A MODIFIED PARTICLE SWARM OPTIMIZATION BASED MAXIMUM POWER POINT TRACKING FOR PHOTOVOLTAIC CONVERTER SYSTEM

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To my beloved wives, sons and daughter for their enduring love, motivation, and support

ABSTRACT

This thesis presents a modified Particle Swarm Optimization based Maximum Power Point Tracking for Photovoltaic Converter system. All over the world, many governments are striving to exploit the vast potential of renewable energy to meet the growing energy requirements mainly when the price of oil is high. Maximum Power Point Tracking (MPPT) is a method that ensures power generated in Photovoltaic (PV) systems is optimized under various conditions. Due to partial shading or change in irradiance and temperature conditions in PV, the power-voltage characteristics exhibit multiple local peaks; one such phenomenon is the global peak. These conditions make it very challenging for MPPT to locate the global maximum power point. Many MPPT algorithms have been proposed for this purpose. In this thesis, a modified Particle Swarm Optimisation (PSO)-based MPPT method for PV systems is proposed. Unlike the conventional PSO-based MPPT methods, the proposed method accelerates convergence of the PSO algorithm by consistently decreasing weighting factor, cognitive and social parameters thus reducing the steps of iterations and improved the tracking response time. The advantage of the proposed method is that it requires fewer search steps (converges to the desired solution in a reasonable time) compared to other MPPT methods. It requires only the idea of series cells; thus, it is system independent. The control scheme was first created in MATLAB/Simulink and compared with other MPPT methods and then validated using hardware implementation. The TMS320F28335 eZDSP board was used for implementing the developed control algorithm. The results show good performance in terms of speed of convergence and also guaranteed convergence to global MPP with faster time response compared to the other MPPT methods under typical conditions (partial shading, change in irradiance and temperature, load profile). This demonstrates the effectiveness of the proposed method.

ABSTRAK

Tesis ini membentangkan Pengoptimaan Kerumunan Zarah berasaskan Pengesanan Poin Kuasa Maksimum yang diubah suai bagi sistem Photovoltaic Penukar. Di seluruh dunia, banyak kerajaan sedang berusaha untuk mengeksploitasi potensi besar tenaga boleh diperbaharui untuk memenuhi keperluan tenaga yang semakin meningkat sebahagian besarnya apabila harga minyak adalah tinggi. Maksimum Pengesanan Poin Kuasa (MPPT) adalah kaedah yang memastikan kuasa dijana dalam sisitem photovoltaic (PV) dioptimumkan di bawah pelbagai keadaan. Oleh kerana teduhan separa atau perubahan dalam sinaran dan keadaan suhu di PV, ciri-ciri kuasa voltan mempamerkan pelbagai puncak tempatan; satu fenomena itu adalah kemuncak global. Keadaan ini membuat ia sangat mencabar bagi MPPT untuk mencari titik kuasa maksimum global. Banyak MPPT algoritma pengesanan telah dicadangkan untuk tujuan ini. Dalam tesis ini, Pengoptimuman Sekumpulan Zarah (PSO) diubah suai - berdasarkan teknik MPPT untuk sistem PV adalah dicadangkan. Berbeza dengan kaedah konvensional MPPT berasaskan PSO, kaedah yang dicadangkan mempercepatkan penumpuan algoritma PSO dengan secara konsisten mengurangkan faktor pemberat dan parameter kognitif dan sosial dengan itu mengurangkan langkah-langkah lelaran dan meningkatkan masa tindak balas pengesanan. Kelebihan kaedah yang dicadangkan ialah ia memerlukan langkah-langkah yang lebih sedikit carian (menumpu kepada penyelesaian yang diingini dalam masa yang munasabah) berbanding dengan kaedah-kaedah lain. Ia hanya memerlukan idea sel siri; dengan itu, ia adalah sistem bebas. Skim kawalan mula-mula diwujudkan pada MATLAB/Simulink dan dibandingkan dengan kaedah MPPT lain dan kemudian disahkan menggunakan pelaksanaan perkakasan. Papan TMS320F28335 eZDSP digunakan untuk melaksanakan algoritma kawalan yang terbina. Keputusan menunjukkan prestasi yang baik daripada segi kelajuan daripada penumpuan dan penumpuan juga dijamin MPP global dengan masa tindak balas lebih cepat berbanding kaedah MPPT lain di bawah keadaan biasa (bayang-bayang separa, perubahan dalam sinaran dan suhu, profil beban). Ini menunjukkan keberkesanan teknik yang dicadangkan.

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M.Abdulkadir, Nigeria

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LIST OF ABBREVIATIONS

ANN	-	Artificial Neural Network
AC	-	Alternating Current
CIS	-	Copper Indium Diselenide
DC	-	Direct Current
DSP	-	Digital Signal Processor
EA	-	Evolutional Algorithm
FLC	-	Fuzzy Logic Control
FOCV	-	Fractional Open-Circuit Voltage
FSCC	-	Fractional Short-Circuit Current
GMP	-	Global Maximum Point
HC	-	Hill Climbing
INC	-	Incremental Conductance
MPP	-	Maximum Power Point
MPPT	-	Maximum Power Point Tracking
MPSO	-	Modified Particle Swarm Optimization
PI	-	Proportional Integral
PO	-	Perturb and Observe
PSO	-	Particle Swarm Optimization
PV	-	Photovoltaic
RHP	-	Right Hand Plane
QIDO	-	Quad-Correlation Control
RCC	-	Ripple Correlation Control
STC	-	Standard Test Conditions

LIST OF SYMBOLS

a, A	-	Diode ideality factor
C	-	Capacitor capacitance
d_{min}	-	Duty cycle minimum
d_{max}	-	Duty cycle maximum
dP/dI	-	Derivative of power to current
dP/dV	-	Derivative of power to voltage
G	-	Solar insolation
G_{best}	-	Global best position
I_{MAX}	-	Maximum power current
I_{PV}	-	Photovoltaic current
I_{SC}	-	Short circuit current
P-V	-	Current versus voltage
I-V	-	Current versus voltage
i_C	-	Capacitor current
i_L	-	Inductor current
i_o	-	Saturation current
K_i	-	Short circuit current coefficient
N_P	-	Number of particles
N_S	-	Number of series cell in PV module
P_{max}	-	Maximum Power
P_{best}	-	Personal best position
P	-	Power
P-I	-	Power versus current

P-V	-	Power versus voltage
R_S	-	Series resistance of PV module
R_P	-	Parallel resistance of PV module
T	-	Temperature
V_{PV}	-	Photovoltaic voltage
V	-	Reference voltage
V_{ref}	-	velocity of PSO particles
V_{MP}	-	Maximum power voltage
V_{OC}	-	Open circuit voltage
V_T	-	Thermal voltage
Φ	-	Perturbation step
V	-	Voltage
V_t	-	Terminal Voltage
V_C , v_C	-	Capacitor Voltage
ω	-	Inertia or weighting factor of velocity of PSO particles
x	-	Position of PSO particles

CHAPTER 1

INTRODUCTION

1.1 Background

Energy is indispensable to human life. Energy is not only a measurement for economic and social improvement, but also a fundamental human necessity. Many countries are trying to find the means to solve energy problems which includes energy importation, environmental pollution, global warming, increasing cost of energy, and energy inefficiency.

Photovoltaic (PV) system has gained wide popularity in the past decade as one of the renewable-energy sources due to the possibility of depletion of conventional energy sources and its high cost as well as its negative effects on the environment. One essential fundamentals of all PV is the efficacy of its maximum power point tracking. The aspect has drawn immense enthusiasm from photovoltaic researchers and industry expert being the most economical means to enhance above all the photovoltaic system efficacy. Maximum power point tracking is primarily an operating point co-coordinating between the photovoltaic module and the DC-DC converter. Nonetheless, maximum power point tracking is not simple and easy to

track because of the non-linear I–V characteristics of the photovoltaic curve and the effect of the changing weather situations (especially irradiation and temperature), tracking the accurate maximum power point (MPP) has been always an intricate issue. The tracking eventually is further sophisticated when all photovoltaic modules do not experience constant radiation.

For the past decades, many MPPT algorithms have been proposed, in which many centered on obtaining optimum maximum power point. Among the renowned power maximizing methods are perturb and observe (P&O), Hill climbing, incremental conductance (INC) and conventional PSO. These methods, nonetheless, fail to track the maximum power point when the irradiance level is not consistent for all PV solar cells or the panels are partially shaded. P&O method frequently leads to wrongful conclusion, oscillation around the maximum power point and it's generally needs to link one or many modifications for general usage. Incremental conductance methods overcome these shortfalls of Perturb and Observe methods but need relatively elaborate detection devices and the choice of the step and threshold is also distressing.

Recently, numerous researchers have presented intelligent MPPT methods for photovoltaic module arrays, both to track MPPs accurately and to improve the dynamic and steady-state tracking performance [2] – [6] . However, these methods are applicable only to MPPT in photovoltaic module arrays without shading. Nevertheless, the appearance of multi-peak output curves because of partial module shading in photovoltaic module arrays is common. Therefore, the development of an algorithm for accurately tracking the true MPPs of complex and nonlinear output curves is crucial. In [7], Ishaque *et al* presented an MPP tracker based on particle swarm optimization (PSO) for photovoltaic module arrays. Although this tracker was capable of tracking global MPPs of multi-peak characteristic curves because of the fixed values adopted for weighing within the algorithm, the tracking performance lacked robustness, resulting in low efficiency when tracking global MPPs. In an instance where the MPPs were tracked successfully, the dynamic response speed was very low. Therefore, this research critically employs PSO with added improvements

that will prevent it from being trapped in local MPPs (i.e., searching only local MPPs on the PV characteristics curves) and enabling it to track global MPPs quickly and consistently on the multi-peak characteristic curves of photovoltaic module arrays.

Invariably the best approach is to employ an evolutionary algorithm (EA) method due to its ability to handle nonlinear objective functions; EA is envisioned to be very effective to deal with MPPT problem. Among the EA methods, particle swarm optimization (PSO) is employed here because it is highly potential due to its simple structure, easy implementation and fast computation capability [6]. Fundamentally, PSO is best known as a search optimization; it is therefore able to locate the MPP for any type of P-V curve regardless of environmental irregularities. It can be used to track the MPP of PV system as the search space of the PSO will be reduced due to fast convergence, and hence, the time required can be greatly decreased.

Interestingly, over the years, one important feature of the PSO that has been ignored or not thoroughly studied by researchers is the searching speed through adaptive learning factors and inertia weight. These factors accelerates convergence of the PSO algorithm by consistently decreasing the weighting factor and the cognitive and social parameters, thereby reducing the steps of iterations and improved the tracking time response. The proposed approach is not only capable of tracking the maximum power point under constant irradiance, but is also able to find the maximum power point under fast changing irradiation conditions. The physical meaning of this modification of the weighting factor and the cognitive and social coefficient is that, larger step sizes are used to increase the particle search velocity during the initial search because the distance to the global optimum is relatively large. This prevents an excessively small step size from making local optimum traps unavoidable.

Furthermore, since the weighting factor ω decreases gradually as the step of iterations increases, this causes the steps in the particle movements to diminish, as

the particles approach the MPP, enabling the particles to track the MPP more accurately. Moreover, in PSO equation, the first term is exploited to maintain the same direction the particle was moving pristinely; thereby controls the converging demeanor of the particle swarm optimization. In order to expedite fast converging, the inertia weight will be culled such that the effect of the velocity equation of the algorithm diminishes during the operation. Therefore, decrementing the value of ω with time is desirable. To get refined solutions, a possible option is to set the inertia weight initially to a bigger value for better exploration and then reduce it gradually. Likewise, the cognitive and social parameter can also be modified as it affects the search ability of PSO. When this is done, the power loss as a result of the oscillation around the MPP is eradicated and the efficiency of the system increases. The theoretical analysis and simulation results illustrate the good performances of the proposed control schemes.

1.2 Thesis Objective, Scope and Contribution

1.2.1 Objectives

This research proposes a modified particle swarm optimization based maximum power point tracking for photovoltaic converter system. The objectives of this research are:

(i) To model and simulate a Solar PV system and identifying its dynamic and transient characteristic.

(ii) To design a PSO-based MPPT method to ensure fast, efficient and reliable tracking of maximum power point under load variations and fast changing environmental conditions.

(iii) To verify and analyze the effectiveness of the proposed control method.

(iv) To test the performance of the developed system using hardware.

1.2.2 Scope of Work

The scope of this thesis includes modelling and simulation of a Solar PV system to identify its dynamic and transient characteristic. A thorough study on the various control methods used by previous researchers for MPPT in photovoltaic applications is conducted. The design, modelling and simulation of an MPPT control system based on a proposed particle swarm optimization control algorithm is carried out. The proposed control method is analyzed to ascertain its performance through computer simulation using MATLAB/Simulink under load and changing environmental conditions. The proposed control method is validated via hardware experiments to test its effectiveness and the performance of the system under load and changing environmental conditions. Comparison of the proposed method with other existing methods is also included.

1.2.3 Thesis Contributions

This research will contribute significantly in developing a modified PSO-based MPPT method for a photovoltaic converter system. The significant contributions of this thesis are listed as follows:

a) A new modified particle swarm optimization based maximum power point tracking method for photovoltaic converter system suitable for changing loads uniform and partial shading conditions.

b) A digital controller based on TMS320F28335 eZDSP board that implement the algorithm of the new modified PSO-based MPPT method.

1.3 Thesis Organizations

This thesis is organized into six chapters. The content of these chapters is outlined as follows:

- Chapter 2 provides an overview of solar photovoltaic (PV) DC-DC converter system focused on the development of the photovoltaic cells modelling methods to identify its dynamic and transient characteristic. It will also identify the factors that influence the characteristics of the photovoltaic cells, and the effects of partial shading on the solar PV system. It will discuss the overview of MPPT control methods of power converter, and methods of interfacing of the solar PV with DC-DC converter used by other researchers; Different MPPT methods are analyzed and compared on the basis of hardware requirement, speed, accuracy, applicability, cost and the sensors used. The merits and drawbacks of the control methods are discussed lastly.

- Chapter 3 this chapter presents a description of the mathematical equations for modelling of PV cells and modules. The presented work is a detailed modeling and simulation of the PV system; it is implemented under MATLAB/Simulink environment. The numerical results for different

temperature and irradiance conditions to identifying its dynamic and transient characteristic are presented. Furthermore, this simulator tool will be used for testing MPPT algorithms' efficiencies and evaluating the effects of different partial shadows conditions. The design model of the boost DC-to-DC converter system is also being presented. Interfacing the boost DC-DC converter with a photovoltaic system is also discussed.

- Chapter 4 presents the proposed modified PSO-based MPPT method for tracking MPP either in uniform irradiance or partial irradiance levels. A simplified structure of the proposed modified PSO-based MPPT model utilizing a boost converter topology has been presented. The proposed control scheme is verified using Simulink models to test the robustness and performance. The simulation results indicate that the converter can track the maximum power point of the photovoltaic system. The results of the proposed method are finally analyzed and compared with other methods.

- Chapter 5 describes the laboratory experimental set-up. A brief explanation is given on the power circuit and gate drives. A detailed description is provided on the implementation of the proposed controller using TMS320F28335 eZDSP and then evaluates the performances of the proposed controller. Verification of the effectiveness of the proposed control method is performed by comparing the tested results, with other established methods under typical load profile and partial shading conditions. The simulation and experimental results are provided.

- Chapter 6 concludes the research works and highlights the contributions and provides possible directions for future research work.

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