IMPROVEMENT OF POWER QUALITY USING FACTS AND DFACTS DEVICES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

Master of Technology

In

Power Control and Drives

By

BANGLAKADI SUMAN

Department of Electrical Engineering

National Institute of Technology

Rourkela

2016

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Under the Guidance of

Prof.Sanjeeb Mohanty

Department of Electrical Engineering

National Institute of Technology

Rourkela

DECLARATION

I hereby declare the work in the thesis regarding "**IMPROVEMENT OF POWER QUALITY USING FACTS AND DFACTS DEVICES**" done by me in partial fulfilment of the requirements of the degree in Master of Technology in Electrical Engineering with the specialization of Power Control and Drives at the National Institute of Technology, Rourkela. The matter contained in this thesis has not been submitted to any other institution/university for the degree.

By

Banglakadi Suman

Date:

National Institute of Technology

Rourkela

CERTIFICATE

This is to certify that the work contained in the thesis "**IMPROVEMENT OF POWER QUALITY USING FACTS AND DFACTS DEVICES**" presented by Banglakadi Suman (Roll No 711EE2096) in partial fulfilment of the requirements of the degree in Master of Technology in Electrical Engineering with the specialization in "**Power Control and Drives"** at National Institute of Technology, Rourkela is the work carried by him/her under his/her supervision and guidance.

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ACKNOWLEGMENT

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ABSTRACT

Power Quality is a measure of to which extent a system supports reliable operation to its loads. A power disturbance involves voltage, current, or frequency variations. Power disturbances can originate in consumer power systems, consumer loads, or the utility because of non-linear loads, adjustable speed drives, traction drives, start of large motor loads, arc furnace, lightning etc. Typical power quality disturbances are voltage variation (voltage swelling, voltage sag) frequency variation & waveform distortion.DSTATCOM is used to improve quality of the power in the distribution system by using an adaptive least mean square based control algorithm for a 3-phase distribution static compensator (DSTATCOM) to mitigate multiple power quality problems such as reactive power, current harmonics, load unbalancing, and so on with self-supporting dc bus voltage of voltage source converter used as a DSTATCOM. The proposed control algorithm is implemented for the extraction of tuned weighted values of fundamental active and reactive power components of distorted load currents which are major components in reference supply currents. Developed DSTATCOM is operated under various operating conditions and its performance is found satisfactory. Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. Sensitive equipment and non-linear loads are common place in both the industrial and domestic environment and disturbances can originate from these loads which includes non-linear loads like adjustable speed drives, traction drives, starting of large induction motor etc., typical power quality disturbance are voltage fluctuation, flickering, sag, swell and spikes in waveforms, harmonic distortion and unbalance.

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CHAPTER-1

INTRODUCTION

1.1 Objective: The objective of shunt compensation is to change the natural characteristic of transmission so as to make it more compatible to the variation in load demand. The capacitors and/or inductors that are connected to the line reduce the overvoltage in light load condition and also the under voltage in full load condition. In this section basic topologies of both variable admittance type and converter based shunt compensators are discussed, which are used to supply reactive power in accordance to the change in voltage that happens because of loading.

1.2 Motivation:

Power Quality is a measure of to which extent a system supports reliable operation to its loads. A power disturbance involves voltage, current, or frequency variations. Power disturbances can originate in consumer power systems, consumer loads, or the utility because of non-linear loads, adjustable speed drives, traction drives, start of large motor loads, arc furnace, lightning etc. Typical power quality disturbances are voltage variation (voltage swelling, voltage sag) frequency variation & waveform distortion.so there is a need for improvement of power quality.

1.3 Thesis outline:The thesis is based on power quality improvement using FACTS and DEFACTS devices by using MATLAB/Simulink.

Chapter-1 Introduction

Chapter-2 Power quality improvement using TCR

Chapter-3 Power quality improvement using DSTATCOM

Chapter-4 Conclusison and Future scope of work

CHAPTER-2

POWER QUALITY IMPROVEMENT USING TCR

2.1 Thyristor Controlled Reactor (TCR) :

TCR consists of an air cored inductor and a bidirectional thyristor valve, depending on the voltage and current rating a number of thyristors can be connected in series or parallel to satisfy the current carrying capacity and voltage blocking capacity. The current in a reactor can be controlled from zero to its maximum rating. The schematic diagram of one such TCR is shown below.

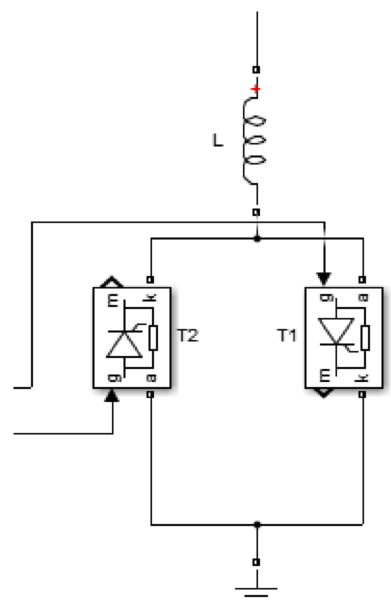
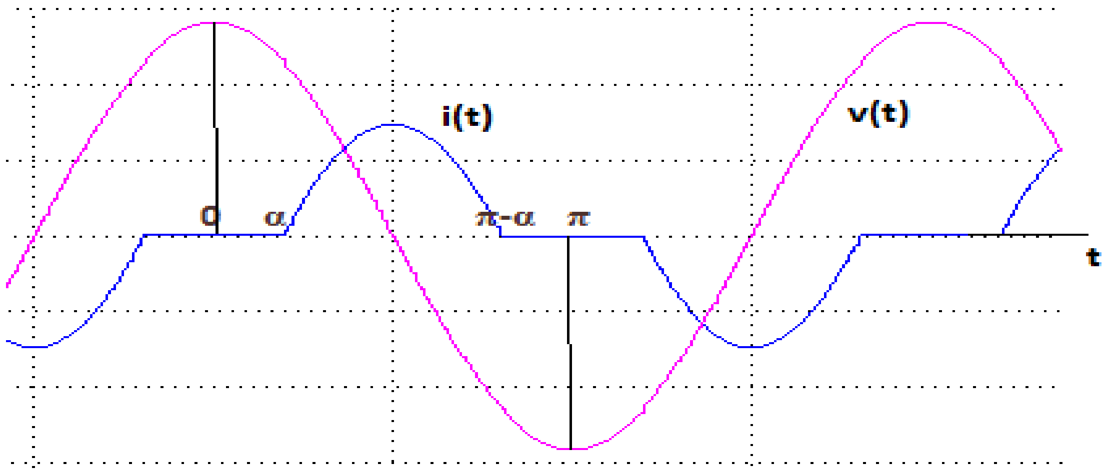


Figure: 2.1.1 a)TCR circuit diagram



b)Voltage-Current waveform for some firing angle

The current in the thyristor T1 in figure is given by

i(t)=$\frac{1}{L}\int_{\alpha}^{\omega t} v(t)\, dt = \frac{v}{\omega L}(sin\omega t - sin\alpha)$, For $\alpha < \omega t < \pi - \alpha$ ……………(2.1.1)

For negative half cycle the expression of current just becomes negative of it and flows through T2.

The fundamental power which deals with the absorption of reactive power can be derived by fourier series method and can be written as follows.

$i_1(t) = \frac{2}{\pi}\int_{\alpha}^{\pi-\alpha} \frac{v}{\omega L}(sin\omega t - sin\alpha)sin\omega t\, d\omega t = \frac{v}{\omega L}(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin(2\alpha))$…(2.1.2)

So the value of susceptance is given by

$B(\alpha) = \frac{1}{\omega L}(1 - \frac{2}{\pi}\alpha - \frac{1}{\pi}\sin(2\alpha))$…………………………………….(2.1.3)

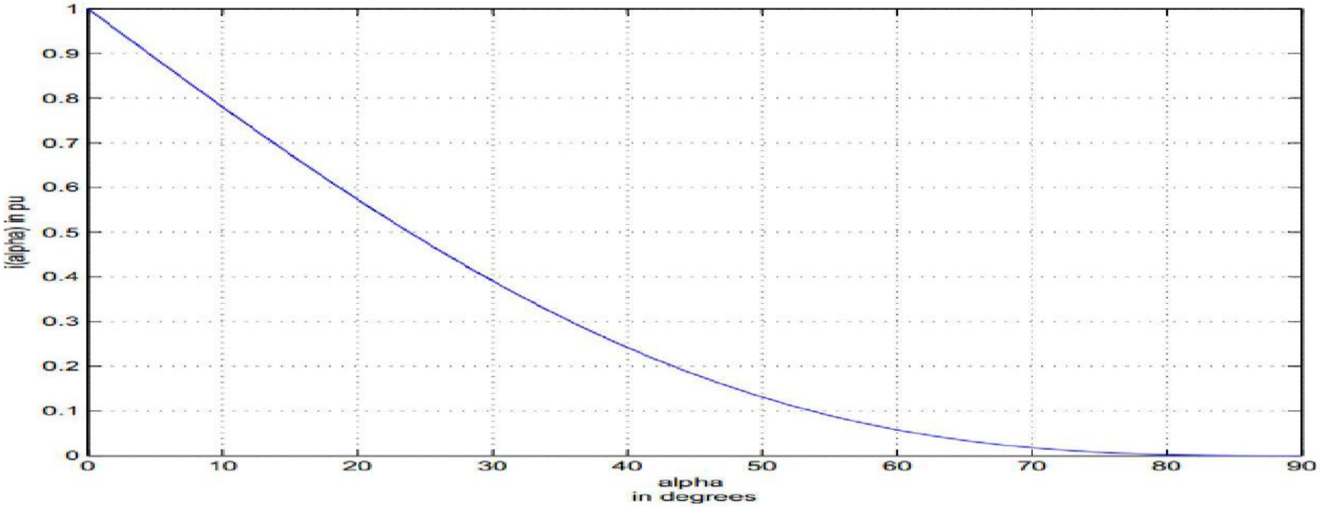


Figure 2.1.2 Relation between Fundamental value of current in TCR and Firing angle.

2.2 Three phase Thyristor Controlled Reactor (TCR) :

The thyristor controlled reactor is used to compensate a three phase system, all the above equation mentioned above holds good but the value of voltage will either be phase to ground or phase to phase depending on connection type either star or delta. In this simulation work the system is assumed to be symmetrical, which is true for transmission line not for distribution lines, so the firing angle of thyristors will be same.

2.3 System Information:

Base VA=100MVA and

Base Voltage=400KV

Table 2.3.1 System taken for three phase TCR simulation

Source Parameters	Emf=1 pu	Z_s=0.05+j 0.2 pu	
Step-up Transformer	$20\sqrt{3}$kV/400kV	100MVA	Z_s=0.004+j 0.16 pu

Step-Down Transformer	400kV/20$\sqrt{3}$ kV	100MVA	Z_s=0.004+j 0.16 pu
TCR transformer	400kV/10$\sqrt{3}$ kV	50MVA	Z_s=0.004+j 0.16 pu
Transmission line length (50kms)	[r1,r0]= [0.01273 0.3864] Ω/km	[L1 L0]= [0.9337e-34.1264e-3] H/km	[C1 C0]= [12.74e-10 7.751e-10] F/km
TCR	Qmax = 0.5 pu		

In this simulation the load reactive power is varied from zero to -0.5 pu in steps of -0.1 pu and the compensator reactive power and source reactive powers are observed.

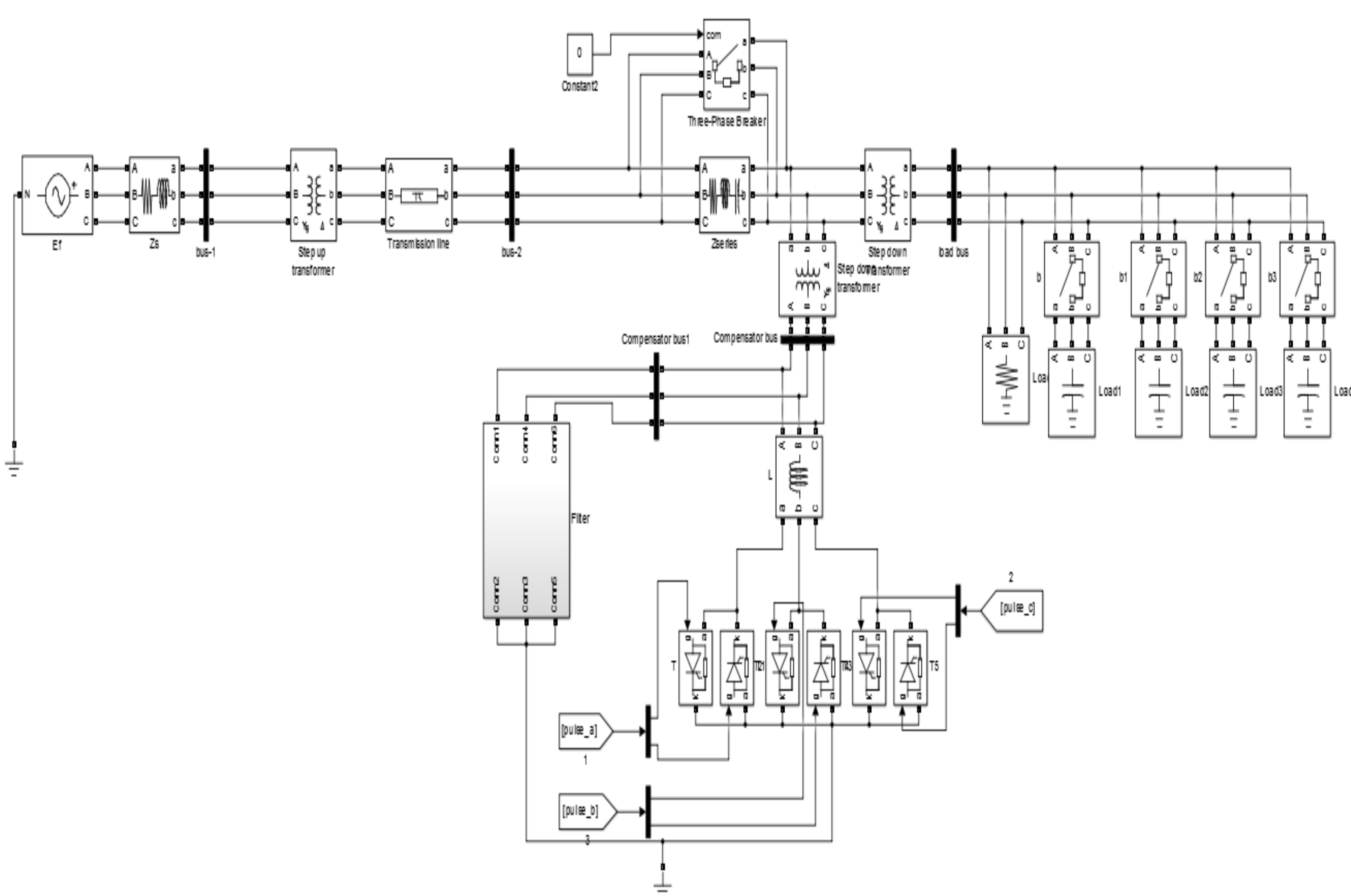


Figure 2.3.1; three phase system for three phase TCR simulation.

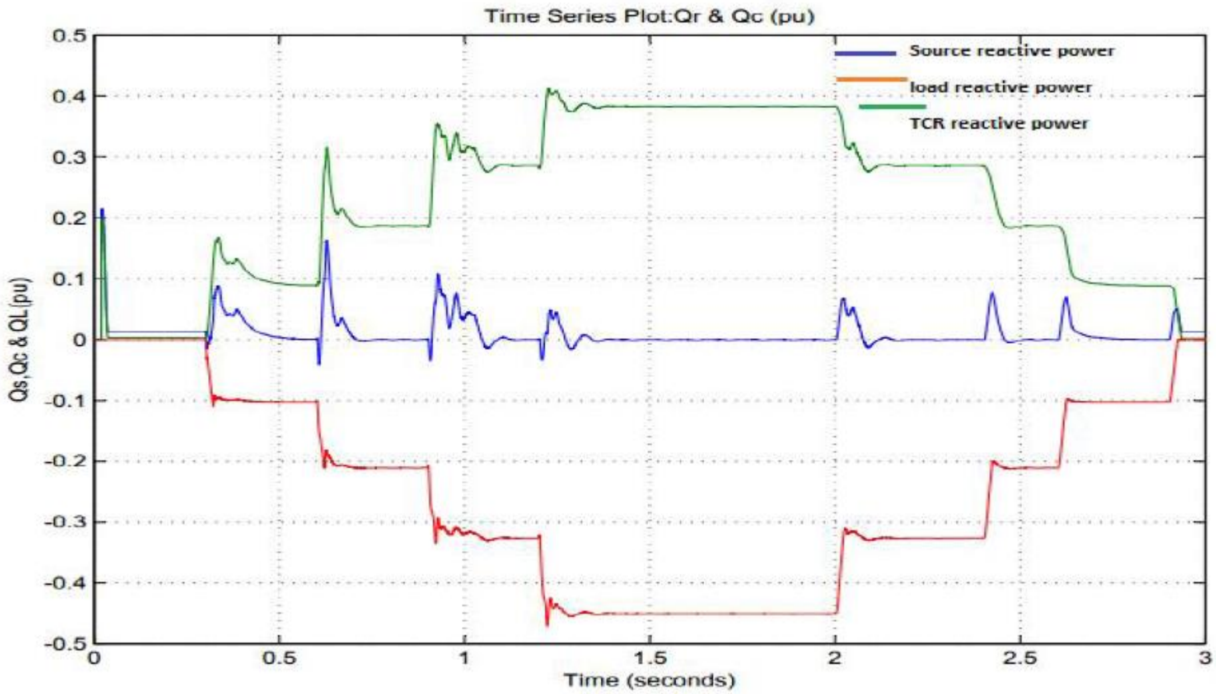


Figure 2.3.2 :Response of 3-phase TCR to step input.

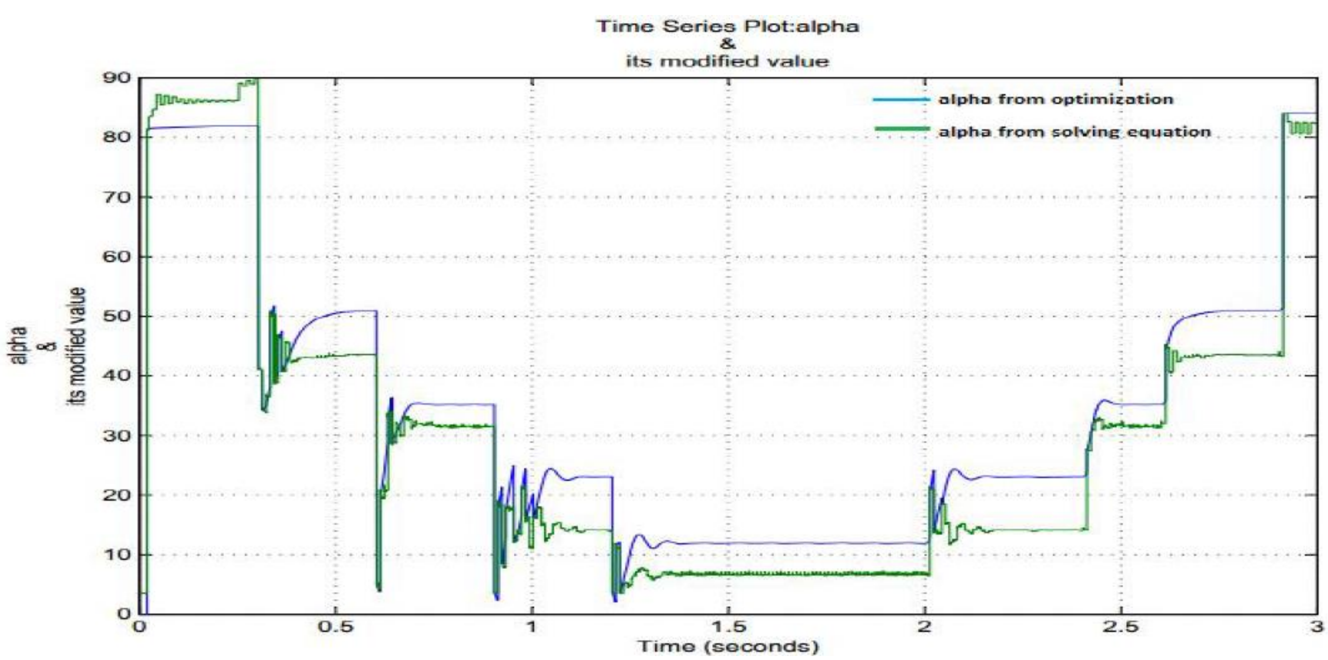


Figure 2.3.3: Variation of firing angle to step inputs.

The reactive power drawn from the source is not zero but has a value around 0.05 pu, but the absolute value of this is around 5 MVAR, so there is a need of minimizing that value and bring it to zero.Gradient based optimization is applied to reduce this to zero and the response after using optimization is shown next.

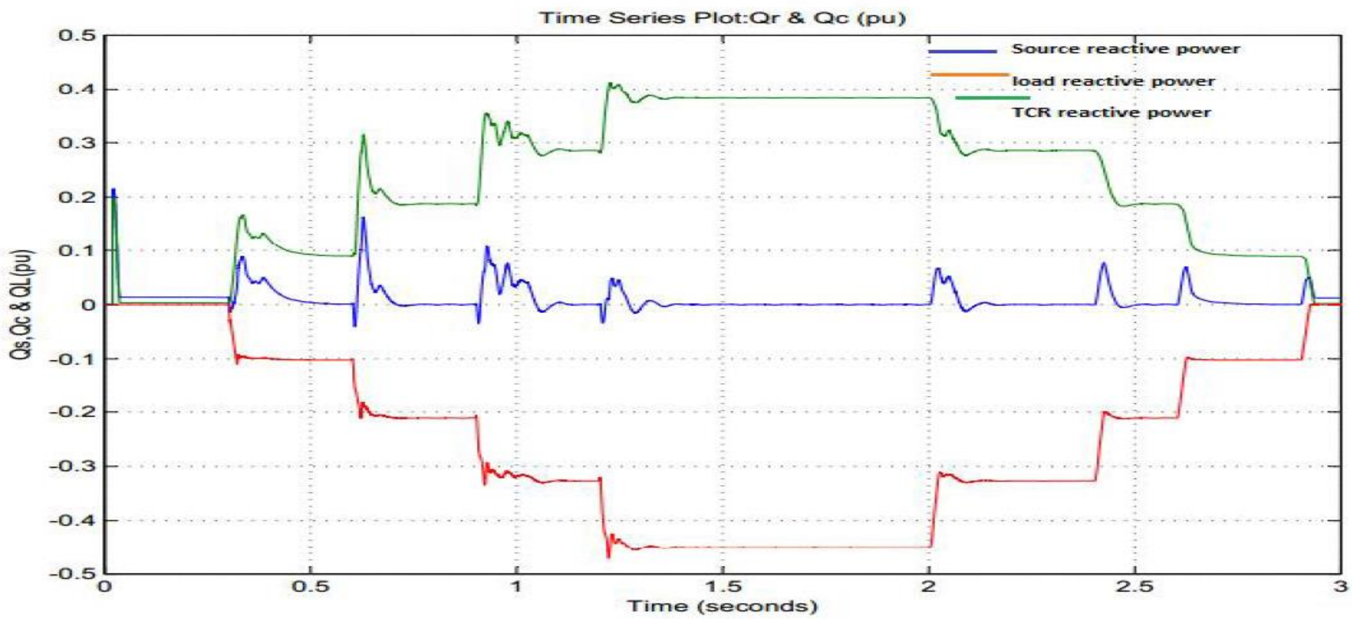


Figure 2.3.4; Response to step inputs after gradient based optimization

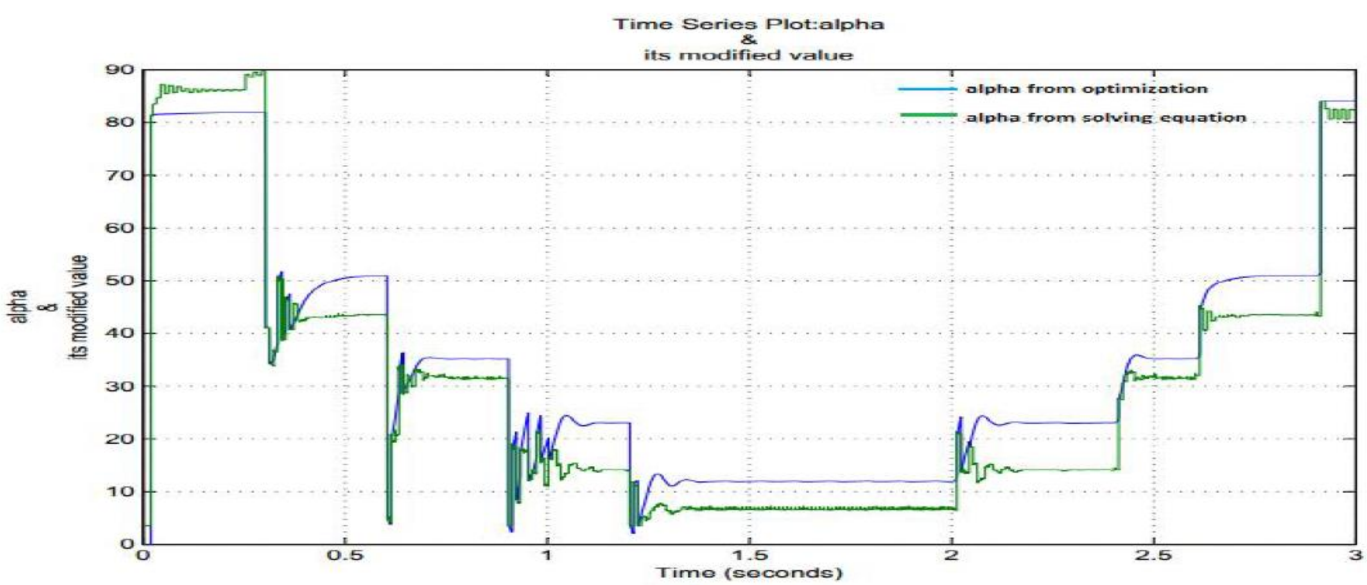


Figure 2.4.5; variation of firing angle to step inputs

2.4 Observation and Conclusion:

The responses obtained after optimization is much better as after some transient the reactive power of source is falling down to zero, actually it is oscillating with magnitude of 0.0005 pu around zero. If there is a need of more accurate control then number of TCR connected in parallel and operated in sequentially can be employed. It is to be noted that both the controller that is the optimization block and the equation solver will work competitively. That means when the alpha value is settled then only the gradient based optimization works, if alpha changes abruptly more than 10 degrees then that firing angle is fed to firing signal generator otherwise the response would be sluggish.

CHAPTER-3

Power Quality Improvement using Distribution Static Compensator (DSTATCOM)

3.1 INTRODUCTION:

various types of nonlinear loads like adjustable speed drives, solid state voltage controllers, rectifiers with filter inductance, switch mode power supplies are connected in the distribution system, which are sole responsible for several problems like voltage unbalance, Voltage Sag/Swell, overvoltage, under voltage, voltage flickering etc.Such types of load involve with the relevant issues like equipment overheating, capacitor blowing, motor vibration, excessive neutral current, poor power factor and communication interference. So the life span of end user equipment decreases and requires a lot of maintenance. So, keeping design consideration for different power levels, different topologies like three leg voltage source converter (VSC)- based, four leg VSC-based, three-leg parallel, three-leg modular, and two-leg modular of DSTATCOM were surveyed.Besides these, the performance of DSTATCOM is depend upon the control algorithm.

In this paper, an adaptive LMS is implemented in a DSTATCOM for the extraction of active and reactive components of three-phase distorted load currents. The performance of this DSTATCOM is observed under both balanced and unbalanced loading conditions. Improved dynamic response and fast convergence are the various compensation of this control algorithm like harmonics suppression, load balancing, unity power factor operation, voltage regulation are presented. The results from this simulation studies indicate the high accuracy and correctness of the DSTATCOM operation to maintain the power quality indices.

3.2 SYSTEM CONFIGURATION:

The typical distribution system consists a three phase nonlinear load which is fed by a three phase balanced source. A novel topology, supercapacitor supported VSC-DSTATCOM is used as a compensator to mitigate the power quality issues. Switching signals for IGBTs of VSC are generated by using instantaneous symmetrical component theory control technique.

3.2.1 System Topology:

The distribution system consists of a three phase supply and a three phase non linear load.The proposed compensator is connected at the point of common coupling(PCC) through an interfacing impedance.The compensator consists of an IGBT based VSC with a dc bus capacitor.The schematic diagram of adaptive LMS control algorithm including both DC and AC voltage bus side control depicted as shown in below figures.

3.2.2 Adaline based LMS Control Algorithm:

The adaline based LMS control algorithm is a new efficient technique in reduction of distortion and power quality improvement through the proper learning process.The basic equations involved in the estimation of different control variables are described below.

The extraction of weighing values of fundamentals active component of load current (w_{pa}, w_{pb}, w_{pc}) are computed based on neural network based control algorithm as follows.

$$w_{pa}(n) = w_{pa}(n-1) + \alpha.\gamma\{ I_{la}(n) - w_{pa}(n-1)u_{pa}(n)\}u_{pa}(n) \qquad (3.2.1)$$

$$w_{pb}(n) = w_{pb}(n-1) + \alpha.\gamma\{ I_{lb}(n) - w_{pb}(n-1)u_{pb}(n)\}u_{pb}(n) \qquad (3.2.2)$$

$$w_{pc}(n) = w_{pc}(n-1) + \alpha.\gamma\{ I_{lc}(n) - w_{pc}(n-1)u_{pc}(n)\}u_{pc}(n) \quad (3.2.3)$$

The mean values of weighing values(Wa) of a.b and c-phase is calculated as follows

$$w_a = \frac{w_{pa} + w_{pb} + w_{pc}}{3} \quad (3.2.4)$$

Then this mean value is fed to the LPF(Low pass filter) with selected value of cut off frequency to obtain the ripple free weighing value(Wp).

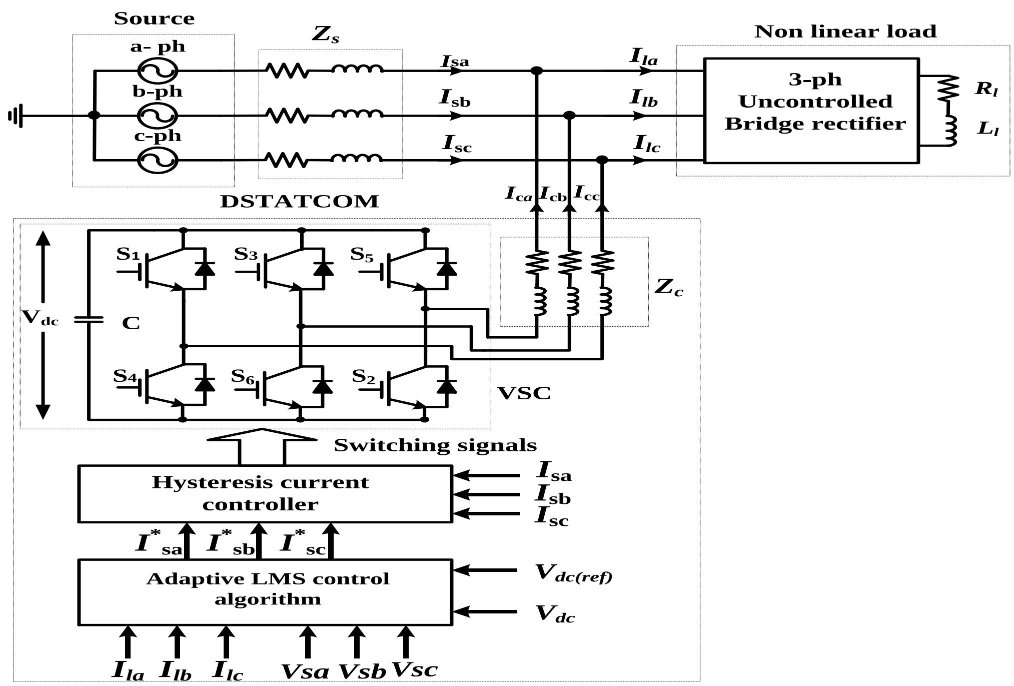


Figure:3.2.1 DSTATCOM using Proposed Topology for distribution system

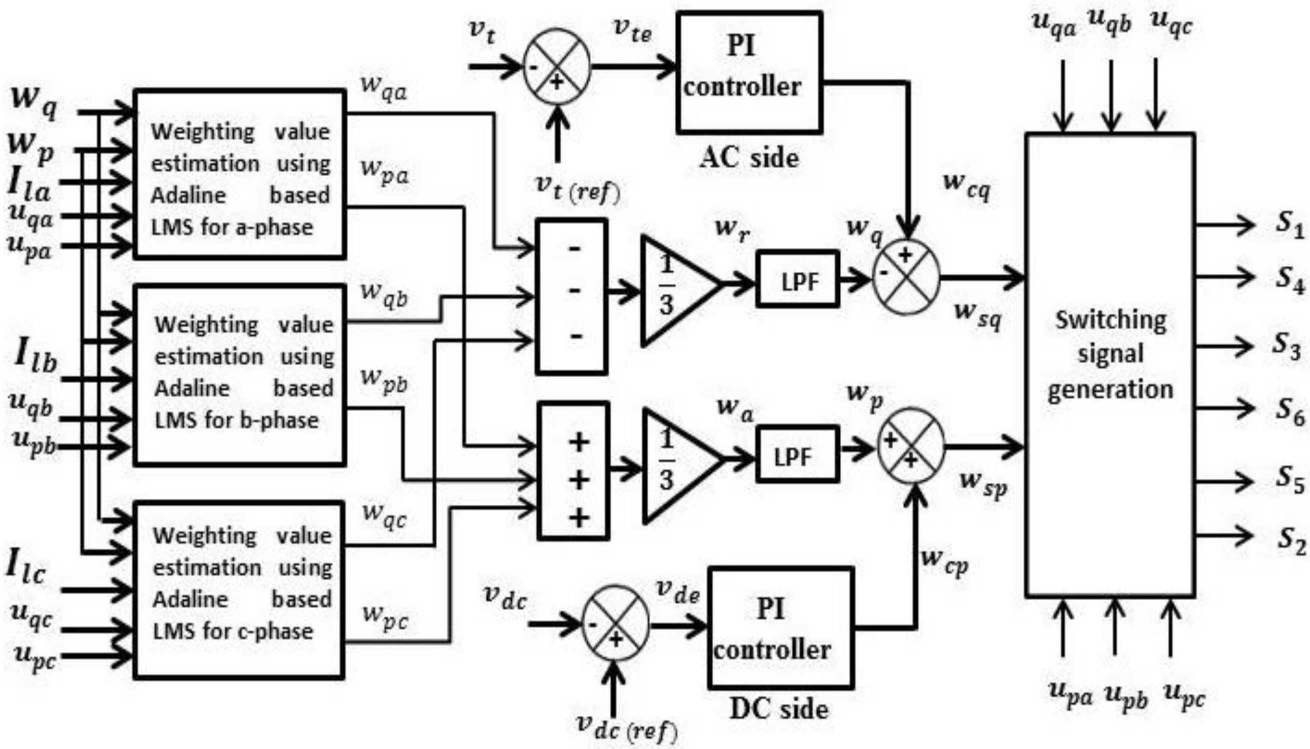


Figure 3.2.2: Adaptive LMS algorithm including bus voltage control.

The extraction of load current(Waa, Wab,Wac) are computed base on neural network control algorithm as follows.

$$w_{qa}(n) = w_{qa}(n-1) + \alpha.\gamma\{ I_{la}(n) - w_{qa}(n-1)u_{qa}(n)\}u_{qa}(n) \quad (3.2.5)$$

$$w_{qb}(n) = w_{qb}(n-1) + \alpha.\gamma\{ I_{lb}(n) - w_{qb}(n-1)u_{qb}(n)\}u_{qb}(n) \quad (3.2.6)$$

$$w_{qc}(n) = w_{qc}(n-1) + \alpha.\gamma\{ I_{lc}(n) - w_{qc}(n-1)u_{qc}(n)\}u_{qc}(n) \quad (3.2.7)$$

The mean values of weighting values(Wr) of a,b and c-phase is calculated as follows.

$$w_r = \frac{w_{qa}+w_{qb}+w_{qc}}{3} \quad (3.2.8)$$

Then this mean value is fed to the LPF(Low pass filter) with selected vealue of cut off frequency to obtain the ripple free weighing value (w_q).

3.3 Computation of in-phase and quadrature unit voltage template:

The in-phase unit voltage templates (u_a, u_b, u_c) are the relation of phase voltages and amplitude of PCC voltage (v_t) estimated as follows.

$$u_{pa} = \frac{v_{sa}}{v_r}; \qquad u_{pb} = \frac{v_{sb}}{v_r}; \qquad u_{pc} = \frac{v_{sc}}{v_r}; \qquad (3.3.1)$$

The quadrature unit voltage templates (u_a, u_b, u_c) are the relation of phase voltages as follows.

$$u_{qa} = \frac{u_{pb} + u_{pc}}{\sqrt{3}} \qquad (3.3.2)$$

$$u_{qb} = \frac{3u_{pa} + u_{pb} - u_{pc}}{2\sqrt{3}} \qquad (3.3.3)$$

$$u_{qc} = \frac{-3u_{pa} + u_{pb} - u_{pc}}{2\sqrt{3}} \qquad (3.3.4)$$

Where v_t can be expressed as

$$v_t = \sqrt{\frac{2(v_{sa}^2 + v_{sb}^2 + v_{sc}^2)}{3}} \qquad (3.3.5)$$

3.4 Estimation of active components of reference source currents:

The difference between reference dc voltage and sensed dc voltages is the error in dc voltage (v_{de}) can be expressed as

$$v_{de} = v_{dc\,(ref)} - v_{dc} \tag{3.4.1}$$

The difference is processed through the proportional integral(PI) controller to control the constant dc bus voltage.The output of PI controller can be expressed as

$$w_{cp} = k_{pa} v_{de} + k_{ia} \int v_{de} dt \tag{3.4.2}$$

The sum of output of PI controller and the average magnitude of active component of load currents is the total active components of reference source current can be expressed as

$$w_{sp} = w_p + w_{cp} \tag{3.4.3}$$

3.5 Estimation of reactive component of reference source currents:

The differences in between reference ac voltage and sensed amplitude of ac bus voltage is the error in ac voltage (v_{te}) can be expressed as

$$v_{te} = v_{t\,(ref)} - v_t \tag{3.5.1}$$

The difference is processed through the PI controller to maintain the constant ac bus voltage.The output of PI controller can be expressed as

$$w_{cq} = k_{pr} v_{te} + k_{ir} \int v_{te} dt \tag{3.5.2}$$

The difference between output of PI controller and average magnitude of reactive component of load currents is the total reactive components of the reference source current can be expresses as,

$$w_{sq} = w_q - w_{cq} \tag{3.5.3}$$

3.6 Estimation of switching signal generation :

Three phase instantaneous reference source active component are estimated by multiplying in phase unit voltage template and active power current component and these are obtained as

$$i_{aa} = w_{sp}u_{pa}, \quad i_{ab} = w_{sp}u_{pb}, \quad i_{ac} = w_{sp}u_{pc} \qquad (3.6.1)$$

Similarly,three phase instantaneous reference source reactive component are estimated by multiplying quadrature unit voltage template and reactive current component and these are obtained as

$$i_{ra} = w_{sq}u_{qa}, \quad i_{rb} = w_{sq}u_{qb}, \quad i_{rc} = w_{sq}u_{qc} \qquad (3.6.2)$$

The summation of active and reactive components of current is called as reference source currents and these are obtained as

$$i_{sa}^{*} = i_{aa} + i_{ra}, \quad i_{sb}^{*} = i_{ab} + i_{rb}, \quad i_{sc}^{*} = i_{ac} + i_{rc} \qquad (3.6.3)$$

The summation of active and reactive components of current is called as reference source currents and these are obtained as

$$i_{sa}^{*} = i_{aa} + i_{ra}, \quad i_{sb}^{*} = i_{ab} + i_{rb}, \quad i_{sc}^{*} = i_{ac} + i_{rc} \qquad (3.6.4)$$

The both actual source currents ($i_{sa,}i_{sb}, i_{sc}$) and the reference source currents ($i_{sa}^{*}, i_{sb}^{*}, i_{sc}^{*}$) of the respective phases are compared then current error signals are fed to hyteresis current controllers(HCC).Their outputs are used to feed the insulated gate bipolar transistors(IGBTs) s_1 to s_6 of the VSC served as a DSTATCOM.

3.6.1 SIMULATION RESULTS & DISCUSSION:

The simulation of the proposed described system is carried out in MATLAB Simulink to observe the performance under the various situations such as with out DSTATCOM and also with DSTATCOM and super capacitor supported DSTATCOM.These different cases are described separately in below.

3.6.2 Without DSTATCOM :

The performance of distribution system are presented as follows.The three phase balanced and sinusoidal source(v_s) is shown in below figure.The three phase source current (i_s) is shown below.The three phase PCC voltage(v_l) is shown ans corresponding THD values are expressed in percentage are 0.00,20.66,12.07 which are shown below.

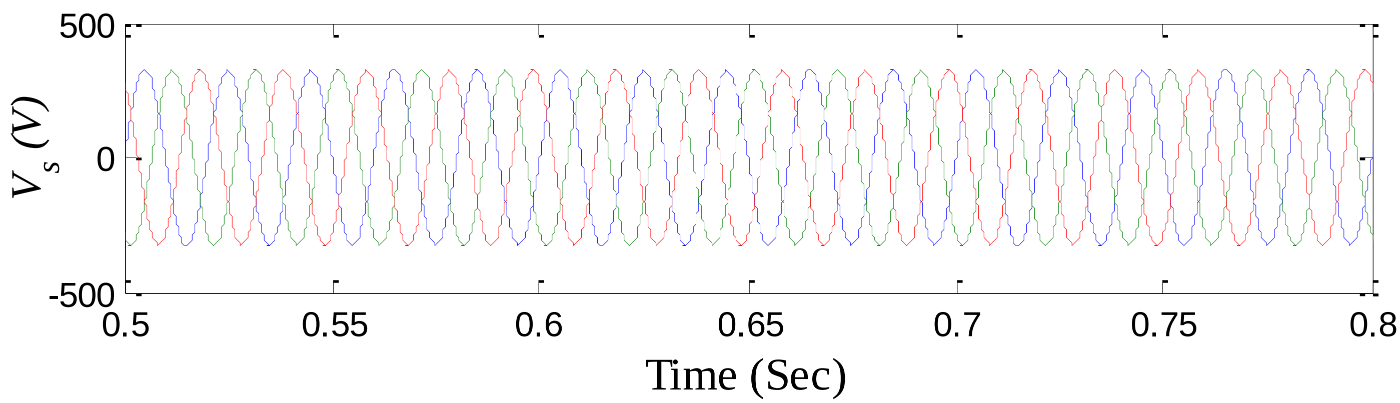


Figure.3.6.1 Source voltage

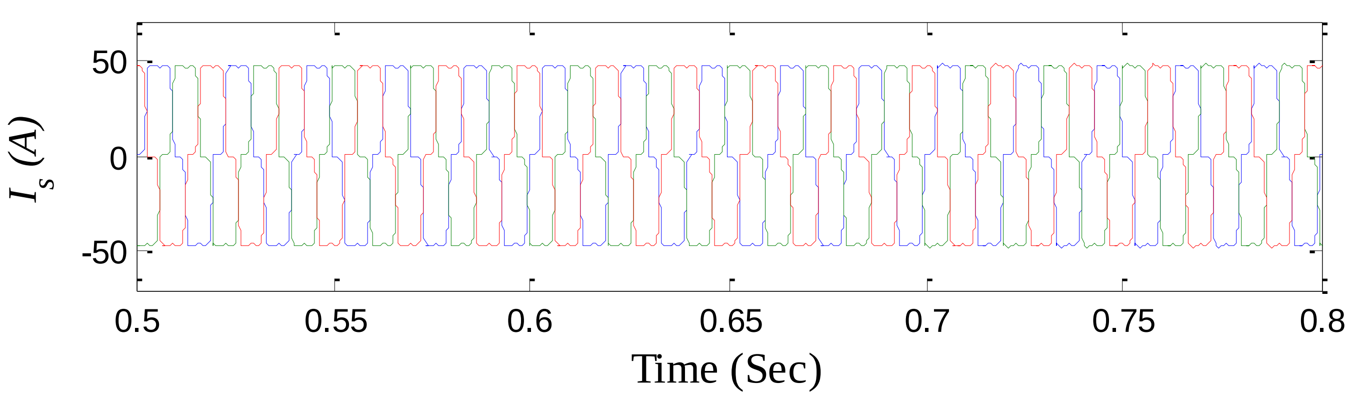


Fig.3.6.2 Source current

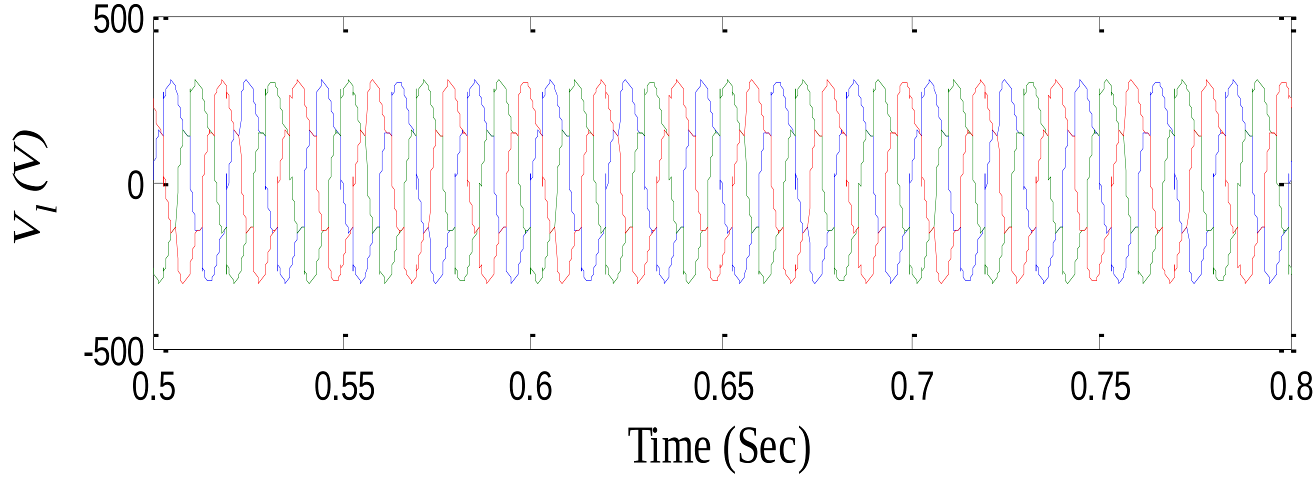


Fig.3.6.3 Load voltage

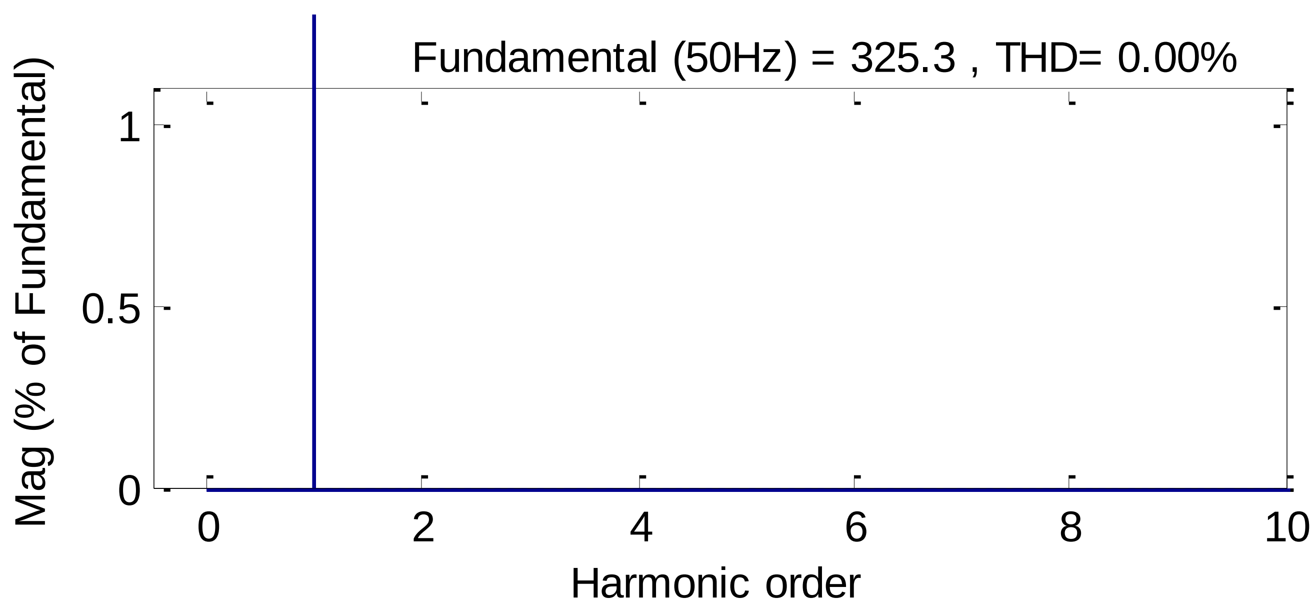


Fig.3.6.4 -THD of source voltage

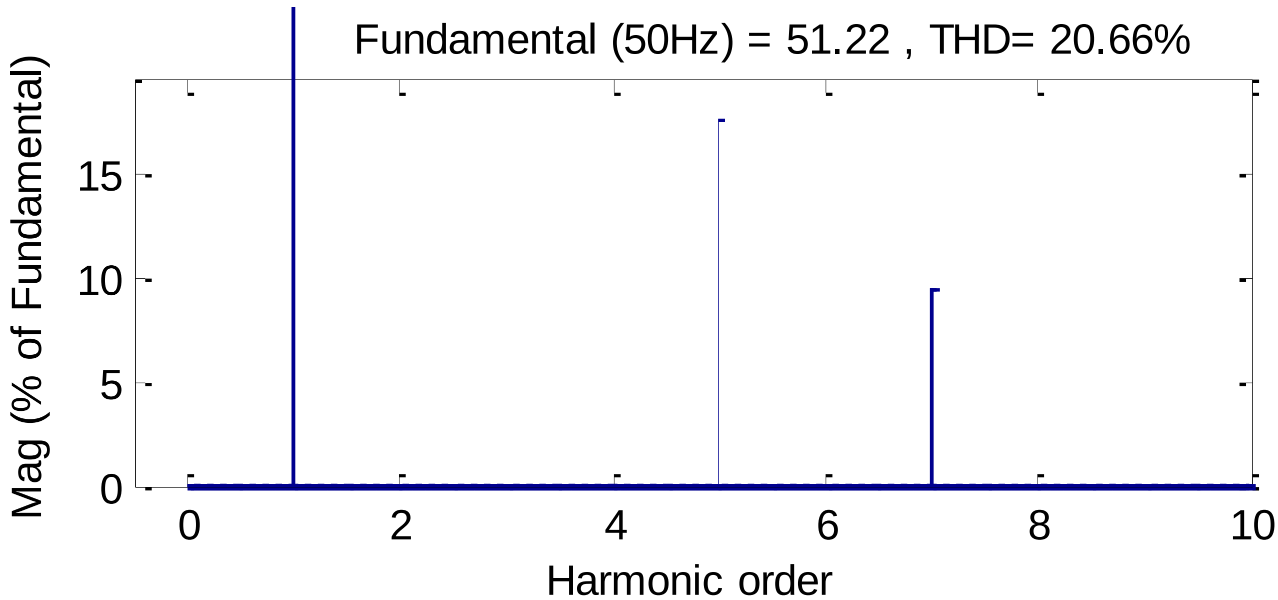


Fig.3.6.5 THD of source current

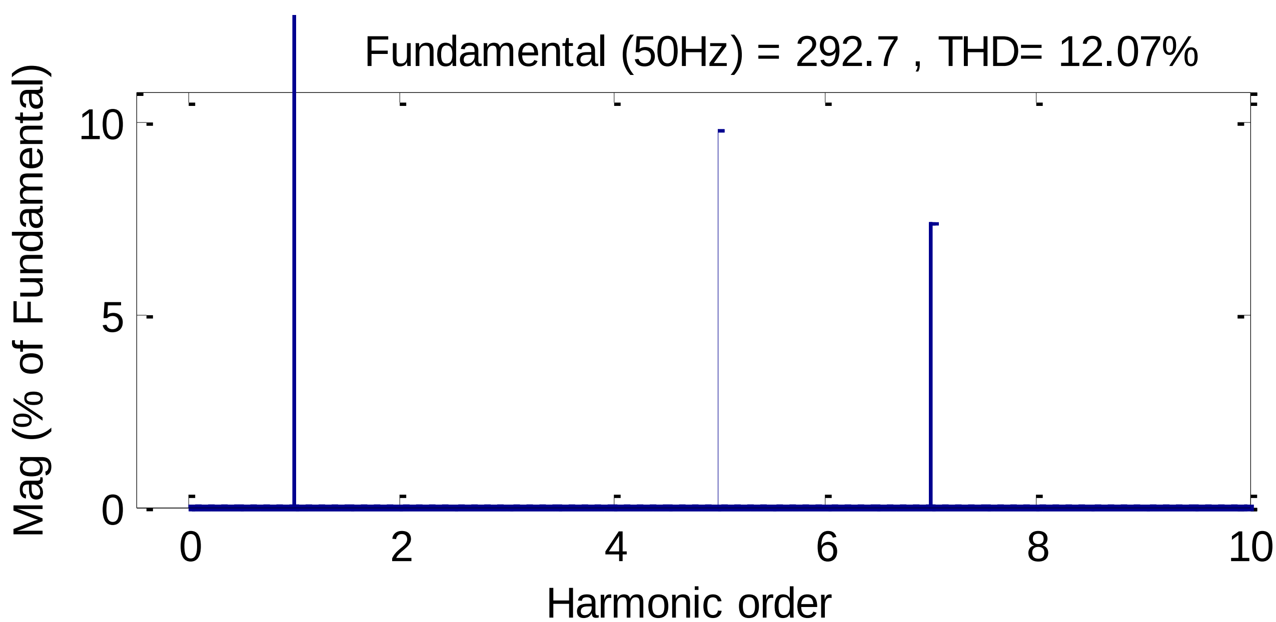


Fig. 3.6.6 THD of PCC voltage

3.6.3 With DSTATCOM under balanced loading condition:

The performance of distribution system under balanced loading condition are presented as follows.The three phase source current,load voltage,load current,compensator voltage,compensator current and dc-link capacitor voltage are shown respectively.The percentage THD values are 4.62,18.28 of source current and load current shown below.Finally it is observed that the dc link voltage is 600V.

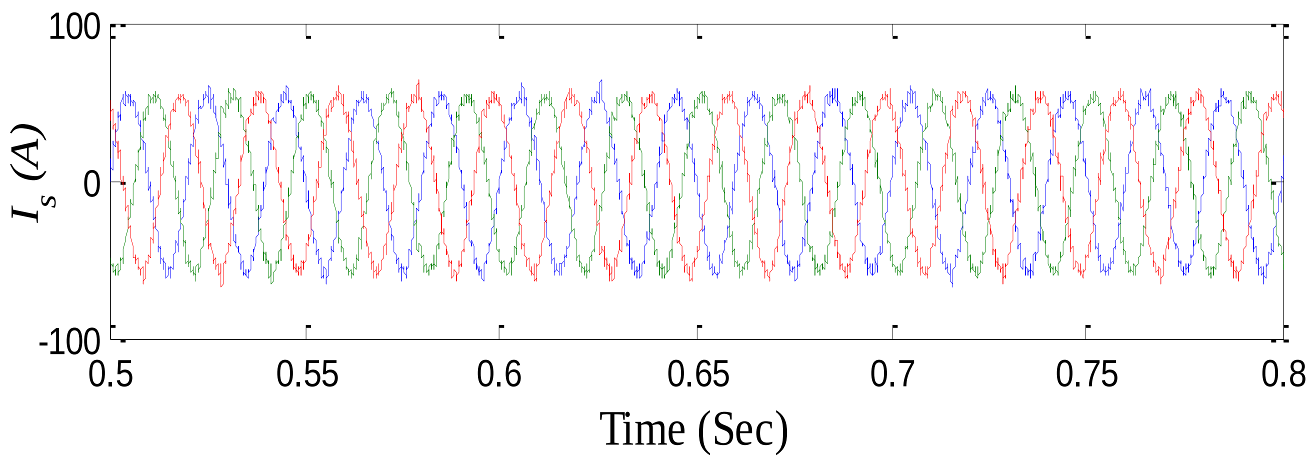


Figure.3.6.7 Source current

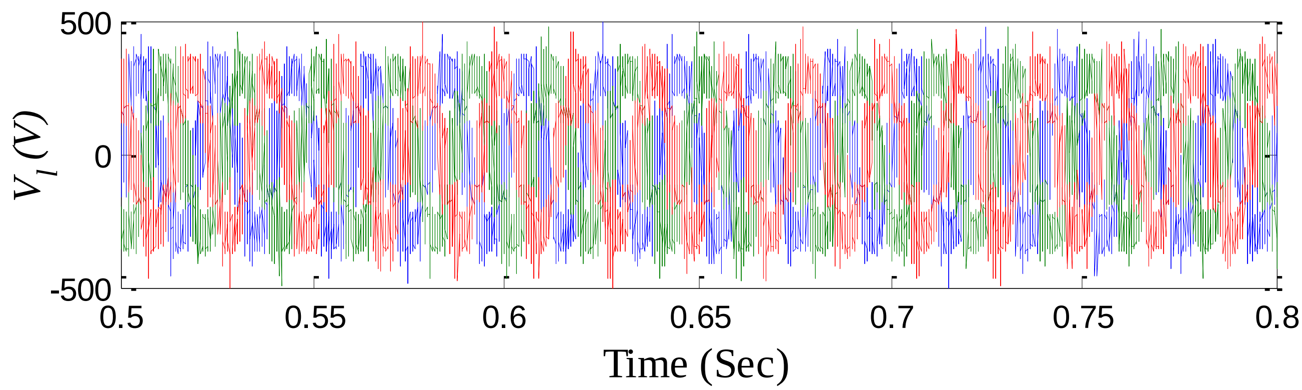


Figure.3.6.8 Load voltage

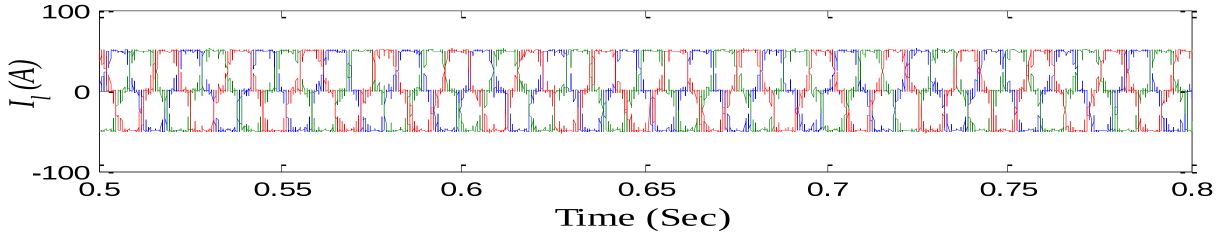


Figure.3.6.9 Compensator voltage

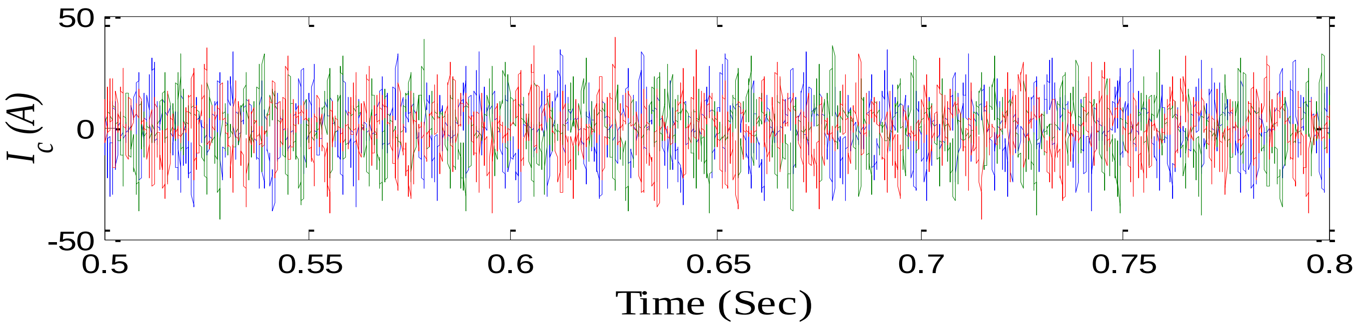


Figure.3.6.10 Compensator current

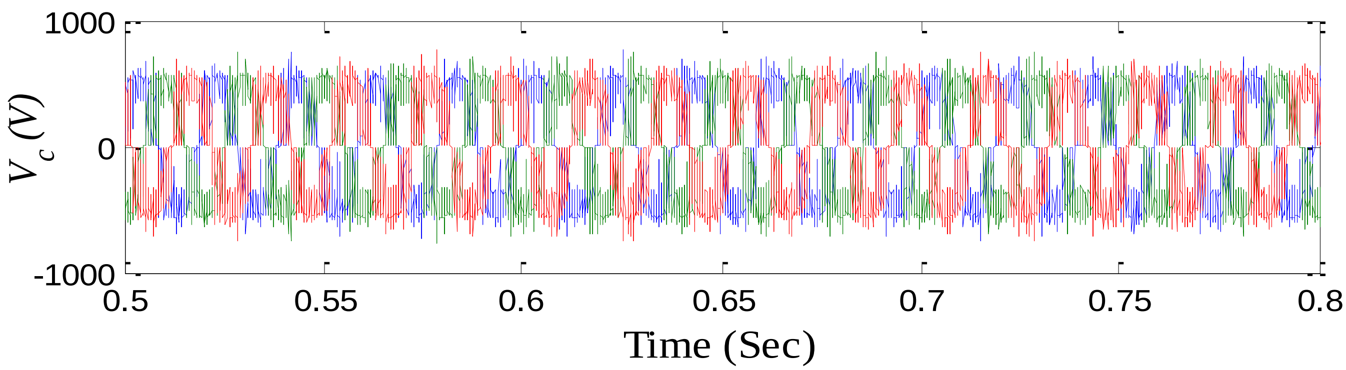


Figure.3.6.11 Compensator voltage

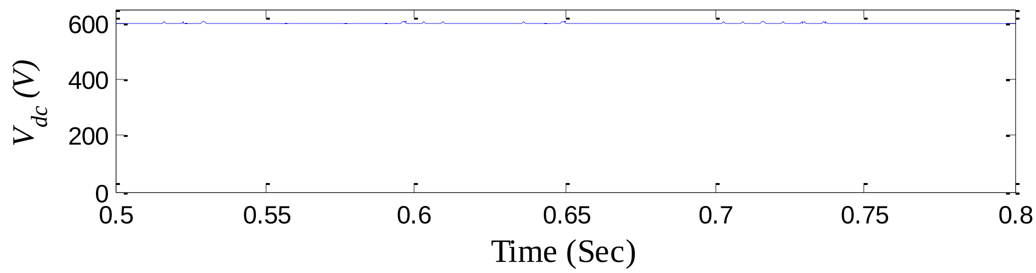


Figure.3.6.12 self-supported capacitor voltage

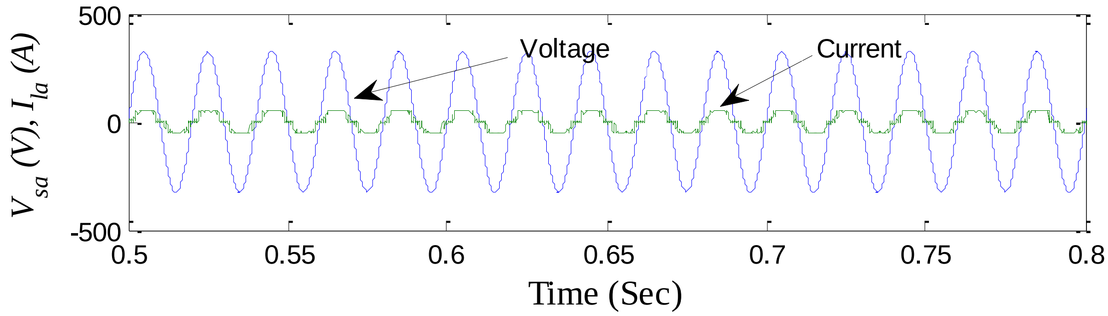


Figure.3.6.13 a-phase Source voltage and load current

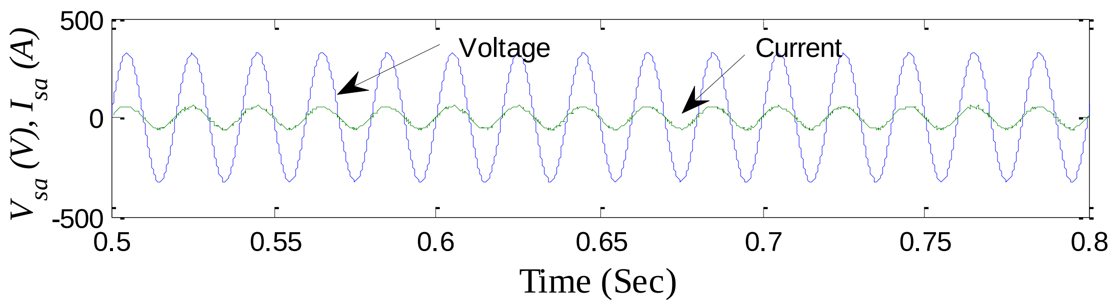


Figure.3.6.14 a-phase Source voltage and Source current

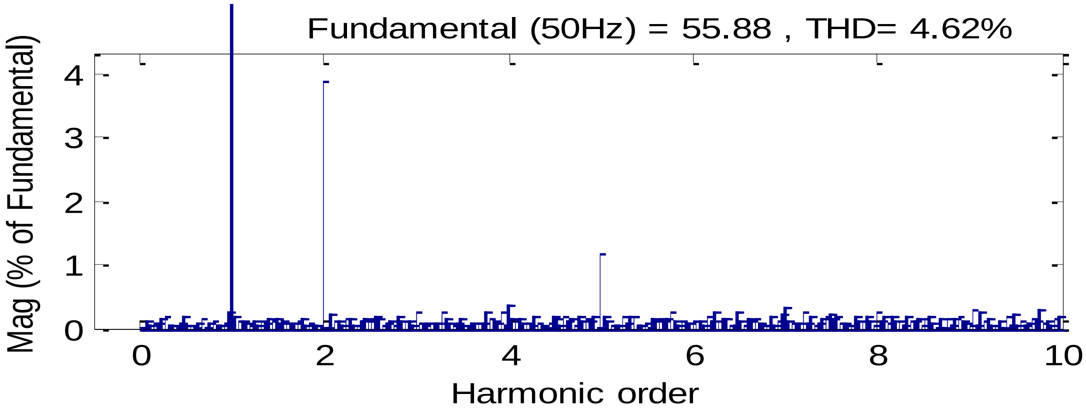


Figure.3.6.15 THD of source current

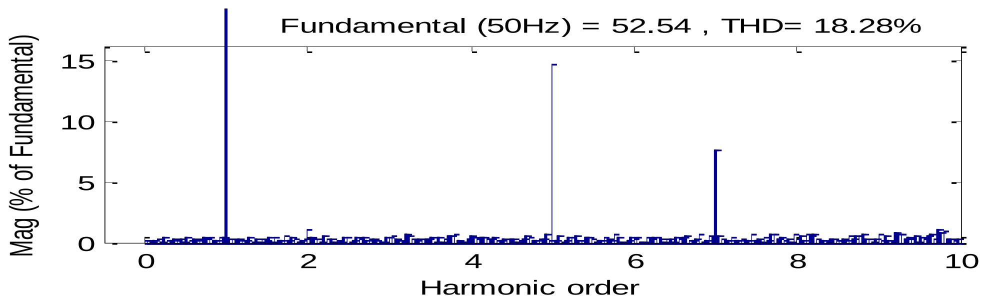


Figure.3.6.16 THD of load current

Table.3.7 performance parameter from simulation studies

Performance parameter	Without DSTATCOM	With DSTATCOM
		balanced
Source current (A),%THD	51.22, 20.66	55.88, 4.62
PCC voltage (V),%THD	292.7, 12.07	299.4, 10.23
Load current (A),%THD	51.22, 20.66	52.54, 8.28
Input power factor	0.98	0.971
Output power factor	0.98	0.908

CHAPTER-4

Conclusion

4.1 Conclusion:

The proposed adaptive Least mean square control algorithm based DSTATCOM was implemented through the MATLAB/Simulink for balanced conditions successfully.This control algorithm was used for the extraction of weighting value of both fundamental active and reactive load currents to derive the reference supply currents for switching the IGBT's of VSC.Various results such as harmonics suppression,load balancing,unity power factor operation voltage regulation at PCC were obtained from this simulation effectively.

Appendix:A

Table.4.1 System parameter for simulation studies

Grid parameters	Source voltage (V_s)=230V, 50Hz Source resistance R_s= 0.5 Ω Source inductance L_s=2mH
Load parameter	3-Ø diode rectifier with RL load R_l= 10Ω L_l=20mH
VSC parameter	R_c=0.25Ω L_c=1.5mH $V_{dc(ref)}$ =600V C_{dc} =2000μF

APPENDIX: B

Rating of VSC = 10 kVA (Safety factor = 0.1), PI regulator gains for dc bus voltage: *kpa* = 0.5, k_{ia} = 10, PI regulator gains at voltage regulation: *kpr* = 4, *kir* = 1.2, noise factor (γ)= 0.1and learning rate (α) = 0.2.

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