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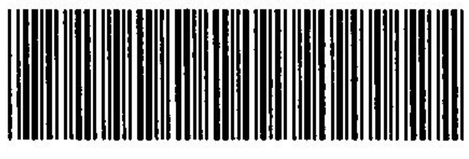
CONTROL STRATEGIES FOR BATTERY ENERGY
STORAGE SYSTEMS FOR MITIGATING
INTERMITTENT PHOTOVOLTAIC



Control strategies for battery energy storage systems for mitigating intermittent photovoltaic generation / Muhamad Zala Daud.

Lihat Sebelah

CONTROL STRATEGIES FOR BATTERY ENERGY STORAGE SYSTEMS FOR MITIGATING INTERMITTENT PHOTOVOLTAIC GENERATION

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THESIS SUBMITTED IN FULFILMENT FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

FACULTY OF ENGINEERING AND BUILT ENVIRONMENT
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2014

STRATEGI KAWALAN BAGI SISTEM PENYIMPAN TENAGA BATERI UNTUK MEMBANTERAS KETERPUTUSAN PENJANAAN FOTOVOLTAN

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TESIS YANG DIKEMUKAKAN UNTUK MEMPEROLEH IJAZAH DOKTOR FALSAFAH

FAKULTI KEJURUTERAAN DAN ALAM BINA
UNIVERSITI KEBANGSAAN MALAYSIA
BANGI

2014

DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged.

11 April 2014

MUHAMAD ZALANI BIN DAUD
P 58248

ACKNOWLEDGEMENTS

Syukur Alhamdulillah for all His blessings for giving me the preserverence and good health troughout the duration of this PhD research. I would like to express sincere appreciation for the intelligent advice, encouragement and guidance of my main supervisor, Prof. Dr. Hjh. Azah Mohamed. Without her tireless assistance, leadership, and confidence in my abilities, this thesis would not come to its timely completion. Many thanks also to my co-supervisor, Prof. Dr. M. A. Hannan for in-depth discussions from time to time on progress of my research work.

Thanks to Power System Research group for providing research grants for attending many national and international conferences and workshops. The data obtained from Power Laboratory's rooftop PV system used for this research is also gratefully acknowledged. My gratitute also should go to all group members for their support and friendship. Special thanks to Dr. Zamri Che Wanik and Mr. Ahmad Asrul Ibrahim for their valuable advice and help on modelling and simulation works.

Thanks to Solar Energy Research Institute, UKM for providing historical solar radiation and temperature data used for this research.

Thanks to the Ministry of Higher Education and Universiti Malaysia Terengganu, Malaysia for the financial support.

Finally my special thank to my family who has been my inspiration since the primary school until this stage of my education. My deepest feelings and thankfulness I would like to dedicate to my wife for her love, friendship and endless support and patience during my postgraduate study.

ABSTRACT

High penetration photovoltaic (PV) power in a power system can lead to voltage instability problems due to intermittencies related to cloud cover. The fluctuated PV power injected directly to the utility grid on a large scale may cause violation of grid system such as unnecessary voltage rise, voltage and frequency deviations at the point of common connection. Earlier studies have indicated that energy storage can compensate for the intermittent nature of PV power and provide mitigation strategy to enhance DC bus voltage regulation. In this thesis, control strategies for a hybrid PV with battery energy storage (BES) system have been proposed to mitigate the intermittent impacts of grid-connected PV systems. To enhance DC bus voltage regulation, BES is interfaced via a buck-boost converter in addition to conventional regulation solely based on voltage-sourced converter (VSC). The control of PV/BES grid-side VSC is initially developed based on conventional voltage-mode and current-mode control schemes. In addition, an optimal control strategy using simplex optimisation method is proposed to provide robust VSC and buck-boost converter control designs. To mitigate PV power fluctuations, BES charge/discharge control is implemented to smooth out the PV output and dispatch the net power on an hourly basis to the utility grid. During power dispatch operation, BES state-of-charge (SOC) is regulated using the SOC-feedback (SOC-FB) control scheme. For continuous charge/discharge over hours of operation, a more accurate BES model is developed to account for effects of variations in terminal voltage, self-discharge resistance and cell impedances. Using the improved BES model, an optimal SOC-FB control scheme is also developed using heuristic optimisation techniques such as genetic algorithm, gravitational search algorithm and particle swarm optimisation. Finally, to maximise the benefits of BES installation, a coordinated control strategy of PV/BES system is developed to enable the system to operate flexibly in normal, power fluctuation and emergency modes of operation. Simulations were carried out using the PSCAD/EMTDC and Matlab/Simulink software and the results show acceptable performances of the developed optimised control strategies. The proposed simplex optimised current-mode control scheme can quickly restore the bus voltage to 1 p.u. (1.82%-2.96% spikes) compared to the conventional non-optimised current-mode (4.2%-8.2% spikes) and voltage-mode (6.6%-18% spikes) control schemes, respectively. The results for PV/BES output power dispatch show significant performance using the optimal SOC-FB control scheme with high efficiency of 90% compared to the methods from previous works. Furthermore, multi-parameter optimisation provides optimal BES sizes which are reduced to within the range of 0.8%-6.9% compared to the initially estimated size. The payback calculation on BES investment shows 170% returns of investment over the 10 years contract. The developed coordinated control strategy for PV/BES also gives satisfactory performance in the studied cases. Thus, the developed enhanced control strategies for PV/BES systems are useful for mitigating the impacts of PV generation intermittency and can be implemented to a new or already installed PV system.

ABSTRAK

Penembusan tinggi kuasa fotovolta (FV) didalam sistem kuasa boleh menimbulkan masalah ketakstabilan voltan disebabkan oleh keterputusan yang berkait dengan penutupan awan. Kuasa FV yang berubah-ubah apabila disuntik terus ke grid utiliti dalam skala yang besar boleh mengakibatkan gangguan sistem grid seperti peningkatan voltan dan penyimpangan voltan dan frekunsi pada titik penyambungan sepunya. Kajian awal menunjukkan bahawa penyimpan tenaga boleh memampas keterputusan kuasa FV dan menyediakan strategi pembenterasan untuk menambahbaik pengaturan voltan bas AT. Dalam tesis ini, strategi kawalan bagi system hibrid FV dengan sistem penyimpan tenaga bateri (PTB) dicadangkan untuk membenteras impak keterputusan sistem FV. Untuk mempertingkatkan pengaturan voltan bas AT, PTB disambung ke penukar turun/naik sebagai tambahan kepada pengaturan konvensional yang menggunakan penukar bersumber voltan (PSV). Kawalan PSV untuk sistem FV/PTB pada mulanya dibangunkan berasaskan kaedah konvensional kawalan mod-voltan dan mod-arus. Sebagai tambahan, strategi kawalan optimum menggunakan kaedah pengoptimum simplex dicadangkan untuk menghasilkan rekabentuk PSV dan kawalan penukar turun/naik yang mantap. Untuk membenteras keterputusan kuasa FV, kawalan caj/discaj PTB dilaksanakan untuk melicinkan pengeluaran FV dan menghantar kuasa bersih setiap jam ke grid utiliti. Semasa operasi penghantaran kuasa, keaadaan caj (KC) PTB diatur menggunakan kaedah kawalan malumbalas-KC (M-KC). Untuk caj/discaj berterusan dalam operasi yang lama, model PTB yang lebih tepat dibangunkan untuk mengambilkira kesan perubahan voltan pengkalan, rintangan discaj-kendiri dan galangan sel. Dengan menggunakan model PTB yang ditambahbaik, kaedah kawalan M-KC yang optimum dibangunkan dengan menggunakan teknik pengoptimum heuristik seperti algoritma genetik, algoritma carian graviti dan pengoptimum kuruman zarah. Akhir sekali, untuk memaksimumkan kebaikan pemasangan PTB, strategi kawalan terlaras bagi sistem FV/PTB dibangunkan bagi membolehkan sistem beroperasi secara fleksibel dalam mod operasi normal, kuasa berubah-ubah dan kecemasan. Simulasi telah dilakukan menggunakan perisian PSCAD/EMTDC dan Matlab/Simulink dan keputusan menunjukkan prestasi yang memuaskan bagi kaedah-kaedah kawalan optimum yang dibangunkan. Kaedah kawalan simplex mod-arus boleh mengembalikan voltan bas ke 1 p.u. dengan cepat (1.82%-2.96% pacak) bebanding skim kawalan konvensional mod-arus yang tidak optimum (4.2%-8.2% pacak) dan skim kawalan mod-voltan (6.6%-18% pacak). Keputusan penghantaran kuasa FV/PTB menunjukkan prestasi yang memberansangkan dengan menggunakan kaedah M-KC optimum dengan kecekapan yang tinggi sehingga 90% berbanding kaedah dari penyelidikan yang lepas. Tambahan pula, pengoptimum pelbagai-parameter memberikan saiz PTB yang optimum dengan saiz dikurangkan dalam julat 0.8%-6.9%. Pengiraan pulangan bagi pelaburan PTB menunjukkan pulangan pelaburan sehingga 170% bagi kontrak selama 10 tahun. Kaedah kawalan terlaras yang dibangunkan untuk FV/PTB turut menunjukkan prestasi yang memuaskan bagi setiap kes yang dikaji. Kesimpulannya, kaedah-kaedah kawalan yang dibangunkan bagi sistem FV/PTB adalah amat berguna untuk membenteras kesan keterputusan penjanaan FV dan boleh dilaksanakan keatas sistem FV yang baru atau yang sediaada.