Simulation of Series Active Power Filter For Voltage Harmonics Compensation

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Abstract- *The two major problems in the electrical industry today are sagging and swelling of line voltage and harmonic currents. Voltage sagging and swelling may result to equipment malfunction and shut down. Harmonics also affect the electrical equipment to fail and deteriorate the waveform of the current. To mitigate the voltage sags and swells, uninterrupted power supply was used. But uninterrupted power supply is an example of non-linear load which creates harmonics in the power system. Active power filters were used to eliminate the harmonics in the system. This study aims to create three models of active power filters that compensate the harmonics, mitigate the voltage sags and swells, and also correct the power factor. The models were simulated to know which of the three active power filter models gives the best performance. The simulation tools that were used in this study were MATLAB/Simulink. Based on the results, the active power filter models compensate the harmonics, mitigate the voltage sags and swells, and correct the power factor of the system. Evaluating the models, the active power filter Model-A gave the best performance by reducing the total harmonic distortion of the system.*

Keywords- active power filter, harmonics, voltage sags and swells, reference frame.

I. INTRODUCTION

Power quality is the superiority of the electrical power supplied to electrical equipment. It determines the fitness of electrical power. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life. Though the modem power system is becoming highly vulnerable to the different power quality problems. The main causes of a poor power quality are harmonic currents, poor power factor, supply-voltage variations, etc. The extensive use of non-linear loads is contributing to increased current and voltage harmonics issues. Furthermore, the penetration level of small/large-scale renewable energy systems based on wind energy, solar energy, fuel cell, etc., installed at distribution as well as transmission levels is increasing power quality problems significantly. Furthermore, Regulation & guidelines of reactive power and harmonic are upcoming issues in distributed power system and industries. By the continuous efforts of power electronics researchers and engineers, it is expected that very soon customer will get high efficient, high quality and reliable power by using power electronics technology.

II. POWER QUALITY ISSUE

The power quality issue is defined as "any occurrence of disturbance in voltage, current or frequency that results in equipment overheating, misbehaving of equipment or damage device". Almost all power quality issues are closely related with power electronics in almost every aspect of commercial, domestic, and industrial application. Equipments like computers, copiers, printers, programmable logic controllers, adjustable speed drives (ASDs), rectifiers, inverters etc. are the example of power electronics devices.
Major issues of poor power quality are as bellow:

- Voltage sag
- Voltage swell
- Transients
- Voltage imbalance
- Voltage Flicker
- Voltage waveform Distortion
- Harmonic Reduction

III. METHODOLOGY & OBJECTIVE OF RESEARCH

Depending on the particular application or electrical problem to be solved, active power filters can be implemented as shunt type, series type, or a combination of shunt and series active filters (UPQC). These filters can also be combined with passive filters to create hybrid power filters. The series-shunt active filter is a combination of the series active filter and the shunt active filter. The shunt active filter is located at the load side and can be used to compensate for the load harmonics. On the other hand, the series portion is at the source side and can act as a harmonic blocking filter. This topology has been called the Unified Power Quality conditioner (UPQC). The series portion compensates for supply voltage harmonics and voltage unbalances, acts as a harmonic blocking filter, and damps power system oscillations. The shunt portion compensates load current harmonics, reactive power, and load current unbalances. In addition, it regulates the dc link capacitor voltage. Moreover one of the serious problems in electrical systems is the increasing number of electronic components of devices that are used by industry as well as residences. These devices, which need high-quality energy to work properly. At the same time, they are the most responsible ones for injections of harmonics in the distribution system. Therefore, devices that soften this drawback have been developed. One of them is the unified power quality conditioner. UPQC has the capability of improving power quality at the point of common coupling on power systems. So, the UPQC is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage flicker/imbalance.

IV. BASIC PRINCIPLE OF SERIES APF

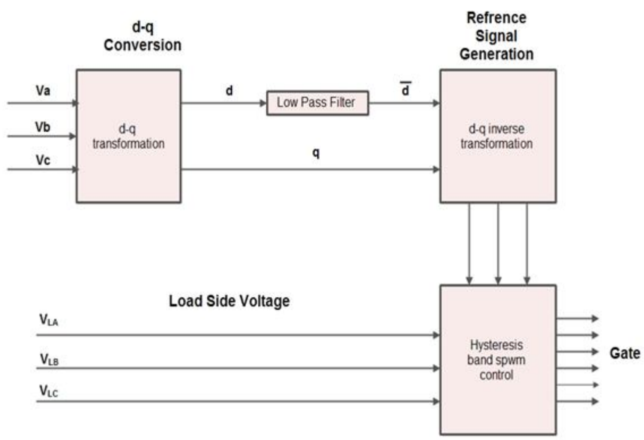


Fig.5.1 Control Algorithm for Series Active Filter

The series APF control algorithm calculates the reference value to be injected by the series APF transformers by comparing the positive sequence component with the load side line voltages.

In equation (5.1), supply voltages V_abc are transformed to d-q-o coordinates.

$$\begin{bmatrix} V_0 \\ V_d \\ V_q \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \\ \sin \omega t & \sin\left[\omega t - \frac{2\pi}{3}\right] & \sin\left[\omega t + \frac{2\pi}{3}\right] \\ \cos \omega t & \cos\left[\omega t - \frac{2\pi}{3}\right] & \cos\left[\omega t + \frac{2\pi}{3}\right] \end{bmatrix} \quad \text{....(5.1)}$$

The voltage in d axes (V_d) given in (5.2) consists of average and oscillating components of source voltages (and V_d^{*}~V_d).the average voltage V_d is calculated by using second order LPF (low pass filter).

$$V_d = V_d^{*} + \sim V_d \quad \text{......(5.2)}$$

The load side reference voltages V_Labc^* are calculated as given in equation (5.3).

The switching signals are assessed by comparing reference voltages V_{Labc}^{*} and the load voltages (V_{Labc}) by hysteresis controller.

$$\begin{bmatrix} V_a^{*} \\ V_b^{*} \\ V_c^{*} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin \omega t & \cos \omega t & 1 \\ \sin\left[\omega t - \frac{2\pi}{3}\right] & \cos\left[\omega t - \frac{2\pi}{3}\right] & 1 \\ \sin\left[\omega t + \frac{2\pi}{3}\right] & \cos\left[\omega t + \frac{2\pi}{3}\right] & 1 \end{bmatrix} \quad \text{....... (5.3)}$$

The three-phase load reference voltages are compared with load line voltages and errors are then processed by hysteresis controller to generate the required switching signals for series APF switches.

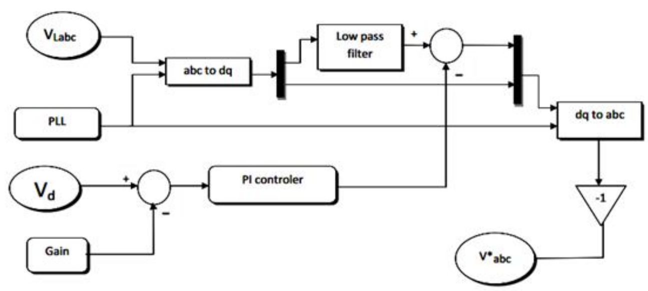
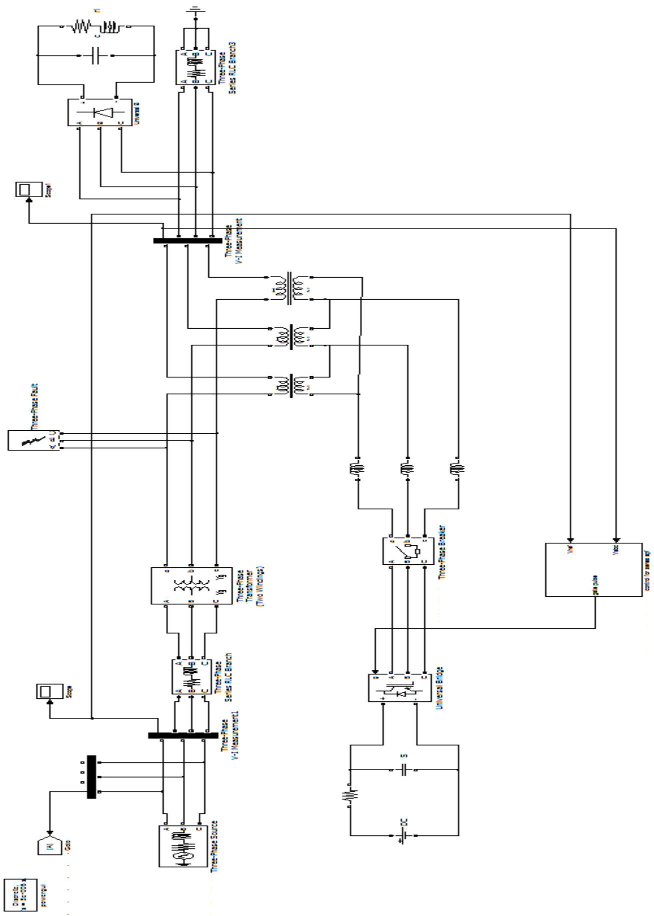


Fig 5.2 Synchronous d-q Reference Frame Based Compensation Algorithm

The synchronous reference frame theory or d-q theory is based on time-domain reference signal estimation techniques. It performs the operation in steady-state or transient state for generic voltage and current waveforms. It allows controlling the active power filters in real time system. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation. The basic structure of SRF controller consists of direct (d-q) and inverse $(d\text{-}q)^{-1}$ park transformations as shown in fig. above. These can useful for the evaluation of a specific harmonic component of the input signals. The reference frame transformation is formulated from a three phase a-b-c stationary system to the direct axis (d) and quadratic axis (q) rotating co-ordinate system. In a-b-c, stationary axes are separated from each other by 120^0. The d-q transformation output signals depend on the load current (fundamental and harmonic components) and the performance of the phase locked loop (PLL). The PLL circuit provides the rotation speed (rad/sec) of the rotating reference frame, where ωt is set as fundamental frequency component. The PLL circuit provides the vectorized 50 Hz frequency and 30˚ angle followed by sinɵ and cosɵ for synchronization. The i_d-i_q phase current are sent through low pass (LPF) for filtering the harmonic components of the load current, which allows only the fundamental frequency components. The LPF is a second order Butterworth filter, which’s cut off frequency, is selected to be 50 Hz for eliminating the higher order harmonics. The

PI controller is used to eliminate the steady-state error of the DC component of the d-axis reference signals. Furthermore; it maintains the capacitor voltage nearly constant. The DC side capacitor voltage of PWM voltage source inverter is sensed and compared with desired reference voltage for calculating the error voltage. This error voltage is passed through a PI controller whose propagation gain (KP) and integral gain (KI) is 0.1 and 1 respectively.

Series Active Power Filter Based on Synchronous Reference Frame Control



6.2.2 Simulation Parameters for Series Active Power Filter

Table 6.1 Parameters of Proposed System (Series APF)

	Parameter	Value
Supply	Fundamental voltage	115 KV
	Frequency	50 HZ
Load	[Non linear] Inductance	1 mH
	Resistance	100 Ω
	Capacitance	1500 µF
	[linear] Inductance	1 mH
	Resistance	1 Ω
DC-Link	Capacitance	2200 µF
	Ref. Voltage	18 KV
Fault	Fault resistance	1 Ω
	Operating time	0.1 to 0.3 sec
Breaker	Operating time	0.15 to 0.3 sec

VIII. RESULTS OF SERIES ACTIVE POWER FILTER

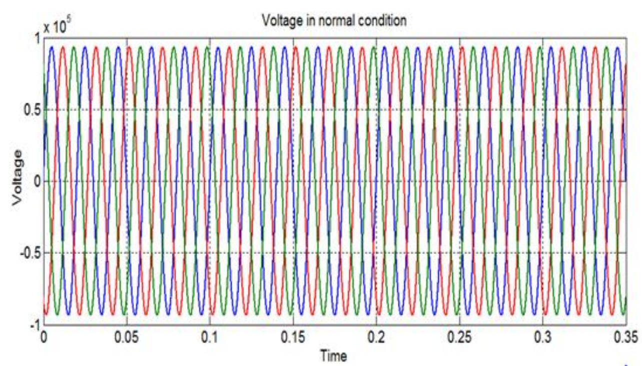


Fig. 6.4 Voltage Wave in Normal Condition

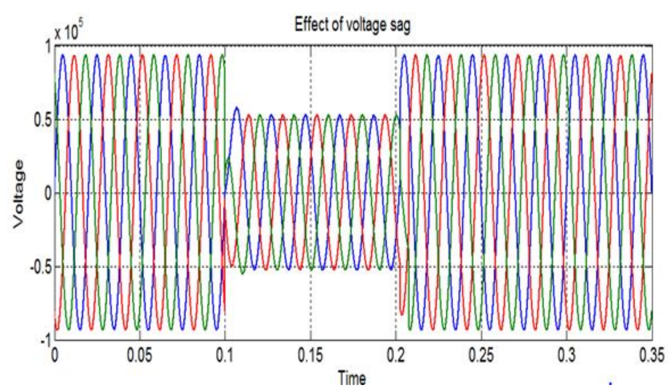


Fig. 6.5 Voltage Wave in Sag Condition

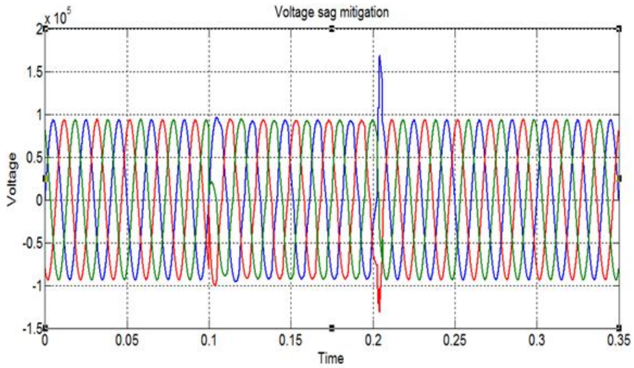


Fig. 6.6 Voltage Wave after Sag Mitigation

Synchronous d-q reference frame theory based controlled series active power filter is implemented on a 115 KV transmission network in MATLAB. Three phase fault creator was used to create voltage sag and it is removed successfully by series APF. Voltage wave forms for without connecting series APF and with connecting series APF is shown in fig. 6.3 and 6.4 respectively.

IX. CONCLUSION

In this paper work on power quality issues were discussed and series active power filter model is proposed to mitigate voltage harmonics. The proposed series active filter model is simulated with refrence frame theory transmission system and it is found that it is possible to mitigate distortion in voltage waveforms of system.

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