

**UNIVERSITY OF GAZIANTEP
GRADUATE SCHOOL OF
NATURAL & APPLIED SCIENCES**

**TRANSIENT STABILITY IMPROVEMENT IN MULTI-MACHINE
SYSTEM USING POWER SYSTEM STABILIZER (PSS) AND
STATIC VAR COMPENSATOR (SVC)**

**M.Sc. THESIS
IN
ELECTRICAL AND ELECTRONICS ENGINEERING**

**BY
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**Transient Stability Improvement in Multi-Machine System Using Power System
Stabilizer (PSS) and Static Var Compensator (SVC)**



**M.Sc. Thesis
in
Electrical and Electronics Engineering
University of Gaziantep**

**Supervisor
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MAY 2016**



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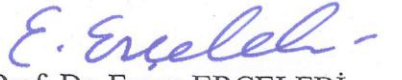

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Khoshnaw Khalid HAMA SALEH

ABSTRACT

TRANSIENT STABILITY IMPROVEMENT IN MULTI-MACHINE SYSTEM USING POWER SYSTEM STABILIZER (PSS) AND STATIC VAR COMPENSATOR (SVC)

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M.Sc. in Electrical and Electronics Engineering
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Modern power systems are equipped with auxiliary equipments to consider power system stability, especially transient stability and small disturbance. Transient stability plays more effect role in stability of power system, during fault and huge disturbance. In this thesis, we offers comparative between power system stabilizer (PSS) and static Var compensator (SVC) used to improve damping oscillation and transient stability. Power system stabilizer is one of the traditionally devices and common controls applied to damp out the low frequency oscillations. The efficiency of a power system stabilizer PSS connected to the exciter and/or governor unit in damping electromechanical oscillations of isolated synchronous generator is verified. Also, the static Var compensator SVC device is a member of shunt flexible AC transmission system (FACTS) family, it is the recent development of power electronics. SVC makes contribution to improve the stability of the power system by controlling the amount of reactive power injected into or absorbed from the power system. The designed model has been tested for multi machine contain of 4 synchronous machine 6 bus with difference load simulated by software program, and took several cases. All simulation results show that SVC is superior to PSS in improving transient stability and damping oscillation.

Keywords: Power system stability, transient stability, PSS, FACTS, SVC, multi-machine system.

ÖZET

ÇOKLU MAKİNE SİSTEMİNDE GÜÇ SİSTEM SABİTLEYİCİ VE STATİK VAR DENGELİYİCİ KULLANARAK GEÇİCİ KARARLILIK İYİLEŞTİRMESİ

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Modern güç sistemleri; güç sistemi kararlılığına, özellikle geçici kararlılığa ve küçük hataları dikkate almak için yardımcı ekipmanlarla donatılmıştır. Hata ve önemli düzensizlik esnasında geçici kararlılık güç sistem kararlığından daha önemli rol oynamaktadır. Bu tezde, sönümlemeli salınımı ve geçici kararlılığı iyileştirmek için kullanılan güç sistem sabitleyici ve statik VAR dengeleyici arasında karşılaştırma sunulmuştur. Güç sistem sabitleyici düşük frekanslı salınımları sonlandırmak için kullanılan genel kontrollerden ve geleneksel aygıtlardan biridir. Tahrik ve/veya kontrol ünitesine bağlanmış güç sistem sabitleyicinin verimliliği izole edilmiş senkron jeneratörün elektromanyetik salınımlarının sönümlenmesinde doğrulandı. Ayrıca, sönt esnek AC sisteminin (FACTS) bir üyesi olan statik VAR dengeleyici (SVC) aygıtı güç elektroniğinin son gelişmesidir. SVC güç sisteminin çektiği veya güç sistemine enjekte edilen reaktif gücün miktarını kontrol ederek güç sisteminin kararlılığının iyileştirmesine katkı yapar. Tasarlanan model, farklı ele alınan durumlar ve yazılımla benzetimi yapılan farklı yükler ile 4 senkron makine 6 bus için test edildi. Tüm benzetim sonuçları, statik sistem kararlılığını ve salınım sönümlerini iyileştirmede statik VAR dengeleyicinin güç sistem sabitleyiciden daha üstün olduğunu gösterdi.

Anahtar kelimeler: Güç sistem kararlılığı, geçici kararlılık, PSS, FACTS, SVC, çok makineli sistem.



Dedicated to

My lovely daughter

My dear parents, my wife and their parents

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LIST OF CONTENTS

	Pages
ABSTRACT	v
ÖZET	vi
ACKNOWLEDGEMENTS	viii
LIST OF CONTENTS	ix
LIST OF FIGURES	xiv
LIST OF TABLES	xix
LIST OF SYMBOLS	xx
CHAPTER 1	1
INTRODUCTION	1
1.1 general information	1
1.2 motivation of the thesis	3
1.3 aims of the thesis	3
1.4 thesis organization	4
CHAPTER 2	5
LITERATURE SURVEY	5
2.1 Introduction	5
2.2 Literature Survey	5
2.3 Place of Work in the Literature	10

CHAPTER 3	11
POWER SYSTEM STABILITY	11
3.1 Introduction	11
3.2 Categories of Stability	12
3.2.1 Steady State	12
3.2.2 Dynamic State	13
3.2.3 Transient State	14
3.3 The Classification of Power System Stability	14
3.3.1 Voltage Stability	15
3.3.2 Frequency Stability	19
3.3.3 Rotor Angle Stability	20
3.3.3.1 Synchronous Machine Characteristic	21
3.3.3.2 Small Signal Rotor Angle Stability	24
3.3.3.3 Transient Stability	26
3.3.4 Swing Equation	27
3.3.5 Swing Equation of Multi Machine Power System	31
3.3.6 Machines Swinging Coherently	32
3.3.7 Methods for Improvement Transient Stability	33
CHAPTER 4	36
FACTS , STATIC VAR COMPESATOR (SVC) AND POWER SYSTEM STABLIZER (PSS)	36
4.1 Flexible alternative current transmission system (FACTS)	36

4.1.1 Facts Controllers.....	37
4.2 Static var compensator (SVC).....	40
4.2.1 General Information about Static Var Compensator (SVC).....	40
4.2.2 Categories of SVCs	42
4.2.2.1 SVC of the TCR-FC category	42
4.2.2.2 SVC of the TCR-TSC category	45
4.2.3 Control system of SVC.....	49
4.2.4 SVC V-I Characteristic	50
4.2.5 SVC Component.....	52
4.2.5.1 General Performance Index of SVC	52
4.2.5.2 Structure of SVC.....	52
4.2.6 Modelling of SVC	58
4.3 Load Modeling.....	59
4.3.1 General Information on Load Modeling.....	59
4.3.2 Types of Load Models.....	61
4.3.2.1 Static load models	61
4.3.2.2 Dynamic Load Representation.....	63
4.4 Power System Stabilizer (PSS).....	67
4.4.1 General Information about Power System Stabilizer (PSS).....	67
4.4.2 Principle Operation of PSS.....	69
4.4.3 Actions of PSS.....	70

4.4.3.1 Inter-area (Long-cycle) Mode Power Oscillation	70
4.4.3.2 Local Mode Power Oscillation	71
4.4.3.3 Complex Power Oscillation	72
4.4.4 PSS Applied to the Turbine Governor	72
CHAPTER 5	74
SIMULATION STUDIES	74
5.1 System Model.....	74
5.2 Power System Stabilizer (PSS) with system.....	76
5.3 Static Var Compensator (SVC) with System.....	77
CHAPTER 6	79
RESULTS AND SISCOSSION	79
6.1 Introduction	79
6.2 The Simulation Results of multi-machine system.....	79
6.3 Cases Studies and Results.....	79
6.3.1 Case Comparison between using only PSS and SVC at maximum critical clearing time.	80
6.3.2 Comparison between using only PSS and PSS with SVC at clearing time equal (147) ms	83
6.3.3 Loss of a Generator in the System.....	88
6.3.4 Case study with change the location of SVC and effect on the system	92
6.3.5 Sudden change of the system load.....	96
6.3.6 Fault with Starting operation.....	100

6.3.7 Comparison between using only PSS and PSS with two SVC at clearing time = 147 ms.....	104
6.3.8 Effect of use double transmission line on improve transient stability	109
6.4 Discussion and Result.....	111
CHAPTER 7	113
CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK	113
7.1 Conclusion of this study.....	113
7.2 Future Work.....	115
REFERENCES	116

LIST OF FIGURES

	Pages
Figure 3.1 Dynamic State.....	14
Figure 3.2 Transient State	14
Figure 3.3 Power System Stability.....	15
Figure 3.4 A Humble Circular System for explain of Voltage Stability.....	16
Figure 3.5 Reception end Voltage, current and Power as a function of Load Request for the System of Figure 3.4	17
Figure 3.6 $VR - PR$ Characteristic of the System with different Load Power Factors.....	18
Figure 3.7 Frequency Stability	19
Figure 3.8 Single Line Illustration of Two Machine.....	21
Figure 3.9 Idealized Model of Tow Machine.....	22
Figure 3.10 illustrations the phasor chart of relationship between generator and motor voltages	22
Figure 3.11 Power Transmission Typical of a Tow-Machine System.....	23
Figure 3.12 Omit the rotor angle.....	24
Figure 3.13 Nature of Small Disturbance with Constant Field Voltage	25
Figure 3.14 is explain when the automatic voltage regulator (AVR) is attendance and the response of generator.....	26

Figure 4.1 General Symbol of FACTS Devices.....	37
Figure 4.2 Series FACTS Controller.....	38
Figure 4.3 Shunt FACTS Controller	39
Figure 4.4 Unified Series-Series FACTS Controller	39
Figure 4.5 Coordinated (a) Series and (b) Shunt Controller	40
Figure 4.6 basic configuration of SVC	41
Figure 4.7 SVC Substation.....	42
Figure 4.8 Basic single-line circuit drawing of an SVC of the TCR-FC category	43
Figure 4.9 Basic circuit illustration of one leg (phase) of an SVC of the TCR-FC-category display the major voltage, current, and reactive power parameters	43
Figure 4.10 Reactive power interchange typical of an SVC of the TCR-FC-category.....	44
Figure 4.11 Basic singleline circuit drawing of SVC of theTCR-TSC category	46
Figure 4.16 Control and Protection System of SVC	53
Figure 4.17 Thyristors valve of SVC	54
Figure 4.18 (a) Thyristors valve pipe, (b) closed-loop pure cool-water system	55
Figure 4.19 High efficient air-cooling system	56
Figure 4.20 Filter Banks of SVC	56
Figure 4.21 TCR reactor of SVC	57
Figure 4.22 Model of SVC controller	58
Figure 4.23 Power System Configuration Identifying Parts of the System Represented as load at a Bulk Power Delivery Point Bus A.....	60

Figure 4.24 Steady State Equivalent Circuit of an Induction Motor.....	64
Figure 4.25 Stator Equivalent Circuit of an Induction Motor.....	64
Figure 4.26 Load Response for a Step Change in Voltage	66
Figure 4.27 Block diagram of the PSS.....	67
Figure 4.28 washout circuit.....	68
Figure 4.29 Additional control loop for the AVR system block diagram.....	69
Figure 4.30 Supplementary control loop for the AVR system phasor diagram.....	70
Figure 4.31 Single-frequency PSS	72
Figure 4.32 Multi-input PSS	72
Figure 5.1 Simulation Model.....	75
Figure 5.2 Power System Stabilizer (PSS) with System Model	76
Figure 5.3 Block Parameters of SVC Mode	77
Figure 5.4 PI controller of SVC System Model.....	78
Figure 6.1 Block Parameters of Fault Breaker with 148ms.....	80
Figure 6.2 Rotor Angle Difference of G1to G2, Case 1	81
Figure 6.3 Rotor Angle Difference of G2 to G3, Case 1	81
Figure 6.4 Terminal Voltage on B1, Case 1.....	82
Figure 6.5 Transmission Line Active Power of G1, Case 1.....	82
Figure 6.6 Block Parameters of Fault Breaker with 147ms.....	83
Figure 6.7 Rotor Angle Difference of G1 to G2, Case2	84
Figure 6.8 Rotor Angle Difference of G3 to G4, Case2	85

Figure 6.9 Terminal Voltage on B1, Case2.....	85
Figure 6.10: Terminal Voltage on B6, Case2	86
Figure 6.11 Transmission Line Active Power of G1, Case2	86
Figure 6.12 Transmission Line Active Power of G3, Case2	87
Figure 6.13 Rotor angle difference of G1 to G2, Case 3	89
Figure 6.14 Rotor angle difference of G3 to G4, Case 3	90
Figure 6.15 Terminal voltage onB1, Case 3	90
Figure 6.16 Terminal voltage on B6, Case 3	91
Figure 6.17 Transmission line active power of G1, Case 3	91
Figure 6.18 Transmission line active power of G3, Case 3	92
Figure 6.19 Rotor angle difference of G1 to G2, Case 4	94
Figure 6.20 Rotor angle difference of G3 to G4, Case 4	94
Figure 6.21 Terminal voltage on B1, Case 4	95
Figure 6.22 Terminal voltage on B6, Case 4	95
Figure 6.23 Transmission line active power of G1, Case 4	96
Figure 6.24 Rotor angle difference of G1 to G2, Case 5	98
Figure 6.25 Rotor angle difference of G3 to G4, Case 5	98
Figure 6.26 Terminal voltage on B1, Case 5	99
Figure 6.27 Transmission line active power of G1, Case 5	99
Figure 6.28 Rotor angle difference of G1 to G2, Case 6	101
Figure 6.29 Rotor angle difference of G3 to G4, Case 6	102

Figure 6.30 Terminal voltage on B1, Case 6.....	103
Figure 6.31 Terminal voltage on B6, Case 6	103
Figure 6.32 Transmission line active power of G1, Case 6	103
Figure 6.33 System Model with Using Two SVC	104
Figure 6.34 Rotor angle difference of G1 to G2, Case 7	106
Figure 6.35 Rotor angle difference of G3 to G4, Case 7	106
Figure 6.36 Terminal voltage on B1, Case 7	107
Figure 6.37 Terminal voltage on B6, Case 7	107
Figure 6.38 Transmission line active power of G1, Case 7	108
Figure 6.39 Transmission line active power of G3, Case 7	108
Figure 6.40 System Model with Double Transmission Line between G1 and G2 ..	109
Figure 6.41 Rotor angle difference of G1 to G2, Case 8	110
Figure 6.42 Transmission line active power of G1, Case 8	110

LIST OF TABLES

	Pages
Table 6.1 Comparison between PSS and PSS with SVC at (cl = 147ms)	87
Table 6.2 Comparison between PSS and PSS with SVC while losing one generator	89
Table 6.3 Comparison between PSS and PSS with SVC when changing location of SVC.....	93
Table 6.4 Comparison between PSS and PSS with SVC when suddenly change the load.....	97
Table 6.5 Comparison between PSS and PSS with SVC at Starting Operation	101
Table 6.6 Comparison between PSS and PSS with one SVC and Tow SVC	105

LIST OF SYMBOLS

FACTS	Flexible Alternating Current Transmission System
PSS	Power System Stabilizer
SVC	Static var Compensator
AVR	Automatic Voltage Regulator
TCR-FC	Thyristor Control Reactor-Fixed Capacitors
TCR-TSC	Thyristor Control Reactor- Thyristor Switched Control
P_a	Power Acceleration
P_e	Electric Power
P_m	Mechanical Power
T_e	Electrical Torque
T_m	Mechanical Torque
T_a	Accelerating Torque
T_D	Damping Torque
P	Active Power
Q	Reactive Power
ω	Speed
δ	Power (Rotor) Angle
$\Delta\delta$	Angular Deviation of the Rotor

$\Delta\omega$	Deviation of the Speed
B	SVC Susceptance
B_C	Capacitive Susceptance
B_L	Inductive Susceptance
K_P	Proportional Gain of Real Power
K_i	Integral Gain of Real Power
G	Generator
V_{ref}	Reference Voltage
ms	mili Second
CL	Clearing Time

CHAPTER 1

INTRODUCTION

1.1 General Information

Nowadays power system is a complex nonlinear interconnected network. This complex system forming interconnected, generator power plants, transformers, transmission lines and difference of loads. The interconnected have the benefit like reduced the operating cost, fuel cost, sources sharing, diversity of loads and improved reliability of the system [1]. Also the interconnected of power system has created problems, e.g. low frequency electro-mechanical oscillation produced via electrical disturbances [2].

For this cause maintain of the stability of the system is difficult and improvement of power system transient stability has become an important problem.

Electric services are currently required to work their system such as that makes well application of existing system conveniences [3].

The analyses of stability of the system is very complex and significant part of the power system analysis. The stability of power systems has been and stays to be of main anxiety in system process.

The important factor for planning of new facilities is the degree of stability of the power system. Continues electric service is required to provide the reliability of the power system, for this cause the power system need be designed to be stable with any small or great disturbance [4].

The distance among interconnections of power system these days is general practice that provides to increase electro-mechanical oscillation in the range of (0.1 – 0.3) HZ, this oscillation caused by electrical disturbances. The oscillations of the power system

must be damped completely because the result of increase electro-mechanical oscillation may cause the power system lost the stability.

During many years ago, the electromechanical oscillation are utmost problem that offering a protest to control system and electric engineers. These oscillations in some cases especially in difficult cases are not damped enough and causes to mechanical exhausting of the generation units and unbalancing power transfer through the transmission lines and increasing load over the transmission lines.

The stability is one of the interest operation of the power system. In the some previews years, a new technique has been found to damping the low frequency oscillation is called power system stabilizer (PSS) [5].

Power system stabilizer is one of the traditionally devices and common controls applied to damp out the low frequency oscillations. The main character of PSS is to present controlling signal acting through the excitation system for oscillation damping [6].

Nowadays, PSS used with a generator excitation system that the application of PSS is to enhance convenient damping signal to the generator excitation system to overcome with parameter oscillations. The input signal of PSS may be either the frequency difference between the input mechanical power and the output electrical power of the generator. The output signal is used as an additional input to the excitation system which is proved to be effective in execution there allocated functions.

Also PSS proposals a supplementary feedback signal, and they damage a disadvantage of susceptible to make a large difference in the voltage.

However system is damping is small at best and may not damp the electromechanical oscillations effectively, it is needs to use and addition new device with PSS [6].

It obligation be capable of supplying stabilization signals through a wide area of operating conditions and disturbances. With nonlinear system, the PSS is limited [7].

Moreover, regarding complex power system, new technology are used, which is called FACTS (Flexible Alternating Current Transmission System) controller. FACTS (Flexible Alternating Current Transmission System) is the recent development of power electronics assistances in providing the stability of the power system. FACTS

controller is able of controlling the network condition in a quite rapid way. It is can be enhance the transient stabilities and voltage stability and steady state stability of complex power system [8].

FACTS devices can reveals the solutions of these problems in the power system, by using these controllers the operational flexibility is more effective for the power systems. Electromechanical oscillations show in the system due to the interaction of two different sets of generation units through transmission line or by the variation of loads.

FACTS controllers categorized are vast types, such as shunt type, series type, mutual series-series type and mutual series- shunt type.

With FACTS device, there are group of controller, not only single power controller to control one or more parameters of the system such as, phase angle , damping oscillation at different frequency, voltage, current and impedance [9].

1.2 Motivation of the Thesis

The thesis shows the comparison between two controls that connecting with power system to damping electromechanical oscillation and improving transient stability. The controllers consist of power system stabilizer (PSS) and one of FACTS equipment family it is static var compensator (SVC). Power system stabilizer (PSS) is exaction control that connected with generator exactor. PSS is used to enhance damping electromechanical oscillations of the generator with small disturbance, but improving transient stability of power system that caused by large disturbance is needed to mere effective controller it is called FACTS device used as static equipment with power system, for my thesis we chose one of FACTS device family it is static var compensator(SVC).

1.3 Aims of the Thesis

The aims of the thesis

1. Simulation the 500 KV of multimachine power system, it is consist of four machine and connected with each other by long transmission lines and variation of loads.

2. Improving and investigating the influence of transient stability of multi machine using power system stabilizer (PSS) and one of FACTS equipment family is static var compensator (SVC), by making the comparison between them to remain the system in stable when occurring the large disturbance and effect of each of (PSS) alone and adding (SVC) to the system to damping electro mechanical oscillation and enhancement transient stability. The simulation of nonlinear time domain will show the efficiency of between using only PSS and coordination of PSS with SVC for damping these oscillations under three phase fault with ground in a fast way and strong style in order to get more stability for the power system.

3. The above aims are achieved using software program.

1.4 Thesis Organization

This thesis is organized into seven chapters:

Chapter 1: This chapter gives an introduction of the work, including Motivation and the Aims of the thesis as well as the organization of the project.

Chapter 2: This chapter explains literature survey to the work

Chapter3: This chapter explain the power system stability and inter- area oscillations of multi machine power system with some details.

Chapter 4: This chapter introduce a general information about SVC and PSS and modeling with details.

Chapter 5: This chapter represents the simulation of the suggested test system and explain parameters.

Chapter 6: This chapter shows the results of the cases on the study and discussion of the results.

Chapter 7: This chapter discuss the conclusion and suggestions for future work

CHAPTER 2

LITERATURE SURVEY

2.1 Introduction

Transient suppression and stability improvement are very important in power system design and process. So, many studies and searches have Presented different methods and to enhance the transient stability of power system. This chapter establishes an overall, up to date literature survey.

2.2 Literature Survey

Chan, Kee Han (PHD thesis, 2002) this research presented in this thesis addresses these issues and develops a direct time phase domain model for conducting multi machine transient stability analysis where asymmetrical operating conditions and represented the impact of modem power electronics controllers. This study is a drive towards the solution of transient stability in real-time, where the results produced are in actual world time. Models of power electronics controllers in the direct time phase-domain are also explained in this thesis. The two models of the FACTS family used in the study are Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), the power electronics controllers are incorporated into the multimachine environment in place of the analysis of transient and power excellence related issues [10].

M A. Abido Y. L. Abdel-Magid (2003) from the paper investigated Improve stability of the power system by preparing strong synchronized of a power system stabilizer (PSS) and a static VAR compensator (SVC) with stabilizer. The study presented the assortment proposal problematic of strong excitation and SVC-based controllers through varied array of loading conditions and system formations is expressed as an optimization issue through an eigenvalue-created objective task.

They also offer a singular value decomposition (SVD) based method to evaluate and amount the controllability of the slightly damped electromechanical modes via diverse control inputs. The suggested stabilizers are verified on a weakly-connected power system. The study shows nonlinear simulation results and eigenvalue investigation to enhance power system stability by synchronized proposal of a PSS and a SVC-based controller [8].

D. Raghu Rama Reddy (MSc thesis, 2007) this thesis presents a nonlinear control structure for designing Static Synchronous Compensators (STATCOM). He proposed the calculated model of STATCOM that is signified by a Euler-Lagrange (EL) system conforming to a regular of EL limitations. In this study, the energy-dissipative properties of this typical are completely kept below the d-q axis transformation. He used the differential geometry approach by employing the Park's transformation to explore the power system dynamics with assuming STATCOM below the synchronous d-q mount. He applied the PSCAD/EMTDC program for analysis of the system performance. The simulation results demonstrate that the suggested STATCOM controller is able to efficiently increase transient stability of the power system [11].

Dr. Ibrahim Hamarash (2007) he presented an assessment of the planned north of IRAQ Power System to maintain stability under small and large disturbances during normal and abnormal operating conditions. To achieve this objective, a complete mathematical model in the form of block diagram, based on manufacturers and/or IEEE standards and benchmarks data, has been derived for the system using MATLAB/SIMULINK/ SIMPOWERSYSTEMS tools. The model represents accurately all the power system components involved in physical phenomena of system dynamic oscillations. The model contains 53 transmission lines, 35 nodes and 6 generation stations. The system is simulated under different configurations and the dynamic behavior associated with each configuration is studied [12].

Laxmidhar Sahu (MSc thesis, 2011) this study proposes the development of transient stability of a multi-machine power system with a STATCOM. The research also presents modeling both of SVC and STATCOM for power system steady state operation. He used STATCOM as a controller to improve transient stability and

damping by dynamically controlling output reactive power. This work investigated the influence of transient stability upgrading of the multi-machine power system it consists of a three machine, nine bus at different fault. The suggested system is too evaluated for diverse fault clearing times [13].

Dr. Tarlochan Kaur and Sandeep Kakran (2012) in this work shunt FACTS device static var compensator (SVC) is used Transient Stability enhancement of extensive Transmission Line System. They show the effect of Shunt FACTS devices and it is an significant part in improving the transient stability, growing transmission ability and damping low frequency oscillations. The study tested on a two difference area power system for improving the transient stability. The study making by a Simulink model in MATLAB software program. They originate in the research that the transient stability of the system is very influenced through SVC and determined that the transient stability of two zone power system with changed loads at diverse buses increases by using SVC [14].

N. A. Arzeha, M. W. Mustafa and R. Mohamad Idris (2012) they, introduced a fuzzy controller combined with the classical PI controller for static var compensator (SVC) to damping power system disturbance. They present the comparison between PI controller and fuzzy controller for SVC and The benefits of the PI controller is saved and combined with benefits of the fuzzy controller to enhancing transient stability. The F-SVC controller has been verified in a 2-machines 3-bus power system where many parameters counting the alteration of rotor angle between the machines, speed of the machines, terminal voltage and the transmission line active power have been noted. The results illustrations the F-SVC controller better performance compared to conventional SVC in damping oscillations and improving transient stability of the noted parameters after the system is exposed to disturbance [15].

Dhaval N Tailor, Bhavesh Bhalja, Vijay Makawana (2012) this paper motivation on the important of PSS (power system stabilizer) and SVC (static var compensator) to increase the transient stability of power system in many abnormal condition. This work presents the simulation result of model for different fault from different place condition with PSS and without PSS and show how the system lost stability with only PSS, also they used SVC as a controller to remain the system in stable when occurring

the large disturbance like three phase fault. The study examined on two identical zones, each zone contains two generating units armed with rapid static exciters and the system simulated by MATLAB software. The results of this study show that solitary by PSS cannot keep stability but in some states or condition it is require connecting additional equipment like FACTS device to continue system in stability [16].

Satvinder Singh, Atma Ram, Nitin Goel, Pawan Kumar (2013) they present during the research the different types of FACTS devices for example static var compositor (SVC) and unified power flow controller (UPFC) to the power system stability improvement of a multi-machine power system. The dynamics of the system is studied at the event of a large disturbance. This work make comparison between UPFC and SVC to improving transient stability of power system. The study tested on multi machine of difference area and the system is simulated in MATLAB/Simulink. The simulation results determine the active and strength of the suggested UPFC for transient stability enhancement of the system [17].

Salma KESKES¹, Wissem BAHLOUL², M.B.A KAMMOUN (2014) During the paper they tried to solving the problem of transient stability of a single-machine-infinite-bus (SMIB) with connecting SVC. The research manifested that connecting static var Compensation like a new and modern technique instead power system stability (PSS) to enhance transient stability. The work decrease power system modeling from seventh to third order. A mathematical dynamic typical was similarly offered in a first order transfer function form. Simulation results show that SVC more effective than PSS only to improving transient stability of power system [18].

Rajeev Kumar Verma & Sangeeta Mishra (2014) this study show the transient stability and damping of power oscillations have been evaluated with SVC. They study is suggested to enhance transient stability in test system consist of 14 Bus 5 machine System with utilizing SVC. The results with utilizing SVC the rotor angle characteristic curves show fewer overshoots and damped oscillations in a slighter period, also The reaction characteristics take fewer period to reach the last steady value and system reached to the stability [19].

Ali, E. S.a and. Abd-Elazim, S. M b (2014) they proposed the estimates of new way via coordinated project of Power System Stabilizers (PSSs) and Static Var Compensator (SVC) in a multimachine power system by statistical process. They suggested the design issue of the controller is framed as an optimization issue and Bacterial Swarming Optimization (BSO) is used to examine for best controller parameters. This work they improved stability presentation of the System by decreasing the time field impartial function, in which the nonconformities in speed are shared. This work tested on multimachine consist of tree machine and nine bus, the general system are simulated on the computer program by Simulink tool box in Matlab software. Simulations outcomes guarantee the effectiveness of the projected coordinated controller in provided that decent smoothing oscillations of power system above an extensive array of loading settings and major disturbance [20].

Bablesh Kumar Jha, Ramjee Prasad Gupta, Upendra Prasad (2014) in this paper present a modern optimal control approaches for enhancement of transient stability. They used coordinated effect of power system stabilizer (PSS), static var compensator (SVC) with conventional method and by increasing inertia of machine to improving transient stability. With utilizing of PSS, SVC and by rising inertia process for the examination system the electromechanical oscillation for generator electrical power has been decreased and the steady case power assignment has been boosted. This work tested on three machine nine bus and simulation results using E-TAP Software. The results show better response in terms of electromechanical oscillation has been achieved in case of with PSS and SVC [21].

Karuppiah, Malathi, Selvalakshmi (2014) this work present the new controller for static var compensator (SVC) and Static Synchronous Compensator (STATCOM) instead conventional controller to improving transient stability. The new method is fuzzy logic controller for SVC and STATCOM and comparing with PI controller for smoothing the rotor angle swings and thus to increase the stability of the power system. They observed several numerous limitations such as rotor angle deviation, bus's voltage also active power transfer on lines. The act of the suggested fuzzy logic controller for SVC and STATCOM has been studied for a three phase fault in 2-machines 3-bus system with MATLAM simulation. The results obtained of this

research are compared by that of classical PI controller and the Fuzzy controlled SVC and STATCOM provides well results than SVC and STATCOM with PI controller to improving transient stability [22].

Urmila Bainsla, Mohini, Kiran Rani, Dr. Anju Gupta (2015) they presents the enhancement of transient stability of several machine power system connecting Static Var Compensator. They used SVC as an active FACTS device in controlling voltage at required bus by means of reactive power compensation. The work tested on IEEE 3 machine 9 bus system combined with SVC controller that simulated by MATLAB/Simulink. Results of this study show that oscillations in speed and rotor angle difference of the generators are smoothed out speedy with the insertion of SVC therefore enhancing the transient stability of the system [23].

2.3 Place of Work in the Literature

This study presents a method which be able to damping oscillations and improve transient stability by coordinating the power system stabilizer (PSS) and static var compensator (SVC) so as to enhance stability of power systems. Also this work using only PSS and coordinate PSS with SVC with multi machine system and comparing the results to show which of them better to remain system in stable and enhance transient stability.

CHAPTER 3

POWER SYSTEM STABILITY

3.1 Introduction

The possessions of a power system that allows it to persist in case operating equilibrium below standard operating condition and revert a passable state of equilibrium after being underwent to a disturbance defined as stability of the power system. There are several diverse ways may be cleaned the instability in a power system that it is depends on configuration and operating mode. When the system underwent to the transient disturbance must be evaluate the behavior of power system with this situation. The disturbance that underwent to the system may be slight or severe. In the format of load change from the system happen permanently, also the system regulate itself to the varying condition is called small disturbance. The system must be able remaining abundant disturbance of sever nature, for example loss of one generator or sudden increase of the load, short-circuit on a transmission lines or loss of a line between two generators or tow subsystems [24].

The stability of power system explains the capability of the electrical power system in situation of operation of a given initial to return the state of the operating balance after hardship a physical disturbance with all variables of a system is limited. The complete power system intact reminder without any shaking to back from generators or variation loads to balance between opposing forces is the condition of stability [25].

Power systems depending on synchronous machines for generations of electrical power, for this cause the important condition for disease system operation, that must be all synchronous machines stay in synchronism. Generally, the dynamic of generator rotor angle and power angle relations is affected of this part of stability [24].

Instability can be occurred not only by loss synchronism, such as the system can come to be unstable by voltage collapse of the load while the load is induction motor on transmission line and system contain synchronous generator.

There are many supposition commonly complete to shorten the issue and concentrate the elements effecting the precise type of stability issue [24].

3.2 Categories of Stability

The organization of power system stability proposed here is created on the subsequent considerations:

- The physical nature of the causing instability
- The extent of the disturbance measured
- The equipment, procedures and period distance
- The best suitable ways of evaluation and suggesting of stability [24].

There are highly nonlinear power systems that function in a continually varying situation in terms of loads, generators, productions and main operating parameters; the system stability counts on the conditions of initial operation and the disturbance nature. Typically, power system stability is classified into steady state stability, transient state stability and dynamic state stability [19].

- Steady state
- Dynamic state
- Transient state

3.2.1 Steady State

This is the capability of an electrical machine of power system to return to its former status. In other terms, in a power system, the rotors of each synchronous machine in the system rotate at the similar regular electrical speed. Through steady state process,

the electrical power out with the mechanical power in are balanced. The mechanical power input to the shaft by the prime mover is the product of torque and speed [19].

$$P_m = \omega T_m$$

The mechanical torque is in the same direction of rotation.

Steady State Stability studies are limited to small and piecemeal variations in the system operating conditions. Essentially focus on limitation the voltage on buses to their minimal values. Similarly phase angles between two buses are small and check for the overcapacity of the transmission lines and power tools.

Machine operating into an infinite bus or just a few machines undergoing one or more small disturbance [26].

3.2.2 Dynamic State

Dynamic state stability this is the capability of a power system to keep stability below constant slight and sudden disturbances. Dynamic instability is more possible than steady state stability. Small disturbances are constantly happening in power systems (e.g. due to various loadings and vagaries in turbine speeds), which are slight enough not to reason the system to lose synchronism, but they do arouse the system into the case of normal oscillations. The amplitude of oscillation is large in dynamic instability system and these continue for an extended period, the system under damped as shown in figure 3.1. This type of instability conduct establishes a serious danger to safety of the system and causes actual hard operating conditions [19].

The system be able to explained by linear differential equations, and can be settled by a linear and constant additional stability control [26, 27].

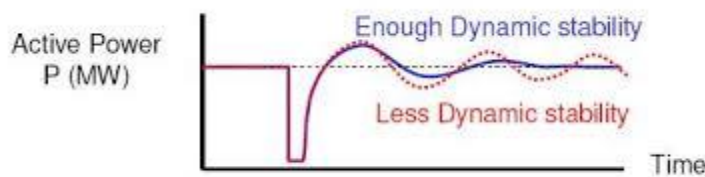


Figure 3.1 Dynamic State

3.2.3 Transient State

Transient stability is the capability of power system to retain synchronism while it is suddenly subjected to a severe transient disturbance. The variations in angular differences with large disturbance may possibly be as huge to reason the machines to fall out of step. This category of instability termed transient stability: following a significant disturbance, the synchronous alternator the machine power (load) angle varies as a result of immediate acceleration of the rotor shaft. The transient stability could determine whether the load angle returns to a steady value following the clearing of the disturbance. Transient stability is a rapid phenomenon, normally happening within one second for a generator near to the reason of disturbance as clearing in figure 3.2.

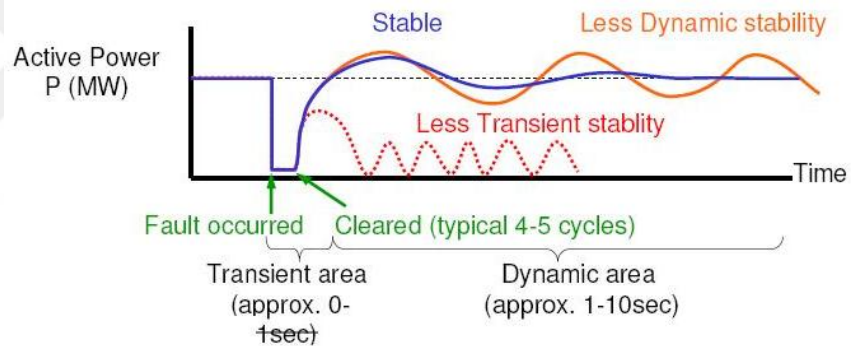


Figure 3.2 Transient State

3.3 The Classification of Power System Stability

The classification of power system stability as shown in Figure 3.3[30], explain different related connections by considering. Dissection of this systems using idealized

models explain to know essential Properties of each type of stability problem.

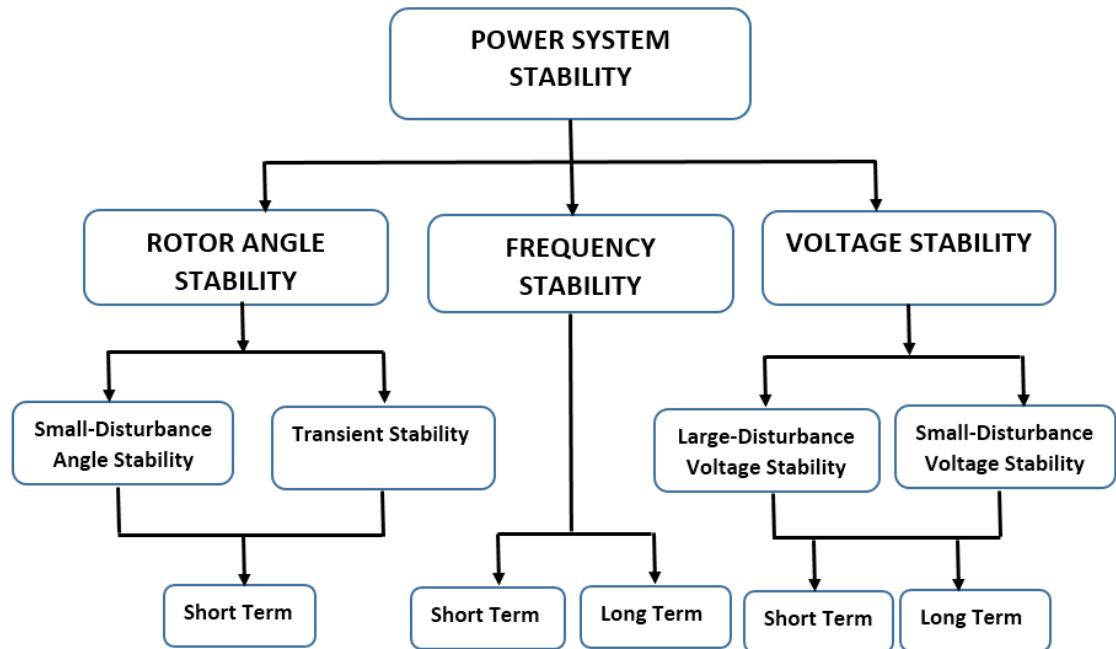


Figure 3.3 Power System Stability

3.3.1 Voltage Stability

Voltage stability is anxious with the capability of a power system to keep stable suitable voltages at completely buses in the system after being exposed to a disturbance under normal operating conditions.

Advance fall or increases voltage on certain buses with solitary mild excursions of generator angles is caused to instability of the power system. The disability of the power system to continue an appropriate equilibrium of reactive power during the system is the major factor causing voltage instability.

Within a provide operational situation for totally bus in the system is a base for voltage stability, at the same bus the voltage improved after the voltage amount rises while injected the reactive power, for minimum one bus the system that it is voltage unstable when the voltage amount (V) reductions as the reactive power addition (Q) at the similar bus is improved [24].

There are many different methods causes voltage instability, we can explain by assuming the two terminal network as shown in figure 3.4 [24]. The network forms of a continual voltage source (E_s) with a load (Z_{LD}) over a series impedance (Z_{LN}). The area of the load assisted over a transmission line via a big system is represented.

I Is expression for current from the figure 3.4.

$$\tilde{I} = \frac{\tilde{E}_s}{\tilde{Z}_{LN} + \tilde{Z}_{LD}} \quad (3.1)$$

Where \tilde{I} and \tilde{E}_s are phasors, and

$$\tilde{Z}_{LN} = Z_{LN} \text{ang} \theta$$

$$\tilde{Z}_{LD} = Z_{LD} \text{ang} \phi$$

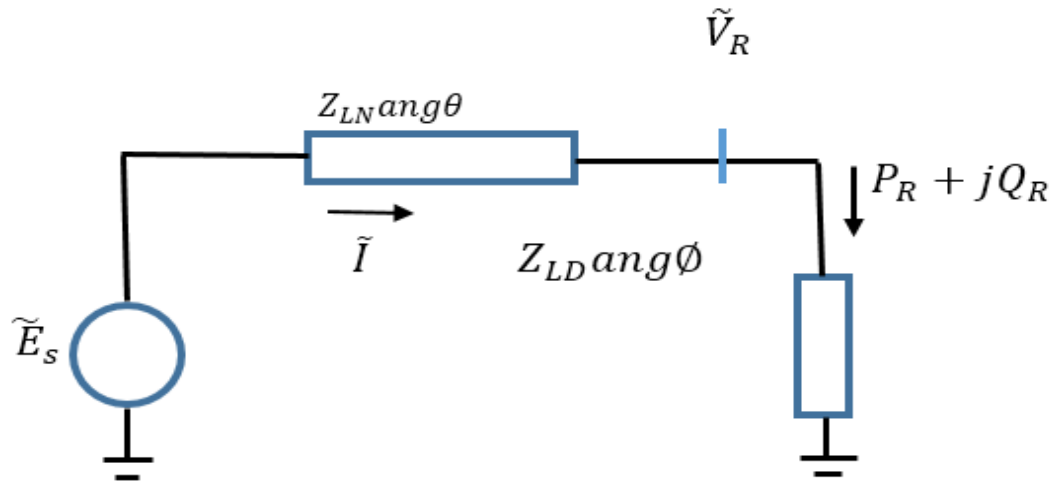


Figure 3.4 A Humble Circular System for explain of Voltage Stability

Specified the magnitude of the current as

$$I = \frac{E_S}{\sqrt{(Z_{LN} \cos \theta + Z_{LD} \cos \phi)^2 + (Z_{LN} \sin \theta + Z_{LD} \sin \phi)^2}}$$

This can be articulated as

$$I = \frac{1}{\sqrt{F}} \frac{E_S}{Z_{LN}} \quad (3.2)$$

Where

$$F = 1 + \left(\frac{Z_{LD}}{Z_{LN}}\right)^2 + 2\left(\frac{Z_{LD}}{Z_{LN}}\right)\cos(\theta - \phi)$$

The magnitude of the receiving end voltage is specified by

$$\begin{aligned} V_R &= Z_{LD}I \\ &= \frac{1}{\sqrt{F}} \frac{Z_{LD}}{Z_{LN}} E_S \end{aligned} \quad (3.3)$$

The power supplied to the load is

$$\begin{aligned} P_R &= V_R \cos \phi \\ &= \frac{Z_{LD}}{F} \left(\frac{E_S}{Z_{LN}}\right)^2 \cos \phi \end{aligned} \quad (3.4)$$

When decreased Z_{LD} that mean the load demand is increasing, and at starting P_R increases quickly after that gradually increases until reaching extreme, then which it decreases. By the way, can be transmitting the maximum value of active power with constant voltage source through an impedance as shown in figure 3.5[24].

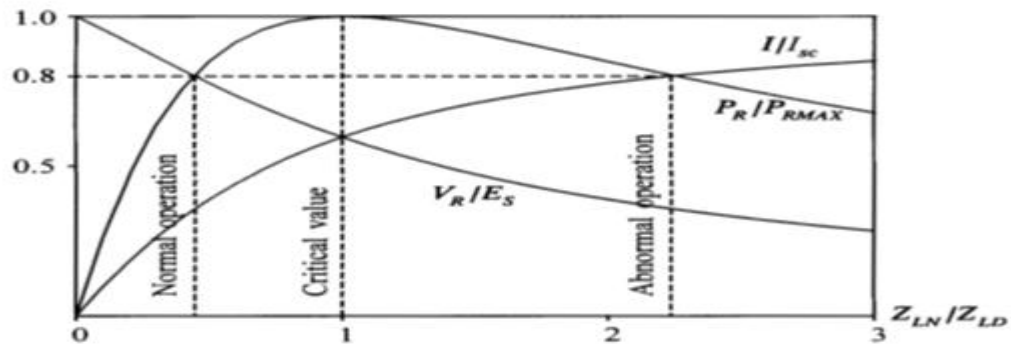


Figure 3.5 Reception end Voltage, current and Power as a function of Load Request for the System of Figure 3.4

The two equations 1.3 and 1.4 explain the load-power has a major impact on the power voltage characteristics of the system. This is demonstrate that the active and reactive power transfer is a function to voltage fall in the transmission line.

In fact the voltage stability depends on connection between Voltage and active and reactive power as shown in the figure 3.6 [24].

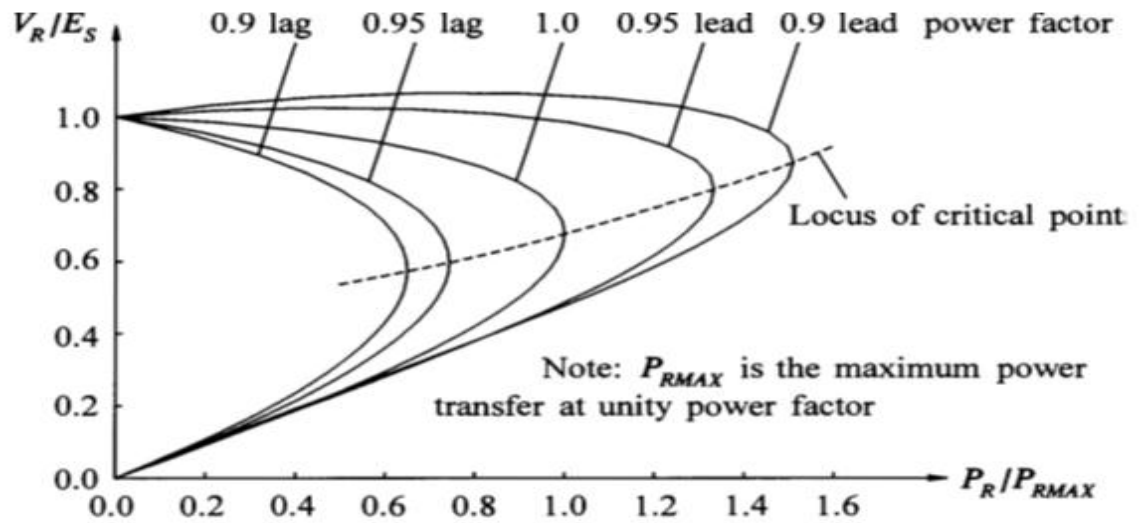


Figure 3.6 $V_R - P_R$ Characteristic of the System with different Load Power Factors

Voltage stability can classify into two branches as explain in the following

1. Large disturbance voltage stability is ability of the system to control voltage when subjected huge disturbance, such as loss of generation, circuit contingencies or faults on the system. The relations of both incessant and isolated controls and safeties and the system load characteristics used to determine this ability. Long term dynamic simulations are needed for investigation because the nonlinear dynamic achievement of a system above an interval time to the interactions of each equipment such as generator field-current regulators, this interval dilated from seconds to tens of minutes.

The following system control actions and following a given disturbance, voltage at all buses arrive reasonable steady case ranks.

2. Small disturbance voltage stability is ability of the system to control voltage when subjected small disturbance like increase variation load of the system. This type of stability is resolute by the continuous and discrete control, load characteristics at an assumed moment of time.

Originally of a steady state nature is the basic operations contributing to small disturbance voltage stability. Static analysis can be actively applied to set stability margins, recognize factors impacting stability, and search an extensive range of system conditions and large amount of post contingency [28].

3.3.2 Frequency Stability

Capability of a power system to compensate for a power deficit, Frequency Deviation Occurs when the large load suddenly changed in the system or generating unit rapidly connected or disconnected to the system.

The frequency instability occurring by imbalance is originally enclosed from the kinetic energy of rotating rotors of turbines, generators and motors. The frequency stability can be explained by figure 3.7.

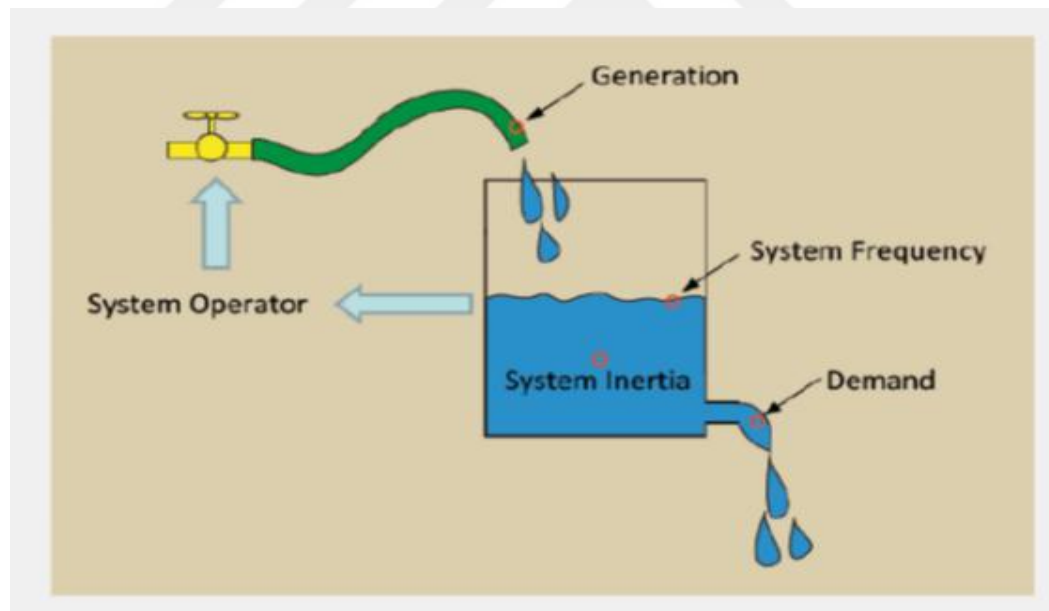


Figure 3.7 Frequency Stability

1. Long-term stability is commonly anxious with system response to large disturbance that include after the common system design criteria. Long term suppose that inter-machine synchronizing power oscillation have fall out, the

result being unvarying system frequency [29]. The concentrate is on the longer and slower-period phenomena that association big measure system and on the resultant large, continual mismatches between generation and exhaustion of active and reactive power. The duration time of long-term between a few minutes to 10 minutes.

The imbalance between the power brought via the turbine and that spent of the load system it is caused a long-term deformation. By the way the system frequency will be change with imbalance of kinetic energy of rotating rotors of turbines, generators and motors that initially covered

2. Mid-term stability the concentrate is on synchronizing power oscillation among machines inclusive the influence of particular of the leisurelier phenomena, and may be high voltage or frequency outings. The mid-term retort transference amid short-term and long-term responses. The duration time of mid-term between 10 seconds to a few minutes.

The phenomena analysis and representation used to the system is primarily based to the difference among mid-term and long-term stability.

The dynamic analysis of voltage stability needing simulation of the influences of transformer tap-changing, generator over excitation protection and reactive power limits are applications of mid-term and long-term stability.

3.3.3 Rotor Angle Stability

Rotor angle stability refers to the ability of synchronous machines in a power system to stay in synchronism after subject disturbance. The stability issue include the research of the electromechanical oscillations ingrained in power systems. A main influence is the manner in which the power outputs of synchronous machines alter with their rotors fluctuate. This stability is contingent on the capability of the system to stay in balance between mechanical torque and the electromagnetic torque of each generation unit. To explain the rotor angle stability must be know and understand synchronous machine characteristic.

3.3.3.1 Synchronous Machine Characteristic.

A synchronous machine is consist of two main fundamentals, the field and armature. at normal case, the field is on the rotor and the armature is on the stator. The rotor is driven by a prime mover and the field winding is excited by direct current. The rotating magnetic field of the field winding induced alternating voltages in the three phase armature winding of the stator. The speed of the rotor controls the frequency of the induced alternating voltage and resultant current that movement in the stator winding while a load is joined. The rotor mechanical speed synchronized with the frequency of the stator electrical amounts, hence the nomination synchronous machine [24].

The main condition when interconnected several synchronous machines, the stator voltage and currents of all the machines must have the rotor mechanical speed and frequency of each is synchronized to this frequency. That means the rotor must be synchronism from all interconnected synchronous machines.

The roles of mechanical and electrical torques are opposite compared to those in a generator in a synchronous motors. The mechanical load rotation is opposite with the electromagnetic torque rotation. The rotor position with respect to the rotating field of the stator is delay by increasing the mechanical load.

The correlation among exchange power and angular position of the rotors of synchronous machines are important characteristic of power system stability. To explain nonlinear relationship consider the modest system as in figure 3.8[24], it include two synchronous machines connected by a transmission line with inductive reactance X_L neglecting resistance and capacitance.

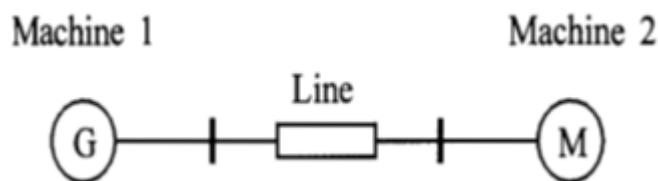


Figure 3.8 Single Line Illustration of Two Machine

The angle between rotors of the two machines is defined as angular separation δ is function to power transfer from the generator to the rotor. The angular separation is include three components, first component is the angle by which the generator rotor clues the rotating field of the stator is called internal angle of the generator δ_G , second is angle by which the stator field of the generator clues that of the motor is called angular difference between the terminal voltages of generator and motor, last component is angle by which the rotor lags the rotating stator field is called motor internal angle. To determine the relationship between power and angle, the figure 3.9[24] displays the typical of the system.

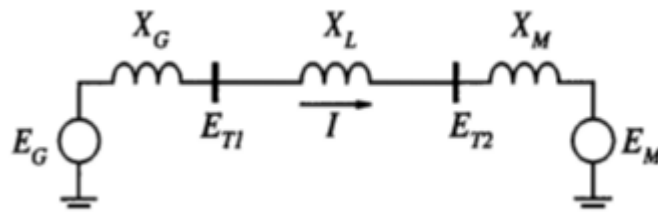


Figure 3.9 Idealized Model of Two Machine

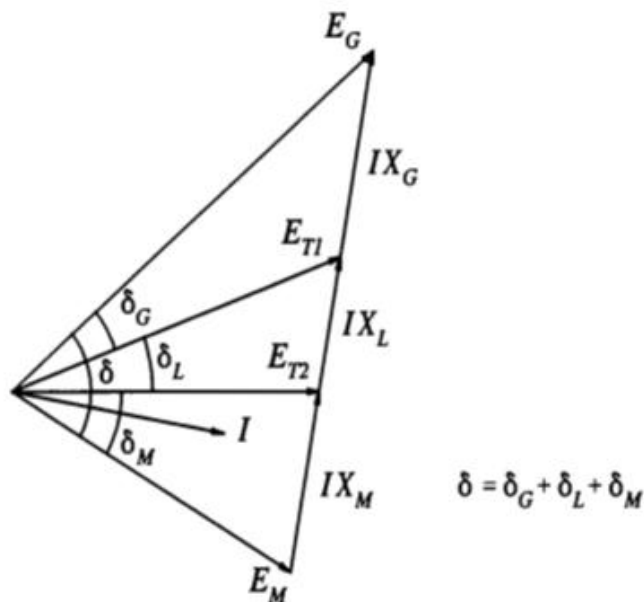


Figure (3.10) illustrates the phasor chart of relationship between generator and motor voltages [24]

The power moved from the generator to the motor is known in the following equation

$$P = \frac{E_G E_M}{X_T} \sin \delta \quad (3.5)$$

$$X_T = X_G + X_L + X_M$$

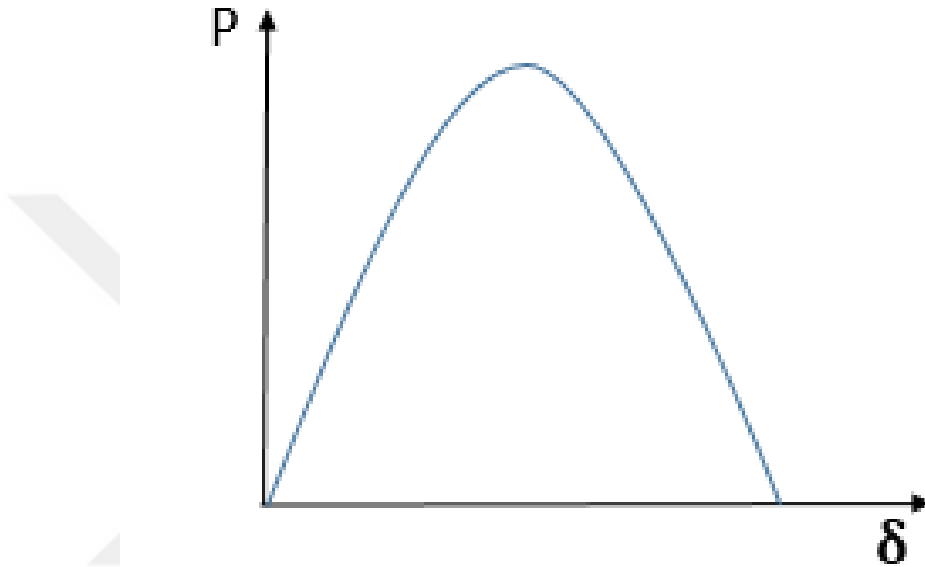


Figure 3.11 Power Transmission Typical of a Tow-Machine System

The alteration in electromagnetic torque ΔT_e of a synchronous generator will result a problem of electric power system that possibly resolved in two components:

- The element of synchronizing torque that in phase with angular deviation of the rotor $\Delta\delta$.
- The element of damping torque that in phase with deviation of the speed $\Delta\omega$

The equation below explain this two components

$$\Delta T_e = \Delta T_s \Delta\delta + T_D \Delta\omega$$

Where

$T_s \Delta\delta$ is the component of changing synchronizing torque with the rotor angle perturbation, T_s is the coefficient of synchronizing torque, $T_D \Delta\omega$ is the section of changing the damping torque in phase with speed deviation, T_D is the coefficient of damping torque.

The presence of these two components of torque for each generation unit can be subjected to the stability of the system [24]. Non-attendance of adequate synchronizing torque influence an increase in the angle of the rotor over an aperiodic mode show in figure 3.12[30]

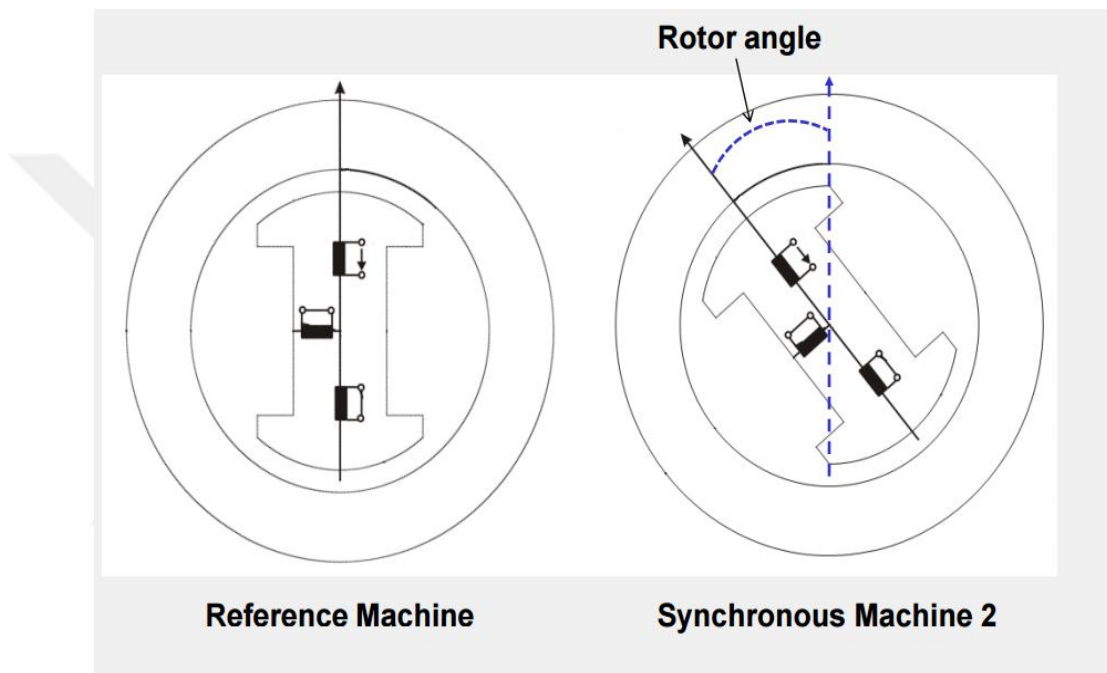


Figure 3.11 Omit the rotor angle

The stability of rotor angle phenomena can be categorized in two forms:

- Stability of small disturbance rotor angle
- Stability of large disturbance rotor angle.

3.3.3.2 Small Signal Rotor Angle Stability

The stability of small signal rotor angle means that the capability of the system to stay in synchronism while underwent to small disturbance. The small variation in loads and tripping of small generators and tripping off line and switching on or off of small loads

caused disturbances occurring continually. The system with small disturbance is considered that the conduct nonlinear system assumed like the linear system. The instability of the system might outcome be able of two formats

Steady rise in rotor angle cause reduce of adequate synchronizing torque.

Rotor electromechanical oscillation of rising amplitude cause of adequate damping torque.

There are several factors such as primary operating, the transmission line strength, and form of controls used to generator excitation are effects to small disturbance of the nature system response as shown in figure 3.13[24]. With non-attendance automatic voltage regulators (AVR) the instability cause reduce of adequate synchronizing torque. Figure3.14 [24], represent the non-oscillatory mode when the system in instability [24].

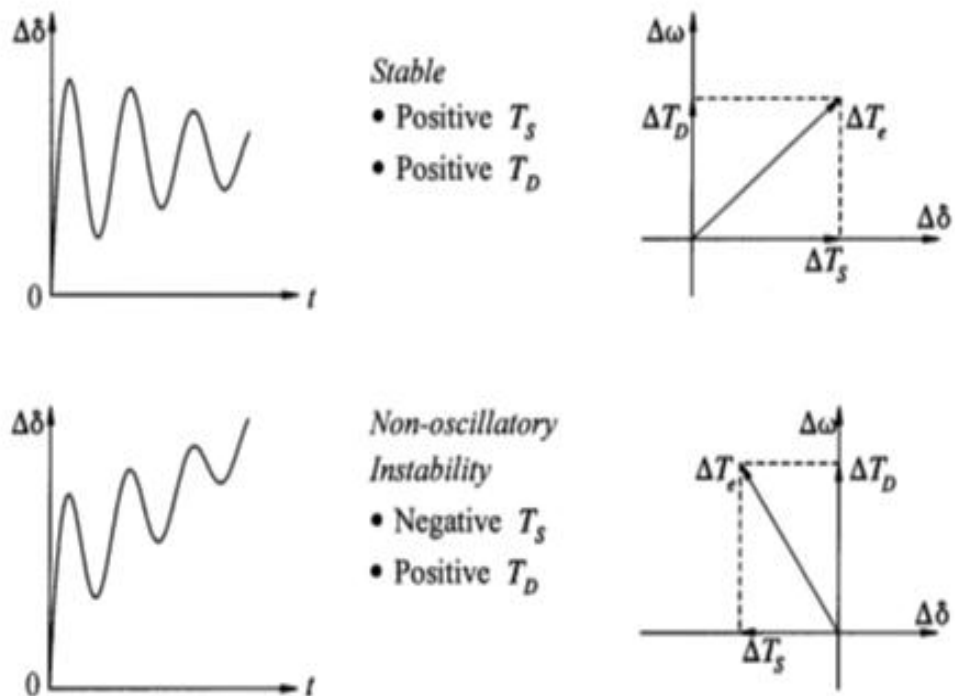


Figure 3.13 Nature of Small Disturbance with Constant Field Voltage

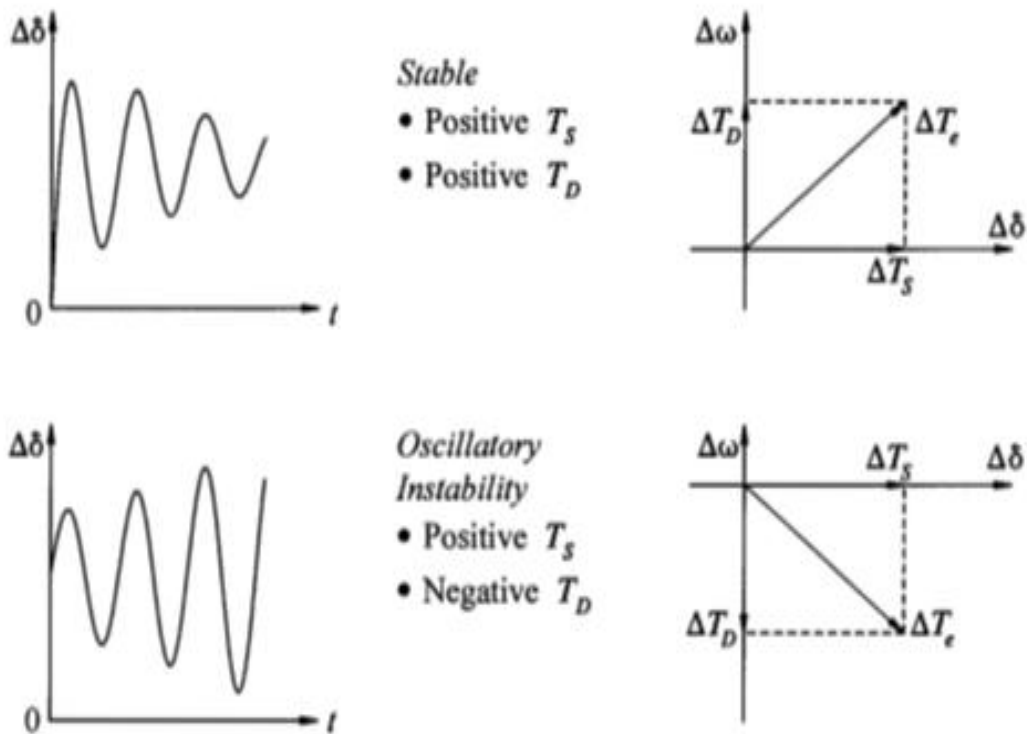


Figure (3.14) is explain when the automatic voltage regulator (AVR) is attendance and the response of generator

3.3.3.3 Transient Stability

The transient stability means the capability of the system remains in synchronism under large disturbance. In a new year's, power systems, on the worldwide, have developed noticeably. In order to get the best out of effectiveness of generation and distribution of electric power, the correlation among single services have improved and the generators have been requisite nearby to parameters for wide periods of time. Nowadays the power systems are below extra strain than previous to avert the investment cost implicated and environmental interceptions. These tendencies have resulted in the necessity to run a power system in stable conditions [31].

Transient stability; the main focus of this topic involves large disturbances such as loss of generation, faults, and sudden exchanging on or off load changes. Following a sudden disturbance on a power system, synchronous machine frequencies suffer transient deviations from synchronous frequency (50Hz), machine power angles (rotor angles) and power transfer change. For a huge disturbance, these variations might be as big as to reason the machines has been shut down.

However, the transient stability study determines the power angles of machine and speed deviations, frequency of the electrical system, active and reactive power flows of the machines, power flows of transmission lines and transformers, as well as the voltage levels of the buses in the system.

When the system remain stable in the first swing after disturbance, in case of two machines then the system is usually confirmed for other next swings. But in case multi machine it is needful to extend the study to insure that the interaction between machines swinging at different rates does not cause instability at first swing or second swing.

3.3.4 Swing Equation

Free body rotation is one of the natural frequency of the turbine and generator will be at 0HZ where the turbine or generator inertias shift with each other without relative displacement of the individual rotor masses. This free body rotation will show as a low-frequency oscillation about 1 to 2HZ when connected to the power system.

The angle between proportional location of the rotor axes and the resulting magnetic field axis is known as the power angle or torque angle. Normally the proportional location of the rotor axes and the resulting magnetic field axis is constant. The rotor will decelerate or accelerate during any disturbance with respect to the synchronously rotating air gap mmf , and a proportional movement begins. The equation representing this relative motion is recognized as the swing equation [32].

Represent a synchronous generator developing an electromagnetic torque (T_e) and running at the synchronous speed (ω_{sm}), if T_m is the driving mechanical torque.

With neglecting losses and under steady state operation the electromagnetic torque and electromechanical torque.

$$T_m = T_e \quad (3.6)$$

A leaving from steady situation due to a disturbance results in an accelerating ($T_m > T_e$) or decelerating ($T_m < T_e$) torque T_a on the rotor.

$$T_a = T_m - T_e \quad (3.7)$$

If J is the joint moment of inertia of the prime over and generator, ignoring frictional and damping torques, from laws of rotation then gets

$$J \frac{d^2\theta_m}{dt^2} = T_a = T_m - T_e \quad (3.8)$$

Where θ_m is the angular displacement of the rotor proportional to the stationary reference axis on the stator, meanwhile which concerned in the rotor speed proportional to the synchronous speed. The angular reference is selected proportional to a synchronously rotating reference structure affecting with continual angular velocity ω_{sm} that is

$$\theta_m = \omega_{sm}t + \delta_m \quad (3.9)$$

Before disturbance δ_m is the rotor position at time $t=0$, counted from the synchronously rotating reference structure.

We get on rotor angular velocity when take Derivative of equation (1.9)

$$\omega_m = \frac{d\theta_m}{dt} = \omega_{ms} + \frac{d\delta_m}{dt} \quad (3.10)$$

Also the rotor acceleration

$$\frac{d^2\theta_m}{dt^2} = \frac{d^2\delta_m}{dt^2} \quad (3.11)$$

By Substituting (1.11) in (1.4), we have

$$J \frac{d^2 \delta_m}{dt^2} = T_m - T_e \quad (3.12)$$

Multiplying (1.12) by ω_m results in

$$J \omega_m \frac{d^2 \delta_m}{dt^2} = \omega_m T_m - \omega_m T_e \quad (3.13)$$

We write the equation (1.13) in forms of power because we know angular velocity times torque equal to the power.

$$J \omega_m \frac{d^2 \delta_m}{dt^2} = P_m - P_e \quad (3.14)$$

The amount $J \omega_m$ is known the inertia constant and is coded by M. It is regarded to kinetic energy of the rotating masses W_k

$$W_k = \frac{1}{2} J \omega_m^2 = \frac{1}{2} M \omega_m \quad (3.15)$$

Or

$$M = \frac{2W_k}{\omega_m} \quad (3.16)$$

Although M is termed inertia constant, actually it is not constant when the rotor angle deviates from the synchronous speed. However, since ω_m does not change by a large amount before stability is lost, M is evaluated at the synchronous speed and is considered to stay constant, i.e.

$$M = \frac{2W_k}{\omega_{sm}} \quad (3.17)$$

The swing equation in terms of inertia constant becomes

$$M \frac{d^2 \delta_m}{dt^2} = P_m - P_e \quad (3.18)$$

It is more appropriate to write the swing equation in expression of the electrical power angle δ . If p is the number of poles of a synchronous generator, the electrical power angle δ is related to the mechanical power angle δ_m by

$$\delta = \frac{p}{2} \delta_m \quad (3.19)$$

And

$$\omega = \frac{p}{2} \omega_m \quad (3.20)$$

The swing equation in relations of electrical power angle is:

$$\frac{2}{p} M \frac{d^2 \delta_m}{dt^2} = P_m - P_e \quad (3.21)$$

Since power system analysis is done in per unit system, the swing equation is generally phrased in per unit. Dividing (1.21) by the base power S_B and substituting for M from (1.16) results in

$$\frac{2}{p} \frac{2W_k}{\omega_{sm} S_B} \frac{d^2 \delta}{dt^2} = \frac{P_m}{S_B} - \frac{P_e}{S_B} \quad (3.22)$$

There is an important quantity is called H constant or per unit inertia constant

$$H = \frac{\text{Kinetic energy in MJ at rated speed}}{\text{Machine rating in MVA}} = \frac{W_k}{S_B} \quad (3.23)$$

Seconds and its value ranges from 1 to 10 seconds. Depending on the size and types of machines.

By substituting in equation (1.22), we get

$$\frac{2}{p} \frac{2H}{\omega_{sm}} \frac{d^2 \delta}{dt^2} = P_{m(pu)} - P_{e(pu)} \quad (3.24)$$

Where $P_{m(pu)}$ is the per unit mechanical power and $P_{e(pu)}$ is electrical power. The electrical angular velocity is regarded to mechanical

Angular velocity by

$$\omega_{sm} = \left(\frac{2}{p}\right) \omega_s$$

Equation (1.24) in terms of electrical angular velocity is:

$$\frac{2H}{\omega_s} \frac{d^2\delta}{dt^2} = P_{m(pu)} - P_{e(pu)} \quad (3.25)$$

The equation (1.25) is often expressed in terms of frequency f_0 , and to simplify the notation, the subscript pu is omitted and the powers are understood to be in per unit:

$$\frac{2H}{\pi f_0} \frac{d^2\delta}{dt^2} = P_m - P_e \quad (3.26)$$

Where δ is in electrical radian. If δ is expressed in electrical degrees, the swing equation becomes

$$\frac{2H}{180f_0} \frac{d^2\delta}{dt^2} = P_m - P_e \quad (3.27)$$

3.3.5 Swing Equation of Multi Machine Power System

In a multi machine system a common system base must be chosen
Let G_{mach} = machine rating (base) [33]

G_{system} = system base

We can write the equation (2.26) by this form

$$\frac{G_{mach}}{G_{system}} \left(\frac{H_{mach}}{\pi f} \frac{d^2\delta}{dt^2} \right) = (P_m - P_e) \frac{G_{mach}}{G_{system}} \quad (3.28)$$

Or

$$\frac{H_{system}}{\pi f} \frac{d^2\delta}{dt^2} = (P_m - P_e) \text{ pu in system base}$$

Where

$$H_{system} = H_{mach} \left(\frac{G_{mach}}{G_{system}} \right) \quad (3.29)$$

= machine inertia constant in system base

3.3.6 Machines Swinging Coherently

Machines which swing together are called coherent machines. Consider the swing equations of two machines on a common system base [33].

$$\frac{H_1}{\pi f} \frac{d^2 \delta_1}{dt^2} = P_{m1} - P_{e1} \quad (3.30)$$

$$\frac{H_2}{\pi f} \frac{d^2 \delta_2}{dt^2} = P_{m2} - P_{e2} \quad (3.31)$$

Since the machine rotors swing together (coherently or in unison),

$$\delta_1 = \delta_2 = \delta$$

Adding Eq. (1.30) and (1.31),

$$\frac{H_{eq}}{\pi f} \frac{d^2 \delta}{dt^2} = P_m - P_e \quad (3.32)$$

Where

$$P_m = P_{m1} + P_{m2}$$

$$P_e = P_{e1} + P_{e2} \quad (3.33)$$

$$H_{eq} = H_1 + H_2$$

The two machines swinging coherently are thus reduced to a single machine as in Eq. (1.32). The equivalent inertia in eq. (1.33) can be written as

$$H_{eq} = H_{1mach} \left(\frac{G_{1mach}}{G_{1system}} \right) + H_{2mach} \left(\frac{G_{2mach}}{G_{2system}} \right) \quad (3.34)$$

The above results are easily extendable to any number of machines swinging coherently.

But if the two machines swinging non coherently the relative power angle

$$\delta = \delta_1 - \delta_2 \quad (3.35)$$

Subtracting Eq. (1.29) and (1.30)

$$\frac{H_{12}}{\pi f} \frac{d^2 \delta_1}{dt^2} = P_{m12} - P_{e12} \quad (3.36)$$

Where

$$H_{12} = \frac{H_1 H_2}{H_1 + H_2} \quad (3.37)$$

$$P_{m12} = \frac{H_2 p_{m1} - H_1 p_{m2}}{H_1 + H_2} \quad (3.38)$$

$$P_{e12} = \frac{H_2 p_{e1} - H_1 p_{e2}}{H_1 + H_2} \quad (3.39)$$

3.3.7 Methods for Improvement Transient Stability

A power system may be subjected to huge disturbance, with this disturbance a power system will undergo from an emergency case and this case may be very severe. The time of transient state is very short and the synchronous machines may be out of synchronism. Then, all power system must have control techniques to save on stability of the system at every emergency case.

Therefore, stability control techniques and transmission system proposals have also been evolved to increase general system stability. The control parameters and factors that improve transient stability are explained as below subsections [33].

1. Excitation system control: when a fault happens, the voltage at all buses of the system is reduced. Then the automatic voltage regulators senses that the voltage is reduced at generator terminals, which performance inside the excitation system to repair generator terminal voltages. The fundamental topical of excitation system is to damp the first rotor angle swing resulting the fault. This is accomplished by improving the voltage practical to the field winding of the generator through action of the amplifiers in the forward path of the voltage regulators. The rises air-gap flux uses a restraining torque on the rotor, which be wont to leisurely down its motion.

2. Turbine valve control: recent electro dynamic turbine-governing systems have the capability to close turbine valves to reduce unit acceleration through severe system

faults near the unit. Directly the control action starts the valve closing after it is sensing changes between mechanical input and electrical output, caused decrease the input power.

3. Earlier fault clearing times: fast circuit breakers and safety units are used to decrease the fault clearing time. That will reduction the rotor acceleration of the synchronous machine.

4. Decreasing the reactance of transmission line: another method used to rise the general system stability is to decrease the reactance of transmission lines. System proposal plans aimed at dropping system reactance consist of:

a- Minimum transformer reactance

b- Series compensation of lines.

c- Extra transmission lines in parallel between two points are a common means of decreasing reactance.

5. Rising the system voltage: rising the voltage leads to a rise in the electrical power of the system at an identified mechanical power, then it is helps the system to keep stability of the system.

6. Increasing the inertia constant H of the machines: the greater H continual is the lesser angular swing will be through any time period. This inertia constant must be taken into computation in the plan stage of an electric station to supply additional stable machine at stark disturbance.

7. Using braking resistance: this practice is measured a good method or device to increase transient stability of the power system. It performances as a load injected quickly in the system to exhaust the transient power of generators that effects after a big disturbance.

8. Using FACTS devices: Flexible Alternative Current Transmission System (FACTS) controllers are a new techniques and very effective devices, also possible method to growth the power flow controllability and improve stability of power system. The

FACTS device are different types with connecting with power system, may be connected in series or shunt or a mixture of series and series shunt [33].



CHAPTER 4

FACTS , STATIC VAR COMPESATOR (SVC) AND POWER SYSTEM STABLIZER (PSS)

4.1 Flexible alternative current transmission system (FACTS)

Modern power system becoming actual problematic to completely use the present transmission system properties due to several causes, like environmental regulation, principal estimate, rights of techniques problems, building cost of new transmission lines, deregulation plans, etc. Electric services are currently required to operate their system in such a way that makes superior application of surviving transmission aperiens. Flexible Alternative Current Transmission System (FACTS) controllers, created the fast evolution of power electronics technology, have been presented in period new years for enhanced employment of existing transmission aperiens. By the growth of FACTS performance, it develops probable to rise the power transfer controllability and boost power system's stability. Newly, Flexible Alternative Current Transmission System (FACTS) controllers have been represented to enhance the transient stability of power systems [34, 35].

During the previous period, FACTS technology such as a control devices have been suggested and employed.

Enforcement of FACTS equipment in power systems, indications to superior improvement of power system in numerous facets.

By using FACTS devices and their convenient control can be improved, damping oscillation Voltage stability and power system stability [36].

Here different formulae of FACTS equipment, some of which are connected in series and the others are connected in shunt or a combination of series and series shunt connected to transmission lines. The FACTS equipment is group of controllers instead single high power controller which can be connected in coordination or individually with other to control many of the connected system limitations such as voltage, phase angle ,current, impedance, and of oscillations at alteration frequencies beneath the average frequency.

Amongst all FACTS equipment, static var compensators (SVC) is one of more effective role in reactive power compensation and voltage provision since of its attractive steady state presentation and working appearances. The SVC be able to also rise transmission ability, damping low frequency oscillation, and enhancing transient stability [37].

4.1.1 Facts Controllers

Flexible AC Transmission System (FACTS), Alternating current transmission systems blending power electronic-based and more static controllers to improving controllability and boost power transfer ability.

FACTS Controller a power electronic-based system and other static equipment that there be able to other static Controllers which are not created of power electronics source control of several alternating current transmission system parameters. Figure 4.1, shows general symbol of FACTS devices.

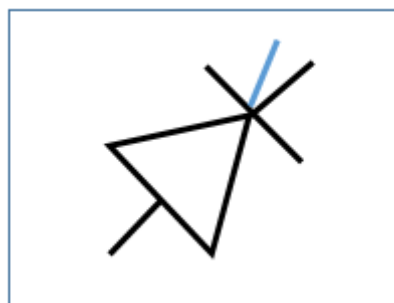


Figure 4.1 General Symbol of FACTS Devices.

FACTS devices controller is categorized into four parts that connected to transmission lines.

- a. Series FACTS Controllers
- b. Shunt FACTS Controllers
- c. Combined Series-Series FACTS Controllers
- d. Combined Series-Shunt FACTS Controllers

a. Series FACTS Controllers, this type of FACTS controller coupled in series to the line with principle injects voltage and with changing impedance like reactor, capacitor or a power electronic created changing provenance as showed in figure 4.2. The series FACTS Controllers only equipping variable reactive power while the voltage and line current are same phase quadrature. Another phase relation will contain management of active power as well. [35, 38].

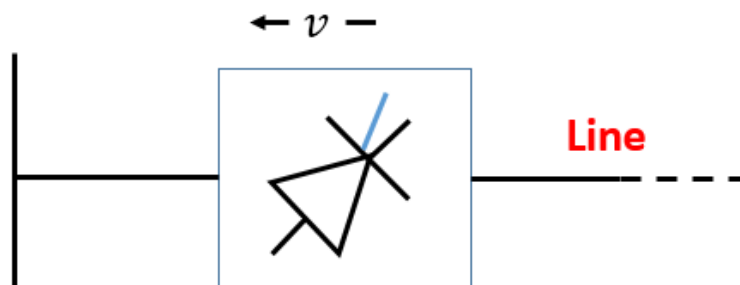


Figure 4.2 Series FACTS Controller

b. Shunt FACTS Controllers: this type of FACTS controller connected in shunt with the line with principle injects voltage and with inconstant impedance like reactor, capacitor or a power electronic created inconstant current as showed in figure 4.3. The series FACTS Controllers only equipping inconstant reactive power while the current is in phase quadrature with the line voltage. Other phase correlation include control of active power as well [35, 38].

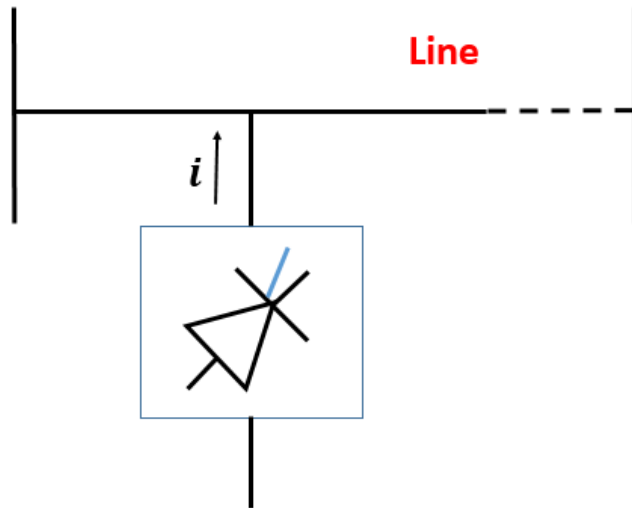


Figure 4.3 Shunt FACTS Controller

c. Combined Series-Series FACTS Controllers: this type of FACTS controller are the grouping of isolation Series FACTS Controllers which are controlled in a coordinated method in many transmission system. Figure 4.4, show this type of controllers. This configuration of FACTS controllers is transfers active power via power link amid the lines and increasing series reactive power compensation for all lines. The existence of power link among series controllers known this formation as “Unified Series-Series Controller” [35, 38].

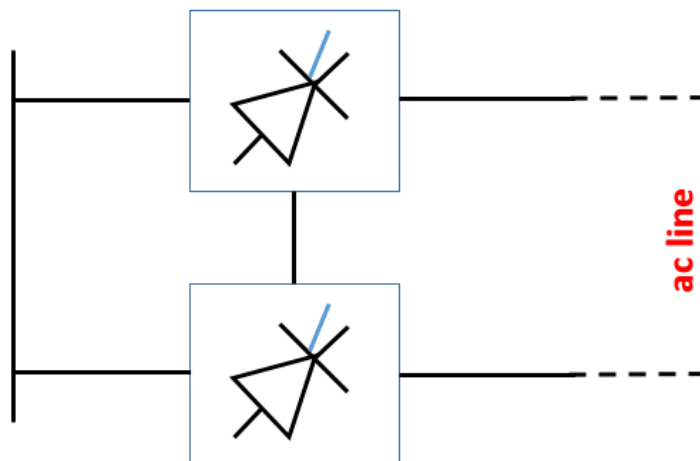


Figure 4.4 Unified Series-Series FACTS Controller

d. Combined Series-Shunt FACTS Controllers: - this type of FACTS controller are the grouping of isolation Series and shunt FACTS Controllers which are controlled in a coordinated method in many transmission system as show in figure 4.5 a , Or a Unified Power Flow Controller with series and shunt elements as show in figure 4.5 b. with this type of controller can be active power interchange among the series and shunt controllers by power link when the Shunt and Series FACTS Controllers are unified. [35, 38].

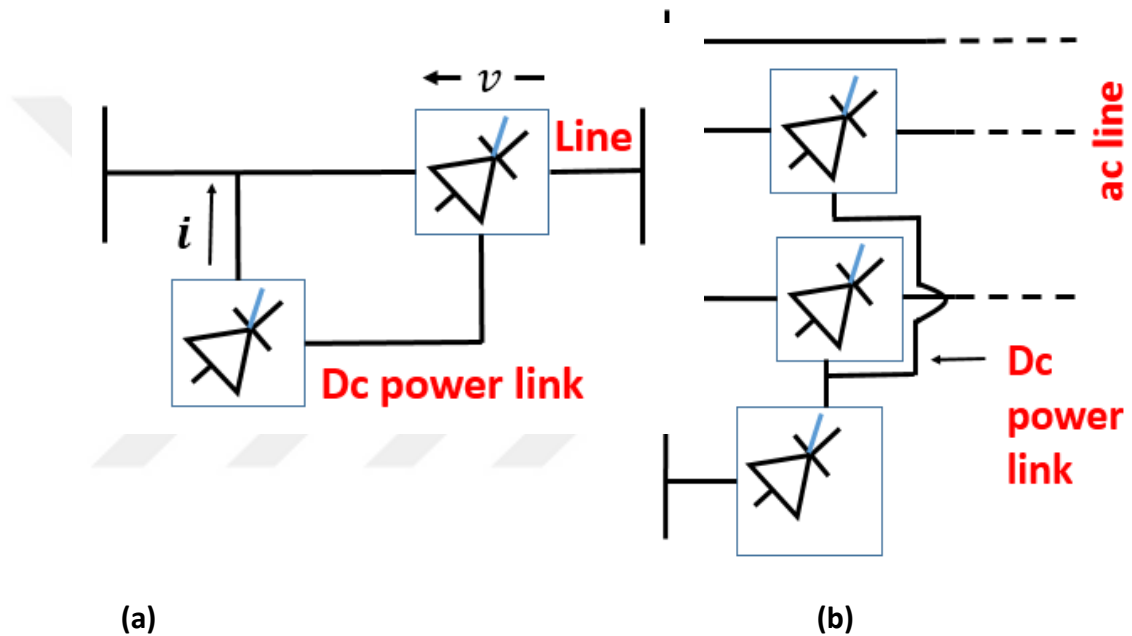


Figure 4.5 Coordinated (a) Series and (b) Shunt Controller

4.2 Static Var Compensator (SVC)

4.2.1 General Information about Static Var Compensator (SVC)

Static Var compensator is a member of FACTS family, which is based on power electronics. SVC is one of the shunt joined FACTS equipment. According to definition of IEEE, Static Var Compensator (SVC): A shunt-linked static var producer or absorber whose productivity is set to conversation capacitive or inductive current so as to keep or control exact limitations of the electrical power system. The basically objective is to source a rapid performing, exact, and changeable quantity of reactive power to the system to which they are joined. SVCs achieve this by switching in or

out several thyristor-switched capacitors (TSCs), and by regulating the firing angle of a thyristor-controlled reactor (TCR) as shown in figure 4.6[13]. Also there are some SVCs equipping a steady quantity of reactive power with included a numbers of fixed capacitors (FCs) [13].

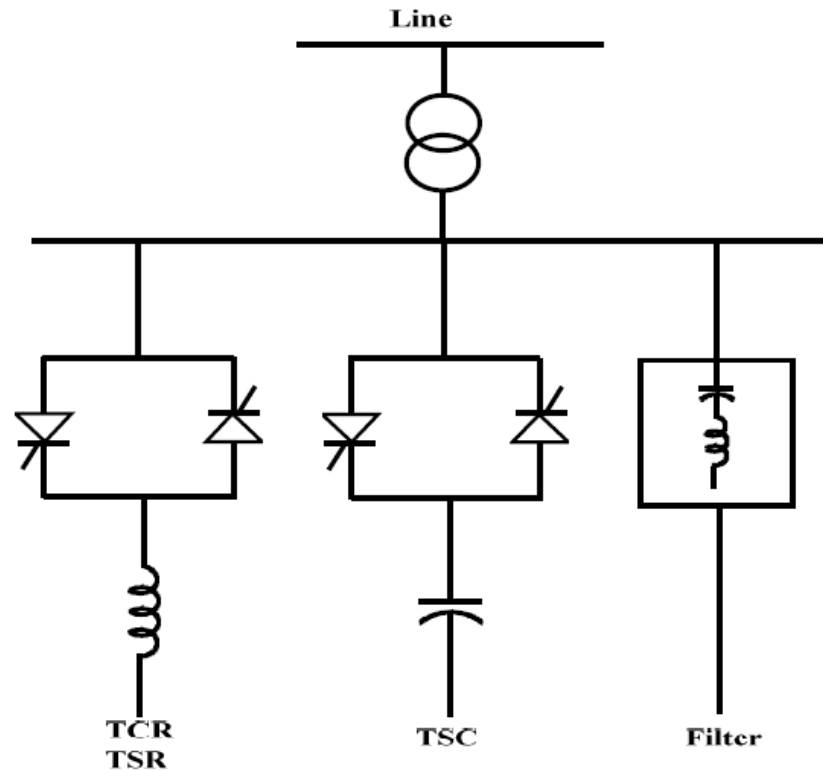


Figure 4.6 basic configuration of SVC

An SVC includes capacitors and reactors connected in shunt by a thyristor, by which switching can be quickly controlled. Also can using SVC for voltage compensation at the end of the receiving ac transmission lines, thus substituting groups of shunt capacitors. SVCs presentation a numeral of benefits by comparing with groups of shunt capacitors, like abundant boost control of compositing voltage of receiving end of the ac transmission line and throughout change of the system load the line stability is improved.

Generally SVCs with compensating dynamic reactive power will correct dynamic power factor especially in manufacturing factories operating that needs big unsystematic summits of reactive power. The power factor of the plant can be increase

with using SVC the voltage variations in input of the plant, and decrease operating cost of plants [39]. Figure 4.7[39] shown the SVC substation.



Figure 4.7 SVC Substation

4.2.2 Categories of SVCs

Generally SVCs divided in tow elementary type, it is depending on group of the components that explained in this study, and those types are the TCR-FC category and the TCR-TSC category. Both categories of SVCs are demonstrate in detail in the next two subsequent.

4.2.2.1 SVC of the TCR-FC category

The SVC of the TCR-FC category consists of a thyristor control reactor-fixed capacitors (TCR-FC) that TCR absorbs reactive power from the ac power system to which the SVC is joined, with many fixed capacitors (FC) s, which source reactive power to the system which the SVC is connected. Figure 4.8[39] represent circuit diagram of an SVC of the TCR-FC category [39].

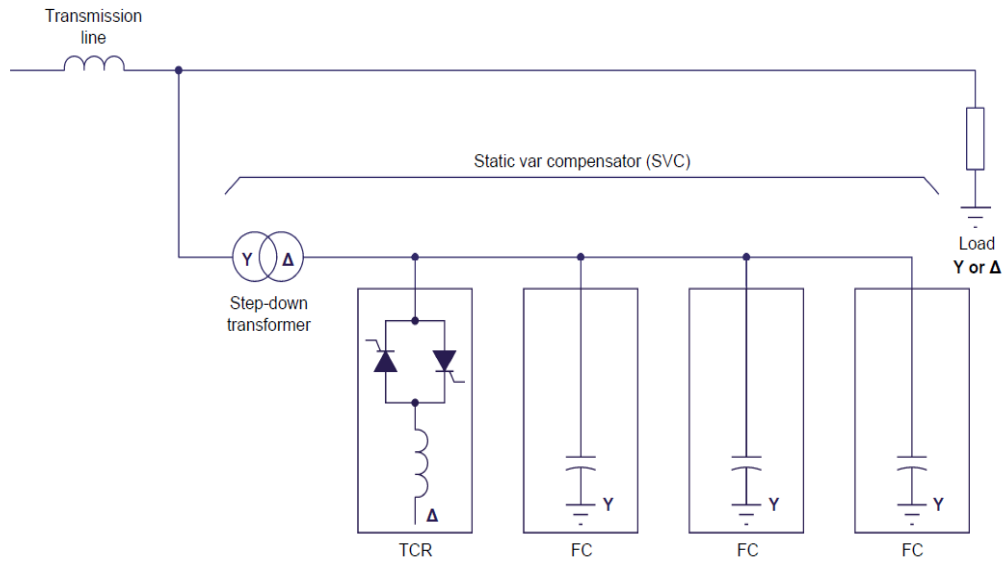


Figure 4.8 Basic single-line circuit drawing of an SVC of the TCR-FC category

FCs cannot be switched in or out, because reactance quantity is fixed (they source a constant quantity of reactive power). Furthermore the quantity of reactive power absorbed by the TCR, also be able to set as required from a greatest rate (TCR firing angle =90) to zero (TCR firing angle =180). Figure 4.9[39] show reactive power, current, and the main voltage parameters linked to one leg (phase) of an SVC of the TCR-FC category [39].

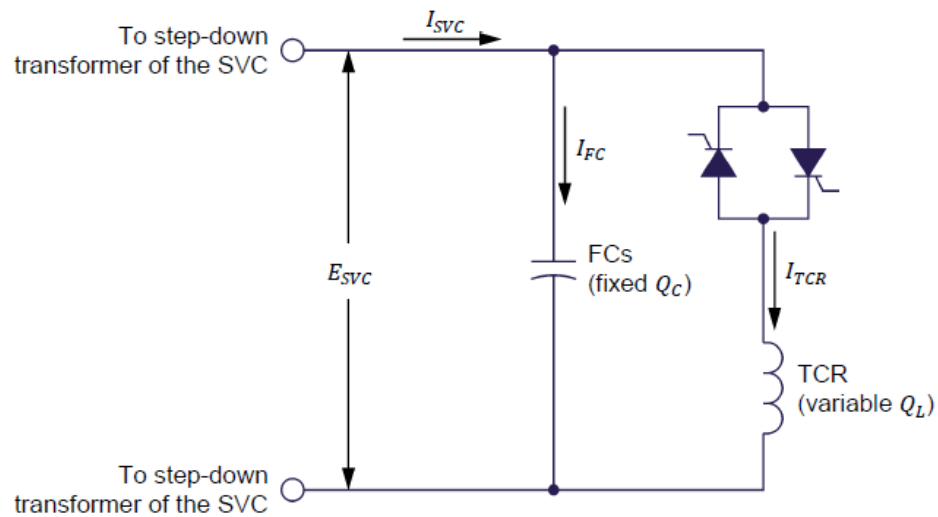


Figure 4.9 Basic circuit illustration of one leg (phase) of an SVC of the TCR-FC-category display the major voltage, current, and reactive power parameters

The composition voltage in the ac power system when joined to an SVC of the TCR-FC category the quantity of reactive power required so the TCR firing angle must adjusted and reactive power absorbed by the TCR substitutes the fixed quantity of reactive power (Q_c) abounding by the FCs. When the system absorbs reactive power then the SVC has to source reactive power to compensate the voltage in the power system that means the quantity of reactive power absorbed by the TCR reductions because the TCR firing angle is raised. SVC supply the maximum reactive power and TCR absorb the minimum the reactive power. The quantity of reactive power supplied by the SVC is maximal, when the TCR is set to the non-conducting state. The reactive power ranking of the FCs and the highest quantity of reactive power are equal of an SVC of the TCR-FC category.

Contrariwise, while the system supplies reactive power then the SVC has to absorb reactive power to compensate the voltage in the power system that means the TCR must absorb enough reactive power to, initially, the FCs supplying the constant quantity of reactive power that completely balance, then, furthermore, absorb enough additional reactive power to compensate for the reactive power provided by the ac power system linked to the SVC. TCR-FC type of an SVC require the power rating of the TCR to be upper than that of the FCs, By another way the SVC that connected to power system would not be capable to absorb reactive power. Figure 4.10[39] explain the reactive power interchange discriminatory.

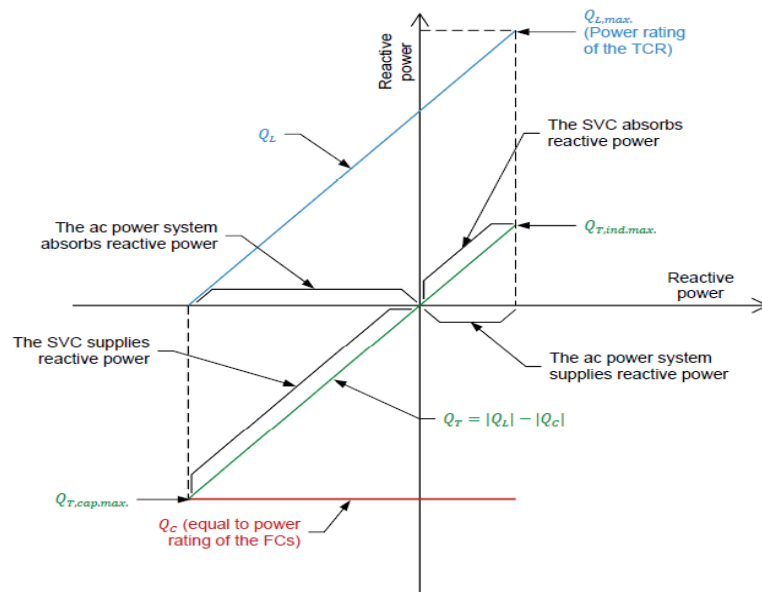


Figure 4.10 Reactive power interchange typical of an SVC of the TCR-FC-category.

As explained in above figure, the SVC of the TCR-FC category interchanges through the ac power system to which it is linked, the full reactive power Q_T is equal to the difference between changeable reactive powers Q_L absorbed by the TCR and the constant reactive power Q_C provided by the FCs. The full reactive power Q_L of an SVC of the TCR-FC category therefore domains from the highest capacitive reactive power $Q_{T.cap.max.}$, which is equal to the reactive power ranking Q_C of the FCs, to the highest inductive reactive power $Q_{T.ind.max.}$, which is equal to the difference between reactive power rankings $Q_{L.max}$ of the TCR and the reactive power ranking Q_C of the FCs. The SVC supplies reactive Power, while the whole reactive power Q_T in the SVC is negative. Conversely, the SVC absorbs reactive power when the total reactive power Q_T in the SVC is positive.

The control and observing components of the SVC must be more successfully so as to SVC of the TCR-FC category to work correctly. When the SVC connected to the power system, there are two major mission that the SVC controller necessity implement to coverage the reactive power requisite are shortened below.

- To accurately meet between the quantity of reactive power that necessity be absorbed by the TCR and the quantity of reactive power required for exact compensation of the voltage in the ac power system linked to the SVC, captivating into calculation the quantity of reactive power provided by the FCs.
- To regulator the TCR firing angle (and, therefore, the rms rate of the current influx in the TCR) therefore that the quantity of reactive power absorbed by the TCR agrees to the value resolute on top of [39].

4.2.2.2 SVC of the TCR-TSC category

The SVC of the TCR-TSC category consists of a thyristor control reactor- and several thyristor switched control (TCR-TSC), that TCR absorbs reactive power from the ac power system to which the SVC is joined, with many thyristor switched control (TSC), which source reactive power to the system which the SVC is joined. Figure 4.11[39] represent circuit drawing of an SVC of the TCR-FC category [39].

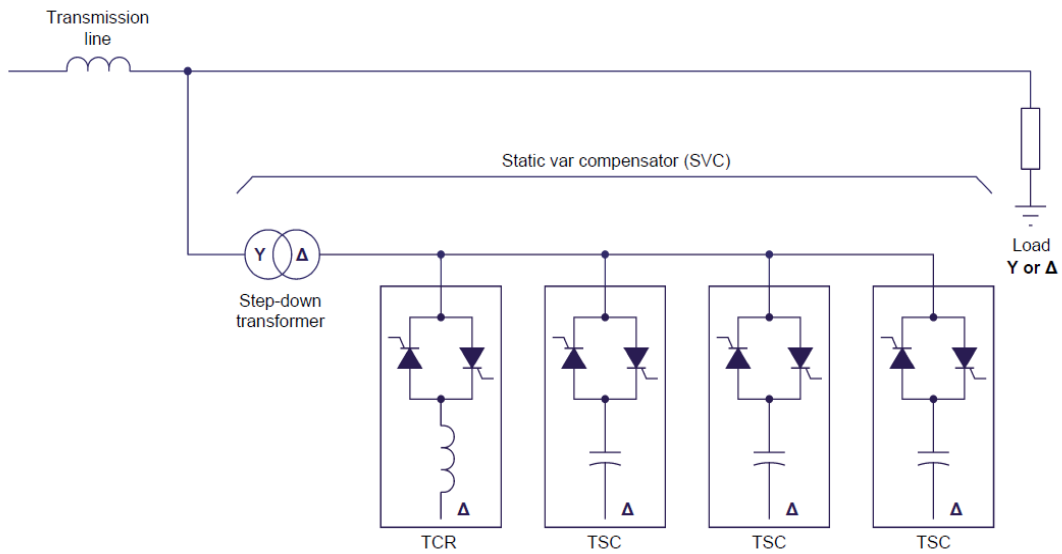


Figure 4.11 Basic single-line circuit drawing of an SVC of the TCR-TSC category.

According to the above figure, the capacitors of this category of SVC are controlled by thyristors and can only be switched in or switched out. By changing the number of TSCs that are switched in, the quantity of reactive power provided by the TSCs can only be adjusted gradually. The TSCs supply the maximum amount of reactive power when the higher the number of TSCs that are switched in. The TCR can be adjusted as required from a fully-conducting state (TCR firing angle = 90°) to a non-conducting state (TCR firing angle = 180°), thus allowing exact and constant adjustment of the quantity of reactive power which the SVC interchanges through the ac power system to which it is connected. Figure 4.12[39] shows the circuit diagram of reactive power, current, and the main voltage parameters joined to one leg (phase) of an SVC of the TCR-TSC category.

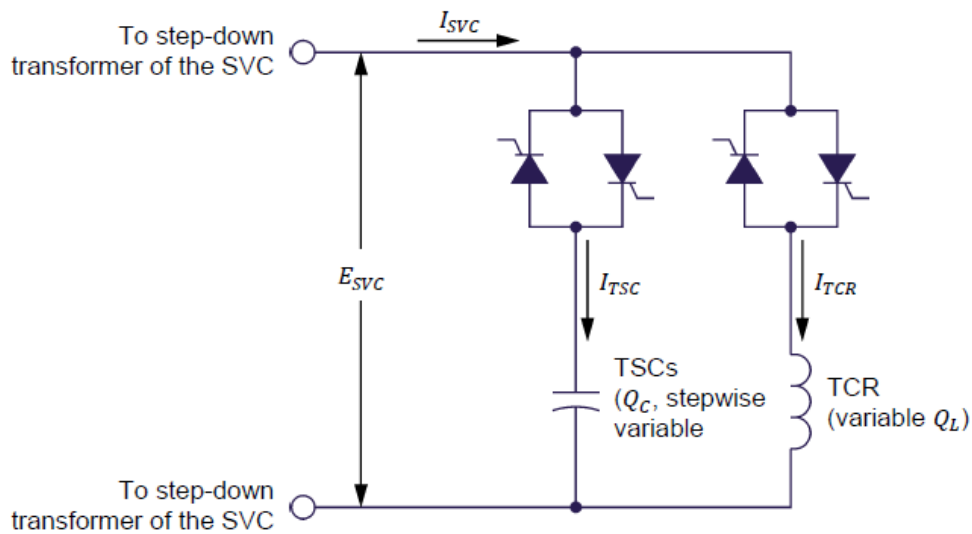


Figure 4.12 Basic circuit diagram of one leg (phase) of an SVC of the TCR-TSC category Displaying the major voltage, current, and reactive power parameters

The composition voltage in the ac power system when joined to an SVC of the TCR-FC category the quantity of reactive power required so the all TSCs are switched out and the TCR is regular with case of the non-conducting (TCR firing angle = 180°). When a number of TSCs are switched in that mean the SVC has to source reactive power to compensate the voltage in the ac power system so as to the reactive power they source overdoes the quantity of reactive power the SVC to source compensate voltage of the ac power system. The quantity of reactive power absorbed by the TCR properly offsets the surplus of reactive power provided by the TSCs, when the TCR firing angle is then adjusted.

In case firing angle of the TCR is set to 180° , the reactive power ranking of the TSCs that are presently switched in ,when the quantity of reactive power increases and exceeds to compensate the voltage in the ac power system that supplied by SVC. On the other hand, in case firing angle of the TCR is set to 90° the reactive power ranking of the TSCs that are presently switched out, while the quantity of reactive power decreases to compensate the voltage [39].

In the case when the TCR firing angle regular on 180° that mean the SVC be source to increasing compensate voltage of the ac power and the quantity of reactive power overrides from the TSCs that are presently switched in and other TSCs switched in gradually. In the other case when the quantity reactive power of the ac power system less than that the SVC provides then the TCR firing angle regular on 90° and TCR absorb the quantity reactive power so the TSCs necessity be switched out. In the two cases when the system sourced to reactive power then the TCR firing angle must be readjusted and absorb the reactive power by SVC, the higher quantity reactive power provide to the ac system when the TCR firing angle arranged on 180° that mean nonconducting case, and all TSCs switched in, contrariwise the higher quantity of reactive power is absorb by SVC when the TCR firing angle arranged on 90° and all TSCs switched out.

Figure 4.13 explain the reactive power interchange discriminatory [39].

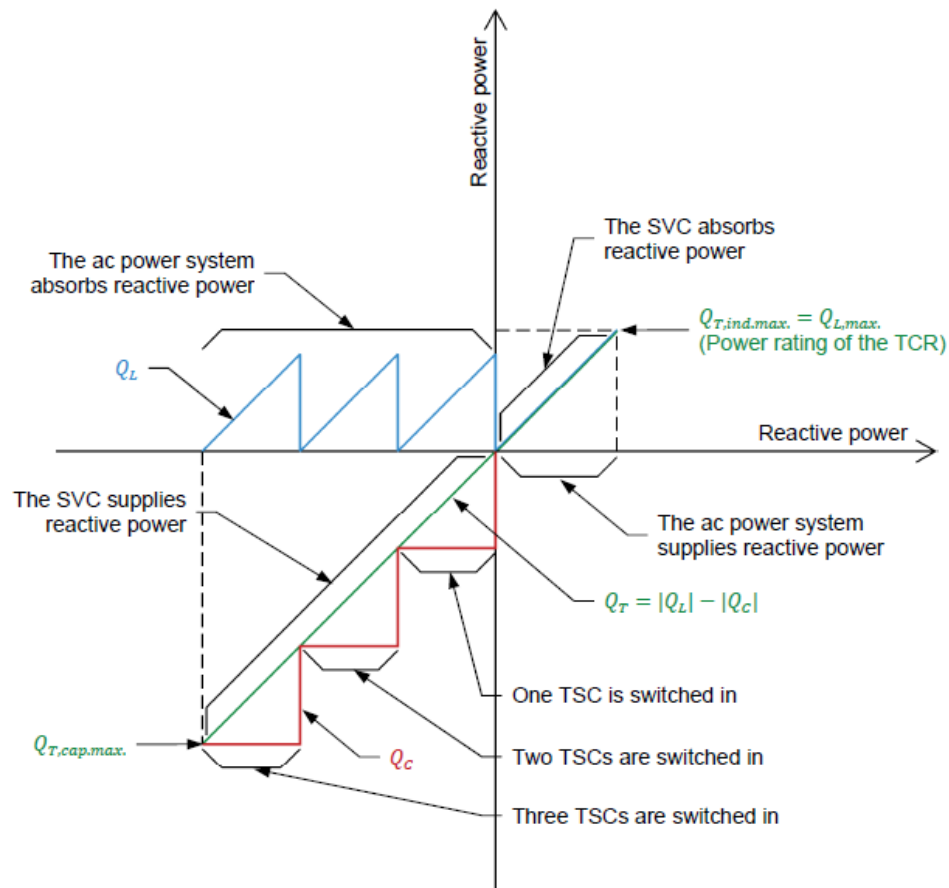


Figure 4.13 Reactive power interchange typical of an SVC of the TCR-TSC-category

As illustrated in above figure, The difference between the changeable reactive power Q_L absorbed by the TCR and the reactive power Q_C (gradually changeable) provided by the TSCs is equal to the full $Q_{L.max}$ reactive power Q_T which an SVC of the TCR-TSC type interchange with the ac power system to which it is linked. The full reactive power Q_L of an SVC of the TCR-TSC category therefore arrays from the highest capacitive reactive power $Q_{T.cap.max}$, which is equal to the full reactive power ranking of the TSCs, to the highest inductive reactive power $Q_{T.ind.max}$, which is equal to the reactive power ranking $Q_{L.max}$ of the TCR. The SVC is linked to power system provides reactive power, when the full reactive power Q_T in an SVC is negative. Contrariwise, the SVC is jointed to power system absorbs reactive power, when the full reactive power Q_T in an SVC is positive.

The control and observing components of the SVC must be more successfully so as to SVC of the TCR-TSC category to work correctly. When the SVC jointed to the power system, there are four main assignment that the SVC controller must execution to meet the reactive power requisite are shortened below.

- By the SVC is linked to the power system can define the numeral of TSCs necessary and the quantity of reactive power that the TCR must absorb to exactly meet the reactive power requisite.
- To match the necessary quantity of TSCs resolute above by switch TSCs in and out.
- To control and regulate the TCR firing angle (and, consequently, the rms value of the current flowing in the TCR) so that the quantity of reactive power absorbed by the TCR agrees to the value resolute above.
- To reduce voltage transients in the ac power system to which the SVC is linked via correctly coordinate the TSC switching control and TCR firing angle control [39].

4.2.3 Control system of SVC

- The control system of SVC is displayed in Figure 4.14[40] It consists of :
- Measurement system.

- Voltage regulator.
- Distribution unit.
- Synchronizing system.

The measurement system part measures the voltage of positive-sequence to be controlled. Measurement system based on Fourier transformation using a one-cycle running average. A voltage regulator part a voltage regulator that uses the voltage error i.e. the difference among the measured voltage V_m and the reference voltage V_{ref} is used to determine the SVC susceptance B, which is required to retain the system voltage fixed. A distribution part that determines the TSCs (and ultimately TSRs) that must be switched in and out, and calculates the firing angle M of TCRs. A synchronizing system consists of a pulse producer that send suitable pulses to the thyristors and a phase-locked loop (PLL) synchronized on the secondary voltages [40].

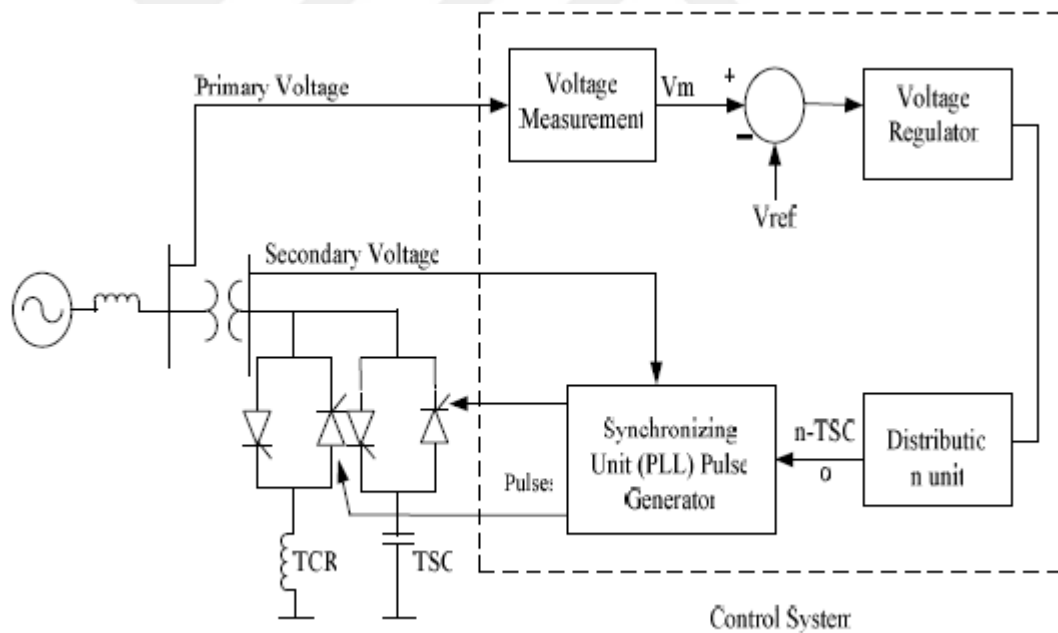


Figure 4.14 the Control System of SVC

4.2.4 SVC V-I Characteristic

The steady state control characteristics of a mutable impedance form SVC is shown in Figure 4.15[40]. Generally the SVC worked in two various modes, voltage regulation mode and var control mode (the SVC susceptance is saved constant), the SVC is worked in voltage regulation mode, it performance the following V-I characteristic.

While the SVC susceptance B remain in the highest and lowest susceptance values enjoined by the total reactive power of capacitor banks ($B_{c_{max}}$) and reactor banks ($B_{L_{max}}$), the voltage is controlled at the reference Voltage V_{ref} . In spite of, normally use the voltage droop between (1- 4%) at maximum reactive power output [40]. The V-I characteristic has the slope is positive (3 - 5%) , it is helps stable parallel action of more than one SVC joined at the same or adjacent buses and avoid SVC beating the confines too frequently [41].

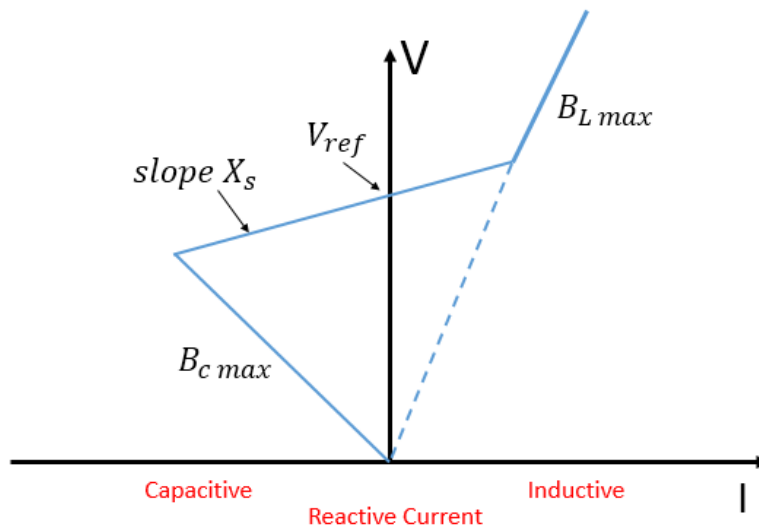


Figure 4.15 the V-I Characteristic Curve of SVC

The following three equations is explained the V-I characteristic of SVC [40].

The regulation range of SVC is ($B_{c_{max}} < B < B_{L_{max}}$)

$$V = \frac{1}{B_{c_{max}}}$$

$$V = V_{ref} + X_s \cdot I$$

SVC is fully capacitive ($B = B_{c_{max}}$)

$$V = \frac{1}{B_{L_{max}}}$$

Where

V = positive Type equation here.sequence voltage (p.u.)

I =Reactive current (p.u. / P_{base}) ($I >$ indicates an inductive current)

X_s = Slope or droop reactance (p.u. / P_{base})

B_{cmax} = Maximum capacitive susceptance (p.u. / P_{base})

With all TSC_s in service, no TSR or TCR

B_{Imax} = Maximum inductive susceptance (p.u. / P_{base})

With all TSR_s in service or TCR_s at full conductive, no TSC

P_{base} = Three phase base power

4.2.5 SVC Component

4.2.5.1 General Performance Index of SVC

- The dynamic capacity of SVC is between (0 – 400)MVar
- Control-base rated voltage on the bus is between (6 – 500)KV
- Rated voltage of SVC is between (6 – 66)KV
- Response time of controller is less than (15)ms
- Availability of SVC is more than (99%)
- Biggest loss of SVC is less than (0.8%)[42]

4.2.5.2 Structure of SVC

Thyristor controlled reactor (TCR) type of SVC is fundamentally formed capacitor (filter branch and TCR branch, containing thyristors valves, control and protection system, cooling system, TCR reactor and other devices.

a. Control and protection system

The control system is layered and distributed it is help SVC to be simple and strengthen and reliability. Also the control system as shown in figure 4.16[42] based on digital

signal parallel processing can recognize the calculation of the real time control signal, and the response time of the controller less than 10ms. The control system supply with local and remote operator workstation to supervise all devices in real time and the suitable human-machine interface (HMI). With adopting dual excessive digital protection caused to the control system is fast, flexible major protection and microcomputer protection is safe and reliable. The control system is providing several control modes, like synchronous three-phase control, split control and three-phase equilibrium, reactive power and voltage control. Adopting an assortment of communication to easily communication with other station automation system because it is need the high-speed data transfer [42].



Figure 4.16 Control and Protection System of SVC

b. Thyristors valves

The structure of thyristors valve as shown in figure 4.17[42] is very strong and compact with multilayer shape, and the frame adopts the private metallic material. The thyristors valves is built up of thyristors which can hold out the system maximum over current/overvoltage with the reactor. Also the thyristors valve has capability the smooth dynamic response and high potential taken from the high potential panel and triggering. It adopts photoelectric triggering mode with anti-jumping ability, which can guarantee the SVC operating in safe and reliability, efficient and appropriate maintenance:

- Rated voltage from 6 to 66 KV.
- Rated current of 4000A (phase current).
- Trigger style is photoelectric trigger.
- Cooling process is closed-loop pure water cooling, or high efficient air-cooling.
- Gives the special capability of preventing and hold out false firing.
- Normal firing system and forced-firing system.
- Overvoltage protection is safe.
- Idealistic static and dynamic voltage sharing circuit. [42]



Figure 4.17 Thyristors valve of SVC

c. Cooling system

There are two method to cooling the SVC that is explained below

1. Closed-loop pure water-cooling

The control system, accuracy design of regulation and protection function of SVC must be running under cooling and safe temperature. Several parameters are show in real time, such as cooling water temperature, cooling water flex, and cooling water pressure, cooling water resistivity, valve hall temperature and water level in the vessel. All core components must choose high quality product. The water-cooling control

system will send alarm signal to the SVC control system in case leakage of the water more than normal and setting value. Also the water-cooling control system prevent the water freeze which ability ensure the circulating cooling water not to freeze in the cold places. Also has annual availability not less than (99.5%) [42].figure 4.18 (a) and (b) [42] shows cooling system with closed loop.

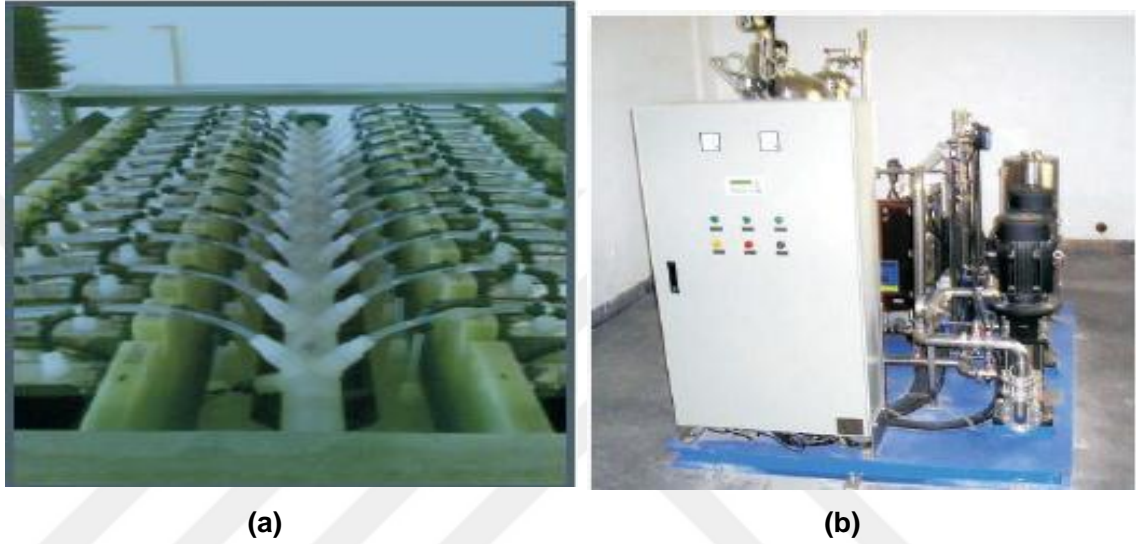


Figure 4.18 (a) Thyristors valve pipe, (b) closed-loop pure cool-water system

2. High efficient Air-cooling

This method having high heat transfer efficiency with heat transferred by working media phase change.it is more safely in running and reliably, preserve high efficiency and conveniently. Air-cooling is more appropriate for small and medium size capacity of SVC as shown in figure 4.19[42]. Also this type of cooling system no corrosion, no pollution and low noise. [42]



Figure 4.19 High efficient air-cooling system

d. Filter Banks

Filter banks as shown in figure 4.20[42] consist of many numbers of filter branches. They supply capacitive reactive power. The harmonic generated via the load and the TCR are needed the filtering of harmonics [42].



Figure 4.20 Filter Banks of SVC

e. Thyristors control reactor (TCR)

TCR is dry, air-core and epoxy resin curing. Each phase may be divided into two reactors. The manufacturing error from each phase is ($\pm 3\%$) and for three phase is ($\pm 2\%$). Adopting a structure of multiple conductors wound in parallel and multiple enclosure, and adopting small round section aluminum wires as coil conductor, which ability guarantee low swirl current and loss current, and equal voltage distributing along height of coils. TCR is more suitable and simple for installation and maintenance, also no tinder, and safely and reliably in running. TCR no need to cooling system it is natural cooling. [42].figure 4.21[51] shows TCR reactor of SVC.



Figure 4.21 TCR reactor of SVC

f. Other equipment

There are several equipment connected with SVC such as circuit breakers, isolating switches, surge arresters, current transformers etc. those devices give the guarantee and overall performance of SVC [42].

4.2.6 Modelling of SVC

In case of steady state analysis, it is enough to model the steady state control characteristics of SVC. For low frequency phenomena and AC network transients are neglected in case transient stability, steady state representing of SVC may be enough as a first guesstimate. The dynamics of SVC controller used to model the damping contribution of SVC. An exemplary transfer function modelling of the SVC controller is explained in figure 4.22[41]. The output is B_{svc} and the delays show in by the GPG are modelled approximately via the transfer function.

$$G_c(\delta) = \frac{e^{-\delta T_d}}{1 + \delta T_s}$$

Where T_d is nearly $T/12$ for a six pulse converter and T_s is $T/4$ where T is the period of supply voltage. T_s Symbolizes the transducer time constant. Filters are neglected in this model [41].

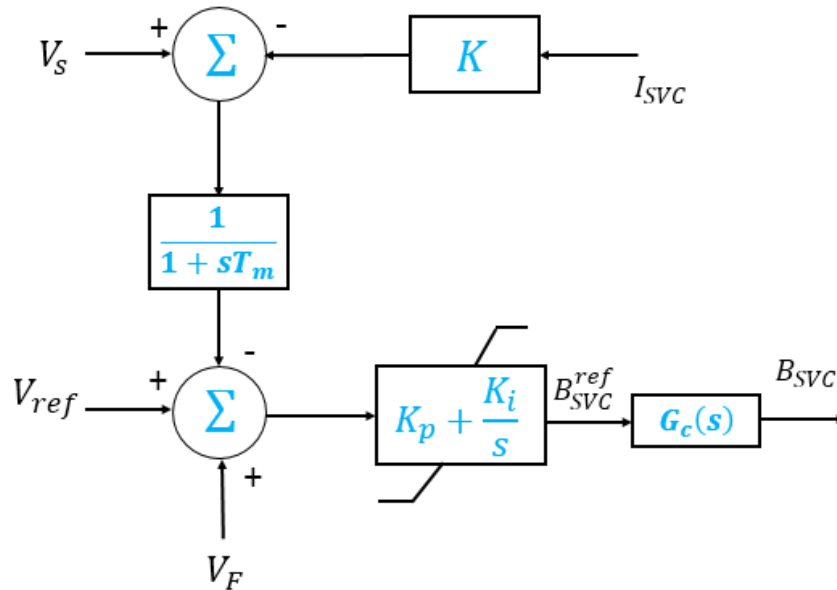


Figure 4.22 Model of SVC controller

A time-varying susceptance B_{svc} is the output of SVC. The implication of this in the system results in a time changing admittance matrix which can be intricate. By the use of compensation theorem, the implication of a single SVC in the network can be handled which enables the calculation of SVC current by Thevenin's equivalent of the system at the SVC bus. To calculate the SVC current must be updated this equivalent at every time step [41].

4.3 Load Modeling

4.3.1 General Information on Load Modeling

The load modelling is very substantial in stability studies. The problem in the evaluation of dynamic performance of power system is posed by the difficulty in obtaining data, not by the complexity in load models. During early days, when AC network analyzers were used for study, the representation of load is simplicity by treating them as constant impedances, it was common for appropriateness in calculations. Nowadays digital computer programs use instead AC network analyzers, the practice of modelling loads as constant impedances was continued and justified for the following causes [41].

- The representation of the load is less critical, for first swing stability of generators feeding radially into a load center.
- The solution will be simple with use constant impedance loads result in linear network equations.
- Obtain data on the response of system loads to disturbances are tricky and not available [41].

By the way, there are several efforts to obtain the data on load by measurements at high voltage substations [44, 45].

The study of stability of power system and power flow, the mutual exercise is to show the composite load characteristics as seen from majority power delivery points. As explained in figure 4.23[38], the total load characterized at a transmission substation (bus A) commonly consists of, in addition to the connected load equipment, impact

step-down transformers of substation, subtransmission feeders, distribution transformers, distribution feeders, and reactive power compensation equipment [38].

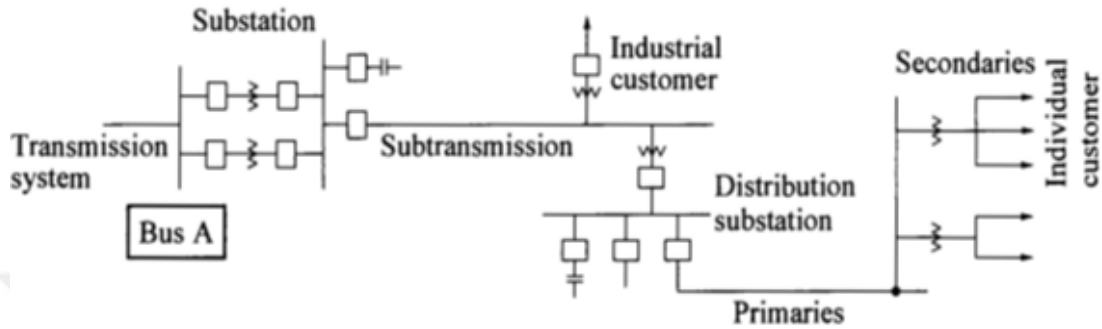


Figure 4.23 Power System Configuration Identifying Parts of the System Represented as load at a Bulk Power Delivery Point Bus A

The importance of load modelling is extremely felt in voltage stability analysis. The voltage collapse is major problem in power system, it is critically dependent on the response of the system load.

The various load of power system is a mix of the following components

- (a) Residential
- (b) Commercial
- (c) Industrial
- (d) Agricultural (irrigation pumps)
- (e) Power plant (auxiliary motors)

The possibility of using standard model for each component is advantage of a component based approach, because no need for system measurements [41].

4.3.2 Types of Load Models

The models of the load traditionally classified into two main types: static loads and dynamic loads.

4.3.2.1 Static load models

A static load model represent the features of the load at any instantaneous of time as algebraic functions of magnitude of the bus voltage and frequency at that instantaneous time [46].

We can express static load by two methods:

a. Polynomial Representation

In this method the active and reactive power loads showed via quadratic polynomials given by

$$\frac{P}{P_o} = a_0 + a_1 \left(\frac{V}{V_0}\right) + a_2 \left(\frac{V}{V_0}\right)^2 \quad (4.1)$$

$$\frac{Q}{Q_o} = b_0 + b_1 \left(\frac{V}{V_0}\right) + b_2 \left(\frac{V}{V_0}\right)^2 \quad (4.2)$$

Where P_o is initial values of active power and Q_o is reactive power at initial value of Voltage V_a . The coefficients a_0 , a_1 and a_2 are the fractions of the constant power, constant current and constant impedance components in the active power loads. Similar comments apply to the coefficients b_0 , b_1 and b_2 also we have

$$a_0 + a_1 + a_2 = 1$$

$$b_0 + b_1 + b_2 = 1$$

With constant power type loads, the cases involving tough voltage drops is not viable. The load current is also expected to reach zero, when the load current zero. Hence exponential load impersonation is more useful for a larger voltage excursion.

b. Exponential Representation

In this method, not only depending on the voltage but also frequency Variations has effect. Commonly the active power can be represented as [47].

$$\frac{P}{P_o} = c_1 \left(\frac{V}{V_o}\right)^{m_{p1}} (1 + k_p \Delta f) + (1 - c_1) \left(\frac{V}{V_o}\right)^{m_{p2}} \quad (4.3)$$

Where

c_1 is the frequency dependent fraction of active power load

m_{p1} is the voltage exponent for frequency dependent component of active power load

m_{p2} is the voltage exponent for frequency independent component of active power load

Δf is the per unit frequency deviation (from nominal)

k_p is the frequency sensitivity coefficient for the active power load.

The reactive power load is expressed as

$$\frac{Q}{P_o} = c_2 \left(\frac{V}{V_o}\right)^{m_{q1}} (1 + k_{q1} \Delta f) + \left(\frac{Q_o}{P_o} - c_2\right) \left(\frac{V}{V_o}\right)^{m_{q2}} (1 + k_{q2} \Delta f) \quad (4.4)$$

Where

c_2 is the reactive load coefficient-ratio of initial uncompensated reactive load to total initial active power load P_o .

m_{q1} = is the voltage exponent for the uncompensated reactive load

m_{q2} = is the voltage exponent for the reactive compensation term

k_{q1} = is the frequency sensitivity coefficient for the uncompensated reactive power load

k_{q2} = is the frequency sensitivity coefficient for reactive compensation

The second expression on the R.H.S. of Equation (4.4) shows to a first approximation, the effect of reactive compensation and losses in the subtransmission and distribution system between the bus and the various loads. The first expression is made up of individual load components using their power factors.

The second expression is based on the difference between this value and the initial reactive power at the bus [41].

4.3.2.2 Dynamic Load Representation

The change of voltage and frequency with response of most components loads is very quickly, and the response is reached very fast in the steady state. This is correct at least for humble amplitudes of voltage and frequency change.

There are several situation where it is need to calculation for the dynamics of load composite. Load dynamic modeling is often require for study of interarea oscillation, voltage stability, and long-term stability. Also study of systems with large concentrations of motors needs dynamic load exemplification [24].

a. Induction Motor Model

The simplest induction motor model is to consider only the dynamics of the rotor inertia explained by

$$\frac{d\omega_m}{dt} = \frac{1}{2H} [T_E(S) - T_M(\omega_m)] \quad (4.5)$$

Where ω_m is the motor speed in per unit T_M is the mechanical torque in per unit is a

Function of ω_m given by

$$T_M = T_{M0}(A\omega_m^2 + B\omega_m + c)$$

T_E is the electrical torque in per unit is a function of the motor slip S and is computed from the steady state equivalent circuit shown in Figure 4.24[41]. H is the inertia constant of the motor. T_E Is given by the expression

$$T_E = I_2^2 \frac{R_t}{S}$$

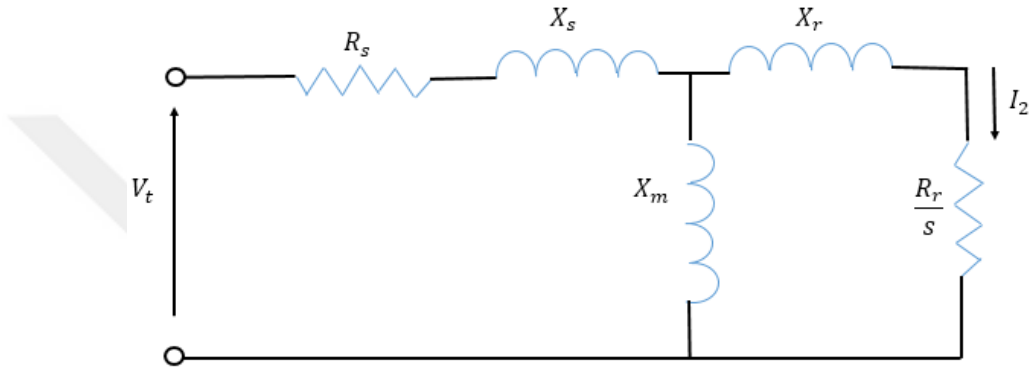


Figure 4.24 Steady State Equivalent Circuit of an Induction Motor

The model is modified, If rotor flux transients are included, Figure 4.25[41] explain the stator equivalent circuit

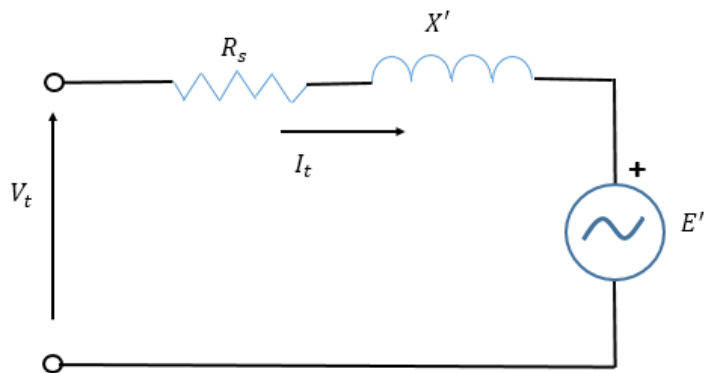


Figure 4.25 Stator Equivalent Circuit of an Induction Motor

Where E' is a complex voltage source introduced by

$$\frac{dE'}{dt} = -j2\pi f S E' - \frac{1}{T_0} [E' - j(X - X')I_t] \quad (4.6)$$

Where

$$T_0 = \frac{X_r + X_m}{2\pi f R_s}$$

$$I_0 = \frac{V_t - E'}{R_s + jX'} = i_Q + j i_d$$

f is the operating frequency, X and X' are given by

$$X = X_s + X_m$$

$$X' = X_0 + \frac{X_m X_r}{X_m + X_r}$$

Using D-Q components, Equation (4.6) can also be represented in expression of real variables

E'_D And E'_Q

$$\frac{dE'_D}{dt} = -(\omega_s - \omega_m)E'_Q + \frac{1}{T_0}(X - X')i_Q - \frac{1}{T_0}E'_D$$

$$\frac{dE'_Q}{dt} = -(\omega_s - \omega_m)E'_D + \frac{1}{T_0}(X - X')i_Q - \frac{1}{T_0}E'_Q \quad (4.7)$$

Where

$$\omega_s = 2\pi f$$

The electrical torque T_E is given by

$$T_E = E'_D i_D + E'_Q i_Q$$

b. General Load Model

The dynamic response of loads to small changes in the bus voltage can be measured and aggregated load model can be defined. Figure 4.26[41] shows the voltage step with a typical response of active power load active power [41].

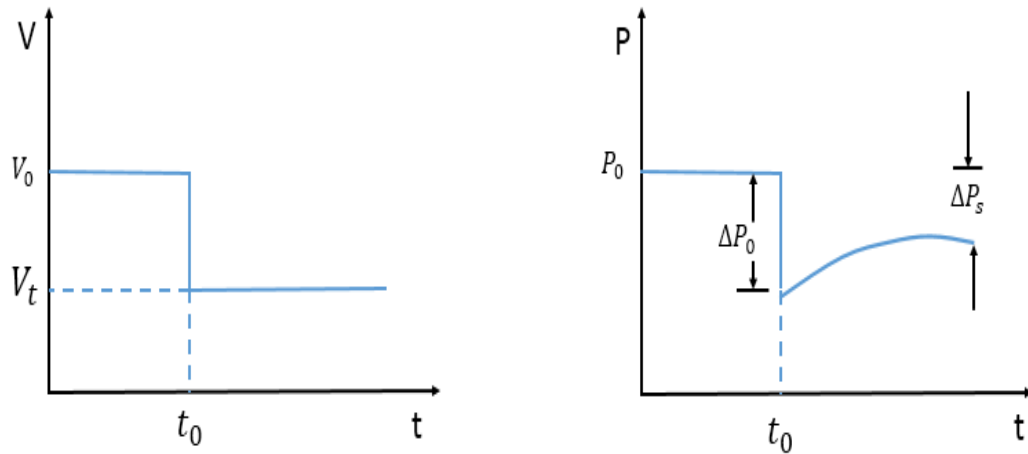


Figure 4.26 Load Response for a Step Change in Voltage

This response can be represented by the differential equation as [48].

$$T_P \frac{dP}{dt} + P = P_s(V) \frac{dV}{dt} \quad (4.8)$$

The load behavior is determined by two load functions and a time constant T_p .

P_s is the static load function and is viable in steady state. k_p is the dynamic load function.

Figure 5.17 also shows the transient and steady state power increments [41]

ΔP_0 and ΔP_s

Can be acquired as

$$\Delta P_0 = P(t_0^-) - P(t_0^+) = \frac{1}{T_p} [K_P(V_0) - K_P(V_1)]$$

$$\Delta P_s = P(t_0^-) - P(\infty) = P_s(V_0) - P_s(V_1)$$

Where

$$K_P(V) = \int_0^V k_p(\sigma) d\sigma$$

4.4 Power System Stabilizer (PSS)

4.4.1 General Information about Power System Stabilizer (PSS)

High performance excitation systems are fundamental for maintaining and enhancing steady state and transient stability of modern synchronous generators, apart from providing fast control of the terminal voltage. For both hydraulic and thermal units, bus fed static exciters with thyristor controllers are used. [49-50] the function of PSS is to add appropriate damping signal to the generator excitation system to cope with parameter oscillations. Power system stabilizer is a generator control used in feedback to enhance the damping of rotor oscillation due to signal disturbance, the disturbance may be caused even by small changes in the reference voltage regulator exciter, resulting in ever increasing rotor oscillations. A PSS is one of the greatest cost-effective ways of improving power system stability. Also power system stabilizer (PSS) is a device which offers extra supplementary control loops to the automatic voltage regulator (AVR) system and/or the turbine-governing system of a generating unit [41]. Figure 4.27[51] show the structure of (PSS), the PSS input signal can be either the frequency difference between remote regions, machine speed deviation or its acceleration power which is the difference between the mechanical input power and the output electrical power of the generator. The output signal is applied as a supplementary input to the excitation system.

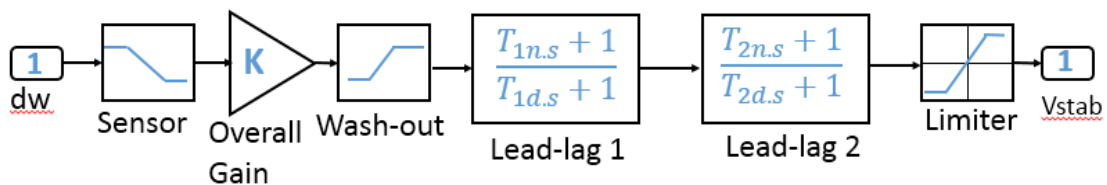


Figure 4.27 Block diagram of the PSS

The function of each PSS block is summarized briefly below:

a. The General Gain

It is used for determines the amount of damping producer by the stabilizer.

b.Washout Filter

The main function of washout filter is to remove the steady state alignment case occurred at the controller output. It is a kind of high pass filter. It is common to select time constant T_w , between 1-20 s in the literature.

The PSS is in prospect to reply only to transient variations in the input signal not to the dc offsets in the signal. This is checked by subtracting from it the low frequency components of the signal got by transitory the signal during a low pass filter as shown in figure 4.28[41].The washout circuit works basically as a high pass filter and it must permit all frequencies that are of benefit [41].

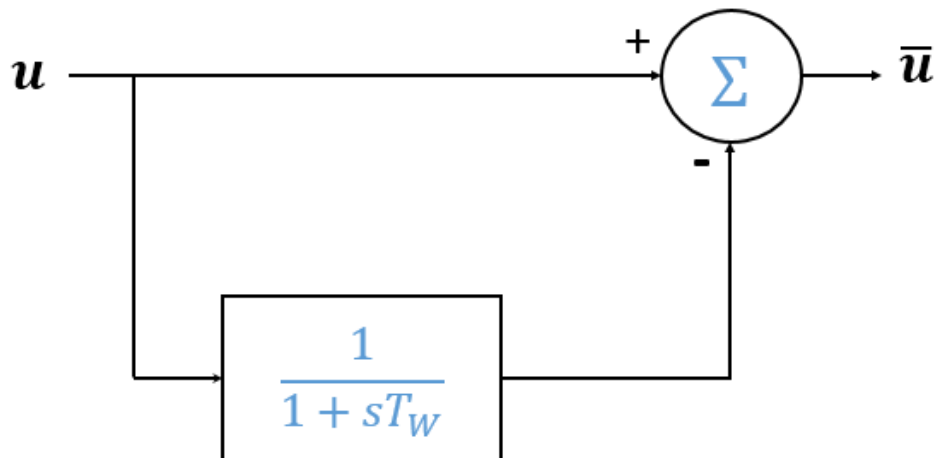


Figure 4.28 washout circuit

c.Lead-Lag block

Lead-lag block performs the required phase compensating function for the PSS output, so that the necessary lead or lag function is realized to damp effectively. The transfer function of the lead - lag block is inscribed as:

$$T_S = \frac{(1+sT_1)(1+sT_3)}{(1+sT_2)(1+sT_4)} \quad (4.9)$$

Where, $T_1 - T_4$ are time constants, which are strategically chosen for the required phase shift to the PSS output signal. The choice of these time constants are the most difficult ones in PSS design stage.

d. The Limiter

The main function of the limiter is to give permission to passing a frequency signal of swing mode.

4.4.2 Principle Operation of PSS

The important and main concept of power system stabilization is to introduce that in the steady state, the voltage controller should be determined by the voltage error ΔV only when the speed deviation is zero or approximately zero. However, the speed of generator is not constant, and the change in rotor angle caused to oscillations of rotor swings and ΔV . The main function of the PSS is to add a supplementary signal which compensates for the ΔV oscillations and supply a damping composite that is in phase with $\Delta\omega$. Figure 4.29[52] shows that signal of PSS (V_{PSS}) is added to the main voltage error signal ΔV . The signal of PSS (V_{PSS}) must be equal to zero in steady state case so that it does not distort operation of the voltage regulation.

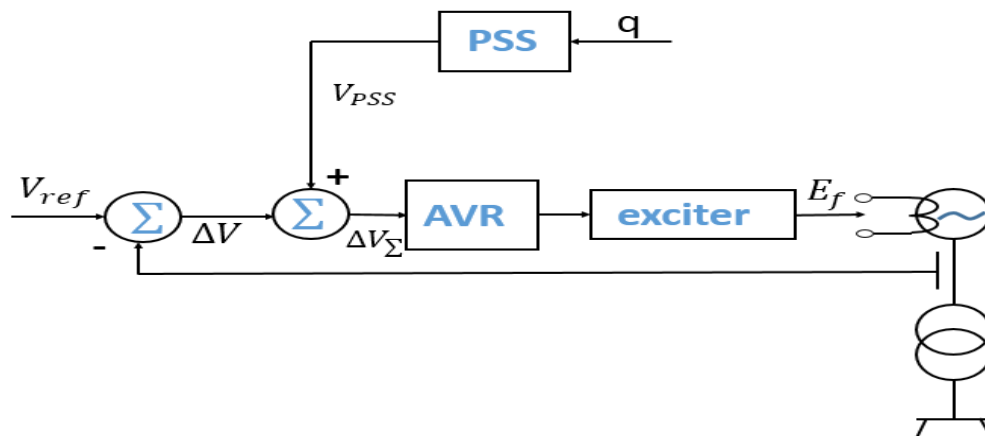


Figure 4.29 Additional control loop for the AVR system block diagram

The phasor diagram of the signals in the transient state is explained in figure 4.30[52]. It is assumed that each signal varies sinusoidally with the frequency of rotor swings

torsional oscillations is main problem, relates to selecting a measurement position on the shaft that properly represents the speed deviation of the rotor magnetic poles [52]. Figure 4.30 explained this type of PSS. This type of PSS, produces transient oscillations in the voltage and reactive power that are unnecessarily forced by the PSS If the mechanical power does change.

The properties of this type is

- Frequency is 0.2 to 0.5Hz
- Frequency PSS is a Single, such as $\Delta P, \Delta\omega$ or Δf .
- The whole system oscillates as a result of long-distance, large-capacity power transmission
- This type of PSS is more effective [53].

4.4.3.2 Local Mode Power Oscillation

If the local mode of oscillation is of main anxiety (specially for the state of a generating station transmitting power over extended distances to a load midpoint) the analysis of the problem can be abridged by considering the model of a single machine (the generating station is characterized by an equivalent machine) joined to an infinite bus (SMIB) [41].

A simplified form of the PSS shown in Figure 4.31[53] can be obtained by neglecting the shaft speed measurement and only measuring the generator real power P_e . With this arrangement only one input signal is required but can only be used when the mechanical power can be assumed to be constant.

The properties of this type is

- The frequency is about 1Hz.
- Single oscillates of generator against the system.
- Frequency PSS is a Single, such as $\Delta P, \Delta\omega$ or Δf .
- This type of PSS is more effective [52].

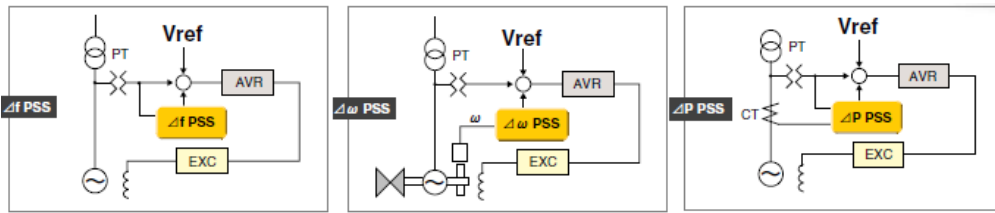


Figure 4.31 Single-frequency PSS

4.4.3.3 Complex Power Oscillation

Complex power oscillation mode, such as local mode and inter-area mode. The input of this type is ΔP signal and $\Delta\omega$ or Δf signal. Multi-input PSS is more effective. Figure 4.32 show the multi input signal PSS [53].

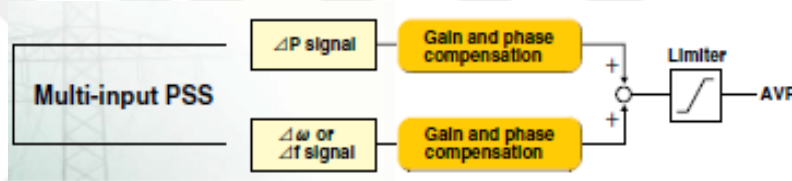


Figure 4.32 Multi-input PSS

4.4.4 PSS Applied to the Turbine Governor

Since the power system consist of more generators and all generators connected with each other by the transmission lines, by the way any change in the voltage from one generator effect on the dynamic response of the other generators of power system. So the improves damping oscillation of one generators by using PSS does not need improve the damping oscillation of the other generators. Subsequently a local design may not supply the universal optimal solution and a coordinated composition procedure is eligible. The advantage of this coordination is boosts the design calculation and is generally useful only for loading conditions and configurations of the network. When an acute fault occurs such as three phase fault in the power system, the configuration of network with postfault and load condition may be different result from prefault condition and damping swings is weakly. All the factors caused that using the turbine governor is good for damping the local and interarea oscillations.

Using a PSS signal with the turbine governing systems to enhancing damping oscillation is not new idea, since 1972 there is some solution and using PSS for hydro turbines. The principle for enhancing damping oscillation with using a PSS to the excitation system is same when adding a PSS with the turbine governor. A phase shift between the oscillations in the speed deviation $\Delta\omega$ and the turbine mechanical power are represent by time constant in the turbine governor. The PSS transfer function represent via the turbine governor that must be chose the frequency of rotor oscillations it compensates the phase shift, since the control loop of PSS is equal to $\Delta\omega$, that it is input signal of PSS. According to the swing equation, change of force between the mechanical power (Δp_M) and the oscillations in the speed deviation $\Delta\omega$ are in phase and enhance positive damping.

Turbine governor dynamics are low coupled with those of the rest of the power system, then it is the main advantage of applying a PSS loop to the turbine governor. Also the other advantage of the PSS is do not depend on the parameters of the power system [52].

CHAPTER 5

SIMULATION STUDIES

5.1 System Model

The multi-machine system used to control the power flow in a transmission system 500 KV suggested to study transient stability improvement by using PSS and SVC shows in a figure 6.1 that it is simulated by software program. The system consist of four generator that all of them is hydro power station. The capacity each of the generator 1 and generator 3 are (1000) MW and generator 2 and generator 4 with capacity (5000) MW, generator 2 is set as swing bus to balancing the power of the system. this system is configured in loop case and it contain of 6 buses where interconnected via the six transmission as shown in figure 5.1 , distance each of transmission line 1 and 2 are 350KM located between G1 and G2, and transmission line 2 and 3 are 350KM located between G3 and G4 and transmission line 5 and 6 are 400KM connecting each of G1 and G3 also G2 and G4. there are four transformers connecting with the system, two of transformers (Tr1 and Tr3) (13.8KV/500KV)(1000MVA) and other (Tr2 and Tr4) (5000MVA) to make the system voltage (500)KV. The system is fed the dynamic resistive loads , they are connecting with the system in the difference places such as (100MW) on bus 2, (4800MW) on bus 3, (4800MW) on bus 4, (100MW) on bus 5 and (100MW) on bus 6. with three phase fault breaker using with system, also in some cases using three phase breaker.

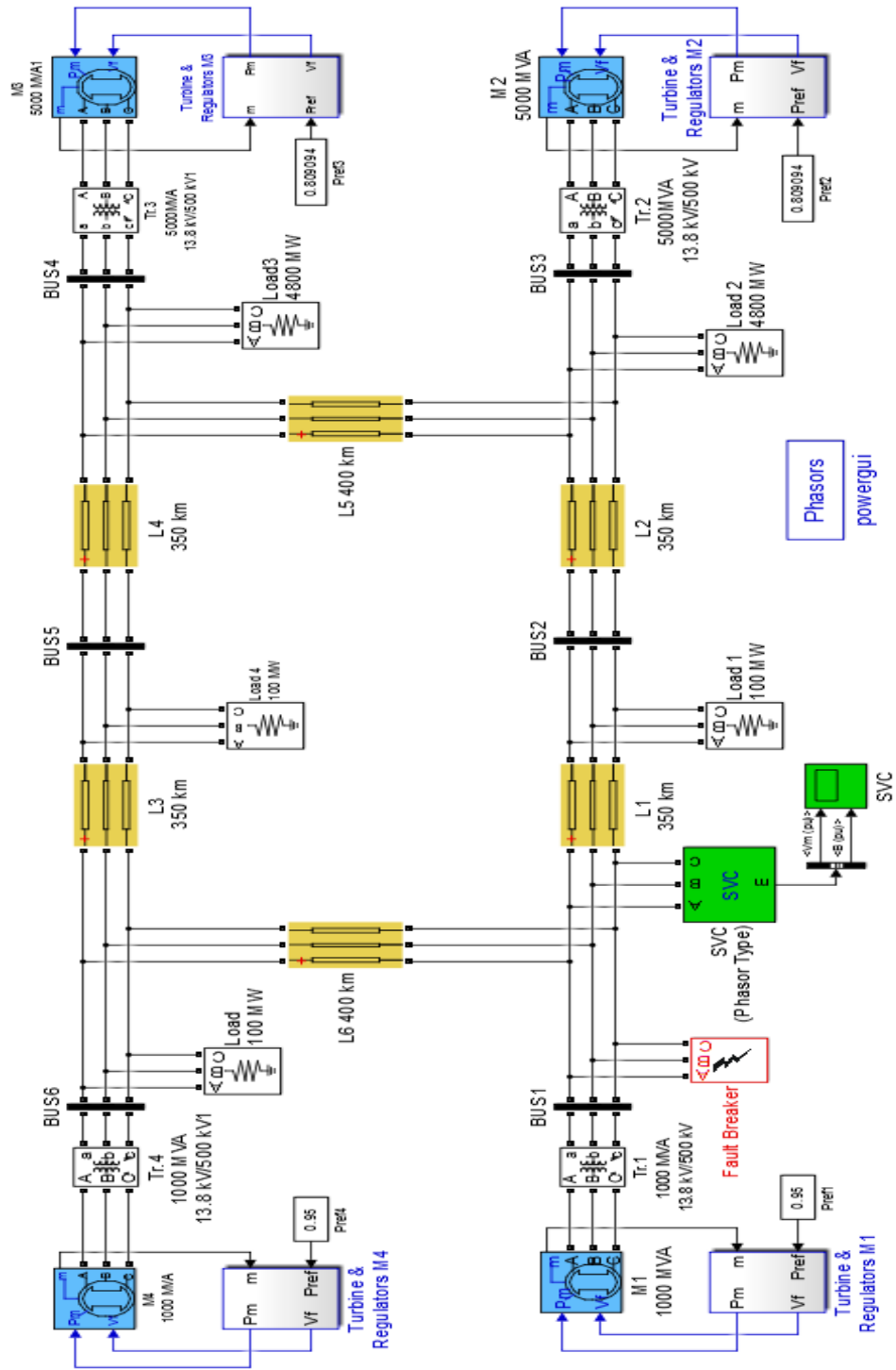


Figure 5.1 Simulation Model

5.2 Power System Stabilizer (PSS) with system

The type of the Power System Stabilizer (PSS) that using with the test system is generic. It is controlling excitation used with the synchronous machine. The difference between the mechanical power and the electrical power is power acceleration used as input signal and the output of PSS is gives voltage stable to the Excitation System block as shown in figure 5.2. The model entails of a low-pass filter with several parameters such as sensor time constant ($15e-3$), Gain (2), Wash-out time constant (0.7), Lead-lag time constants: [T_{num} T_{den}] [$60e-3$ 0.5] and Output limits: [V_{Smin} V_{Smax}] [-0.15 0.15] as shown in figure 6.2.

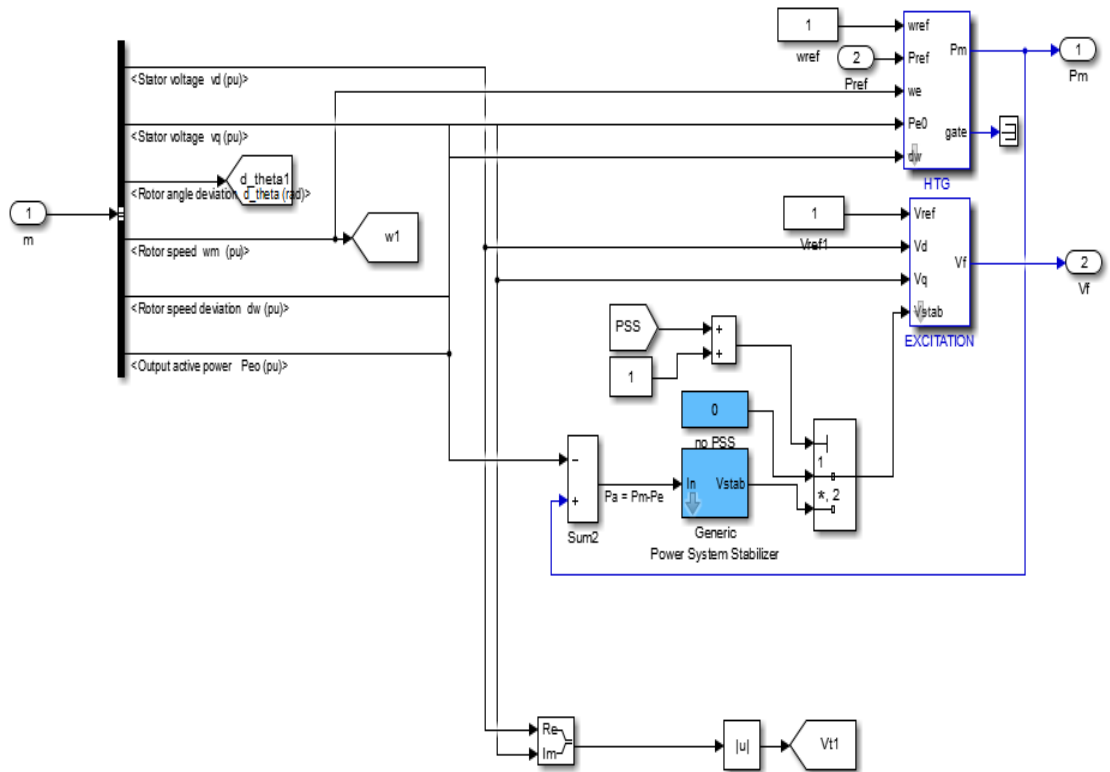


Figure 5.2 Power System Stabilizer (PSS) with System Model

5.3 Static Var Compensator (SVC) with System

The Static Var Compensator block is a phasor model and effective for transient stability enhancement of multi-machine systems, it is connected such as shunt compensator with the transmission line, also the SVC is valued 200 mva capacitive and 200 mva inductive. To use this type must chose phaser simulation in powergui block from MATLAB simulation. The phaser type is better and faster than detailed type to use with system because this type reduced the simulation time by using network differential equation instead algebraic equation [54]. The SVC mode of action to 'Voltage regulation as shown in figure 5.3, with several parameters such as Reference voltage ($V_{ref} = 1\text{pu}$), (Droop $X_s = 0.03 \text{ pu/Pbase}$) and Voltage regulator [$K_p = 10\text{puB/puV}$ $K_i = 300\text{puB/puV/s}$].the control that used with SVC is PI controller as shown in figure 5.4.

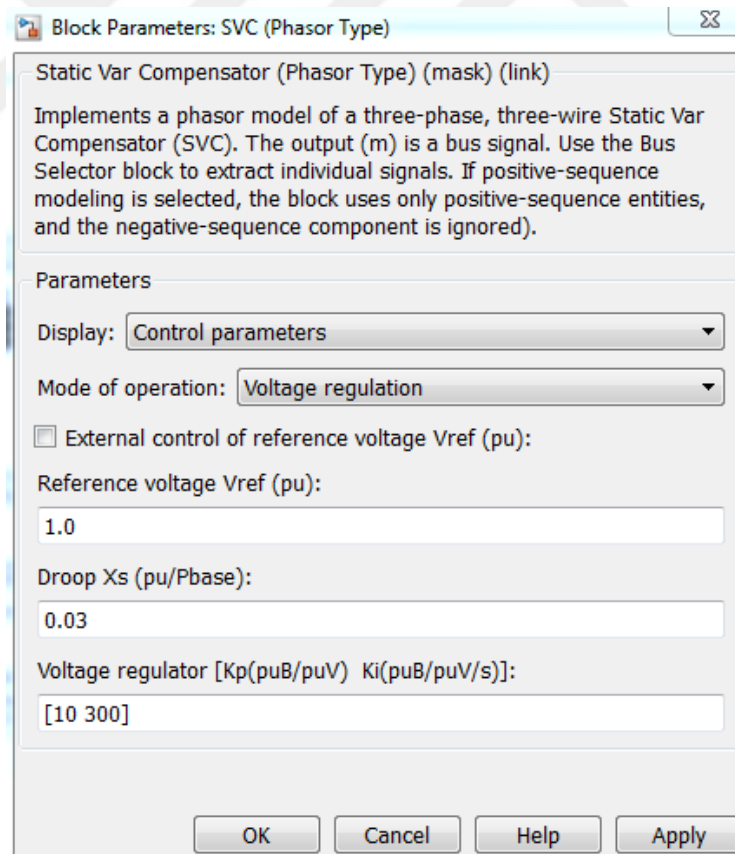


Figure 5.3 Block Parameters of SVC Mode

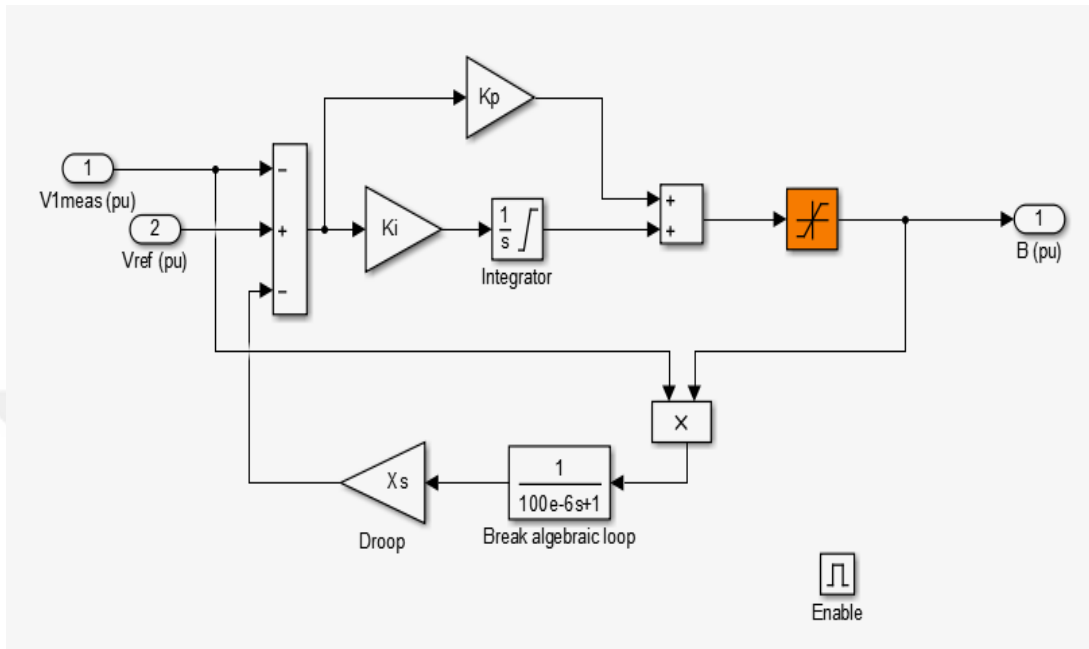


Figure 5.4 PI controller of SVC System Model

CHAPTER 6

RESULTS AND DISCUSSION

6.1 Introduction

In this chapter the designed simulation system has been used to carry out the measurements and tests, to prove and represent results of the system. The results acquired for the system that simulated by software program are illustrated and compared.

6.2 The Simulation Results of multi-machine system

The modeling and simulating of the multi-machine to improve transient stability of the system simulated by program software package version, Simulink provides a graphical editor, customizable block libraries, and solvers for modeling and simulating dynamic systems.

All system when connected more than one machine with each other is very difficult control all parameters, in this study we connected four machine and via long transmission line and different load are non-linear system which depends on more than one parameters. Also we used PSS that it is connected with generator and SVC connected with transmission line in different places of the system to improve transient stability of multi-machine.

6.3 Cases Studies and Results

The comparison between PSS and SVC was conducted in a multi-machine system, as shown in figure 7. This system consists of 4 machines and 6 buses. The system was originally available in software with two machines and three buses, but in order to

consider more cases in this work, the number of machines and buses were increased. For obtaining more reliable and high performance in stability of the system and improving transient stability by using the good equipment to stay the system in stability without losing the stability ,we taken many cases in this study which explained below .

6.3.1 Case Comparison between using only PSS and PSS with SVC at maximum critical clearing time.

In this case compared between using only PSS and PSS with SVC for a critical clearing time equal 148ms ($t_c = 148$ ms), The disturbance applied is three phase fault to ground near a generator 1 on bus 1 at time equal 5 second as shown in figure 6.1.

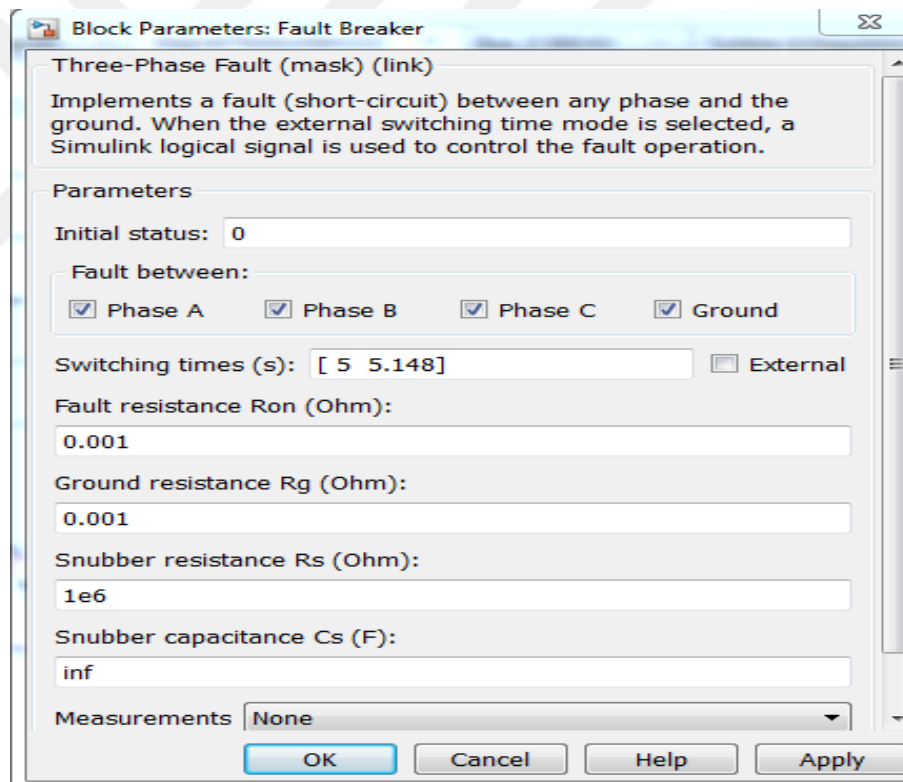


Figure 6.1 Block Parameters of Fault Breaker with 148ms

This case explain the response of the system after large disturbance by three phase to ground at maximum clearing time and the results show the system losing the stability with using PSS alone and the system remains in stable with adding SVC. The results of this case indicated of several important parameters such as rotor angle and terminal voltage and transmission lines active power. Figures (6.2 -6.5) show the rotor angle

difference of G1 of the test system, rotor angle difference of G3, the terminal voltage on B1 and transmission line active power of G1.

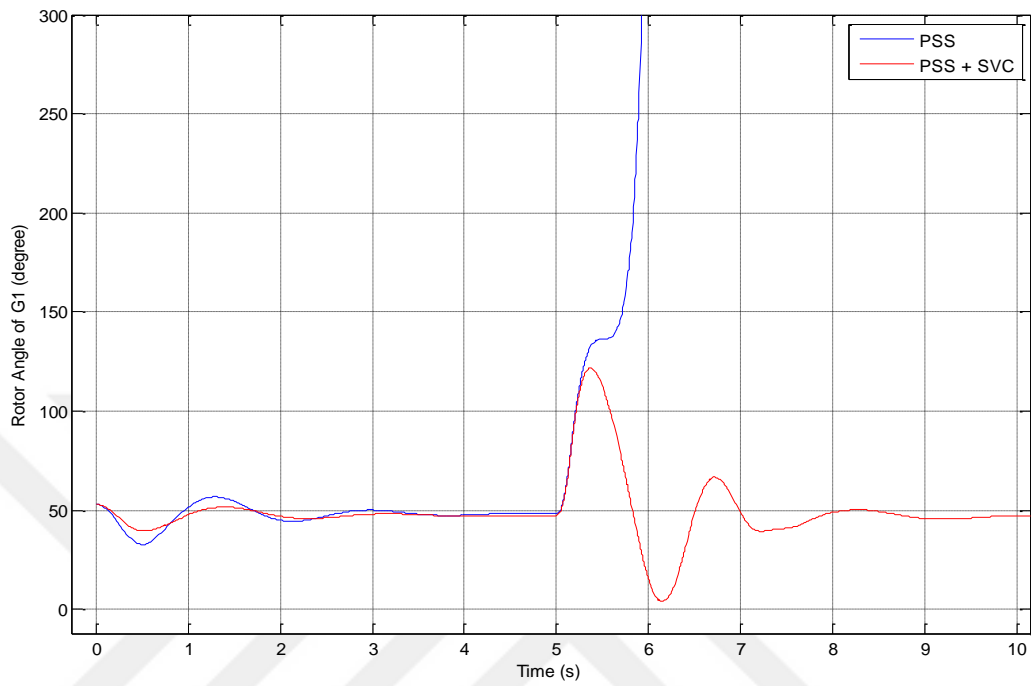


Figure 6.2 Rotor Angle Difference of G1 to G2, Case 1

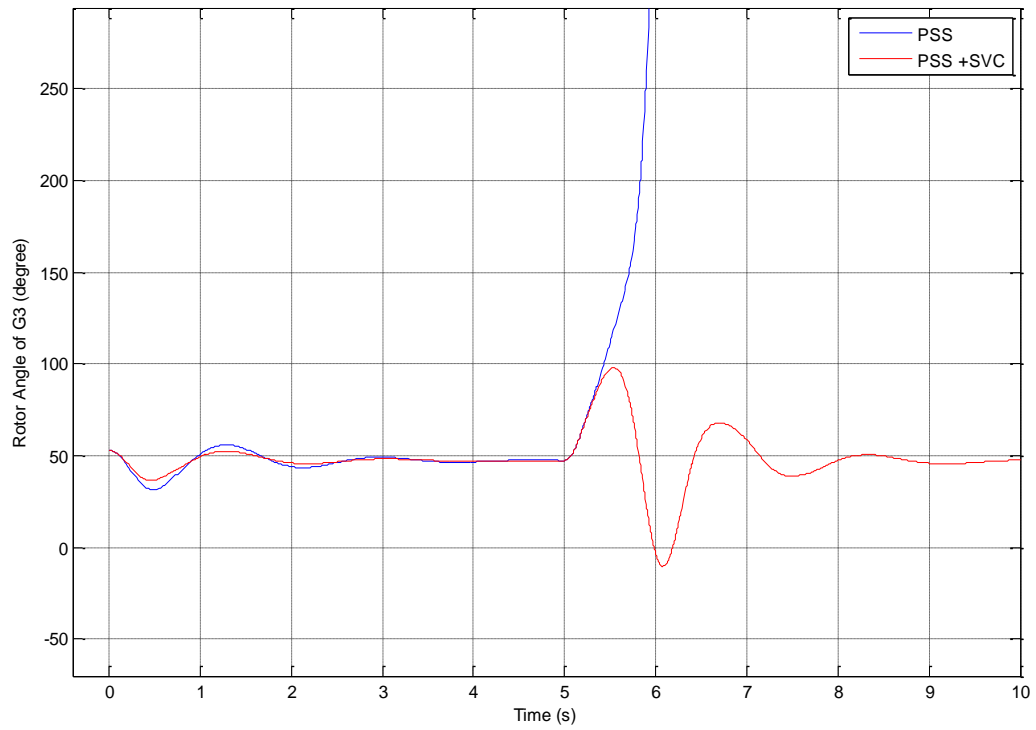


Figure 6.3 Rotor Angle Difference of G2 to G3, Case 1

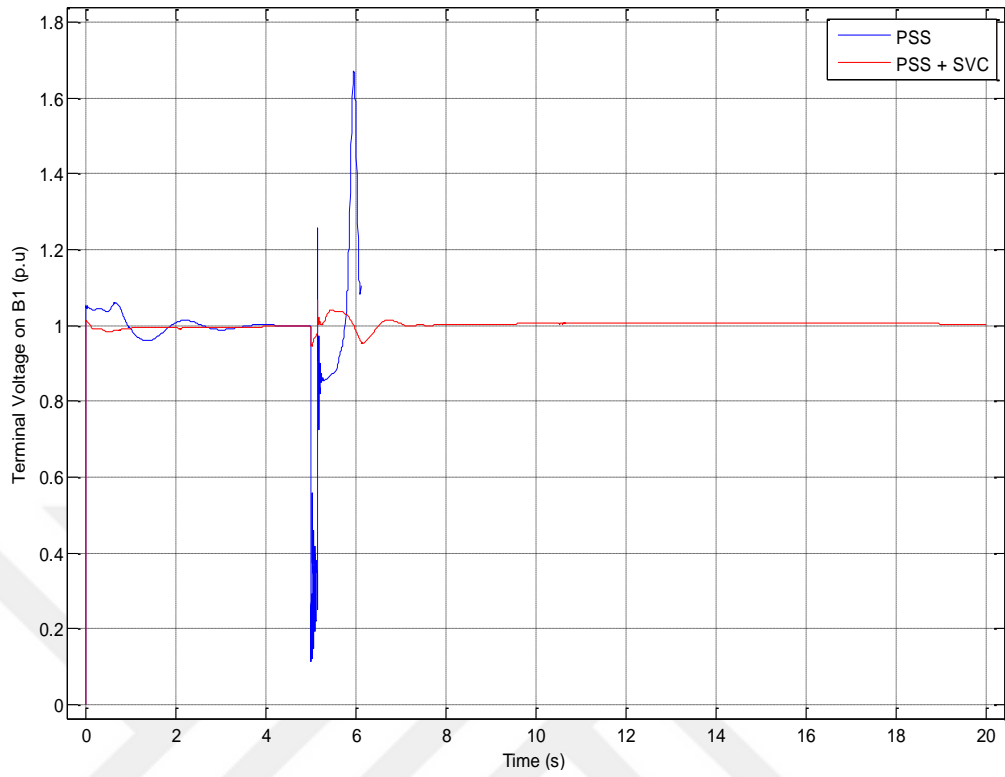


Figure 6.4 Terminal Voltage on B1, Case 1

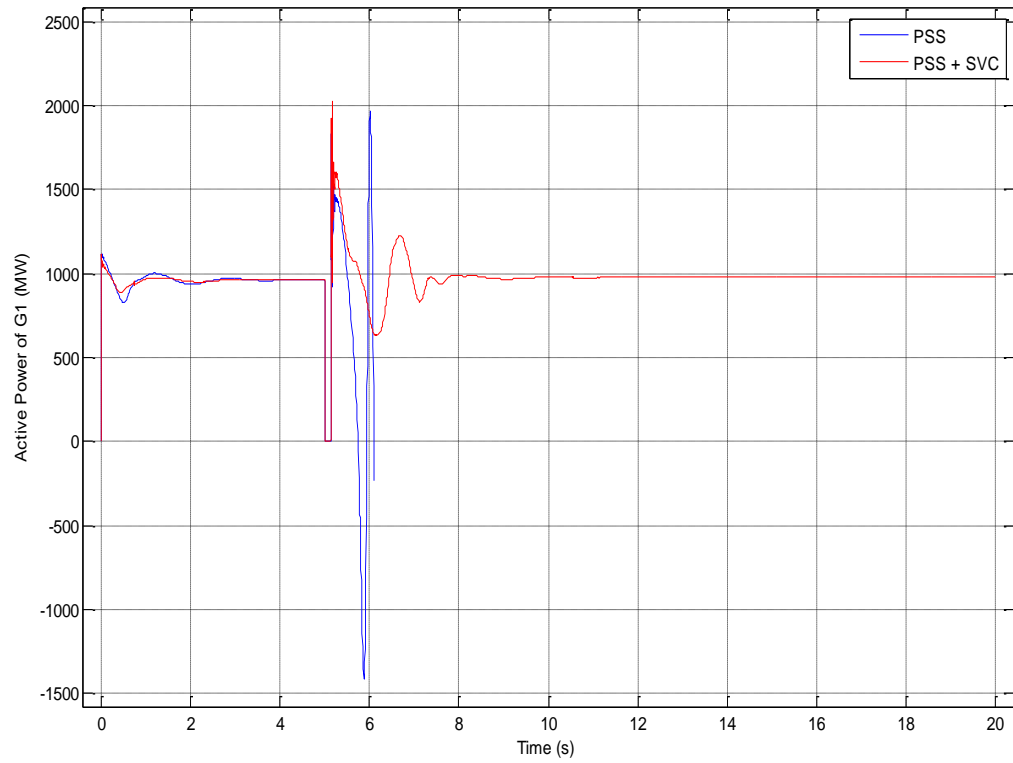


Figure 6.5 Transmission Line Active Power of G1, Case 1

6.3.2 Comparison between using only PSS and PSS with SVC at clearing time equal (147) ms

This case explain the maximum clearing time at 147 ms that the system remain in stable with both of using PSS alone and PSS with SVC. The comparison between PSS and SVC shown in this case to improve the transient stability of the system after applied three phase fault to ground near a generator 1 on bus 1 at time equal 5 second as shown in figure 6.6.

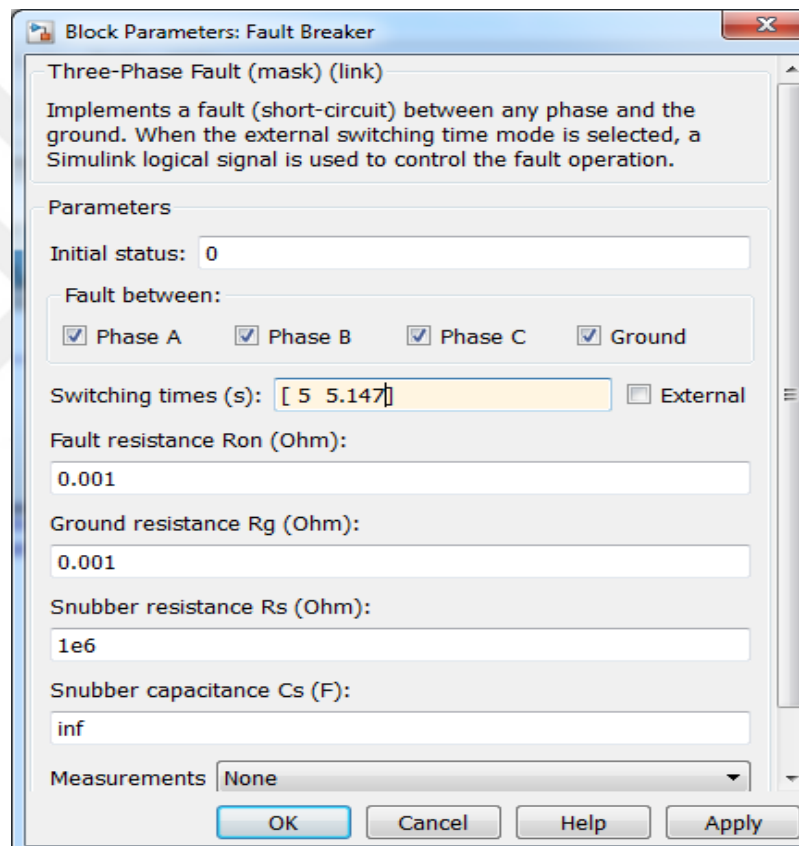


Figure 6.6 Block Parameters of Fault Breaker with 147ms

In this case after operation the proposed system under the large disturbance via three phase fault with ground at fifth second with clearing time 147 ms in figure 5.1, with applied each of the PSS solely and coordinate of PSS with SVC to damping oscillation and enhancement the transient stability of the system.

Table 6.1 lists the performance comparison between using (PSS) and (PSS with SVC) and indicated the effect on each of the rotor angle and terminal voltage and active power. Figure 6.7 and 6.8 shows the rotor angle difference of G1 and rotor angle difference of G3 are less oscillated and stabilized faster with using SVC, that the rotor angle of G1 to G2 and the rotor angle of G3 to G4 ; SVC settled faster with settling time is (11second and 10.3second) than with only PSS (13s and 12.3second), and the peak amplitude of both rotor angle with SVC reduced with value is 118 and 93 degrees, respectively, With only PSS, the corresponding values are 130 and 128 degrees. . Figure 6.9 and 6.10 shows the terminal voltage on B1 and B6 are less oscillated and stabilized faster with using SVC, that with peak amplitudes of 1.115 p.u and 1.18 p.u, and settling times of 10s and 10s, compared to only PSS with peak amplitudes of 1.275 p.u and 1.25 p.u and settling times of 12second and 12second. . Fig. 6.11 and 6.12 show the transmission line active power values of G1 and G3, that the transmission line active power with using SVC is less oscillated and settled faster with settling time 10 second compared with using only PSS more oscillated with settling time 12 second.

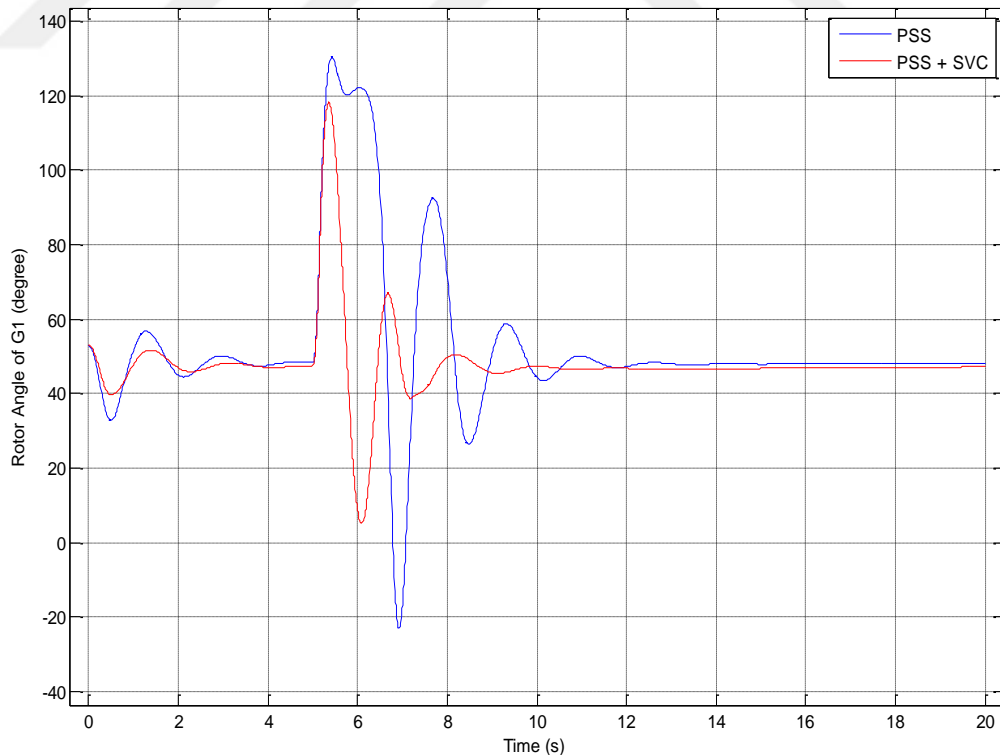


Figure 6.7 Rotor Angle Difference of G1 to G2, Case2

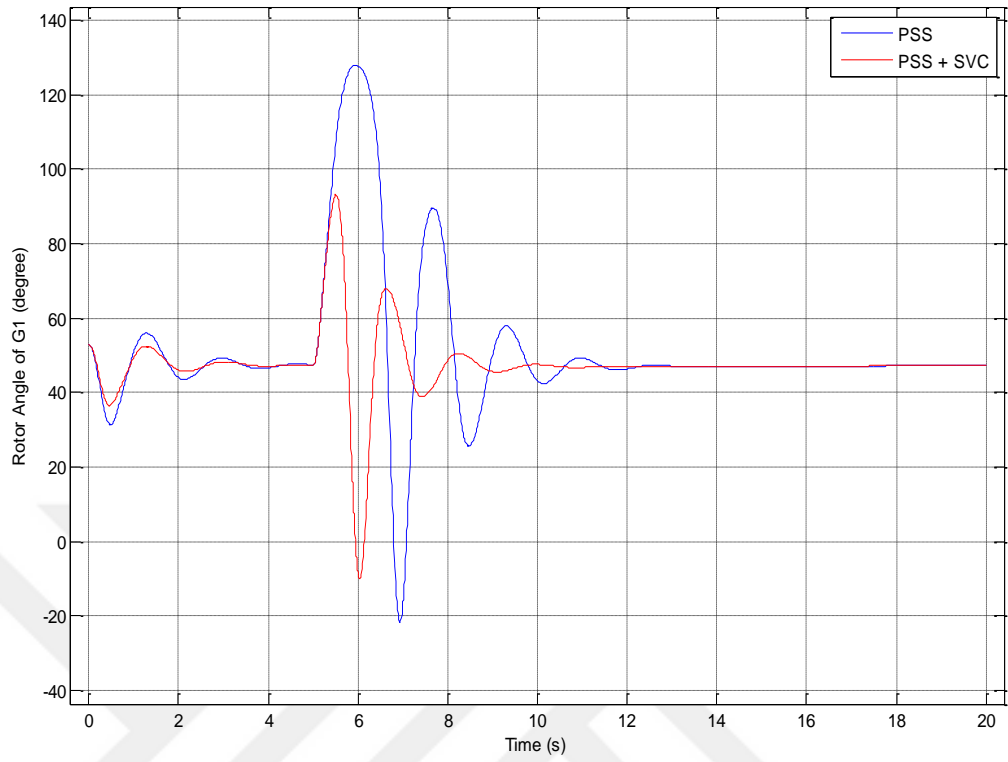


Figure 6.8 Rotor Angle Difference of G3 to G4, Case2

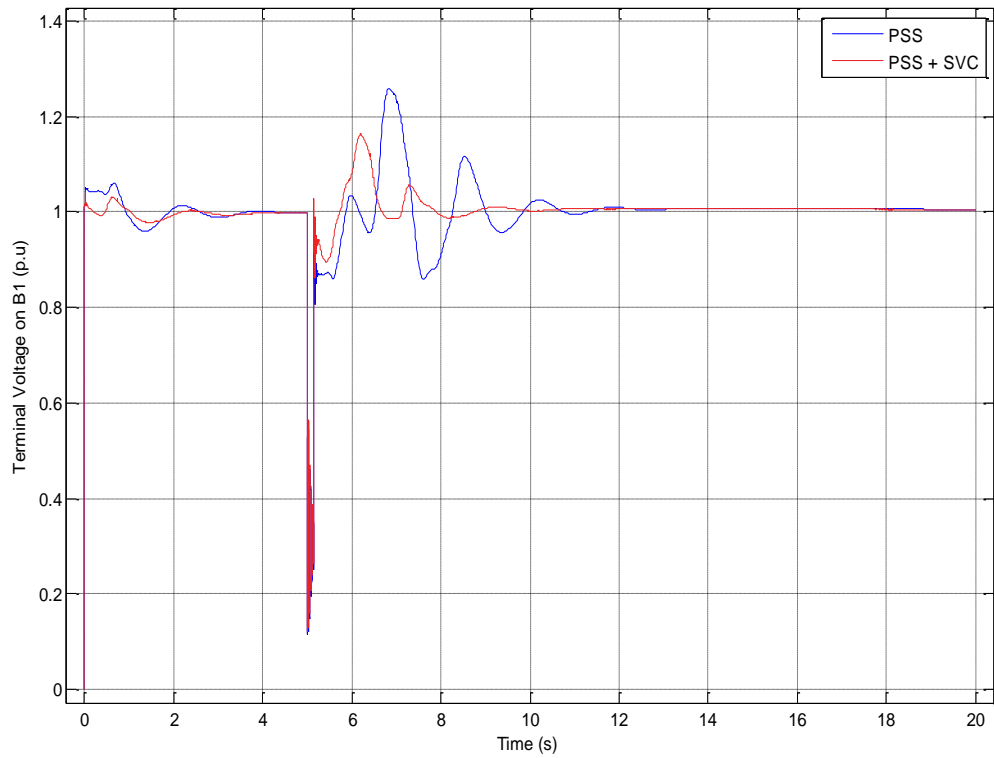


Figure 6.9 Terminal Voltage on B1, Case2

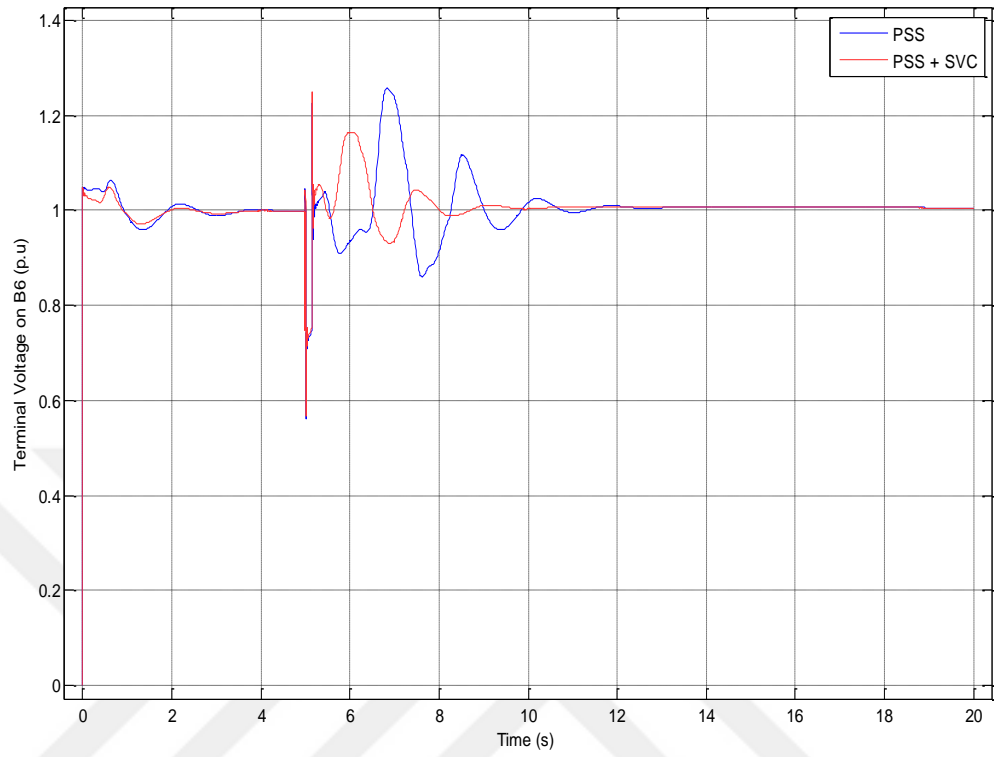


Figure 6.10: Terminal Voltage on B6, Case2

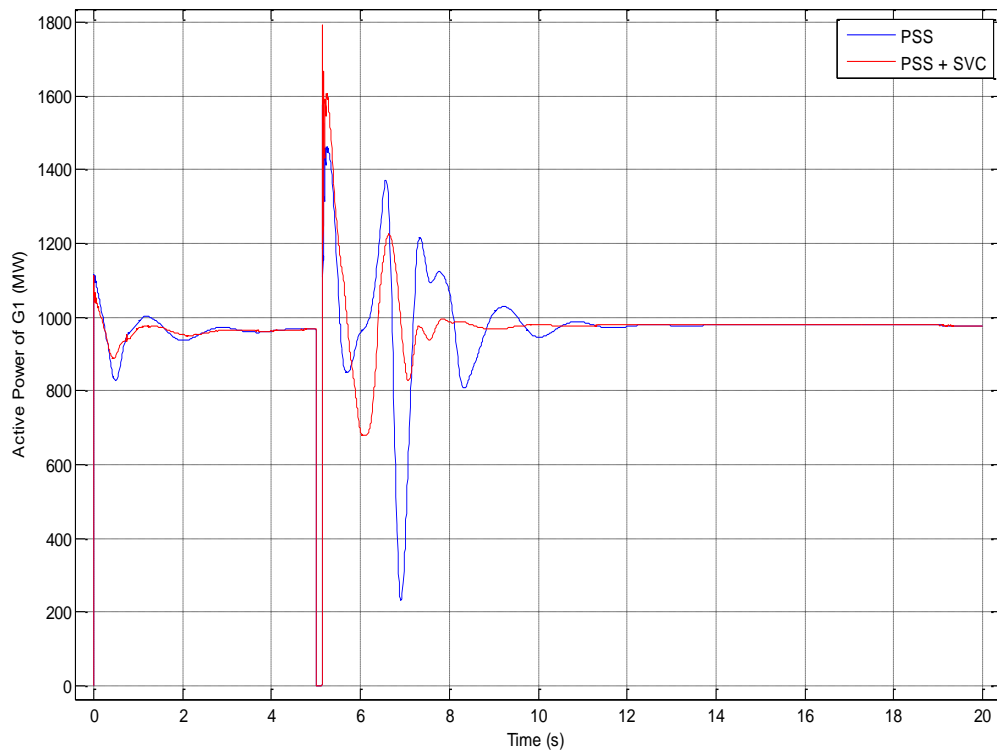


Figure 6.11 Transmission Line Active Power of G1, Case2

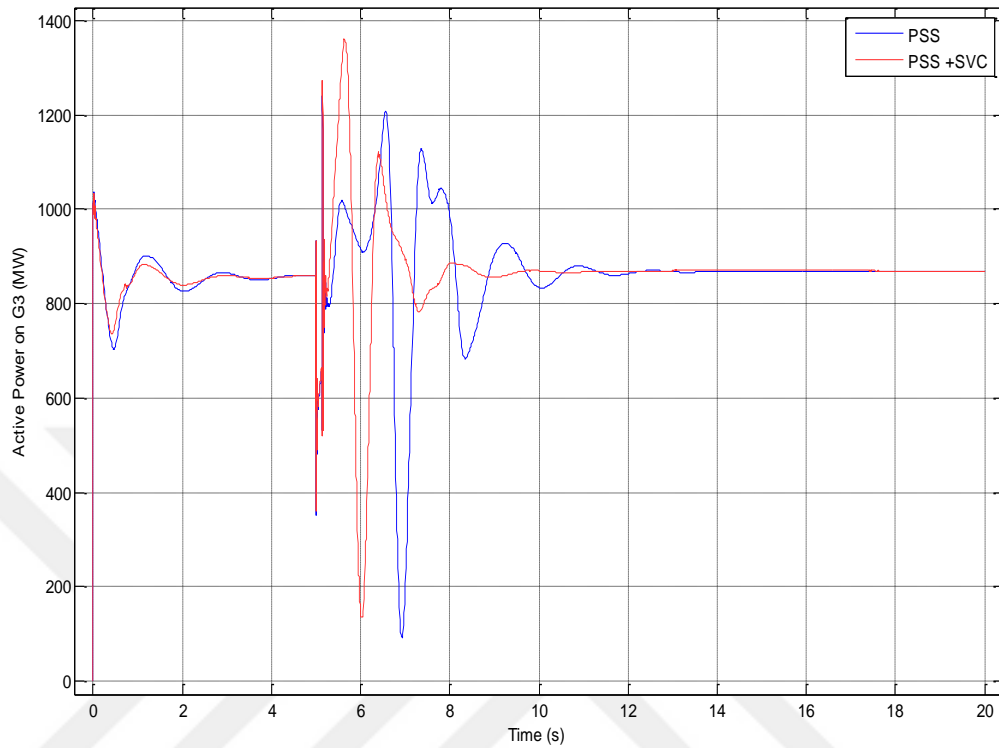


Figure 6.12 Transmission Line Active Power of G3, Case2

Table 6.1 Comparison between PSS and PSS with SVC at (cl = 147ms)

Parameters	PSS		PSS + SVC	
	Peak	Ts (s)	Peak	Ts (s)
Rotor angle of G1	130 (deg.)	13	118 (deg.)	11
Rotor angle of G3	128 (deg.)	12.3	93 (deg.)	10.3
Terminal voltage on Bus 1	1.275 (p.u)	12	1.15 (p.u)	10
Terminal voltage on Bus 6	1.25 (p.u)	12	1.18 (p.u)	10
Active power of G1	1470 (MW)	12	1470 (MW)	10
Active power of G3	1470 (MW)	12	1350 (MW)	10

6.3.3 Loss of a Generator in the System

In one of these cases, which is considered as a large disturbance of the system. It is losing one or more than one generators for a certain time then returning back to the system, this makes the system to be situated in the transient stability. Thus in this case the explanation and comparison of the PSS solely and the combination of SVC together with PSS for damping the system oscillation.

The disturbance is in such way that it occurs while the system losses the generator 3 at the tenth second for the period of 152 ms, then it returns back to the system. This phenomena large disturbance in the system, hence it instable the system. In order to make the system stabilized, the use of SVC and PSS is essential.

Also this case is a worst case that faces the system and this cause's big disturbance because during this time Rotor Angle has maximum swing and Amplitude and needs the minimum clearing time to solve this disturbance to return the system in stability otherwise it is losing synchronism and the system will be shutdown.

Table 6.2 lists the performance comparison and effect of each PSS alone and coordinate PSS with SVC while the system losses the generator with test system. Figures 6.13 and 6.14 shows that those rotor angle difference of Generator 1 and Generator 3 are less oscillated and stabilized more rapidly with the coordinate PSS and SVC with peak amplitude (110 and 128)degree than using only PSS with peak amplitude (150 and 134)degree. Another parameter that also been observed is terminal voltage as shown in figure 6.15 and 6.16, the terminal voltage is less oscillated and stabilized faster with connecting SVC with the test system with peak amplitude (1.2 and 1.25)p.u than only using PSS with (1.48 and 1.43)put. Figure 6.17 and 6.18 shows the active power of the transmission line has been oscillated earlier with peak amplitude (1937 and a1550)MW with SVC than using PSS alone with peak amplitude (2000 and 2250)MW.

Table 6.2 Comparison between PSS and PSS with SVC while losing one generator

Parameters	PSS		PSS + SVC	
	Peak	Ts (s)	Peak	Ts (s)
Rotor angle of G1	150 (deg.)	16	110 (deg.)	14.3
Rotor angle of G3	134 (deg.)	16	128 (deg.)	14.4
Terminal voltage on Bus 1	1.48 (p.u)	15.8	1.2(p.u)	14.2
Terminal voltage on Bus 6	1.43 (p.u)	14	1.25 (p.u)	13
Active power of G1	2000(MW)	15	1937(MW)	13
Active power of G3	2250(MW)	14	1550(MW)	13

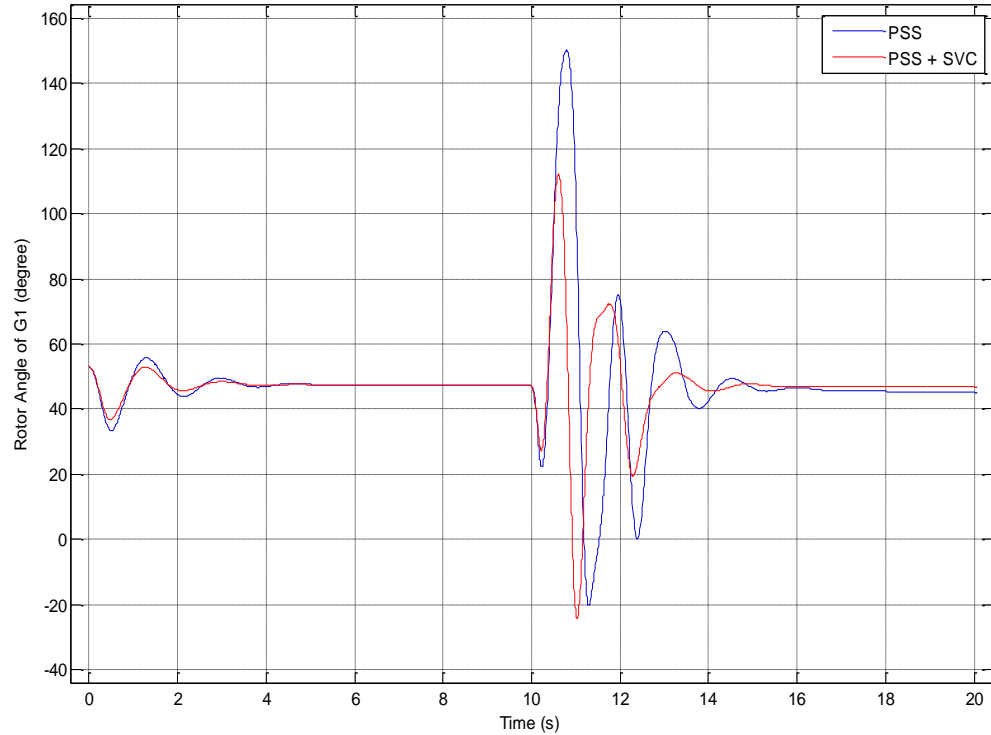


Figure 6.13 Rotor angle difference of G1 to G2, Case 3

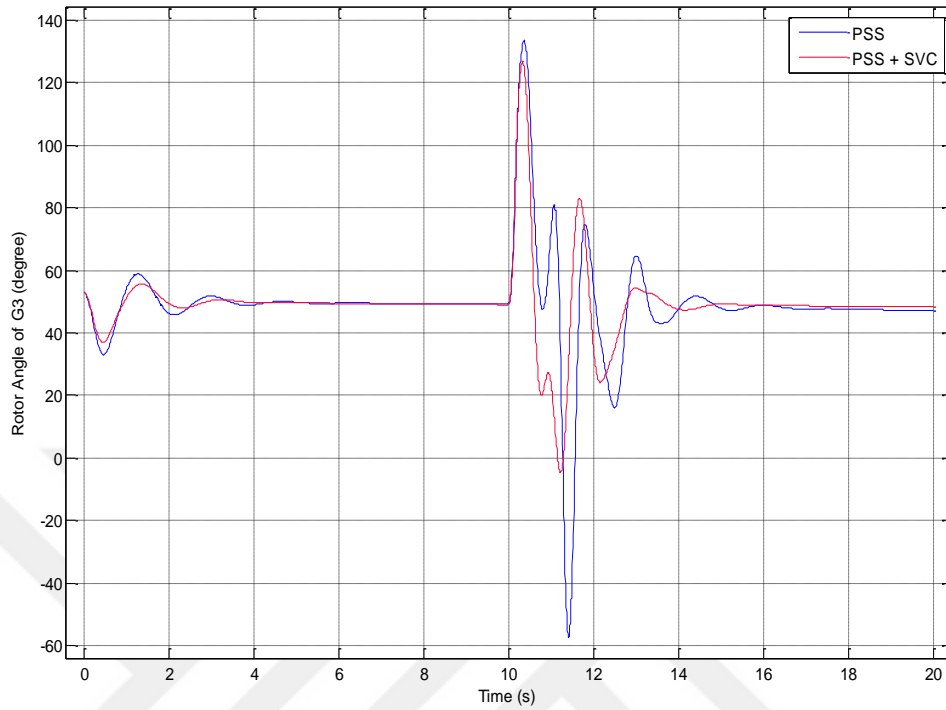


Figure 6.14 Rotor angle difference of G3 to G4, Case 3

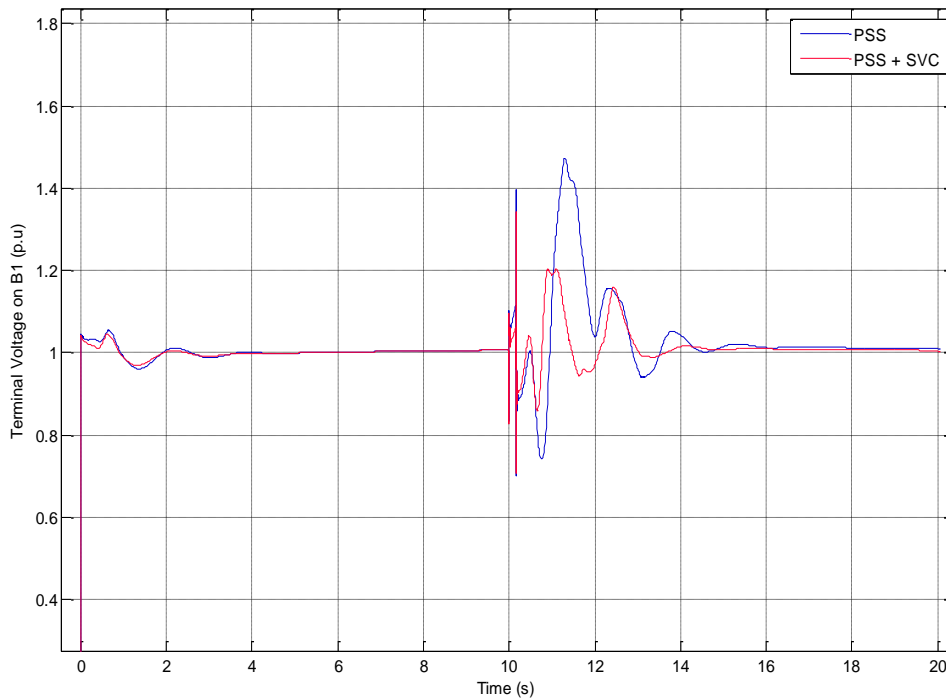


Figure 6.15 Terminal voltage on B1, Case 3

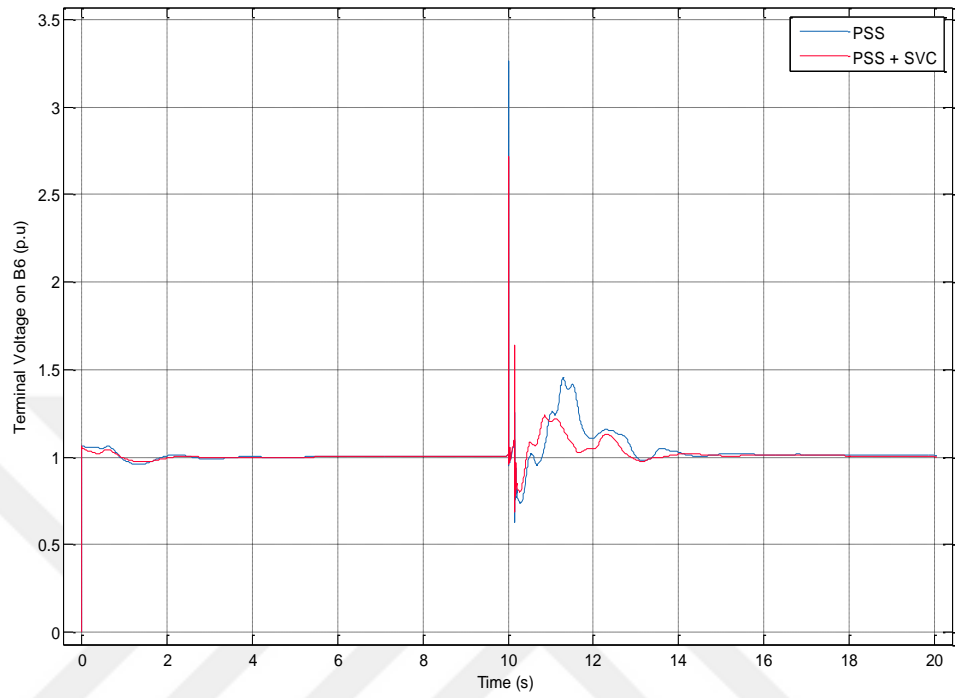


Figure 6.16 Terminal voltage on B6, Case 3

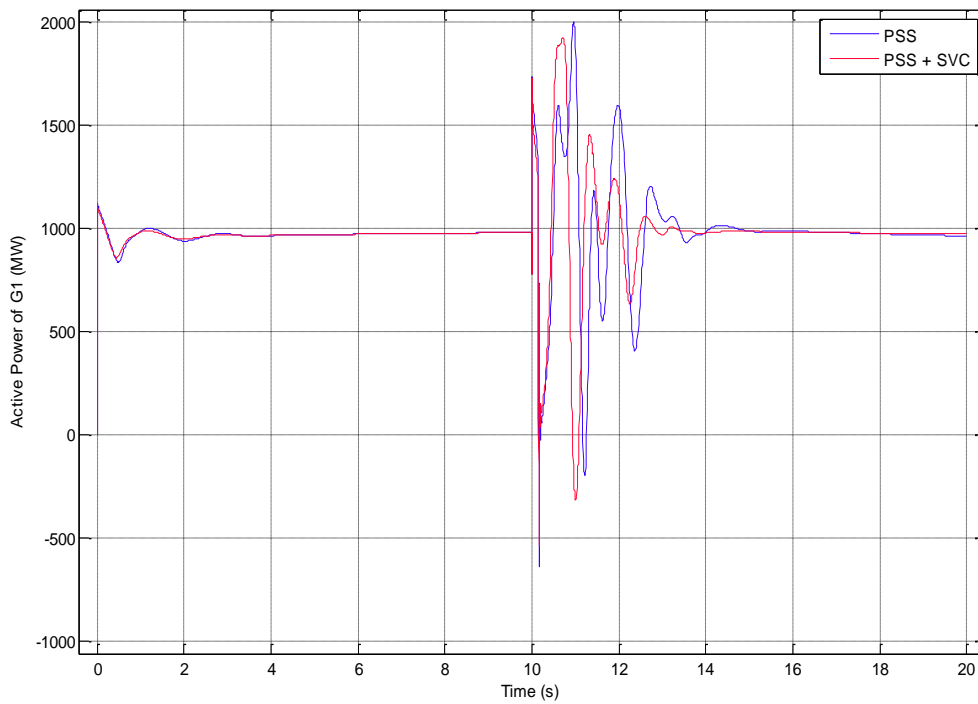


Figure 6.17 Transmission line active power of G1, Case 3

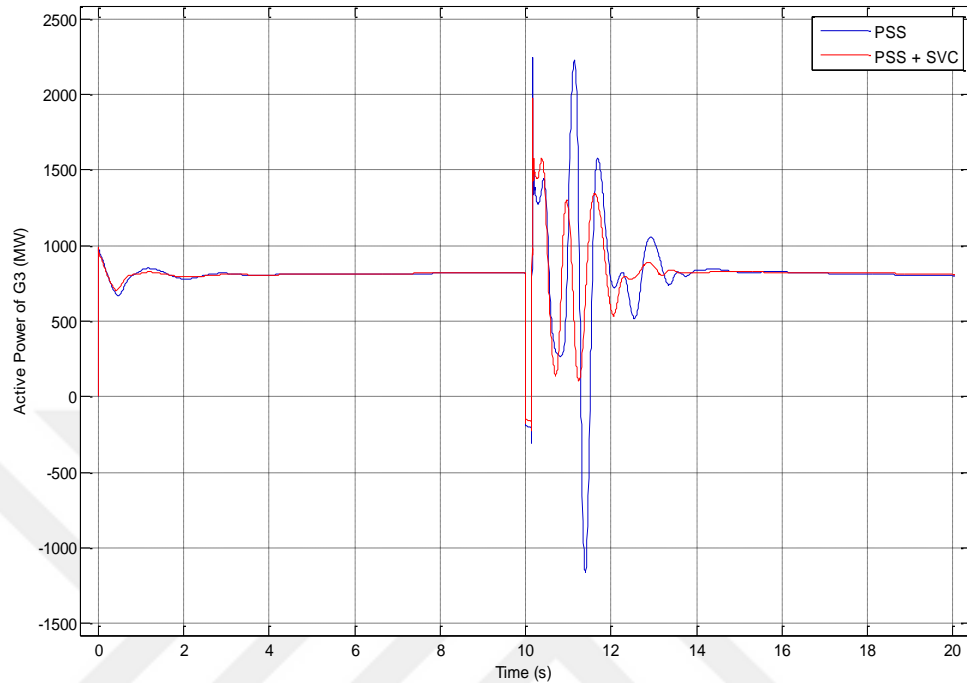


Figure 6.18 Transmission line active power of G3, Case 3

6.3.4 Case study with changing the location of the SVC and effect on the system

In this case we make comparison between using only PSS and PSS with SVC but with changing the location of SVC that connected to the test system to show the effect on the system to damping oscillation and improvement transient stability during large disturbance.

The large disturbance occurred by three phase fault with ground between generator 1 and generator 2 on the bus 2 at fifth second with clearing time 210ms. The results show the effect of location of SVC with generator.

Also this case explained that the location of the fault has effect on the transient stability by comparing the results with case two. thus when the fault occurring near the generator is more effective than it is far from the generator it is clear by comparing the result of this case with case two when the fault happened near generator 1 the maximum clearing time is (147ms) to return the system to stability but when the

location of the fault far with distance 305 km from generator 1 on bus 2 the maximum clearing time will be (210ms).

The comparison applied in this case each of the PSS alone and PSS with SVC together, and effect of change the location of SVC that connected with the system in other hand. Figure 6.19 and 6.20 shows rotor angle difference of Generator 1 and rotor angle difference of Generator 3, the results shows again using SVC is better than using only PSS and in also when connected the SVC near generator 1 on bus 1, the results good with peak amplitude (108 and 82 degree) than with connected SVC in middle generator 1 and generator 2 on bus 2 with peak amplitude (110 and 85 degree). figure 6.21 and 6.22 show that the terminal voltage on Bus 1 and terminal voltage on Bus 6 when connected the SVC near generator 1 on bus 1 oscillates less and stabilizes with peak amplitude (1.14 and 1.14 p.u) than with connected SVC in middle generator 1 and generator 2 on bus 2 with peak amplitude (1.15 and 1.15 p.u). The transmission line active power of G1 shows in figure 6.23, when connected the SVC near generator 1 on bus 1 oscillating less and stabilizing better) than with connected SVC in middle generator 1 and generator 2 on bus 2. Table 3 lists comparison data between using only PSS and PSS with SVC in difference location of test system. The results shown in table 6.3.

Table 6.3 Comparison between PSS and PSS with SVC when changing location of SVC

Parameters	PSS		PSS + SVC on bus 2		PSS + SVC on bus 1	
	Peak	Ts (s)	Peak	Ts (s)	Peak	Ts (s)
Rotor angle of G1	126 (deg.)	10.5	110 (deg.)	10	108 (deg.)	10
Rotor angle of G3	100 (deg.)	10.5	85 (deg.)	10	82 (deg.)	10
Terminal voltage on Bus 1	1.275 (p.u)	10.5	1.15 (p.u)	10	1.14 (p.u)	10
Terminal voltage on Bus 6	1.155 (p.u)	10.5	1.15(p.u)	10	1.14 (p.u)	10
Active power of G1	1920 (MW)	9	1920 (MW)	8	1910 (MW)	8

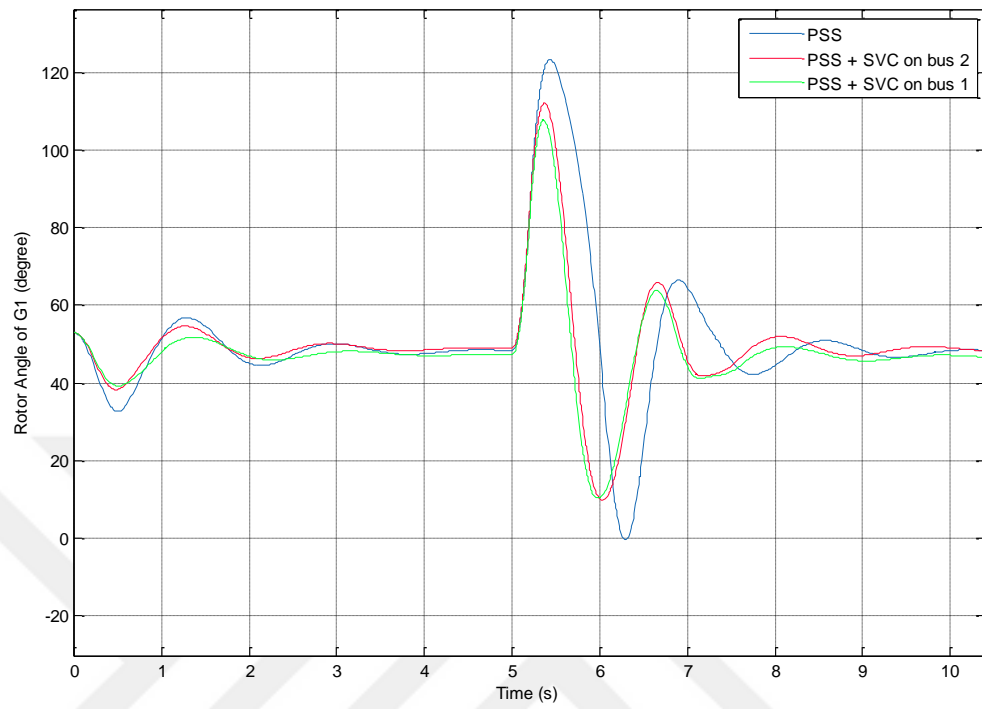


Figure 6.19 Rotor angle difference of G1 to G2, Case 4

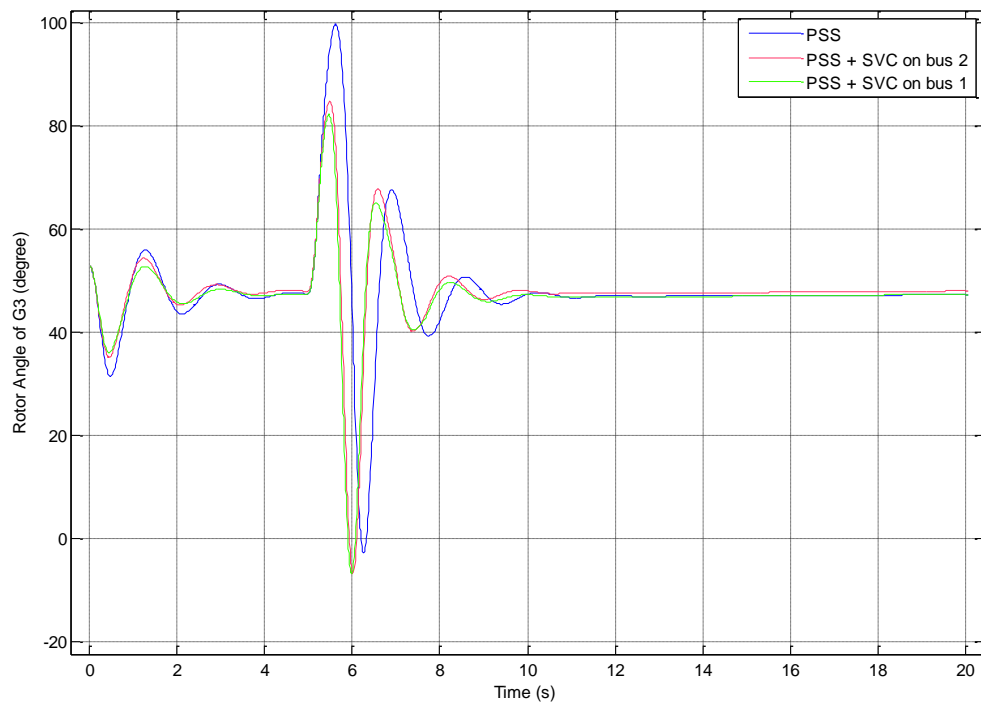


Figure 6.20 Rotor angle difference of G3 to G4, Case 4

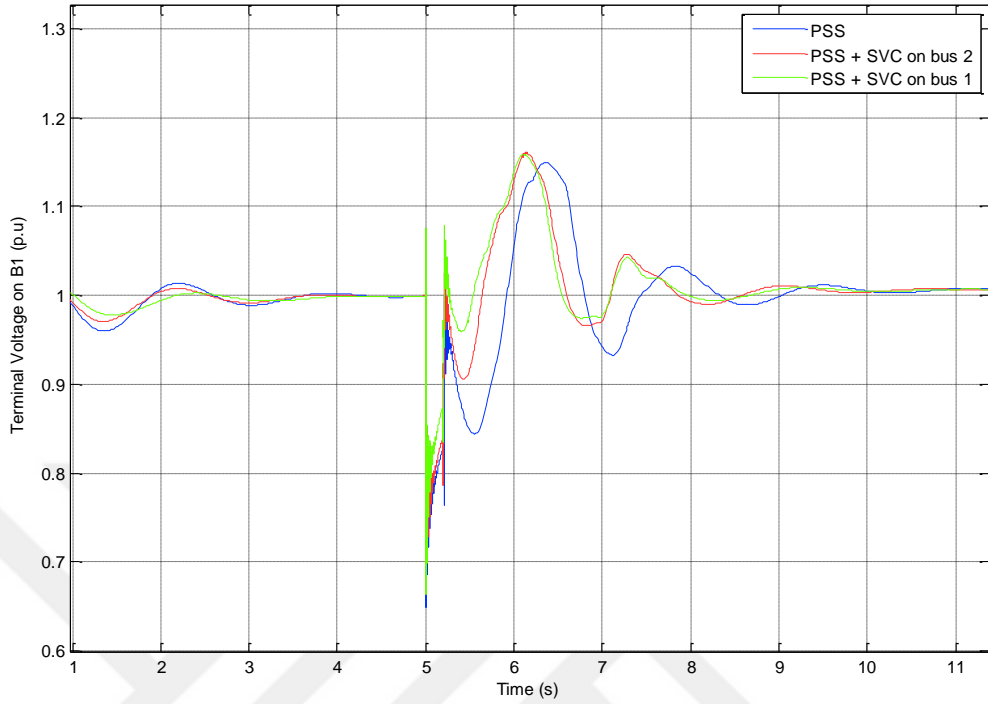


Figure 6.21 Terminal voltage on B1, Case 4

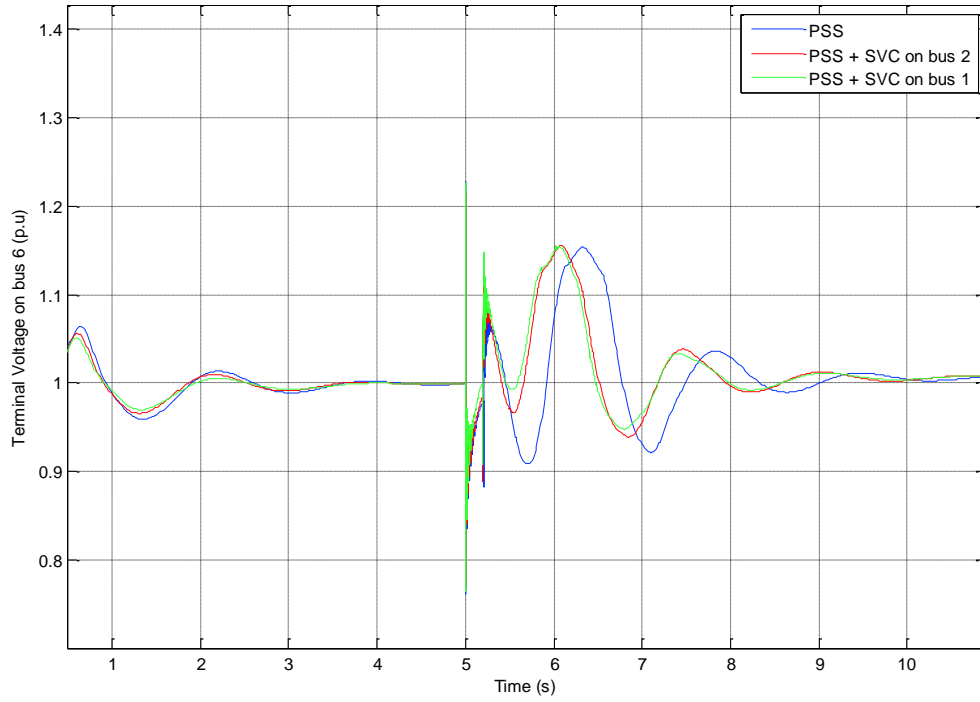


Figure 6.22 Terminal voltage on B6, Case 4

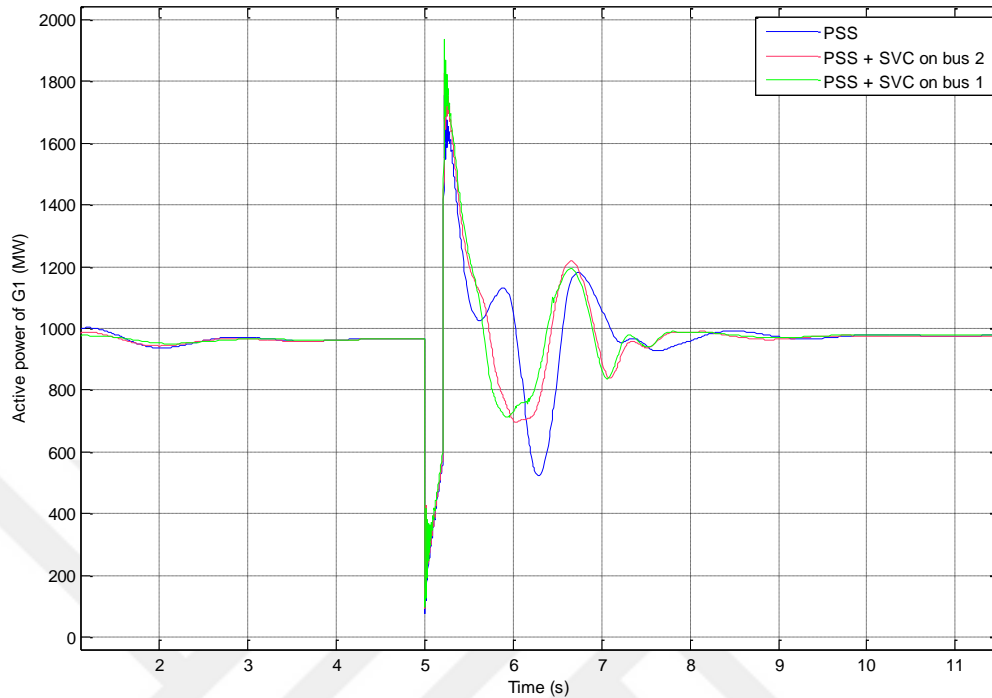


Figure 6.23 Transmission line active power of G1, Case 4

6.3.5 Sudden change of the system load

Another case that changes the system from stable to unstable and go through transient stability, is a sudden increase or decrease of the system load which makes disturbance and oscillation in the system. Therefore, the comparison between utilizing PSS alone and the grouping of SVC with PSS has been shown to enhance the system's damping oscillation and transient stability.

The test system is been arranged in such a way that a portion of the load of 4.8 megawatt on bus 3 near the second generator is lost in the fifth second with clearing time of 459 ms then it recover back. Consequently the great disturbance and high oscillation is generated within the system.

The comparison between using (PSS) and (PSS with SVC) also in the same time two different place for SVC has been applied, and designated the effect on each of the parameters of rotor angle and terminal voltage and active power presented in table 6.4 . Figure 6.24 and 6.25 expressions the rotor angle difference of G1 and rotor angle

difference of G3 are less fluctuated and stabilized quicker with using SVC, that the rotor angle of G1 to G2 and the rotor angle of G3 to G4 ; SVC smoothed faster with relaxing time is (10.5second and 11second) than with only PSS (12s and 12.5second), and the peak amplitude of both rotor angle with SVC reduced with value is 147 and 105 degrees, respectively, With only PSS, the corresponding values are 152 and 107 degrees. . Figure 6.26 illustration the terminal voltage on B1 is less oscillated and stabilized faster with using SVC that with peak amplitudes of 1.1 p.u, and settling time of 9s, compared to using only PSS with peak amplitudes of 1.23 p.u and settling time of 12 second. Figure 6.27 show the transmission line active power values of G1, that the transmission line active power with using SVC is less oscillated and settled faster with settling time 8.5 second compared with using only PSS more oscillated with settling time 12 second.

Table 6.4 Comparison between PSS and PSS with SVC when suddenly change the load

Parameters	PSS		PSS + SVC on bus 2		PSS + SVC on bus 1	
	Peak	Ts (s)	Peak	Ts (s)	Peak	Ts (s)
Rotor angle of G1	157(deg.)	12	152(deg.)	11	147(deg.)	10.5
Rotor angle of G3	125(deg.)	12.5	107(deg.)	12	105(deg.)	11
Terminal voltage on Bus 1	1.23 (p.u)	12	1.17 (p.u)	11	1.1 (p.u)	9
Active power of G1	1315(MW)	12	1315(MW)	10	1437(MW)	8.5

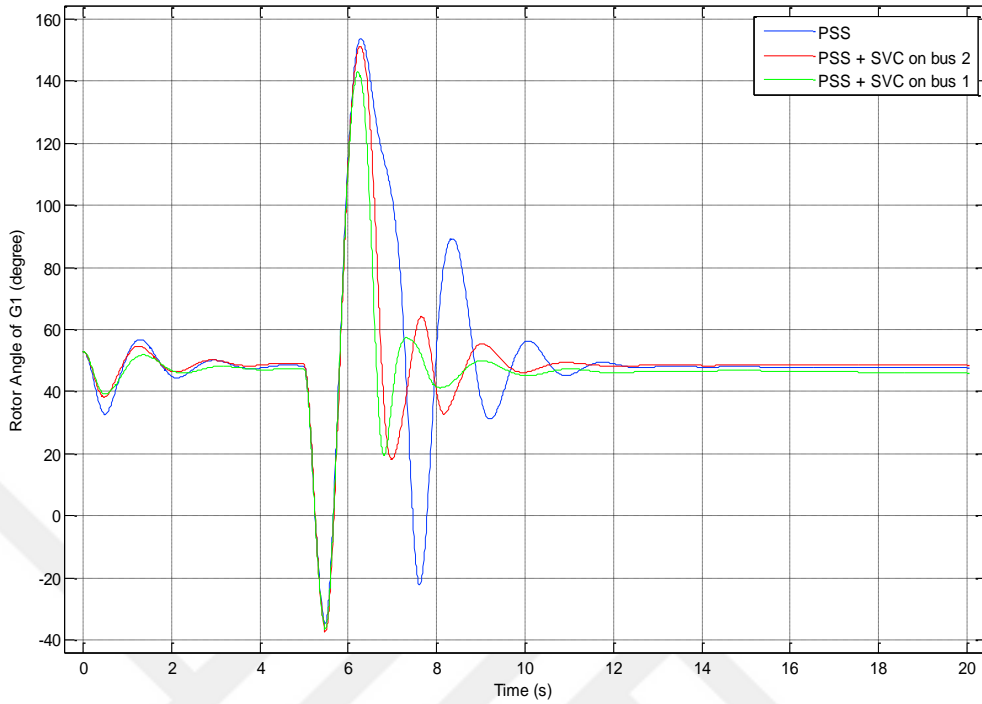


Figure 6.24 Rotor angle difference of G1 to G2, Case 5

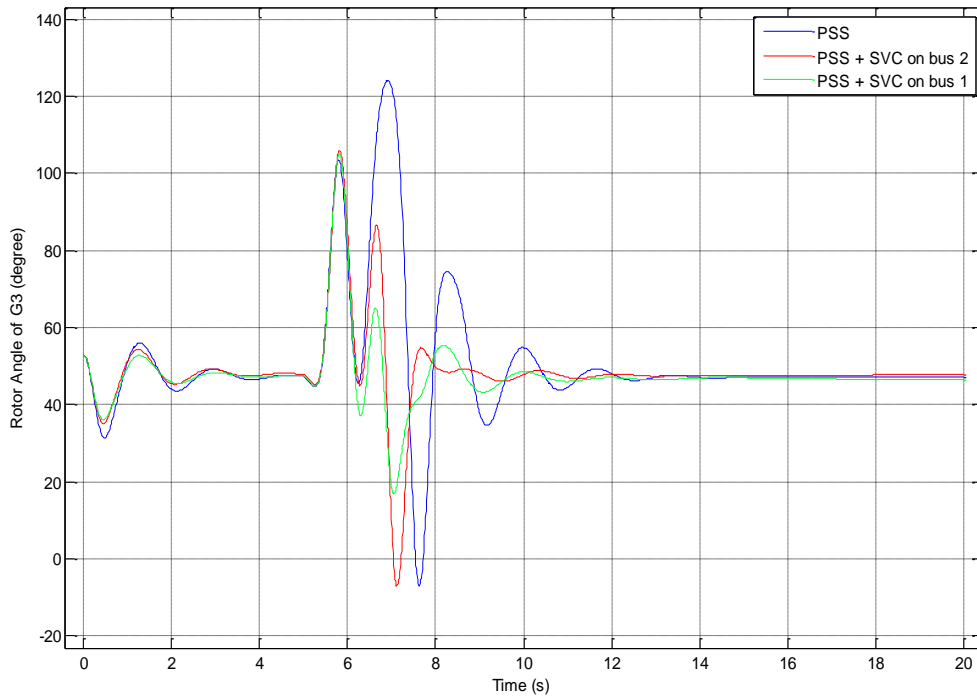


Figure 6.25 Rotor angle difference of G3 to G4, Case 5

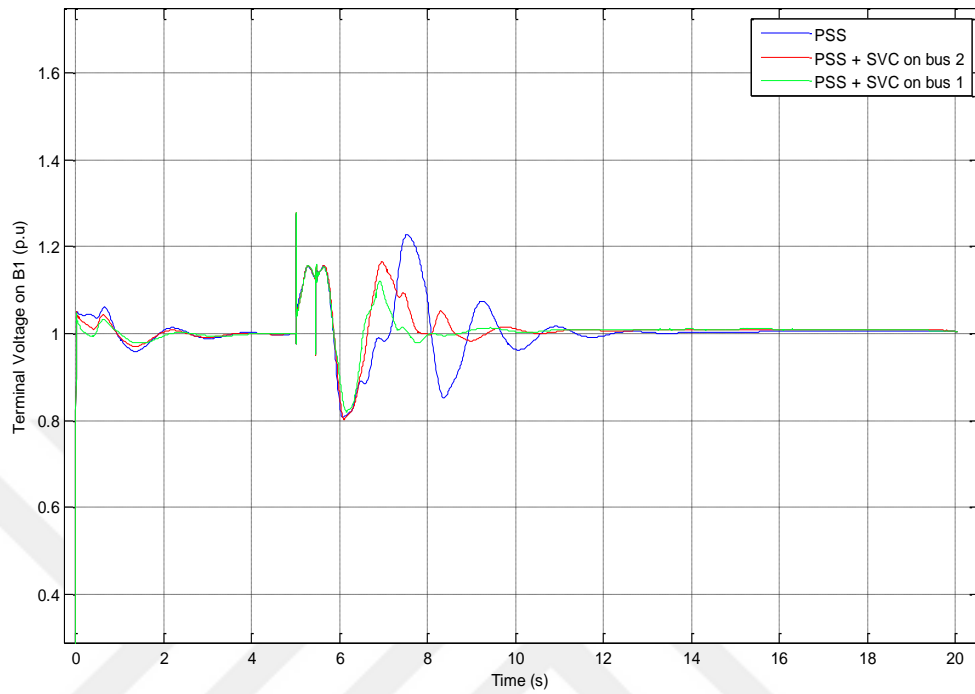


Figure 6.26 Terminal voltage on B1, Case 5

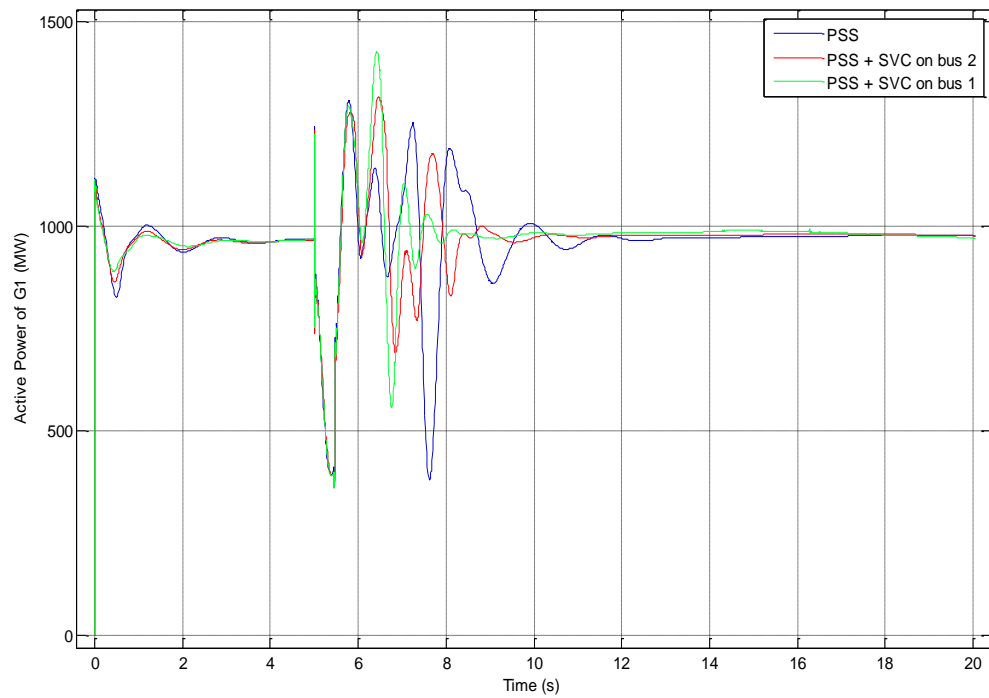


Figure 6.27 Transmission line active power of G1, Case 5

6.3.6 Fault with Starting operation

The purpose of this case is occurred three phase fault at starting operation to show the effect of using PSS and PSS with SVC to damping oscillation and improvement transient stability.

We know all system at starting operation have been oscillation and with occurred disturbance at starting this oscillation will be greater than to illustration how damping this oscillation the disturbance occurred on the test system by three phase fault to ground at (0) second with clearing time 162 mili second near generator 1 on bus 1 and connected SVC in tow difference place of the system, first near generator 1 on bus 1 and second place between generator 1 and generator 2 on bus 2.

Table 6.5 lists the performance comparison and effect of each PSS alone and coordinate PSS with SVC at starting operation also effect change in location of SVC with test system. Figures 6.28 and 6.29 shows that those rotor angle difference of Generator 1 and Generator 3 are less oscillated and stabilized faster with the coordinate PSS and SVC. Another parameter that also been observed is terminal voltage as shown in figure 6.30 and 6.31 , the terminal voltage is less oscillated and stabilized faster with connecting SVC with the test system at (5.4 and 5.5)second than only using PSS at (7) second. Figure 6.32 shows the active power of the transmission line has been oscillated faster with peak amplitude (1255 and a1325) MW with SVC than using PSS alone with peak amplitude (1375) MW.

Table 6.5 Comparison between PSS and PSS with SVC at Starting Operation

Parameters	PSS		PSS + SVC on bus 2		PSS + SVC on bus 1	
	Peak	Ts (s)	Peak	Ts (s)	Peak	Ts (s)
Rotor angle of G1	138 (deg.)	5.5	132 (deg.)	5.2	130 (deg.)	5
Rotor angle of G3	128 (deg.)	6.5	102 (deg.)	5.5	100 (deg.)	5.4
Terminal voltage on Bus 1	1.28 (p.u)	7	1.185 (p.u)	5.5	1.180 (p.u)	5.4
Terminal voltage on Bus 6	1.25 (p.u)	6.5	1.245(p.u)	5	1.20(p.u)	4.8
Active power of G1	1375 (MW)	5.8	1325 (MW)	4.5	1255 (MW)	4.4

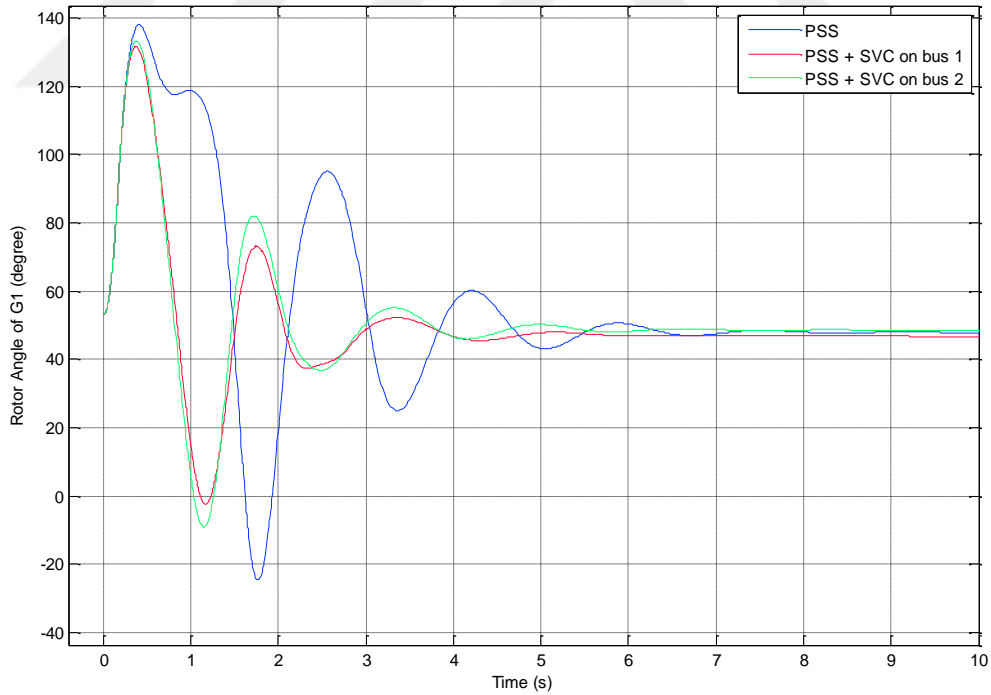


Figure 6.28 Rotor angle difference of G1 to G2, Case 6

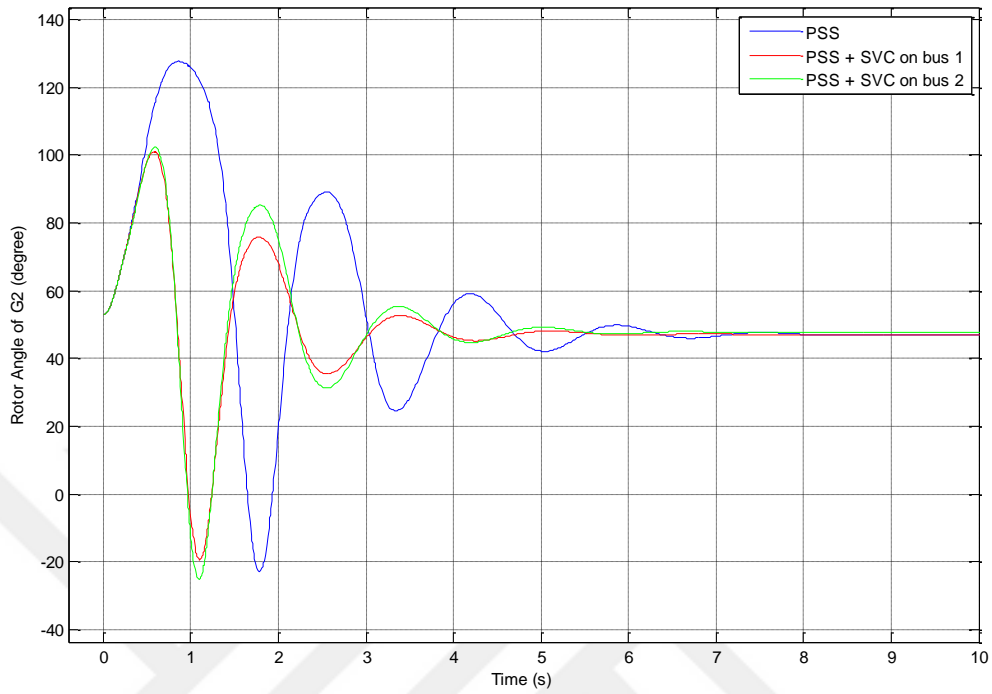


Figure 6.29 Rotor angle difference of G3 to G4, Case 6

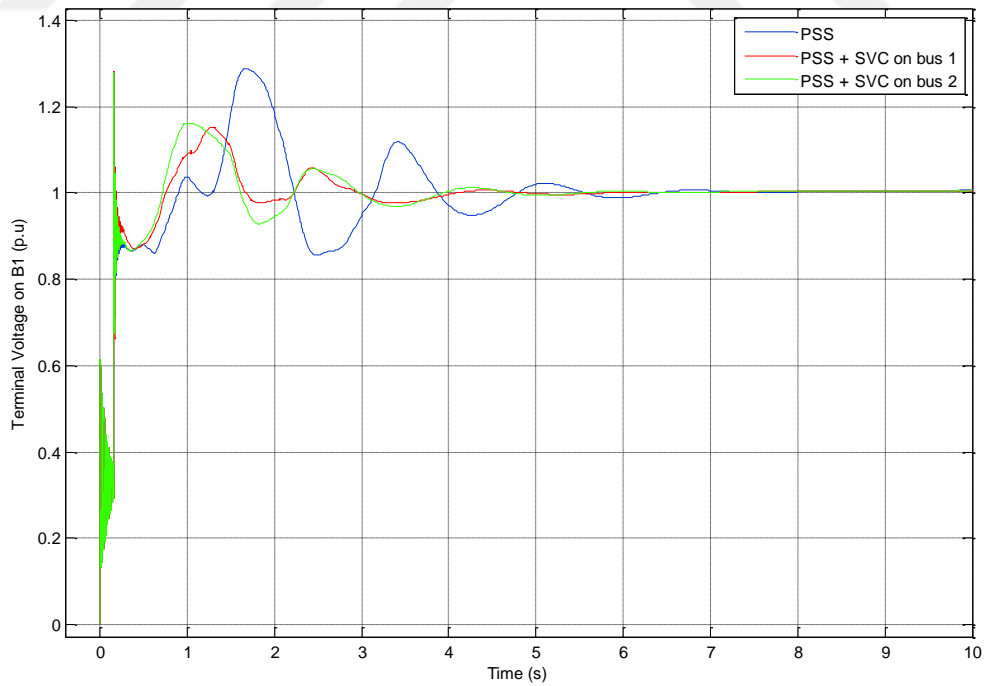


Figure 6.30 Terminal voltage onB1, Case 6

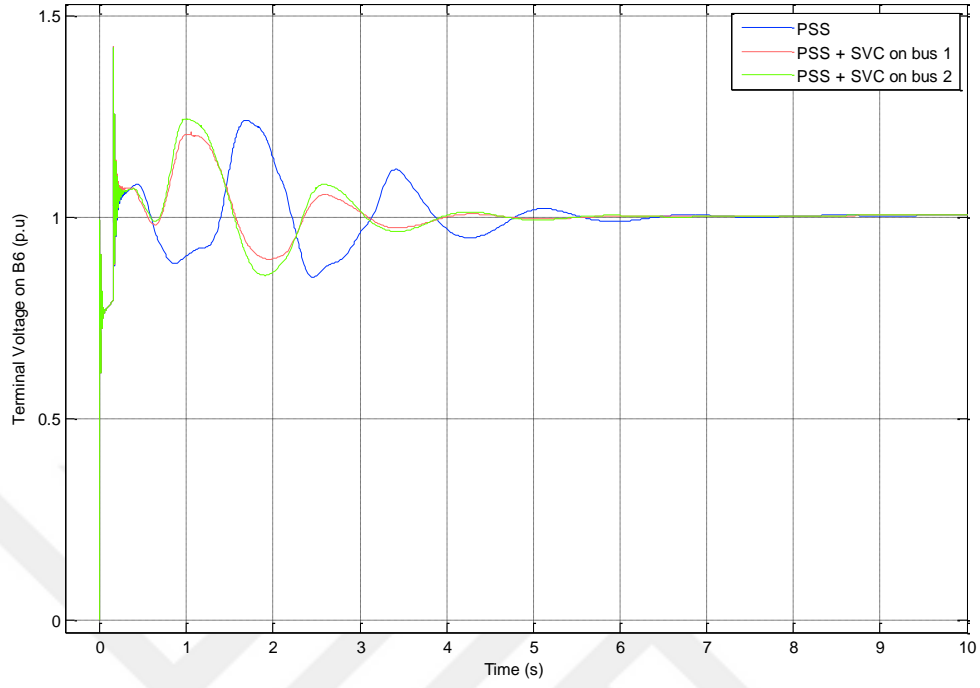


Figure 6.31 Terminal voltage on B6, Case 6

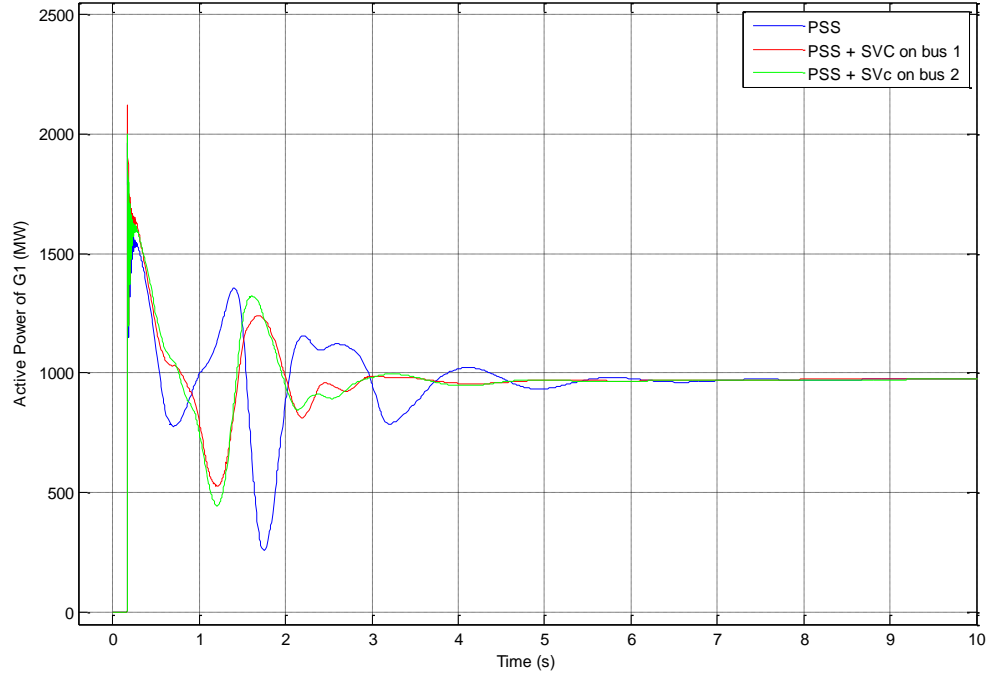


Figure 6.32 Transmission line active power of G1, Case 6

6.3.7 Comparison between using only PSS and PSS with two SVC at clearing time = 147 ms

The purpose of this case is explain effect of using tow SVC with PSS and comparison the results with using only one SVC with PSS of the system to damping oscillation and enhance transient stability.

The comparison between using PSS alone and two SVC with PSS in two different locations was made. The first SVC was connected to the system in a location the same place near generator 1 on bus 1, and the second was connected near Generator 3 with bus 6 as shown in figure 6.33.

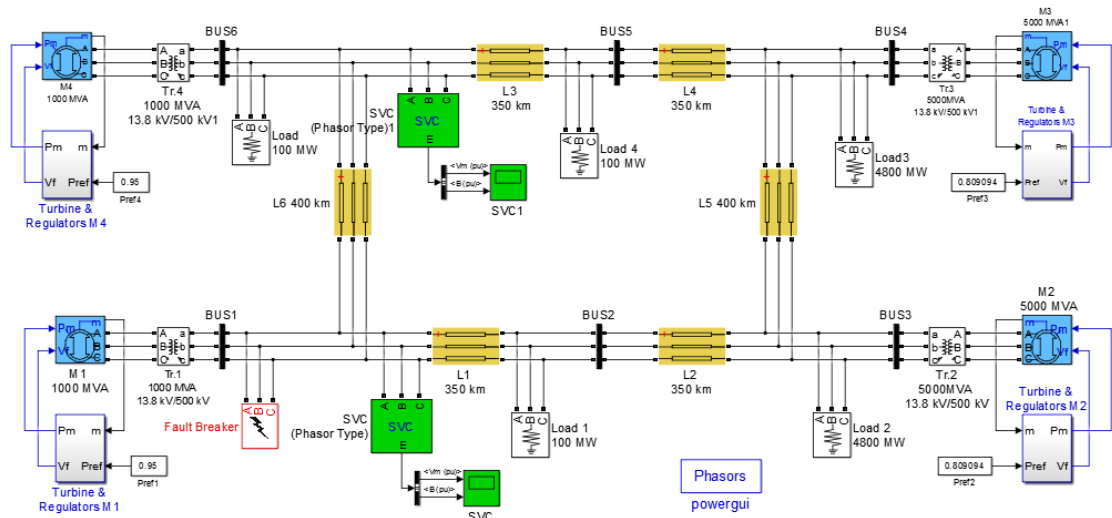


Figure 6.33 System Model with Using Two SVC

In this case after operation with applied each of the PSS solely and coordinate of PSS with two SVC and the proposed system under the large disturbance via three phase fault with ground near generator 1 at fifth second with clearing time 147 ms. The results show that using two SVCs with PSS is better than using only one SVC with PSS.

Figure 6.34 and 6.35 show that rotor angle difference of Generator 1 and rotor angle difference of Generator 3 with using two SVC with the test system settled faster with settling time is (10second and 10second) than with using only PSS with the system (13second and 12.3second), and the peak amplitude of both rotor angle with SVC

stabilized faster with values of 115 and 85 degrees than using only PSS with the test system with values of 130 and 128 degrees. Figure 6.35 and 6.36 show that the terminal voltage on Bus 1 and terminal voltage on Bus 6 with using two SVC oscillates less and stabilizes with peak amplitude (1.175p.u and 1.16p.u) and settled faster with settling time (10 second and 9 second) compared to using only PSS with test system, where the peak amplitude is (1.275p.u and 1.25p.u) and settling time (12 second and 12second). Figure 6.37 and 6.38 show the transmission line active power of G1 and line power of G3 with using tow SVC with test system oscillating less and stabilizing better with settling time (8.5 second and 10 second) than with using only PSS with settling time (12 second and 12 second).

Table 6.6 lists comparison data between using only PSS, one SVC and using two SVC. All data shows that connected tow SVC with test system is better compared with using PSS alone and PSS with one SVC.

Table 6.6 Comparison between PSS and PSS with one SVC and Tow SVC

Parameters	PSS		PSS + SVC		PSS + 2 SVC	
	Peak	Ts (s)	Peak	Ts (s)	Peak	Ts (s)
Rotor angle of G1	130 (deg.)	13	118 (deg.)	11	115 (deg.)	10
Rotor angle of G3	128 (deg.)	12.3	93 (deg.)	10.3	85 (deg.)	10
Terminal voltage on Bus 1	1.275 (p.u)	12	1.15 (p.u)	10	1.175 (p.u)	10
Terminal voltage on Bus 6	1.25 (p.u)	12	1.18 (p.u)	10	1.16 (p.u)	9
Active power of G1	1470 (MW)	12	1470 (MW)	10	2000 (MW)	8.5
Active power of G3	1470 (MW)	12	1350 (MW)	10	1300 (MW)	10

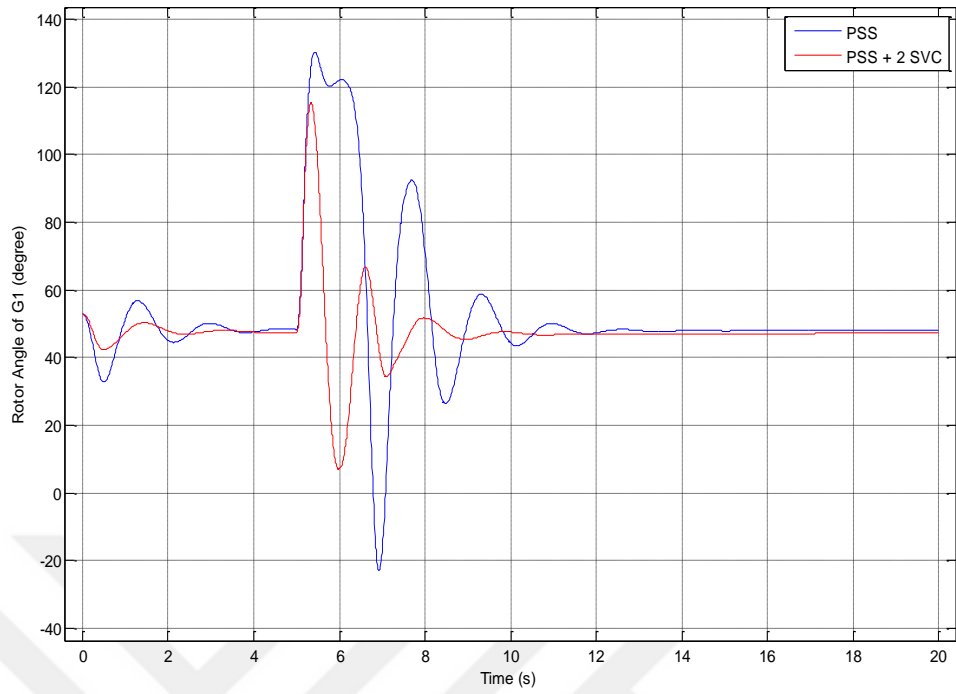


Figure 6.34 Rotor angle difference of G1 to G2, Case 7

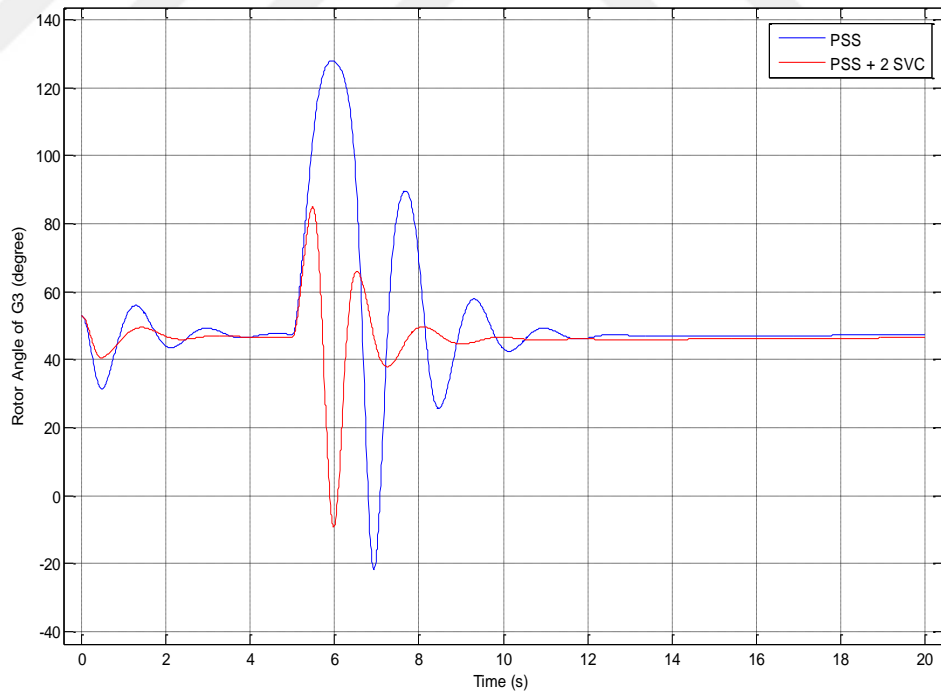


Figure 6.35 Rotor angle difference of G3 to G4, Case 7

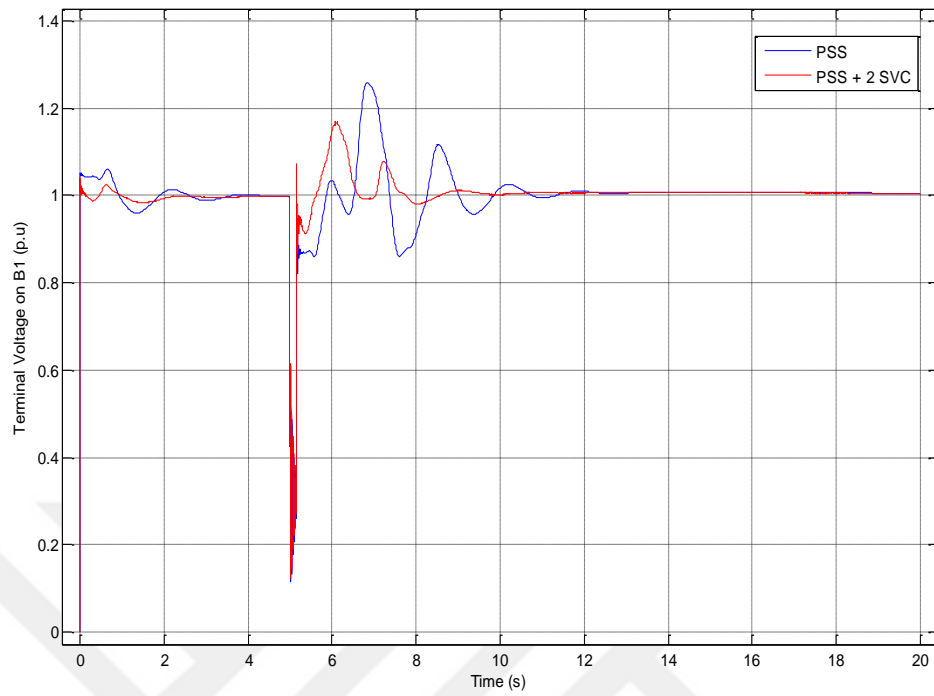


Figure 6.36 Terminal voltage on B1, Case 7

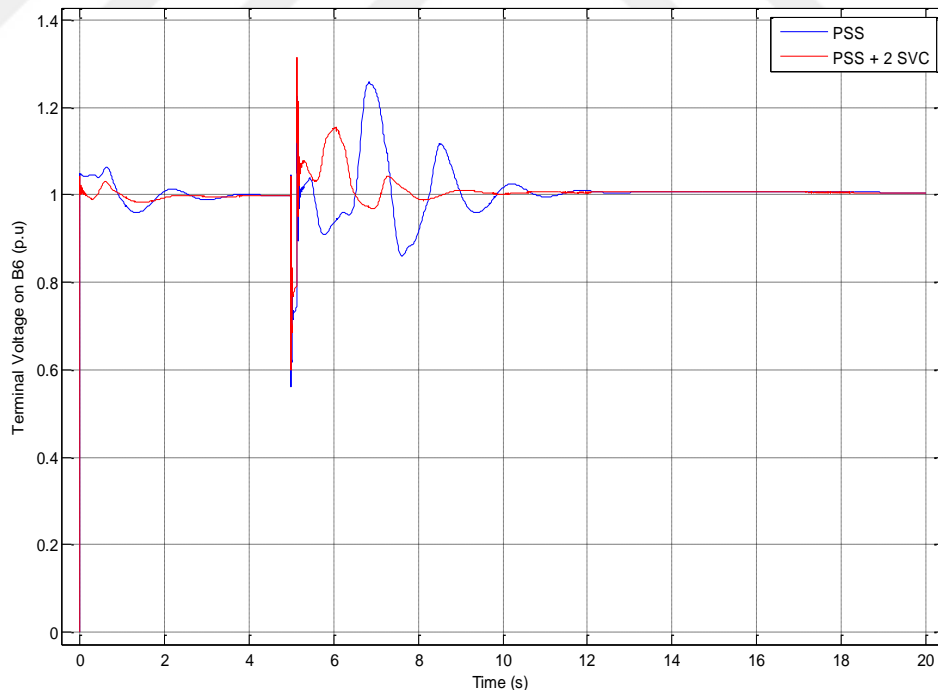


Figure 6.37 Terminal voltage on B6, Case 7

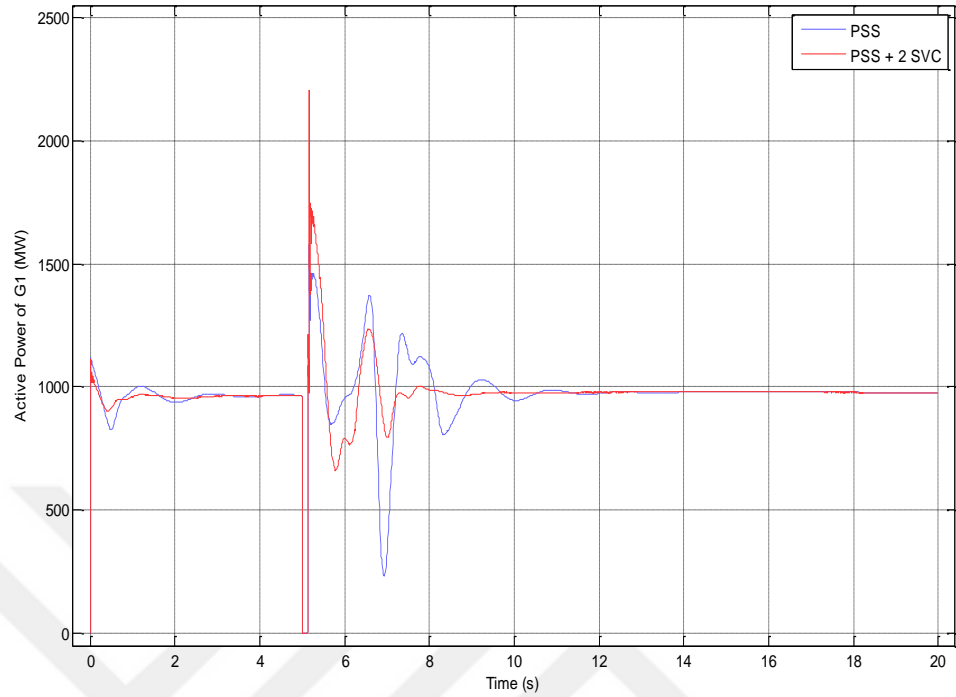


Figure 6.38 Transmission line active power of G1, Case 7

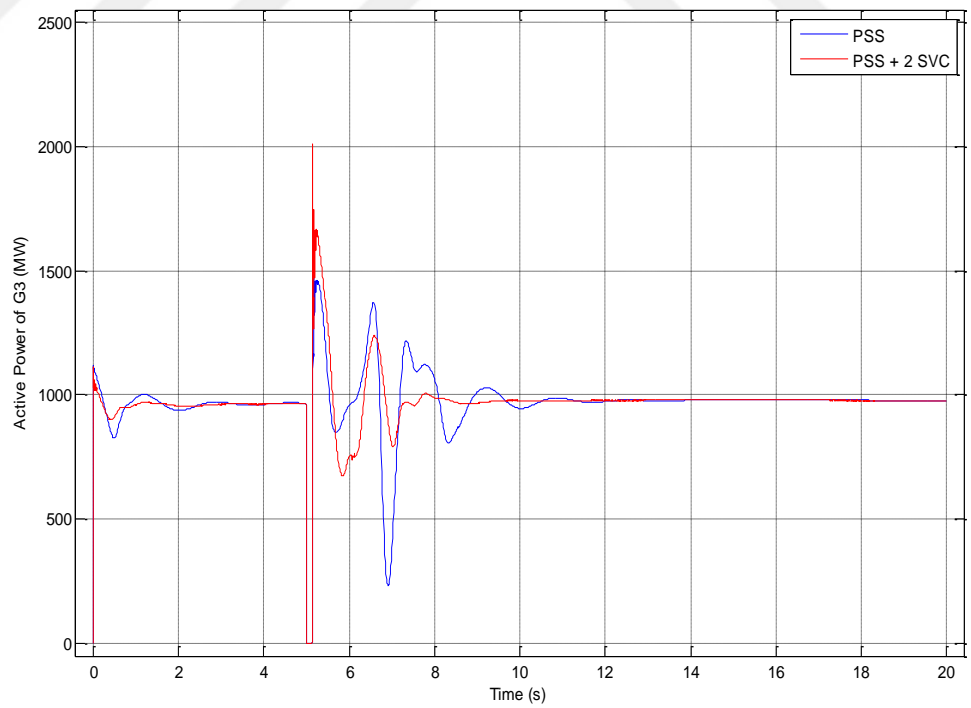


Figure 6.39 Transmission line active power of G3, Case 7

6.3.8 Effect of using double transmission line on improve transient stability

The system that designed for this study , all generators connecting by single transmission line but for explain the effect of using double transmission line instead single transmission for enhance transient stability we took this case by connecting other transmission line in parallel between generator 1 and generator 2 as shown in figure 6.40 . This case shows that the maximum clearing will be (188ms) with comparing case two it is (147ms).

The figure 6.41 shows the difference rotor angle between G1 and G2 by using double transmission line is less swing and faster stabilized with settling (8.5s) than using single transmission line with (12s). Also figure 6.42 explain active power of generator 1 with using double transmission is smoothed with time (8.55s) than using single transmission line with (10.5s), because of increasing power flow and decreasing rotor angle.

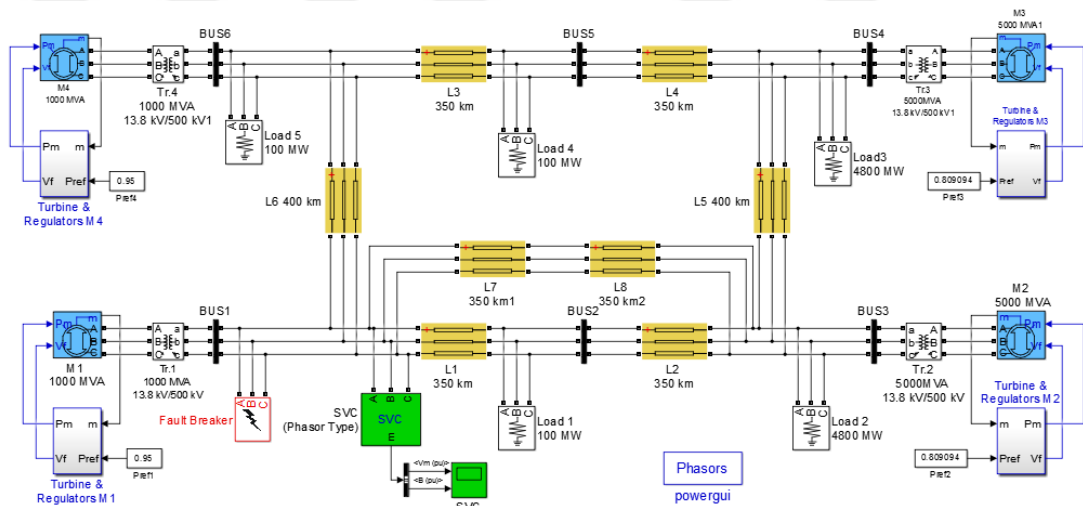


Figure 6.40 System Model with Double Transmission Line between G1 and G2

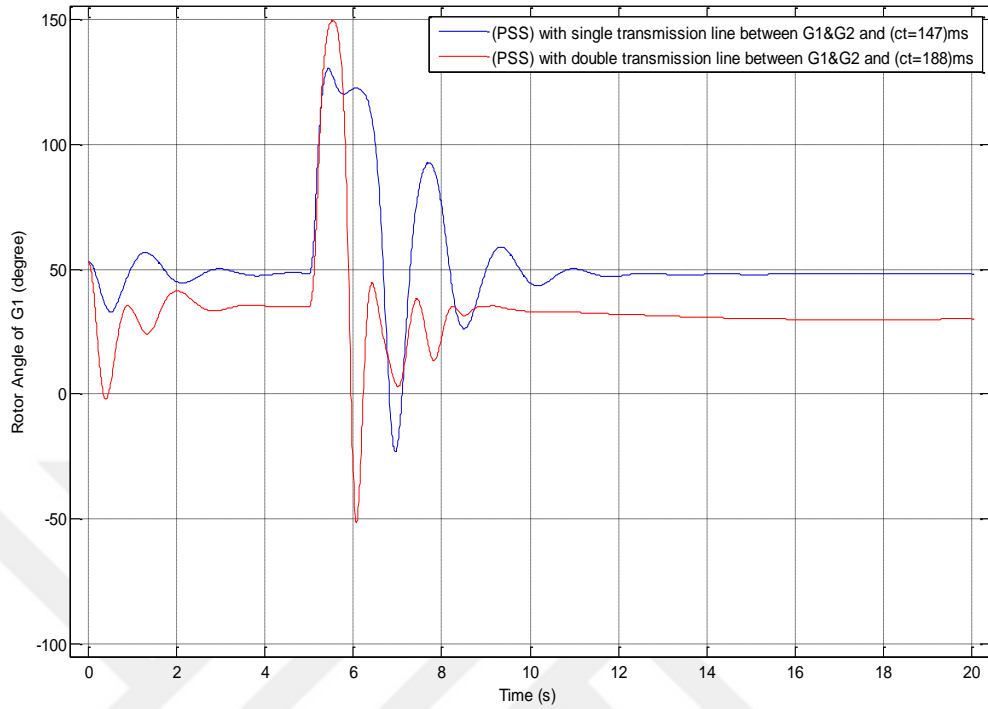


Figure 6.41 Rotor angle difference of G1 to G2, Case 8

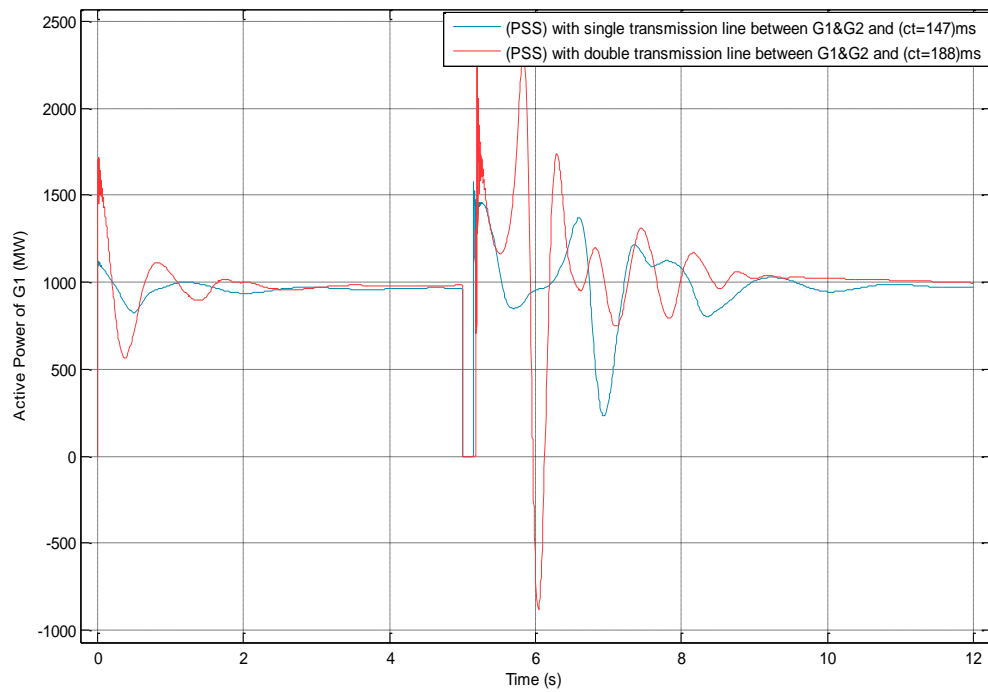


Figure 6.42 Transmission line active power of G1, Case 8

6.4 Discussion and Result

In order to improve one of the unstable system which is the transient stability by means of the PSS alone or PPS and SVC together to compare their result and outcome, it is been necessary to suggest a system that is consists of the connection of four machines (generators) and six buses in a long transmission lines. For this purpose the simulation has been made by using Software program.

In this study, seven cases were found to explain the transient stability improvement. In the first case it has been indicated that after introducing the three phases to ground fault with maximum clearing time of 148 ms, the test system lost synchronism and went unstable by using only PSS. On the other hand, the system remains stable while using SVC combined with the PSS in it.

The second case is same as the first case, the system stayed stable using both PSS independently and PSS with SVC. This has been made by reducing the maximum clearing time into 147 ms. This process also indicated the comparison between PSS and coordinate of PSS and SVC, which was made to highlight their effect. Moreover, this reduction has caused damping in oscillation and the system transient stability enhancement of all parameters.

Missing one of the generators in the system resulted in state of the transient stability this has been presented in case three. For this purpose, the third generator disconnected to the system from the 10th second for the period of 152 ms, hence the system disturbance and transient stability occurred. Similarly to previous cases outcome it is better to use SVC and PSS rather than utilizing only PSS for oscillation damping.

Fourth case is about importance of changing the SVC location of the system and the impact is made. This is to identify the distance of SVC from the generators and how the impact changes accordingly, thus the damp of oscillation and transient stability is achieved. For this reason the creation of three phases to ground fault is made, in the middle of transmission line, between generator one and two. This effect has been made firstly, by locating SVC in the middle of the transmission line near the fault on the second bus. Secondly, the SVC is located near generator one on the first bus. The result

showed that if the SVC is located adjacent to the generators, damping in oscillation and the system transient stability is enhanced.

Another case that causes the system to be in transient stability is the fluctuation of its load. In order to achieve this process, the sudden cut of system load has been made for a period of 459 ms. Consequently the system become disturbed and unstable. For that matter PSS solely and PSS with additional SVC has been used, in the same time two different place for SVC has been utilized. According to all the gained results, it made obvious that using the one with SVC is better as compared to PSS alone for stabilizing the oscillation in a short period.

Another case is about comparing the results of using either PSS or PSS with SVS together, during the start of the system operation. Hence three phase to ground fault is created at zero second with clearing time of 162ms. Consequently, we discovered that the use of SVC in the beginning of system operation is better to damp the oscillation and improve transient stability of the system.

Using Two SVC separately in different position in the system is another case has been taken, this is to distinguish the result while using one SVC in the system as compared to using two SVC in the similar system. For this purpose a fault near generator one has been created and SVC one is placed near generator one on the first bus, and second SVC near generator two on the sixth bus. The obtained result from this case shown that effect of using two SVC is much better than using one SVC, for stabilizing the oscillation.

Finally using double transmission line to improve transient stability is another case has been taken, this is comparison between using double and single transmission line in the system and effecting on the system. by compression the results in this case with case two shows that using double transmission line more effective to improve transient stability.

CHAPTER 7

CONCLUSIONS AND SUGGESTIONS FOR FUTURE WORK

7.1 Conclusion of this Study

This study is about transient stability improvement in multi-machine by using PSS and SVC, through the usage of a simulation software program. This work is concluded mainly in the following points:

1. Firstly, making a system such as a test system. In which it consists of four generator (machine) and six buses, while all of them are connected via a long transmission line, and load distribution in different places in the system.
2. Utilizing each PSS with exciter of generators for damping oscillation, also one of the members of FACTS which is SVC in a parallel way with the system. The results of PSS alone and with SVC are compared for improving transient stability.
3. Using PSS separately and combined with SVC in a multi-machine system for controlling all the parameters is a very hard task. When disturbance is occurred in any part of the system, this effects on all the other generators, this makes all the parameters to change. For explaining the comparison of them results and enhancement of the transient stability, eight different cases has been selected. Moreover, the effect of those cases has been shown on each parameters of rotor angle, terminal voltage and active power.

According to the results of all the cases the following facts has been discovered.

- When Fault occurs during the maximum clearing time of 148ms by using only PSS, the system loses synchronism and become unstable. Whereas the

availability of SVC and PSS with the same clearing time value with swing and oscillation, the system returns to stable mode.

- In the critical clearing time which is 147ms, the system remains stable with both PSS alone and combined of PSS and SVC, but the second one is much better for damping oscillation than using PSS alone. This shows the advantage of SVC for resolving Transient Stability.
- Losing one or more generator in the system is a worst case that faces the system and this cause's big disturbance. This is because during this time rotor angle has maximum swing and amplitude, also the quickest time is needed for the generator to reconnect to the system and the time is 152ms otherwise the system is out of synchronism and shuts down.
- When the location of the Fault is far from the generator, the effect is less on the transient stability, thus rotor angle has fewer swing and least amplitude. The clearing time value is 210ms when the distance of the fault from the generator 1 is 350 km. But clearing time decreases to 147ms when the fault occur near the generator 1.
- As the location of SVC is closer from the generator, the effect of occurring fault is less on the generator. This is significantly better for fixing transient stability.
- The effect of changing load on the system makes is develop transient stability. Therefore the impact of using SVC and PSS together for damping oscillation is better than using PSS alone in the system.
- The impact of occurring fault during the beginning of operation of any system is very significant, as at the beginnings every system has oscillation until the system becomes stable. In that case utilizing SVC and PSS in much better for damping oscillation and improving transient stability.
- Using two SVC in two different locations is better than using one SVC for fixing transient stability, because availability of SVC near each generators supports the generator to be synchronism.

- Using double transmission line is better than using single transmission line, as in this case power flow is increased and rotor angle is decreased which help to fix transient stability.

7.2 Future Work

1. In this research we can change the type and generators for different ones, such as steam station, wind or PV. This is for explaining the effect of PSS and SVC on transient stability improvement.

2. Using a different sort of PSS instead of generic type, for example (multi band PSS).

3. Using a different control of SVC instead of PI control such as Fuzzy logic controller, by means of enhancing transient stability in better and more precise way.

REFERENCES

- [1] Hingorani, N. G., & Gyugyi, L. (2000). Understanding facts. IEEE press.
- [2] Edris, A. A. (1997). Proposed terms and definitions for flexible AC transmission system (FACTS). *IEEE Transactions on Power Delivery*, **12**(4).
- [3] Kumkratug, P. (2009). Application of UPFC to increase transient stability of inter-area power system. *Journal of Computers*, **4**(4), 283-287.
- [4] Stagg, G. W., & El-Abiad, A. H. (1968). Computer methods in power system analysis. McGraw-Hill.
- [5] Eslami, M., Shareef, H., & Mohamed, A. (2012). Coordinated design of unified power flow controller and power system stabilizer to enhance power system stability. In *Power System Technology (POWERCON), 2012 IEEE International Conference on* (pp. 1-6). IEEE.
- [6] Larsen, E. V., & Swann, D. A. (1981). Applying power system stabilizers Part III: Practical considerations. *Power Apparatus and Systems, IEEE Transactions on*, **(6)**, 3034-3046.
- [7] Patel, H. D., & Majmudar, C. (2011). Fuzzy logic application to single machine power system stabilizer. In *Engineering (NUiCONE), 2011 Nirma University International Conference on* (pp. 1-6). IEEE.
- [8] Abido, M. A. (2005). Analysis and assessment of STATCOM-based damping stabilizers for power system stability enhancement. *Electric Power Systems Research*, **73**(2), 177-185.
- [9] Mathur, R. M., & Varma, R. K. (2002). Thyristor-based FACTS controllers for electrical transmission systems. John Wiley & Sons.
- [10] Chan, K. H. (2002). Transient analysis and modelling of multimachine systems with power electronics controllers for real-time application (Doctoral dissertation, University of Glasgow).
- [11] Reddy, D. R. R. (2007). Improving Transient Stability of Power Systems by using passivity-based Nonlinear STATCOM Controller (Doctoral dissertation, National Institute of Technology Rourkela).
- [12] Hamarash, I. (2007). Modeling & Simulation of Planned Kurdistan Regional Power System/Iraq, Department of Electrical and Computer Systems Engineering. PO Box 35, Monash University, Clayton Victoria 3800, Australia.
- [13] Sahu, L. (2011). Modeling of STATCOM and SVC for Power System Steady State Operation and Enhancement of Transient Stability of a Multi Machine Power System by STATCOM (Doctoral dissertation).

- [14] Kaur, D. T., & Kakran, S. (2012). Transient Stability Improvement of Long Transmission Line System by Using SVC. *IJARIEE*.
- [15] Arzaha, N. A., Mustafa, M. W., & Idris, R. M. (2012). Fuzzy-based Static VAR Compensator controller for damping power system disturbances. In *Power Engineering and Optimization Conference (PEDCO) Melaka, Malaysia, 2012 Ieee International* (pp. 538-542). *IEEE*.
- [16] Tailor, D. N., Bhalja, B., & Makawana, V. Roll of PSS and SVC for improving the Transient Stability of Power System. *International Journal of Engineering and Advanced Technology (IJEAT) ISSN, 2249-8958*.
- [17] Singh, S., Ram, A., Goel, N., & Kumar, P. (2013). Transient Stability Enhancement of Multi-Machine System Using FACTS Controllers. *International Journal of Engineering Science and Innovative Technology, 2(2)*.
- [18] Keskes, S., Bahloul, W., & Kammoun, M. B. A. (2014). Transient stability enhancement of power system equipped with power system stabilizer by static var compensator. In *Renewable Energy Congress (IREC), 2014 5th International* (pp. 1-6). *IEEE*.
- [19] Singh, B. (2011). Applications of FACTS controllers in power systems for enhance the power system stability: a state-of-the-art. *International Journal of Reviews in Computing, 6*.
- [20] Ali, E. S., & Abd-Elazim, S. M. (2015). Stability improvement of multimachine power system via new coordinated design of PSSs and SVC. *Complexity, 21(2)*, 256-266.
- [21] Jha, B. K., Gupta, R. P., & Prasad, U. (2014). Combined Operation of SVC, PSS and Increasing Inertia of Machine for Power System Transient Stability Enhancement. *International Journal of Applied Power Engineering (IJAPE), 3(1)*, 15-22.
- [22] Karuppiyah , Malathi, Selvalakshmi .(2014). Transient Stability Enhancement Using Fuzzy Controlled SVC and STATCOM. *International Conference on Innovations in Engineering and Technology (ICIET'14), 3(3)*.
- [23] Bainsla, U., Mohini, K. R., & Gupta, A. (2015). Transient stability enhancement of multi machine system using static var compensator. *International Journal of Engineering Research and General Science, 3(3)*.
- [24] Kundur, P. (1994). Power system stability and control (**Vol. 7**). N. J. Balu, & M. G. Lauby (Eds.). New York: McGraw-hill.
- [25] Zarghami, M. (2008). Inter-area oscillation damping in large scale power systems with unified power flow controllers. ProQuest.
- [26] Grainger, J. J., & Stevenson, W. D. (1994). Power system analysis. McGraw-Hill.
- [27] Shih. Min. hau, Power System, Basic Concepts and Application, Internet
- [28] Shelto, M. L., Winkelman, P. F., Mittelstadt, W. A., & Bellerby, W. J. (1975). Bonneville power administration 1400-MW braking resistor. *Power Apparatus and Systems, IEEE Transactions on, 94(2)*, 602-611.

- [29] Kimbark, E. W. (1964). Suppression of ground-fault arcs on single-pole-switched EHV lines by shunt reactors. *IEEE Transactions on Power Apparatus and Systems*, **3(83)**, 285-290.
- [30] Venayagamoorthy, G. K. (2005). Optimal control parameters for a UPFC in a multimachine using PSO. In *Intelligent Systems Application to Power Systems, 2005. Proceedings of the 13th International Conference on* (pp. 6-pp). *IEEE*.
- [31] Tumilty, R. M., Bright, C. G., Burt, G. M., Anaya-Lara, O., & McDonald, J. R. (2007, May). Applying Series Braking Resistors to Improve the Transient Stability of Low Inertia Synchronous Distributed Generators. In *19th International conference on Electricity Distribution*.
- [32] Saadat, H. (1999). Power system analysis. WCB/McGraw-Hill.
- [33] Kothari, D. P., & Nagrath, I. J. (2003). Modern power system analysis. Tata McGraw-Hill Education.
- [34] Song, Y. H., & Johns, A. (1999). Flexible ac transmission systems (FACTS) (**No. 30**). *IET*.
- [35] Hingorani, N. G., & Gyugyi, L. (2000). Understanding facts. *IEEE press*.
- [36] Haque, M. H. (2006). Damping improvement using facts devices. *Electrical Power Syst. Res*, **76(9-10)**.
- [37] Padiyar, K. R., & Devi, A. L. (1994). Control and simulation of static condenser. In *Applied Power Electronics Conference and Exposition, 1994. APEC'94. Conference Proceedings 1994., Ninth Annual* (pp. 826-831). *IEEE*.
- [38] Padiyar, K. R. (2007). FACTS controllers in power transmission and distribution. New Age International.
- [39] Festo Didactic Ltée/Ltd, (2015). Electricity and New Energy, Static Var Compensator (SVC). Courseware Sample 86370-F0.
- [40] Sabai, N., Maung, H. N., & Win, T. (2008). Voltage control and dynamic performance of power transmission system using static var compensator. *World Academy of Science, Engineering and Technology*, **42, 426**.
- [41] Padiyar, K. R. (2008). Power system dynamics. BS publications.
- [42] Ponovo, (2011). Static var compositor (SVC). Power advanced Technology Company.LTD.
- [43] Kundur, P., Klein, M., Rogers, G. J., & Zywno, M. S. (1989). Application of power system stabilizers for enhancement of overall system stability. *Power Systems, IEEE Transactions on*, **4(2)**, 614-626.
- [44] Kent, M., Schmus, W., McCrackin, F., & Wheeler, L. (1969). Dynamic modeling of loads in stability studies. *IEEE Transactions on Power Apparatus and Systems*, **5(PAS-88)**, 756-763.
- [45] Srinivasan, K., Nguyen, C. T., & Robichaud, Y. (1979). Closed Loop Load Response to Random Perturbations. *Power Apparatus and Systems, IEEE Transactions on*, **(5)**, 1591-1595.

- [46] Price, W. W., Chiang, H. D., Clark, H. K., Concordia, C., Lee, D. C., Hsu, J. C., ... & Srinivasan, K. (1993). Load representation for dynamic performance analysis. *IEEE Transactions on Power Systems*, **8(2)**, 472-482.
- [47] Price, W. W., Wirgau, K. A., Murdoch, A., Mitsche, J. V., Vaahedi, E., & El-Kady, M. A. (1988). Load modeling for power flow and transient stability computer studies. *Power Systems, IEEE Transactions on*, **3(1)**, 180-187.
- [48] Hill, D. J., PAL, M., Wilsun, X., Mansour, Y., Nwankpa, C., Xu, L., & Fischl, R. (1993). Nonlinear dynamic load models with recovery for voltage stability studies. Discussion. Authors' response. *IEEE Transactions on Power Systems*, **8(1)**, 166-176.
- [49] Kundur, P., Klein, M., Rogers, G. J., & Zywno, M. S. (1989). Application of power system stabilizers for enhancement of overall system stability. *Power Systems, IEEE Transactions on*, **4(2)**, 614-626.
- [50] Lee, D. C., & Kundur, P. (1986). Advanced excitation controls for power system stability enhancement. *CIGRÉ paper*, **38(01)**.
- [51] Rafiee, Z., Ganjefar, S., & Fattahi, A. (2010). A new PSS tuning technique using ICA and PSO methods with the fourier transform. In *Electrical Engineering (ICEE), 2010 18th Iranian Conference on* (pp. 806-811). *IEEE*.
- [52] Machowski, J., Bialek, J., & Bumby, J. (2011). *Power system dynamics: stability and control*. John Wiley & Sons.
- [53] Nambu, M. (1997). Stabilizer for power system .*U.S. Patent No. 5,604,420*. Washington, DC: U.S. Patent and Trademark Office.
- [54] Jovcic, D., & Pillai, G. N. (2005). Analytical modeling of TCSC dynamics. *Power Delivery, IEEE Transactions on*, **20(2)**, 1097-1104.