ONLINE AUTO-TUNED PROPORTIONAL-INTEGRAL CONTROLLER USING PARTICLE SWARM OPTIMIZATION FOR DUAL ACTIVE BRIDGE DC-DC CONVERTER

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Doctor of Philosophy

UNIVERSITI MALAYSIA PAHANG

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SUPERVISOR'S DECLARATION

We hereby declare that We have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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ABSTRAK

Penyusutan bahan bakar fosil sebagai sumber tenaga utama dunia disebabkan oleh krisis tenaga global telah membawa kepada pengembangan terhadap tenaga bersih dan pengangkutan mesra alam. Perkembangan ini berkembang bersama dengan ekosistem lengkap, termasuk sistem pengecas kenderaan elektrik (EV). Permintaan yang kuat untuk pengecasan EV yang cepat memicu pertumbuhan kemajuan teknologi di stesen pengecasan EV, terutama pada bahagian penukar DC-DC. 'Dual active bridge' (DAB) adalah antara penukar DC-DC yang popular dalam bidang kajian kerana mempunyai ciri yang menarik; aliran tenaga dua arah, pengasingan galvanik dan ketumpatan daya tinggi. Penyelidikan ini mengkaji keberkesanan pengawal yang mantap dalam DAB di mana objektifnya adalah untuk mengurangkan ralat keadaan tetap, 'e_{SS}' dan peningkatan tindak balas dinamik. Oleh kerana pengawal linear seperti pengawal 'proportional-integral' (PI) mempunyai beberapa kelemahan dari segi kestabilan dan prestasi dalam sistem bukan linear, satu kawalan voltan secara terus melalui sudut pergeseran fasa, ϕ menggunakan pengoptimuman kawanan partikel (PSO) yang dinamakan sebagai PSO-d diperkenalkan untuk menilai prestasi DAB tanpa pengawal linear klasik. Kajian ini juga meneroka pengoptimuman parameter pengawal PI dalam DAB dari sudut ketepatan dan tindak balas dinamik, di mana parameter K_P dan K_I dioptimumkan secara kecerdasan komputasi. Ini adalah kerana penalaan manual terhadap pengawal PI hanya memberikan prestasi yang memuaskan hanya sekiranya pemboleh ubah yang mempengaruhi tidak menyimpang jauh dari keadaan penalaan asal. APSO-PI adalah penalaan PI secara automatik yang menggunakan algoritma PSO di mana nilai optimum K_P dan K_I ditala pada permulaaan proses kawalan sahaja. Kedua-dua prestasi PSO-d dan APSO-PI telah dibandingkan dengan kaedah konvensional iaitu 'Ziegler-Nichols' (ZN-PI). Walaubagaimanapun, pengawal dengan nilai PI yang tetap memberikan tindak balas yang sama terhadap sebarang perubahan dalam sistem dan tidak dapat mengawal keluaran sistem dengan sepenuhnya terutama ketika berlakunya perubahan yang dinamik. Akhirnya, satu kaedah di mana PI diselaraskan secara automatik dalam talian dengan menggunakan PSO (OPSO-PI) telah dicadangkan untuk menghasilkan kekuatan yang lebih tinggi daripada APSO-PI. OPSO-PI adalah teknik yang membenarkan penalaan semula parameter K_P dan K_I selaras dengan perubahan sistem. Prestasi untuk keempat-empat pengawal (ZN-PI, PSO-d, APSO-PI dan OPSO-PI) telah diuji dengan teliti melalui pelaksanaan masa nyata. Pelbagai ujian telah berjaya dilaksanakan dengan menggunakan 'Typhoon hardware-in-the-loop' (Typhoon-HIL), berdasarkan penukar DAB 200 kW yang dikendalikan pada frekuensi pensuisan 20 kHz dengan modulasi peralihan fasa tunggal (SPS). Sistem ini bukan sahaja diuji dalam keadaan 'steady-state', tetapi juga dianalisa dalam variasi beban, perubahan voltan keluar yang diinginkan, perubahan beban dan perubahan voltan masuk. PSO-d dapat mencapai ketepatan yang lebih tinggi daripada kaedah tradisional ZN-PI. Walau bagaimanapun, prestasi teruk PSO-d dalam tindak balas dinamik meletakkan pengawal ini sebagai yang paling perlahan di kalangan semua pengawal. Setelah membuat penilaian dan analisis yang teliti, didapati bahawa kedua-dua APSO-PI dan OPSO-PI memberikan prestasi yang sangat baik dengan menghasilkan kawalan ketepatan yang lebih tinggi daripada PSO-d sambil mengekalkan tindak balas yang lebih cepat daripada ZN-PI. APSO-PI adalah pengawal terpantas di antara semua pengawal. Walaubagaimanapun, OPSO-PI adalah pengawal yang unggul dengan ketepatan 97.4% tetapi sedikit perlahan dalam tindak balas dinamik berbanding APSO-PI. Dengan keputusan yang cemerlang ini, pengecas EV berpotensi untuk dibangunkan dengan pengawal yang pantas dan tepat.

ABSTRACT

The decline of fossil fuels as main world energy sources due to the global energy crisis has brought to the proliferation of clean energy and environmentally friendly transportation. This development grows together with a complete ecosystem, including an electric vehicle (EV) charger system. The strong demand for fast EV charging sparks the growth of technological advancements in an EV charging station, especially on DC-DC converter. The dual active bridge (DAB) is among the popular DC-DC converters in literature due to its attractive feature; bidirectional power flow, galvanic isolation and high power density. This research investigated the effectiveness of a robust controller in DAB, where the objective is to minimize steady-state error, e_{SS} and improved dynamic response. Since the linear controller such as the proportional-integral (PI) controller has some flaws of stability and performance in the nonlinear system, a direct control voltage through a phase-shift angle, ϕ using particle swarm optimization (PSO), namely PSO-d was introduced to evaluate the DAB performance without a classic linear controller. This research also explores the optimization of PI controller parameters in DAB in term of accuracy and dynamic response, where K_P and K_I coefficients were optimized by computational intelligence. The PI optimization is concerned because the traditional manual tuning of the PI controller only delivers satisfactory performance as long as the affecting variables do not deviate far from the original tuning condition. APSO-PI is an auto-tuned PI using the PSO algorithm where the optimal values of K_P and K_I were tuned at the initial control process only. Both performances of PSO-d and APSO-PI were compared to the conventional Ziegler-Nichols (ZN-PI) method. However, the controller with fixed gains has the same reaction to the changes and gives limitation by not fully controlling the system output as needed, especially in dynamic change. Ultimately, an online auto-tuned PI using PSO (OPSO-PI) was proposed to produce higher robustness than the APSO-PI. The OPSO-PI with re-tuning approach allows the update process of K_P and K_I parameters concerning the system change. The performance for all four controllers (ZN-PI, PSO-d, APSO-PI and OPSO-PI) were rigorously tested through real-time implementation. The tests were made possible using Typhoon hardware-in-the-loop (Typhoon-HIL), based on a 200 kW DAB converter operated at 20 kHz switching frequency with single phase-shift (SPS) modulation. The tests were carried out in steady-state and various test cases such as variation of loads, desired output voltage step-change, load step-change, and input voltage step-change. The PSO-d was able to achieve higher accuracy than the traditional ZN-PI. However, PSO-d's subpar performance in dynamic response put the controller as the slowest about the four. After thorough evaluation and analysis, both APSO-PI and OPSO-PI gave excellent performance by producing higher accuracy control than PSO-d while maintaining a faster response than ZN-PI. APSO-PI was the fastest controller. Meanwhile, OPSO-PI was a superior controller with 97.4 % accuracy with a bit sacrifice on dynamic response compared to APSO-PI. With these remarkable outcomes, there is a potential for the EV charger to have a rapid and accurate controller.

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