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PI CONTROLLER BASED SHUNT CONNECTED THREE PHASE ACTIVE POWER FILTER

Abhilasha N. Salunkhe[1], Dr. Paresh J. Shah[2]

[1]PG Scholar, Department of Electrical Engineering, SSBT's College of Engineering & Technology, Jalgaon.
[2]Professor, Department of Electrical Engineering, SSBT's College of Engineering & Technology, Jalgaon.

Abstract – *In recent years the large scale use of the power electronic equipment has led to an increase of harmonics in the power system. The harmonics results into a poor power quality and have great adverse economic impact on the utilities and customer so to mitigate current harmonic we were used shunt active power filter (SHAF). Proportional integral (PI) technique is utilize to control the performance of SHAF. The projected PI with SHAF monitoring structure under steady working circumstances is established to recover the power quality is simulated with MATLAB/ SIMULINK.*

Key Words: **Harmonics, Shunt Active Filter, DC link voltage, PI controller.**

1. INTRODUCTION

The large scale use of the non-linear loads such as adjustable speed drives, traction drives, etc. [1] and power converters has contributed for the deterioration of the power quality and this has resulted in to a great economic loss. Thus it is important to develop the equipment that can mitigate the problem of poor power quality.

Power Quality (PQ) [2], is defined as "any power problem established in voltage, current or frequency deviation which leads to damage, malfunctioning, disoperation of the consumer equipment". Poor power quality causes many damages to the system, and has a contrary economic impact on the utilities and customers. Highly automatic electric equipment, in particular, causes enormous economic loss every year. The problems of harmonics can be reduced or mitigated by the use of power filters. The Active power filters have been proven very effective in the reduction of the system harmonics [3]. One of the most severe and common power quality problem is current harmonics. Particularly, voltage harmonics [1] and power distribution equipment problems result from current harmonics.

The voltage generated at the generating station is not purely Sinusoidal. Due to the non-uniformity of the magnetic field and the winding distribution in a working AC machine, voltage waveform distortions are created, and thus the voltage obtained is not purely sinusoidal. The distortion at the point of generation is very small (about 1% to 2%), but still it exists. Due to this deviation from the pure sine wave, voltage harmonics occurs.

Each time a pure AC voltage is realistic to load, after that load current drawn by the load is proportional to the voltage and impedance and monitors the covering of the voltage waveform. These loads are referred to as linear loads (loads where the voltage and current follow one another without any distortion to their pure sine waves) [4]. Some loads cause the current to vary disproportionately with the voltage during each half cycle. These loads are defined as non-linear loads. The current harmonics and the voltage harmonics are generated because of these non-linear loads.so due to non linear load effects many problem's like electro-magnetic interference (EMI), power system voltage fluctuations low low power factor, low energy efficiency, and so on. Hence, it is necessary to compensate this effects [5].

2. ORGANIZATION OF CONTROL CONVERTERS

The accuracy in the estimation of the ac grid voltage parameters has a strong influence in the overall performance of grid-connected power converters. A precise synchronization algorithm is needed to estimate the grid voltage parameters, i.e., voltage amplitude, frequency, and phase angle, as these values are needed for conducting an accurate control of the active and the reactive power delivered to the grid. In addition, a precise monitoring of the grid conditions is mandatory in order to determine the most suitable operation mode of the converters, as well as for supporting properly the connection and disconnection maneuvers. Due to the significance of the control of microgrids under generic grid conditions, the synchronization system should be able to confirm a proper behavior under unbalanced and distorted voltage conditions. The synchronization system should be able to work on both grid-connected and island modes by using power converters. Change between these two process the synchronization unit should provide precise synchronization signals which allow the grid-forming power converter for establish a stable voltage. In the island mode, the synchronization system works as an oscillator at a fixed frequency $\omega*$. In transient operation, the voltage generated by the grid-forming power converter should be resynchronized with the restored grid voltage. The synchronization system slowly varies the phase angle and frequency of the island's voltage to resynchronize with the grid voltage. All the grid-feeding power converters linked to such microgrid would be exposed to the re-joining frequency and phase angle transients, so that this maneuver has to be prepared in a stable and secure way.

2.1. Synchronous Reference Frame Phase-Locked Loop

The phase-locked loop technology has extensively been used to synchronize grid-connected power converters with the grid voltage. In three-phase systems, the synchronous reference frame phase-locked loop (SRF-PLL) has been broadly used for this purpose. The structure of the SRF-PLL is depicted in Fig.1. By using Park transformation when the abc reference frame into the rotating dq reference frame then SRF-PLL decodes the three-phase instantaneous voltage waveforms. The angular position of this dq reference frame is controlled through a feedback control loop which drives the vq component to zero. In this synchronization structure, the estimated grid frequency is ω^l. As depicted in Fig. 1, the value of the rated frequency is normally included as a feed forward ω^l in order to improve the dynamics of the phase estimation θ^l, which is obtained by integrating ω^l. [6]–[9]. In spite of the good behavior of the SRF-PLL under balanced grid conditions, its performance is deteriorated when the three phase input signal becomes unbalanced or distorted [10], [11].

To overcome this drawback, some advanced grid synchronization techniques have been proposed in the literature. This is for instance the case of the decoupled double-synchronous reference frame PLL, which is an enhanced PLL that stems from the same operation principle as the SRF-PLL, but improves its phase-angle and magnitude estimation under unbalanced conditions [12], [13].

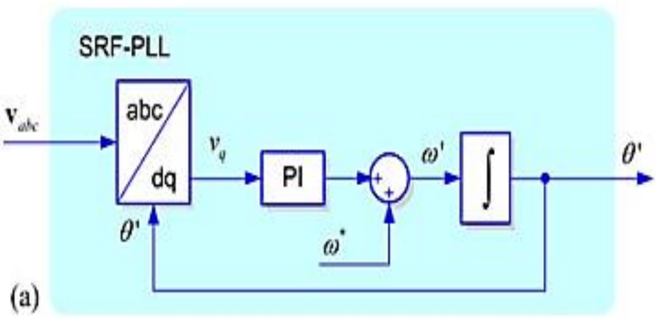


Fig.-1 Block diagram of SRF PLL

2.2. Stationary Reference Frame Frequency-Locked Loop

As an alternative to PLL-based synchronization structures, other implementations based on a frequency-locked loop (FLL) can be used. Among different proposals, the synchronization structures based on the implementation of a second-order generalized integrator (SOGI) and an FLL to detect the grid voltage components, $V^l_{\alpha\beta}$ and $qV^l_{\alpha\beta}$, as well as the grid frequency ω^l [14], as is presented in Fig. 2, have proven to be effective and accurate under generic conditions. The SOGI is implemented in both $\alpha\beta$ axis, giving rise to a dual-SOGI (DSOGI) structure, which is an adaptive bandpass filter that provides the filtered version of the input voltage vector $V^l_{\alpha\beta}$, as well as its quadrature component $qV^l_{\alpha\beta}$. The resonance frequency of the DSOGI is the grid frequency estimated by the FLL. One of the main advantages of using an FLL lays on the fact that this structure is less sensitive than the PLL to phaseangle jumps that may occur in the grid voltage during transient grid faults, thus improving its performance under abnormal grid conditions [15].

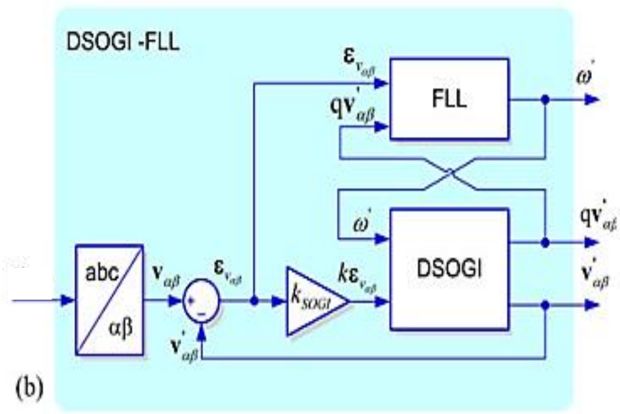


Fig.-2 Block diagram of DSOGI FLL

This interesting feature of the FLL provides a fast dynamic response with low overshooting, thus allowing a fast and a smooth transition between the grid-connected and the islanded operating modes of the microgrid.

3. DC LINK VOLTAGE REGULATION BY USING PI

Fig. 3 shows the construction of the controller circuit. System contains of PI controller, limiter and three phase sine wave generator for reference current and switching signals generation [16]. It is known that the real power of the system changes and that is compensated by the DC link capacitor voltage. The fresh capacitor voltage is matched with a reference voltage and error signal which is given to the PI controller.

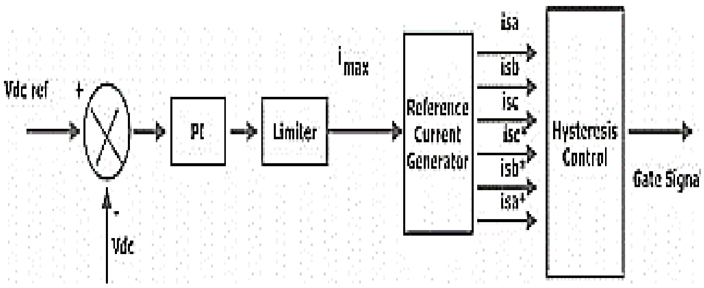
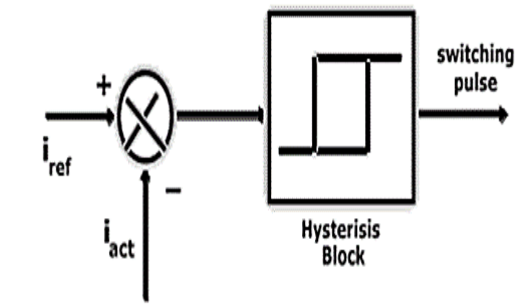


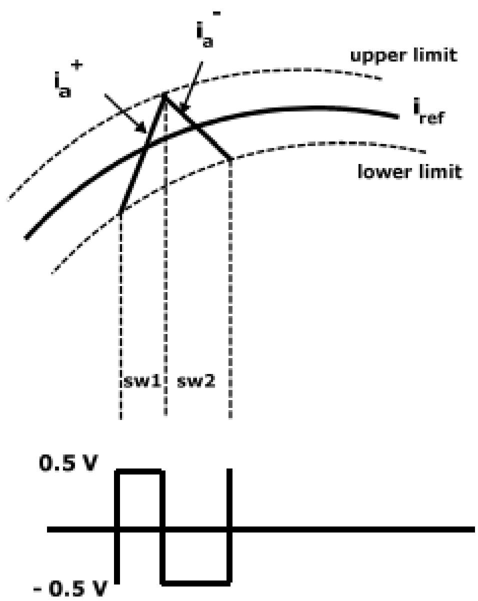
Fig.-3 Conventional PI Controller

Then the error signal passing through a PI controller, which gives to zero steady error in tracking the reference current signal. The output of the controller is in peak value of the supply current (Imax), which is composed of two components: (a) fundamental active power component of load current and (b) loss component of APF; to maintain the average capacitor voltage to a constant value. This peak value of the current (I_{max}) is multiplied with the respective source voltages for generate the reference compensating currents. Hysteresis band gives error signal which compared and sense actual current (I_{sa}, I_{sb}, I_{sc}) and reference current (I^*_{sa}, I^*_{sb}, I^*_{sc}).

Fig. 4 shows how the error signal is generated by comparing the two currents. The output of this hysteresis band is used to give the gating signal, which controls the converter switches and using this gating signal the compensating current are generated. The source currents are prepared to monitor the sinusoidal reference current, within a fixed hysteretic band. The width of hysteresis window, harmonic spectrum and the device switching frequency is determines by the source current pattern. In this scheme, each phase of the converter is controlled independently. To increase the current of a particular phase, the lower switch of the converter associated with that particular phase is turned on while to decrease the current the upper switch of the respective converter phase is turned on. With this, one can realize the potential and feasibility of PI controller [17], [18].



(a) Current Wave of Current Controller



(b) Current Controller Waveform

Fig.-4 Hysteresis Band

4. SIMULATIONS

Table-1 System parameters used in Simulink

System parameters	Values
Source voltage	300V(Peak)
DC Link Capacitance	1.3mF
Load impedance	50Ω,100mH
FLC	7*7 Triangular
Sample Interval	5e-5 s
Smoothing Reactance	1.8mH,120µF

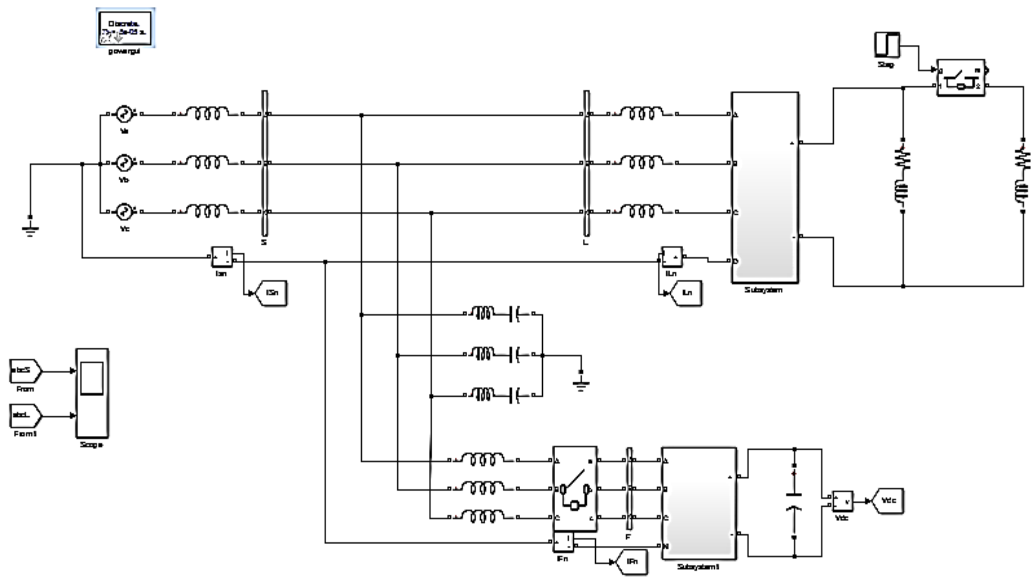
The three-phase three-wire system with a non-linear load is equipped with shunt active filter for mitigating the current harmonics. PI controller and FLC are used to control the shunt active filter under non linear load condition. Table 1 shows the system parameters of the source voltage condition circuit that has been analyzed.

MATLAB Model of Compensation Principle of SHAF

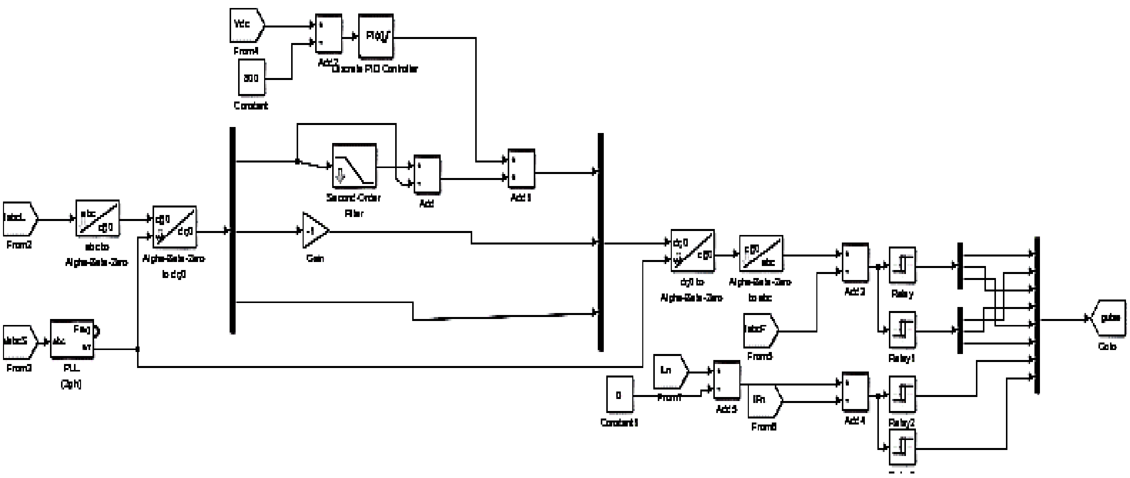
Fig. 5 shows the MATLAB modules of compensation principle of SHAF system and PI controller. The bridge of eight IGBTs block set is used to build three phase voltage source inverter. The inductor, capacitor, resistor are include in the filter design. This filter illuminates the higher order harmonic. From the scope the compensation status is observed. Reference generator block detect the sag voltage and convert this in to two stationary voltages. The pulse generator block generates pulses form PWM topology. The block can be used to fire the forced commutated devices IGBTs of three phase inverter.

The pulses of measured voltages are generated by comparing a repeating waveform to a reference modulating signal. The modulating signals can be generated by means of selecting sectors of hexagon, calculating switching time and selecting switching pulses. Once the sag is appearing on one of the feeder, reference signal generate pulse for three phase inverter. This PWM pulses applied to the gates of the IGBTs for triggering. The inverter circuit converts DC signal in to AC signal. The output voltage is then measure on the scope labeled as result. Because of the LC filter pure sine wave output is obtained.

From the FFT analysis the THD of a periodic distorted signal is measured graphically. The THD is measured for voltage. The total harmonic distortion the ratio of RMS value of total harmonics of the signal, divided by the RMS value of its fundamental signal.



(a) Compensation principle of SHAF



(b) PI Controller with SHAF

Fig.-5 MATLAB Models

5. RESULT ANALYSIS

Fig. 6 indicates waveforms of source current, load current and remunerating current with PI controller. SHAF filter current insert into grid current after 0.06 seconds. Up to 0.06 sec, grid current completely affected by load current, but when filter current is injected after 0.06 seconds and we can see that grid current waveform becomes completely sinusoidal by using PI controller.

Fig. 7 shows the power factor it is clear from the figure after compensation power factor is nearer to unity that is 0.9705. The three-phase three-wire system with a non-linear load is equipped with shunt active filter with PI controller for mitigating the current harmonics. For harmonic calculations during compensation the FFT analysis is used. Every one of these parts are demonstrated exclusively, coordinated and after that comprehended to reproduce the framework THD for PI model utilizing FFT investigation is 2.22% which is shown in fig 8.

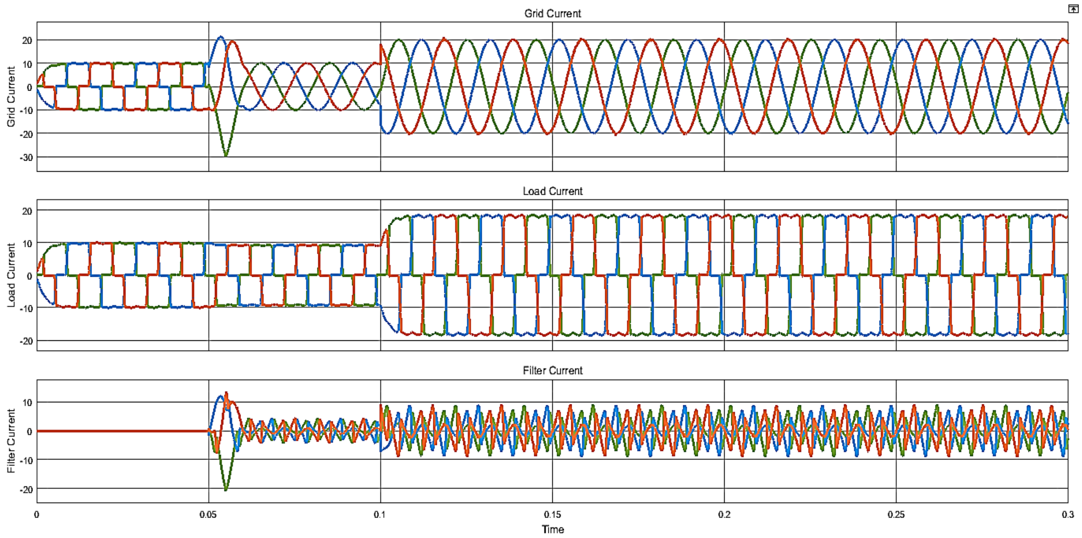


Fig.-6 Waveforms of Source Current, Load Current and Remunerating Current with PI Controller

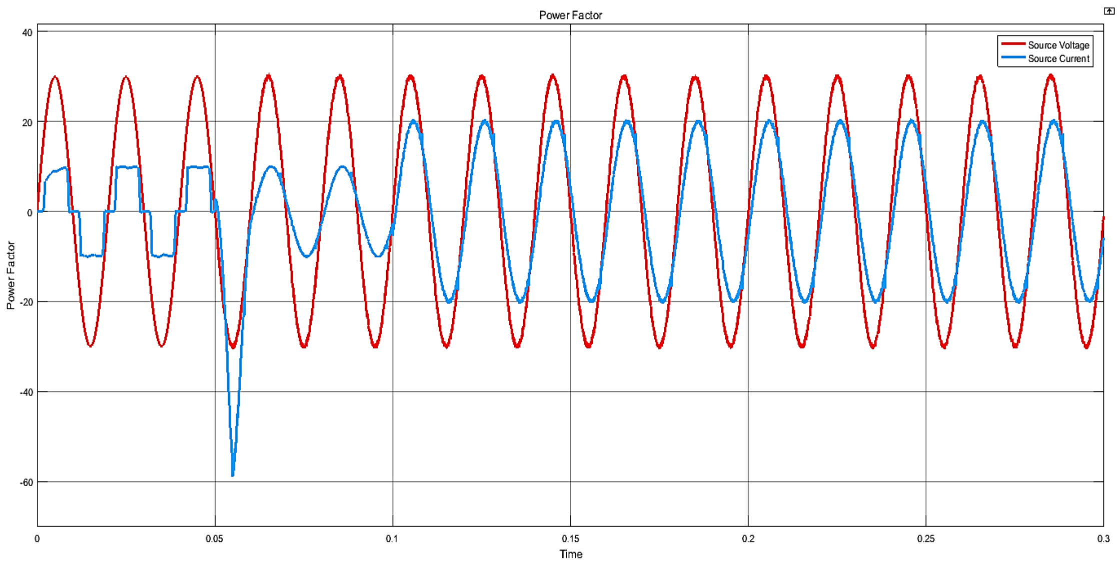


Fig.-7 Power Factor for APF with Conventional PI Controller

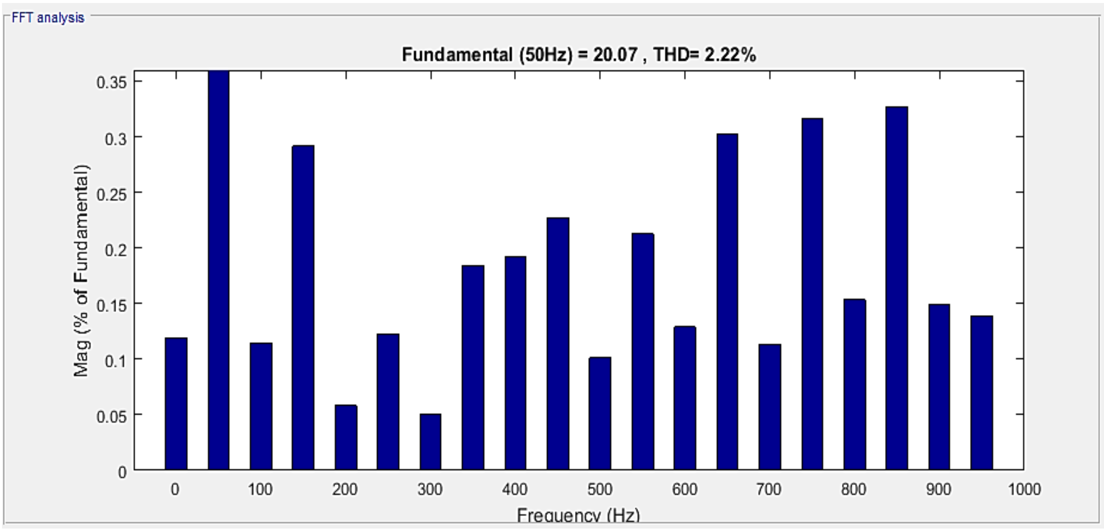


Fig.-8 FFT Source Current with PI Controlled APF

6. CONSLUSION

Improvement of power class and relative power compensation for renewable based power generation has been proposed in this system. Major advantages of projected system are related to its simplicity, demonstrating and implementation. A model has been developed in MATLAB SIMULINK and simulated to verify the results. PI controller offers fast alternation to mitigate current harmonic and improve power quality by using the shunt active filter, which gives total THD 2.22% as well as improve power factor.

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