Fractional Order PID Controlled Interleaved Boost converter Fed Shunt Active Filter System

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ABSTRACT

Interleaved Boost Converter (ILBC) is a better converter between Photo Voltaic (PV) source and shunt active power filter. This paper deals with comparison of time domain outputs of PI and Fractional Order PID(FOPID) controlled ILBC fed shunt active filter in a grid connected PV system. The aim of this work is to minimize current ripple using ILBC between PV system and filter to improve the dynamic performance of shunt active filter. Closed loop monitored PI and FOPID systems are modeled, and the corresponding results are presented. MATLAB results of load voltage, current, converter voltage and currents with FOPID exhibits enhanced dynamic response. The proposed FOPID controlled ILBC Fed Shunt Active Filter system (ILBCFSAF) has advantages like low settling time, less peak over shoot and reduced steady state error in load voltage. The simulation results of ILBCFSAF are compared with the corresponding hardware results.

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1. INTRODUCTION

Distribution sources such as Photo-Voltaic (PV) generation system, and wind power systems have become popular since they are green power source. The DC-AC inverter can be used as Shunt Active Filter(SAF) whose output is controlled by pulses to convert dc power of PV into ac and to inject equivalent currents to compensate harmonics. The pulses are produced by a controller which monitors the deviation between system voltage and input dc voltage of converter. Conventionally PI or PID controllers are used for this purpose but suffer from frequent tuning of their parameters for different load and disturbance conditions. The step up converters have drawbacks of low voltage gain and low power rating. Interleaved Boost converter has reduced ripple currents in both the input and output sides.

Different steps involved in design of MPPT controller and evaluation of the need of storage devices, load take off strategies of PV system is presented in [1]. Effect of partial shading on building Integrated PV systems, causes and mitigation techniques using software and hard ware solutions is presented in [2]. A fractional-order PID (FOPID) controller is designed in[3] to control a DC-DC boost converter in a PV-system. To obtain the best system performance, parameters of the proposed controller are tuned by using Particle Swarm Optimization (PSO) algorithm. Analysis and hardware implementation of two phase ILBC is proposed in [4] where in design of magnetic component i.e., inductor is studied. High gain four stage ILBC is proposed in [5] which is a combination of two 2 phase interleaved boost converters to obtain smooth output ripple current, increase in power rating and efficiency. Basic concepts regarding design of ILBC which involves selection of inductors, input and output capacitors, power switches etc., was given in[6]. As far as the controlling of SAF is concerned, the Instantaneous Power Theory (IPT) and its application to power conditioning given by Akagi [7] is the basis for SAF. A detailed review of SAF with respect to control techniques and topology is presented by Bhimsingh[8].A method to evaluate the performance of utility interactive PV system is given by Abouzahr[9]. The design of SAF with output LCL filter is given by Tang[10]. The control algorithm of SAF for voltage regulation and PFC is depicted by Haddad[11]. A selection methodology for the number of phases and analysis of the input current ripple with CCM and DCM is for an ILBC is given in [12]. A study of various PV fed Active filters with respect to their circuit and control methods is presented in [13]. To investigate various Power Quality issues such as THD, phase imbalance and excessive neutral currents etc., a predictive control technique using FLC is proposed in [14] where in FLC is applied for MPPT. A single-phase dual-stage PV-Grid system with active filtering capability is constructed in [15] with simple circuits such as current transducer. The system used a boost chopper as MPPT controller.

Lot of research on single stage PV grid-connected system with power quality improvement has been done so far but not many studies are available on Boost Converter topologies used to boost the low magnitude PV voltages. In this paper, a novel high capacity grid-connected PV system based on Interleaved Boost converter fed Shunt active filter is proposed, which has reduced current ripple.The problem formulation involves improving dynamic response of ILBCFSAF system. The pulse width applied to the ILBC is adjusted to obtain constant voltage at the output. The FOPID is proposed to improve the dynamic response.

The content of this paper is organized as follows: Section.2 deals with description of existing and proposed system. Control schemes of the systems are described in the 3rd section. Simulation results are described in section 4. A prototype model with hard ware components is developed, the details of which are presented in section 5. The work is concluded in section 6.

2. DESCRIPTION OF THE PROPOSED SYSTEM

The block diagram of conventional SAF system is shown in Figure 1. The SAF is connected near the non linear load.

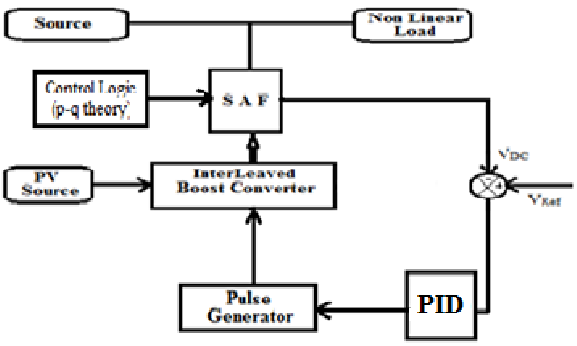


Figure 1. Block diagram of conventional system

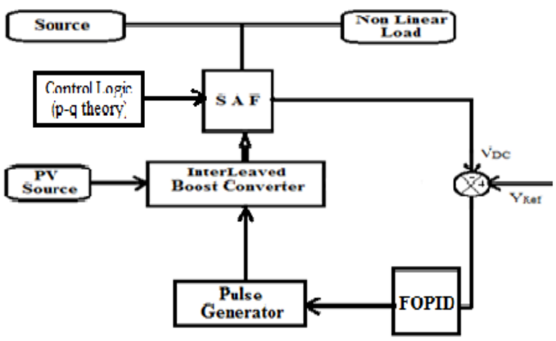


Figure 2. Block Diagram of Proposed ILBCFSAF System

Block diagram of the proposed ILBCFSAF system is shown in Figure.2. A three phase voltage source inverter is made to work as SAF and is the key component of the system, dc required to charge the capacitor of the SAF is obtained from ILBC. Actual voltage of this DC Link capacitor is compared. With the reference voltage and the voltage error is applied to the FOPID. The output of the FOPID controls the pulse width applied to ILBC.

3. RESEARCH METHOD

3.1. Inter Leaved Boost Converter

ILBC overcomes the drawbacks of conventional boost converters, its static and dynamic performances are poor. Hence, an effective control of these converters is needed. Though conventional PI or PID controllers are useful, tuning of these for different loads is problematic. This paper proposes a fractional order PID controller for controlling ILBC to derive good dynamic response of the load voltage. The circuit diagram of ILBC is shown in Figure.3.

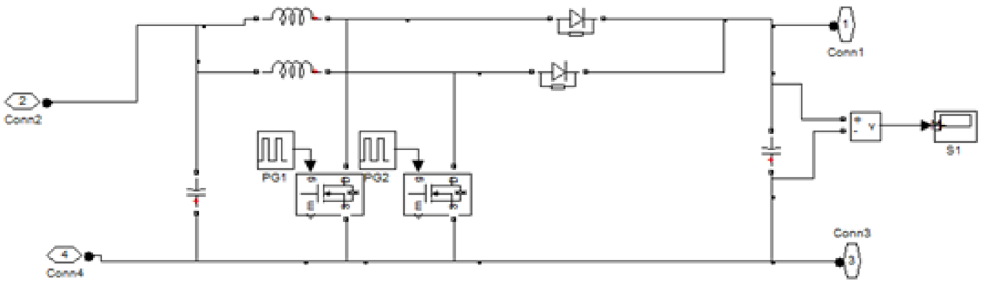


Figure 3. Circuit diagram of ILBC

The design considerations of ILBC are as follows
L and C for ILBC are determined using

$$L = V_i D/f I \tag{3.1}$$

$$C = D/2.f.R \tag{3.2}$$

L1 and L2 works out to 130mH and C workout to 470μF

3.2. Control of SAF

p-q theory is used for controlling the three leg VSI inverter. As this thery is based on α-β-0 frameed quantities, Conversion of source voltages and currents in to this frame is done using a transformation matrix C.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = C \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} ; \qquad \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = C \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{3.3}$$

where $$C = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \tag{3.4}$$

The active and reactive power demanded by the load can be decomposed into

$$p_L = \overline{p_L} + \widetilde{p_L} ; \qquad q_L = \overline{q_L} + \widetilde{q_L} \tag{3.5}$$

The reference source currents in the α-β-0 frame are as follows:

$$\begin{bmatrix} i_{sRf0} \\ i_{sRf\alpha} \\ i_{sRf\beta} \end{bmatrix} = \frac{1}{v_\alpha^2+v_\beta^2} \begin{bmatrix} v_0 & 0 & v_\beta & -v_\alpha \\ v_\alpha & -v_\beta & 0 & v_0 \\ v_\beta & v_\alpha & -v_0 & 0 \end{bmatrix} \times \begin{bmatrix} \bar{p}L_{\alpha\beta} + \bar{p}L_0 \\ 0 \\ 0 \\ 0 \end{bmatrix} = \frac{\bar{p}L_{\alpha\beta} + \bar{p}L_0}{v_\alpha^2+v_\beta^2} \begin{bmatrix} 0 \\ v_\alpha \\ v_\beta \end{bmatrix} \tag{3.6}$$

Assuming Ls= 10mH, the capacitance of SAF is calculated by

$$f_s = 1/2\pi\sqrt{L_s C_s} \tag{3.7}$$

Pulse width of inverter is found to be 0.66ms for a supply frequency of 50Hz.

3.3. Proposed FOPID Controller

The enhanced version of conventional PID controller is the fractional order PID (FOPID) controller and is designed on the basis of fractional calculus. For many decades, PID controllers have been very popular in industries due to their simplicity of design and good performance. As a result of, continuous efforts to improve their quality and robustness,in the field of automatic control, the fractional order controllers would lead to more precise and robust control performances.

In order to implement the control Scheme of a SAF in a closed loop, the DC capacitor voltage of the converter Vdc is sensed and then compared with the reference value Vdcref. The error e(n) = Vdcref – Vdc is in frequency domain. The output and inputs of the controller are related as follows:

$$Vo(s) = Vi(s)\,(K1+ K2/Sm+K3Sn) \tag{3.8}$$

where m and n are fractions.

4. SIMULATION RESULTS AND ANALYSIS

Open loop controlled ILBCFSAF system with reduction in solar irradiation as a result of partial shading or ony other effect is shown in Figure 3.1 line is modelled as series combination of resistance and reactance. ILBC at the input of inverter is shown as a subsystem. Linear and non linear loads are connected in parallel at the receiving end. The output voltage of solar system is shown in Figure 3.2 and its value reduces from 220 V to 180 V as a result of fall in input irradiation . The output voltage of ILBC is shown in Figure 3.3 and its value is 320 V.

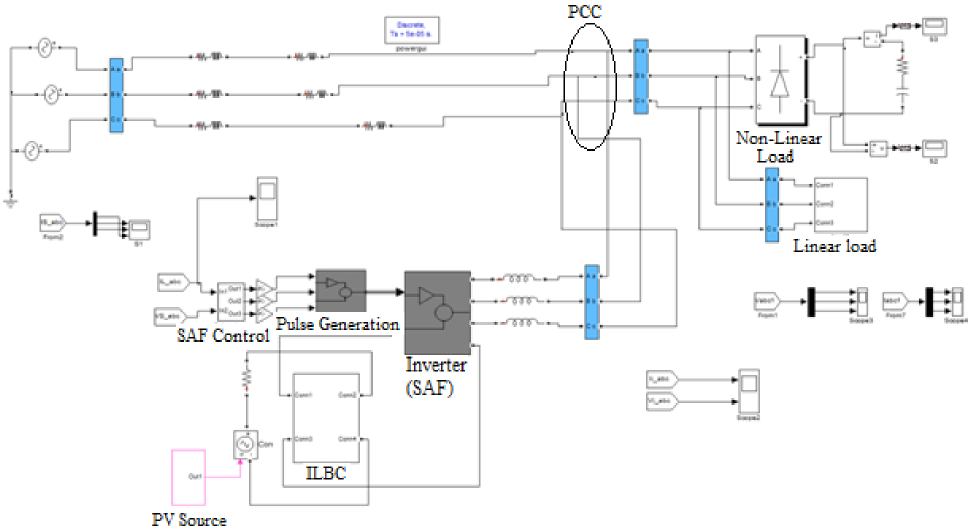


Figure 3.1. Open loop controlled ILBCFSAF system with reduction in solar Irradition

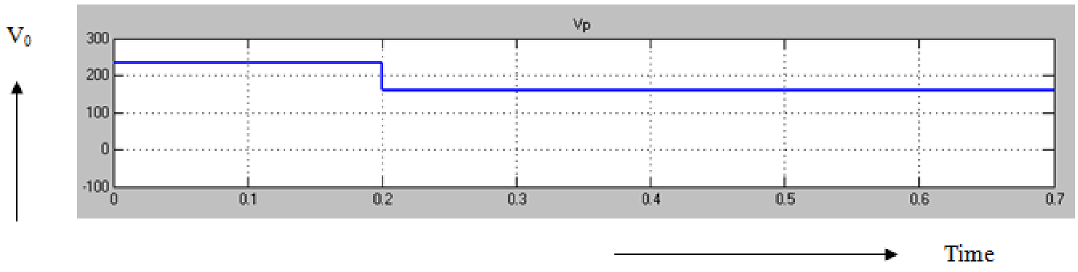


Figure 3.2. Output voltage of solar system

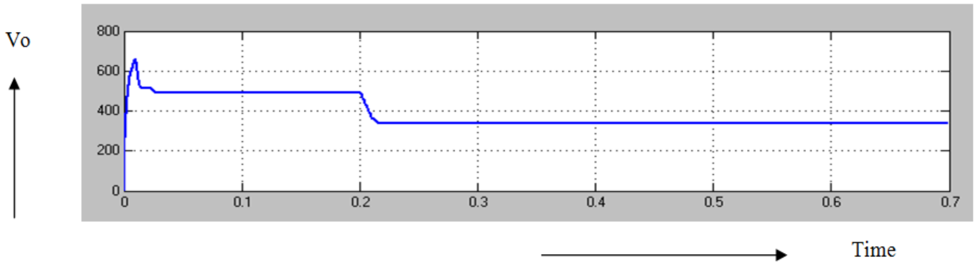


Figure 3.3. Output voltage of ILBC

The output current of linear load is shown in Figure 3.4 and its peak value is reducing at 0.2 sec. The output voltage of non linear load is shown in Figure 3.5 and its peak value is 300 V. The RMSoutput current of non linear load is shown in Figure 3.6 where in it can be studied that the current is reduced from 4A to 3A due to reduction in the output of solar system.

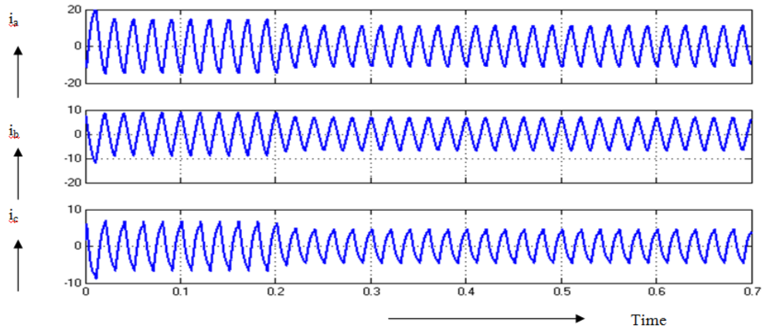


Figure 3.4. Output current of linear load

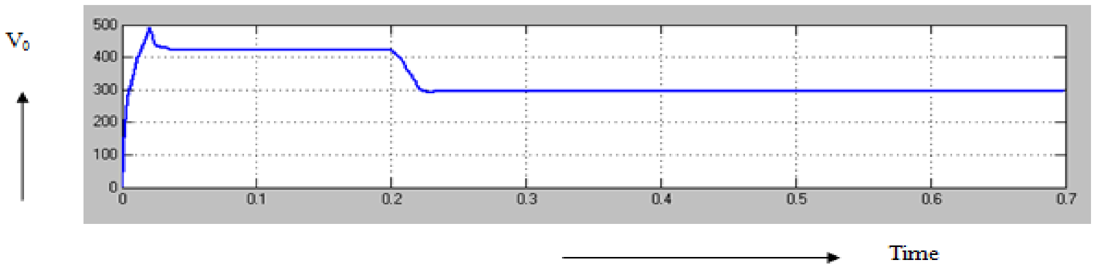


Figure 3.5. Output voltage of non linear load

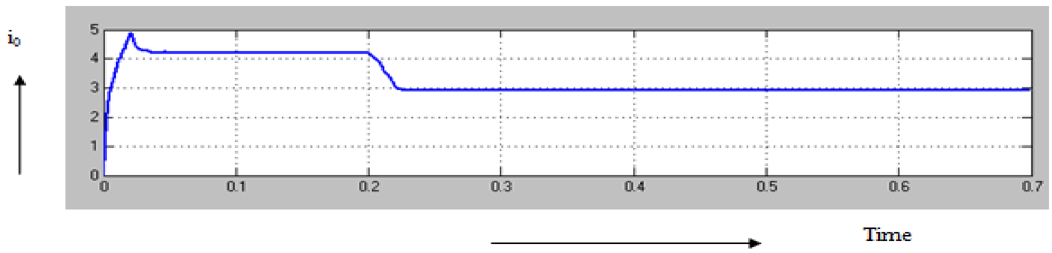


Figure 3.6. Output Current of non linear load

The closed loop ILBCSAF system with PI controller is simulated. The output of ILBC is senced and is compared with the reference voltage. The error is applied to a PI controller. The output of PI controller is applied to a comparator. The comparator produces updated pulse for driving MOSFETS of ILBC. The output voltage of solar system is shown in Figure 4.1 and its value is 160 V. The source current is shown in Figure 4.2 The output voltage of ILBC is shown in Figure 4.3 and its value is 500 V. The output current of linear load is shown in Figure 4.4 and its peak value is 6.5 A. The output voltage of non linear load is shown in Figure 4.5 and its value is 450 V. The RMS output current of non linear load is shown in Figure 4.6 and its value is 4.5A. Here the action of controller can be identified in regaining the reduction in load current as a result of disturbance in PV system. The frequency spectrum of source current is shown in Figure 4.7 to study the SAF action, the THD content is 4.8%. It can be seen that the output of ILBC, output of linear load and output of non linear load regulated.

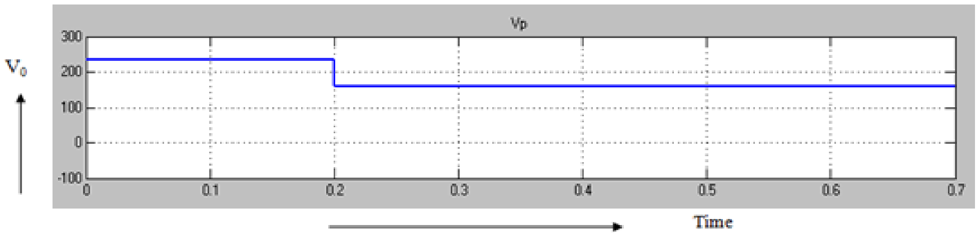


Figure 4.1. Output voltage of solar system

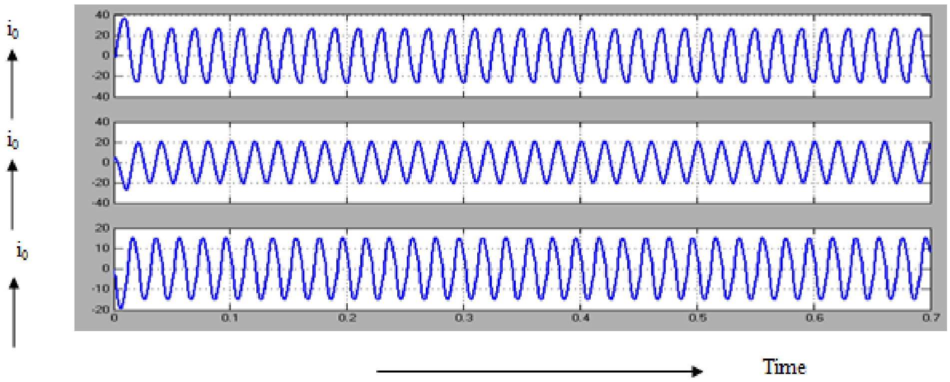


Figure 4.2. Source current waveforms

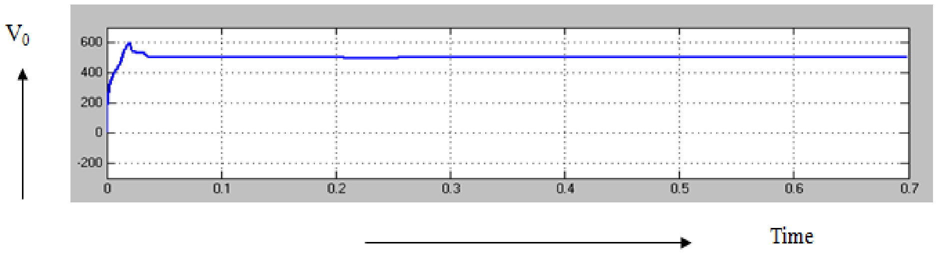


Figure 4.3. Output voltage of ILBC

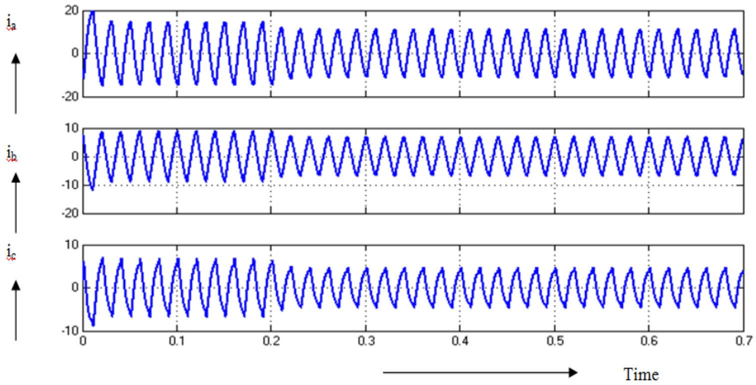


Figure 4.4. Output current of linear load

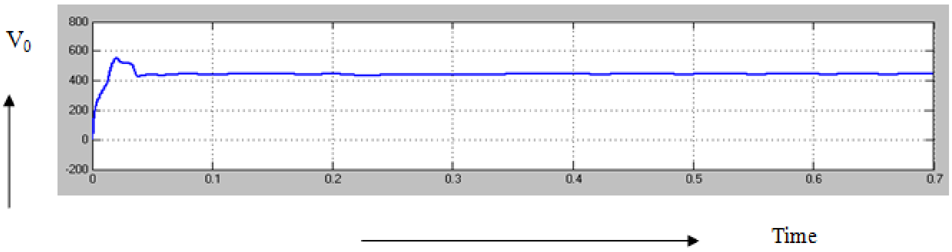


Figure 4.5. Output voltage of non linear load

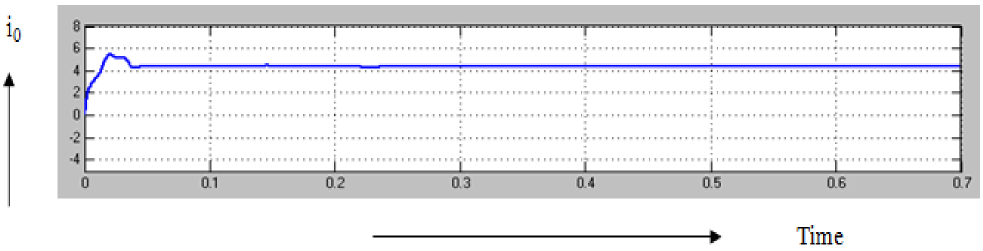


Figure 4.6. Output current of non linear load

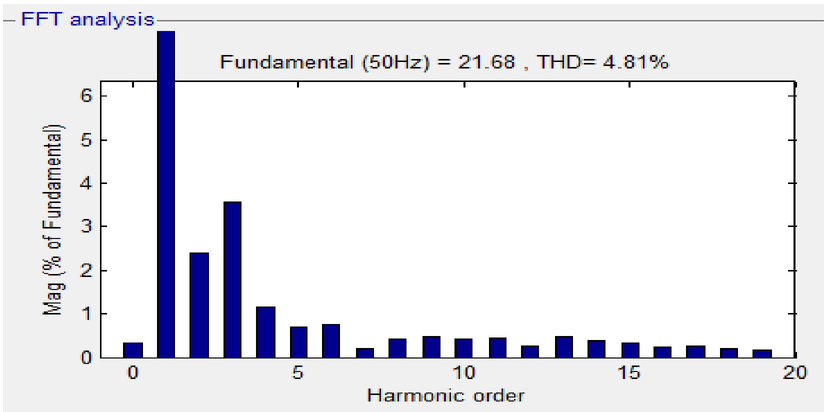


Figure 4.7. Frequency Spectrum of Source current

The closed loop ILBCFSAF system with FOPID controller is shown in Figure 5.1. The PI controller in the closed loop is now replaced by FOPID. The output voltage of solar system is shown in Figure 5.2 and its value is 160 V. The source current is shown in Figure 5.3. The output voltage of ILBC is shown in Figure 5.4 and its value is 500 V.

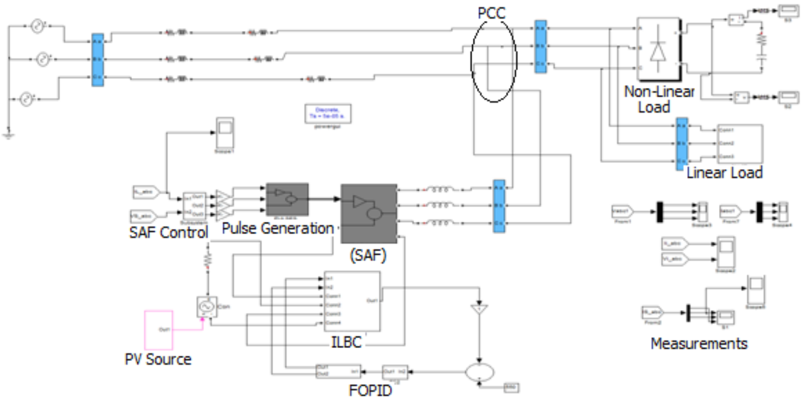


Figure 5.1. Closed loop ILBCSAF system with FOPID

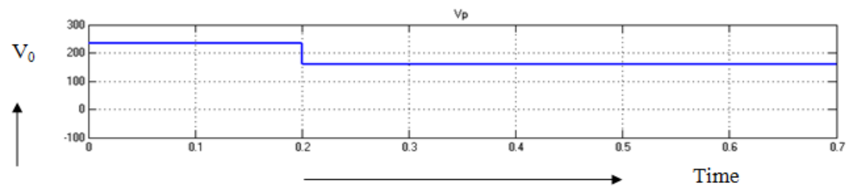


Figure 5.2. Output voltage of solar

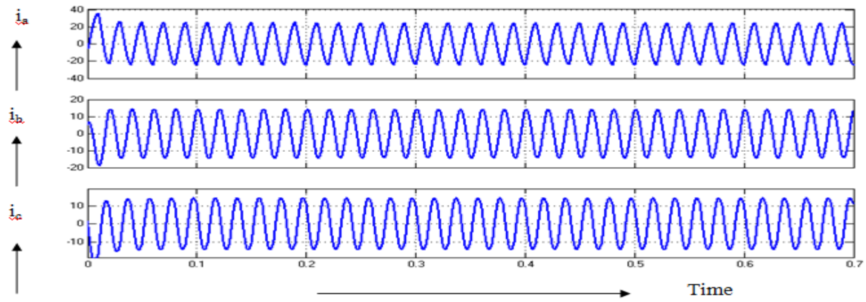


Figure 5.3. Source current

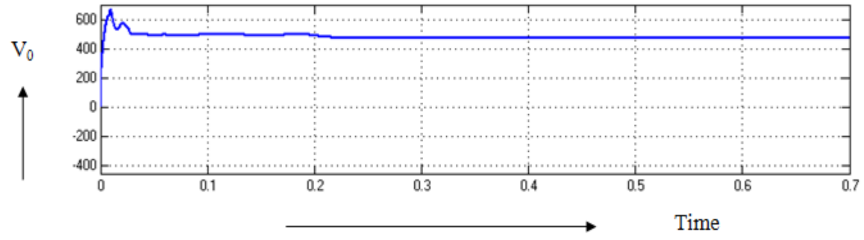


Figure 5.4. Output voltage of ILBC

The output current of linear load is shown in Figure 5.5. The RMS output voltage of non linear load is shown in Figure 5.6 and its value is 400 V. The voltage response with FOPID is much smoother than that of PI controlled system.

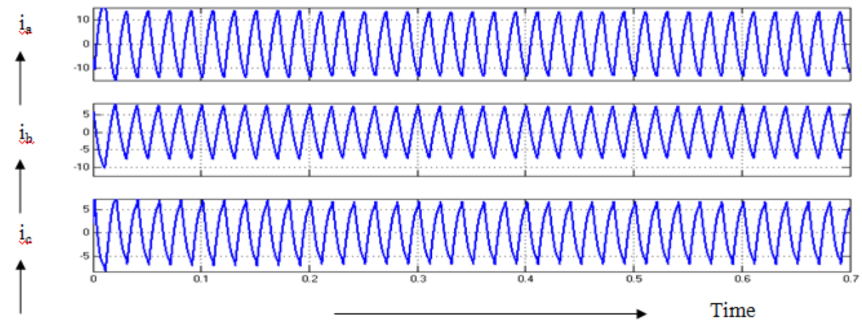


Figure 5.5. Current through linear load

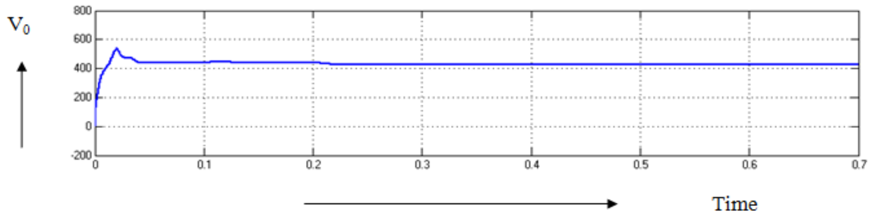


Figure 5.6. Output voltage of non linear load

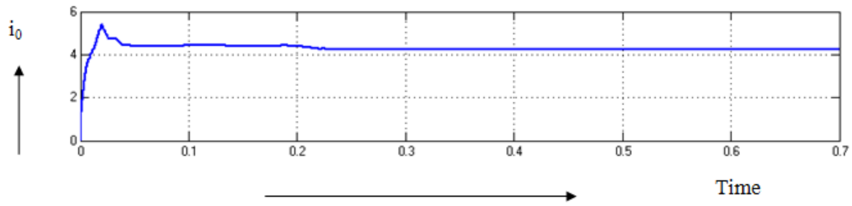


Figure 5.7. Output current of non linear load

The RMS output current of non linear load is shown in Figure 5.7 and its value is 4.5 A. The frequency spectrum of source current is shown in Figure 5.8 and the THD content is 2.9%. The summary of Time Domain parameters of non linear load current is shown in Table-1. The settling time is reduced from 0.23 to 0.21 sec and steady state error is reduced from 9.5 V to 3.6 V. Summary of source current THD is given in Table-2. The THD content is reduced by 1.9% by replacing PI with FOPID controller. The Comparison of Real & Reactive Power supplied by the soure for loads is shown in Table-3. The real and reactive powers increase with the addition of SAF. This increase is due to increase in the voltage and reduction in THD.

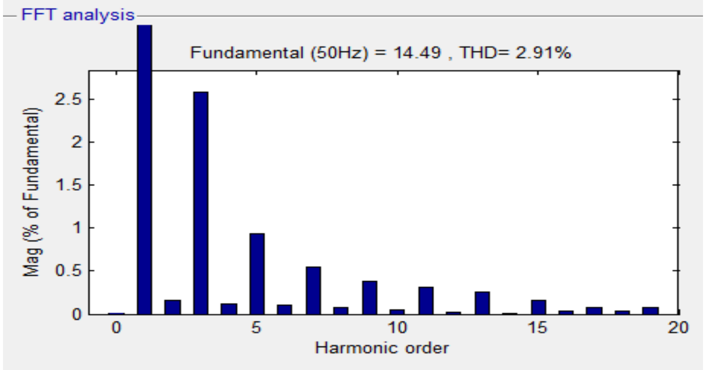


Figure 5.9. Frequency Spectrum for Source current

Table 1. Summary of Time Domain Parameters of non linear load current

Type of Controller	Peak time (s)	Setting time (s)	Steady state error (V)
PI	0.21	0.23	9.5
FOPID	0.20	0.21	3.6

Table 2. Source current THD with PI & FOPID controller

Controller	THD
PI	4.81%
FOPID	2.91%

Table 3. Comparison of Real & Reactive Powers supplied by source

Shunt active filter	Real Power (MD)	Reactive Power (MVAR)
Without shunt active filter	0.0179	0.0057
With shunt active filter	0.0358	0.0090

5. EXPERIMENTAL RESULTS

The prototype with hardware components for open loop system is fabricated and tested in the laboratory to verify the feasibility of the proposed system. The snap shot of the complete kit is shown in Figure 6.1. It consists of a solar panel and other control circuitry including PIC16f84A Controller, MOSFETs, Voltage Regulators etc,. The list of important components is given in Table 4.

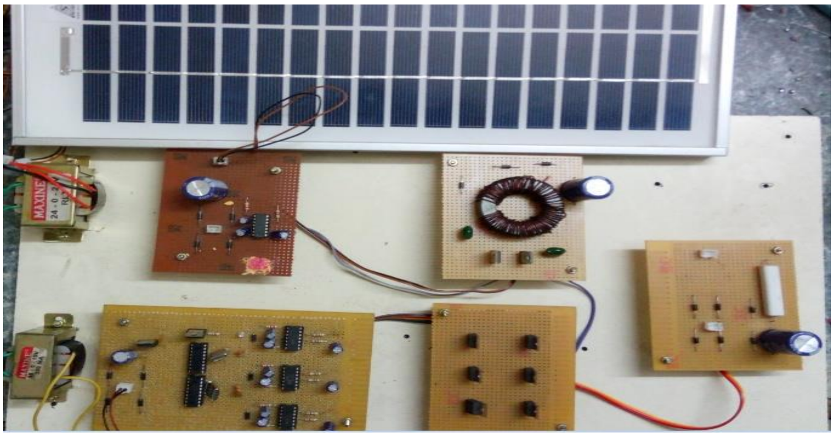


Figure 6.1. Hardware prototype of the proposed ILBCSAF system

The output waveforms are shown in Figure 6.2. The solar output voltage is shown in Figure 6.2 (a) which is observed to be around 12V. The switching pulses of Boost converter are shown in Figure 6.2(b). The boosted output voltage of the converter shown in Figure 6.2(c) which is observed to be of 135V and is ripple free.

The inverter side voltages and pulses of MOSFET are presented in Figure.6.3 below. The switching pulses of S1, S3 are shown in Figure.6.3 (a) while for S2, S4 are given in Figure.6.3 (b). The AC output voltage injected by inverter is shown in Figure.6.4

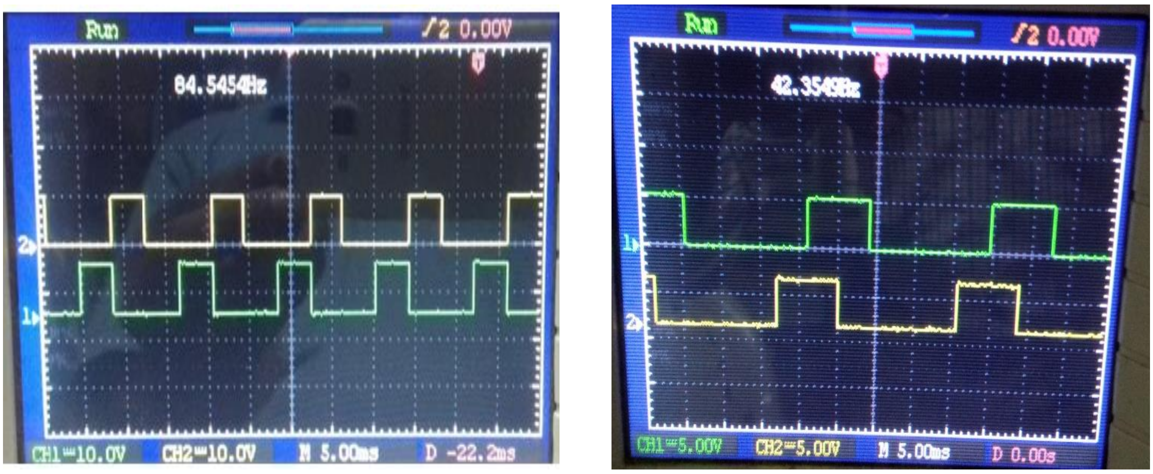
Table 4. List Of Components

	Power Supply Unit	Driver Circuits	Pulse Generating Circuit
MOSFET IRF840 Capacitors	Diodes	Resistors R1:100ohm	Microcontroller
C:147uf	IN4007	R2: 1k	pic16f84a
Resistors R:10K,1/2 w	Capacitor C2:	R3 : 330ohm	Crystal oscillator: 4mhz
Inductors L1:60UH	1000uf/250v	R4: 22k	Capacitors
		Opto-oupler IR2110	C1:33pf
		Diode IN4007	C2:470uf
		Capacitor 1000mf/25v	C3:47uf
			Zener diodes:5.1v

Figure 6.2(a). Solar output voltage

Figure 6.2(b). Switching pulses

Figure 6.2(c). Output of Boost converter



(a). Switching pulses for S1 and S3 (b). Switching pulses for S2 and S4

Figure 6.3. Switching pulses of inverter

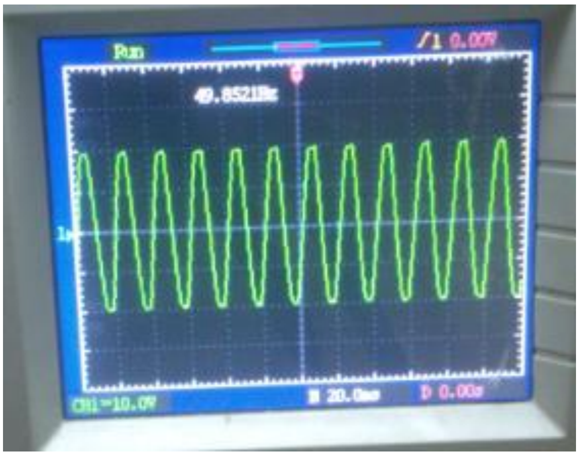


Figure 6.4 Output voltage of SAF

Figure.6.5. Output voltage of nonlinear load

6. CONCLUSION

ILBCFSAF system controlled by PI and FOPID are modelled and simulated using SIMULINK. The simulation results of PI and FOPID controllers are presented and analysed. The settling time with FOPID for output voltage is 0.21 sec and steady state error in voltage is as low as 3.6V. Therefore the response of FOPID based ILBCSAF system is better than that of PI controlled system. The advantages of proposed system are low ripple content of PV voltage and current injected at PCC and improved time domain response of load voltage.The disadvantage of proposed system is that hardware count of ILBC is twice that of normal boost converter. This work deals with comparison PI and FOPID based ILBCFSAF systems.

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