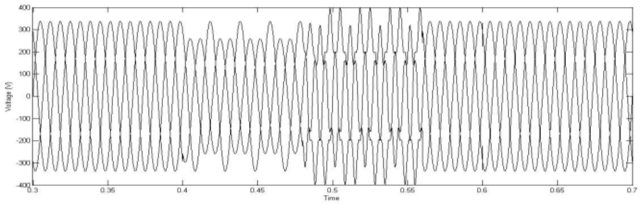

Fig. 6.1. Distorted source voltage

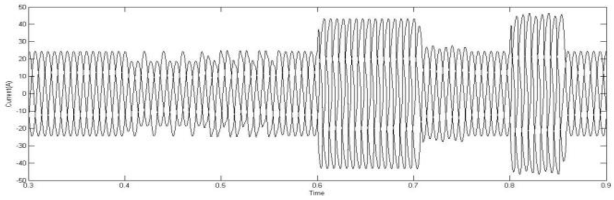

Fig. 6.2. Source Current

In source voltage, at time interval 0.4 to 0.44 seconds two phases i,e.. R and Y phases having 25% of voltage sag has been occurred and 0.44 to 0.45 second in two phases i,e.. Y and B phases having 25% voltage swell takes place as shown in figure 6.1. The figure 6.2 and 6.4 shows the source current and the load current due to loads and distorted supply without compensating devices.

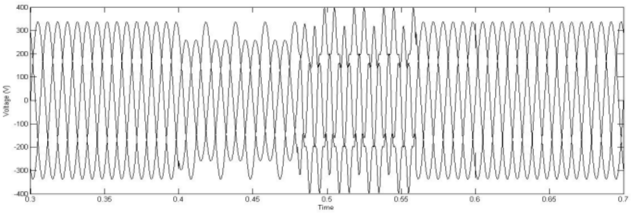

Fig. 6.3. Distorted voltage at load terminal without any compensating devices

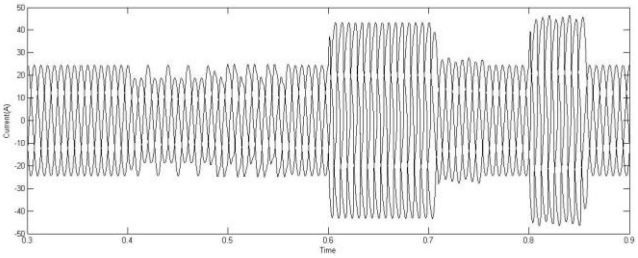

Fig. 7.4. Load Current

The voltage Sag and voltage swell in the source voltage is compensated and the load voltage is maintained as constant by injecting the voltage through series inverter with solar system as shown in figure 6.5.

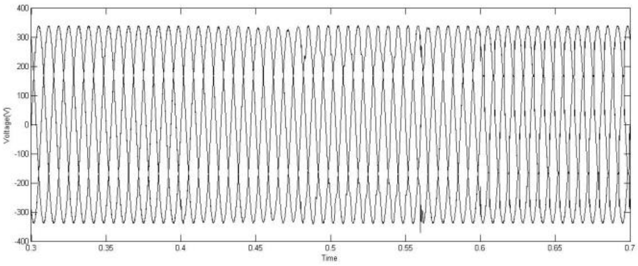

Fig.6.5. Load voltage with series APF

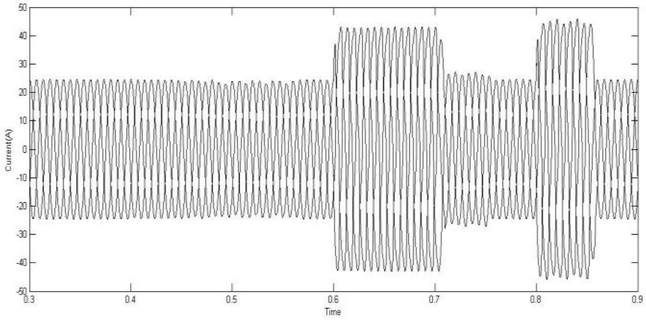

Fig. 6.6. Load current with series APF

At PCC the nonlinear load is connected to the system for a time interval 0.6 to 0.7 due to this harmonics content in current is increases. The harmonic content in load current is shown in figures 6.7.

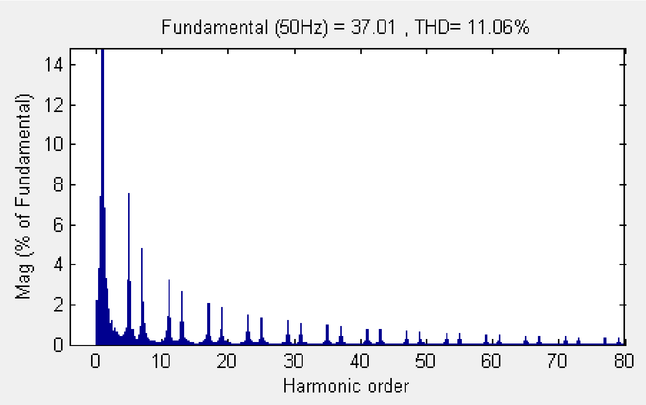

Fig. 6.7. Harmonic spectrum of load current without Series APF

The harmonic spectrum of load current is shown on figure 7.8. From figures 7.7 and 7.8, the harmonic content in load current is decreased from 11.06% to 8.08%.

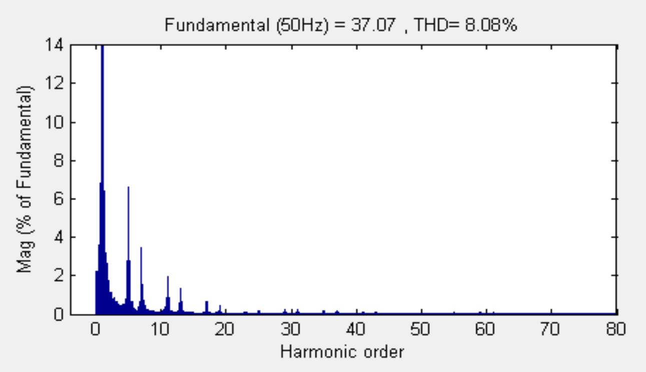

Fig. 7.8. Harmonic spectrum of load current with Series APF

VII. CONCLUSION

The steady state analysis of series APF with solar system is presented in this paper. The MATLAB/Simulink based simulations is done in order to verify the analysis proposed. The series APF injects in phase voltage during voltage sag condition and out of phase during voltage swell condition at PCC to maintain constant voltage. Due to using of series APF with solar system the complexity of controlling APF to inject voltages and maintain the dc link capacitor voltage as constant is reduces. In this proposed configuration the dc link capacitor voltage is maintained as constant by solar system then the simple unit template technique is used to control the APF to inject the voltage during voltage sag/Swell conditions.

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