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Enhancement of Power quality in PMSG based DG set using Fuzzy logic controller

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ABSTRACT: This paper presents the improvement of power quality in PMSG (Permanent Magnet Synchronous Generator) based DG (Diesel Generator) set supporting three-phase loads utilizing STATCOM (Static Compensator). A 3-leg VSC (Voltage Source Converter) with a capacitor on the DC link is utilized as STATCOM. The reference source current for the system is assessed utilizing an Adaline based control strategy using fuzzy logic controller (FLC). A PWM (Pulse Width Modulation) current controller is used for generation of gating beats of IGBTs (Insulated Gate Bipolar Transistors) of three leg VSC of the STATCOM. The STATCOM is used for voltage control, harmonics elimination, power factor improvement, and load adjusting and load compensation. Hence, the DG set is keep running at consistent speed so that the frequency of supply stays steady independent of loading condition. The system can be implemented by using matlab/simulink software. The fuzzy controller results are compared with the results of Adaline based PI controller.

KEYWORDS: STATCOM, FLC, VSC, IGBTs, PMSG, PWM, DG Set, Power Quality.

I. INTRODUCTION

The popularity of PMSG grows day to day in the wind power industry due to their potential use in WECS (Wind Energy Conversion Systems) [1-4]. The progression in the field of rare earth permanent magnet with high field strength, like neodymium–iron–boron (Nd–Fe–B) has given lot of liberty in the field of automation industry [5-7]. These generators are very strong because of its high power to weight ratio, brushless Operation, efficiency, reliability and ruggedness. More electric systems employ PMSG because; the occurrence of a fault in a phase or converters will be confined to that phase [8]. Variable speed wind turbines equipped with multi-pole permanent magnet synchronous generator (PMSG) and full-scale frequency converter are, for example, announced to be very attractive and suitable for application in large wind farms. [9]. Because of its simple structure and efficient energy production, more large size wind turbine generator systems will adopt PMSG. Usually the WECS with PMSG is connected to grid via an AC-DC-AC converter system [10]. A disadvantage of PMSG is that the excitation can't be altered and hence the voltage regulation varies with load. Since the PMSG is compact in size, these generators have potential applications in DG (Diesel Generator) set based isolated supply systems. The diesel generator sets are run at a constant speed with the diesel engine as a prime mover. There is no issue of frequency control in these supply systems. The main task in DG sets based supply systems is to maintain the constant terminal voltage. Suitable design of rotor with Nd–Fe–B magnet can reduce the voltage regulation of PMSG. Chan et. al. [11] has presented the analysis of PMSG with Nd-Fe-B permanent-magnet rotor feeding isolated resistive load. The generator exhibits inverse saliency which results in improvement of voltage regulation. Conditions for achieving zero- voltage regulation of the generator are deduced based on two-axis theory. According to Chen et. al. [12], voltage regulation can restrict the useful capacity of PMSG. The solution adopted was to employ a capacitor connected across the generator AC terminals providing additional excitation due to the capacitor current flowing in the stator coils. According to Rahman et.al. [13], a fixed capacitor thyristor controlled reactor scheme is used to regulated terminal voltage by controlling the thyristor ignition angle. Errami et.al.[14] Proposed a novel variable structure Direct Torque control scheme for WECS based on the PMSGs in order to maximize the generated power. In the research work on DG sets, very little attention has been paid to potential use of PMSG in DG sets standalone supply systems. The source impedance of DG set is high and the unbalance and distorted currents leads to the unbalanced and distorted three-phase voltages at PCC. All these factors lead to the increased fuel consumption and reduced life of the DG sets. This forces to operate these DG sets with derating, which results into increased cost of the system. Instead of this a STATCOM can be used with three-phase DG set to feed unbalanced loads without derating the DG set and within the same cost involved. Moreover, STATCOM can provide compensation for harmonics and reactive power that facilitates to the load the DG set up to its full kVA rating. [15-21]. In addition, it can be used for load balancing, harmonics elimination, load compensation and reactive power compensation. In the proposed system with PMSG driven by diesel engine, STATCOM is used for voltage control of the PMSG. The Adaline-based algorithm is an adaptive method for extracting reference current signals. The proposed system uses an Adaline-based control algorithm which is simple and needs less computational efforts [22]. Here, we are using Fuzzy controller over conventional PI controller.

II. SYSTEM CONFIGURATION

The proposed system comprising of a PMSG based DG set, a three leg VSC, and straight/nonlinear loads, is appeared in Fig. 1. A RC channel is utilized for separating high frequency swell from voltage at PCC (Point of Common Coupling). A 3-leg VSC is utilized a STATCOM. The VSC is connected with PCC through three interfacing inductors. The interfacing inductors connected between three legs of VSC and PCC are utilized to channel the high frequency swells from current. The proposed system utilizes an extraordinarily outlined PMSM of 3.7 kW, 50 Hz, 4-post, 230 V.

III. CONTROL ALGORITHM

Fig.2 exhibits an Adaline based control calculation utilized as a part of the proposed system for estimation of reference source streams. The Adaline based control calculation gauges amplitude of basic parts of active and reactive parts of load streams. It utilizes a settled stride estimate which may have any an incentive from 0.1 to 1 for quick merging. In phase furthermore, quadrature stage unit formats are utilized for estimation of reference source currents.

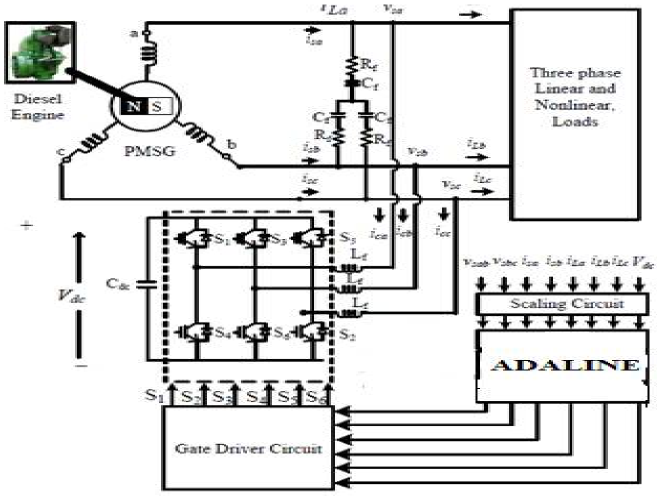

Fig. 1 Configuration of PMSG based DG set feeding three phase loads.

A. Extraction of Quadrature Phase and In-Phase Unit Templates

In-phase unit templates are extracted by dividing instantaneous phase-voltages by amplitude of phase voltages (Vt) as,

$$u_{ap} = v_{sa}/V_t \,,\ u_{bp} = v_{sb}/V_t,\ u_{cp} = v_{sc}/V_t \quad (1)$$

Where, v_{sa}, v_{sb} and v_{sc} are instantaneous phase-voltages which are obtained from sensed lined voltage obtained as [19].

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$$\begin{pmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{pmatrix} = \frac{1}{3}\begin{bmatrix} 2 & 1 \\ -1 & 1 \\ -1 & -2 \end{bmatrix}\begin{bmatrix} v_{sab} \\ v_{sbc} \end{bmatrix} \qquad (2)$$

The amplitude of phase voltages is obtained from instantaneous phase voltages as [19],

$$V_t = \sqrt{\frac{2}{3}(v^2{}_{sa} + v^2{}_{sb} + v^2{}_{sc})} \qquad (3)$$

The quadrature unit templates are extracted using in-phase unit templates as,

$$u_{aq}=(- u_{bq}+ u_{cq})/\sqrt{3} \qquad (4)$$

$$u_{bq}=(3u_{aq}+ u_{bq} -u_{cq})/2\sqrt{3} \qquad (5)$$

$$u_{cq}=(3u_{ap}+ u_{bp} -u_{cp})/2\sqrt{3} \qquad (6)$$

B. Estimation of Active Power Component of Reference Source Current

The Adaline limits the mistake between real load current and its evaluated weight by improving the weights of dynamic and reactive parts of load streams. The weight vector for dynamic part of load current of each stage is communicated as [22]

$$W_p(n) = W_p(n-1) + \mu^*\{i_L(n) - \{W_p(n) \times u_p(n)\}\}^*u_p(n) \qquad (7)$$

Where, μ is fixed step size having any value from 0.1 to 1. Here the step size in proposed system is taken to be 0.2.

For a three phase system, the weight of active component of load current is given as,

$$W_p(n) = \frac{W_{ap}(n) + W_{bp}(n) + W_{cp}(n)}{3} \qquad (8)$$

where $W_{ap}(n)$, $W_{bp}(n)$ and $W_{cp}(n)$ are weights corresponding to active components of load currents in phase ‘a’, phase ‘b’ and phase ‘c’ respectively.

The weight of active power component of reference source current is obtained by adding weight vectors of (8) to the weight obtained from the output of DC link voltage PI (Proportional-Integral) controller. The input to DC link PI controller is an error voltage given as,

$$V_{dcr}(n)=V_{dcref}(n)-V_{dc}(n) \qquad (9)$$

Where, $V_{dc}(n)$ is sensed voltage on DC link voltage and $V_{dcref}(n)$ is reference voltage of the DC link.

The output of the PI controller of DC link can be given as,

$$W_{qSTAT}(n)=W_{qSTAT}(n-1)+k_{pdc}\{V_{dcer}(n)-V_{dcer}(n-1)\}+k_{idc}V_{dcer}(n) \qquad (10)$$

Where, k_{pdc} and k_{idc} are proportional and integral gain parameters of the PI controller of DC link.

The final estimated weight of the amplitude of active power component of reference source current is given as,

$$W_{pT}(n)=W_{qSTAT}(n-1)+ W_p(n) \qquad (11)$$

The instantaneous active components of 3-phase reference source currents are obtained by multiplying weight vector of active power component and in-phase unit templates as under,

$$i^*{}_{sap}(n) = W_{pT}(n) * u_{ap}(n) \qquad (12)$$

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Vol. 6, Issue 9, September 2017

$$i^*_{sbp}(n) = W_{pT}(n) * u_b(n) \quad (13)$$

$$i^*_{scp}(n) = W_{pT}(n) * u_{cp}(n) \quad (14)$$

C. Estimation of Reactive Power Component of Reference Source Current

The weight vector for reactive power component of load current of each phase is given as,

$$W_q(n) = W_q(n-1) + \mu * \{i_L(n) - \{W_{qT}(n) \times u_q(n)\}\} * u_q(n) \quad (15)$$

Final weight of reactive component of load current is given as,

$$W_q(n) = \frac{W_{aq}(n) + W_{bq}(n) + W_{cq}(n)}{3} \quad (16)$$

where $W_{aq}(n)$, $W_{bq}(n)$ and $W_{cq}(n)$ are weights corresponding to the reactive components of load currents in phase 'a', phase 'b' and phase 'c' respectively.

The output of terminal voltage PI controller is considered weight of receptive power part of STATCOM current. The yield of the terminal voltage PI controller is given as,

$$W_{qSTAT}(n) = W_{qSTAT}(n-1) + k_{pv}\{V_e(n) - V_e(n-1)\} + k_{iv}V_e(n) \quad (17)$$

where, k_{pv} and k_{iv} are gain parameters of terminal voltage PI controller and $Ve(n)$ is error voltage. The error voltage is computed as,

$$V_e(n) = V_{tref}(n) - V_t(n) \quad (18)$$

Where, $V_{tref}(n)$ is amplitude of reference terminal phase voltage and $V_t(n)$ is the amplitude of instantaneous phase voltage at PCC.

The weight of reactive segment of load current is subtracted from the output of terminal voltage PI controller to get the weight vector of reference source current as,

$$W_{qT}(n) = W_{qSTAT}(n-1) + W_q(n) \quad (19)$$

The instantaneous reactive components of three phase reference source currents are obtained weight of reference source current and quadrature phase unit templates as,

$$i^*_{saq}(n) = W_{qT}(n) * u_{aq}(n) \quad (20)$$

$$i^*_{sbq}(n) = W_{qT}(n) * u_{bq}(n) \quad (21)$$

$$i^*_{scq}(n) = W_{qT}(n) * u_{cpq}(n) \quad (22)$$

D. Estimation of Reference Source Currents

The instantaneous reference source currents are acquired by including instantaneous active and reactive power parts of reference source currents as under,

$$i^*_{sa} = i^*_{sap} + i^*_{saq};\ i^*_{sb} = i^*_{sbp} + i^*_{sbq};\ i^*_{sc} = i^*_{scp} + i^*_{scq} \quad (23)$$

The estimated reference source currents and sensed source currents are compared with each other and error is given to the PWM current controller to generate gating pulses for IGBTs of VSC of STATCOM [10].

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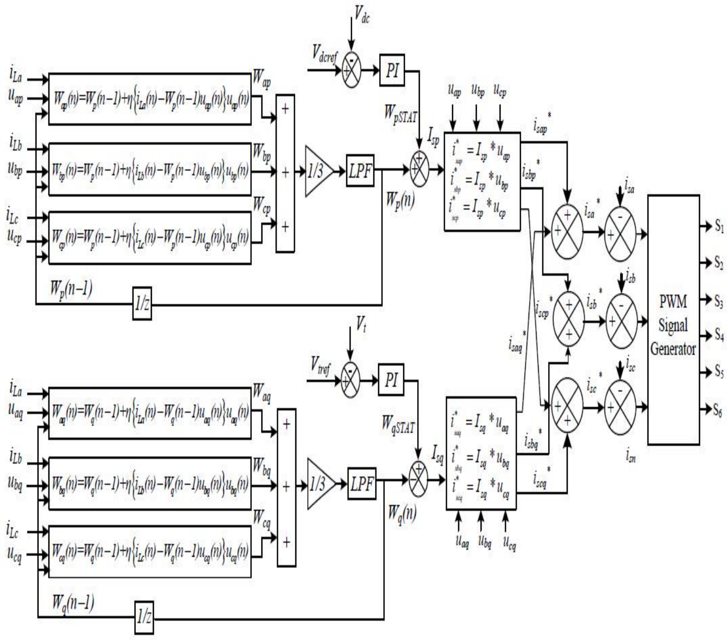

Fig.2 Adaline based control algorithm for PMSG Based DG set feeding three-phase loads

IV.FUZZY LOGIC CONTROLLER

Fuzzy rationale is a type of numerous esteemed rationales in which reality estimations of variables might be any genuine number somewhere around 0 and 1. By differentiation, in Boolean rationale, reality estimations of variables may just be 0 or 1. Fuzzy rationale has been stretched out to handle the idea of halfway truth, where reality quality may extend between totally genuine and totally false. Besides, when etymological variables are utilized, these degrees might be overseen by particular capacities.

Normally fuzzy rationale control system is made from four noteworthy components exhibited on Figure fuzzification interface, fuzzy induction motor, fluffy principle grid and defuzzification interface. Every part alongside fundamental fuzzy rationale operations will be depicted in more detail below.

1. The selection of appropriate inputs and their fuzzification.
2. The definition of the input and output membership functions.
3. The definition of the Fuzzy Rule Base.
4. The defuzzification of the output obtained after the processing of the linguistic variables with the help of a proper defuzzification technique.

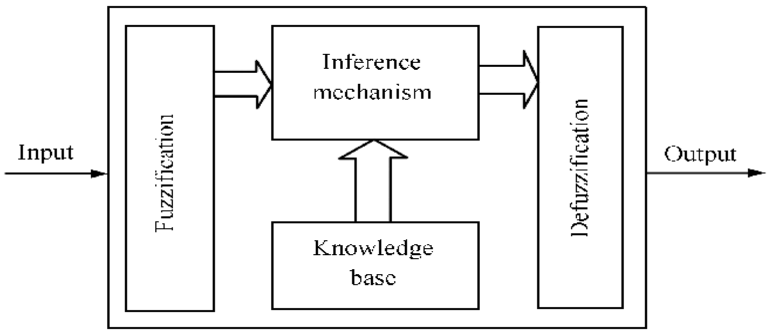

Fig3: block diagram of fuzzy logic controller

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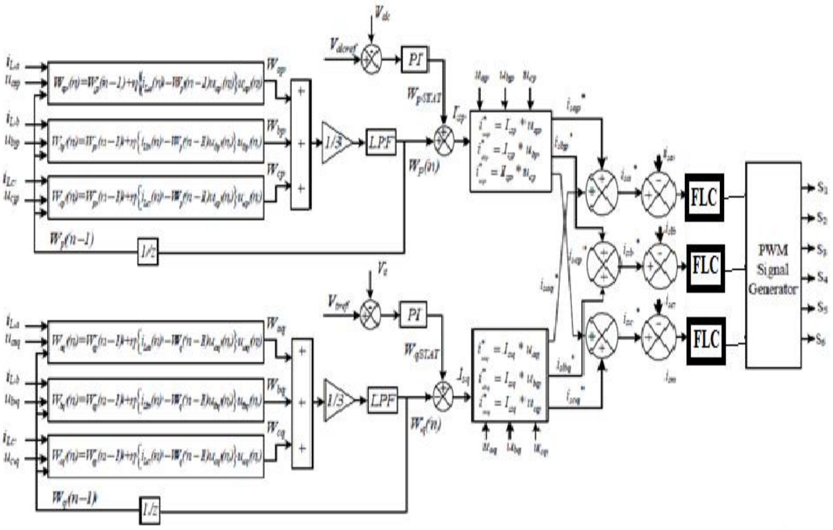
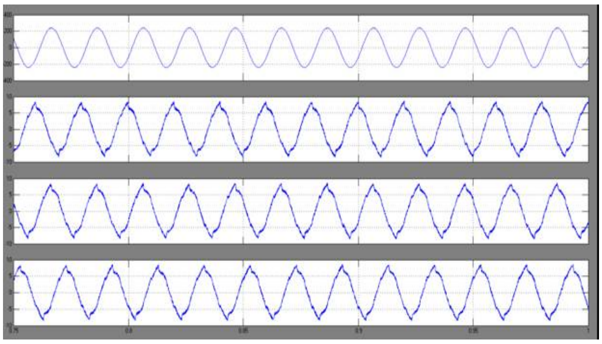


Fig4. Control block diagram of fuzzy logic controller

V. SIMULATION RESULTS AND DISCUSSIONS

Performance of the system is analyzed under linear and nonlinear loads at steady state and transient conditions. Linear load is a simple RL type load. The nonlinear load is realized by using a three phase rectifier with a resistance on DC link. An inductor is also connected in series with resistance to inject harmonics in current on ac input. The performance at linear and nonlinear loads is also given here.

Simulation results using pi controller:



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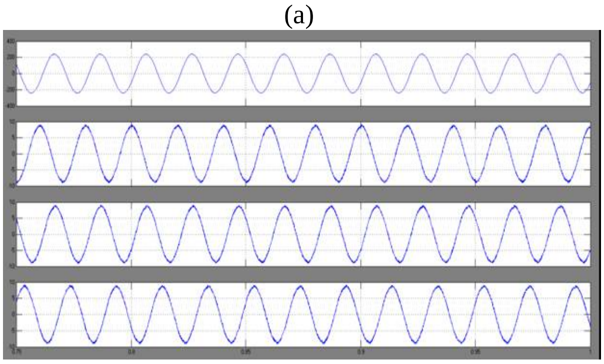

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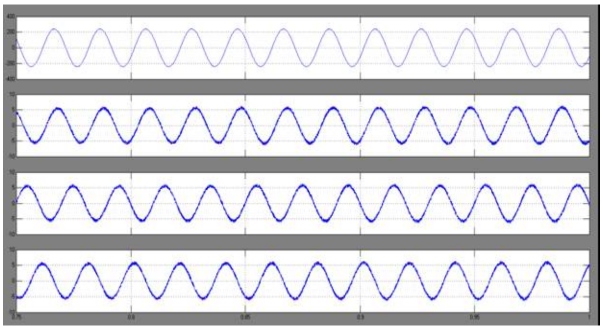

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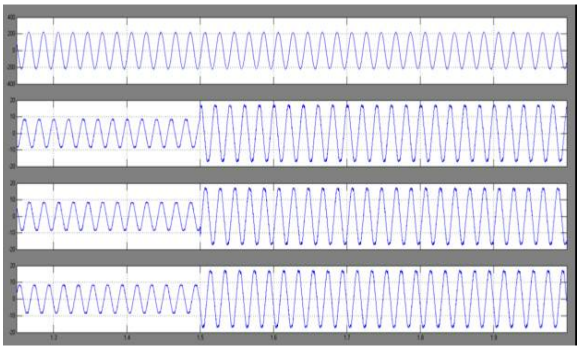
Fig3. Performance under balanced linear loads (a) v_{sab} and i_{sabc}(b) v_{sab} and i_{Labc} (c) v_{sab} and i_{cabc}



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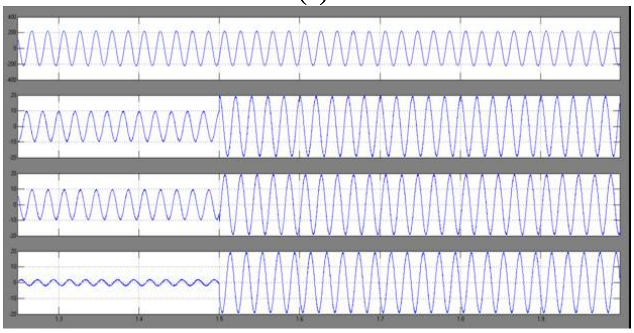

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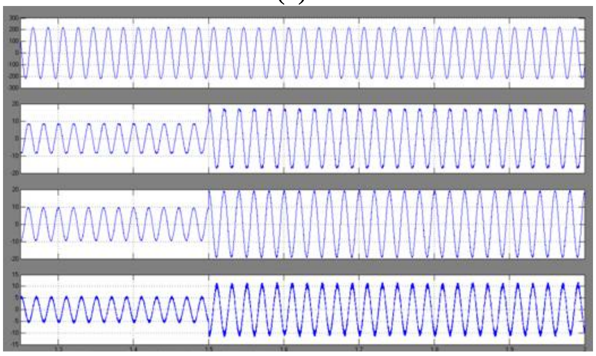

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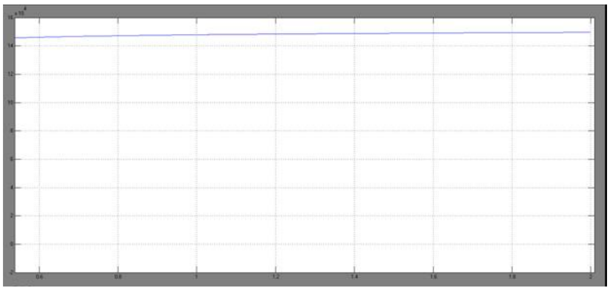
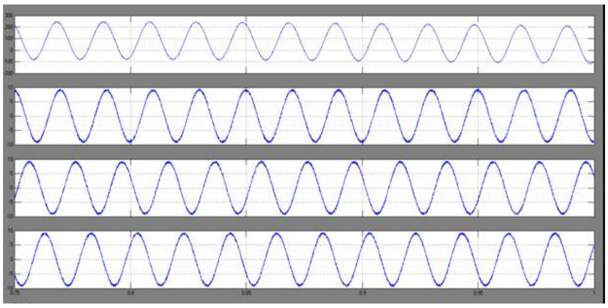


(d)

Fig4. Dynamic performance at linear loads (a) v_{sab}, i_{sa},i_{sb} and i_{sc} ,(b) v_{sab}, i_{La},i_{Lb} and i_{Lc} (c) V_{dc}, i_{sa},i_{La} and i_{Ca} *(d)*V_d



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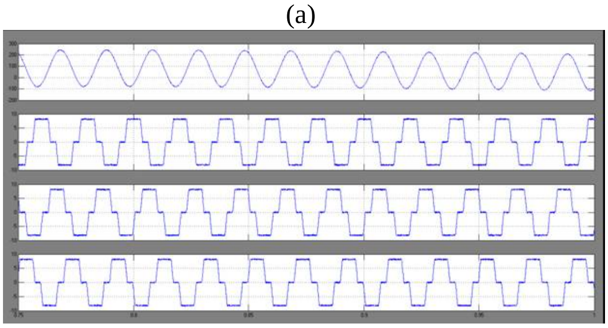

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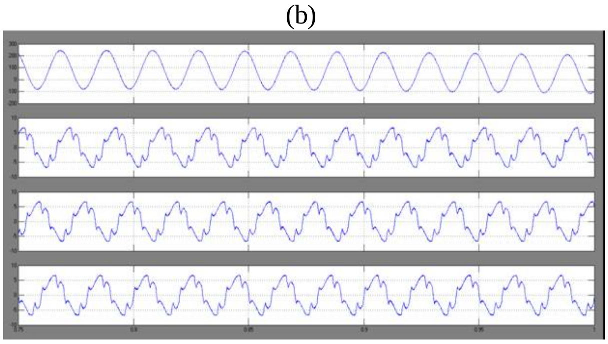

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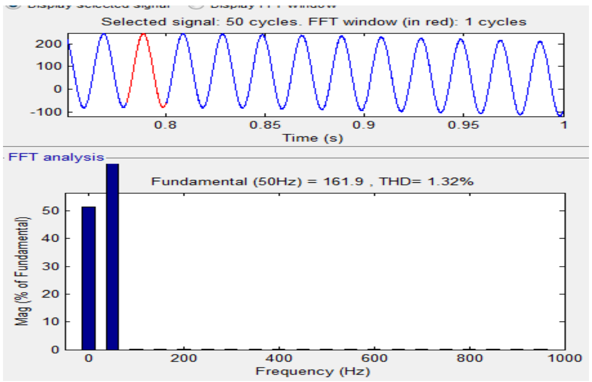

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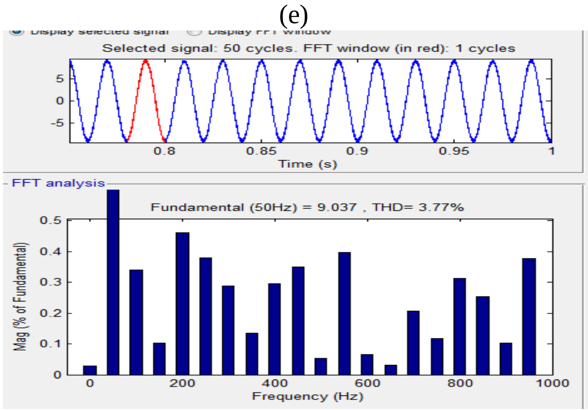

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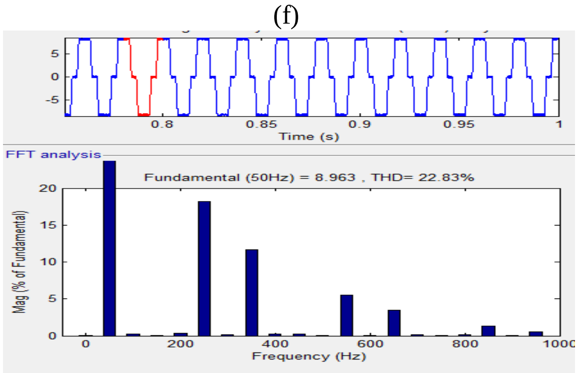

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Fig.5. Performance under balanced nonlinear loads (a) v_{sab} and i_{sabc} (b) v_{sab} and i_{labc} (c) v_{sab} and i_{cabc} (d) P_{sabc} and Q_{sabc} (e) THD of v_{sab} (f) THD of i_{sa}(g) THD of i_{La}

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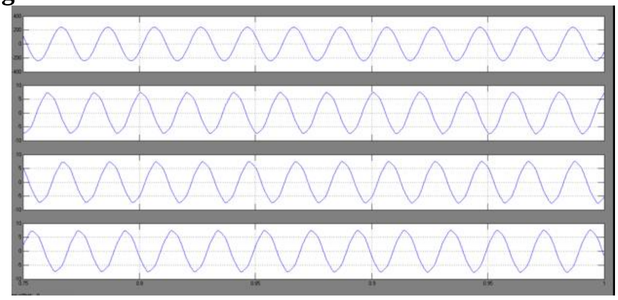
Simulation results of fuzzy logic controller:



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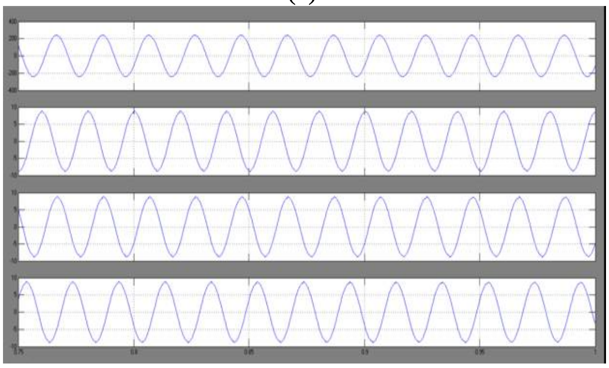

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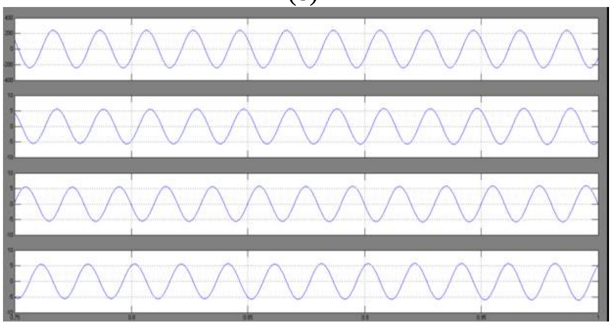

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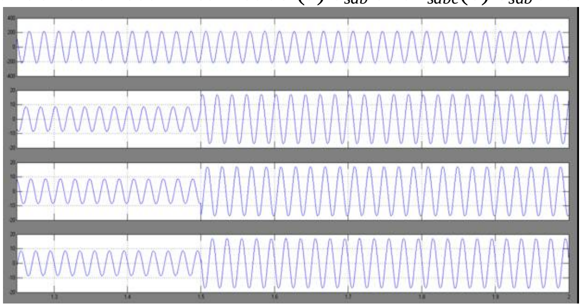

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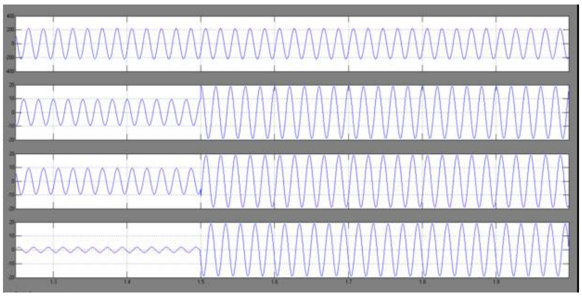

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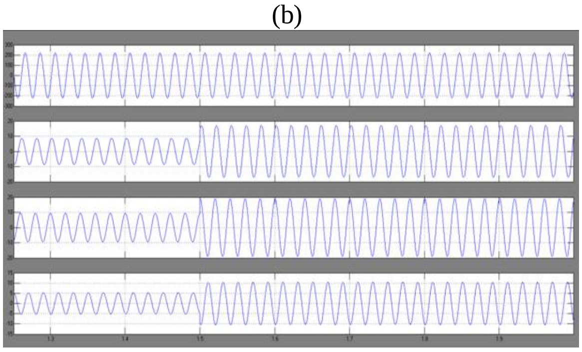

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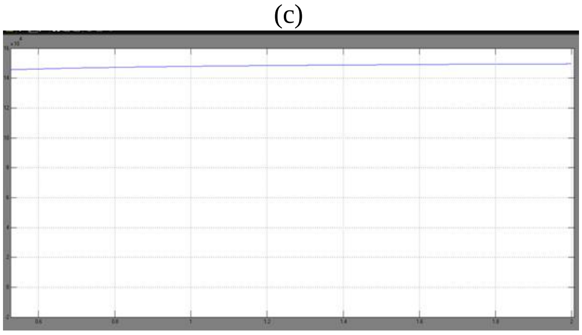

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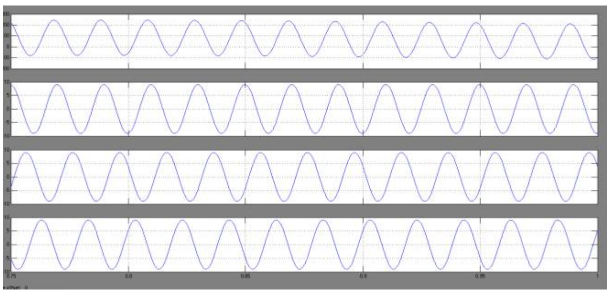

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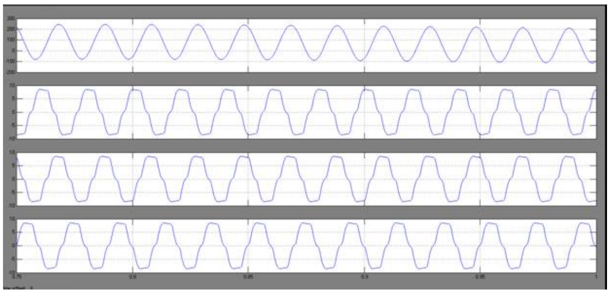

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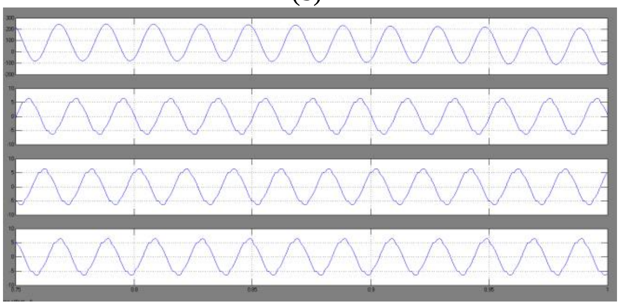

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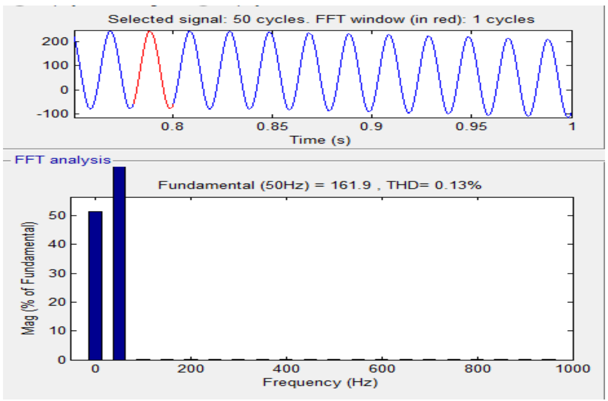

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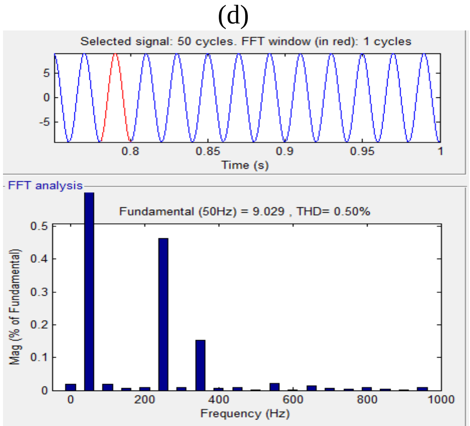

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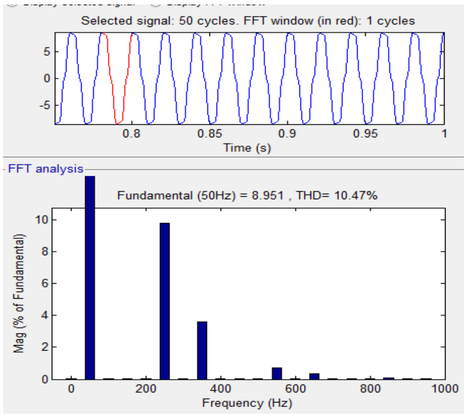

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Fig5. Performance under balanced nonlinear loads (a) v_{sab} and i_{sabc} (b) v_{sab} and i_{labc} (c) v_{sab} and i_{cabc} (d) THD of v_{sab} (e) THD of i_{sa} (f) THD of i_{La}

VI. CONCLUSIONS

STATCOM has been used to power quality improvement of the PMSG based DG set for voltage control, harmonic elimination, and load adjusting. It has also been found that the STATCOM maintains the balanced source currents when the load is highly unbalanced due to removal of load from phase 'c'. The load balancing has additionally been accomplished by proposed system with reduced weight on the winding of the generator. The proposed system is a constant speed DG set so there is no provision of frequency control in the control algorithm.

Under nonlinear loads, the load current of DG set is a quasi square with a THD of 10.47 %. The STATCOM has been found capable to eliminate these harmonics and thus the THD of source currents has been limited to 0.50 % and the THD of terminal voltage has been observed of the order of 0.13%. This is possible with the Fuzzy controller. Therefore, the THDs of source voltage and currents have been maintained well within limits of IEEE-519 standard under nonlinear load.

Therefore, the proposed PMSG based DG set along with STATCOM can be used for feeding linear and nonlinear balanced and unbalanced loads. The proposed PMSG based DG set has also inherent advantages of low maintenance, high efficiency and rugged construction over a conventional wound field synchronous generator based DG set.

Hence, ADALINE based fuzzy controller has given the better results compared to PI controller.

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