UNIVERSITI PUTRA MALAYSIA

APPLICATION OF ROBUST CONTROLLER IN LARGE INDUCTION MOTOR FOR MITIGATING VOLTAGE SAGS

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By

MAHDI HEDAYATI

Thesis Submitted to the School of Graduate Studies, University Putra Malaysia, in Fulfillment of The Requirements for the Degree of Doctor of Philosophy

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Dedicated to my wife *Maryam for* her immense patience and allegiance while studying my PhD specially during the last year and to my son *Hirad* for his love

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

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Chairman: Norman Mariun, PhD

Faculty: Faculty of Engineering

This research presents a new study on H_∞ robust controller based on loop shaping procedure for a static synchronous compensator (STATCOM) installed at terminals of the large induction motor.

The space vector pulse width modulation (SVPWM) drive system is one of the most significant apparatus in industrial application of induction motors that utilization of this equipment is considered in this thesis and compared with static var compensator (SVC) installed at terminals of motor. It is shown that the dynamic behaviour and performance of SVC is better than SVPWM drive system for starting of the induction motor, so the time for motor speeding up is slower with lower transients, while the variations of induction motor current are in the sufficient range.

A comparison between proportional-integral (PI) controllers of different shunt flexible alternating current transmission systems (FACTS) shows that STATCOM is

more effective and has a better dynamic performance than SVC, so the parameters of peak time and voltage sag by using the STATCOM for starting of large induction motor without and with load are significantly decreased. The results from simulations prove that STATCOM is significantly proficient to ensure good power quality and more effective than SVC for decreasing transients, voltage profile improvement and getting better dynamic behavior of motor's rotor speed while symmetrical and unsymmetrical voltage sags are considered.

Whereas FACTS devices have nonlinearity nature; using the conventional PI control theory with system linearization around nominal point is not a suitable method, besides, there exists the uncertainty in the system. So developed robust control theory that covers stability and performance criteria under all system uncertainties, has been applied for the controller design in power system to assure fast and stable regulation under wide range of operating circumstances.

Among the different robust methods used to design the controller of shunt FACTS, H_∞ loop shaping procedure is known to be one of the effective and feasible control methods. So this method is considered to simulate robust controller for STATCOM installed at terminals of the large induction motor. The dynamic behaviors of induction motor are analyzed while the uncertainty of system parameters, STATCOM parameters and external disturbances are considered. Besides, in all previous research works, a robust control design using H_∞ loop shaping method through Graphical Loop Shaping (GLS) technique or Normalized Coprime Factorization (NCF) approach is proposed. In this thesis, both mentioned methods have been considered in the design of robust controller and have been compared together and with conventional PI controller.

It is clearly observed that the output response of robust controllers using GLS and NCF methods are similar and surely have better dynamic performances than PI controller. A development has been determined that GLS method is more robust than NCF against variations of system parameters and STATCOM parameters. PI controller is not very strong against changing of system parameters and STATCOM parameters when compare with GLS and NCF methods, even the system goes to instability for a certain operating point.

Another development will be presented when these H_∞ robust controllers and conventional PI controller are tested for external disturbances consist of a load disturbance and a sinusoidal disturbance on system performance. The results of simulations prove that all controllers are able to damp these disturbances, but both GLS and NCF methods are more robust than PI controllers to remove these perturbations. It is obviously shown that GLS method has better dynamic performance than NCF method to reject the disturbances and stronger than NCF method against load disturbance and sinusoidal disturbance uncertainties.

Finally, for validation of the designed systems, this research is compared with other works. It is concluded that results of the designed controllers for SVC and STATCOM having parameters and specifications of other research works are similar with the simulation results of the mentioned work.

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

APLIKASI ALAT KAWALAN TEGAR PADA MOTOR INDUKSI BESAR UNTUK MENGURANGKAN PENURUNAN VOLTAN

Oleh

MAHDI HEDAYATI

Februari 2012

Pengerusi: Norman Mariun, PhD

Fakulti : Fakulti Kejuruteraan

Penyelidikan ini mengetengahkan kajian baru dalam alat kawalan tegap H_∞ berdasarkan prosedur pembentukan untuk pemampas statik segerak atau "static sysnchronous compensator (STATCOM)" yang dipasang pada terminal motor aruhan yang besar.

Sistem pemacu ruang vektor modulasi lebar denyut atau "space vector pulse width modulation (SVPWM)" ada salah satu perkakas yang paling penting di dalam aplikasi industri motor aruhan yang mana penggunaan perkakas ini diambil kira di dalam tesis ini dan perbandingan dibuat diantara pemampas statik var atau "static var compensator (SVC)" yang dipasang pada terminal motor. Hasil kajian menunjukkan kelakuan dinamik dan prestasi SVC lebih baik daripada sistem pemacu SVPWM untuk memulakan motor aruhan, oleh itu masa untuk motor memecut adalah lebih perlahan dengan sambutan fana yang lebih rendah, sementara variasi arus motor aruhan berada di dalam julat yang mencukupi.

Perbandingan di antara alat kalawan kamiran berkadaran atau “proportional-integral (PI)” konvensional yang mempunyai pirau sistem transmisi arus ulang-alik boleh ubah atau “flexible alternating current transmission systems (FACTS)” berbeza menetapkan STATCOM adalah lebih berkesan dan mempunyai prestasi dinamik yang lebih baik berbanding SVC, oleh itu pembolehubah masa puncak dan voltan lendut yang menggunakan STATCOM untuk memulakan motor aruhan yang besar dengan dan tanpa beban didapati berkurangan dengan ketara. Keputusan dari simulasi membuktikan STATCOM adalah sangat cekap untuk memastikan kualiti kuasa yang baik dan lebih berkesan berbanding SVC bagi sambutan fana yang menurun, pembaikan taraf voltan dan mendapat kelakuan dinamik yang lebih baik bagi kelajuan motor semasa voltan simetri dan tidak simetri diambil kira.

Sementara perkakas FACTS semulajadi tidak linear; menggunakan teori kawalan PI konvensional dengan pelinearan sistem lingkungan titik nominal adalah tidak sesuai, Di samping itu, terdapat ketidakpastian di dalam sistem. Oleh yang demikian, teori kawalan tegar sedia ada yang meliputi kestabilan dan ciri-ciri prestasi di bawah keseluruhan ketidakpastian sistem, telah digunakan untuk rekaan alat kawalan di dalam sistem kuasa untuk memastikan pengaturan yang cepat dan stabil di bawah julat keadaan operasi yang besar.

Di antara kaedah H_∞ tegar berbeza yang digunakan untuk mereka bentuk alat kawalan pirau FACTS, prosedur pembentukan gelung H_∞ dipilih sebagai kaedah terbaik untuk mereka bentuk alat kawalan. Oleh itu, kaedah ini diambil kira untuk mesimulasi alat kawalan tegar untuk STATCOM yang dipasang pada terminal motor aruhan yang besar. Kelakuan dinamik motor aruhan dianalisa sementara ketidakpastian pada pembolehubah sistem, pembolehubah STATCOM dan gangguan

luaran diambil kira. Di samping itu, di dalam semua kajian yang lalu, Rekaan alat kawalan tegar menggunakan kaedah pembentukan gelung H_∞ melalui teknik pembentukan gelung geraf atau " Graphical Loop Shaping (GLS)" atau pendekatan faktor co-prima nominal atau Normalized Coprime Factorisation (NCF) telah dicadangkan. Di dalam tesis ini, kedua-dua kaedah tersebut telah dibandingkan bersama alat kawalan PI konvensional.

Adalah didapati bahawa sambutan luaran alat kawalan tegar menggunakan kaedah GLS dan NCF hampir sama dan sudah pasti mempunya prestasi dinamik yang lebih bagus berbanding alat kawalan PI. Pembangunan telah dikenal pasti bahawa kaedah GLS adalah lebih tegar berbanding NCF berhadapan variasi pembolehubah sistem dan STATCOM. Alat kawalan PI tidak begitu kuat berhadapan perubahan pembolehubah sistem dan pembolehubah STATCOM apabila dibandingkan dengan kaedah GLS dan NCF, walaupun sistem itu tidak stabil untuk titik operasi yang pasti.

Satu lagi keadaan dibentangkan apabila alat kawalan tegar H_∞ dan alat kawalan PI konvensional diuji dengan gangguan luaran yang mengandungi gangguan beban dan gangguan sinusoid ke atas prestasi sistem. Keputusan simulasi membuktikan kesemua alat kawalan boleh mengatasi gangguan-gangguan ini, tetapi kaedah GLS dan NCF lebih tegar berbanding alat kawalan PI untuk menghilangkan usikan tersebut. Jelas sekali kaedah GLS mempunyai sambutan dinamik yang lebih baik berbanding kaedah NCF untuk melenyapkan gangguan dan lebih kuat dari NCF berhadapan gangguan beban dan gangguan ketidakpastian sinusoid.

Akhir sekali, untuk mengesahkan sistem yang telah direka bentuk, penyelidikan ini dibandingkan dengan hasil penyelidikan lain. Kesimpulannya, keputusan dari alat

kawalan SVC dan STATCOM yang mempunyai pembolehubah dan spesifikasi yang sama dengan hasil penyelidikan terdahulu adalah setara dengan keputusan yang diperole.

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Last but not least, to my families, thank you for the prayers and encouragements that have given to me all these years and of course not forgetting my wife and son for their love and understanding.

I certify that a Thesis Examination Committee has met on 17 February 2012 to conducts the final examination of Mahdi Hedayati on his thesis entitled" Application of Robust Controller in Large Induction Motor in Mitigating Voltage Sags" 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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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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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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MAHDI HEDAYATI

Date: 17 February 2012

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