UNIVERSITI PUTRA MALAYSIA

SIMULATION AND DEVELOPMENT OF UNIFIED POWER FLOW CONTROLLER USING MULTILEVEL INVERTER

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

January 2010

Dedicated to my parents, brothers, husband, and daughters
For with their prayers and loves, have given me strengths

Abstract of thesis presented to the Senate of Universiti Putra Malaysia
in fulfilment of the requirement for the degree of Doctor of Philosophy

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January 2010

Chairman : Senan Mahmood Abdullah, PhD

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Heavily loaded transmission lines and the inability to control the amount and direction of power flows have became major concerns to the power utilities. Some of the solutions taken by the power utilities are by expanding the size of power system network in terms of building new transmission lines, using higher rating equipments and installing more generating units. The power utilities also have improved the transmission lines capability and better utilizing of existing power system networks.

The power flows in the transmission lines in accordance to their series impedance, voltage magnitude at the sending end and receiving end, and phase angle between these two voltage ends. Electromechanically controlled devices have been used to control the power flow which is now steadily being replaced with static devices. The problem with these electromechanically controlled devices is sometimes they do not react fast enough especially during disturbances. Furthermore, they are subjected to wear and tear which requires regular monitoring and servicing.

The advancement in power electronics devices, which provide faster response compared to the electromechanical ones and require less maintenance as they do not wear and tear easily has attracted great interest from the researchers. Among these power electronics devices, Unified Power Flow Controller (UPFC) has gained a lot of attention due to its ability to control, simultaneously or selectively, all the three of power system parameters i.e. line impedance, voltage magnitude and phase angle.

In this work, UPFC's simulation model has been designed and developed as a power system device to investigate the behaviour of the system under normal and abnormal conditions. A small-scale laboratory model has also been constructed to validate the findings obtained from the simulation model. To avoid high frequency components produced in Pulse Width Modulation (PWM), a 3-level Neutral Point Clamped (NPC) multilevel inverter has been proposed as the series inverter for the UPFC using Space Vector Modulation (SVM). The shunt inverter for UPFC is composed of a 6-pulse diode bridge rectifier and a line commutating thyristor bridge. A triggering circuit for the simulation model for the SSSC has been improved for Matlab/Simulink module. For the laboratory model, a switching circuit consists of PIC, optocouplers, IGBTs drivers and monostable multivibrators has been successfully constructed.

The proposed 3-level NPC inverter has been shown to have a better feature in terms of Total Harmonics Distortion (THD) with a simulation value of 13.36% V_{LL} and experimental value of 15.65% V_{LL}. The THD value is lower compared to a similar work of 16.46%.

The additional voltage phase shift, ϕ produced by the SSSC has been shown to affect the phase shift between the sending end voltage and receiving end voltage. As the line impedance and both voltages are usually constant, any variation in phase shift between the two voltages will affect the amount of power flows in the transmission lines and its direction. The THDs of the voltage and current of the SSSC when connected between two busbars have been determined and a good agreement between the simulation and laboratory results has been achieved. From the simulation, the THD value of line voltage is approximately 1.3% which is lower compared to other work of 2.49% and 3.58%.

A comprehensive controllable UPFC using real power transfer algorithm and reactive power compensation algorithm has been successfully designed and constructed as a simulation model that is able to stabilize voltage with required power for fast changing loads.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SIMULASI DAN PEMBANGUNAN PENGAWAL ALIRAN KUASA BERSATU MENGGUNAKAN PENYONGSANG BERBILANG ARAS

Oleh

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Talian penghantaran yang dibebani berlebihan dan ketidakbolehan mengawal jumlah dan arah pengaliran kuasa telah menjadi perhatian utama pengendali kuasa. Di antara penyelesaian yang diambil oleh pengendali kuasa adalah dengan memperbesarkan saiz rangkaian sistem kuasa dari segi membina talian penghantaran baru, menggunakan peralatan berkadaran tinggi dan memasang lebih banyak unit penjanaan. Pengendali kuasa juga telah mempertingkatkan kebolehan talian penghantaran dan menggunakan dengan lebih baik rangkaian sistem kuasa sedia ada.

Kuasa mengalir di dalam talian penghantaran mengikut galangan sesiri, magnitud voltan di hujung penghantaran dan hujung penerimaan, dan sudut fasa di antara dua hujung voltan ini. Peranti terkawal elektromekanikal telah digunakan untuk mengawal pengaliran kuasa di mana kini mula digantikan dengan peranti statik. Masalah peranti terkawal elektromekanikal ini ialah ia kadangkala tidak bertindak dengan cukup pantas terutama semasa gangguan. Tambahan lagi, peranti ini terdedah

kepada haus dan lusuh di mana ia memerlukan pengawasan dan perkhidmatan yang teratur.

Kemajuan dalam peranti elektronik kuasa, di mana ia menyediakan tindakbalas yang lebih cepat berbanding peranti elektromekanikal dan memerlukan kurang penyelenggaraan kerana ia tidak haus and lusuh dengan mudah telah menarik banyak perhatian daripada penyelidik. Di antara peranti elektronik kuasa ini, Pengawal Aliran Kuasa Bersatu (PAKB) telah menarik banyak perhatian disebabkan oleh kebolehannya untuk mengawal, serentak atau memilih, kesemua tiga parameter sistem kuasa, iaitu galangan sesiri, magnitud voltan dan sudut fasa.

Di dalam kerja ini, model simulasi PAKB telah direka dan dibangunkan sebagai peranti sistem kuasa untuk menyelidik kelakuan sistem di dalam keadaan normal dan tidak normal. Sebuah model skala-kecil makmal juga telah dibina untuk mengesahkan penemuan yang diperolehi dari model simulasi. Untuk mengelak komponen frekuensi tinggi yang terhasil dalam modulasi denyut lebar (MDL), penyongsang berbilang aras 3-aras titik neutral terkapit (TNT) telah dicadangkan sebagai penyongsang sesiri bagi PAKB dengan menggunakan modulasi vektor ruang (MVR). Penyongsang pirau untuk PAKB terdiri daripada penerus jejambat diod 6-denyut and jejambat thyristor talian tukarterbit. Litar pemicuan bagi model simulasi SSSC telah ditambahbaikan untuk modul Matlab/Simulink. Bagi model makmal, litar pensuisan yang terdiri dari PIC, pengganding optik, pemacu IGBTs and pembilang getar monostabil telah berjaya dibina.

Penyongsang 3-aras TNT yang dicadangkan telah menunjukkan mempunyai sifat yang lebih baik dari segi nilai herotan harmonik seluruh (HHS) dengan nilai simulasi 13.36% V_{LL} dan nilai ekperimen 15.65% V_{LL}. Nilau HHS ini adalah lebih rendah dibandingkan dengan kerja lain iaitu 16.48% .

Fasa berubah voltan tambahan, ϕ yang terhasil oleh SSSC telah ditunjukkan boleh mempengaruhi fasa anjakan di antara voltan hujung penghantaran dan voltan hujung penerimaan. Galangan sesiri dan kedua-dua voltan adalah tetap, mana-mana perubahan dalam fasa berubah di antara dua voltan akan mempengaruhi jumlah aliran kuasa dalam talian penghantaran dan arahnya. THD voltan dan arus SSSC apabila bersambung dengan dua busbar telah ditentukan dan persamaan yang baik telah diperolehi dari keputusan simulasi dan makmal. Dari simulasi, nilai HHS voltan talian adalah lebih kurang 1.3% yang mana ia lebih rendah apabila dibandingkan dengan kerja lain iaitu 2.49% dan 3.58%.

PAKB bolehkawal komprehensif menggunakan algoritma pindahan kuasa aktif dan algoritma penebusan kuasa reaktif telah berjaya direka dan dibina sebagai model simulasi yang boleh menstabilkan voltan dengan kuasa yang diperlukan untuk tindakbalas beban yang pantas berubah.

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Last but not least, to my families, thank you for the prayers and encouragement that have given to me all these years and not forgetting my husband and daughters for their love and understanding.

I certify that a Thesis Examination Committee has met on 21 January 2010 to conduct the final examination of Nashiren Farzilah Binti Mailah on her thesis entitled "Simulation and Development of Unified Power Flow Controller using Multilevel Inverter" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

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NASHIREN FARZILAH BINTI MAILAH

DATE : 25 JANUARY 2010

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LIST OF ABBREVIATIONS

AC	Alternating Current
AEP	American Electric Power
APOD	Alternative Phase Opposition Disposition
DC	Direct Current
EMC	Electromagnetic Compatibility
EPRI	Electric Power Research Institute
FACTS	Flexible Alternating Current Transmission Systems
FC	Flying Capacitor
GTO	Gate Turn Off
IGBT	Insulated Gate Bipolar Transistor
MDC	Modified-Diode-Clamped
MOSFET	Metal Oxide Semiconductor Field Effect Transistor
MPC	Multi Point Clamped
NPC	Neutral Point Clamped
PD	Phase Disposition
PI	Proportional Integral
PLL	Phase Lock Loop
PSC	Phase Shifted Carrier
PWM	Pulse-Width-Modulation
SPWM	Sinusoidal Pulse-Width-Modulation
SSSC	Static Synchronous Series Compensator
STATCOM	Static Synchronous Compensator
SVC	Static Var Compensator

SVM	Space Vector Modulation
TCSC	Thyristor Controlled Series Compensator
THD	Total Harmonics Distortion
UPFC	Unified Power Flow Controller
VSI	Voltage Source Inverter
V_1	Generation voltage at busbar 1
V_2	Sending end voltage at busbar 2
V_3	Receiving end voltage at busbar 3
X	Series line impedance
ΔV	Additional voltage
$\|\Delta V\|$	Additional voltage magnitude
ϕ	Additional voltage phase shift
P_{23}	Active power transferred between busbar 2 and 3
Q_{23}	Reactive power transferred between busbar 2 and 3