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FUZZY LOGIC CONTROLLER BASED MULTIFUNCTIONAL GRID INTERFACED SOLAR PV SYSTEM

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ABSTRACT

The main objective of this project is to present a grid supported solar energy conversion system with an adjustable DC link voltage for CPI (Common Point of Interconnection) voltage variations. A two stage circuit topology is proposed wherein; the first stage is a boost converter which serves for MPP (Maximum Power Point) tracking and the second stage is a grid tied VSC (Voltage Source Converter),which not only feeds extracted solar photovoltaic energy into the three phase distribution system but also serves for harmonics mitigation, reactive power compensation and grid currents balancing. An interweaved DFSOGI (Double Frequency Second Order Generalized Integrator) based control algorithm is proposed for control of this multifunctional VSC which possesses the feature of good steady state performance along with fast dynamic response even under sudden load changes at CPI.

Keywords*: PV system, Boost converter, Fuzzy logic controller, DFSOGI,SRF.*

I. INTRODUCTION

Solar energy is one of the most famous sources of renewable energy. With the development of control tools, photovoltaic systems are no longer limited to active power generators in the utility grid, but they also contribute to the improvement of the power quality, which became a field of interest for many researches in the last decades In order to improve the power quality, various traditional passive filter and modern active filter have been developed. Unlike the passive filters, the active filters have many advantages and functions such as harmonic filtering, reactive power compensation for power factor correction,.....etc. The controller is one of the main parts of the APF. The conventional PI controller requires precise linear mathematical model of the system, which is difficult to obtain under parameter variations, nonlinearity, and load disturbances. In last decades, Fuzzy logic (FL) controller has been successfully applied to many control problems, as they need no accurate mathematical models of the uncertain nonlinear systems under control.FL can be considered as logic models that use such (If...Then) rules to establish qualitative relationships between model inputs/outputs.

This paper proposes a combined system of a three-phase shunt APF, and photovoltaic generator (PVG) to solve the power quality problems by filtering harmonic currents generated by nonlinear load and compensating reactive power for power factor correction. The synchronous reference frame (SRF) theory is used to extracted the reference compensating currents while fuzzy logic controller is proposed for controlling the dc-side capacitor voltage and the harmonic currents of the PVG-

APF (PVG and shunt APF). The P&O MPPT is used to increase the efficiency of the PVG and extract the maximum PV power from the PVG. The proposed PVG-APF is validated through numerical simulations using Matlab/Simulink environment.

Photovoltaic system modelling and characteristics pv cell equivalent circuit

A photovoltaic cell is a sensor consisting of a semiconductor material (PN junction) that absorbs light energy and transforms it to electrical power. When the junction is illuminated, it has the particularity that it can function as a

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generator, producing a photocurrent proportional to irradiance. In literature, various proposed models of the photovoltaic solar cell are presented, such as a single-diode model, two-diode model . In this paper, the used model is based on a single-diode equivalent circuit taking into account the series and parallel resistors as shown in Fig.1 this model consists of a photo-current *Iph*, a diode in parallel with the current source, a shunt resistor *RSh*, and a series resistor *RS*.

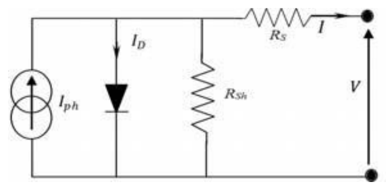

Fig. 1. PV Solar cell circuit model (single-diode).

The PV cell produced only a few watts of power, since this power is insufficient to supply most devices, the voltage and current must be increased and therefore increasing the power. To increase the voltage, the cells are connected in series, and in parallel to increase the current. The combination of these cells in series and in parallel is called PV module.

In this study, the CS5P-220M module is used. The technical characteristics of the module are presented in the Table.1.

The *I -V* and *P-V* characteristics of the PV module under standard test conditions (STC, i.e., irradiance G =1000 W/m^2 and temperature T=25C°) are shown in Fig.2. In this figure, the PV module has nonlinear voltage-current characteristics, and there is only one unique operating point for a PV generation system with a maximum output power under constant condition of temperature and irradiance.

Table.1 Electrical characteristics of the CS5P-220M PV module

Electrical characteristics	Symbols	Values
Maximum power at STC	*Pmpp*	219.72 W
Maximum power voltage	*Vmpp*	48.315 V
Maximum power current	*Impp*	4.5475 A
Open circuit voltage	*Voc*	59.261 V
Short circuit current	*Isc*	5.0926 A
Temperature coefficient of I_{sc}	*αsc*	5.532 m A/C°
Temperature coefficient of V_{oc}	*βoc*	-0.1110 V/C°

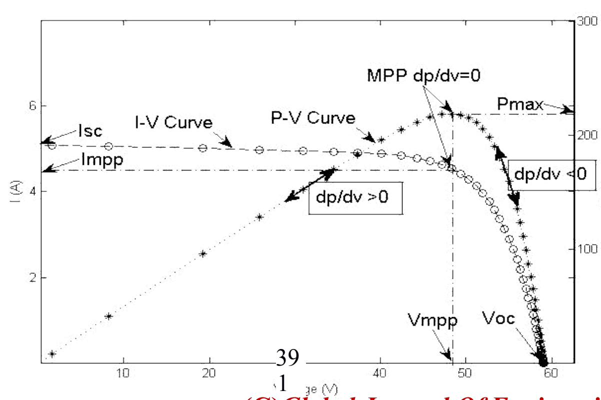

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Fig. 2. I–V and P–V characteristics of a PV module at STC.

DC-DC boost converter:-

The DC-DC boost converter (Fig. 3) is used to interface between the PV array and the load for optimal system operation. The output voltage of the DC-DC boost converter

(*Vout)* and the voltage of the PV array (*V)* are related to the duty cycle *D* by the following equation

Vout/V = 1/1-D

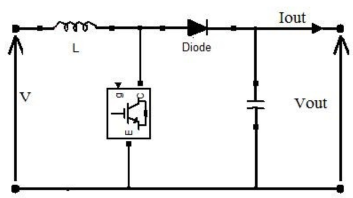

Fig. 3. DC-DC Boost converter circuit diagram

Fuzzy logic controller

This is the second in a series of six articles intended to share information and experience in the realm of fuzzy logic (FL) and its application. This article will continue the introduction with a more detailed look at how one might use FL.A simple implementation will be explained in detail beginning in the next article. Accompanying outside references are included for interested readers.

1) Define the control objectives and criteria: What am I trying to control? What do I have to do to control the system? What kind of response do I need? What are the possible (probable) system failure modes?

2) Determine the input and output relationships and choose a minimum number of variables for input to the FL engine (typically error and rate-of-change-of-error).

3) Using the rule-based structure of FL, break the control problem down into a series of IF X AND Y THEN Z rules that define the desired system output response for given system input conditions. The number and complexity of rules depends on the number of input parameters that are to be processed and the number fuzzy variables associated with each parameter. If possible, use at least one variable and its time derivative. Although it is possible to use a single, instantaneous error parameter without knowing its rate of change, this cripples the system's ability to minimize overshoot for a step inputs.

4) Create FL membership functions that define the meaning (values) of Input/Output terms used in the rules.

5) Create the necessary pre- and post-processing FL routines if implementing in S/W, otherwise program the rules into the FL H/W engine.

6) Test the system, evaluate the results, tune the rules and membership functions, and retest until satisfactory results are obtained.

Table 2. Fuzzy control rule of the dc voltage

E\∆*E*	NB	NM	NS	ZO	PS	PM	PB

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NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

DFSOGI

An interweaved DFSOGI (Double Frequency Second Order Generalized Filter) based control approach is proposed which solves the tradeoff between steady state and dynamic performances, while processing the rapidly vanishing conventional energy sources (fossil fuels) have put an alarming energy crisis situation in front of the world. Moreover, the deteriorating environmental conditions have moved world's attention towards nonconventional green energy sources. The solar energy has provided a new cost feasible alternative. The grid parity for solar energy conversion systems. Solar PV (Photovoltaic) energy generation systems can be broadly classified into two main categories which are standalone and grid interfaced. Several standalone systems for PV power generation systems considering rural electrification, three port converters for PV application, PV based battery charging station and battery energy management. The batteries are integral part of standalone PV based system.

However, they require frequent maintenance and timely replacement. Therefore, battery-less grid interfaced PV generation systems are more preferred where the grid is available. The initial investment to setup a PV plant is high because of high cost of PV panels. Hence the aim is to extract maximum power from available capacity once a PV plant is installed.

Synchronus reference frame (SRF):-

The SRF based control algorithm for active power filters have been proposed. The SRF based control algorithm provides an advantage that all three phase load currents are processed simultaneously. The DC component of direct axis current corresponds to uniformly distributed average power consuming component of load current. Therefore, only one low pass filter is required to estimate DC component of direct axis current. However, in case of unbalanced operation, the second harmonic is the dominant component in the direct axis current. In order to achieve good steady state response under unbalanced operation, the cut off frequency for low pass filter is to be set very low. However, the low cutoff frequency causes poor dynamic response. Therefore, there is a tradeoff between steady state and dynamic performances in SRF based control approach.

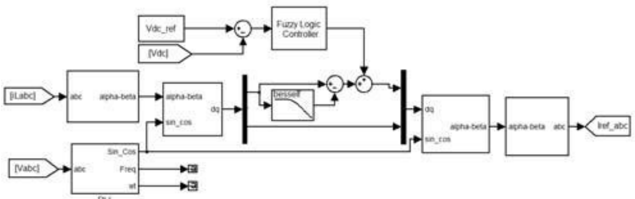

Fig 4. Simulink block diagram for SRF theory

II. PROBLEM FORMULATION AND STATEMENT

In developing countries like India, power quality is one of the most prevalent issues which not only cause economic losses but also irregular supply of electricity. It hampers functioning of industries and factories, due to shortage of power supplied to them. It causes shortage of power supply to homes. It leads to loss of revenue by Government as individual enterprises may opt to install their own power generators, increases corruption in form

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of bribes and many more. Ultimately it is the country's economy which suffers along with the country's political reputation.

Problem statement

In the existing system, the controlling of the STATCOM is done by using the PI controller. The dc power which is produced by the solar pv cell for the compensation of the reactive power in the distribution system (load). The PI controller couldn't maintain the total harmonic distortion as per the IEEE standards. so we need an efficient controller to reduce the total harmonic distortion which can also improve the dynamic performance of the system.

III. PROPOSED SYSTEM

In conventional power systems, the grid provides ancillary services such as frequency regulation, voltage support, spinning reserves etc. These services are typically not free, i.e., generators are paid for ancillary support in regions which have such a market. The objective is to propose a power management system which would tap the future energy markets for frequency and voltage regulation and create an enhanced value for PV systems.In this thesis, control over the active and reactive power output of a PV system is proposed. Three energy sources, namely, a PV array, battery storage and the grid are integrated together by means of three converters and controlled by three controllers to provide bi-directional flow of active and reactive power. With the suggested technique, PV systems can deliver a variable amount of active and reactive power based on the amount demanded from the grid. This enables grid frequency and voltage support. Thus, frequency and voltage management may be possible even under islanded operating conditions.From the thesis, the main contributions of this thesis are: Development of the power management scheme between a community-based PV system, an energy storage system and the grid that provides frequency and voltage support to the grid.

In this project, a two stage multifunctional solar energy conversion system is proposed which not only feeds the solar energy into the distribution system but also serves the purpose of harmonics mitigation, reactive power compensation and grid currents balancing at the same time. The utilization factor of the grid tied VSC is better as it also serves for power quality improvement in night time. An interweaved DFSOGI based control algorithm is proposed to serve all aforementioned purpose. The interweaved DFSOGI algorithm is a combination of SFR and SOGI (SOGI Second Order Generalized Filter) based algorithm. A wide variety of results are shown to demonstrate the performance of interweaved DFSOGI based control algorithm. Moreover, unlike previous work with constant DC link voltage, an adjustable DC link voltage based control approach is proposed here. The DC link voltage of VSC is adjusted with respect to CPI voltage variation. The adjustable DC link voltage not only helps in reduction of switching losses in all the power devices (the VSC and the boost converter) but also in reduction of high frequency ohmic losses in the interfacing converter. The reduction in losses is achieved not only at under voltage but also at nominal CPI voltage. The concept of loss reduction by adjusting DC link voltage for VSC in hybrid filters where in, reactive power requirement of the filter is satisfied by adjusting the DC link voltage. A three-phase PV inverter with adjustable DC link voltage .A single-phase solar based system with adjustable DC link voltage is demonstrated. However, all these systems are different from point of view of circuit topology. Therefore, there is a wide difference in work presented in and the proposed work.

The steady state performance for which is recorded from PV array simulator. The MPP efficiency is around 99.7% for both the insolation levels (1000 W/m2 and 500 W/m2). The steady state performance for reactive power compensation for balanced linear CPI voltage (vsab) with grid, load and VSC currents. As under balanced loading condition, the three phase currents for all the phases are equal hence only one phase quantities are shown. The reactive power compensation can be observed form Figs. the power taken from the grid the load power which is at pf of 0.8 lag. It can be observed that sign for power absorbed from the grid is negative and the DPF (Displacement Power Factor) is -1 which shows that power is being supplied to the grid at unity power factor. shows the power supplied by the VSC. The power supplied by the VSC is divided between load and grid. *vsab* with three phase grid, load, VSC currents respectively. It can be observed that load currents for phase "a" and "b" are nonsinusoidal and

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for that of phase "c" is zero, which shows that the load is nonlinear and unbalanced. However, the grid currents (as are balanced (can be observed from magnitude) and sinusoidal. The VSC currents are so adjusted that the grid currents are balanced and sinusoidal. harmonics spectra of grid load and VSC currents. The THD of load current is 21.8 % however that of grid current is of order of 2%. The THD of VSC current is higher as compared to grid current as it consists of load current harmonics. The power supplied by the grid and power absorbed by the load are given in The power supplied by the grid is negative which shows power is being supplied into the grid.

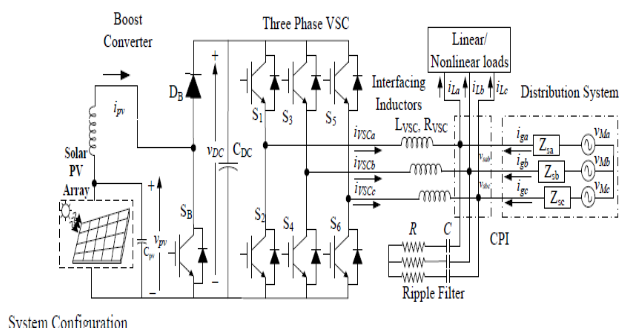

Fig 5.Proposed system

Control approach

The detailed block diagram of proposed control approach is shown below. There are two main power circuits in the proposed circuit topology. The duty ratio for boost converter is decided on the basis of MPPT control algorith of boost converter is connected to the DC link of the VSC. The DC link voltage of the VSC is adjusted in real m. The input voltage of boost converter is continuously adjusted such that the PV array operates at MPP. The output time considering the CPI voltage. Therefore, with the proposed control approach, both input and output voltages of boost converter are adjusted in real time. Moreover, the VSC is controlled such that the grid deals with only real power exchanges even when local load demands reactive power or harmonics. The proposed control algorithm also presents a solution for balancing grid currents.

A. maximum power point tracking

A composite InC based MPPT algorithm is used. A range of voltage for peak power is known with the knowledge from fractional Voc MPPT [4] which is 0.7Vocmax to 0.9Vocmax, where Voc is open circuit voltage and Vocmax is maximum open circuit voltage. The voltage for peak power is always searched in this range for fast search of Vmpp. The InC algorithm works in order to minimize the difference between the incremental conductance and the conductance offered by the PV array. At first, the reference PV array voltage is estimated based on the InC principle then that reference voltage is used to estimate the duty ratio of boost converter. For calculation of incremental conductance and are estimated as,

$$\Delta I_{PV} = I_{PV}(k) - I_{PV}(k-1)$$
$$\Delta V_{PV} = V_{PV}(k) - V_{PV}(k-1)$$

where IPV (k) and VPV (k) are the instantaneous sampled current and voltage of the solar array. The governing equations for InC based MPPT algorithm is as,

$$\frac{\Delta I_{PV}}{\Delta V_{PV}} = \frac{-I_{PV}}{V_{PV}}, at\ MPP$$
$$\frac{\Delta I_{PV}}{\Delta V_{PV}} > \frac{-I_{PV}}{V_{PV}}, \text{ Left of MPP on } P_{PV} \text{ v/s } V_{PV} \text{ curve}$$

The reference PV voltage and sensed DC link voltage are then used to estimate the duty ratio for the boost converter. The governing equation for estimating duty ratio is,

$$D_{ref}(k) = 1 - \frac{V_{PVref}(k)}{V_{DC}(k)}$$

This reference duty ratio is used to generate switching logic for boost converter.

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Impact Factor- 5.070

b. Control approach for three-phase vsc :-

The three phase VSC is controlled to achieve the objective of reactive power compensation, harmonics mitigation, grid currents balancing and regulation of DC link voltage to desired adjustable reference value. A total of nine quantities are sensed to control the SECS, which are line voltages (vsab and vsbc), DC link voltage (vDC) and grid currents (iga and igb), load currents (iLa and iLb), PV array voltage (vPV) and PV array current (iPV). The phase voltages are estimated from the sensed line voltages and then the synchronization signals are estimated from the phase voltages. To estimate the synchronization signals at first amplitude of phase voltages is estimated. The amplitude of phase voltages is estimated as,

$$V_z = \sqrt{\frac{2(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)}{3}}$$

This amplitude is used to determine the synchronization signals of CPI voltage which contains the phasor information of all phase voltages. The synchronization signals are estimated as,

$$z_a = \frac{v_{sa}}{V_z},\ z_b = \frac{v_{sb}}{V_z},\ z_c = \frac{v_{sc}}{V_z}$$

The control objective for the VSC is to maintain the grid currents balanced sinusoids at unity power factor. To achieve the aforementioned objective, the peak of grid currents is estimated, which is common for all three phases. The grid current consists of three main parts, which are average power consuming component of load current, PV array contribution and losses of the SECS. The average power consuming component of load current is estimated using interweaved DFSOGI based control algorithm. At first the direct axis component (id) of three phase load currents is estimated. The average value of direct axis component (ILg) represents the average power consuming component of load current distributed uniformly in all three phases. In ordertoeestimate

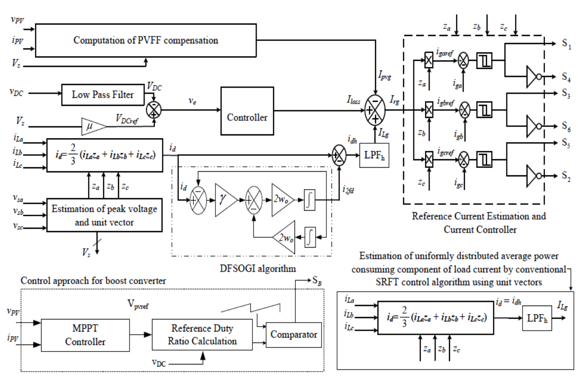

Fig 4.2 Control Diagram of Proposed system

The cut off frequency of low pass filter depends on several aspects related to nature of the load. In case the load currents are balanced sinusoidal, the id is a DC value which can directly be used without used as ILg and without using a low pass filter. However, in case the load currents are balanced and non sinusoidal (representing balanced nonlinear load), the id consists of a DC with superimposed ripple component corresponding to load current harmonics, then in order to estimate ILg the id is passed though a low pass filter. The cut off frequency of low pass filter is decided by lowest order ripple frequency in id. In case of three-wire balanced nonlinear load the 5th and 7th harmonic are the lowest order harmonics in the load currents. The lowest order ripple frequency is 6th as the 5th harmonics is positive sequence and 7th harmonic is negative sequence. A low pass filter tuned to line frequency can be used to suppress this ripple. In case of unbalanced load currents, the second harmonic component is the dominant part of id. In order to suppress the dominant second harmonic component, conventionally a low pass filter with a low cut off frequency is used. However, the dynamic response for estimation of ILg is adversely affected by

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Impact Factor- 5.070
reduction of cut off frequency. Hence, there is a compromise between the steady state and the dynamic performances of conventional SRFT in case of unbalanced loads at CPI. The proposed interweaved DFSOGI based control

DFSOGI based control algorithm is interwoven with direct axis current control based algorithm such that the double frequency component of id quashed separately. The estimation of double frequency component with DFSOGI is given as,

$$\frac{I_{2fd}(s)}{I_d(s)} = \frac{2\gamma\omega_o s}{s^2 + 2\gamma\omega_o s + \omega_o^2}$$

where ωo is the nominal line frequency and γ is the convergence factor. The second harmonic component present in the id is subtracted in real time. The resultant value is designated as idh, which is then passed though a low pass filter to suppress ripple component corresponding to harmonics in load current. However, the cutoff frequency for low pass filter can be kept comparatively higher, as the dominant second harmonic component is already quashed by interweaved DFSOGI algorithm.

Fig. shows the comparison of the proposed interweaved DFSOGI based algorithm with conventional SRF algorithm. Fig. 3 (a) shows simulated steady state and dynamics performances. In Fig. 3 (a), it can be observed that before time t = 0.15 s, the loads are balanced and nonlinear hence id contains only high frequency ripples corresponding to load current harmonics. However at t = 0.15 s, when one of the load line is opened, the load currents are unbalanced. The id for unbalanced load contains large second harmonic component along with average DC value. The DFSOGI is used to detect and quash double harmonic component separately. The ILg represents the uniformly distributed average power consuming component of load current. It can be easily observed that the ILg estimated by DFSOGI based algorithm is quite smooth as compared to that of conventional SRF algorithm.

IV. SIMULINK AND RESULTS

In this section, the proposed system is validated through numerical simulations using Matlab/Simulink environment. The PVG consists of eight series connected PV module from CS5P-220M panel model. The parameters used for the proposed PVG-APV system

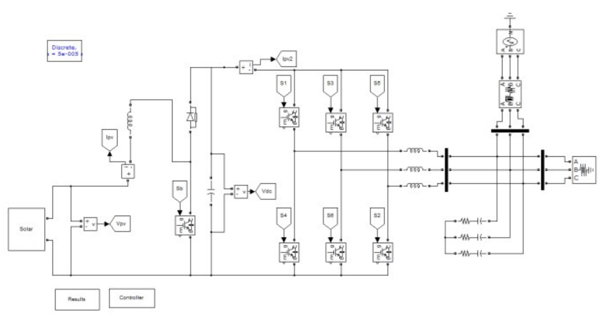

Fig: Simulink diagram

Results

CASE 1:- sudden load removal

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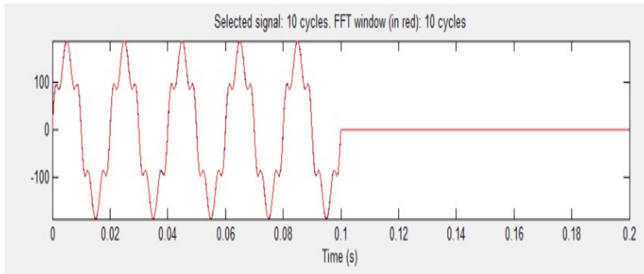
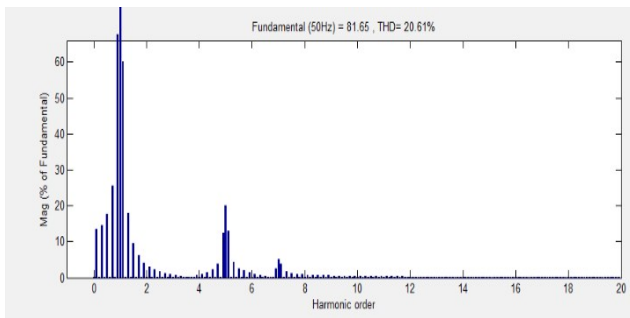
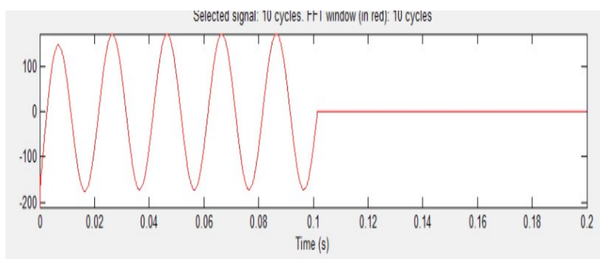
Impact Factor- 5.070



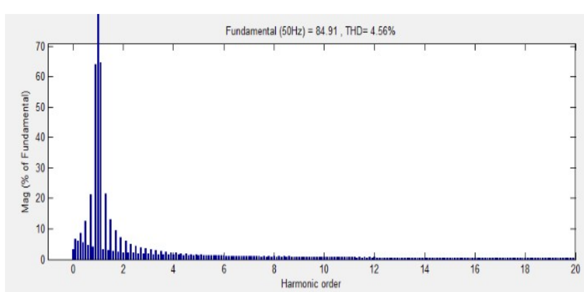
Load current in phase C with PI controller



THD of Load current in phase C with PI controller



Load current in phase C with fuzzy logic controller



THD of Load current in phase C with fuzzy logic controller

ISSN 2348 – 8034
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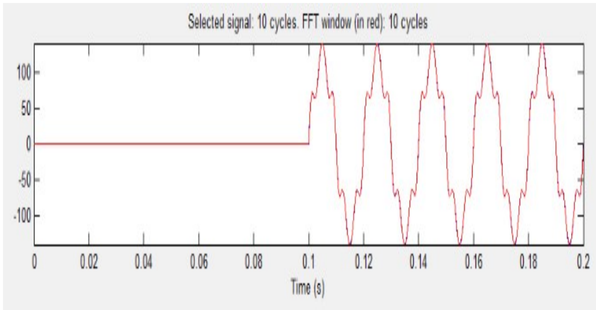
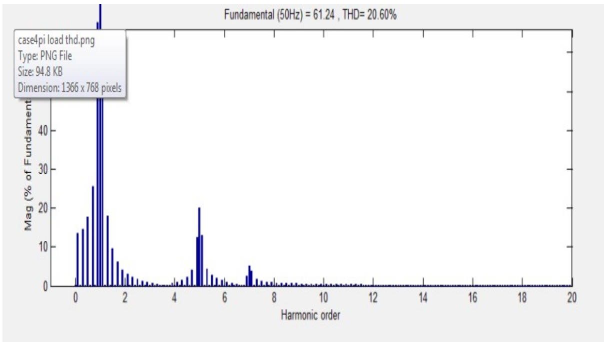
Impact Factor- 5.070

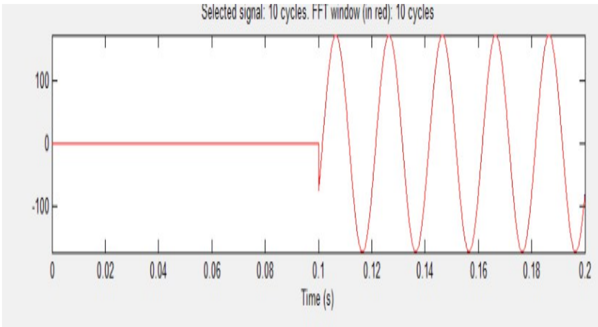
CASE 2: sudden load inclusion



Load current in phase C with PI controller



THD of Load current in phase C with PI controller



Load current in phase C with fuzzy logic controller

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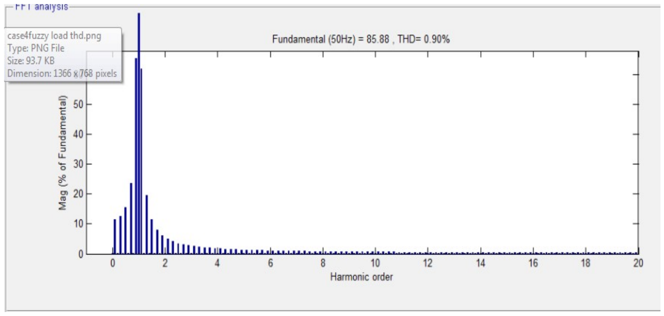

THD of Load current in phase C with fuzzy logic controller

V. CONCLUSION

A two-stage grid tied multifunctional solar energy conversion system has been proposed. The proposed system not only feeds the available solar energy into the grid but also helps in power quality improvement at CPI. The physical significance of all salient internal signals of control algorithms has been presented to make the proposed algorithm intuitive and simple to understand. A PVFF term has improved the dynamic response for changes in PV array power and CPI voltage variation. An interweaved DFSOGI based control algorithm has been proposed and its comparison with conventional SRF theory has been shown to demonstrate its effectiveness. Moreover, an adjustable DC link voltage structure for CPI voltage variation is included in the proposed control algorithm. A comparison of proposed adjustable DC link voltage structure algorithm with fixed DC link based algorithm has been shown which demonstrates direct benefits in terms of increased energy output. The proposed system not only helps in improving the voltage power quality but also helps in reduction of distribution losses. The proposed system yields increased energy output using the same hardware resources just by virtue of difference in DC link voltage control structure. The THDs of the grid currents are found less than 5% (within IEEE-519 standard) even under nonlinear loads at CPI. Test results have shown the feasibility of proposed system.

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