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POWER QUALITY IMPROVEMENT USING FUZZY LOGIC CONTROL OF PERMANENT AND NON-PERMANENT MAGNET MACHINES USING DSTACOM

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ABSTRACT-Distribution Static Compensator (DSTATCOM) can improve the power quality of distribution power system. In power distribution network, distribution static compensator (DSTATCOM) is used for enhancing power quality. This concept proves the application of DSTATCOM for brushless drives to improve power quality in the system reducing harmonics. In this concept mainly concerned with the power quality improvement in a multi machine system using FACTS based STATCOM device with a wind turbine (WT) is connected to the grid this is helps to maintain the voltage stability and also improvement in the power factor and harmonic reduction in the source and load side. More robust controllers such as based on Fuzzy logicapproach are required for the DSTATCOM to provide adequate dynamic voltage control and to improve power quality and stability of the distribution power system. Study of fuzzy logic controlled DSTATCOM for improving the power quality In terms of THD of a distribution power system is simulated by using MATLAB/Simulink environment.

Keywords: Non-linear loads, Power quality, Distribution network, Fuzzy logic controller

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I. Introduction:

The power quality plays a vital role in industries as well as transmitting the generating power to the utility it is necessary to minimize the power quality issues [1] such as power losses, harmonics, power factor , reactive power flow through the transmission line etc. In general, Non- linear loads like motordrives induces non-identical terminal voltage at point ofcommon coupling and source currents.Inorder to meet PQ standard limits, it may benecessary to include some sort of compensation. Modern solutions can befound in the form of active rectification oractive filtering.

Modern industrial processes are mainly based on electronic devices such as PLC"s, [2] power electronic devices, drives etc., and since their controls are sensitive to disturbances such as voltage sag , swell and harmonics , voltage sag is most important power quality problems It contributes more than 80% of power quality (PQ) problems that exist in power systems [2], and more concern problems faced by many industries and utilities. By definition, a voltage sag is an rms (root mean square) reduction in the AC voltage at the power frequency, for duration from a half-cycle to a few seconds.

Flexible A transmission systems(FACTS) is an idea developed based on power electronic controllers, which controls the values of different electrical parameters. FACTS technology makes use of high speed thyristors for switching in or out transmission line components for the required performance of the system. There are different types of FACTS devices namely shunt connected devices and series connected devices.Dstatcom is a shunt connected FACTS device.It is a reactive source that can be controlled and it iscapable of absorbing or generating reactive power.Dstatcom consists of coupling transformer, voltagesource converter, DC energy storage device andnecessary control circuits[3].During voltage sagdstatcom supplies the required voltage and duringvoltage swell dstatcom limits the voltage magnitudewith in a particular value. A proper control techniqueis essential for the effective working of the dstatcom [3].The dstatcom can provide compensation inboth inductive and capacitive mode.

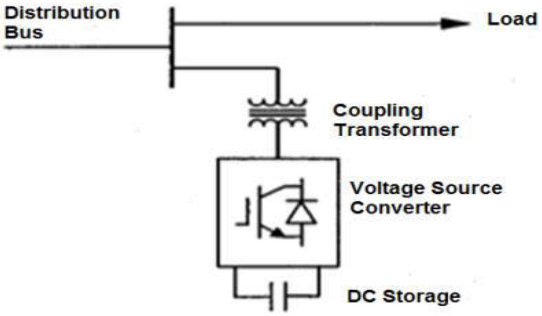


Fig. 1. Block Diagram of Dstatcom

Brushless DC electric motor (BLDC motors, BL motors) or also called as electronically commutated motors are synchronous motors which are supplied by a DC source through an inverter which produces an AC electric output to drive the motor.Brushed motors develop a maximum torque when stationary, linearly decreasing as velocity increases [4]. The BLDC Motor used to make low power rating application devices such as Refrigerator, Washing Machine, House-hold appliances, Medical Equipment, Wide speed range of servo drives and industrial robots. BLDC drives are used for its high efficiency, fastdynamic response and small size etc. For the operationof BLDC Drive first need to convert AC supply powerto DC power using rectifier circuit and then DC powerto variable magnitude and variable frequency ACpower to feed BLDC. BLDC operates on two modevector control and direct torque control.Disadvantages of brushed motors can be eliminated in brushless motors; they include higher efficiency and a lower susceptibility to mechanical wear. These benefits come at the cost of potentially less rugged, more complex, and more expensive control electronics. A typical brushless motor has a rotating permanent magnets and a fixed armature, which eliminates the problem associated with connecting current to the moving armature.

There will be an electronic controller instead of brush/commutator which switches the phases which makes rotor to rotate. Because the controller must direct the rotor rotation, the controller requires some means of determining the rotor's orientation/position (relative to the stator coils.) Some designs use hall-effect sensors or a rotary encoder to directly measure the rotor's position. Others measure the back EMF in the un-driven coils to infer the rotor position, eliminating the need for separate Hall Effect sensors, and therefore are often called sensor-less controllers. There will be no generation of back-EMF with stationary rotors which were employed in the controllers which sense rotor position based on back-EMF. Other sensor-less controllers are capable of measuring winding saturation caused by the position of the magnets to infer the rotor Position.

Brushless DC motors are of permanent magnet type (BLDC) and non-permanent magnet type (SRM). Permanent magnet type brushless motors are now a day's not preferred and so non-permanent magnet type brushless motors were developed like SRM.

In this paper detailed model and results were discussed for conventional non-linear load with DSTATCOM, Fuzzy controlled BLDC motor drive and SRM drive with DSTATCOM to improve power quality even when drives are connected. Here in this paper, the detailed model with reduced dc-link voltage rating having non-linear loads (one with only three phase bridge diode rectifier and the other is increased non-linear load, i.e. three phase bridge diode rectifier driving BLDC and SRM) connected to distribution network. The series capacitor is used to reduce the dc-link voltage while simultaneously compensating the reactive power required by the load [4], so as to maintain unity power factor without compromising the performance of the DSTATCOM.

II. DSTATCOMWITH BRUSHLESS DRIVE

A. Conventional DSTATCOM

The distribution static compensator (DSTATCOM) is a shunt active filter, which induces compensating currents into the point of common coupling (PCC) (the common point where load, source, and DSTATCOM are connected) such that the harmonic neutralization, correction of power factor are done. The voltage rating of dc-link capacitor decides the compensation performance of any active filter [4]. In general, the dc-link voltage should have higher value than the peak value of the line-to-neutral voltages. This is employed to have compensation at the peak of the source voltage. The dc-link voltage should be greater than or equal to 6 times the phase voltage of the system for distortion-free compensation [4]. When the dc-link voltage is less than this limit, there will be insufficient resultant voltage to drive the currents for compensation. Reference value of the dc-bus capacitor voltage mainly depends upon the requirement of reactive power compensation of DSTATCOM. The primary condition for reactive power compensation is that the magnitude of reference dc-bus capacitor voltage should be higher than the peak of source voltage at the PCC. Due to these criteria, many researchers have used a higher value of dc capacitor voltage based on their applications. Having high value of dc-link capacitor, the voltage source inverter (VSI) becomes bulky and the switches used in the VSI also need to be rated for higher value of voltage and current which in turn, increases the entire cost and size of the VSI. Figure 2 shows the power circuit of the neutral clamped VSI topology based DSTATCOM which is considered the conventional topology in this study.

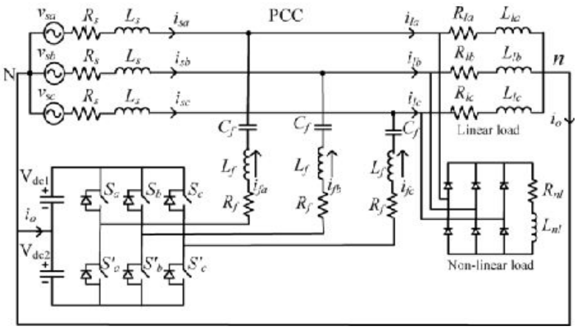


Fig.2: Circuit of Conventional DSTATCOM

B. DSTATCOM with BLDC Drive

A BLDC motor is a permanent magnet synchronous that uses position detectors and an inverter to control the armature currents. The BLDC motor is sometimes referred to as an inside out dc motor because its armature is in the stator and the magnets are on the rotor and its operating characteristics resemble those of a dc motor. Instead of using a mechanical commutator as in the conventional dc motor, the BLDC motor employs electronic commutation which makes it a virtually maintenance free motor. There are two main types of BLDC motors: trapezoidal type and sinusoidal type. In the trapezoidal motor the back-emf induced in the stator windings has a trapezoidal shape and its phases must be supplied with quasisquare currents for ripple free operation. The sinusoidal motor on the other hand has a sinusoidally shaped back – emf and requires sinusoidal phase currents for ripple free torque operation.

In general, the PMSM can be classified into two types depending on back-emf wave shape production, i.e. sinusoidal and trapezoidal wave shapes. The one that is operated in sinusoidal is normally referred to as permanent magnet AC motor or brushless AC motor. The latter one that produces trapezoidal back-emf wave shape is normally called as brushless DC motor (BLDC). It can be shown that the production of torque in BLDC is quite similar to that of brushed DC motor with simple control algorithm [5] [6].

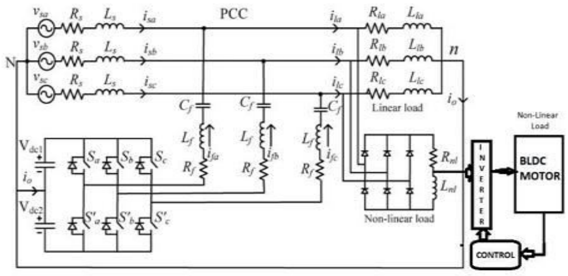


Fig.3: circuit of DSTATCOM with BLDC drive

Fig.3 shows the circuit representation of the system consisting of BLDC drive introducing non-linearity in the system and that non-linearity is reduced by DSTATCOM.

C. DSTATCOM With SRM Drive

Switched reluctance machines are used in electric vehicles, washers, dryers and aerospace applications as the machine is brushless, fault tolerant, maintenance free and rugged and simple in construction. However, some of its limitations are noise, torque ripple and low torque to volume. Noise and low torque to volume have been addressed in the segmented switched reluctance machine (SSRM). SSRM has full-pitched winding while concentrated winding is used in variable switched reluctance machine (VSRM).

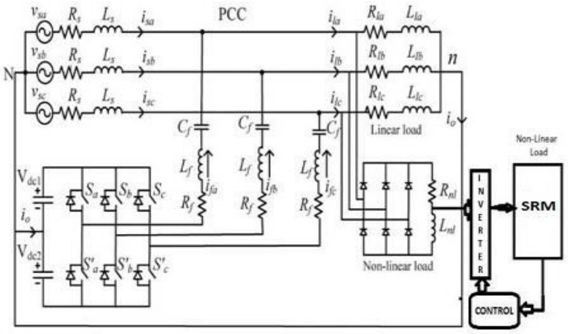


Fig.4: circuit of DSTATCOM with SRM drive

Fig.4 shows the circuit representation of the system consisting of SRM drive introducing non-linearity in the system and that non-linearity is reduced by DSTATCOM. Segmented (SSRM) can give double torque than SRM for the same frame size. This torque increase is due to the increase in aligned flux, while the torque of SSRM increases with the use of full pitch winding, the end winding volume of the motor also increases by a factor which depends on the ratio of motor air gap diameter (D) to stack length (L) This arrangement is particularly more effective for machines with D/L ratio [9] equal to and greater than two.

III. MODELLING OF SRM & BLDC DRIVE

The design specifications for the SRM comprise of the required power output, N in rpm, allowable peak phase current i in Amps, and available ac supply voltage V_p for the system.

Knowing the speed and power output will automatically fix the torque to be developed by the machine as

$$T_{req} = \frac{P_{kw}}{2\pi\left(\frac{N}{60}\right)} Nm \quad (1)$$

In the preliminary design process of SRM, first we need to fix the values of voltage current, i.e., power rating of the machine. Then by having the speed, stack length or stator core length the preliminary design process can be started for both 8/6 pole and 6/4 SRM. Initially by fixing outer diameter and the number of poles of stator and rotor, design procedure for calculating stator pole arc, stator yoke width can be calculated. The bore diameter is initially assumed to be equal to the frame size. The stack length can be initially chosen to be equal to the distance between the mounting holes in a foot mounted machine. With the selection of preliminary values of Do, L, D, ßs and ß, the design process is continued. Only Do is fixed and can change only with the change of the entire frame size.

Now, the B-H characteristics of the material, which will be used in the stator and rotor stampings, have to be examined. The “knee” point of the characteristics is noted down and it is generally a good design practice to limit the maximum flux density (in Tesla) in any part of the machine to a value. It can be observed that the maximum flux density will be at the stator poles and therefore while designing the machine; the stator pole can be assumed to be operating at a flux density equal to the knee value obtained from the B-H characteristics. Assuming that the stator pole flux density Bs is assumed to be equal to B the rest of the machine can be designed. Design experience has shown that it is good practice to fix the flux density of the stator yoke $B_y$at approximately half the value of B_{max} and the rotor core flux density B at about 80% of the maximum value. This practice causes a reduction of noise in the machine.

The power output equation of a rotary SRM is given by:

$$P = K\, D_{in}^2\, A_s\, B_s\, L\, N_r \quad (2)$$

Where,

$$K = K_1\, K_2\, K_e\, K_d \quad (3)$$

Here,

$$K_1 = 1 - \frac{1}{\sigma_s \sigma_u} \quad (4)$$

Power equation can be written as

$$D_{in} = \left[\frac{P}{K\, A_s\, B_s\, L N_r}\right]^{1/2} \quad (5)$$

Stator pole arc,

$$\beta_s = \frac{2\pi}{P_S P_R/2} \quad (6)$$

Stator pole width,

$$S_{PW} = \frac{D_{in}}{2} \beta_S \frac{\pi}{180} \quad (7)$$

Stator pole area,

$$A_{SP} = \frac{D_{in}}{2}\beta_S\frac{\pi}{180}L \tag{8}$$

Stator yoke width,

$$S_{YW} = \frac{A_{SY}}{L}, \tag{9}$$

Where,

$$A_{SY} = \frac{A_{SP}}{2} \tag{10}$$

Stator pole height,

$$h_s = \frac{D_O}{2} - \frac{D_{in}}{2} - S_{YW} \tag{11}$$

Rotor pole width,

$$R_{PW} = \left[\frac{D_{in}}{2} - A_g\right] * \beta_R * \frac{\pi}{180} \tag{12}$$

Rotor pole area,

$$R_{PA} = \left[\frac{D_{in}}{2} - A_g\right] * \beta_R * \frac{\pi}{180} * L \tag{13}$$

Rotor yoke width,

$$R_{YW} = A_{RY} / L \tag{14}$$

Where,

$$A_{RY} = A_{SP} / B_S \tag{15}$$

Rotor pole height,

$$h_r = \left[\frac{D_{in}}{2} - A_g\right] - \frac{D_{sh}}{2} - R_{YW} \tag{16}$$

A BLDC motor is a permanent magnet synchronous that uses position detectors [10] and an inverter to control the armature currents. The bldc motor is sometimes referred to as an inside out dc motor because its armature is in the stator and the magnets are on the rotor and its operating characteristics resemble those of a dc motor. Instead of using a mechanical commutator as in the conventional dc motor, the bldc motor employs electronic commutation which makes it a virtually maintenance free motor. There are two main types of BLDC motors: trapezoidal type and sinusoidal type. In the trapezoidal motor the back-emf induced in the stator windings has a trapezoidal shape and its phases must be supplied with quasi square currents for ripple free operation. The sinusoidal motor on the other hand has a sinusoidally shaped back – emf and requires sinusoidal phase currents for ripple free torque operation. The shape of the back – emf is determined by the shape of rotor magnets and the stator winding distribution.

The sinusoidal motor needs high resolution position sensors because the rotor position must be known at every time instant for optimal operation. It also requires more complex software and hardware. The trapezoidal motor is a more attractive alternative for most applications due to simplicity, lower price and higher efficiency. BLDC motors exist in many different configurations but the three phase motor is most common type due to efficiency and low torque ripple. This type of motor also offers a good compromise between precise control and number of power electronic devices needed to control stator currents. Position detection is usually implemented using three Hall - an effect sensor that detects the presence of small magnets that are attached to the motor shaft. Typically, a Brushless dc motor is driven by a three-phase inverter with, what is called, six-step commutation. The conducting interval for each phase is 120^0 by electrical angle. Each interval starts with the rotor and stator field lines 120 a part and ends when they are 60^0 apart. Maximum torque is reached when the field lines are perpendicular. The commutation phase sequence is like AB-AC-BC-BA-CA-CB. Each conducting stage is called one step. Therefore, only two phases conduct current at any time, leaving the third phase floating. In order to produce maximum torque [11], the inverter should be commutated every 60^0 so that current is in phase with the back EMF.

D.FUZZY CONTROL SCHEME

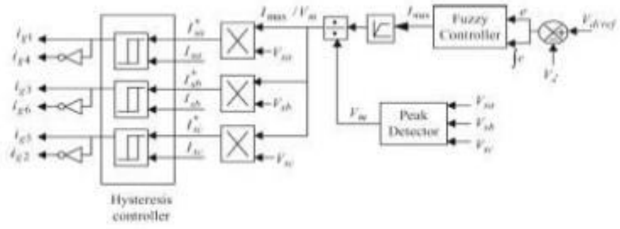


Fig5. Improved DSTSTCOM controlscheme with Fuzzy controller

In a fuzzy logic controller, thecontrol action is determined from theevaluation of a set of simple linguistic rules.The development of the rules requires athorough understanding of the process to becontrolled, but it does not require amathematical model of the system. Theinternal structure of the fuzzy controller is shown in Fig. 5.

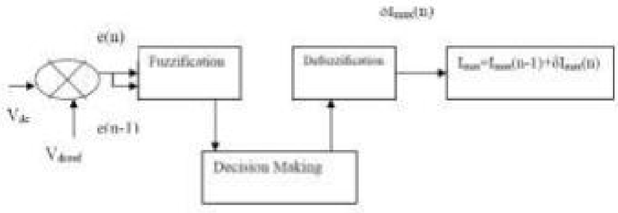


Fig 6.fuzzy controller

A fuzzy inference system (or fuzzy system)basically consists of a formulation of themapping from a given input set to an outputset using fuzzy logic as shown in fig 6. Thismapping process provides the basis fromwhich the inference or conclusion can bemade.

A fuzzy inference process consists of thefollowing steps:

Step 1:Fuzzification of input variables.

Step 2: Application of fuzzy operator(AND,OR,NOT) in The IF(antecedent) partof the rule.

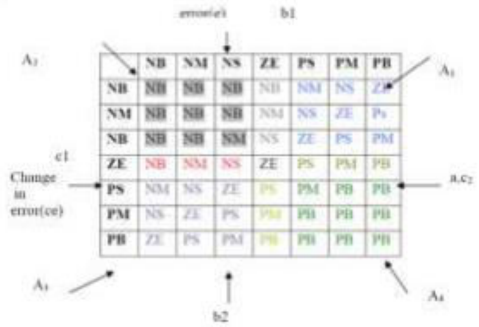
Step 3: Implication from the antecedentto the consequent (THEN part of the rules).

Step 4: Aggregation of the consequentsacross the rules.

Step 5: Defuzzification

The crisp inputs are converted tolinguistic variables in fuzzification based onmembership function (MF). An MF is acurve that defines how the values of afuzzyvariable in a certain domain are mapped to amembership value μ (or degree ofmembership) between 0 and 1. Amembership function can have differentshapes. The simplest and most commonlyused MF is the triangular-type, which can besymmetrical orasymmetrical in shape. Atrapezoidal MF has the shape of a truncatedtriangle. Two MFs are built on the Gaussiandistribution curve: a simple Gaussian curveand a two-sided composite of two differentGaussian distribution curves. The bell MFwith a flat top is somewhat different from aGaussian function. Both Gaussian and bellMFs are smooth and non-zero at all pointsand fuzzy rules are tabulated in table 1.

Table.1 fuzzy rules



	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	Ps
NB	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

IV. MATLAB/SIMULINK RESULTS

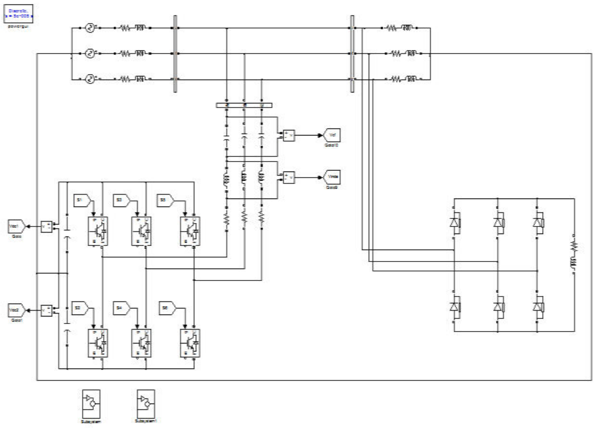


Fig 7.Simulink model of conventional DSTATCOM

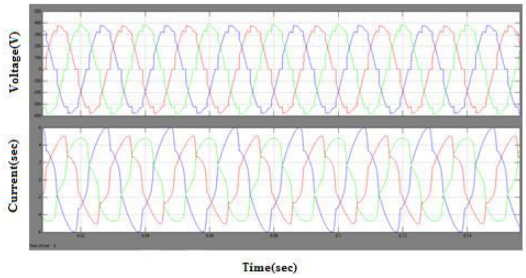


Fig 8. Source voltages and Source currents without DSTATCOM

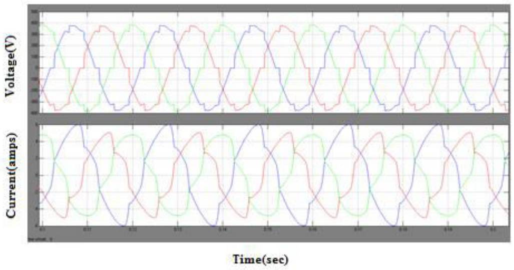


Fig 9. Load voltage and load currents without D-statcom

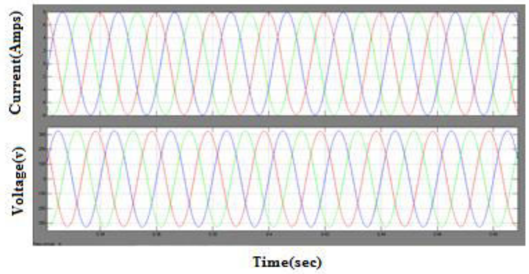


Fig 10. Source current and source voltage with conventional
DSTATCOM

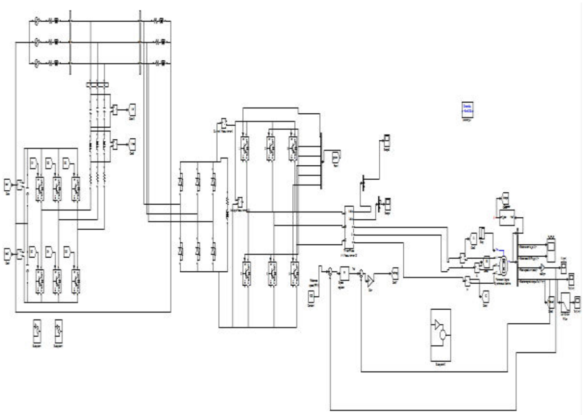


Fig 11. Simulink model of BLDC drive with DSTATCOM

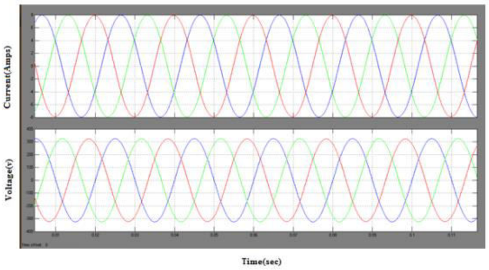


Fig 12. Source current and source voltage of BLDC drive with
DSTATCOM

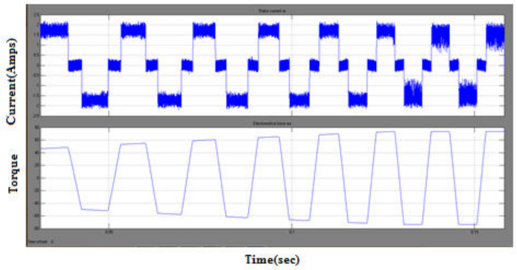


Fig 13. Stator current and back EMF of BLDC drive with
DSTATCOM

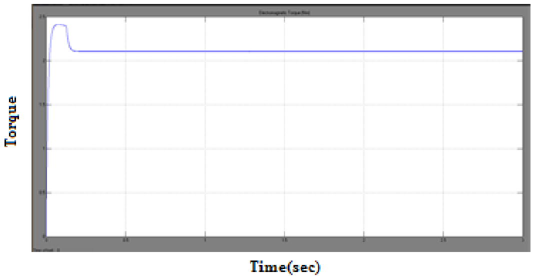


Fig 14. Torque of BLDC drive with DSTATCOM

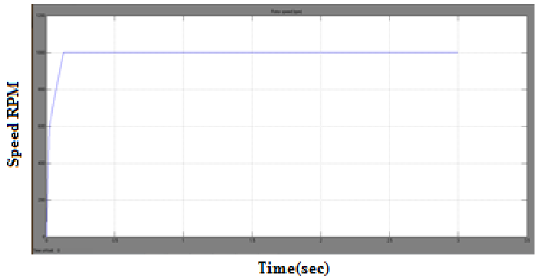


Fig 15 Speed of BLDC drive with DSTATCOM

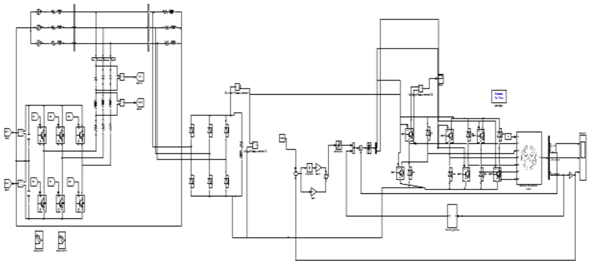


Fig 16. SRM drive with DSTATCOM

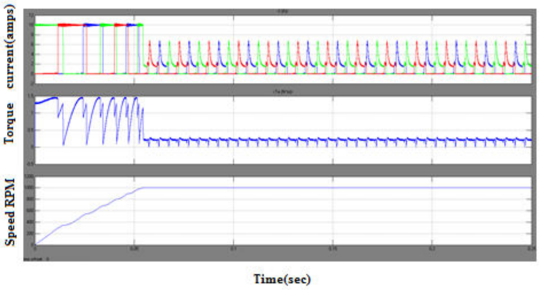


Fig 17: Stator current and Torque and speed of SRM drive with DSTATCOM

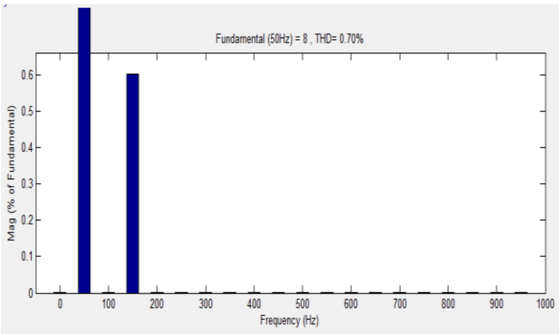


Fig 18. FFT analysis of DSTATCOM THD=0.70%

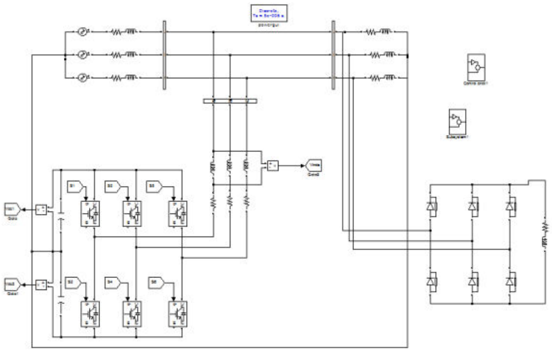


Fig 19.Simulink model of Fuzzy based DSTATCOM

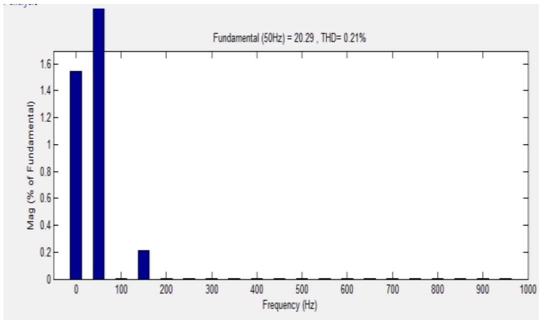


Fig 20. FFT analysis of Fuzzy THD=0.21%

From figures 18 and 20 Total harmonic distortion is reduced when compared to PI controller with fuzzy controller. THD at PI controller is 0.70% whereas by implementing fuzzy logic controllerTHD come down to 0.21%. The total system performance will be increased by using fuzzy logic controller.

V. CONCLUSION

In this project Power Quality Improvement using Fuzzy Logic Control of Permanent and Non-Permanent Magnet Machines Using DSTACOM is presented. Each output can be regulated independently in this converter by multiplexing a single inductor. Compared withconventional two-stage multiple-output ac/dc converters, the proposed single-stage multiple output ac/dc converter benefits from significant overall cost saving, small size, and light weight of the device. Experimental results have been presented to verify the FFT analysis results and to demonstrate the advantage of the proposed converter.

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