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Simulation and Design of D-STATCOM to Mitigate Power Quality Problems using Synchronous Reference Frame with Feeding Wide Variety of Static and Dynamic Loads

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Abstract—*Static Synchronous Compensator (STATCOM) is a device capable of solving the power quality problems at the power system. These problems happen in milliseconds and because of the time limitation it requires the STATCOM that has Continuous reactive power control with fast response. In this way, optimal exploitation of STATCOM by controllers has been a controversial issue in various reputable journals. One of the most common controlling devices in the market is the indirect current control technique and instantaneous reactive power technique. In this article, the STATCOM is controlled by PI and Hysteresis controllers using SRF technique. This work presents a method capable of designing DSTATCOM to reduce harmonic distortion and correct the power factor to improve power quality. The DSTATCOM with SRF Theory feeds a wide variety of loads. The performance of the system is simulated for linear, non-linear load and Asynchronous machine. Simulation results justify enhanced power quality of the system with DSTATCOM application.*

Keywords*: Programmable Source, D-SATACOM, Capacitive filter, Power Quality, PI & Hysteresis controller, Motor load.*

1. INTRODUCTION

Power quality is that which is denoted in terms of (PQ) is that term in which at rated voltage and frequency power distribution bus voltage waveform is maintaining nearly sinusoidal waveform. Power quality mainly deals with the continuity of the power supply and the quality of the power which we are using. For power system economic operation the power quality level should be maintained [1, 2]. Need of Power Quality is very essential in this era because when the power that we are generated have to take long distance to utilize it by the consumers through that distance the quality of power is reduced by the distance so that the power quality which the consumers get has lots of issues regarding voltage. Therefore the power quality should be good and it contains less line losses to improve the power quality.

Power quality problems, which is very important in power sector has a major problem which requires the treatment in up gradation in power quality. It provides solution in a very optimized and efficient way. The problems which we going to show if not compensate than it will crest a disturbance technically as well as economically. [3,7] Voltage Sag , Voltage Spikes, Voltage Surges, Flickering, Blackouts, Brownouts, Very Short Interruptions, Over Voltage, Voltage Unbalance, Electrical Noise, Long Interruptions, Transients, Harmonics, Voltage Fluctuations. Solution to power quality, There are various solution for the improvement of the power quality through which all this given above problems in power quality can be mitigate due to which the losses in the line improved and can be solved the problem of power quality in a great manner. Some of the power quality solution is given below as:- Dynamic Voltage Restorer (DVR), Harmonic Filters, Distribution Static Compensator, Constant Voltage Transformers, Isolation Transformers, Static VAR Compensator, Surge Arrestors, Unified Power Quality Conditioner. FACTS devices are the devices which are used in transmission system and in distribution system to compensate the losses that occurs in the system. It is generally used in the AC transmission network and is a stationary device. FACTS mean Flexible Alternating Current Transmission System which is based on power electronics which can control or increase the power when required. The AC system which is interconnected, these devices helps to regulate the good power, reliability of the system and the security of the system as well.

In this research paper a distributed static compensator using Synchronous reference frame is used to compensate the reactive power and it is also used to mitigate the harmonics. We observed various advantages of proposed control technique over other conventional techniques like indirect current control technique and Instantaneous reactive power technique. In this SRF based DSTATCOM we are using VSC that is voltage source converter and a capacitor that is DC link which is connected parallel with voltage source converter for the purpose of generating the reactive power or it can also absorb it as the situation needed [2-4].

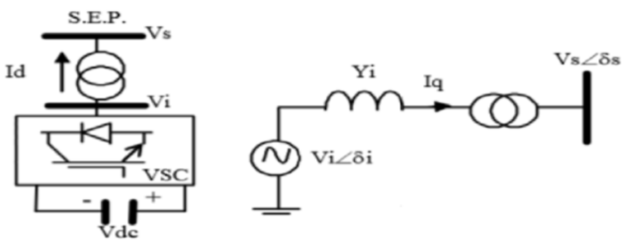

Fig. 1: Simplified STATCOM

The simulation results show the enhancement power quality in distribution network. The proposed SRF based system are tested in MATLAB Simulink.

2. D-STATCOM CONFIGURATION

Static compensator is basically used in transmission and distribution system, when it is used in the distribution system then it is termed as distribution static compensator (D_STATCOM). The distribution static compensator response time is very quick than that of the static var compensator. Basically a D_STATCOM is used to compensate the reactive power and it is also used to mitigate the harmonics and improves the power factor.

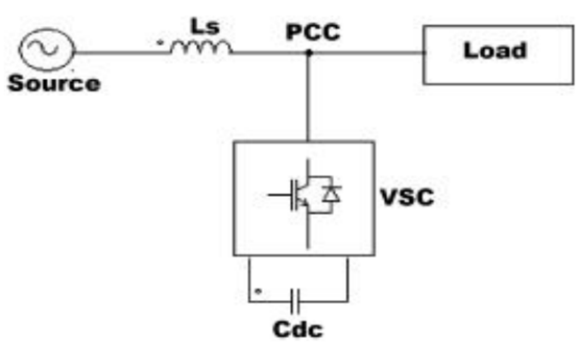

Fig. 2: Simplified D-STATCOM

In schematic Fig. 2 Distribution static compensator we are using VSC that is voltage source converter and a capacitor that is DC link which is connected parallel with voltage source converter for the purpose of generating the reactive power or it can also absorb it as the situation needed.[1,3-5].The AC supply terminals of voltage source converter are connected to a particular point which is called common coupling point by an inductance which may be the leakage inductance or filter inductance of transformer coupled. Connection of the DC capacitor is on the one side of the converter which we are using, is the main storage element of the reactive energy and also takes the converter input current. The capacitor which we are using in the parallel is also charged by a battery source, Converter can itself recharge. In this system whenever the AC terminal voltage is equal to the voltage of the voltage source converter that we are getting in the output than there is no reactive power produce in the system but if the AC terminal voltage is greater than its output, the mode of operation of the DSTATCOM is capacitive and vice versa.

3. PROPOSED THEORY

The configuration of SRF technique as shown in Fig. 3 The conventional SRF method [3] can be used to extract the harmonics contained in the supply voltages or currents. For current harmonic compensation, the distorted currents are first transferred into two-phase stationary coordinates using α− β transformation (same as in p-q theory). After that, the stationary frame quantities are transferred into synchronous rotating frames using cosine and sine functions from the Phase-Locked Loop (PLL). The sine and cosine functions help to maintain the synchronization with supply voltage and current. The conventional SRF algorithm is also known as d-q method, and it is based on a−b−c to d−q−0 transformation (park transformation). Here the Proportional Integral controller is used to eliminate the steady state error of the DC-component of the inverter and maintains the dc-side capacitor voltage constant. The dc capacitor voltage is sensed and compared with reference voltage to calculate the error voltage. In accordance to the PI controller, output is subtracted from the direct axis (d axis) of harmonic component for eliminating the steady state error [8].

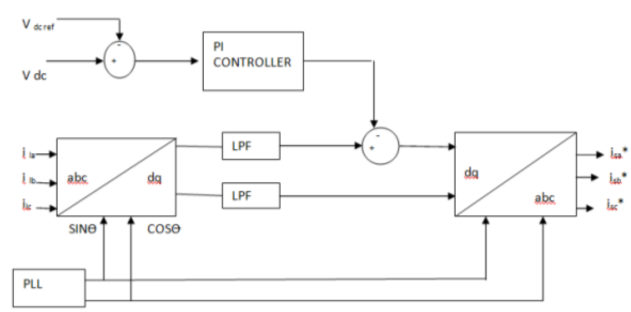

Fig. 3: Synchronous Reference Frame Controller

PWM based hysteresis current controller is employed over instantaneous reference supply currents and sensed supply currents. If $i_{sa} < (i_{sar}-h_b)$, the upper switch is turned 'OFF' and lower switch is turned 'ON'. If $i_{sa} > (i_{sar}+h_b)$, the upper switch is turned 'ON' and lower switch is turned 'OFF'. In this way, the switching logic for other two phases is obtained and the controller is able to regulate the currents in a band around the desired reference value [2].

4. SIMULATION OF PROPOSED SYSTEM

Simulation is power way to reduce development time and ensure the proper fulfillment of critical steps. In this research, simulations were performed, which allowed the study of its behavior under different operation conditions and permitted the tuning of some controller parameters together with optimization of the D-STATCOM component values. MATLAB/Simulink and the power system block set were used as simulation tools in this development, as it offered an integrated environment between designing control algorithms and the electrical network models.

Simulation of each component

Each component of the DSTATCOM was simulated and tested. Major simulated block models together with accompanying waveforms are presented.

PI Controller

A PI controller is a control loop feedback mechanism (controller) widely used in industrial control systems (Programmable Logic Controllers, SCADA systems, Remote Terminal Units etc.). A PI controller calculates an “error” value as the difference between a measured process variable and a desired set point. Simulation of PI controller is shown below:

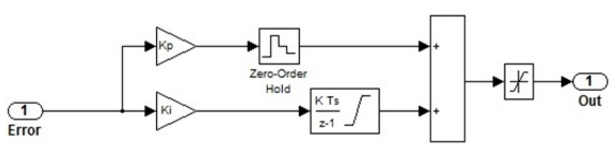

Fig. 4: Simulation circuit of PI Controller

Hysteresis Controller

In this technique in order to estimate the reference current command, the source voltages and load currents of two phases are measured and their harmonic components are computed. Using fundamental load current (I1), fundamental volatge (V1), harmonic components of voltage (V3, V5 ………..) and their respective angles($\theta1\theta2\theta3\theta4\theta5$……),

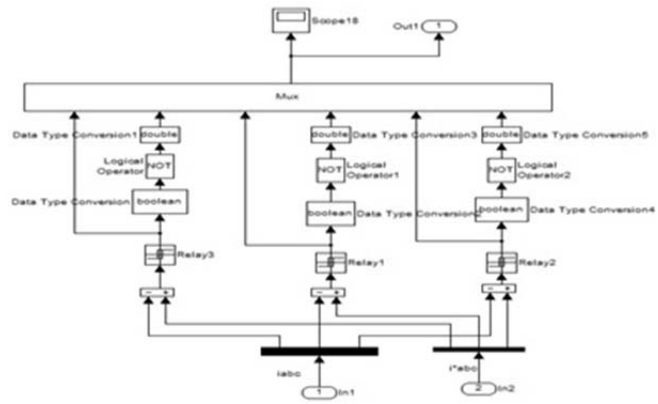

Fig. 5: Simulation circuit of a Hysteresis Controller

D_STATCOM with different loading condition Linear Load

Resistive load is taken as a linear static load which is generally used in the distribution system.

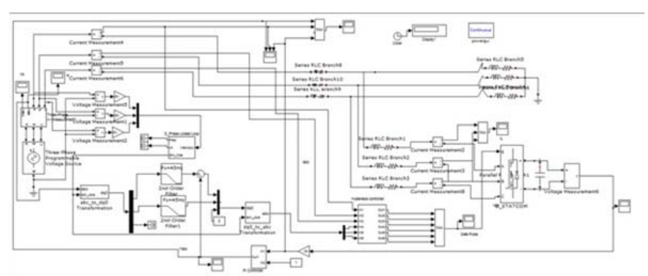

Fig. 6: Simulation circuit of D_STATCOM using SRF for Linear Load

Non Linear (Static Inductive) Load

Non Linear Load is taken as a nonlinear Static Inductive which is basically used in the distribution system.

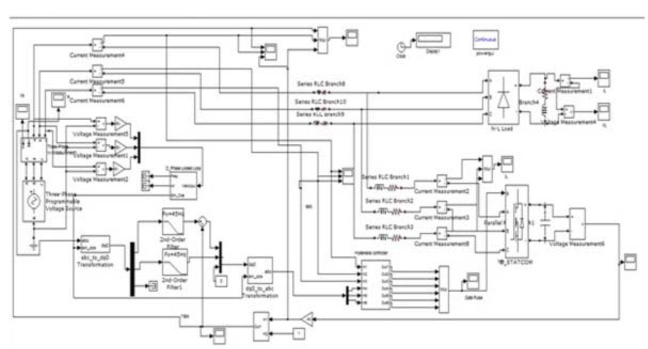

Fig. 7: Simulation circuit of D-STATCOM using SRF for

Non Linear (Induction motor) Load

Induction motor load is taken as a nonlinear dynamic load which is basically used in the distribution system.

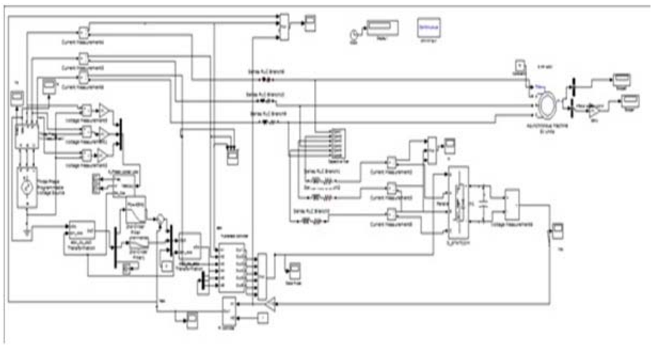

Fig. 8: Simulation circuit of D-STATCOM using SRF for Non Linear dynamic Load

5. RESULTS & ANALYSIS OF SRF BASED D-STATCOM

Performance characteristics for the D-STATCOM system using SRF control strategy are given in below Figure's to illustrate its steady state and transient behavior. The necessary parameters of the system are given in Appendix.

Linear Load

Performance of D-STATCOM connected to a Non isolated system feeding linear loads is shown in Figure 9 to 14. The results for the non-linear load the total harmonic distortion for the load current is given by simulating the model above and that is 0.33 % for 50 Hz.

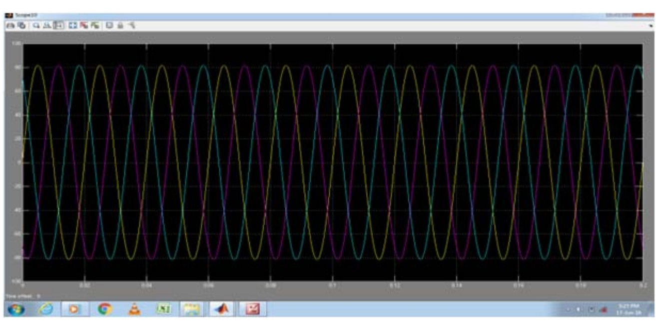

Fig. 9 Source voltage for linear load using SRF Technique

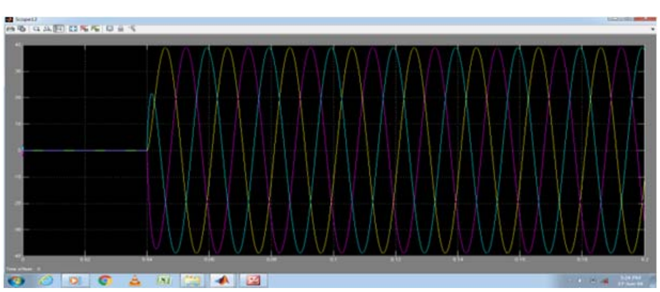

Fig. 10 Source Current for linear load using SRF Technique

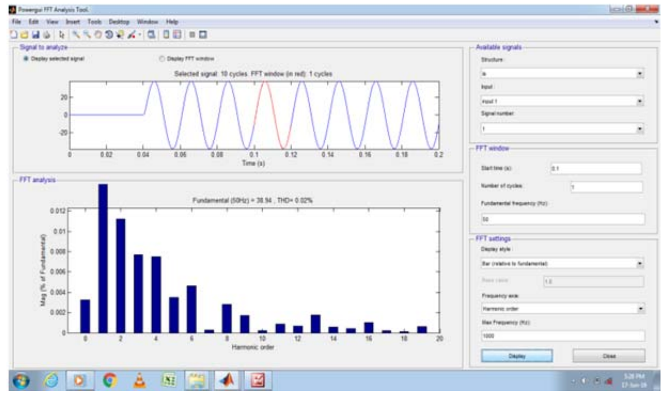

Fig. 11 THD of Source Current for linear load using SRF Technique

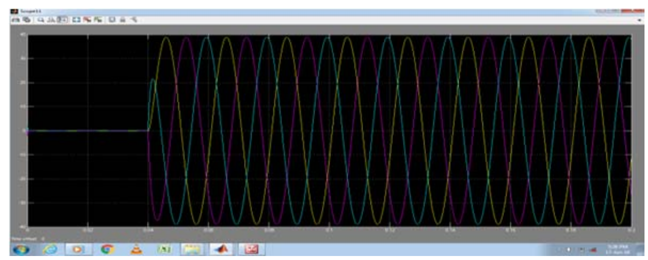

Fig. 12: Load Current for linear load using SRF Technique

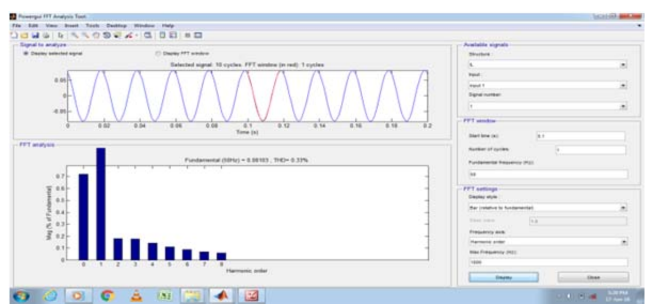

Fig. 13 THD of Load Current for linear load using SRF Technique

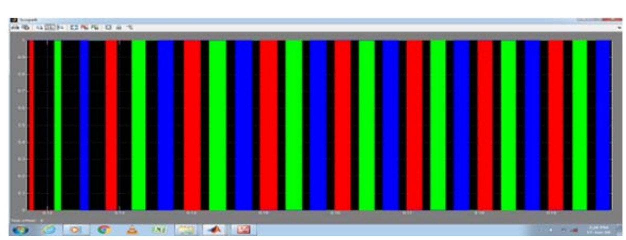

Fig. 14 Gate Pulse for linear load using SRF Technique

A model of D-STATCOM system has been developed in MATLAB environment using Power System Block-set. The performance of the developed model is tested under a wide variety of loading conditions. Above figure shows the compensated waveforms and total harmonic distortion of supply voltage, Supply current as well as load currents. It is observed that the supply current THD has been reduced to 0.02% and load current of 0.33%. This is verified IEEE-519 rule for linear load. It is clearly shows the above compensated technique SRF is more reliable and efficient control technique over indirect current control technique and Reactive power technique. The supply currents are sinusoidal, balanced and slightly leading with respect to supply voltages. This is necessary to compensate for the line impedance drop.

Non-linear (Static) Inductive Load

Performance of D-STATCOM connected to a Non isolated system feeding Non linear (Static) inductive load is shown in Figure 15 to 20. To mitigate the harmonics and improve power quality in distribution system.

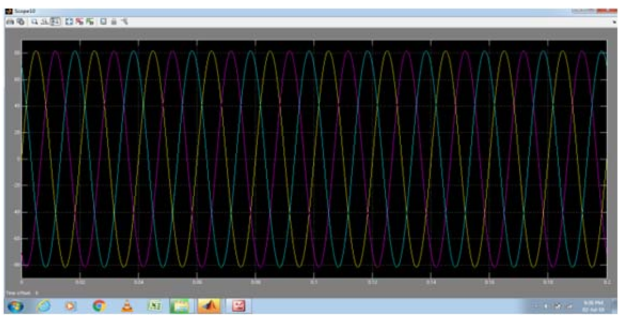

Fig. 15 Source voltage for Non linear Static load using SRF Technique

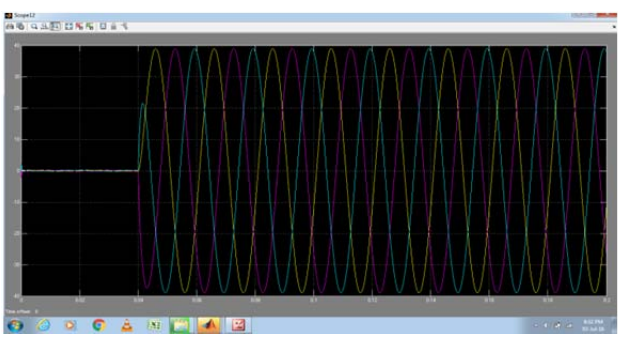

Fig. 16 Source Current for Non linear Static load using SRF Technique

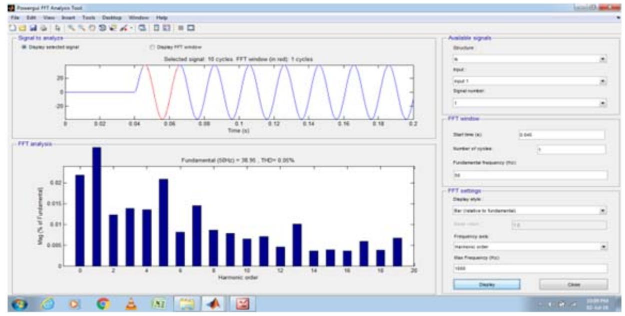

Fig. 17 THD of Source Current for Non linear Static load using SRF Technique

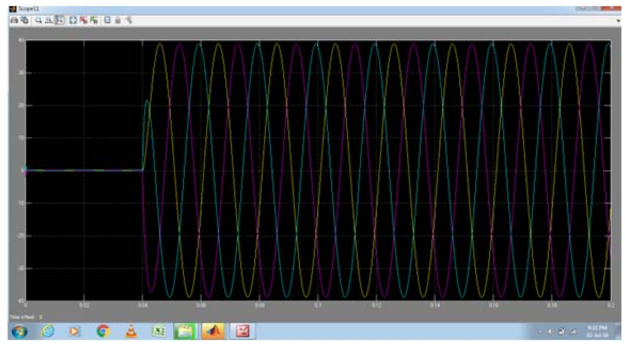

Fig. 18 Load Current for Non linear Static load using SRF Technique

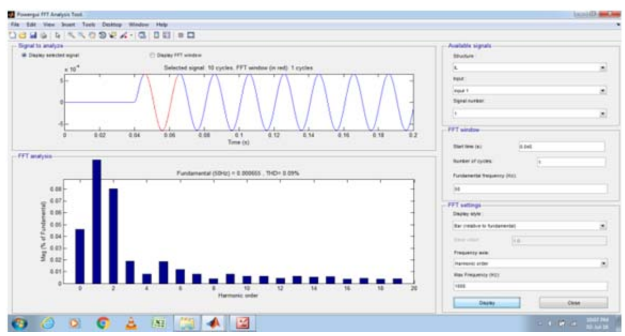

Fig. 19 THD of Load Current for Non linear Static load using SRF Technique

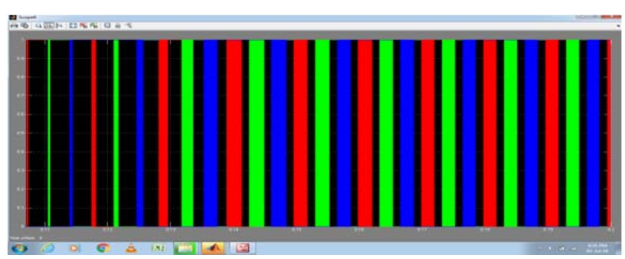

Fig. 20 Gate pulse for Non linear Static load using SRF Technique

Above figure shows the compensated waveforms and total harmonic distortion of supply voltage, Supply current and load currents. It is observed that the THD in the supply current THD has been reduced to 0.05% and load current of 0.09%. This is verified IEEE-519 rule for Nonlinear Static load. It is clearly shows the above compensated technique SRF is more reliable and efficient control technique over indirect current control technique and Reactive power technique because SRF not only mitigate harmonics in nonlinear static load end it is also capable to reduce harmonics in source end. The supply currents are sinusoidal, balanced and slightly leading with respect to supply voltages.

Non-linear (Induction Motor) Load

Simulation of proposed system with dynamic induction motor load into the MATLAB the following results we get shows variation of Motor load current wave form, Compensating current, Source voltage & current wave form when load is motor, Stator current of motor, Rotor speed of motor, Harmonics order of load current when load is Induction motor. Harmonics order of source current and voltage when load is Induction motor.

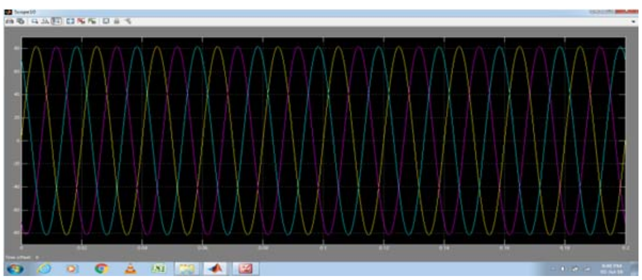

Fig. 21 Source voltage for Non linear Dynamic IM load using SRF Technique

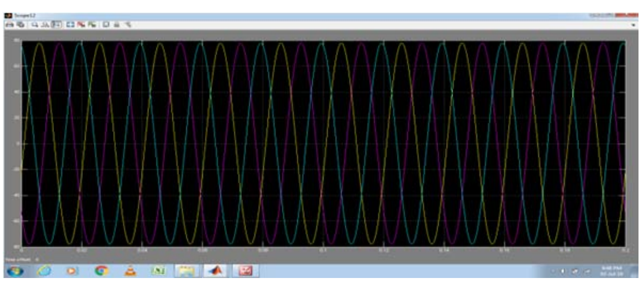

Fig. 22 Source Current for Non linear Dynamic IM load using SRF Technique

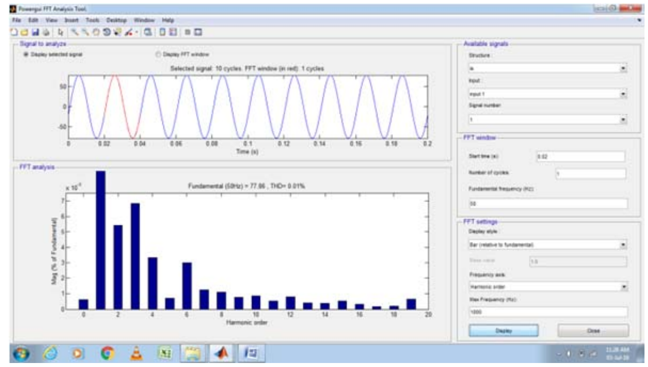

Fig. 23 THD of Source Current for Non linear Dynamic IM load using SRF Technique

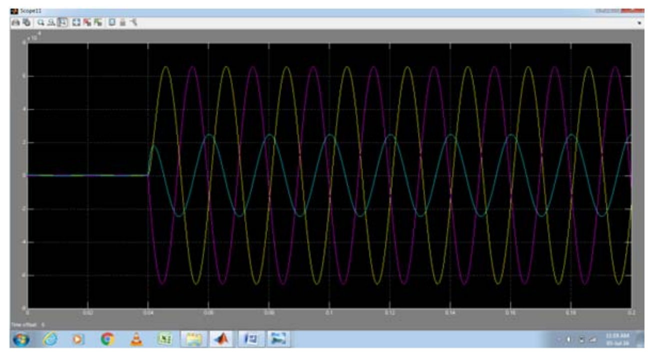

Fig. 24 Load Current for Non linear Dynamic IM load using SRF Technique

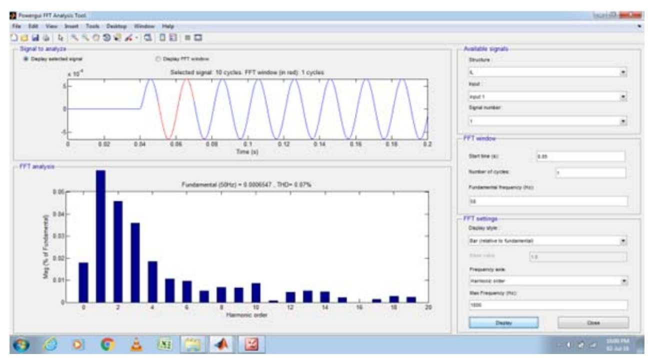

Fig. 25 THD of Load Current for Non linear Dynamic IM load using SRF Technique

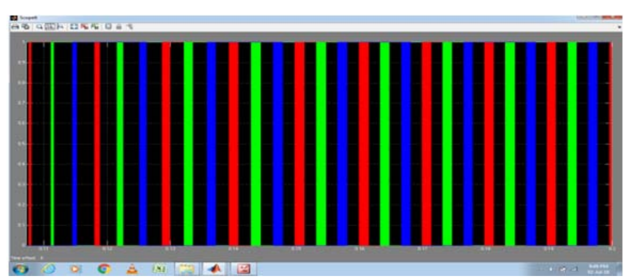

Fig. 26 Gate pulse for Non linear Dynamic IM load using SRF Technique

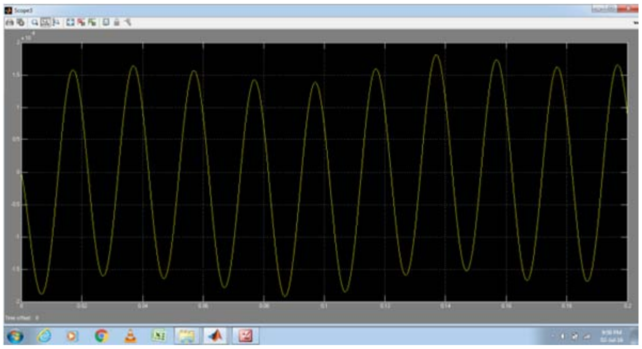

Fig. 27 Stator current of Non linear Dynamic IM load using SRF Technique

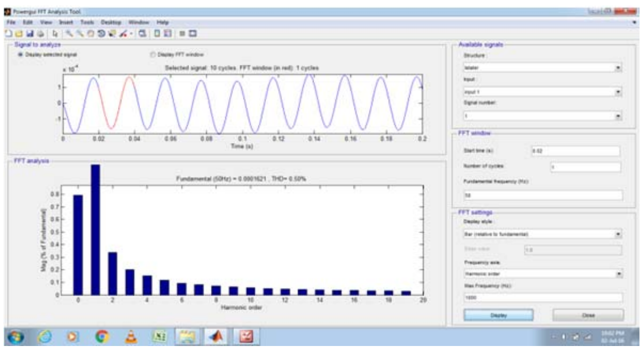

Fig. 28 THD Stator current of Non linear Dynamic IM load using SRF Technique

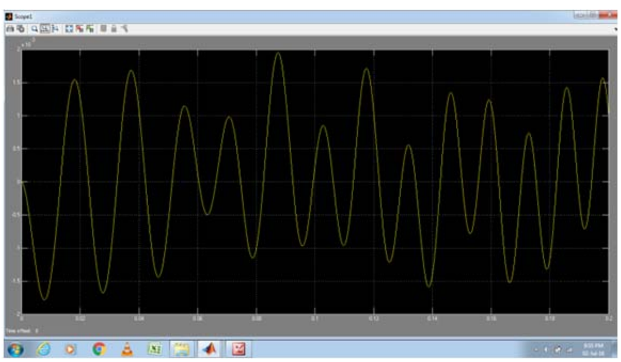

Fig. 29 Rotor current of Non linear Dynamic IM load using SRF Technique

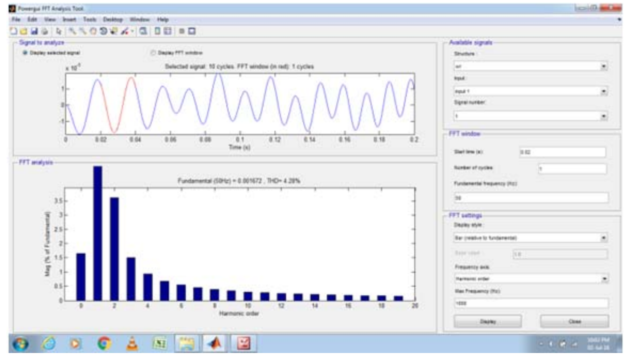

Fig. 30 THD Rotor current of Non linear Dynamic IM load using SRF Technique

Above figure shows the compensated waveforms and total harmonic distortion of supply voltage, Supply current, load currents as well as IM Rotor and Stator current also. It is observed that the THD in the supply current THD has been reduced to 0.01% and load current of 0.07% and IM Rotor and Stator current of 0.50% and 4.28%. This is verified IEEE-519 rule for linear load. It is clearly shows the above compensated technique SRF is more reliable and efficient control technique over indirect current control technique and Reactive power technique because SRF not only mitigate harmonics in nonlinear static load end it is also capable to reduce harmonics in source end.

Table 5.1: Comparison of THD

Type of Load	THD % Without Compensation	THD % With Compensation	
		IS	IL
Linear Load	There is no need of uncompensated system because we follow IEEE 519 rule. (i.e. current harmonics is less than 5% for non isolated system)	0.02%	0.33%
Non Linear(Static) Load		0.05%	0.09%
Non Linear(Dynamic IM) Load		0.01%	0.07%

6. CONCLUSION

A model of D-STATCOM has been developed in MATLAB environment using Power System Block-set. The performance of the developed model is tested under a various loading conditions. It is found that DSTATCOM is capable of minimizing the harmonics and reactive power compensation. Synchronous reference frame control scheme has been applied over the sensed and reference supply currents for DSTATCOM and it has been found to be a simple technique. Only one PI controller is required to regulate terminal voltage and thus reduces computation effort. The control algorithm of the D-STATCOM is flexible and has been tested for power quality improvement for linear as well as nonlinear and Induction motor load. D-STATCOM is able to reduce harmonics in at PCC and supply currents to less than 5% IEEE 519 standards.

Table no.1 insures the effectiveness of proposed SRF technique. D-STATCOM reduces harmonics in load current to a large extent and provides quality power.

7. PARAMETERS OF THE PROPOSED SIMULATED SYSTEM FOR L&NL (STATIC AND DYNAMIC) LOADS

Voltage (line -line) (Vn)– 100 Vrms, Frequency (Fn) – 50 Hz, P = 2.0, I = 0.15, D = 0, Lc= 1*10-3H, Rc=1.0Ω, hb=1, C1=1e-6, Nominal Power (Pn)– 5 H.P., Voltage (line -line) (Vn)– 338 and 340 Vrms, Frequency (Fn) – 50 Hz , Stator Resistance (Rs) – 1.1115 ohm and Inductance (Lls)– 0.00059 H, Rotor Resistance (Rr`)- 1.08 ohm and Inductance (Llr`)- 0.00059 H, Mutual Inductance (Lm)- 0.20 H, Inertia (J) – 0.020 Kgm2 , Friction Factor (F) – 0.0057 N.M.S. , Pole Pair (p) – 2,Lc= 5*103H, Rc = 0.1Ω, hb=0.1-0.5, CA=5000F, RL = 1000 Ω. Second order LPF Cut of frequency 45 Hz, Damping factor 0.707.

8. NOMENCLATURE

V_a, V_b, V_c - Instantaneous Voltages

L_s , R_s - Per Phase Source Inductance and Resistance

$V_{san}, V_{sbn}, V_{scn}$ - Three Phase Instantaneous Input Supply Voltages

V_{er} - Voltage Error

K_p , K_i - Proportional and Integral Constants

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