VOLTAGE STABLIZATION OF WIND ENERGY CONVERSION SYSTEM BY MPFC CONTROLLER

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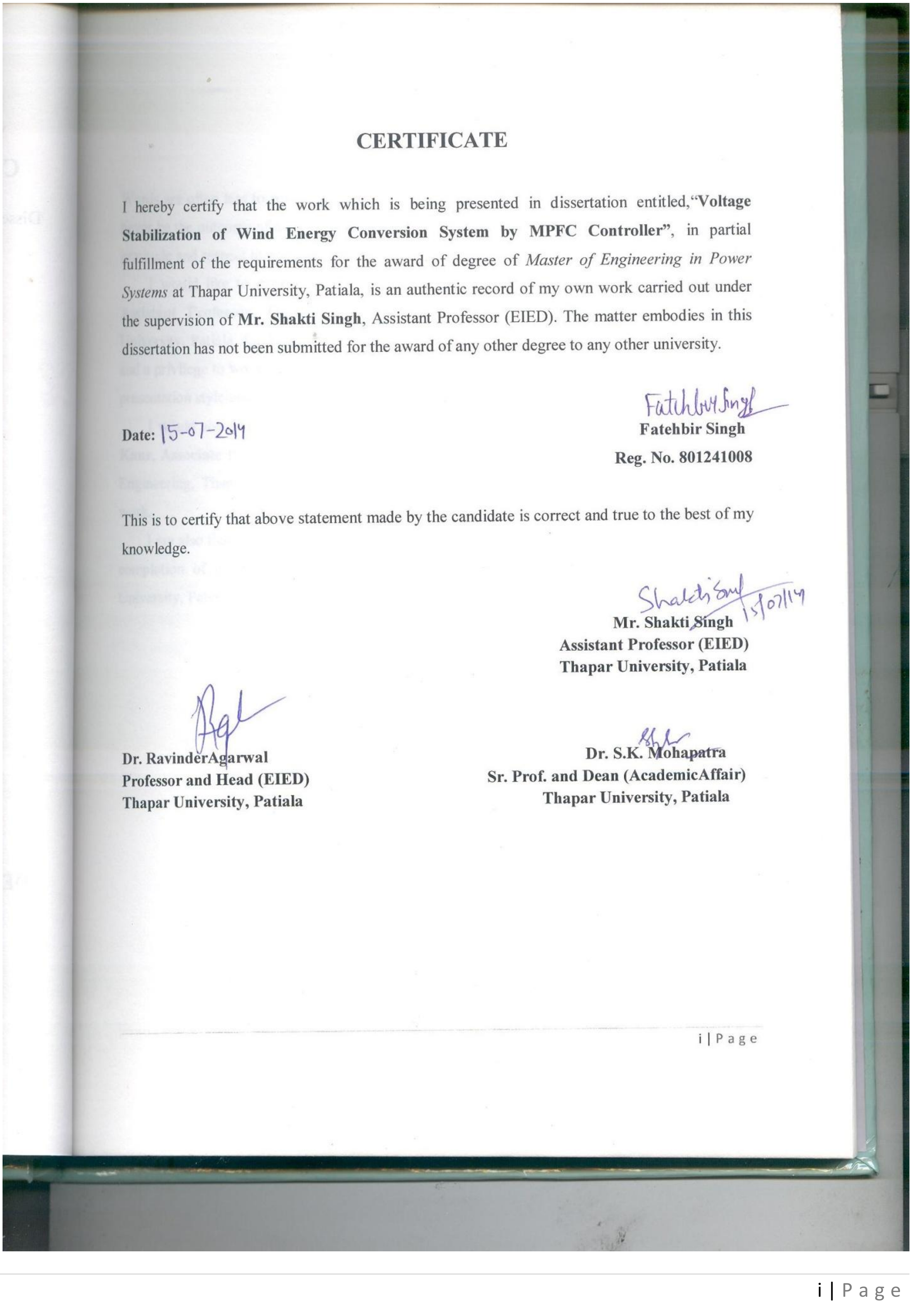

CERTIFICATE

I hereby certify that the work which is being presented in dissertation entitled,"**Voltage Stabilization of Wind Energy Conversion System by MPFC Controller**", in partial fulfillment of the requirements for the award of degree of *Master of Engineering in Power Systems* at Thapar University, Patiala, is an authentic record of my own work carried out under the supervision of **Mr. Shakti Singh**, Assistant Professor (EIED). The matter embodies in this dissertation has not been submitted for the award of any other degree to any other university.

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ABSTRACT

The need to exploit ample renewable energy sources such as wind and solar is growing due to world energy shortage, financial and environmental pollution concerns. Wind energy has made significant progress over the last decades and evolved as one of mature and fastest growing renewable technology due to its nature of intermittent,inexhausitable,adundant and enviormental friendly source of electricity generation. However, the voltage stabilization problem of a wind energy system is dependent on changing wind conditions and varying electric load conditions. Novel techniques are proposed using dynamic stabilization and compensation schemes driven by effective controllers to ensure voltage stabilization under varying wind and electric load conditions.

In this dissertation a Modulated Power Filter Compensator controller is used proposed to improve the voltage profile of wind energy conversion system against changing wind and load condition.Different PWM techniques have been proposed for MPFC Controller. The proposed controller is tested on system using Matlab/Simulink environment and it is found that Chaos based SVPWM MPFC controller provides better stabilization of voltage as compared to the SVPWM MPFC controller and PWM based MPFC controller. Harmonic contents in load end voltage and load end current gets reduced in Chaos based MPFC controller as compared to other PWM based MPFC controller.

LIST OF ABBRIVATIONS

DFIG	-	Doubly Fed Induction Generator
DG	-	Distributed Generation
DSP	-	Digital Signal Processing
DVR	-	Dynamic Voltage Restorer
FACTS	-	Flexible AC Transmission System
GTO	-	Gate Turn Off Thyristor
IGBT	-	Insulated Gate Bipolar Transistor
MPFC	-	Modulated Power Filter Compensator
MPPT	-	Maximum Point Power Tracking
P	-	Proportional
PD	-	Proportional Derivative
PI	-	Proportional Integral
PID	-	Proportional Integral Derivative
PSS	-	Power System Stabilizer
PWM	-	Pulse Width Modulation
SEIG	-	Self Excited Induction Generator
STATCOM	-	Static Synchronous Compensator
SPWM	-	Sinusoidal Pulse Width Modulation
SVPWM	-	Space Vector Pulse Width Modulation
UPFC	-	Unified Power Flow Controller
VSI	-	Voltage Source Inverter
WECS	-	Wind Energy Conversion System

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Chapter - 1

INTRODUCTION

1.1 Overview

Use of electricity generation from renewable energy sources increased rapidly in the last decade as industrial sector become more aware about fossil fuel shortages and their environmental impacts. Wind energy has become the best source of electricity as it directly converts kinetic energy of air mass into electricity [1]. Mostly large size wind turbines in the world use three phase asynchronous (squirrel cage) induction generator for their low lost, reliability and less maintenance. So a self excited asynchronous induction generator driven by a wind turbine called a standalone Wind Energy Conversion Scheme. The problem of voltage stabilization in WECS depends on the varyingwind and load conditions.

Different compensation techniques have been proposed to ensure the generator voltage stabilization under varying wind and load conditions. Many current controls and schemes of compensation are used for generator bus voltage stabilization. The basic need for these schemes are their fast response during transient state, low ripple current, stable operation and robustness against variation of the system. Among the FACTS devices, the UPFC flow controller is oftenly used due to its better regulating capabilities**.** The UPFC is a combination of shunt and series branches, which are used interchangeably. Located at the point of the WECS in the distribution network, it is possible to simultaneously control the WECS bus voltage magnitude and/or series reactive power flow that WECS exchanges with the network [2]. In some cases STATCOM is used in order to provide regulation for induction generator terminal voltage and PSS for damping of oscillations which are produced in the system [8].The ramp control scheme can be an alternative which gives constant switching frequency operation, but the undesirable feature being steady state error and phase delay in steady state since this controller is designed in a stationary reference frame where P or PI controller cannot track the sinusoidal variable reference [10]. The Predictive Current Control scheme can also be used which have advantageous features of constant switching frequency and small current ripple but under parameter mismatch conditions, even full knowledge of machine parameter and operating condition cannot give satisfactory results [12].

So we can employ multiloop control scheme that has benefits of good dynamic response, stable operation and robustness against system variation.

Different compensation scheme are used, one of which include dual loop compensation scheme which delivers easy implementation and low voltage ripple as their advantageous feature [13]. Another type of compensation used is thyristor control series compensation which provides variable impedance control in transmission lines [14]. These compensation schemes used have many merits and applicable nearly to all kinds of wind energy systems [16].

1.2 Objective of work

The objective of the dissertation is to study the problem of voltage stabilization of Wind Energy Conversion System using Matlab/Simulink enviorment. The work has also been done to explore the response of Wind Energy Conversion System using MPFC Controller. Different PWM techniques like space vector based PWM and Chaos based SVPWM are proposed for MPFC controller to solve the problem of voltage stabilization of Wind Energy Conversion System.

1.3 Literature Review

Brod and Novotny [10] demonstrated the behavior and limitation of current controllers commanding currents in a three phase load. An overview of several controllers were presented in the paper and performance was computed by comparing the simulation result of different controllers.

Rowan and Kerkma [11] discussed detailed Modeling of synchronous current regulator and the result obtained were compared for the purpose of model verification and from the result. It was found that stationary sine, triangle and hysteresis current regulators had their steady state characteristics dependent on the system parameter whereas the synchronous current controller characteristics are independent of system parameter.

Le-Huy and Dessaint [12] discussed an adaptive current control method using a PWM inverter for a synchronous motor drive. Analysis of control scheme in the two modes was presented and studied by simulation and implementation of proposed current control scheme using microprocessor based system was considered.

Vincenti and Jin [13] analyzed direct six switch PWM rectifier for correcting the input imbalance. An unbalance transfer matrix is generated in terms of input voltage. Gating signals are generated by solving the unbalance transfer matrix.

Helbing and Kiuady [15] discussed an advanced form of series compensation. Equivalent series compensation was increased by proper selection of thyristor firing angle. The mathematical equations describing the voltages and currents through the different electrical items were developed, analyzed and later verified using the EMTP analysis program.

Jin *et.al.* [16] discussed a new static VAR compensator.Problems of large low-order harmonics and slow response present in the conventional thyristor-controlled-reactor based compensators can be solved using a pulse-width-modulated (PWM) AC converter.

Espinoza *et.al.* [41] discussed the space vector technique and its implementation of active filter applications was presented. Also, this paper addressed the issue of modeling and simulating the space vector PWM technique.The modeling of the space vector technique using the program PSIM was described in this paper, and results were provided for illustration.

Yu *et.al.* [37] demonstrated three commonly used PWM techniques, Space Vector PWM technique, Sinusoidal PWM technique and Hysteresis PWM technique with stress on their implementation. Experimental results were also presented for all three PWM techniques.

Machowski *et.al.* [23] discussed an excitation control strategy for a synchronous generator using the Lyapunov’s direct method and the nonlinear system equations. The control strategy required neither phase compensation nor wash-out circuit’s characteristic of standard power system stabilizers (PSS).

Muljadi and Butterfield [21] demonstrated the operation of variable speed wind turbines with pitch control. Two methods to control the aerodynamic power were investigated pitch control and generator load control, both of which were employed to control the operation of the wind turbine.

Muljadi and Butterfield [6] discussed pitch control operation of the variable speed wind turbine. The system was controlled to generate maximum energy while minimizing loads. In this paper two control strategies for aerodynamic power was discussed.

Lov *et.al.* [17] discussed modeling of large dynamic systems, e.g. wind energy conversion system which was done using Matlab/Simulink software which had a wide rangeof block as a wind turbine model, generator model, power electronics model and grid model in it.These blocks use differential equations of the models and requires different simulation steps.

Dizdervi. *et. al.* [2] demonstrated a FACT based UPFC Controller, which was used with WECS to mitigate with problem of voltage support and power flow control in the distribution network.

Kwasinski and Karen [36] discussed that classical space vector modulation (SVM) was functionally identical to double-sided uniform-sampled pulse width modulation (UPWM). Since UPWM was conceptually simple and involves few steps, it is possible that computation may be reduced in practice.

Sharaf and Wang [32] demonstrated a low cost dynamic capacitor compensation scheme which was employing a real time error tracking and PID controller to stabilize an isolated stand alone wind energy output. The novel DCC scheme was used as a voltage stabilization regulator Scheme.

Sharaf and Zhao [31] demonstrated a novel voltage stabilization scheme using a FACT based dual switching universal power stabilization for the standalone wind energy system.

Ang and Chong [34] discussed analysis of functionalities and tuning methods present in the software and hardware modules of PID Controller. Many PID modules had been developed in order to improve performance, but standardizing and modularizing PID control was desired, though challenging.

Mufti *et.al.* [25] discussed some self-tuning control strategies for isolated wind-diesel power generation systems. Modeling and studies on both single-input single-output (SISO) as well as multi-input multi-output (MIMO) self tuning regulators, applied to a typical system were described in the paper.

Rathnakumar *et.al.* [39] demonstrated a new software implementation for two level inverter by using space vector modulation technique. This software implementation was done by combination Matlab and PSIM software packages. The simulation study of space vector modulation technique of two levels Inverter gave us an idea that space vector modulation technique utilizes DC bus voltage more efficiently and generates fewer harmonics than SPWM.

Sharaf and Wang [1].discussed a voltage stabilization and power quality enhancement scheme using a PWM switched modulated power filter compensator (MPFC), which was tri-loop

Controlled (voltage, current and dynamic power signals at the load bus). The error signal to controller was used to stabilize a standalone wind driven induction Generator.

Redeemer *et.al*. [28] demonstrated the effects of power quality distortions such as voltage decrease and voltage increase of electrical devices in Mazandaran wood and paper industries. Using the actual data, the impact of voltage sag on the main line of motor drive was investigated. In addition, the impact of harmonics on the distribution transformers was studied.

Jayaramaiah *et.al.* [4] discussed a DSP based controller for standalone WECS System using I.G. This controller used a PWM VSI and it regulates the voltage when SEIG is subjected to a sudden application of removal of load.

Lu *et.al*. [44] demonstrated two new pulse width modulation (PWM) schemes viz Chaos-based sinusoidal PWM (CSPWM) and Chaos-based space vector PWM. Chaos-based PWM strategies utilize a chaotic changing switching frequency to spread the harmonics continuously to a wideband area so that the peak harmonics can be reduced greatly.

Cui *et.al.* [45] discussed a new chaotic pulse width modulation (PWM) scheme was given and was being implemented for AC motors, which functions to significantly reduce the harmonic peaks and hence the noise. The key was to employ the Chua's circuit for the generation of the desired chaotic sequence.

Sharaf *et.al* .[30] demonstrated a Modulated Power Filter Compensator for the distribution system with scattered renewable wind energy interfaced. A tri-loop error operated controller was used to regulate the PWM Switching of the compensator. Correction of power factor and power quality improvement were proved under different operating conditions, like under different load and wind velocity excursions conditions.

Zhang and Yu [40] discussed three space vector pulse width modulation (SVPWM) schemes, called 7-segment space vector modulation (SVM), 5-segment SVM and 3-segment SVM Technique.The modulation signals, DC bus voltage utilization, and output line voltage harmonic of these schemes were analyzed by the MATLAB software.

Li *et.al.* [43] demonstrated a chaos-based pulse width modulation to spread the harmonics of the DC–DC converters continuously and evenly over a large frequency range, thereby decreasing the effect of EMI. Periodic and chaotic response of DC–DC converters under certain parametric situations were simulated, experimentally verified and analyzed.

Narayana ***et.al.*** [22] discussed a maximum power point tracking controller in order to obtain maximum power output of a wind turbine generator system. Windspeed forecasting techniques were considered for the predictive optimum control system of wind turbines to reduce response time of the MPPT controller.

Malarvizhi and Baskaran [29] demonstrated the design of a Static Synchronous Compensar which was based on Cascaded H-Bridge–Multi Level Converter .To investigate the performance of the STATCOM connected in parallel with the transmission line, an induction generator based wind farm had been considered in this paper.

Dang ***et.al*** .[3] discussed that introduction of DG of varying output capacities at various locations along the feeder can reduce the line losses.

Amin ***et.al.***[9] demonstrated the impact of wind energy conversion system on the power system, the impact of WECS was minimized by the use of STATCOM to regulate the induction generator terminal voltage.

Vasconcello ***et.al.***[27] discussed the use of computer simulation to find out the influence of the total and individual harmonic distortions of the current and of the voltage on a bus bar that is on power factor correction and that feed both linear and non-linear loads.

Ganeshkumar and Rajesh [38] demonstrated the comparison between the sinusoidal pulse width modulation and improved asymmetric space vector modulation for voltage source converters when the switching frequency was as low as 9 times that of line frequency. Total harmonic distortion of output current can be reduced significantly, by adding two pulses in each line cycle when the fundamental voltage crosses zero.

Ferdosian ***et.al*** **.[**7] discussed the UPFC which was used in combination with WECS and controller was used to improve the low voltage ride through wind energy and to provide stability against rotor oscillation during a fault.

Lai and Chen [8] demonstrated three PWM techniques with constant switching frequency and related random PWM techniques for full bridge DC/DC converter and it was found that new random PWM techniques significantly reduce the harmonic intensity and improves the efficiency of the system.

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1.3 Author' s contribution

The major problem in WECS is voltage fluctuations which occur due to varying wind and continuously changing load conditions. The proposed chaosbased SVPWM MPFC controller is implemented to solve voltage stabilization problem in WECS. The proposed technique implemented on giving problem yield satisfying results which are compared with other PWM techniques and hence prove to be better.

1.4 Organization of the Thesis

As per the proposed thesis titled as "Voltage Stabilization of Wind Energy Conversion System by using MPFC Controller " it consists of five chapters.

Chapter first provides a detailed introduction, objective, brief literature review pertaining to proposed problem and Author's contribution.

Chapter second presents the introduction of Wind Energy Conversion System.

Chapter third describes the problem of voltage stabilization in Wind Energy Conversion System and different approaches which have been proposed to stabilize the voltage.

Chapter four discuss simulation result and comparison of different proposed techniques.

Chapter fifth describes the scope of future extension of the work.

Chapter-2

WIND ENERGY CONVERSION SYSTEM

2.1 Introduction

The wind energy conversion system converts kinetic energy present in the wind stream into electricity.This conversion of kinetic energy into electricity is a two stage process, first process includes conversion of kinetic energy into mechanical energy by a wind turbine rotor which rotates due to wind stream, thus producing mechanical power and second process include the wind turbine which drives the electric generator that results in the electric power output. WECS are generally classified as either stand-aloneor electric grid connected WECS.

The stand-alone WECS consists of a wind turbine that drives the induction generator and having self excited capacitor connected across the generator bus [17]. The WECS feeds the electric loads such as linear loads, non linear loads and motorized loads. Voltage stability is the serious problem in wind energy conversion systemusing induction generator, especially under variable wind speed condition and continuously changing load conditions [18].

2.2 Main Componentsof WECS

The Wind Energy Conversion System consists of following components:

1. Wind Turbine
2. Gear box
3. Induction generator or Synchronous Generator
4. Stabilization Interference scheme and stabilization Controller
5. Electric loads

2.2.1 Wind Turbine

Wind Turbines are the prime movers that drives the electric generator through the kinetic energy present in the wind and converts them to the mechanical energy and transfers this mechanical energy as input torque to a generator which produces electric energy [20].Two types of wind Turbine operation are there constant wind speed turbine operation and variable wind speed turbine operation. The constant wind speed turbine can be used as a base. The variable speed operation of the turbine was based on the max energy and steady state limit of turbine. The steady state limit is on the basis Power Coefficient (Cp) –Tip Speed Eatio (TSR) curve provided.

Tip speed ratio is the ratio between the speed of the tip of the blade and wind speed. The Coefficient of power of a wind turbine is a measurement of how much turbine converts the energy of wind into electricity[21].

$$C_p = \frac{\text{Electric energy produced by wind turbine}}{\text{Total Energy available in the wind}} \qquad (2.1)$$

Wind speeds vary continuously but the wind turbine rotor is required to move it at an optimal rotor speed for a definite wind speed as the wind rotor speed cannot be changed instantaneously Therefore, the output of the wind turbine rotor to wind speed variation affects the performance of the system [22]. Wind turbine takes energy by slowing down the wind. For 100% efficiency of wind turbine, it should stop 100% of wind, but if wind turbine has only one blade, it may be the case that most of the wind does not pass through blade so normally two blade wind turbine is used so as to extract the maximum energy from wind

$$\text{TSR} = \frac{\text{Wm} * \text{R}}{\text{V}} \qquad (2.2)$$

Where

Wm=Rotor speed mechanical in rad/sec

R=Radius of blade in m

V=Velocity of wind in m/sec

Mechanical power developed is

$$P_{\text{mech}} = 0.5\rho A C_P V^3 \qquad (2.3)$$

where

ρ= Air density in (kg/m^3)

A=Swept area in (m^2)

C_p =Power coefficient of wind turbine

V= Wind velocity (m/s)

The targeted power that is at max C_P is given by:

$$P_{target} = 0.5\rho A C_{Ptarget} \left[\frac{R}{TSR_{Target}}\right]^3 W_m{}^3 \qquad (2.4)$$

$$P_{target} = K_p RPM^3 \qquad (2.5)$$

where

P_{target} =Target power (at maxC_P)

K_p =Computed wind turbine data

RPM =Rotor speed

At low and medium wind speeds, the pitch angle is being controlled to allow the wind turbine to operate at its optimal condition. In the high wind speed areas, the pitch angle is increased shedding some of the aerodynamic wind power. The change of the power coefficient – tip speed ratio curve occurs when we change pitch angle as shown in Fig. 2.1

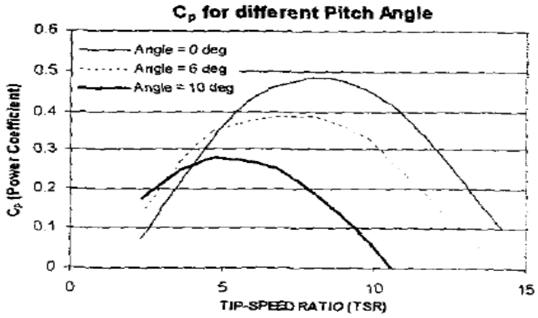


Fig. 2.1 Power coefficient versus tip speed ratio curve [21].

2.2.2 Gear Box

The main function of gearbox is to perform the conversion of torque and speed for the system considered. Gears are used for power transfer from one shaft to another. Since the input power in an ideal gear box issame as the output power, the torque and speed varies in the inverse proportions [19].

2.2.3 Electrical Generator

From the view point of electricity production wind turbine must confirm to the power quality standards such as voltage stability and absence of various harmonics and flicker on the electric grid. As it has to face a highly variable load torque, which is being supplied by the wind turbine rotor,it differs from the other generator used in an electrical grid. Nearly all the wind schemes used employ Faraday’s laws of electromagnetic induction for conversion of mechanical energy to electrical energy. The Faraday’s law can be mathematically expressed as

$$\mathrm{e(t)} = -\frac{\mathrm{N d\emptyset}}{\mathrm{dt}} \qquad (2.6)$$

where

$\mathrm{e(t)}$= Emf induced in the coil

N = Number of turns of the coil

$\frac{d\emptyset}{dt}$ = Rate of change of flux linkage with coil.

AC Generator generally used are: Synchronous generator and induction generator or asynchronous generator. In synchronous generator the rotor winding current is generally supplied by exciter which is also rotating. In Induction machine, rotor current is induced in the rotor winding by combining time variability of the stator current and relative motion of the rotor with respect to the stator

Specially three main types of wind turbine Generator systems are used:

a) Direct drive synchronous generator: It allows variable speed operation, the synchronous generator can have wound rotor or can be excited using a permanent magnet generator.it is a multipole low speed system requiring no gearbox for its connection with wind turbine. Active pitch control is employed in this type of system.

b) Direct grid squirrel cage induction generator: It employs constant speed operation. The wind turbine is connected to the gearbox. Active pitch control and passive stall effect are used for control purpose.

c) Doubly fed induction generator: It is used in variable speed operation. The rotor winding is given power through back to back voltage source converter. Active pitch control is being used for limiting the rotor speed [24].

2.2.4. Facts based Stabilization Scheme

FACTS devices are previously used for the transmission system, whereas custom power devices are used for distribution control. The introduction of custom power devices such as UPFC, STATCOM, DVR, solid state current limiter helps in limiting the power quality problems [11]. Improvement in the semiconductor switching technology helps in power quality problem mitigation. For e.g. UPFC works well with the power flow problem, the DVR can be used as a voltage improving device in the system against voltage sag problems, whereas STATCOM is used for improvement of voltage as well as for reactive power compensation [14].

For standalone WECS the output of turbine changes due to wind speed variations and sudden load change, as result of which output of generator bus fluctuates.So for stabilization, interference scheme and controllers are used [26]. Dynamic switched capacitor compensation scheme is normally used for compensating for the bus voltage change. This scheme includes switching of inverter by the use of ideal switches through PWM controller, which is fed from tri-loop controller. The tri-loop controller includes a controller for voltage,current and power. The summation of these signals is given to the PID controller whose output is given to the PWM controller for controlling the switching of inverter and hence the output of the wind [1].

2.2.5. Hybrid Loads

In the present Scenario, the loads on distribution system is not same as that of a few decades ago i.e. all loads are not linear today. Due to the technological developments like semiconductor technology advancement, microprocessor etc., the trend of electric load changes so today, both linear as well as nonlinear load exists [27]. Increased use of nonlinear load on the power system causes power quality distortion problem. Power distortion includes power interruption, increase of voltage, decrease of voltage, spikes of voltage in the system that have a severe impact on the power system [28]. A nonlinear load in a power system is identified by the introduction of a switching action and consequently interruptions in current. This behavior gives us current with different components that are integral multiples of the fundamental frequency of the system. These components are called harmonics. The magnitude and angle of a harmonic is dependent on the circuit and on the load drives.

Chapter-3

Voltage Stabilization of Wind Energy Conversion System using MPFC

3.1 Introduction

Electricity generation from wind energy contain voltage flucatuation and flickers. The most commonly used generator in a wind energy system is induction generator, but they do not provide any voltage stabilization as they are absorber of reactive power so the voltage stability problem in a wind energy system can be controlled by using fixed and switching capacitor [29]. Voltage stability is a major problem in standalone wind energy conversion scheme using induction generator, under severe wind variation and dynamic load variation. So a novel stabilization scheme is used that ensures voltage stability, efficient power utilization and boosts power quality for a stand-alone wind energy conversion scheme [32].

3.2 MPFC For Voltage stabilization of the wind energy system

MPFC controller is used to provide voltage stabilization against varying wind and load condition.In order to improve the power quality problem in the distribution system that is merged with distributed generation, a switched modulated power filter compensator which is driven by a tri-loop error controller is used. MPFC controller consists of the following elements:

1. Tri- loop dynamic error driven controller
2. Three phase diode bridge
3. Switched capacitor
4. PWM controlled ideal switches
5. Resistance and inductance

The low cost MPFC scheme is effective in voltage stabilization for both linear and nonlinear electrical load excursions [1].

The MPFC belongs to the family of several FACTS devices and compensators. Fig.3.1 shows the proposed MPFC layout. The MPFC consists of a switched capacitor and a power filter. Two IGBT switches (S1 and S2) are controlled by two complementary signals. Therefore, the equivalent AC admittance may be easily changed with different switching states.

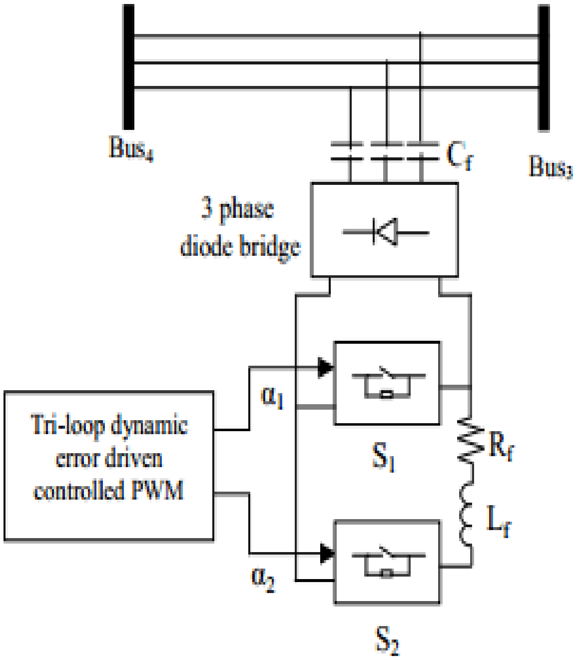


Fig. 3.1 MPFC controller

With switch S1 is opened and switch S2 is closed, the resistor and inductor will be part of the circuit and the capacitor forms a low-pass power filter with the inductor via the diode bridge. If switch S1 is closed position and switch S2 is open position, the resistor and inductor will bypass and the capacitor bank will form a capacitive admittance and gives reactive power to the AC utility grid. In order to control the IGBT switches, a novel tri-loop dynamic error-driven PID controller is being employed [30].

3.2.1. Tri- loop Dynamic Error Driven Controller

A tri-loop circuit error driven controller has simplicity in the circuit and it is fast in operation [1].The tri-loop error driven controller consists of three basic loops. The main loop consists of the voltage stabilization loop, which act as tracking the error of the voltage of the load bus and taken in the form of the root mean squared value and ensure that voltage is kept at the 1p.u. The second loop consists of the current of load bus and acts as the current loop. It gives variation of wind generator current or varying load condition. The third loop is the dynamic power load tracking additional loop that can keep a near to maximum energy utilization under varying wind and load conditions [31].

Generator voltage tracking main loop:- Any variations in wind speed and loads excursions will be mainly seen on the generator voltage after some delay due to the system and inertia time constants. Therefore, this loop tracks the error of generator voltage and keeping the generator bus voltage Vg to be around 1 p.u. By setting control signal weight Gama-V=l, the voltage loop is selected to ensure the voltagestabilization.

Generator current tracking loop: -The other loop is dynamic current tracking loop which describes any unexpected generator output current variations due to either wind speed or electric load variations. The signal weight is set to Gama-I=l.

Generator power tracking supplement loop: -This is an additional loop which records and minimizes any dynamic generator power exchange mismatch. The loop gain is set at Gama P=. 5 [1].

The total error signal (Et) is the combination of all three basic loops, namely the voltage control loop, dynamic current loop and power loop which are multiplied by the loop assigned gained factors and then it is fed to the PID controller whose proportional, integral and derivative gains are 0.5, 0.05 and 0.01 respectively [32].

The PID controller is the most common form of feedback.In control mechanism today, more than 95% of the control loops provided are of PID type. PID Controller offers three functionalities to both steady state and transient state response[33]. A standard PID controller transfer function is generally written as

$$G(s) = K_P + K_I \frac{1}{s} + K_D\, s \qquad (3.1)$$

$$= K_P \left(1 + \frac{1}{T_i\, S} + T_D s\right) \qquad (3.2)$$

where

K_P =Proportional gain

K_I =Integral gain

K_D =Derivative gain

$T_i =$ Integral time constant

$T_D =$ Derivative time constant

For optimal performance of a system the value of proportional gains, integral gains and derivative gains are mutually dependent in tuning.

Table 3.1. Effect of independent P, I, D Tuning

Closed Loop Performance	Rise Time	Overshoot	Settling Time	Steady State error	Stability
Increasing K_P	Decrease	Increase	Small Increase	Decrease	Degrade
Increasing K_I	Small Decrease	Increase	Increase	Large Decrease	Degrade
Increasing K_d	Small Decrease	Decrease	Decrease	Minor Change	Improve

Generally, derivative action is important as it provides useful phase lead action to offset phase lag condition caused by integrator. It is also particularly helpful in decreasing the period of the loop and there after fastening its recovery from disturbances. It has a most interesting effect on the behavior of plants having second order and that have very less dead-time than plants having first order [35].

The output of PID Controller is given to the saturation block. The saturation block imposes upper and lower limits on the input signal. When the input lies in the range specified by a lower limit and upper limit, then the output will be input. When the input is less than the lower limit the output is lower limit, but when the input is greater than upper limit the output is the upper limit value. When the lower and upper limits have same value the block output is that value. The output of saturation block is given to the PWM generator, which generates two complementary pulses which are given to switches.

3.3 PWM Generation Techniques

The AC/DC converters consist of power electronics devices like IGBT or GTO that are characterized by theirswitch mode operation. The capability of forming sinusoidal currents is provided by the introduction of the sophisticated technique called Pulse-Width Modulation (PWM). This technique provides the sequences of width-modulated pulses to control power switches [36]. There is a pulse of fixed amplitude in each PWM period.However, the duration of the pulses varies from pulse topulse according to a signal of modulation. When a PWM signal is being given to the gate of a power transistor, it causes on and off intervals of the transistor to change from one PWM interval to another PWM interval according to the same signal of modulation. The advantages of PWM based power converter are:

- Lower power dissipation
- Easy to implement and control
- No temperature variation- and aging-caused drifting or degradation in linearity [37].

Fig.3.2 shows block diagram representation of different PWM techniques used for stability of the wind energy output.

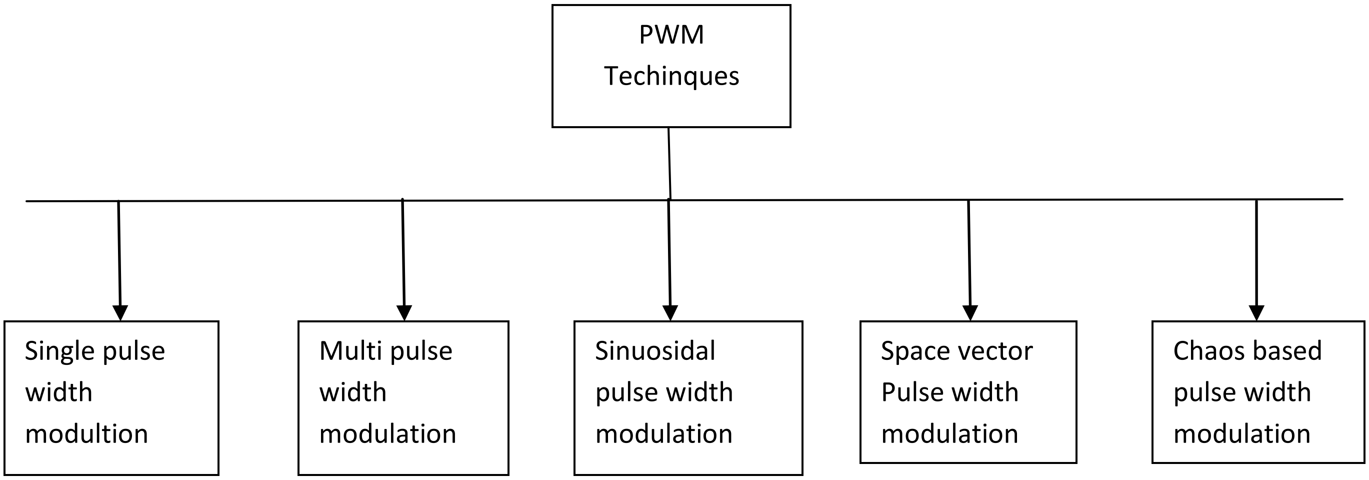


Fig.3.2 Different PWM Techniques

3.3.1 Sinusoidal Pulse Width Modulation

The control techniques which are based on the PWM solve the problem regarding the switching frequency of the VSI. They employ a fixed switching frequency which makes it easier method to reducing the switching harmonics.The most easy, well known PWM technique is the sinusoidal PWM. This technique uses a control device which gives us the voltage reference of the inverter from the difference between the measured current and its reference value. The reference voltage is then compared with a carrier triangular wave. The output of comparison givesus the switching function for the VSI [37]. The approach which determines the time period of such pulses is what which makes the difference between various PWM methods. For example, in SPWM Technique, which is an analog domain method, the time period of each pulse is found by comparison of a sinusoidal reference wave and a triangular carrier waveform as shown in Fig.3.3 When modulating index increases, the amplitude of the fundamental voltage increases proportionally causing harmonics to decrease. Under over modulation ($m > 1$), the fundamental voltage does not increase linearly but more harmonics appear in the output [38].

In sinusoidal PWM we generate PWM outputs by using sine waves as modulating signals. On comparing sine wave with triangular high frequency wave, the on and off instant of PWM signal can be found as shown in Fig. 3.3 The modulating wave frequency determines the frequency of the voltage output. The maximum amplitude of the modulating wave gives us the modulation index, which in turn controls the value of output voltage. In this technique distortion factor gets improved significantly as compared to other ways of multi-phase modulation technique. It vanishes all harmonics less than or equal to 2p-1, where "p" is defined as the number of pulses per half cycle of the sine wave [37].

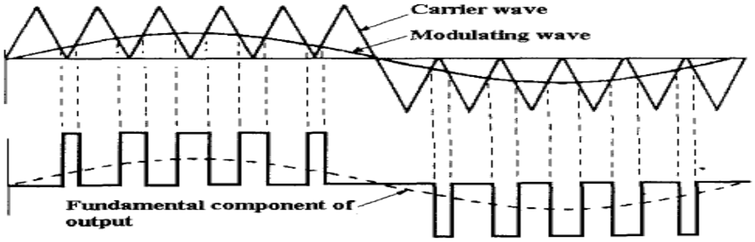


Fig.3.3 Principle of sinusoidal PWM method [37].

3.3.2 Space Vector PWM Control

3.3.2.1. Introduction

Space vector modulation technique was first introduced by German researchers in 1980s. This technique has shown several benefits over the traditional PWM technique and has been proven to be inherently generating superior PWM waveforms. The concept of space vector is obtained from the rotating field of AC machine which is used for modulation of the output voltage of the inverter. In this modulation technique the three phase quantities can be changed to their equivalent two phasequantity either in synchronously rotating frame (or) stationary frame. From these two-phase components, the reference vector is founded and it can be used for modulating the output of inverter [39]. The basic difference between SVM technique and PWM technique is that it treats the inverter as a whole unit, which is not the case when compared to PWM technique. This technique is based on the decaying of a reference vector of voltage into voltage vector dependable on a six pulse inverter [37].

3.3.2.2 Features of Space Vector PWM

1. It gives us the wide linear modulation range
2. It gives us the low base band harmonics than regular PWM or other sine based modulation methods
3. 15% more output voltage than conventional modulation, i.e. better DC-link utilization
4. More efficient use of DC supplies voltage
5. SVM increases the output capability of the inverter without distorting the line output voltage waveform
6. Advanced and computation intensive PWM technique
7. Higher efficiency
8. Prevent un-necessary switching hence less commutation losses
9. Waveform generation for all 3-φ can be achieved simultaneously, while in SPWM three different references for three phases should be compared with carrier wave
10. Online computation is possible by lookup table[39].

The SVPWM technique is commonly used in both inverter and rectifier controls. Compared to the sinusoidal pulse width modulation, SVPWM is more suited for digital implementation and can boost the obtained maximum output voltage with a maximum line voltage reaching 70.7% of the DC link voltage (compared to SPWM’s 61.2%). Moreover, it can give a better voltage total harmonic distortion factor. Different algorithms for utilizing SVPWM to modulate the inverter or rectifier. The aim in each modulation technique is to lower the switching losses, maximize the utilization of bus, reduce harmonic content in the output, and achieve precise control [40]. In SVPWM Technique, Let the three phase sinusoidal voltage component be,

$$Va = Vm \sin \omega t \qquad (3.3)$$

$$Vb = Vm \sin (\omega t - 2\pi/3) \qquad (3.4)$$

$$Vc = Vm \sin(\omega t - 4\pi/3) \qquad (3.5)$$

When this voltage is applied to the AC machine it produces a flux which is rotating in the air gap of the machine.The rotating flux component could be represented as a single rotating voltage vector. The magnitude and angle of therotating vector could be found by means of Clark’stransformation. The representation of rotating vector in the complex plane is shown in Fig.3.4

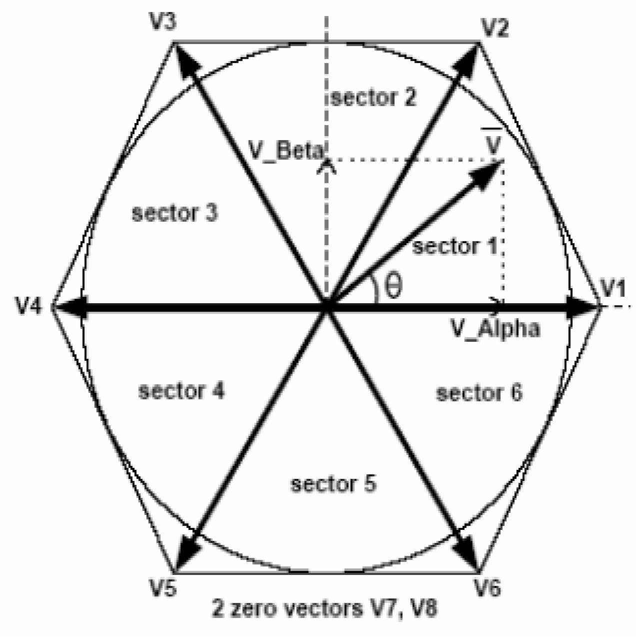


Fig. 3.4 Space vector Representation of Inverter output Voltage [37].

Space vector PWM implementation requires, voltage equations in the abc referenceframe to be transformed into the stationary dq reference frame that consists of thehorizontal (d) and vertical (q) axes as shown in Fig.3.5

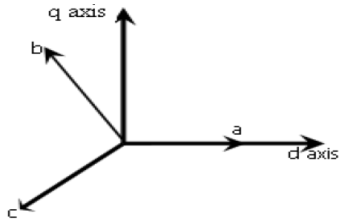


Fig.3.5 The relationship of abc reference frame and stationary dq reference frame

From Fig. 3.5 the relation between these two reference frames is below

$$\mathrm{f}_{\mathrm{dq}\,0} = \mathrm{k}_{\mathrm{s}}\mathrm{f}_{\mathrm{abc}} \qquad (3.6)$$

where

$$\mathrm{K}_s = 2/3\begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & -\sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix}$$

$$\mathrm{f}_{\mathrm{dq}\,0} = [\mathrm{f}_{\mathrm{d}} \quad \mathrm{f}_{\mathrm{q}} \quad \mathrm{f}_0]^{\mathrm{t}}$$

$$\mathrm{f}_{\mathrm{abc}} = [\mathrm{f}_{\mathrm{a}} \quad \mathrm{f}_{\mathrm{b}} \quad \mathrm{f}_{\mathrm{c}}]^{\mathrm{t}}$$

f =denotes either voltage or current variable

Six non-zero vectors $(V_1 - V_6)$ shape the axes of a hexagonal as depicted in Fig.3.4 and supplies power to the load. The two adjacent two non-zero vectors have an angle of 60 degrees. Meanwhile, two zero vectors ($V_{0,}V_7$) are at the origin and apply zero voltage to the load. The eight vectors are known as the basic space vectors and are givenby $V_0, V_1, V_2, V_{3,}V_4, V_5, V_6$ and V_7. The same transformation is applied to the desired output voltage to get the desired reference voltage vector, V_{ref} in the d-q plane [37].

3.3.2.3 Switching States

For 180° mode of operation, six switching states and additionally two more states are there. Of these eight states to be coded in binary (one-zero representation), three bits are required (2^3 =8) and also, as always upper and lower switches are turned off in complementary fashion, it is sufficient to represent the status of either upper or lower arm switches. Status of the upper bridge switches will be given and the lower switches will it's opposite. Let "1" denote the switch is ON and "0" denote the switch in OFF.

Let us assign each switching state as a vector in the complex plane:

V_0 = 000 (Q_1, Q_3 and Q_5 OFF and Q_2,Q_4 and Q_6 ON)
V_1 = 100 (Q_1 ONQ_3 and Q_5 OFF)
V_2 = 110 (Q_1 and Q_3 ON; Q_5 OFF)
V_3= 010 (Q_3 ON; Q_1 and Q_5OFF)
V_4 = 011 (Q_3 and Q_5 ON; Q_1 OFF)
V_5 = 001 (Q_5 ON; Q_1 and Q_3 OFF)
V_6= 101 (Q_1 and Q_5 ON; Q_3 OFF)
V_7 = 111 (Q_1, Q_3 and Q_5ON andQ_2,$Q_4$and Q_6 OFF)

Of these vectors, V_1 to V_6 are non-zero, while V_0 and V_7 are zero. Forecasting the images of these vectors (same magnitude and adjacent switching states will have 60 degree phase difference) on to the α-β plane will form six sectors and result in a hexagon as shown in Fig.3.4[42]. The magnitude of the six non-zero vectors are equal to $\sqrt{\frac{2}{3}}\, V_d$, where V_d is the amplitude of the DC voltage source of the inverter and factor $\sqrt{\frac{2}{3}}$ is due to the three-phase-to-two phase transformation [37].

The reference V_{ref} is rotating space-vector type of three-phase voltage. The estimation of V_{ref} In the α-β plane at any period will lie in the area of any one of the sectors.The time integral value of V_{ref} can be approximated by the sum of the products of the two vectors and their time widths.Starting from time t_0, V_{ref} moves to t_1 and an approximation for the time integral can then written as

$$\int_{t_0}^{t_1} V_{ref} = T_1 V_1 + T_2 V_2 \qquad (3.7)$$

Where T_1 and T_2 represent the time widths for vectors V_1 and V_2 respectively and the integration over the time interval t_0 to t_1 are the sampling period (much less than period corresponding to one sector). By regulatingT_1 and T_2, right hand side of this expression can be made close to left-hand side value. Thus, by keeping the inverter-switching mode as V_1 for a time period T_1 and V_2 for a time period T_2, the pulse pattern during the period t_0 to t_1 is found. The same approximation (by V_1 and V_2) is repeated for all samplings of this sector[42].

Table 3.2 Switching vector and their corresponding voltages:

Voltage Vector	Switching Vectors			Line to Neutral Voltage			Line to Line Voltage		
	A	B	C	V_{an}	V_{bn}	V_{cn}	V_{ab}	V_{bc}	V_0
V_0	0	0	0	0	0	0	0	0	0
V_1	1	0	0	2/3	-1/3	-1/3	1	0	-1
V_2	1	1	0	1/3	1/3	-2/3	0	1	-1
V_3	0	1	0	-1/3	2/3	-1/3	-1	1	0
V_4	0	1	1	-2/3	1/3	1/3	-1	0	1
V_5	0	0	1	-1/3	1/3	2/3	0	-1	1
V_6	1	0	1	1/3	-2/3	1/3	1	-1	0
V_7	1	1	1	0	0	0	0	0	0

3.3.3 Chaos-Based PWM Strategies

Traditional PWM composes of many harmonic components. The distribution of harmonics is influenced by the carrier. It was suggested that the chaotic behavior of DC–DC converters under certain parametric conditions can be used to reduce EMI in such a case chaos is very desirable. It is also known that due to the cluster harmonics around the multiples of carrier frequency in the output waves of the conventional PWM, it is difficult to control the electromagnetic interference (EMI). Therefore combining chaos theory with the PWM, a chaos-based pulse width modulation (CPWM), is proposed to distribute the harmonics of the DC–DC converters continuously and evenly over a wide frequency range. Consequently the EMI can be reduced. Furthermore the output waves and spectral properties of the EMI will be analyzed as the carrier changes with different chaotic maps [43]. Cluster harmonics around the multiples of switching frequency are present in conventional SPWM and SVPWM output waves due to their fixed switching frequencies. Chaos-based PWM strategies employing a chaotic changing switching frequency to widen the harmonics continuously to a large area so that the peak harmonics can be reduced greatly. This is an effective way to decrease the harmonic and reduce ripple current and torque in induction motor drives [44].

3.3.3.1 Chaotic Sequences

Consider a simple one-dimensional Tent map

$$x_{n+1} = 1 - 2|x_n - .5| \tag{3.20}$$

$$= \begin{cases} 2x_n & 0 \le x_n \le .5 \\ 2 - 2x_n & 0.5 \le x_n \le 1 \end{cases} \tag{3.21}$$

The tent map is simple function capable of chaotic motion. It is highly dependent on initial value x_0. Where x_0 is a proper fraction.

1. If x_0 is a rational number, and its denomintor has the form 2m, then after no more than m+1iterations the sequences end with 0, otherwise after finite iterations the sequences return to themselves and so generates an orbit which is eventually repeating periodically.
2. If x_0 is an irrational, the orbit never ends with 0 and never with cycles. The iteration of the tent map exhibits chaotic behavior

A periodic orbit of a map has been defined here to have period t if the orbit successively cycles through t distinct points. Then, all fractions which have the form2d/5^c create a periodic 2×5^{c-1} orbit Gc of map , where both c and d are positive integers. Multiplied all numbers in Gc by $5^c \times 2$ results in a set of positive integers Hc. Rewriting map as follows:

$$x_{n+1} = \frac{5^c}{2} - |2x_n - .5| \tag{3.22}$$

$$= \begin{cases} 2x_n & 0 \le x_n \le .25 \times 5^c \\ 5^c - 2x_n & 0.25 \times 5^c \le x_n \le .5 \times 5^c \end{cases} \tag{3.23}$$

where n = 0,1,2,--nbelongs to[1,0.5(5^c−1)].when x_0 not a multiple of 5, iteration may create a periodic 2×5^{c-1} orbith_c. Fig.3.6 shows Positive integer sequences of uniform distribution deriving from Eq. (4.2), c=6.

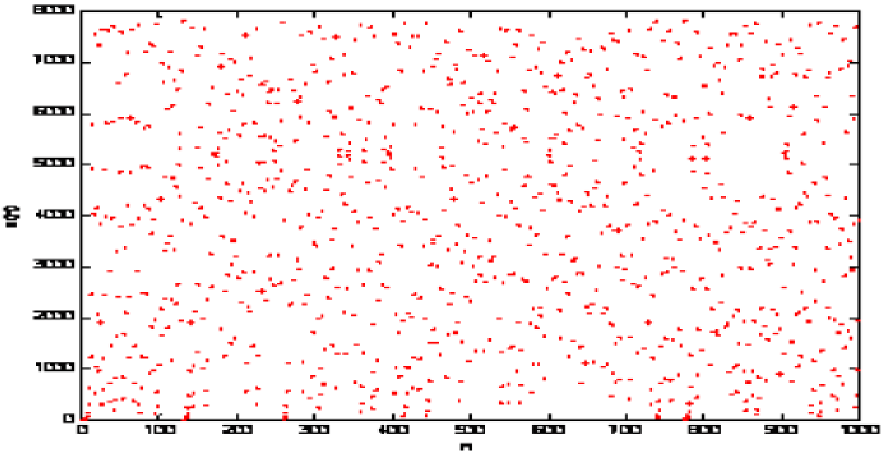


Fig.3.6 Positive integer sequences of uniform distribution deriving from Eq. (3.23),c=6

The arbitrary periodic orbit can be obtained by using different value of c. One of the positive integer sequences generated by iteration equation corresponds to c=6 as shown in Fig. 3.6 [44]. Chaotic sequences are generated deterministically from the dynamical system

$$x_{n+1} = f(x_n) \qquad (3.24)$$

where

f is a smooth function on R^m.

This implies that if you create two orbits with the identical initial data x_0, then the orbits are the same. A bounded sequence of values $\{x_i\}$ where i=1 to infinity coming from is chaotic if

1. $\{x_i\}$ is not asymptotically periodic
2. No Lyapunov exponent vanishes
3. The largest Lyapunov exponent is strictly positive

3.3.3.2 IMPLEMENTATION OF CHAOTIC SEQUENCE

The Chua’s circuit can produce continuous chaotic output with the proper selection of circuit parameters due to its negative resistance. A digital control system shown in Fig.3.7 has been designed for sampling the analog output voltage of the Chua’s circuit and stores the discrete sampled sequence in a unitized form. According to the research, the discrete sequence obtained is still chaotic inheriting the stochastic nature of the original chaotic system. Fig.3.7 shows hardware system used to sample chaotic sequence

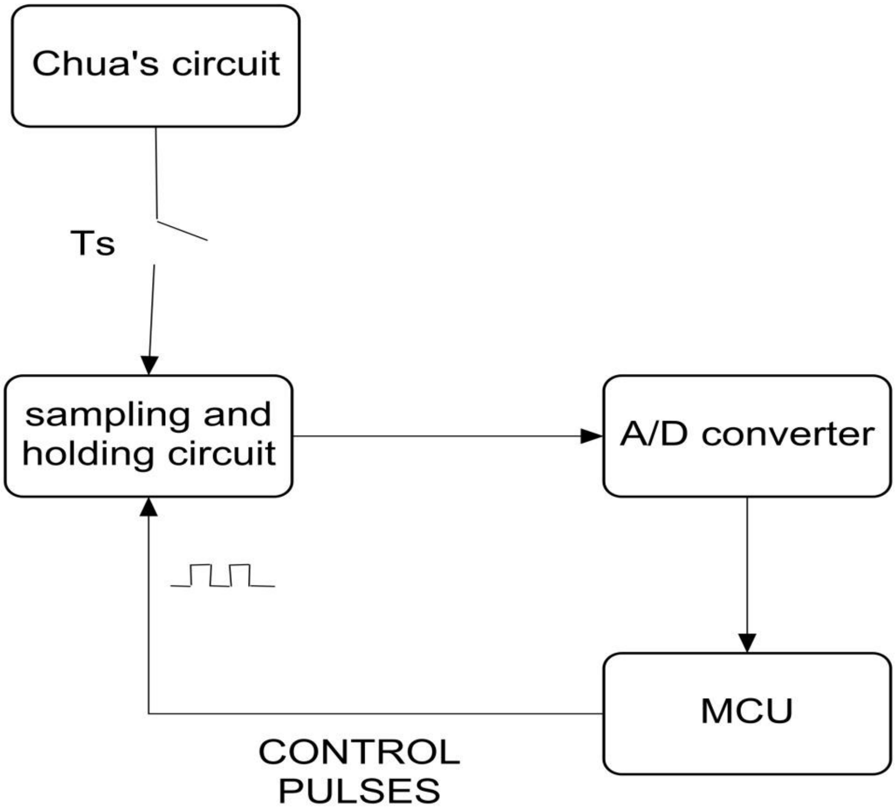


Fig.3.7 Hardware system used to sample chaotic sequence [45].

3.3.3.3 CHAOS-BASED PWM GENERATION

The basic principle of chaos-based PWM is to use a chaotic signal to vary the switching (or carrier) frequency:

$$f_n = f_{low} + (f_{high} - f_{low} + 1)\frac{x_n}{0.5(5^c - 1)} \tag{3.25}$$

Where f_n is the switching frequency of chaotic PWM, Chaotic sequence x_n can be generated simply by iterations, thus switching frequency may be varied from f_{low} to f_{high}. Chaos-based PWM strategies utilized chaotic changing switching frequency to spread the harmonics continually to a large area so that the peak harmonics can be reduced greatly [44].

3.3.3.4 Chaos-based PWM Generator

Chaos based PWM generator is shown in Fig.3.8. Chaos based PWM generates the chaotic sequence and this chaotic sequence is applied to a frequency modulator whose other input is a base carrier frequencywhich then produces output, which is fed as input to the comparter whose other input is reference sine voltage wave which then produces chaos based PWM waves. The chaotic sequence generator is being implemented by using a lookup table present in the ROM of DSP,whose contents have been produced in an offline manner. If the quantity numbers are large enough, thus there will be no effect on the resulting current spectrum. As seen from the Fig.3.8 the chaotic modulation is a very simple addition to an existing sine-triangle modulation.

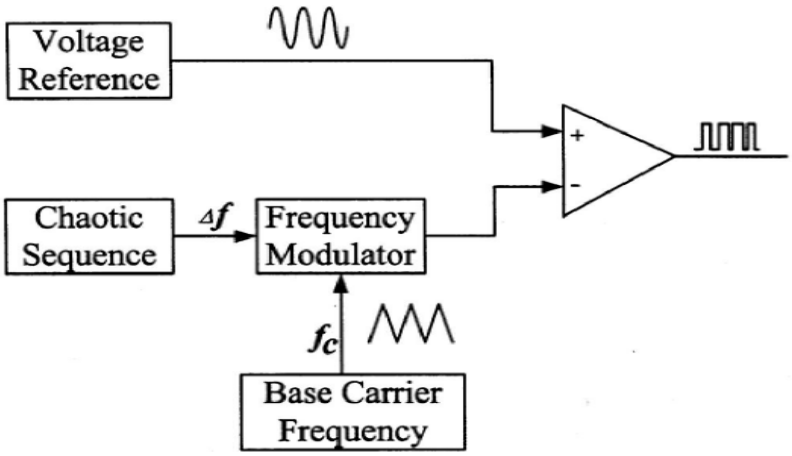
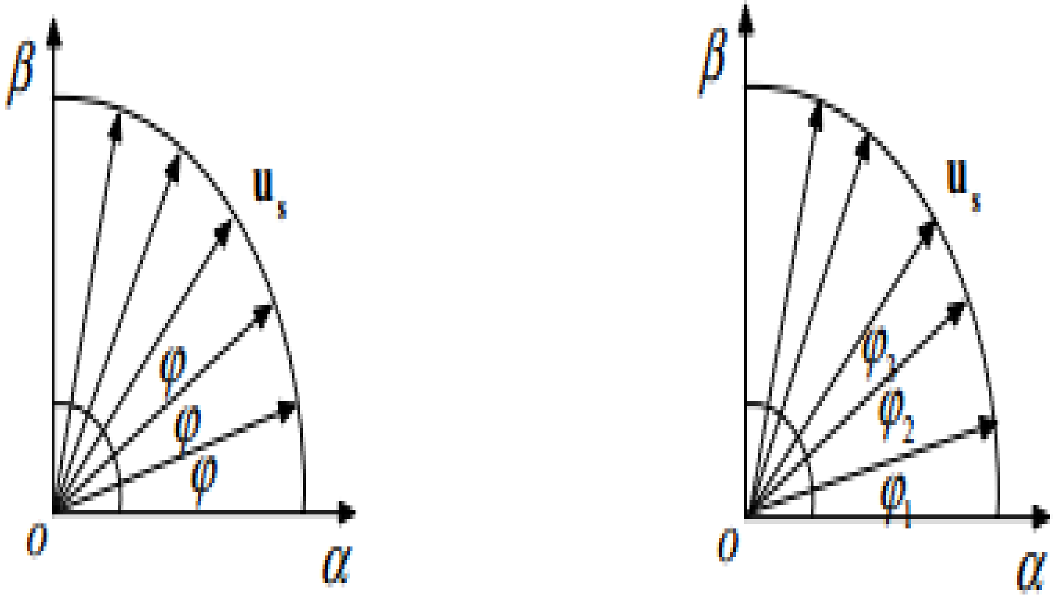


Fig.3.8 Chaos based PWM generator [45].

3.3.3.5 Chaos-based SVPWM

Conventional SVPWM uses fixed switching frequencies $f_s = 1/T_s$, while CSVPWM strategies utilize a chaotic changing switching frequency. Their switching frequencies are varied each cycle. Comparison between the sample intervals of conventional SVPWM and Chaos-based SVPWM can be seen in Fig.3.9.



Conventional SVPWM

Chaos based SVPWM

Fig. 3.9 Comparison between the sample intervals of SVPWM andCSVPWM [44].

Chapter-4

Result and Discussion

4.1 Introduction

The chapters that have been discussed so far provide us the complete knowledge of Wind Energy Conversion System, problem of voltage stabilization associated with it and its solution using MPFC. MPFC controller employ dynamic tri-loop error controller using PWM, SVPWM, Chaos Based SVPWM Techniques which have been simulated in the MATLAB / SIMULINK software and results have been obtained which are given below. The Complete Simulink Models are shown in the Appendix B.

4.2 Results

Case1. Waveforms of different voltages and currentswithout using controller

Fig.4.1 shows variation of voltage v/s time obtained on the load end side of the system.and Fig.4.2 shows variation of current v/s time waveform obtained on load end side of the system

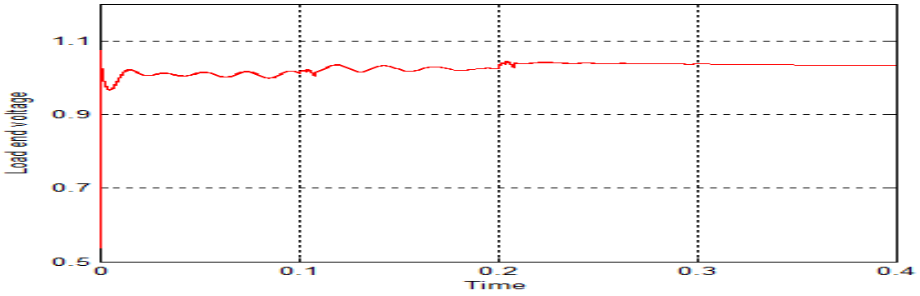


Fig.4.1 Variation of voltage v/s time obtained on the load end side of the system

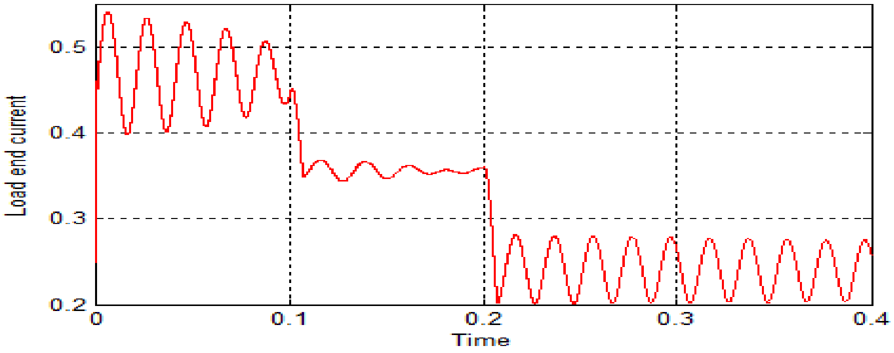


Fig.4.2 Variation of current v/s time waveform on load end side of the system

Fig.4.3 shows variation of voltage v/s time obtained on sending end side of the system and similarly Fig.4.4 shows variation of current v/s time obtained on sending end side of the system

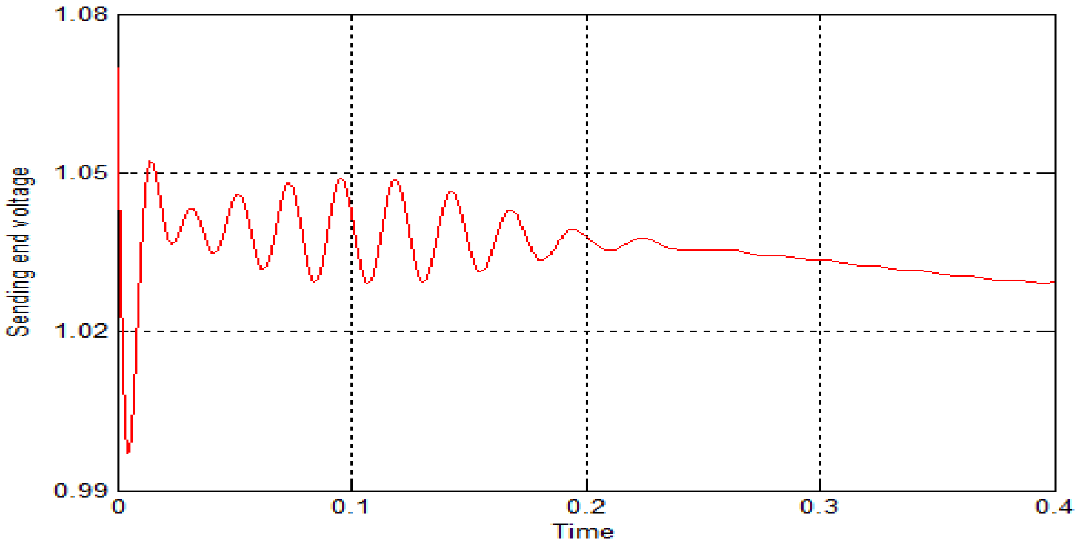


Fig.4.3 Variation of voltage v/s time waveforon sending end side of the system

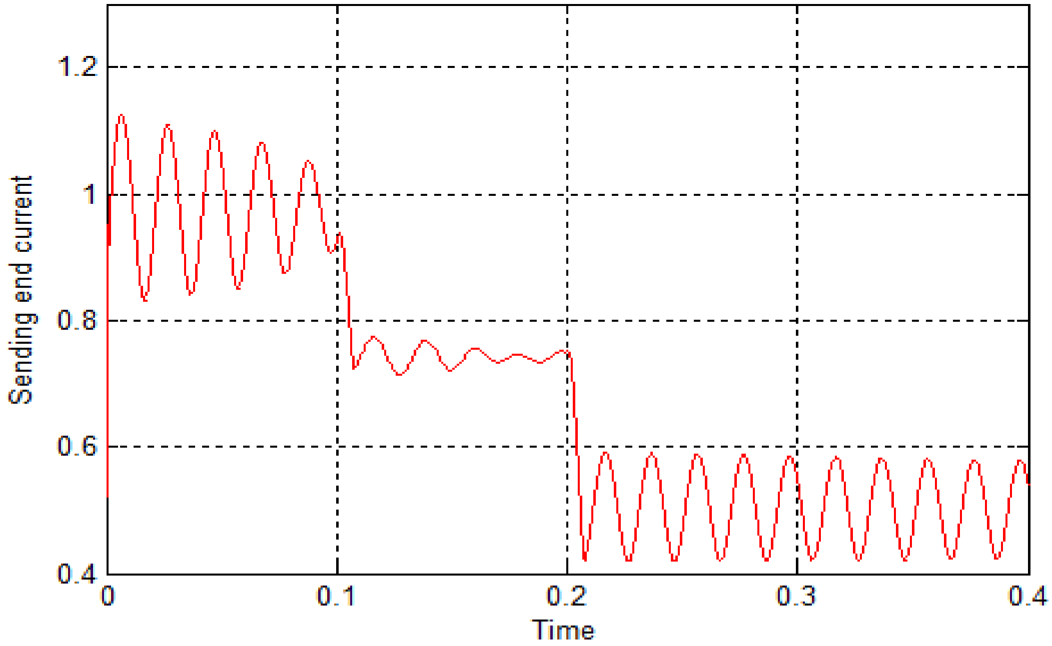


Fig.4.4 Variation of current v/s time waveform on sending end side of the system

Case2.Waveforms of different voltages and currents using MPFC controller employing PWM technique

Fig.4.5 shows variation of voltage v/s time obtained on the load end side of the system and Fig.4.6 shows variation of current v/s time obtained on the load end side of the system and it is observed that voltage gets increased as compared to the system without controller but there exist harmonics in the load voltage and load current output

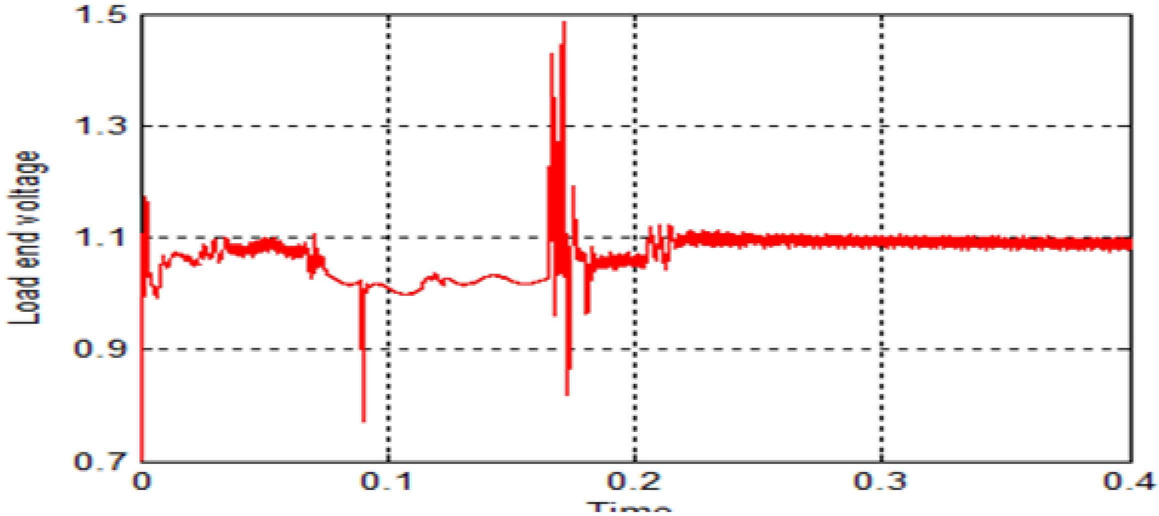


Fig.4.5 Variation of voltage v/s time waveformon load end side of the system

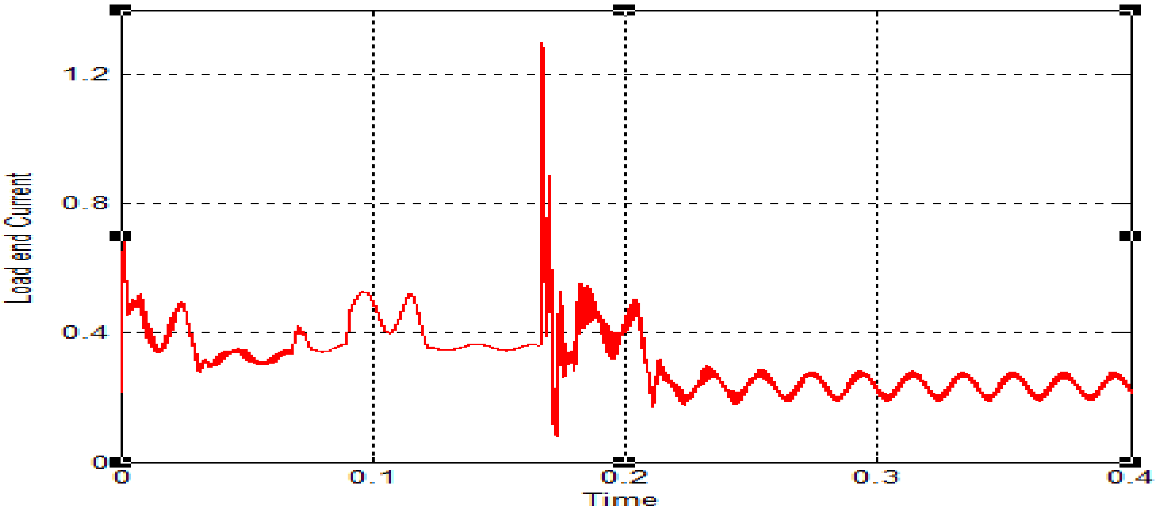


Fig.4.6 Variation of current v/s time waveform on load end side of the system

Fig.4.7 shows variation of voltage v/s time obtained on sending end side of the system and similarly Fig.4.8 shows variation of current v/s time obtained on sending end side of the system and it is found that sending end current contain harmonics though it value gets decreased as compared to system without controller

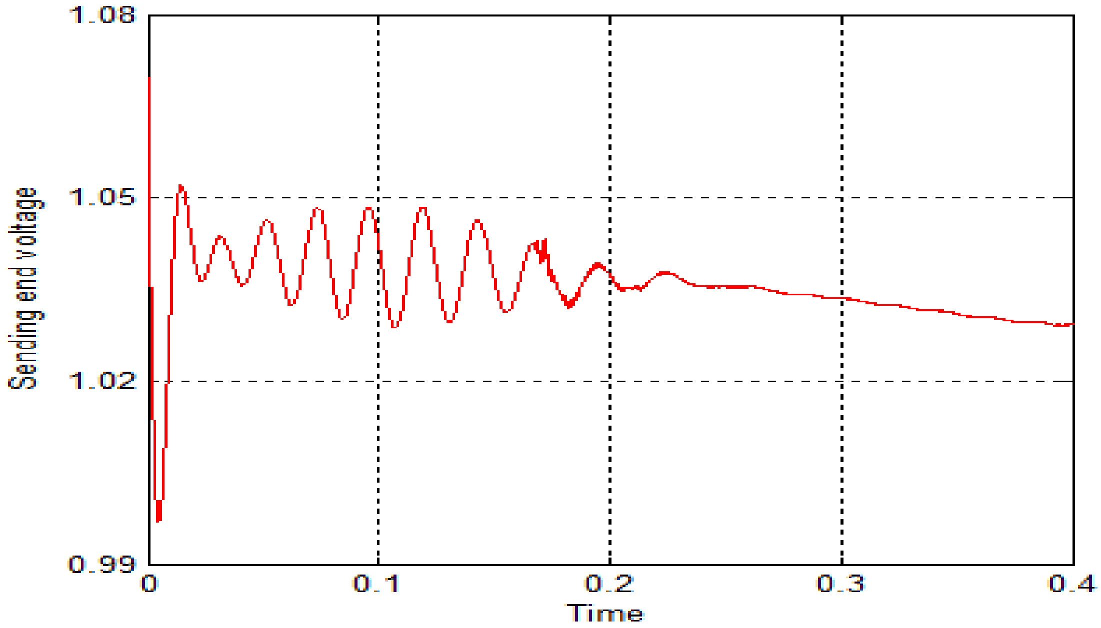


Fig.4.7 Variation of voltage v/s time waveformon sending end side of the system

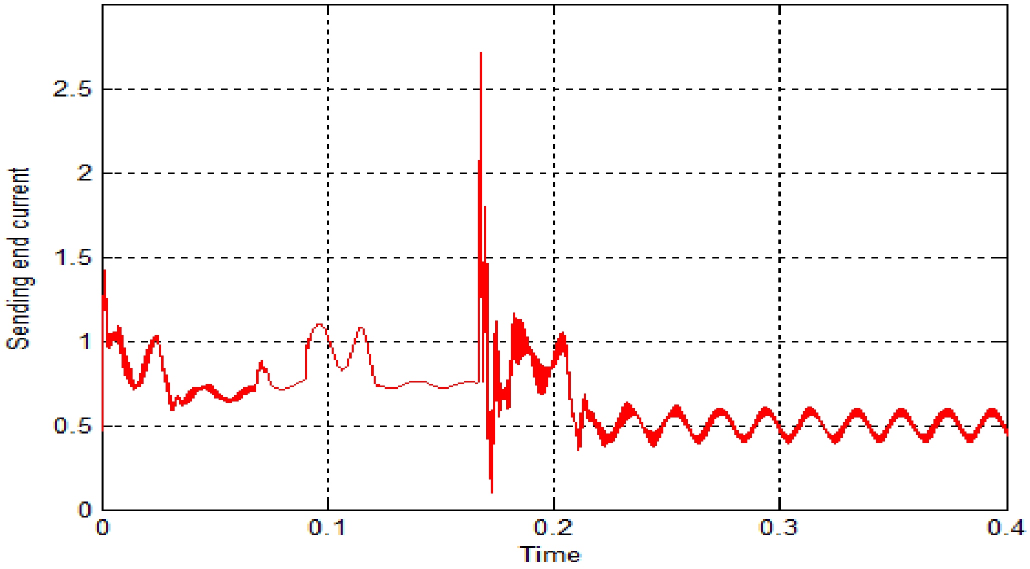


Fig.4.8 Variation of current v/s time waveform on sending end side of the system

Case3.Waveforms of different voltages and currents using MPFC controller employing SVPWM technique

Fig.4.9 shows variation of voltage v/s time obtained on load end side of the system and Fig.4.10 shows variation of current v/s time obtained on load end side of the system and it is observed harmonic contents in the load voltage and load current output gets reduced as compared to the system with PWM based MPFC controller.

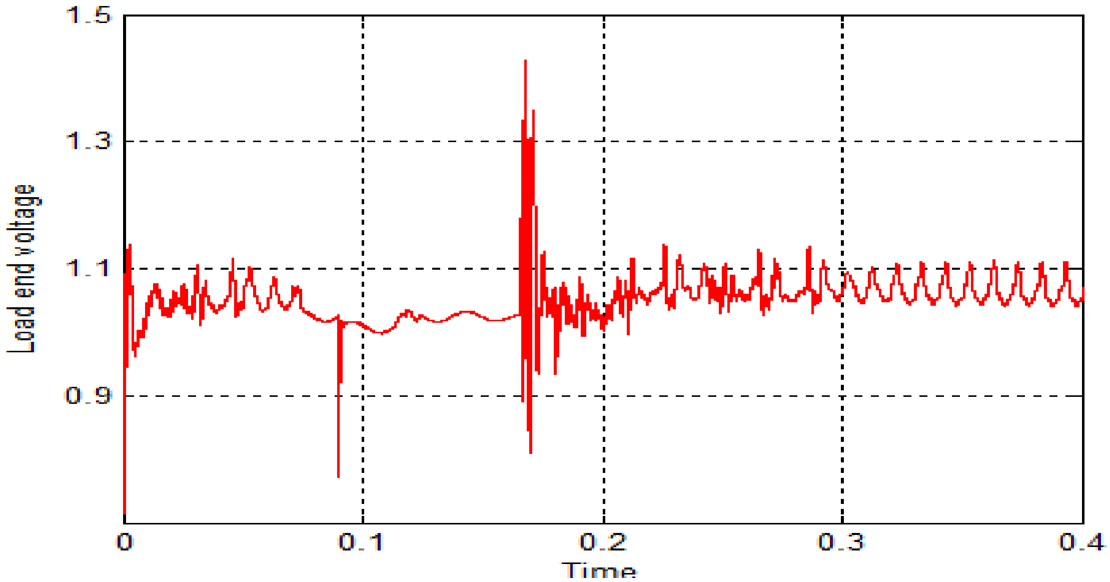


Fig.4.9 Variation of voltage v/s time waveform obtainedon load end side of the system

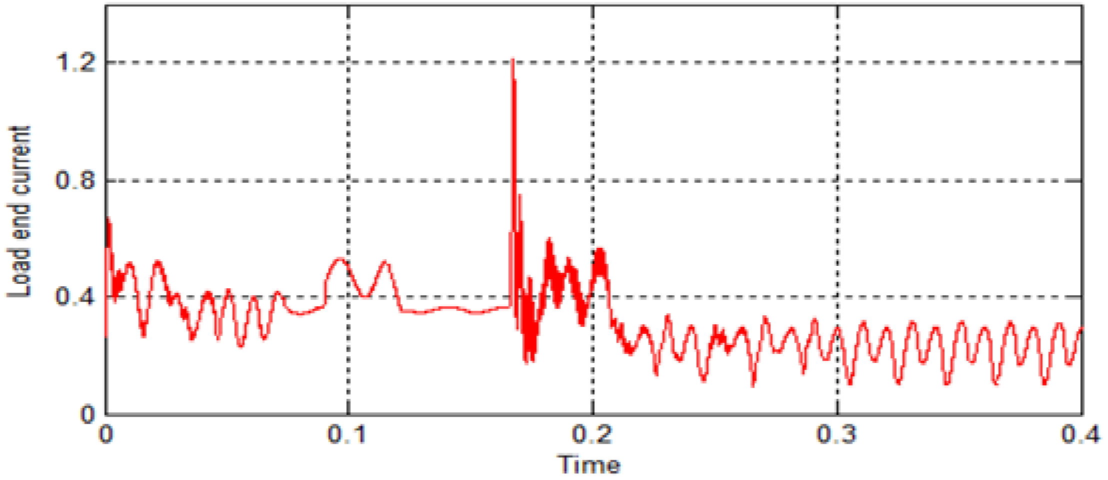


Fig.4.10 Variation of current v/s time waveformobtainedon load end side of the system

Fig.4.11 shows variation of voltage v/s time obtained on sending end side of the system and similarly Fig.4.12 shows variation of current v/s time obtained on sending end side of system and it is found that the harmonics content in the sending end current gets reduced as compared to PWM based controller.

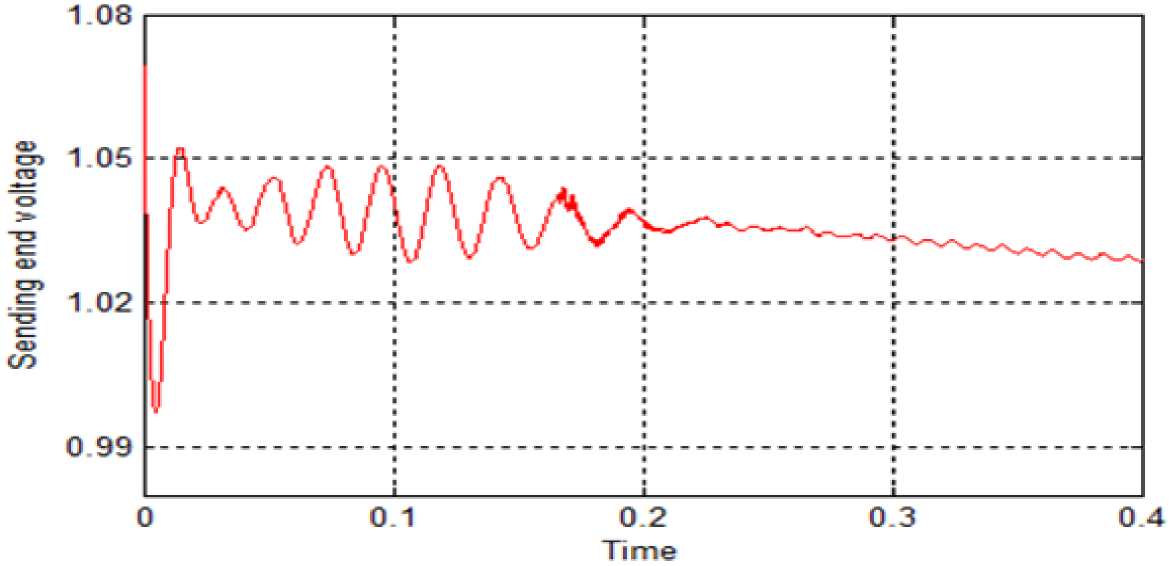


Fig.4.11 Variation of voltage v/s time waveformon sending end side of the system

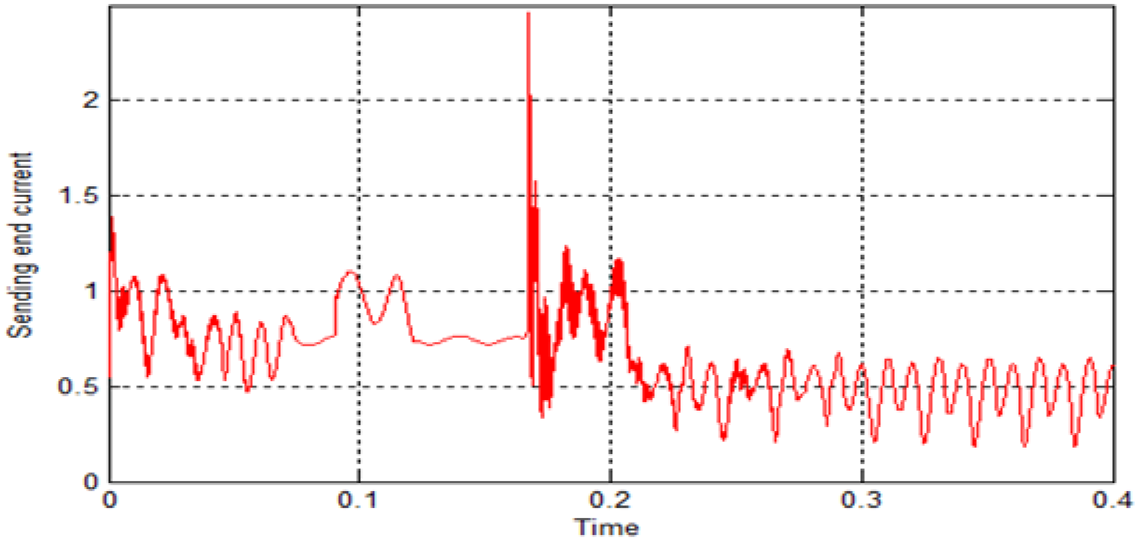


Fig.4.12 Variation of current v/s time waveform on sending end side of the system

Case 4.Waveforms of different voltages and currents using MPFC controller employing Chaos based SVPWM technique

Fig.4.13 shows variation of voltage v/s time obtained on load end side of the system and Fig.4.14 shows variation of current v/s time obtained on load end side of the system and it is observed that harmonic contents in the load voltage and load current output gets reduced as compared to the system with PWM based controller and SVPWM based controller.

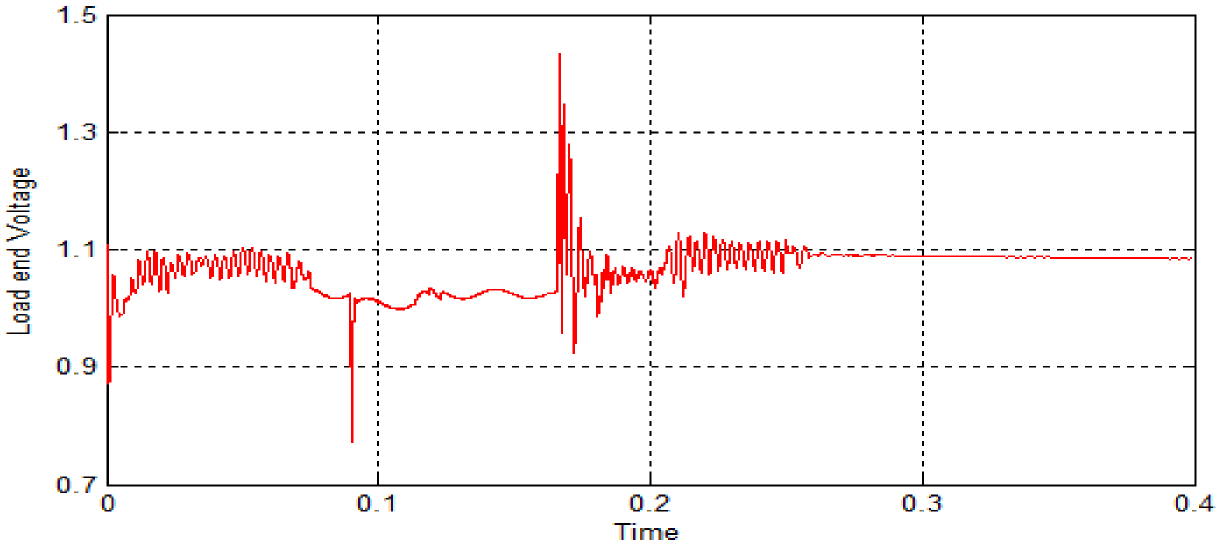


Fig.4.13 Variation of voltage v/s time waveformon load end side of the system

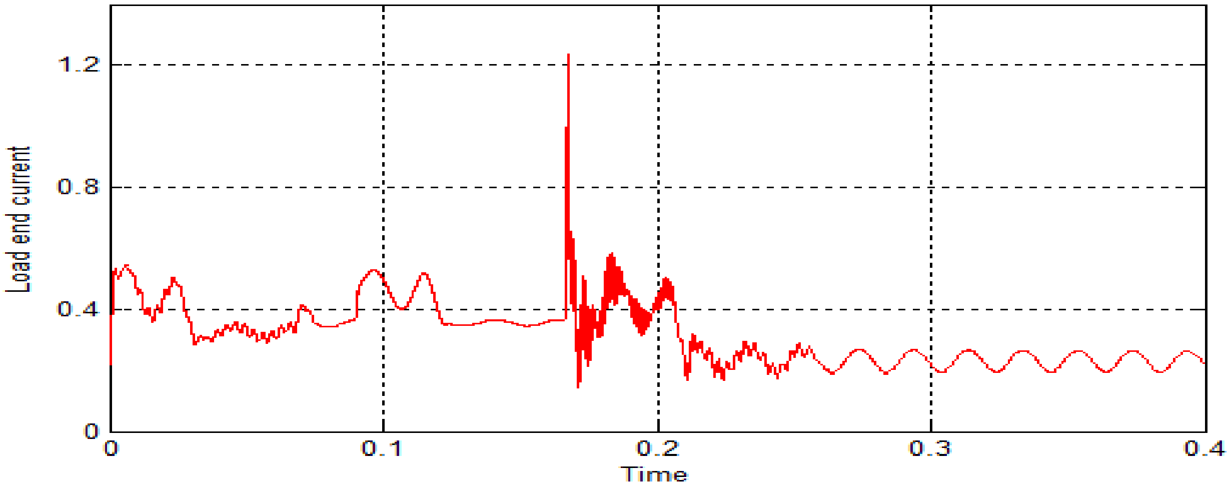


Fig.4.14 Variation of current v/s time waveform on load end side of the system

Fig.4.15 shows variation of voltage v/s time obtained on sending end side of the system and similarly Fig.4.16 shows variation of current v/s time obtained on sending end side of the system and it is found that the harmonics content in sending end current decreases as compared to both PWM based Controller and SVPWM based controller.

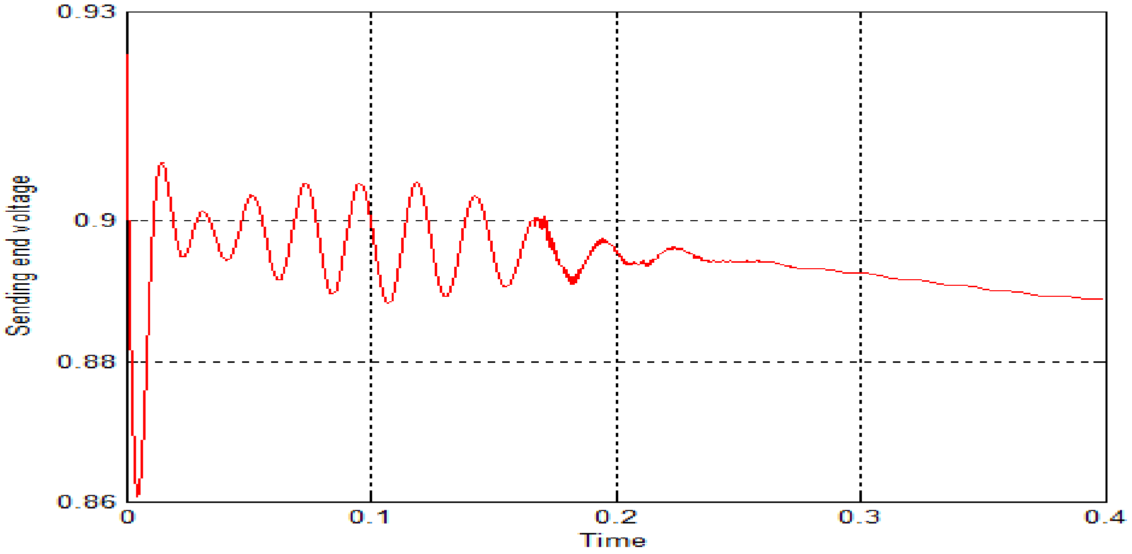


Fig.4.15 Variation of voltage v/s time waveformon sending end side of the system

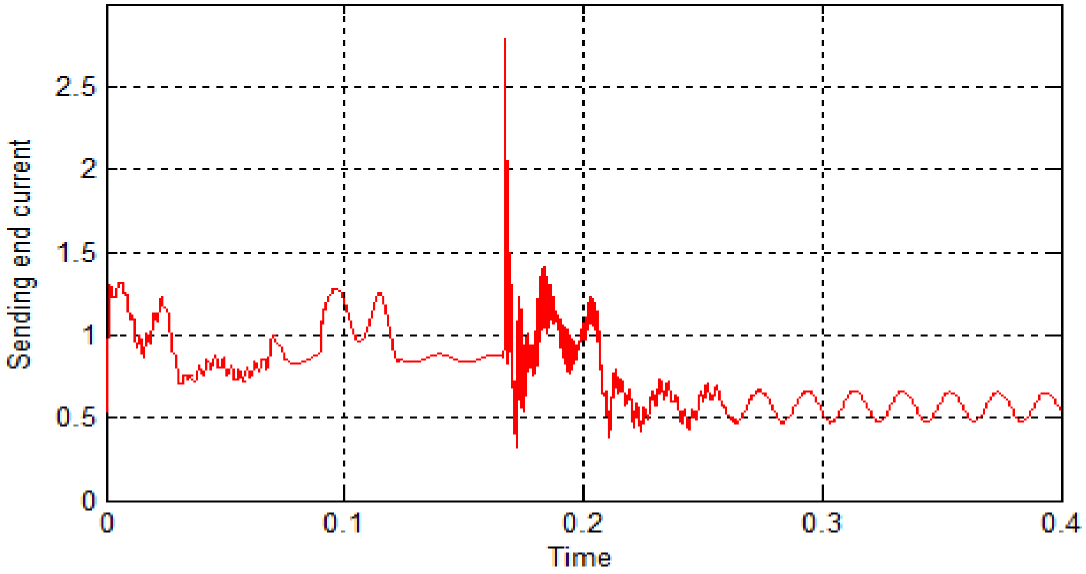


Fig.4.16 Variation of current v/s time waveform on sending end side of the system

4.3 Discussion

Load voltage obtained without controller, that is, in case 1 has low value as compared to the load voltages obtained with the PWM based controller, SVPWM based controller and Chaos based SVPWM controller .Load voltage obtained in the case 2 consists of harmonics, but in case of SVPWM, that is, in case 3, load voltage consist of small amount of harmonics as compared to PWM based Conroller, whereas the harmonic content in a load voltage using Chaos based SVPWM is small as compared to both PWM based controller as well as SVPWM based controller.

Table 4.1 Results obtained with different controllersused

S.No.	Controller With Different PWM Techniques Used	Voltage on load end side	Harmonics contents in the output
1.	Without Controller	Small	Very Small
2.	PWM based Controller	Increased	Large
3.	SVPWM based Controller	Increased	Small as compared to PWM Controller.
4.	Chaos Based SVPWM Controller	Increased	Small as compared to PWM and SVPWM Controller.

Chapter-5

Conclusion and Scope for Future Work

5.1 Conclusion

Voltage stabilization problem of a wind energy system is dependent on changing wind conditions and varying electric load conditions.Problem of voltage stabilization in WECS can be solved using MPFC controller.MPFC controller used has an advantage of stabilizing the wind energy output against varying wind and load conditions. MPFC controller is used in system which consists of both linear and non linear load excursions.MPFC controller employs different PWM techniques for the switching of IGBT switches.PWM techniques used have an advantage of lowering the harmonic contents in the output. The results of different PWM techniques used in MPFC controller are compared and it is found that Chaos based SVPWM MPFC controller is effective in stabilizing the wind energy output as compared to the other PWM techniques based MPFC controllers.

5.2 Scope for future work

Scope of work after implementing different PWM techniques in MPFC controller is summarized as:

1. Since inbuilt blocks for PWM generator and SVPWM generator are used in Simulink model, their mathematical modeling can be done in the near future.
2. PWM techniques used in MPFC controller can be hybridized.

APPENDIX

Appendix-A

Data for various components used in the Matlab Simulink model of Fig.4.18 are as follows:

System per unit base: $\mathrm{S_B} = 3.6\mathrm{MVA}$

$V_B = 11\mathrm{KV/25KV/600V}$

(Generation/Transmission/Load end)

Induction Generator Parameters: $\mathrm{S_G} = 3.6\mathrm{MVA}$

$V_G = 11KV$

Stator: $\mathrm{R}_s = 0.016\ \mathrm{puLI}_s = 0.06\ \mathrm{pu}$

Rotor: $\mathrm{R}'_{\mathrm{r}} = 0.015\ \mathrm{puLI}'_{\mathrm{r}} = 0.06\ \mathrm{pu}$

Transformer Parameters:

a) 11KV/25KV (L-L) Transformer (T1)

Generation side: 11KV/3.6MVA, R=. 002 Pu L=. 08 Pu

Load side: 25KV/3.6MVA, R=. 002 Pu L=. 08 Pu

b) 25KV/600V (L-L) Transformer (T2)

Generation side: 25KV/3.6MVA R=. 002 Pu L=. 08 Pu

Load side: 600V/3.6MVA R=. 002 Pu L=. 08 Pu

Transmission Line/Feeder: Length: 10km

Positive Sequence parameters: R_1 =0. 01273ohms/km

$\mathrm{L}_1 =.93373\mathrm{e}-3\ \mathrm{H/km}$, C_1 =12. 74e-9 F/km

MPFCs power filter: Filter capacitor bank:$\mathrm{C_f}$=1.7 mF/phase

Filter inductance:$\mathrm{L_f}$=30mH

Filter resistance:$\mathrm{R_f} =.25\mathrm{ohms}$

Tri loop error driven PID Controller:$\gamma_v = \gamma_i = 1, \gamma_p = .5$,PID Controller Gains :$K_P = 0.5, K_i = .05, K_d = .01$

Load sequence excursions:

From 0s to 0.2s: linear load 200KVA (50%)

Non linear load 200KVA (50%)

From 0.2s to 0.5s: linear load 200 KVA (50%)

Appendix-B

Simulation diagram of system

Case1.Without Controller: -Fig.4.17 shows a complete Simulink model of the system without using a controller.

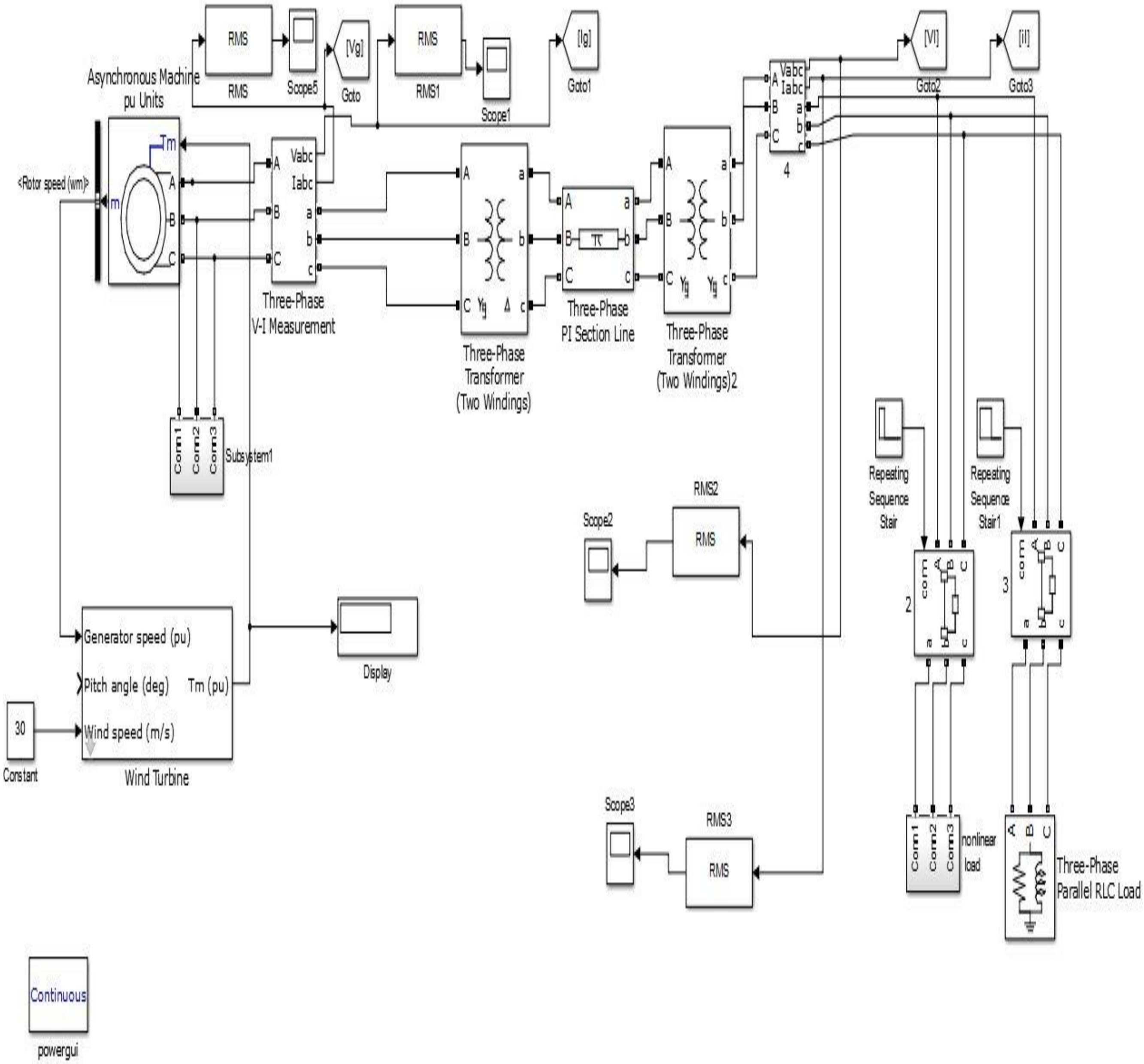


Fig.4.17 Complete Simulink model of the system without using a controller

Case2. With Controller: - Fig.4.18 shows Complete Simulink model of the system using a controller

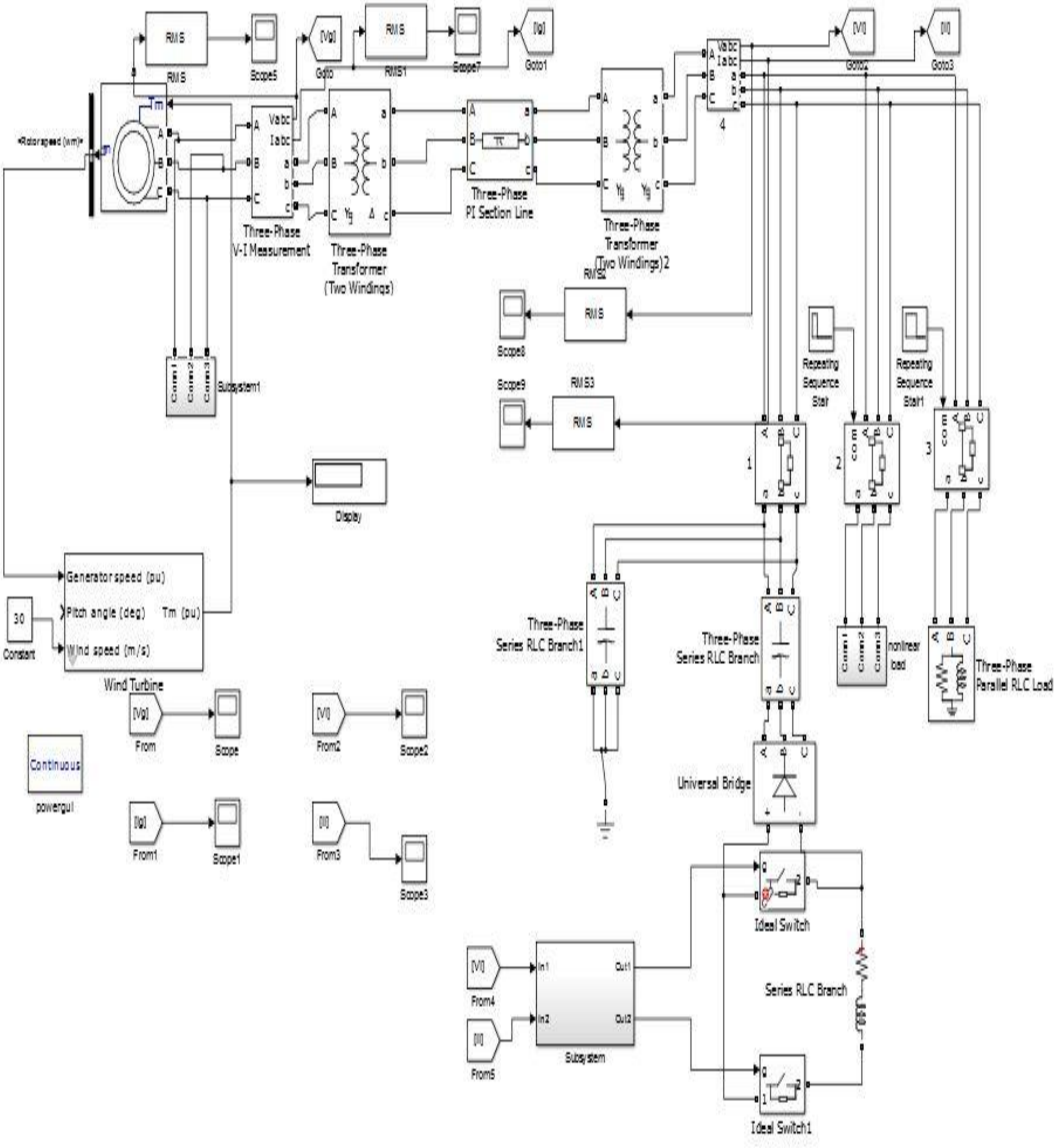


Fig.4.18 Complete Simulink model of the system using a controller

Case3. Subsystem: -Case a).Fig.4.19 shows subsystem for Simulink model of the system usinga PWM based MPFC controller

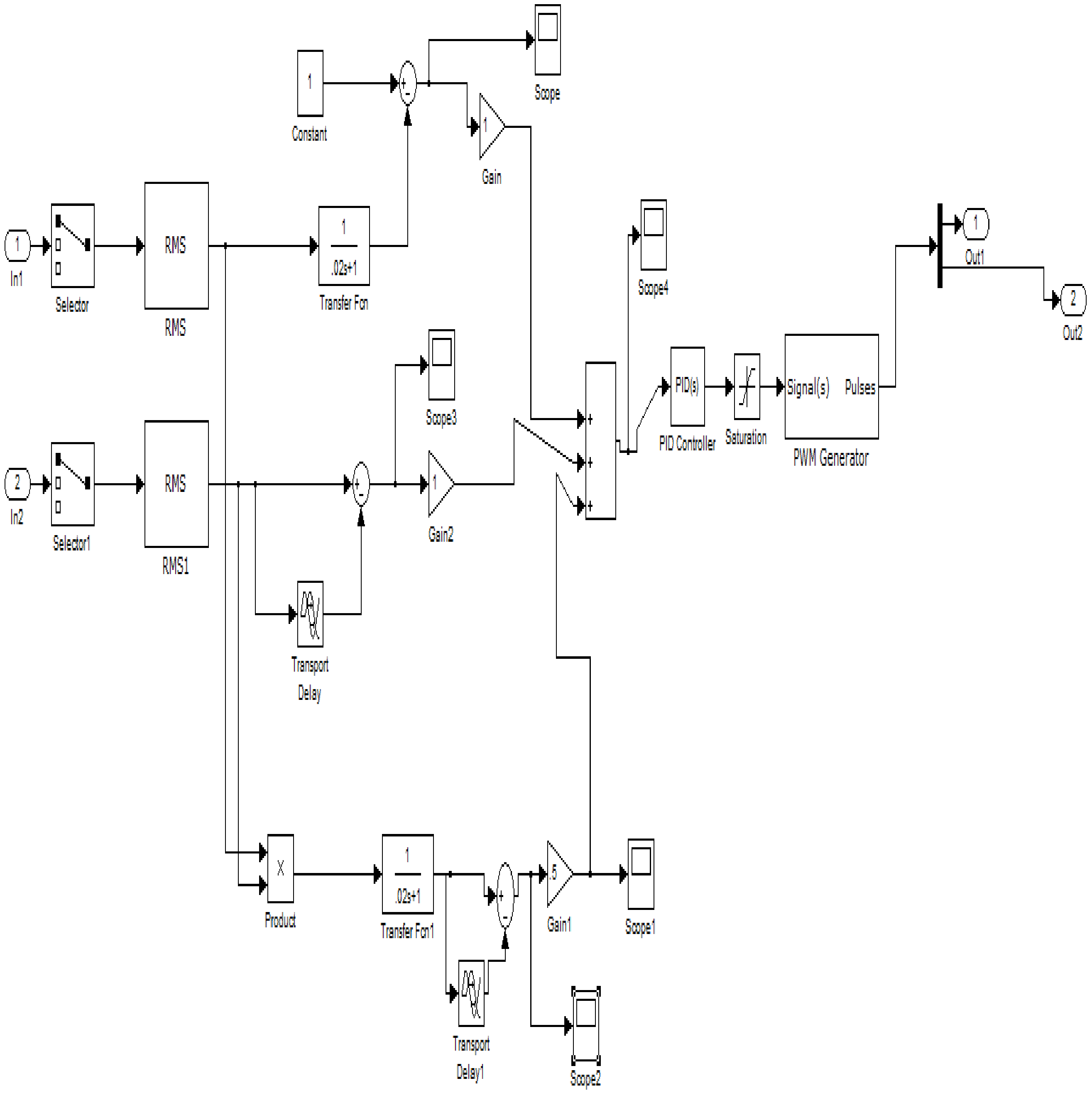


Fig.4.19 Subsystem for Simulink model of the system using a PWM based MPFC controller.

Case b).Fig.4.20 shows subsystem for Simulink model of the system using SVPWM based MPFC controller

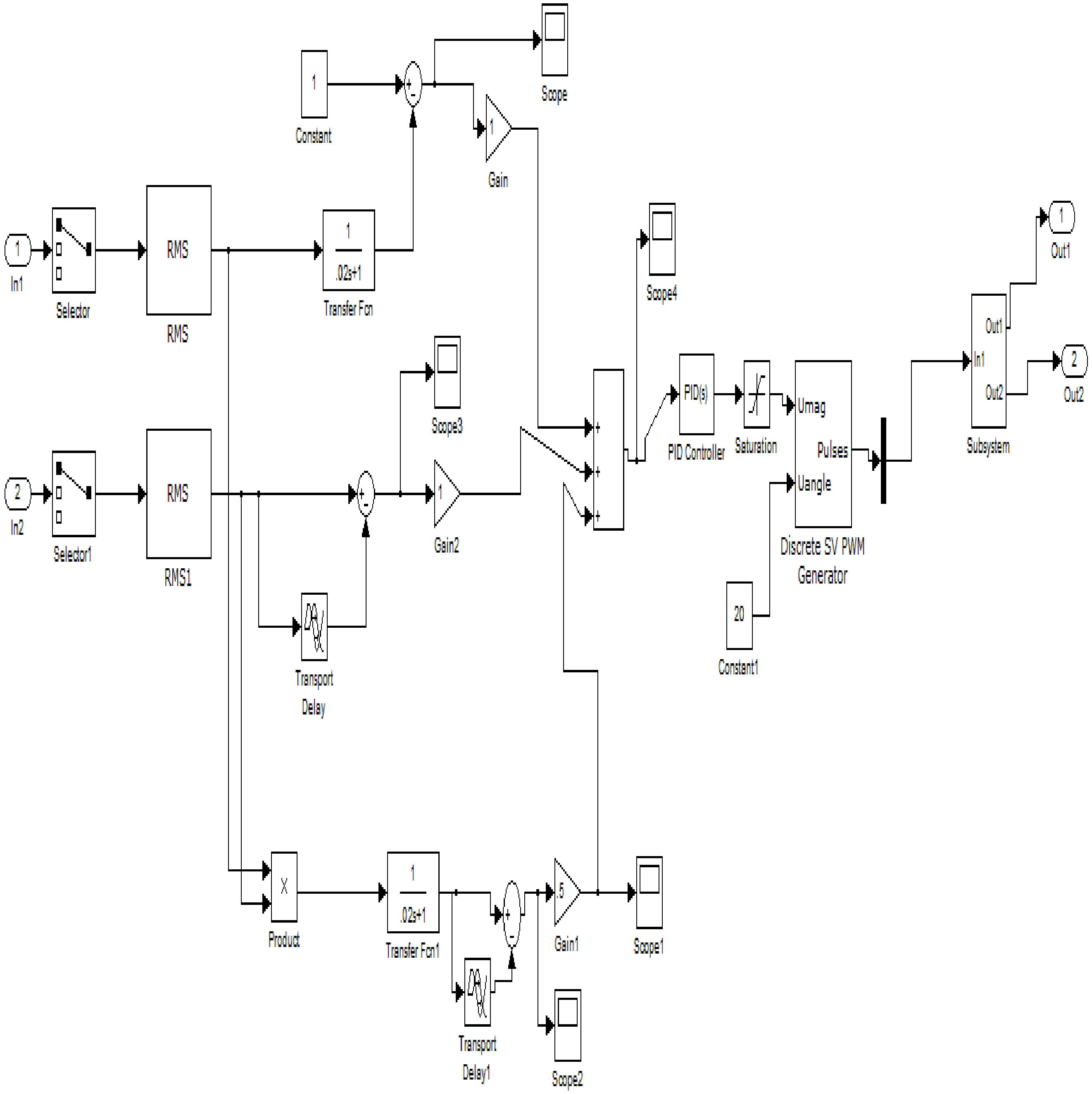


Fig.4.20 Subsystem for Simulink model of the system using SVPWM based MPFC controller

Case c). Fig.4.21 shows subsystem for Simulink model of the system using Chaos based SVPWM MPFC controller.

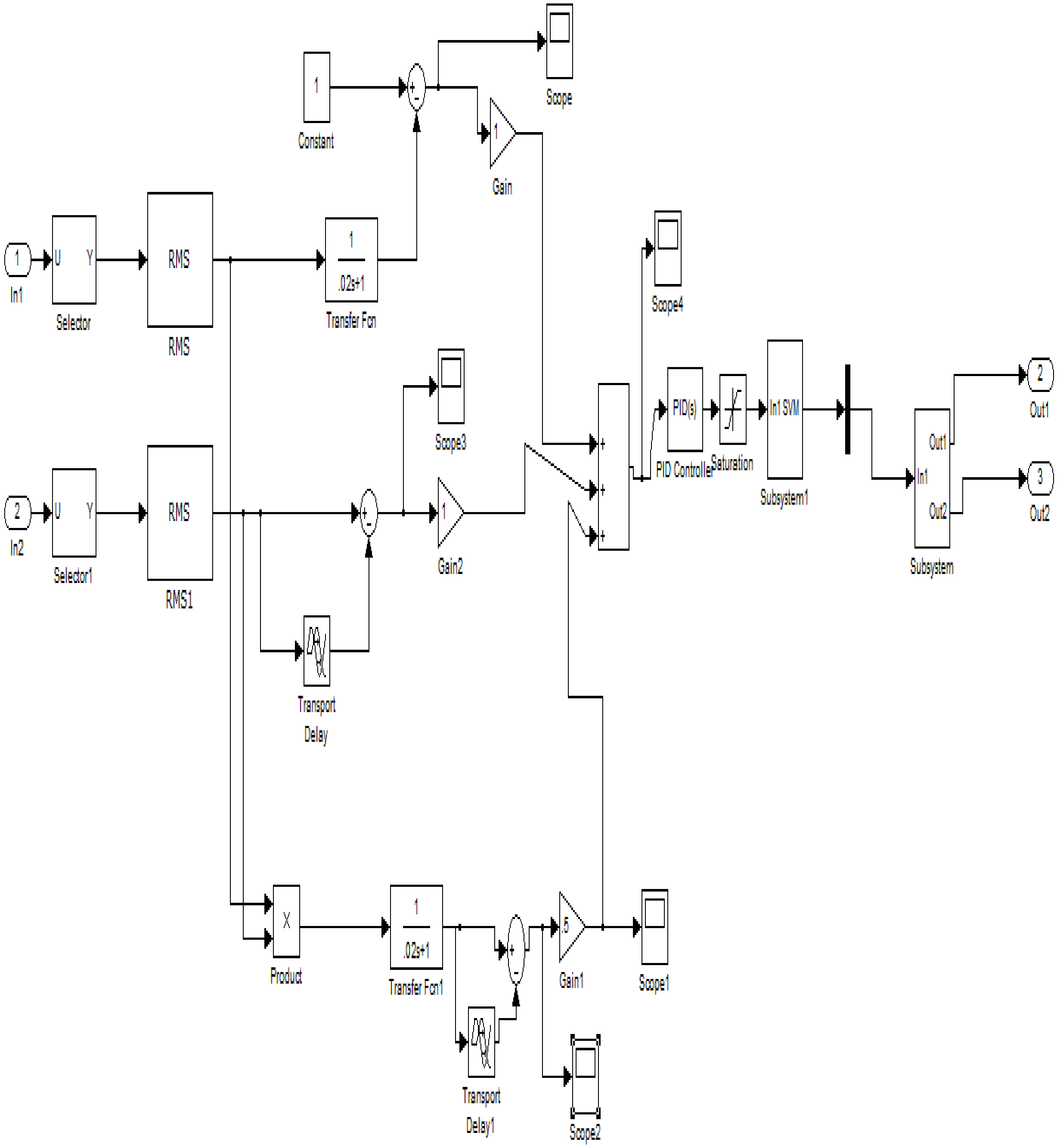


Fig.4.21 Subsystem for Simulink model of the system using Chaos based SVPWM MPFC controller

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