LOAD FLOW MODEL FOR UPFC WITH ESS AND ATC DETERMINATION

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A project report submitted in partial fulfilment of the
requirements for the award of the degree of
Master in Engineering (Electrical-Power)

Faculty of Electrical Engineering
Universiti Teknologi Malaysia

NOVEMBER 2009

ACKNOWLEDGEMENT

All praise, glory and gratitude be to Allah who said in the Holy Qur'an that "He who taught (the use of) the pen and taught the man that which he knew not". Peace be upon the Prophet Muhammad SAW, his family, his companions, and all those who followed him until the Day of Judgment.

First of all I wish to express my deepest gratitude to my thesis advisor Assoc. Prof. Dr. Mohd Wazir bin Mustafa for his invaluable advice, personal attention, and continuous encouragement throughout my master program at Universiti Teknologi Malaysia. It was a great experience working and learning with him and without his continued support and interest, this thesis would not have been the same as presented here.

I am also indebted to Universiti Teknikal Malaysia Melaka (UTeM) for funding my Master study as well. My appreciation is extended to Engr. Prof Dr. Marizan bin Sulaiman as the Dean of FKE at UTeM for giving strong support and encouragement to complete my study.

My fellow postgraduate student should also be recognized for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Their views and tips are useful indeed. Special and deep thanks to my wonderful parents, brother and sister for their moral support and motivation. Last but not least, I extend my thanks and appreciation to everyone who helped to get this work done.

ABSTRACT

A load flow analysis is used for planning and to determine the transmission constraints in the existing networks. The load flow solution gives information about the magnitude and phase angle of the voltage at each bus and real and reactive power flows in each line for given generation, load and transmission network data. By using Flexible AC Transmission System (FACTS) devices namely Unified Power Flow Controller (UPFC) will gives a basic control for transmission line real/reactive power flow and bus voltage/shunt reactive power. UPFC with ESS helps in regulating the power and mitigating the rotor speed instability and damping oscillations. UPFC placement was conducted at each line in the entire network system together with ESS to obtain the most suitable optimum location for most effectiveness performance. The performance of the optimal UPFC and ESS location is checked by applying a fault across a transmission line to which UPFC is connected and the power flow in the line and stability of the system is determined. Available Transfer Capability values indicate allowable highest magnitude of active power (MW) that can be transferred from the source to the sink over and above the already committed uses (base case) of the whole network without exceeding any line thermal loading and bus voltage limits. Finally, simulations were carried out using PSAT software to validate the performance of the UPFC and ESS connected to a transmission line. The effectiveness for UPFC and ESS are demonstrated on IEEE 9 bus and IEEE 24 bus system while for ATC is demonstrated on IEEE 6 bus system and all the results are compared.

ABSTRAK

Analisis aliran beban digunakan untuk merancang dan sekaligus menentukan kekangan penghantaran di dalam rangkaian sediaada. Penyelesaian aliran beban memberikan informasi tentang magnitud dan juga sudut fasa bagi voltan di setiap bas serta aliran kuasa nyata dan kuasa regangan di setiap talian bagi data di rangkaian penjanaan, beban dan penghantaran yang dinyatakan. Dengan menggunakan alatan FACTS iaitu UPFC, kawalan asas bagi aliran kuasa nyata/regangan di dalam talian penghantaran serta voltan bas/kuasa regangan pirau telah dilakukan. UPFC dengan kehadiran ESS dapat membantu dalam pengaturan kuasa serta mengatasi ketakstabilan halaju dan ayunan bagi redaman pada rotor. UPFC ditempatkan di setiap talian pada keseluruhan sistem rangkaian beserta ESS untuk memperoleh lokasi optimum yang paling sesuai bagi membolehkan prestasi yang paling efektif. Untuk menyemak prestasi bagi lokasi optimum UPFC dan ESS, satu kerosakan di kenakan pada talian penghantaran di mana UPFC disambungkan dan seterusnya aliran kuasa pada talian serta kestabilan pada sistem dapat diketahui. Nilai ATC yang dikira menunjukkan magnitud tertinggi bagi kuasa nyata yang masih boleh ditampung oleh talian penghantaran tanpa melangkaui had voltan bas serta had beban talian bagi sistem. Akhir sekali, simulasi telah dilakukan dengan menggunakan perisian PSAT bagi mengesahkan prestasi UPFC dan ESS yang disambung pada talian penghantaran. Keberkesanan UPFC dan ESS ditunjukkan dengan aplikasi pada sistem IEEE dengan 9 bas serta 24 bas manakala bagi ATC, ia didemonstrasikan dengan menggunakan sistem IEEE 6 bas dan seterusnya hasil bagi keseluruhan simulasi dibandingkan.

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LIST OF SYMBOLS

P_{1E}	-	Real Power flow into UPFC
P_{2E}	-	Real Power flow out from UPFC
Q_{1E}	-	Reactive Power flow into UPFC
Q_{2E}	-	Reactive Power flow out from UPFC
m_E	-	Modulation Ratio of shunt UPFC converter
δ_E	-	Modulation Phase of shunt UPFC converter
m_B	-	Modulation Ratio of series UPFC converter
δ_B	-	Modulation Phase of series UPFC converter
ω	-	Rotational Speed
M	-	Mass
R	-	Radius
k	-	Inertial Constant
Z_c	-	Surge Impedence
P_k	-	Real Power Delivered to Bus k
Q_k	-	Reactive Power Delivered to Bus k
*i*th	-	Bus Injected into the Transmission System
Y_{bus}	-	Bus Admittance Matrix
Z_{bus}	-	Bus Impedance Matrix
E_g	-	Excitation Voltage
δ	-	Power Angle
X_g	-	Positive-Sequence Synchronous Reactance
J	-	Element of Jacobian Matrix

LIST OF ABBREVIATIONS

FACTS	-	Flexible AC Transmission System
ESS	-	Energy Storage System
FESS	-	Flywheel Energy Storage System
ATC	-	Available Transfer Capability
TTC	-	Total Transfer Capability
CBM	-	Capacity Benefit Margin
TRM	-	Transmission Reliability Margin
ETC	-	Existing Transmission Commitments

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Power system analysis is fundamental in the planning, design, and operating stages and its importance cannot be overstated. Electric utility industry is undergoing rapid changes of the electricity market in many countries generally and specifically Malaysia. The demand for flexible power flow control is becoming very attractive by the innovative power electronics technology. The load flow analyses cover reactive power flow and control, optimization techniques, and introduction to Flexible Alternating Current Transmission System (FACTS) controllers, three-phase load flow, and optimal power flow. In terms of power flow control in the transmission network, operator cannot do much traditionally except turning on and off the circuits at their terminal. The parameters and network configuration are almost fixed and dynamically uncontrolled infact it is difficult to cope with system load flow control required especially the speed where those mechanical switched or control equipment definitely one step backward compare with the trend of fast on-line decision making nowdays. In this regard FACTS devices were introduced to be one of power systems development in the coming decade.

1.2 Problem Statement

i. Power system tends to become unstable at long transmission line when the power flow is heavy.

ii. Many compensation devices have its own criteria and limitations:-

    i. Fixed Capacitor can only provided its own MVAr, manage low power factor correction and need high maintenance

    ii. Switched Capacitor will create overvoltage, voltage transient and causes harmonic

1.3 Objectives

The following are the main objectives for this project;

i. To study the Unified Power Flow Controller (UPFC) as one of FACTS devices modeling in power systems.

ii. To develop a model of UPFC and ESS in single line diagram for power system steady-state operation.

iii. To determine the impact of Available Transfer Capability (ATC) on power system.

iv. To verify and analyze the effect of UPFC and Energy Storage System (ESS) in damping oscillation while improving system stability.

1.4 Scope of Research

A power system may lose stability in the first swing if it is not equipped with proper transient control devices if there are disturbances. UPFC is the one that able to help reduce the flows in heavily loaded lines and improve stability of power systems. The scopes are as follow:

i. Review on steady state and transient stability analyses on power system.

ii. Develop UPFC with ESS modeling using PSAT in MATLAB for single line diagram of 9 buses test system and large scale system of 24 buses.

iii. Study and review of ATC impact in power system.

iv. ATC computation using Optimal Power Flow in MATLAB by Newton Raphson Load Flow programming.

Finally all test systems will be demonstrated via simulation to illustrate its stability performance.

1.5 Thesis Organisation

This report is organised in 6 chapter.

Following this Chapter 2, introducing the basic operating principles of FACTS device namely UPFC in addition with the present of ESS. Chapter 3 reviewed the Newton Raphson's method in solving load flow analysis which is a backbone of power system analysis and design.

Chapter 4 discusses the operating principles adopted in electrical power system with specific focus on the main issues related to ATC determination. Chapter 5 presents the typical results obtained from extensive tests on a 9 buses and 24 buses system and compares their performances or evaluations with those from Newton Raphson's load flow programmed.

Chapter 6 concludes the findings of the present research together with some suggestions for further investigations. The Appendix A and Appendix B includes supporting materials for the results obtained.

REFERENCES

[1] D. Wenjin and L. Zhihong, "Study on Modeling of Unified Power Flow Controller," in *Automation and Logistics, 2007 IEEE International Conference on*, 2007, pp. 373-377

[2] Michael J. Basler, Richard C. Schaefer from Basler Electric Company Route 143, Box, 269 Highland, IL 62249 USA, "*Understanding Power System Stability*", IEEE paper.

[3] K.K. Leung and D. Sutanto from Department of Electrical Engineering, Hong Kong Polytechnic University, "*An Advanced Unified Power Flow Controller using Energy Storage*", October 2000 5^{th} International Conference in Power System Control, Hong Kong.

[4] N Tambey and Prof M L Kothari from Department of Electrical Engineering, Indian Institute of Technology, New Delhi," *UPFC Based Damping Controllers for Damping Low Frequency Osillations in a Power System*", in Annual Paper Meeting, November 2002.

[5] W. Du, Z. Chen, H. F. Wang, and R. Dunn, "*Energy Storage Systems Applied in Power System Stability Control*," in *Universities Power Engineering Conference, 2007. UPEC 2007. 42nd International, 2007, pp. 455-458*

[6] M.H. Wang and H.C. Chen," *Transient Stability Control of Multimachine Power Systems using Flywheel Energy Injection*", IEE Generation, transmission and Distribution, Vol. 152, No.5, September 2005.

[7] S. Tara Kalyani and G. Tulasiram Das, "*Simulation od D-Q Control System for A UPFC*", in ARPN Journal of Engineering and Applied Sciences, Vol. 2, No. 6, December 2007.

[8] C.R.Fuerte-Esquivel and E. Acha from Department of Electronics and Electrical Engineering, University of Glasglow, UK, "*UPFC: A Critical Comparism of Newton-Raphson UPFC algorithms in Power Flow Study*", Vol.144, No. 5, September 1997.

[9] H.F Wang, M. Jazaeri and Y.J. Cao,"*UPFC:Operating Modes and Control Interaction analysis of UPFC* ", Vol.152, No. 2, March, 2005.

[10] Xiao-Ping Zhang, Christian Rehtanz, Bikash Pal "*Flexible AC Transmission Systems: Modeling and Control*" Springer, March 2006.

[11] S. Samineni, B. K. Johnson, H. L. Hess, and J. D. Law, "*Modeling and Analysis of a Flywheel Energy Storage System For Voltage Sag Correction*," *Industry Applications, IEEE Transactions on,* vol. 42, pp. 42-52, 2006.

[12] Y. Katsuya, Y. Mitani, and K. Tsuji, "*Power system stabilization by synchronous condenser with fast excitation control,*" in *Power System Technology, 2000. Proceedings. PowerCon 2000. International Conference on*, 2000, pp. 1563-1568 vol.3.

[13] X. Ying, Y. H. Song, and Y. Z. Sun, "A*pplication of stochastic programming for available transfer capability enhancement using FACTS devices*," in Power Engineering Society Summer Meeting*, 2000. IEEE*, 2000, pp. 508-515 vol. 1.

[14] Soon-Kin Chai and Arun Sekar, " I*dentify Overloaded Transmission Lines in TTC and ATC Determinations*," 2004 IEEE.

[15] Ying Xiao, Y.H Song and Y.Z Sun," A*pplication of Stochastic Programming for Available Transfer Capability Enhancement using FACTS Devices*," 2000 IEEE.

[16] Gang Li, Shijie Cheng, Jinyu Wen,Yuan Pan and Jia Ma," *Power System Enhancement by a Double-Fed Induction Machine with a Flywheel Energy Storage System*",2006 IEEE

[17] Mohamed Shaaban, Yixin Ni, Hongwei Dai and Felix F.Wu," *Considerations in Calculating Total Transfer Capability*",1998 IEEE.

[18] B.Kalyan Kumar, S.N Singh and S.C Srivastava," *Placement of FACTS controllers using modal controllability indices to damp out power system oscillations",* IET Generation, Transmission and Distribution, Vol 1, No. 2 March 2007.

[19] "*Transmission Enhancement and Expansion*" Electric Industry Restructuring Research Group, January 1998.

[20] J.Duncan Glover, Mulukutla S.Sarma, and Thomas J. Overbye" P*ower System Analysis and Design*", Fourth Edition,2008.

[21] D.P. Kothari and J.S. Dhillon" *Power System Optimization*", 2004 by Prentice-Hall of India.

[22] K.Narasimha Rao, J. Amarnath and K. Arun Kumar " *Voltage Constrained Available Transfer Capability Enhancement with FACTS Devices*", ARPN Journal of Engineering and Applied Sciences, 2006-2007

[23] Dr. Ashwani Kumar " *Available Transfer Capability Assessment in A Restructured Electricity Market*", Department of Electrical Engineering National Institute of Technology Kurukshetra, June 2009.

[24] Solar Energy International (2006)."*Photovoltaics: Design and Installation Manual* ",Gabriola Island, BC:New Society Publishers, pg. 80.