Dynamic Simulation of PV-Alternator Hybrid Power Plant

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Abstract : This paper presents a hybrid system of standalone PV-alternator with new control algorithm The proposed system deals with the inconsistent power generation of solar array and also provides quality power. For obtaining maximum power under changeable operating conditions maximum power point tracking (MPPT) algorithm is used. The PV array is incorporated with a DC-DC zeta converter. Diesel generator set along with zeta converter coordinated for load management and power flow. The admittance based control algorithm is used for Reactive Power Control, Harmonic Mitigation and Load balancing for balanced and unbalanced loads. A 4-leg Voltage source inverter provides neutral current compensation. The MATLAB/SIMULINK is used for analyzing the proposed system under linear and nonlinear loads.

Index Terms*– admittance *based control algorithm, dg set, and four-leg VSI, neutral current compensation, power quality, solar photovoltaic array, and standalone system.

I. INTRODUCTION

Fossil fuels are preferred in order to fulfil the require for energy. However, their finite and harmful content for the environment have led people to try to find for new sources of energy [1]. Although most of the people live in metropolitan cities in the world, the numbers of those settled in rural areas are also remarkable. Electricity is needed in order to supply energy people's basic needs in a rural region. Off-grid PV systems are used for supplying electricity to rural areas. Although their costs are considered as high, off-grid systems are more economical compared to on-grid ones. Even on-grid electricity are quite prevalent, mountain houses, farm houses, transmitter stations, construction sites, sales points by the highways, nomadic communities and farmers cannot benefit from them The cost of installation of an electricity network in those regions with a low population is significantly high. Solar power is free from pollution it is mostly preferred for small scale applications [2]. But the major drawback is the fluctuation of output power of PV module, this makes compulsory of integrating other power resources like diesel engine (DG) set, battery storage, fuel cells etc.

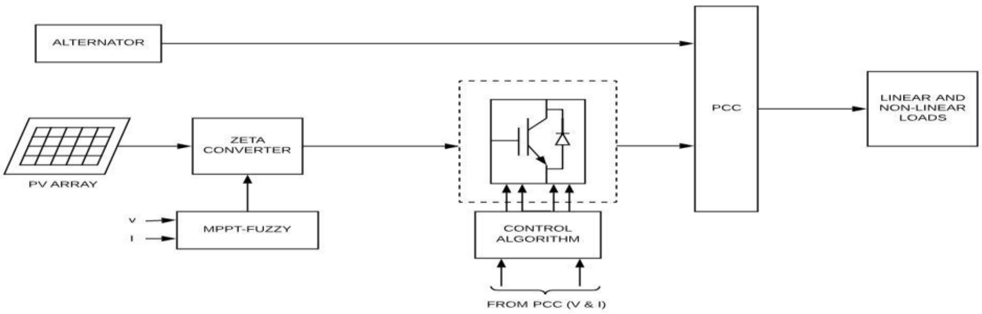

Fig. 1 proposed PV-alternator hybrid power plant

The proposed system consists of a permanent magnet synchronous generator (PMSG), PV array, and zeta converter. This micro grid is a representative of a typical rural hospital power supply system which needs to ensure uninterrupted constant power supply for 24×7 h. Therefore, the PMSG driven by a diesel engine ensures regulated power supply. In order to maintain the efficiency and to reduce the maintenance cost, the DG set is made to operate at 80–100% of its full capacity [3]. This is because, under light-load conditions, the efficiency reduces and the maintenance cost also increases as the DG set is subjected to carbon build up. Usually, to avoid these problems, the DG is operated by keeping a minimum loading of 80% by means of battery charging or the DG is made to turn ON/OFF depending upon the loading. However, the turn ON/OFF of the DG set is usually not recommended.
1) The load may vary frequently. Therefore, the repeated turn ON/OFF of DG increases the mechanical maintenance.
2) The battery life reduces as the discharging current is high during transient periods.

Nowadays, the rapid increase in the use of nonlinear loads such as computers, electronics appliances, medical equipment, refrigerators, etc., has emphasized the concern for power quality in the electrical distribution system. These loads inject harmonics and distort the current and voltage waveforms causing poor power quality problems. The possible provision for the mitigation of the power quality problems is with inclusion of custom power devices. Three-phase four-wire loads are also known to suffer from the problem of neutral current due to nonlinearity and unbalance present in the system. This may produce large amount of neutral current which consists of triplen harmonics. The neutral current may cause overloading of the distribution system and causes additional heat losses, which may be dangerous and poses a serious threat to the connected equipment. A four-leg VSC is used for neutral current compensation in addition to mitigate the current harmonics with other reported advantages. Here, the inputs are the load currents (*i*La, *i*Lb, *i*Lc) and load voltages (*va*, *vb*, *vc*), which are further used for the estimation of the active (*p*) and reactive (*q*) power components using the formula mentioned in this paper. The oscillating component of power is eliminated as it is passed through the low-pass filter (LPF) to obtain *P*dc and *Q*dc. These are used for the estimation of the reference conductance and susceptance, thus giving the value for the reference active and reactive power components. This method facilitates the extraction of the fundamental components and compensates independently for the active and reactive powers even when the system comprises of harmonics and unbalances at the PCC. The compensation allows balanced source currents to be drawn from the network. The controller responds faster under the steady-state and dynamic conditions. The control implementation is realized using a four-leg VSC with admittance control algorithm.

II. PV MODELING

Power generation from solar energy can be grid connected or it can be isolated or standalone power generating system that depends on the utility, location of load area, availability of power grid nearby it [4]. Thus where the availability of grid connection is very difficult or costly the solar can be used to supply the power to those areas. The most important advantages of solar power are that its fuel cost is absolutely zero and solar power generation during its operation do not emanate any greenhouse gases. Another advantage of using solar power for small power generation is its portability; we can carry that whenever wherever small power generation required.

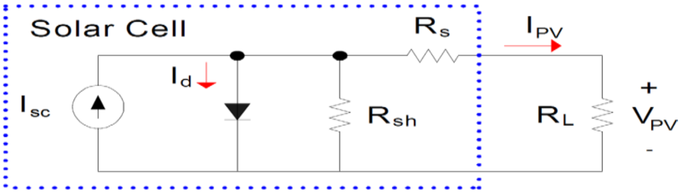

Fig. 2. Equivalent circuit of a solar cell

The above Fig.2 shows equivalent circuit of solar cell consists of single diode model, PV panel is designed for specific rating by using the following equations, by applying KCL to the above circuit we get,

$$I_{PV} = I_{Ph} - I_S - I_{rs} \tag{1}$$

$$I_{ph} = \left[I_{SC} + k_i\left(T_C - T_{ref)}\right)\right]\left[\frac{S}{1000}\right] \tag{2}$$

$$I_{rs} = \frac{I_{SC}}{\left[\exp\left[\frac{qV_{OC}}{N_S kAT_C}\right] - 1\right]} \tag{3}$$

$$I_S = I_{rs}\left[\frac{T_C}{T_{ref}}\right]^3\left[\exp\left(\frac{qE_g\left(\frac{1}{T_{ref}} - \frac{10}{T_C}\right)}{kA}\right)\right] \tag{4}$$

$$I_{pv} = N_P I_{ph} - N_p I_S \times \left[\exp\left(\frac{q(V + I\ R_S)}{N_S AKT_C}\right) - 1\right] \tag{5}$$

Here,

I_{ph} -light generated current.

I_S =Diode saturation current.

I_{rs} =Reverse saturation current.

I_{pv} = Output current of PV-cell.

III. FUZZY-MPPT

There are various algorithms that have been used to track maximum power point, this work proposed fuzzy controller to track MPP of PV system. Fuzzy logic deals with uncertainty in engineering by attaching degrees of certainty to the answer to a logical question. Commercially, fuzzy logic has been used with great success to control machines and consumer products. Fuzzy logic systems are simple to design, and can be understood and implemented by non-specialists in control theory. Another advantage of these controllers in the field of MPPT that there output has minimal oscillations with fast convergence around the desired MPP. Additionally, they have been performing well under sudden changes in the irradiation. The proposed algorithm controls the duty cycle D of the switching signal.

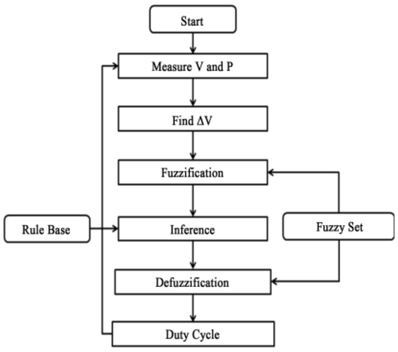

Fig. 3 Algorithm of Fuzzy Logic MPPT

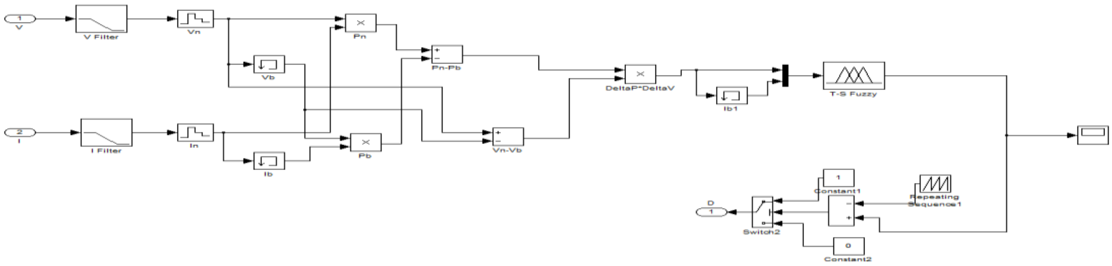

Fig. 4 Simulink Diagram of Fuzzy Logic MPPT

IV. ZETA CONVERTER

The circuit diagram of zeta converter is shown in Fig 5. The zeta converter is able of converting input voltage in to a non-inverted output voltage, having either a lower or higher value than input voltage [5]. It is capable of operating in both continuous and discontinuous modes of operation. The zeta converter consists of components like power electronic switch (S), inductors (L1 and L2), a diode, capacitors (C1 and C2), and a load (R)

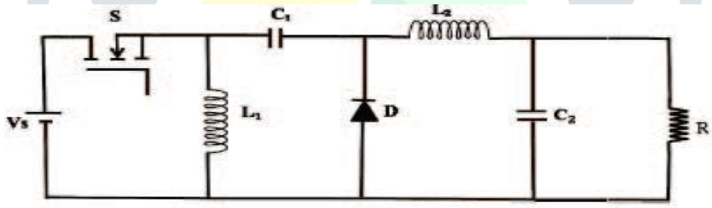

Fig. 5 Circuit Diagram of Zeta Converter

For a Zeta converter operating in the continuous conduction mode, the duty cycle is defined as

$$D = \frac{V_O}{V_{in} + V_O} \qquad 6$$

To determine the value of the inductances L_m and L_0 the peak-to peak ripple current is taken to be approximately 10-20% of the average output current. The values of these inductances are given

$$L_m = L_O = L = \frac{1}{2}\frac{V_{in} D}{\Delta I_L f_s} \qquad 7$$

The coupling capacitor (C1) is designed on the basis of its ripple voltage. The maximum voltage handled by C1 is equal to the input voltage, and it can be given as

$$C_1 = \frac{I_o D}{\Delta V_{c1} f_s} \qquad 8$$

The output capacitor C2 must have enough capacitance to maintain the DC link voltage, and must provide continuous load current at high switching frequency. It can be calculated as

$$C_O \geq \frac{I_O D}{\Delta V_{co}(0.5 f_s)} \quad 9$$

where D is the duty cycle, Vo the DC link voltage, Vin the value of the input voltage, Io the output rated current, fs switching frequency, Vc1 the ripple voltage of the coupling capacitor and Vc0 the ripple voltage of the output capacitor.

V. FOUR-LEG VOLTAGE SOURCE INVERTER

The four leg inverter consists of 8 switches in which 6 switches are used for the 3-phase line and the remaining 2 switches are used to compensate the neutral current. As the pulses are generated from the control circuit which is designed for the inverter for triggering the switches in order to switch on the switches alternatively by using the gate to compensate the harmonics in current and voltage at the point of common coupling.Ripple Filter to filter the switching ripples of a VSC at point of common coupling, a first order low pass filter is employed [6]. Filter consists of a capacitor of value 10 KHz and in series with a resistor of 5 Ω

VI. CONTROL ALGORITHM

The control algorithm extracts the fundamental component of the loads using the admittance control technique. Further, active and reactive power components of the load currents are determined. The proportional integral (PI) control loop produces reactive power (Qcv) for voltage control in order to compensate for any changes in reactive power in support to fluctuations in PCC voltages. The reference susceptance (Bqt) for reactive component of source current is computed by deducting the three phase load reactive power (Qdc) from the PI controller output (Qcv). The reference conductance (Gpt) is estimated using the reference load active power (Pr). Fig. shows the block diagram of the control technique. The evaluation of the control algorithm demonstrates its robustness and relatively faster response.

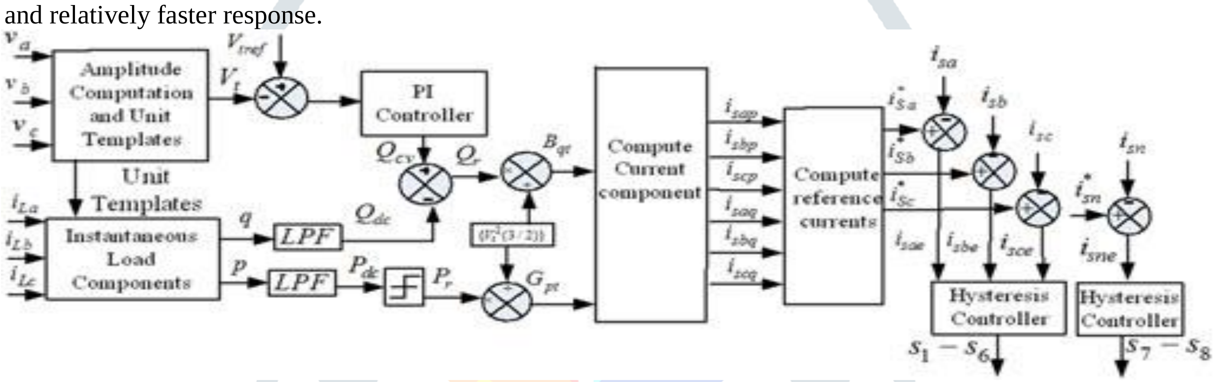

Fig.6 Admittance Based Control Algorithm

4.1 Determination of Unit Templates

The amplitude of PCC voltage V_t and phase voltages are employed for the computation of in-phase unit template

$$V_t = \sqrt{\left\{2 \times \left(v_a^2 + v_b^2 + v_c^2\right)/3\right\}} \quad 10$$

$$u_a = \frac{v_a}{V_t},\ u_b = \frac{v_b}{V_t},\ u_c = \frac{v_c}{V_t} \quad 11$$

The Quadrature unit templates are estimated as

$$w_a = (-u_a + u_c)/\sqrt{3} \quad 12$$

$$w_b = (3u_a + u_b - u_c)/2\sqrt{3} \quad 13$$

$$w_c = (-3u_a + u_b - u_c)/2\sqrt{3} \quad 14$$

4.2 Admittance Control Technique

The instantaneous load active power (p) and load reactive power (q) components are computed as follows. The calculated instantaneous components of load power consist of ac and dc components. The dc components are extracted using LPF

$$p = \{v_t(u_a i_{La} + u_b i_{Lb} + u_c i_{Lc})\} = P_{dc} + P_{ac} \quad 15$$

$$q = -\{v_t(w_a i_{La} + w_b i_{Lb} + w_c i_{Lc})\} = Q_{dc} + Q_{ac} \quad 16$$

The voltage error for the kth instant at PCC is given as

$$V_e(k) = V_{tref}(k) - V_t(k) \quad 17$$

Where $V_{tref}(k)$ the terminal ac is reference voltage amplitude and $V_t(k)$ is the amplitude of three phase sensed ac voltages at PCC as given in above equation 5.8.

The PI controller output for maintaining the PCC voltages at the k^{th} sampling instant is given as

$$Q_{cv}(k) = Q_{cv}(k-1) + k_{pv}[V_e(k) - V_e(k-1)] + k_{iv}V_e(k) \quad 18$$

Where k_{pv} and k_{iv} denote the proportional and integral gains of the PI controller

The reference reactive power component (Q_r) is computed from the difference of the PI controller output (Q_{cv}) and the load reactive power component (Q_{dc}) as

$$Q_r = Q_{cv} - Q_{dc} \qquad 19$$

The active power drawn from the DG set (P_r) is limited to 0.8 $P_r \leq P_{dc} \leq 1.0\, P_r$. The reference source active power component (P_r) is obtained, where PR is rated power of DG set.

The reference conductance G_{pt} and Susceptance (B_{qt}) of the load corresponding to the reference active (P_r) and reactive power (Q_r) components are derived as

$$G_{pt} = P_r / \{V_t^2 (3/2)\} \qquad 20$$

$$B_{qt} = Q_r / \{V_t^2 (3/2)\} \qquad 21$$

$$i_{Sap} = G_{pt} V_t u_a, i_{Sbp} = G_{pt} V_t u_b, i_{Scp} = G_{pt} V_t u_c \qquad 22$$

$$i_{Saq} = B_{pt} V_t w_a, i_{Sbq} = B_{pt} V_t w_b, i_{Scq} = B_{pt} V_t w_c \qquad 23$$

The total reference source currents ($i^*_{Sa}, i^*_{Sb}, i^*_{Sc}$) are obtained as sum of in-phase and Quadrature components of reference source currents of individual phases as

$$i^*_{Sa} = i_{sap} + i_{saq}, i^*_{Sb} = i_{sbp} + i_{sbq}, i^*_{Sc} = i_{scp} + i_{scq} \qquad 24$$

4.3 Neutral Current Compensation

This fourth leg of VSC provides direct control over the source neutral current .The reference neutral current (i^*_{Sn}) is compared with the sensed source neutral current (i_{Sn}), as shown in Fig. 5.1. These are used in hysteresis current controller to produce switching signals for four leg of VSC.

4.4 Performance of System under Linear Load

The response of a standalone system is analyzed under linear load using simpower system toolbox in MATLAB/SIMULINK. The performance of the system is observed during line outage in one of the three phases at time t = 1.5 s to 1.56s, as shown in Fig.4. It is observed that for a subjected load unbalance in the system. The steady state operation of a PV- alternator based hybrid power plant under a linear load is analyzed.

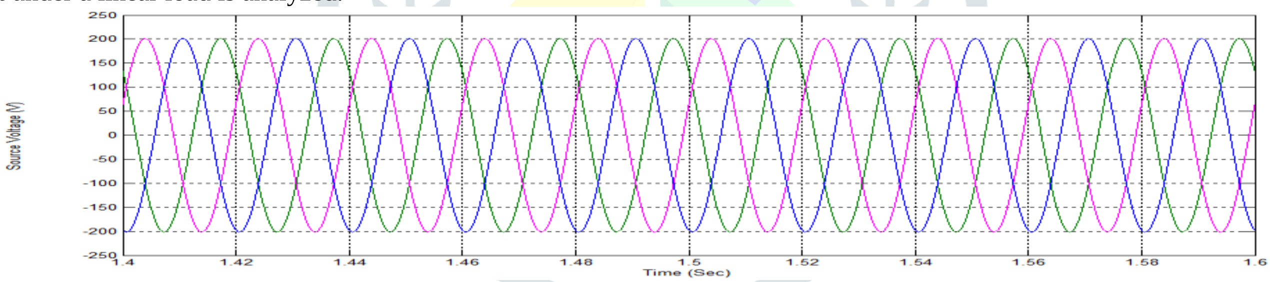

Fig. 7 Source Voltage Waveform

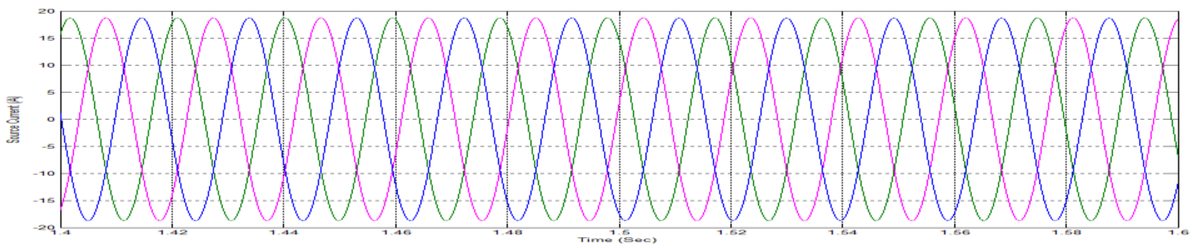

Fig. 8 Source Current Waveform

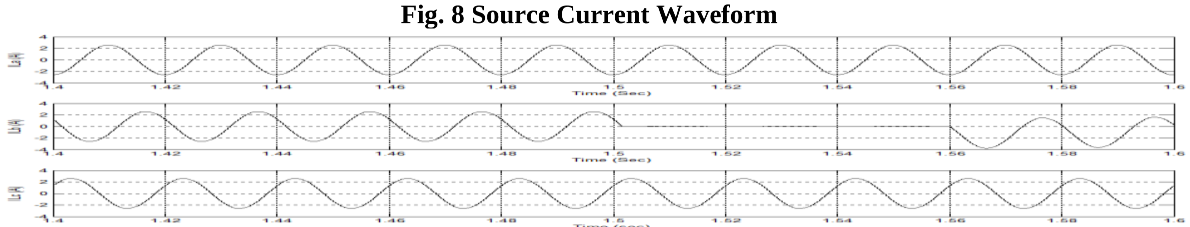

Fig. 9 Load Current Waveforms

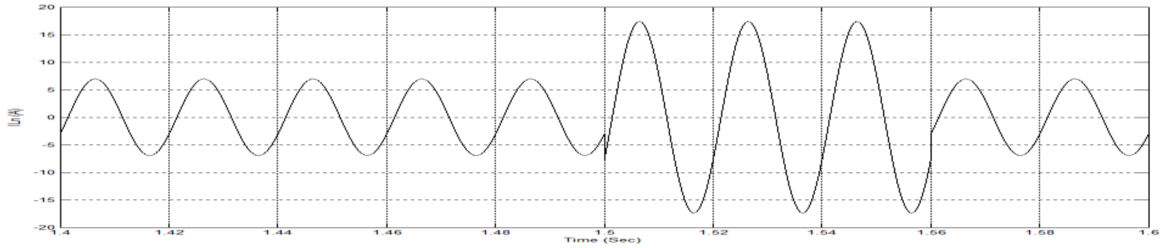

Fig.10 Load Neutral Current Waveform

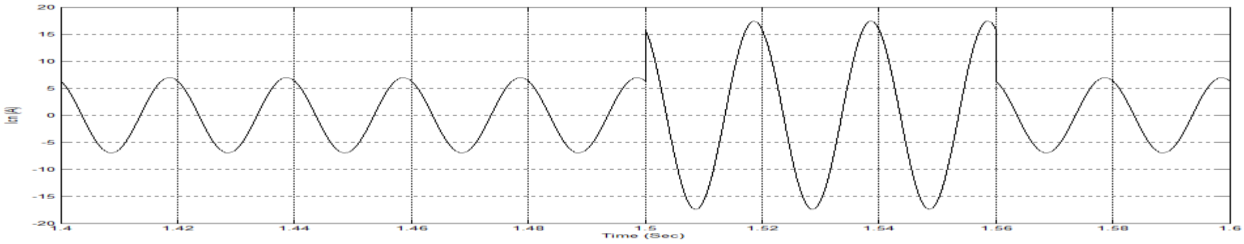

Fig. 11 Compensating Neutral Current Waveform

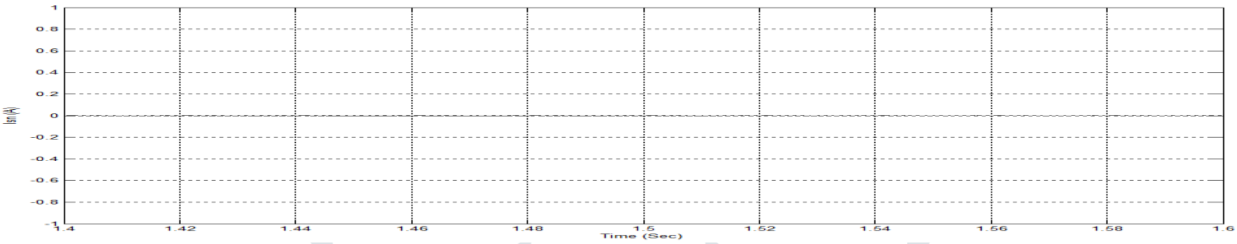

Fig. 12 Resulting Neutral Current Waveform

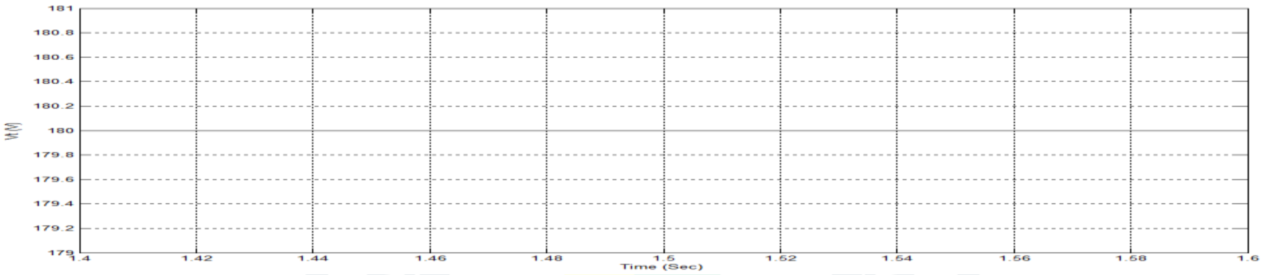

Fig. 13 Terminal Voltage Waveform

4.5 Performance of System under Non-linear Load

The response of a standalone system is analyzed under nonlinear load using simpower system toolbox in MATLAB/SIMULINK. The performance of the system is observed during line outage in one of the three phases at time t = 1.5 s to 1.56s, as shown in Fig.4. It is observed that for a subjected load unbalance in the system

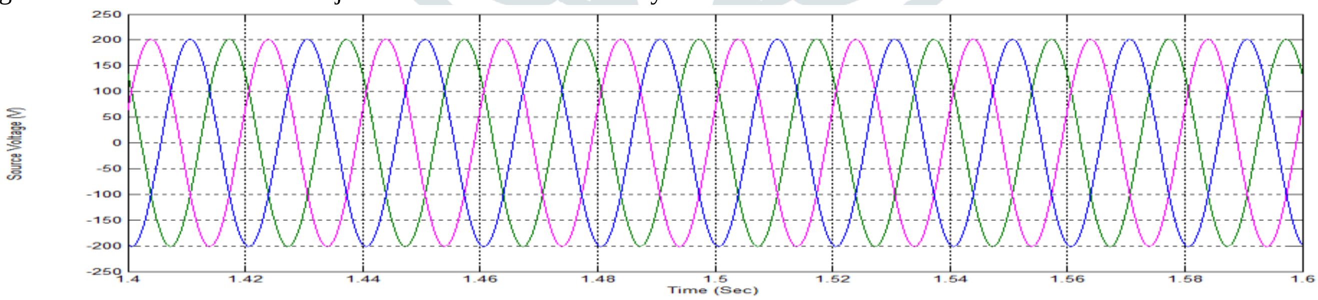

Fig. 14 Source Voltage Waveform

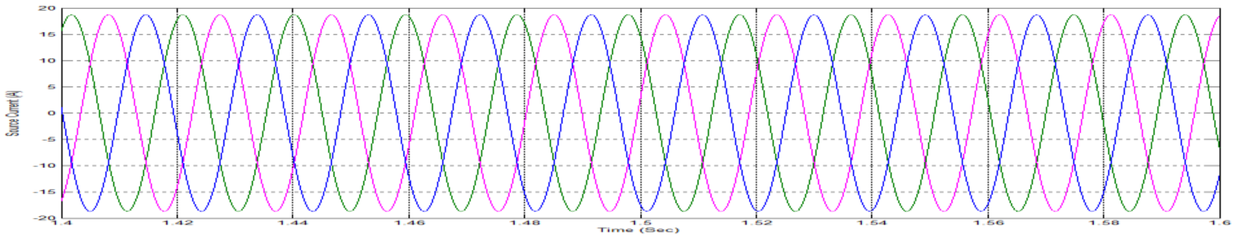

Fig. 15 Source Current Waveform

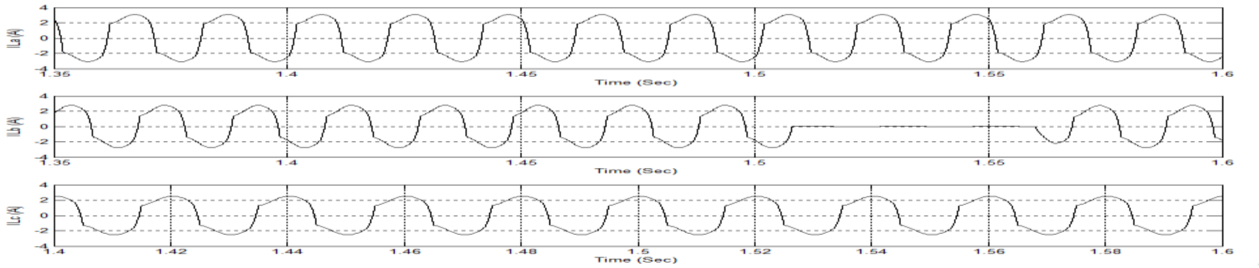

Fig. 16 Load Current Waveforms

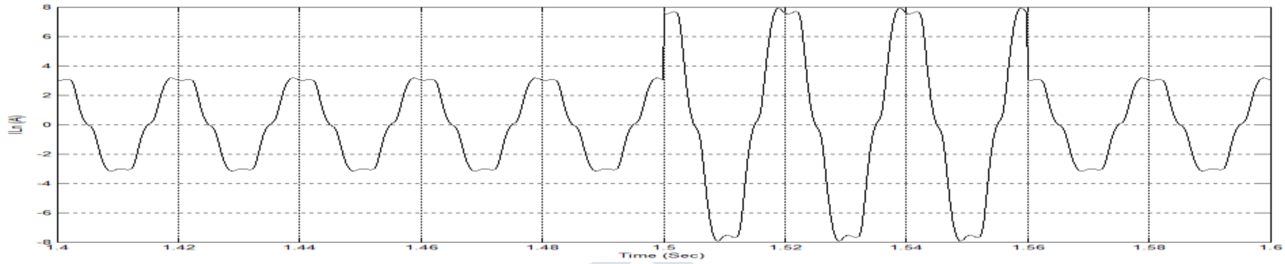

Fig. 17 Load Neutral Current Waveform

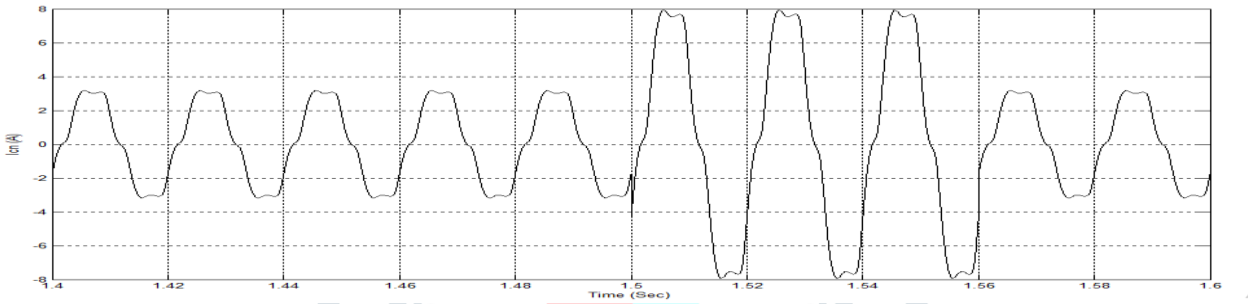

Fig. 18 Compensating Neutral Current Waveform

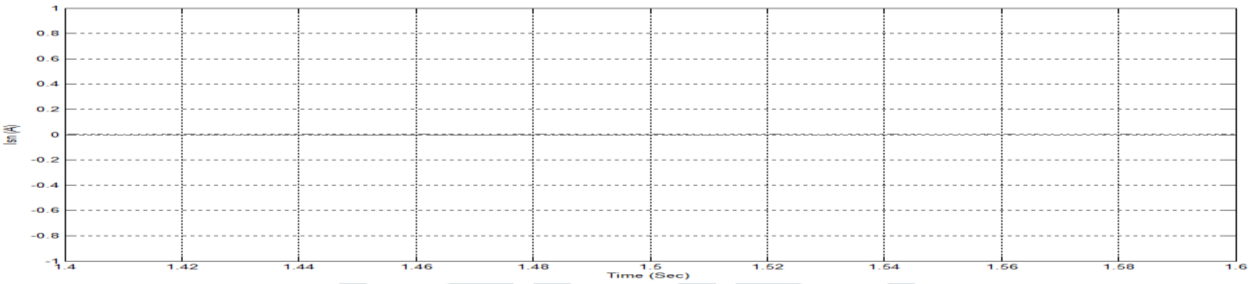

Fig. 19 Resulting Source Neutral Current Waveform

V. CONCLUSIONS

The admittance-based control technique has been used for a PV-alternator hybrid system for an uninterrupted power supply and power quality improvement. The Fuzzy-based MPPT algorithm has delivered maximum solar array power under varying conditions of temperature and irradiation. The technique has been demonstrated to eliminate harmonics, load balancing, and to provide neutral current compensation by incorporating four-leg VSC in the system. The PCC voltage and frequency have been maintained constant. Satisfactory performance of the system has been observed through linear and nonlinear loads.

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