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Grid Interconnection of Fuel Cell at Distribution Level and Power Quality Improvement of a Non Linear Load by Using D-Stat Com

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Abstract: *Active Power Filters (APF) are extensively used to commentate current harmonics and load unbalance. In this work, the existing PV inverter acts as Shunt Active Power Filter (SAPF) that is capable of simultaneously compensating problems like current unbalance current harmonics and also of injecting the energy generate d by renewable energy source. Electrical utilities and end users of electric power are becoming increasingly concerned about meeting the growing energy demand. Maximum amount of energy demand is supplied by the non-renewable sources, but increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it look towards Non Fossil Fuels (renewable energy sources). A Power quality problem is a concurrence manifested as anon standard voltage, current or frequency that results in a failure or a miss operation of endures equipments. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruption which can cost significant financial losses. Electrical drives play an important role in modern industries. In the last two decades a new type of electrical driven armed the Switched Reluctance Motor (SRM) drive is receiving considerable attention from industry in adjustable peed drives since they are characterized by rigid construction ,high operation reliability, high efficiency, high torque to inertia ratio and finally low manufacturing costs. Renewable energy resources (RES) are being increasingly connected in distribution systems utilizing power electronic converters. All of these functions maybe accomplished either individually or simultaneously. This new control concept is demonstrated with extensive MATLAB/ Simulink.*

Keywords: *Active Power Filters (APF), Shunt Active Power Filter (SAPF), Power Quality, Renewable Energy Resources (RES), Switched Reluctance Motor (SRM).*

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I. Introduction

The Switched Reluctance Motor (SRM) drives have recently gained considerable attention among researchers

due to several reasons. Firstly, stator can be easily manufactured as the stator windings are concentrated around

the salient stator poles. Also the salient rotor poles are made up of steel laminations, without conductors or permanent magnets or cage. Due to this rotor structure, extremely high speed can be obtained as compared to rotors with magnets or windings. Secondly, the motor is cost-effective in comparison to conventional induction and synchronous motors, and also it is claimed to have a comparable or even

Higher efficiency over wide range of speed. Due to increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards Renewable Energy Sources (RES) as a future energy solution. In finding solutions to overcome a global energy crisis, the Photo Voltaic (PV) system has attracted significant attention in recent years. The government is providing incentives for further increasing the use of grid-connected PV systems. Renewable Energy Sources are increasingly integrated at the distribution level due to increase in load demand which utilize power electronic converters. Due to the extensive use of power electronic devices, disturbance so occur on the electrical supply network. These disturbances are due to the use of non-linear devices. These will introduce harmonics in the power system thereby causing equipment overheating, damage devices, EMI related problems etc.

Active Power Filters (APF) is extensively used to compensate the current harmonics and load unbalance. This will result in additional hardware requirements. Power quality is one of the most important topics that electrical engineers have been noticed in recent years. Voltages ages one of the problems related o power quality. This phenomenon happens continuously in transmission and distribution systems. During a voltage sag event, amplitude of the effective load voltage decrease from 0.9 of the nominal load voltage to0.1inveryshorttime (less than one minute).Short circuit, transformer energizing, capacitor bank charging etc are causes of voltage sag. Voltage sag has been classified in 7 groups of A-G [1]. According to this classification most of voltage sags are companion with a phase angle jump (types C, D, F and G). Phase angle jump for power electronics systems such as ac- ac and ac-dc

Converters, motor drives etc is harmful[2]. Therefore, phase angle jump compensation is one of the voltage sag mitigation goals. Grid-connected three-phase photovoltaic (PV) systems are nowadays recognized for their contribution to clean power generation. A primary goal of these systems is to increase the energy injected to the grid by keeping track of the maximum power point (MPP) of the panel, by reducing the switching frequency, and by Providing high reliability.

In addition, the cost of the power converter is also becoming a decisive factor, as the price of the PV panels is being decreased [2]. This has given rise to a big diversity of innovative converter configurations for interfacing the PV modules with the grid. Generally, current controlled voltage source inverters are used to interface the intermittent RES in distributed system. Recently, a few control strategies for grid connected Inverters incorporating PQ solution have been proposed .In [3] An inverter operates as active inductor at a certain frequency to absorb the harmonic current. But the exact calculation of network inductance in real-time is difficult and may deteriorate the control performance .A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed in[4].In[5],a control strategy for renewable interfacing inverter based on– theory is proposed. In this strategy both load and inverter current sensing is required to compensate the load current harmonics. The non-linear load current harmonics may result in voltage harmonics and can create a serious PQ problem in the power system network. Active power filters (APF) are extensively used to compensate the load current harmonics and load unbalance at distribution level. This results in an additional hardware cost.

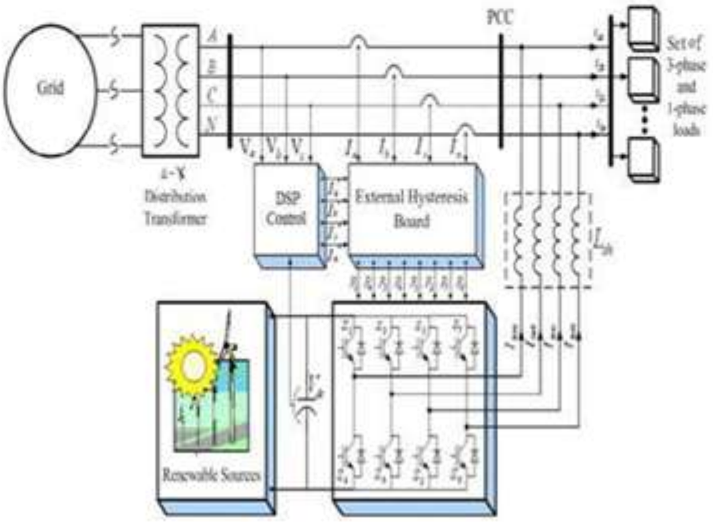

Figure1.Schematic diagram of a DSTATCOM with RES.

Conventionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic appliances however recently there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC)to become one of intelligent controllers to their appliances[3]. With respect to their successful methodology

Implementation, this kind of methodology implemented in this paper is using fuzzy logic controller with feedback by introduction of voltage respectively. The introduction of change in voltage in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal. The fuzzy logic controller serves as intelligent controller for this propose. There centre search literature on SRM concerns the following major aspects: SR machine design and construction. SRM requires a complex controller on account of its non-linear characteristics. Accurate position sensing s required to achieve high performance for converter and controller circuit design. The work reported in this thesis addresses some of these aspects.

II. Distribution Static Compensator (D-Statcom)

AD-STATCOM consists of a two-level VSC, adc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Fig.1 shows the schematic diagram of D-STATCOM.

(1)

$$I_{out} = I_l - I_s = I_l - \frac{V_{th} - v_l}{Z_{th}}$$

$$I_{out} < \gamma = I_l < (-\theta) - \frac{v_{th}}{Z_{th}} < (\delta - \beta) + (\frac{v_{th}}{z_{th}}) < (-\beta)$$

(2)

I_{out} =output current I_L =load current
I_S =source current V_{th}=Thevenin Voltage
V_L =load voltage Z_{th}=Thevenin impedance

Referring to the equation 2.2, output current, I_{out} will Correct the voltage sags by adjusting the voltage drop across the system impedance, (Z_{th}=R+jX). It may be mention that the effectiveness of D-STATCOM in correcting voltage sags depends on:

- The value of Impedance, Z_{th}=R+jX
- The fault level of the load bus

2.1. Voltage Source Converter (VSC)

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the Missing voltage‟. The „missing voltage‟ is the difference Between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages [8, 9]. In addition, D-STATCOM is also capable to generate or absorbs reactive power .If the Output voltage of the VSC is greater than AC bus terminal voltages, D-STATCOM is said to be in capacitive mode. So, it will compensate there active power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and Controllers.
Magnitude of the DSTATCOM output voltages allows
Effectives control of active and reactive power exchanges between D-STATCOM and AC system. In addition, the Converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage [10]. For DSTATCOM the three-phase reference source currents
Are computed Using three-phase AC voltages (Vta,Vtb and Vtc) and DC bus voltage(Vdc) of DSTATCOM. These reference supply currents consist of two components,
One in-phase(I_{spdr}) and Another in quadrature (I_{spqr}) With the supply voltages. The control scheme is represented in
Fig.2.Thebasicequations of control algorithm of DSTATCOM are as follows.

2.2. Computation of In-Phase Components of Reference Supply Current

The instantaneous values of in-phase component of Reference supply currents (I_{spdr}) Is computed using one PI controller over the average value of DC bus voltage of the DSTATCOM (V_{dc}) and reference DC voltage (V_{dcr}) as

$$I_{spdr(n)} = I_{spdr(n-1)} + k_{pd}\{V_{de(n)} - V_{de(n-1)}\} + k_{id}\{v_{de(n)}\} \quad \textbf{(3)}$$

Where V_{den}=V_{dcc} -V_{dcn} Denotes the error in V_{dcc} and average value of V_{dc}. Kpd and Kid are proportional and integral
gains of the DC bus voltage PI controller. The output of this PI controller (Ispdr) is taken as amplitude of in-phase component of the reference supply currents. Three- phase in-phase components of the reference supply currents (i_{sadr}, i_{sbdr}
and i_{scdr}) Are computed using the in-phase unit Current vectors (ua, ub and uc) Derived from the AC terminal voltages (Vtan,VtbnandVtcn), respectively.

$$U_a = \frac{V_{ta}}{V_{\tan}}, U_b = \frac{V_{tb}}{V_{tbn}}, U_c = \frac{V_{tc}}{V_{tcn}}$$

Where Vtm is amplitude of the supply voltage and it is computed as

$$V_{tm} = I_2 - (V_{\tan 2} + V_{tbn2} + V_{tcn2}) \quad \textbf{(4)}$$

The instantaneous values of in-phase component of reference supply currents (isadr, isbdrandiscdr) are computed as

$$I_{sbr} = I_{sdbr} + I_{sbqr} \quad I_{sdr} = I_{spdr} u_{a2}, I_{sbdr} = I_{spdr} u_b, I_{scdr} = I_{spdr} u_c \quad \textbf{(5)}$$

2.3. Computation of Quadrature Components of Reference Supply Current

The amplitude of quadrature component of reference supply currents is computed using a second PI controller over the amplitude of supply voltage (Vtm) and its reference value (v tmr).

$$I_{spdr(n)} = I_{spdr(n-1)} + K_{pq}\{V_{ac(n-1)}\} + K_{iq}\{v_{c(n)}\}$$

$$W_a = \frac{\{-u_b + c\}}{\sqrt{3}}, W_b = \frac{\{u_a\sqrt{3} + u_b - u_c\}}{2\sqrt{3}}, W_c = \frac{\{-u_a\sqrt{3} + u_b - u_c\}}{2\sqrt{3}}$$

Three-phase quadrature components of the reference supply currents (isaqr, isbqrandiscqr) are computed using the output of Second PI controller (Ispqr) and quadrature unit current Vectors (wa, wb and wc) as

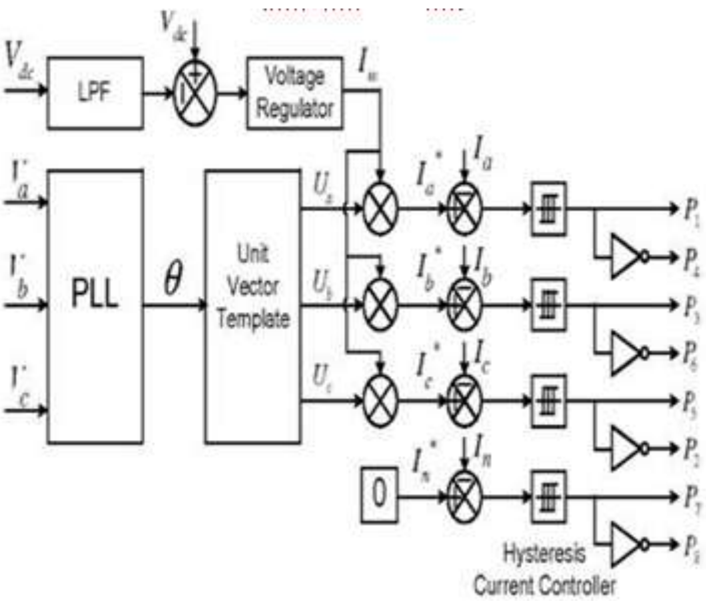

Figure.2. Control method for DTSATCOM.

(6)

Where V (V Vmcn) denotes the error in V and computed value Vtmn from Equation(3)and Kpq and Kiq are the proportional and integral gains of the second PI controller

2.4. Computation Of Total Reference Supply Currents

Three-phase instantaneous Reference Supply Currents (isar,isbrandiscr) are Computed By Adding in (isadr,isbdrandiscdr) phase and quadrature components of supply currents (isaqr,isbqrandiscqr) as

$$I_{sar} = I_{sadr} + I_{saqr} \quad (7)$$

$$I_{scr} = I_{scdr} + I_{scqr} \qquad \textbf{(8)}$$

A hysteresis pulse width modulated (PWM) current controller is employed over the reference (i_{sar},i_{sbr}andi_{scr})

and sensed supply currents (i_{sa},i_{sb}andi_{sc}) to generate gating pulses for IGBTs of DSTATCOM.

III. Matab/Simulink Modeling Of Dstatcom

3.1.Modelling of Power Circuit

Fig.3 shows the complete MATLAB model of DSTATCOM along with control circuit. The power circuit as well as control system are modelled using Power System Block set and Simulink. The grid source is represented by three-phase AC source. Three-phase AC loads are connected at the load end. DSTATCOM is connected in shunt and it consists of PWM voltage source inverter circuit and a DC capacitor connected at its DC bus. An IGBT-based PWM

inverter is implemented using universal bridge Block from Power Electronics subset of PSB. Snubber circuit is connected in parallel with each IGBT for protection. Simulation of DSTATCOM system is carried out for linear and non-linear loads. The linear load on the system is modeled using the block three-phase parallel R-L load connected in delta configuration. The non-linear load on the system is modeled using R and R-C circuits connected at output of the diode rectifier. Provision is made to connect loads in parallel so that the effect of sudden load The three-phase source to load is modeled using appropriate values of resistive and inductive components.

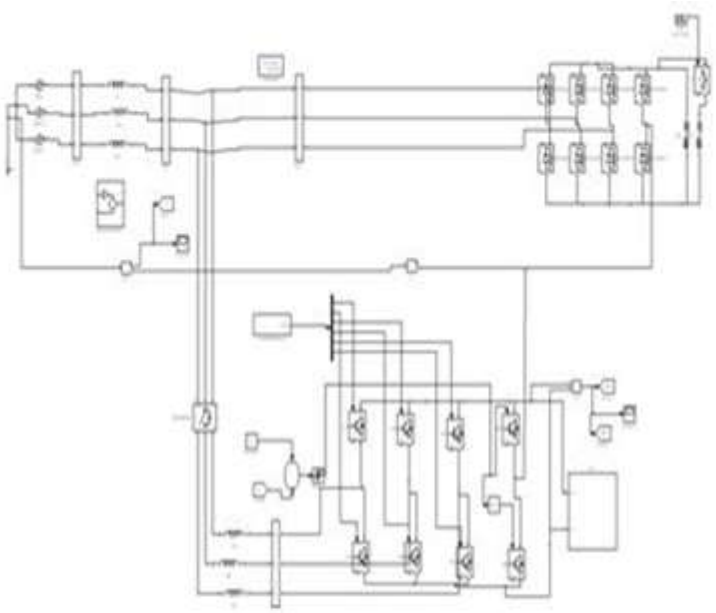

Figure.3. Matlab / Simulink Model of DSTATCOM Power Circuit.

3.2. Modeling of Control Circuit

Fig.4 shows the control algorithm of DSTATCOM with two PI controllers. One PI controller regulates the DC link voltage while the second PI controller regulates the Terminal voltage at PCC. The in-phase components of DSTATCOM reference currents are responsible for power factor correction of load and the quadrature components of voltage at PCC. The output of PI controller over the DC bus voltage (Ispdr) is considered as the amplitude of the in-phase component of supply reference currents and the output of PI controller over

AC terminal voltage (Ispqr) is considered as the amplitude of the quadrature component of supply reference currents. The instantaneous reference currents (i_{sar},i_{sbr} and i_{scr}) are obtained by adding the in-phase supply Reference currents (i_{sadr},i_{sbdr} andi_{scdr}) and quadraturesupply Reference currents (isaqr,isbqrandiscqr). Once the reference supply currents are generated, a carrierless hysteresis PWM Controller is employed over the sensed supply currents (isar, isbrandiscr) to generate gating pulses t o the IGBTs of DSTATCOM. The controller controls the DSTATCOM currents to maintain supply currents in a band around the desired reference current values. The hysteresis controller generates appropriate switching pulses for six IGBT softhe VSI working as DSTATCOM.

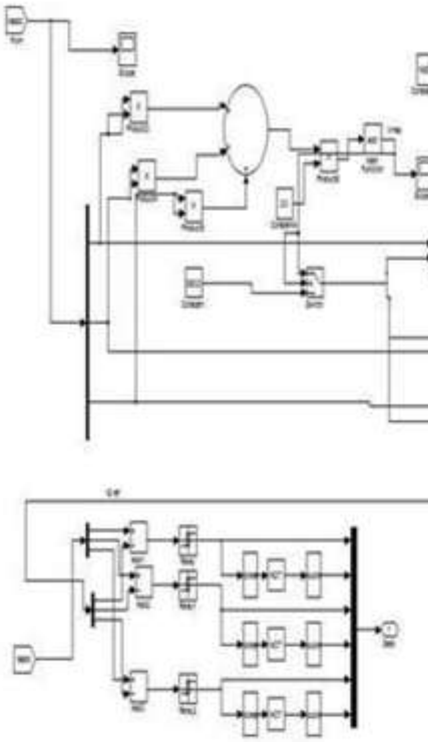

Figure.4. Control Circuit.

IV. Simulationresults

Here Simulation results are presented for two cases. In case one reactive power and harmonic compensation, case two active power, reactive power and harmonic compensation is considered.

4.1. Case One

Performance of DSTATCOM connected to a weak supply system is shown in Fig.5 for power factor correction and load balancing. This figure shows variation of performance variables such a supply voltages (v_{sa}, v_{sb} and v_{sc}), terminal voltages at PCC (v_{ta},v_{tb} and v_{tc}), supply currents (is_a, is_b and is_c),load currents (i_{la}, i_{lb} and il_c),DSTATCOM currents (ic_a, ic_b and ic_c) and DC link voltage (V_{dc}).

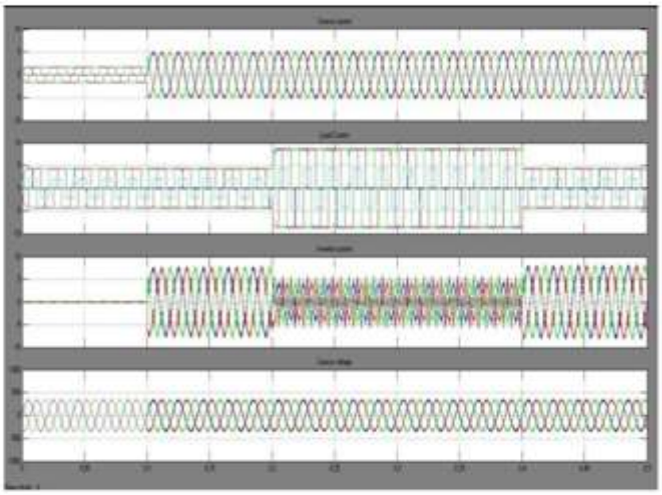

Figure.5. Simulation results for Balanced Non Linear Load

(a) Source current. (b) Load current.(c) Inverter injected current. (d) Source Voltage.
Fig.5 shows the source current, load current and compensator current and induction generator currents plots respectively. Here compensator is turned on a t0.1seconds.

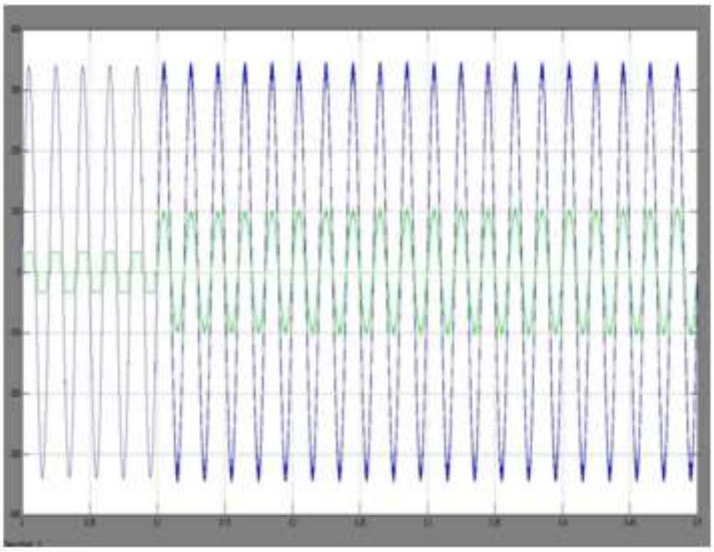

Figure6. Simulation results power factor for Nonlinear Load.

Fig.6 shows the power factor it is clear from the figure after compensation power factor is unity.

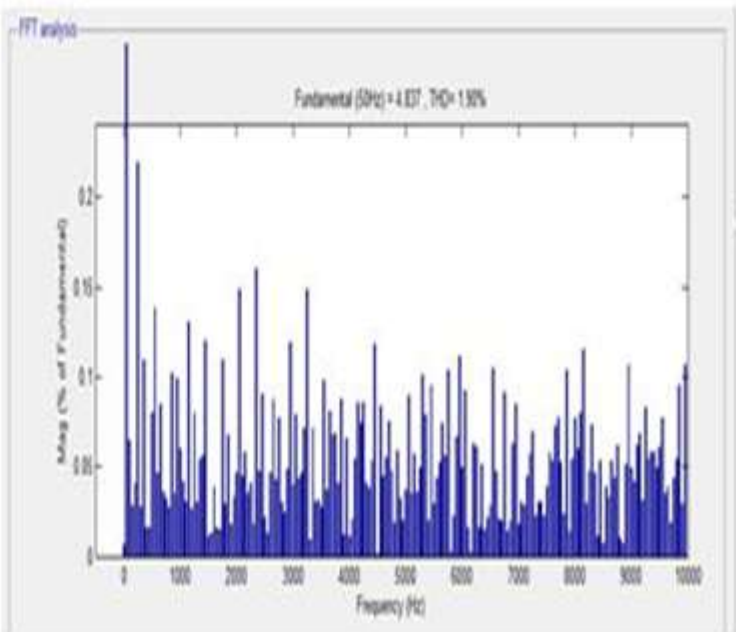

Figure7. Total Harmonic Distortion 1.90% of Source Current.

Fig.8 shows the Source current, load current and compensator current and Source Voltage. From the figure it is clear hat even though load is unbalanced source currents are balanced and sinusoidal.

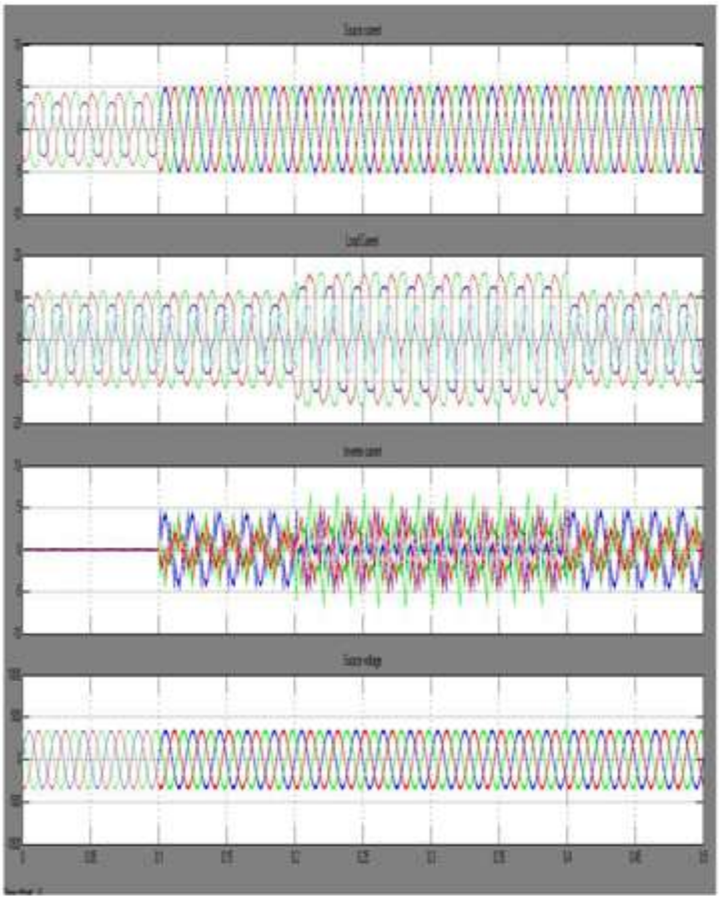

Figure8. Simulation results Non-Linear Unbalanced Load (a) Source voltage (b) source current (c) load current (d) Source Current.

4.2. Case Two

A Balanced three-phase non-linear load is represented by three-phase uncontrolled diode bridge rectifier with pure resistive load at its DC bus. Fig.7 shows the transient responses of distribution system with DSTATCOM without battery for supply voltages (Vsabc), supply currents (Isabc), load currents (ila,ilbandilc), DSTATCOM currents (ica,icb and icc) along with DC link v oltage (Vdc)and its reference value (Vdcr)at Rectifier non linear load.

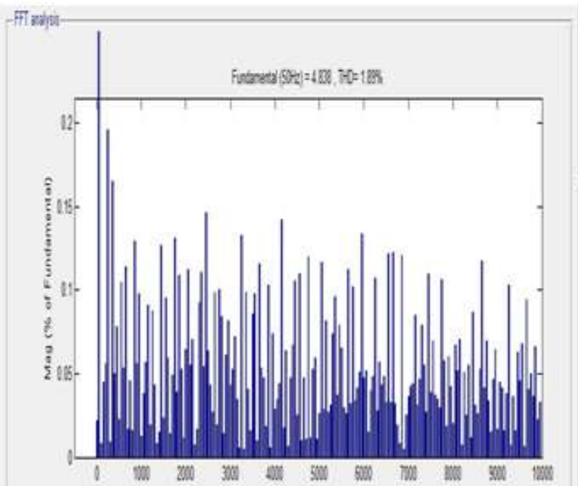

Figure9. Total Harmonic Distortion1.89% of Source Current.

Case 3: Matlab/Simulink Model of DSTATCOM Power Circuit With Balanced Linear Load

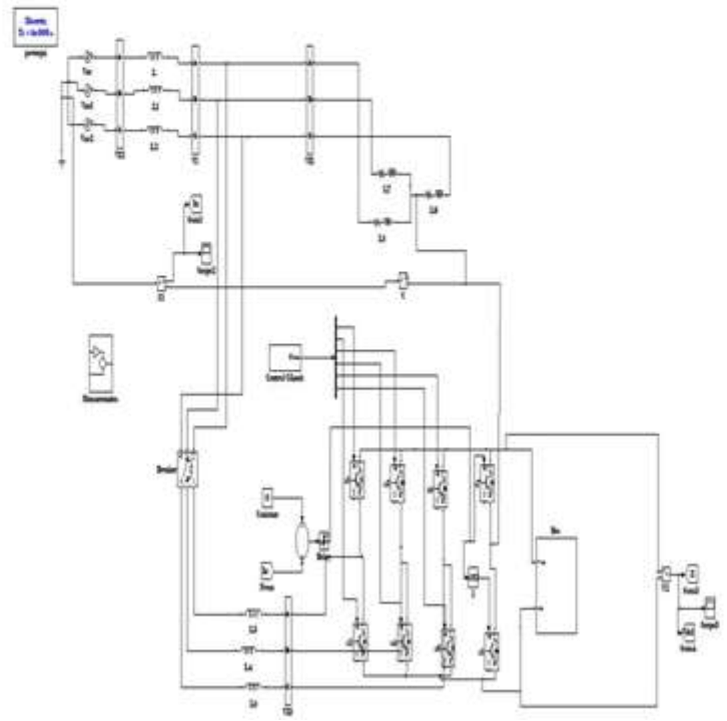

Figure.10. Matlab/Simulink Model of DSTATCOM Power Circuit with Balanced Linear load.

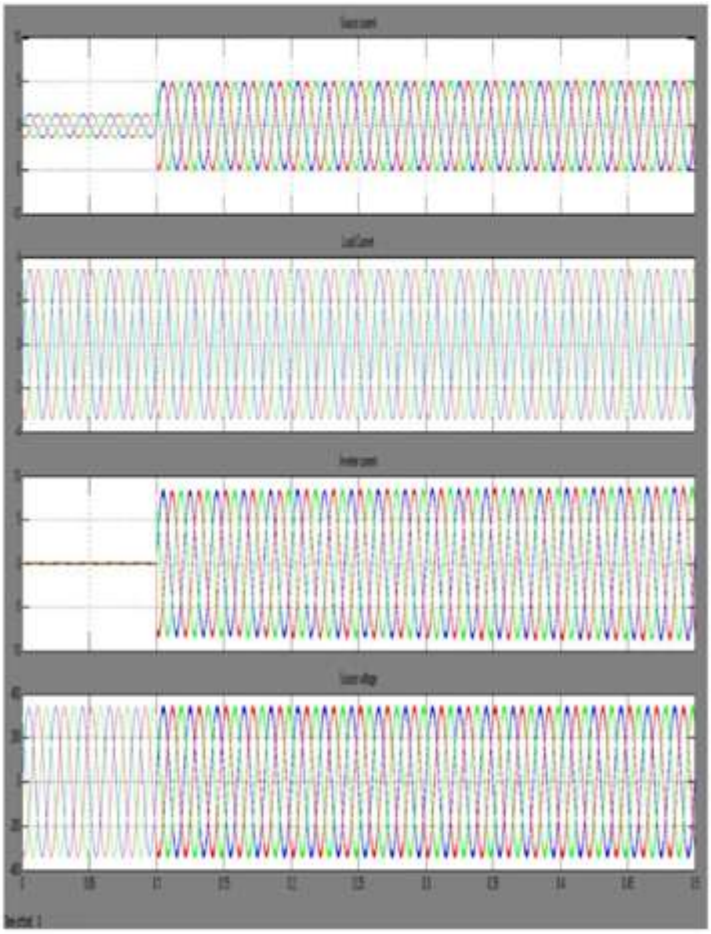

Figure11.Simulation results of balanced Linear load (a) Source voltage (b) source current (c) load current (d) Source Current.

Figure.12. Simulation results of Un-balanced Linear load (a) Source voltage(b)source current(c) load current(d) Source Current SRM Motor connected to the proposed Circuit.

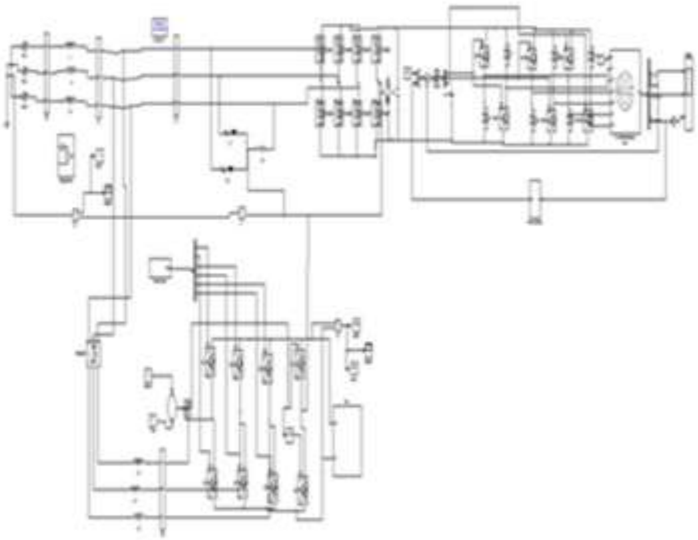

Figure.13.SRM motor connected to proposed circuit.

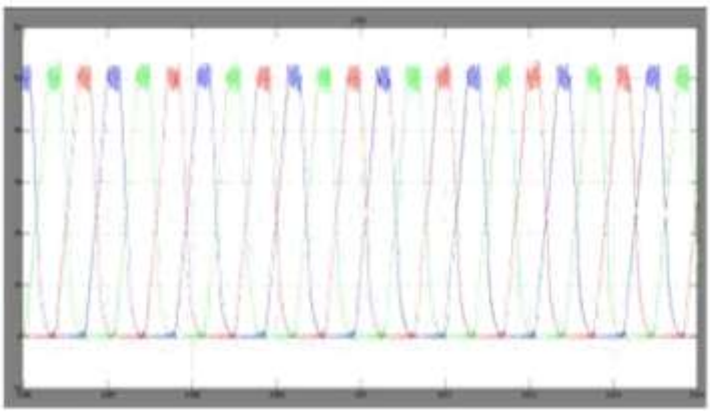

Figure14. Simulated Output waveforms under stator current of D-STATCOM based Switched Reluctance Motor.

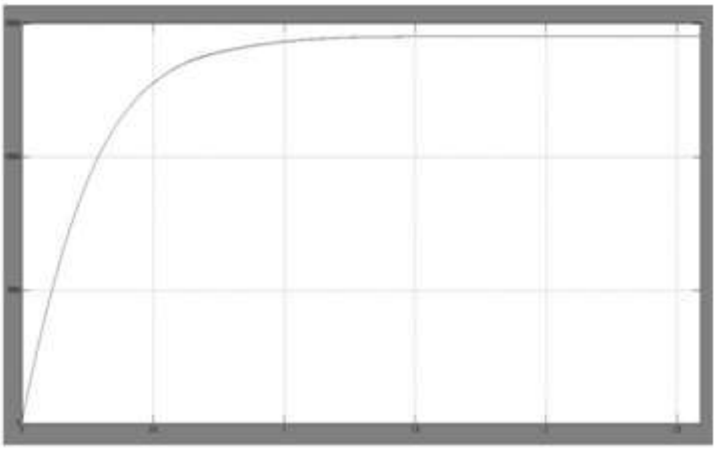

Figure15. Simulated Output waveforms under speed characteristics of D-STATCOM based Switched Reluctance Motor.

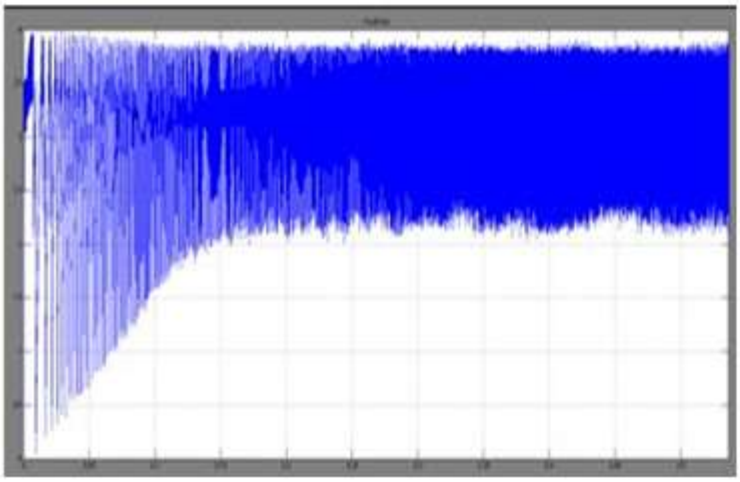

Figure16.Output waveforms under torque characteristics of D-STATCOM based Switched ReluctanceMotor.

V. Conclusion

This paper has presented a novel control of an existing grid interfacing inverter to improve the quality of power at PCC for a 3-phase 4-wire DG system. It has been shown that the grid-interfacing inverter can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. The proposed DSTATCOM with RES system is an efficient mean for mitigation of PQ disturbances introduced to the grid by DERs. DSTATCOM compensator is a flexible device which can operate in current control mode for compensating voltage variation, unbalance and reactive power and in voltage control mode as a voltage stabilizer. The latter feature enables its application for compensation of dips coming from the supplying network. The simulation results show that the performance of DSTATCOM system has been found to be satisfactory for improving the power quality at the consumer premises. Rectifier-based non-linear loads generated harmonics are eliminated by DSTATCOM. When single- phase rectifier loads are connected, DSTATCOM currents balance these unbalanced load currents. Finally, Matlab/Simulink based model is developed and simulation results are presented.

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