# HYBRID MOTH FLAME OPTIMIZATION MPPT ALGORITHM FOR ACCURATE REAL-TIME TRACKING UNDER PARTIALLY SHADED PHOTOVOLTAIC SYSTEM

TIONG MENG CHUNG

Doctor of Philosophy

UNIVERSITI MALAYSIA PAHANG

**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.

_______________________________
(Supervisor's Signature)

Full Name : DR. HAMDAN BIN DANIYAL

Position : ASSOCIATE PROFESSOR

Date : 30 APRIL 2021

_______________________________
(Co-supervisor's Signature)

Full Name : DR. MOHD HERWAN BIN SULAIMAN

Position : ASSOCIATE PROFESSOR

Date : 30 APRIL 2021

**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.

(Student's Signature)

Full Name : TIONG MENG CHUNG

ID Number : PEE17008

Date : 30 APRIL 2021

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TIONG MENG CHUNG

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# ABSTRAK

Modul fotovolta (PV) adalah kumpulan sel solar yang digunakan untuk menjana tenaga elektrik dari sinar matahari. Aplikasi fotovolta dalam penjanaan kuasa semakin popular disebabkan dengan pelaksanaannya yang mudah dan sumbernya yang tidak kunjung habis. Disebabkan ciri-ciri tidak linear, modul PV memerlukan pengesanan titik kuasa maksimum (MPPT). MPPT akan mengubah titik operasi kuasa agar sentiasa berada di titik kuasa maksimum (MPP) pada keluk arus-voltan (I-V). Tetapi dalam keadaan teduhan separa, sistem PV terdedah kepada masalah maksima tempatan yang seterusnya menjadi cabaran yang semakin tinggi bagi MPPT kerana algoritma MPPT biasa tidak berupaya mengesan MPP dengan cekap. Bagi mengatasi masalah ini, kaedah pengkomputeran lembut diadaptasi dalam MPPT oleh beberapa penyelidik, dengan Pengoptimuman Kawanan Zarah – *Particle Swarm Optimization* (PSO) adalah paling menyerlah. Namun, PSO memerlukan kuasa pengiraan yang tinggi. Ini merupakan satu masalah dalam aplikasi masa-nyata dan dalam keadaan sinaran yang terlalu dinamik. Dalam satu perkara lain, dengan penambahbaikan berterusan dan kemunculan algoritma baharu yang menunjukkan prestasi yang lebih unggul dalam menyelesaikan masalah semasa, satu algoritma MPPT berasaskan Pengoptimuman Api dan Kupu-kupu – *Moth Flame Optimization* (MFO) telah dilahirkan. Dalam kajian ini, satu sistem empat modul fotovolta berkapasiti 980 W bersama satu pengubah arus terus *Boost* dimodelkan dalam MATLAB-Simulink sebagai platfom ujian. Satu strategi kawalan terus diadaptasi sebagai pengawal pengubah kuasa arus terus digunakan bagi menggantikan kaedah biasa yang menggunakan pengawal Perkadaran dan Kamiran (PI) tanpa perlu penalaan. Berdasarkan kajian daripada MFO, MFO didapati memiliki kemampuan dalam mengesan titik kuasa maksimum dengan efektif, walaupun terdapat masalah penumpuan pramatang berdekatan dengan MPP. Untuk menghilangkan had tersebut, satu model hibrid baru yang bernama *Hybrid MFO* (HMFO) telah diusulkan berdasarkan gabungan daripada ciri-ciri MFO dan *Perturb & Observe* (P&O), bersama dengan ciri tambahan dalam pengesanan keadaan teduhan separa. Prestasi kedua-dua MFO dan HMFO dibandingkan dengan dua kaedah MPPT yang biasa digunakan iaitu P&O dan PSO. Untuk penilaian prestasi algoritma MPPT masa-nyata dengan lebih terperinci, perkakasan-dalam-gelung – *Hardware-in-the-Loop* (HIL) telah digunakan bagi mencontohi tingkah laku sistem PV dan alat pengubah kuasa. Sementara itu, alat pemproses isyarat digital (DSP) telah digunakan untuk perlaksanaan algoritma dalam kajian. Keempat-empat kaedah diuji di bawah 10 kes ujian sinaran tetap, 30 kes ujian sinaran dinamik dan 100 kes ujian teduhan separa. HMFO telah menunjukkan kebolehan pengesanan MPP yang cepat dan paling cekap di antara kaedah-kaedah pengkomputeran lembut bagi keadaan sinaran tetap. Di bawah keadaan sinaran dinamik, HMFO mampu mencapai MPP lebih pantas dan lebih cekap berbanding PSO and MFO. Di bawah keadaan teduhan separa pula, HMFO menunjukkan kecekapan yang paling tinggi dan masa penumpuan yang paling laju di antara kaedah-kaedah pengkomputeran lembut. HMFO dapat mengesan titik sebenar MPP sebanyak tiga kali ganda berbanding dengan P&O di bawah keadaan teduhan separa dan ia dapat mencapai kecekapan dengan purata sehingga 99.35 %.

## ABSTRACT

Photovoltaic (PV) module is a packed solar cell, used for generating electricity from the sun's energy. The application of PV power generation has gained its popularity with its easy implementation and inexhaustible energy resources. Due to the nonlinear characteristic of PV module, a maximum power point tracking (MPPT) is necessary to adjust the operating point based on the maximum power point (MPP) on the current-voltage (*I*-*V*) characteristic curve. However, under partial shaded conditions, the PV system is prone to local maxima problem and the challenge for MPPT increases, due to most of the commonly used MPPT algorithms were unable to track for the MPP effectively. To overcome the challenge, soft computing methods have been adapted in MPPT by researchers, with Particle Swarm Optimization (PSO) being the most prominent. However, the high computational power of PSO becomes a disadvantage in real-time and highly dynamic MPPT application. In addition, with the continuous improvement effort and the possibility of a new-comer algorithm can show superior results on the current problem, a new MFO based MPPT algorithm was proposed. In this study, a four-module 980 W solar PV system together with a DC/DC Boost Converter model was developed in MATLAB-Simulink as the MPPT algorithm test platform. Direct control strategy was adapted as the regulator for the DC/DC converter to replace the conventional proportional-integral (PI) controller to eliminate the need to tune the PI controller. Based on the study from MFO, it is found that the MFO was having the capability to perform effective tracking, despite its limitation of premature convergence problem near the MPP. To lift the limitation off, a new hybrid model named Hybrid MFO (HMFO) was proposed based on the combination of feature from MFO and conventional P&O, together with an additional partial shading detection feature. The performance of MFO and HMFO was compared with two well-established MPPT methods, namely Perturb and Observe (P&O) and PSO. To further evaluate the real-time performance of the MPPT algorithms, hardware-in-the-loop (HIL) was utilized to emulate the behavior of the PV system and power converter while a digital signal processor (DSP) was used to implement the MPPT algorithms in study. All four MPPT methods were simulated and real-time evaluated under 10 constant irradiance test cases, 30 dynamic irradiance test cases and 100 partial shaded irradiance test cases. HMFO has shown fast tracking and achieved the highest average efficiency among the soft computing methods under constant irradiance conditions. Under dynamic irradiance condition, HMFO was able to reach the new MPP faster and more effective than both PSO and MFO. Under partial shaded conditions, the HMFO was able to show the highest average tracking efficiency and the fastest convergence time among the soft computing method. The HMFO was able to track for true MPP for about three times more than the P&O under partial shaded conditions and it was able to achieve the average tracking efficiency up to 99.35 %.

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