MODEL-FREE WIND FARM POWER PRODUCTION OPTIMIZATION USING MULTI-RESOLUTION OPTIMIZED RELATIVE STEP SIZE RANDOM SEARCH

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

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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

Kajian ini menyelidiki prestasi kaedah *Multi-Resolution Optimize Relative Step Size Random Search* (MR-ORSSRS) untuk meningkatkan jumlah pengeluaran tenaga ladang angin. Penyelidikan ini telah dilakukan mengikut susunan ladang angin *Horns Rev* yang mempunyai 80 turbin angin untuk mengatasi masalah seperti perbezaan arah angin antara $170°, 200°, 220°, 240°, 250°$ dan $270°$, lima turbin angin yang mengalami kerosakan serta perubahan angin yang tidak tertentu. Pengenaan fungsi *Multi-Resolution* daripada (Ahmad *et al.*, 2014) adalah digunakan untuk menambahbaik kadar penumpuan *Optimize Relative Step Size Random Search* demi meningkatkan jumlah pengeluaran tenaga ladang angin secara langsung. Fungsi *Multi-Resolution* (MR) ini boleh meningkatkan kelajuan kadar penumpuan dengan ketara kerana kaedah ini mengusahakan parameter kawalan berdimensi dengan beberapa tahap penambahbaikan. Secara khususnya, fungsi ini memulakan penambahbaikan dengan parameter kawalan dimensi rendah dan meningkatkan jumlah dimensi pada tahap penambahbaikan seterusnya. Oleh itu, usaha pengiraan untuk mendapatkan parameter kawalan optimum boleh dikurangkan. Walaupun MR-SPSA dikenalkan untuk menyelesaikan masalah berdimensi tinggi secara langsung dengan kadar penumpuan yang laju, ia tidak mampu menghasilkan jumlah tenaga ladang angin yang optimum. Ini disebabkan, SPSA merupakan kaedah penambahbaikan yang tidak mempunyai daya ingatan oleh itu, ia tidak berupaya untuk menyimpan parameter kawalan optimum yang dihasilkan. Di samping itu, ORSSRS adalah kaedah penambahbaikan yang mempunyai daya ingatan. Justeru, ia bermampu untuk menyimpan parameter kawalan optimum sementara menghasilkan penambahnaikan yang stabil. Namun demikian, kaedah ORSSRS sendiri tidak mampu membekalkan kadar penumpuan yang mencukupi untuk menyelesaikan masalah ladang angin secara langsung. Oleh itu, fungsi MR digabungkan demi meningkatkan kadar penumpuan kaedah ORSSRS. Dalam kajian ini, prestasi kaedah MR-ORSSRS dibandingkan dengan kaedah MR-SPSA dari segi kadar penumpuan, ketepatan dan kekukuhan dalam peningkatan jumlah pengeluaran tenaga ladang angin. Hasilnya menunjukan kaedah MR-ORSSRS telah menewaskan kaedah penanda aras MR-SPSA dari segi kadar penumpuan bagi semua kes kajian. Khususnya, ia telah menambahbaikan kadar penumpuan untuk kes perbezaan arah angin antara $170°, 200°, 220°, 240°, 250°$ dan $270°$ sebanyak 88.89%, 88.89%, 41.66%, 88.89%, 88.89% dan 66.67% . Sementara itu, 66.67% untuk kes lima turbin angin yang mengalami kerosakan. Selain itu, kaedah MR-ORSSRS telah berjaya meningkatkan jumlah pengeluaran tenaga ladang angin dalam mengatasi masalah pebezaan arah angin antara $170°, 200°, 220°, 240°$ dan $270°$ serta kegagalan turbin angin berbanding kaedah MR-SPSA. Dari segi kadar penumpuan, MR-ORSSRS juga menghasilkan kadar penumpuan yang lebih laju dalam mengatasi masalah perbezaan arah angin sementara kegagalan turbin angin melanda. Oleh demikian, ini telah menunjukan kaedah MR-ORSSRS yang dicadangkan adalah berkesan untuk menghasilkan jumlah pengeluaran tenaga dengan kadar penumpuan yang lebih laju walaupun berlaku kes kegagalan turbin angin dan perubahan angin yang tidak tertentu berbanding dengan kaedah penanda aras MR-SPSA.

ABSTRACT

This study investigates the performance of Multi-Resolution Optimize Relative Step Size Random Search (MR-ORSSRS) based method in maximizing the total power production of wind farms. The performance is investigated based on the Horns Rev wind farm layout which consists of 80 wind turbines under the case studies of different wind directions at 170°, 200°, 220°, 240°, 250° and 270°, five wind turbines failures and non-static wind variations. The implementation of Multi-Resolution (MR) function is used to improve the convergence speed of the Optimize Relative Step Size Random Search in the case of maximizing the total power production of a wind farm in real-time optimization. The MR function is significant in improving the convergence speed since this approach exploits the dimension of the design parameter using several optimization stages. In particular, it firstly adopts a small size of design parameter tuning followed by a bigger size of design parameter tuning in the following stages. Therefore, it is expected that less computation effort is required to obtain the optimal design parameter. Even though the Multi-Resolution Stochastic Perturbation Simultaneous Approximation (MR-SPSA) is developed to solve the real-time high-dimensional problem with faster convergence, the obtained total power production of the wind farm is still not optimum. This is because the SPSA is a memory-less structure type optimization that limits the storage of the best design parameter. Alternatively, ORSSRS based method is a memory type optimization structure. Hence, it can store the best design parameter value while producing consistent objective function. However, the ORSSRS based method alone does not have the sufficient convergence speed to optimize wind farm problem in real time. Therefore, the MR function is implemented to improve the convergence speed of the ORSSRS based method. In this study, the performance of MR-ORSSRS based method is compared with MR-SPSA based method in terms of the convergence speed, accuracy, and robustness in maximizing the total power production of Horns Rev wind farm. The results show that MR-ORSSRS based method outperforms the benchmark MR-SPSA based method in terms of the convergence speed of all the study cases. In particular, it can improve the convergence speed of incoming wind direction at $170°, 200°, 220°, 240°, 250°$ and $270°$ by $88.89\%, 88.89\%, 41.66\%, 88.89\%, 88.89\%$ and 66.67%, respectively. However, in the case of the five wind turbine failures, the speed of the incoming wind direction is 66.67%. Moreover, the MR-ORSSRS based method produces better total power production for wind direction at $170°, 200°, 220°, 240°$ and $270°$, as well as wind turbines failures compared to the MR-SPSA based method. In term of the convergence speed, the MR-ORSSRS based method produces higher convergence speed for all the wind direction cases even in the wind turbines failure cases. Hence, it is proven that the proposed MR-ORSSRS based method is effective in producing better total power production with faster convergence speed even with turbines failure and time-varying wind compared to the benchmark MR-SPSA based method.

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LIST OF SYMBOLS

A	Rotor swept area of the wind turbine
A^{ov}	Overlapped rotor swept area of the wind turbine
D	Rotor diameter of wind turbine
e	Exponential gain
F	Objective function
F^*	Optimum objective function
G	Group of wind turbines
i	The number subjected to wind turbine
j	Number of resolution
m	Maximum number of resolution
n	Total number of wind turbine in wind farm
N	Total number of designed parameter
Q	Power production of wind turbine
$\bar{Q}$	Total power production of wind farm
r	Distance to centreline of wind turbine rotor axis
R	n-dimensional random vector
S	Step size constant
t	Number of iteration
t_{max}	Termination criterion of ORSSRS
T_ω	Time interval for wake to travel throughout wind farm
V_ω	Incoming wind speed
$\Delta\bar{V}$	Differences of aggregated wind velocity
x	Distance to rotor disk plane of wind turbine
X	A set of n wind turbines in wind farm
α	Axial induction factor
β	Update sequence
δ	Negative constant
ε	Termination criterion of MR-ORSSRS
γ	Objective function of resolution
λ	A set of wind turbine
φ	Grouped design parameter of ϑ

φ^*	Grouped optimal design parameter of ϑ^*
$\emptyset$	Roughness coefficient
ρ	Air density
$\mathbb{R}$	Real number
ϑ	Designed parameter
ϑ^*	Optimum design parameter
τ	Time interval for wake to travel to the next wind turbine

LIST OF ABBREVIATIONS

ASSRS	Adaptive Step Size Random Search
BA	Bayesian Ascent
BO	Bayesian Optimization
COE	Cost of energy
DFIG	Doubly Fed Induction Generation
ESC	Extremum-Seeking Control
FS-MPPT	Fixed Step Maximum Power Point Tracking
FSSRS	Fixed Step Size Random Search
GD-MPPT	Gradient-Descent Maximum Power Point Tracking
GT	Game Theoretic
GUI	Graphical user interface
HWFC	Hierarchical wind farm control
IESC	Individual Extremum-Seeking Control
LQR	Linear-quadratic regulator
MAOA	Multi-agent optimization algorithm
MPPT	Maximum Power Point Tracking
MR-ORSSRS	Multi-Resolution Optimize Relative Step Size Random Search
MR-SPSA	Multi-Resolution Stochastic Perturbation Simultaneous Approximation
NESC	Nest Extremum-Seeking Control
ORSSRS	Optimize Relative Step Size Random Search
PDLPO	Payoff-based distributed learning for Pareto optimality
PSO	Particle Swarm Optimization
ROI	Return of investment
RS	Random Search
SAOA	Single-agent optimization algorithm
SDA	Spiral Dynamic Algorithm
SED	Safe experimental dynamics
SPSA	Stochastic Perturbation Simultaneous Approximation
SRS	Sequential Random Search

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