



**MODIFIED DUTY CYCLE SWEEPING MAXIMUM  
POWER POINT TRACKING ALGORITHM FOR  
STANDALONE PHOTOVOLTAIC SYSTEM**

by

**MOHD ASRI BIN JUSOH  
(1640912274)**

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## LIST OF ABBREVIATIONS

MPPT	Maximum Power Point Tracking
PV	Photovoltaic
DC	Direct Current
AC	Alternating Current
SEPIC	Single Ended Primary Inductance Converter
P&O	Perturb and Observe
GP	Global Peak
HC	Hill Climbing
PWM	Pulse Width Modulation
STC	Standard Test Condition
QIDO	Quad Input Dual Output
OCC	One Cycle Control
GA	Genetic Algorithm
ANN	Artificial Neuro-Network
FLC	Fuzzy Logic Controller
GP <sub>MPP</sub>	Global Peak Maximum Power Point
LP	Local Peak
DSP	Digital Signal Processing
DCV	Discontinuous Voltage
RCC	Ripple Correlation Control
SOC	State of Charge
LED	Light Emitting Diode
TAB	Triple Active Bridge
PEMFC	Proton Exchange Membrane Fuel Cell
CCM	Continuous Mode
DCM	Discontinuous Mode
SSA	State Space Averaging
ICI	Input Characteristic Impedance
RAM	Random Access Memory

## LIST OF SYMBOLS

R	Resistor
L	Inductor
C	Capacitor
V	Voltage
I	Current
P	Power
D	Duty Cycle
F	Frequency

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# ALGORITMA PENGESANAN TITIK KUASA MAKSIMUM SAPUAN KITAR

## TUGAS TERUBAHSUAI UNTUK SISTEM FOTOVOLTA MANDIRI

### ABSTRAK

Kecekapan sistem fotovoltaik (PV) selalunya bergantung kepada keberkesanan sel atau modul. Dengan kemajuan dalam panel PV, penukar AT-AT, dan beban/bateri, terdapat tumpuan yang semakin meningkat pada operasi algoritma pengesanan titik kuasa maksimum (MPPT) di bawah pelbagai keadaan sinaran. Algoritma ini terus diperbaiki untuk memastikan prestasi optimum sistem PV dan untuk menangani ciri-ciri PV yang tidak linear di bawah keadaan yang berbeza. Algoritma MPPT semasa, termasuk kaedah konvensional dan pengkomputeran lembut, adalah penting untuk memaksimumkan pengeluaran PV tetapi masih menghadapi cabaran seperti ketepatan penjejakan di bawah keadaan yang kompleks (cth., perubahan cuaca yang cepat dan beransur-ansur), keseimbangan kecekapan dan kestabilan (ayunan di sekitar titik kuasa maksimum dan masa penumpuan), dan pertukaran antara kelajuan penjejakan dan kerumitan. Untuk mengatasi kelemahan tersebut, algoritma sapuan kitar tugas terubahsuai (MDCS) yang dirumus berdasarkan algoritma mendaki bukit dicadangkan dalam kerja ini. Tujuannya adalah untuk meredakan batasan algoritma lazim usik dan cerap (P&O), yang mana (1) arah penjejakan yang berbeza semasa perubahan dinamik dalam sinaran dan (2) kegagalan untuk mengikuti puncak sejagat ( $GP_{MPP}$ ) apabila berlaku peningkatan pesat dalam penyinaran. Kegagalan ini berlaku kerana keputusan yang salah diambil dan terperangkap di puncak kuasa tempatan (LP). Algoritma MDCS diusulkan untuk menghindari arah yang menyimpang dengan memasukkan maklumat perubahan dalam kitar tugas dalam proses penjejakan, perubahan puncak global ( $GP_{MPP}$ ) dan perubahan kuasa keluar ( $P_O$ ). Untuk mengesahkan prestasi, kaedah yang dicadangkan dibandingkan dengan kaedah P&O konvensional dan pengoptimunan kawanan zarah (PSO) di bawah pelbagai keadaan persekitaran menggunakan perisian MATLAB/Simulink® untuk pengesanan simulasi. Penukar AT-AT kearuhan primer hujung tunggal (SEPIC) dibina untuk pengesanan eksperimen dan algoritma MPPT yang dicadang dilaksanakan ke dalam papan pengawal DSP TMS320F28335. Simulasi dan eksperimen dilakukan di bawah keadaan sinaran yang sama. Keputusan menunjukkan bahawa algoritma MDCS yang dicadangkan secara berkesan menyesuaikan diri dengan keadaan cuaca yang berubah-ubah dengan secara automatik mengarahkan titik operasi sistem ke arah kedudukan MPP yang optimum atau terdekat. Algoritma MDCS dianggap sebagai optimum dalam pelbagai aspek, dengan setiap pengukuran pengesanan menunjukkan ketepatan dan kecekapan penjejakan yang cemerlang melebihi 95% merentas majoriti senario yang diuji.

# MODIFIED DUTY CYCLE SWEEPING MAXIMUM POWER POINT TRACKING ALGORITHM FOR STANDALONE PHOTOVOLTAIC SYSTEM

## ABSTRACT

The efficiency of photovoltaic (PV) systems often depends on the effectiveness of the cells or modules. With the advancements in PV panels, DC-DC converters, and loads/batteries, there is an increasing focus on maximum power point tracking (MPPT) algorithms' operation under various irradiance conditions. These algorithms are continuously improved to ensure the PV system's optimum performance and to address the non-linearity of PV characteristics under different conditions. Current MPPT algorithms, including conventional and soft computing methods, are crucial for maximizing PV output but still face challenges such as tracking accuracy under complex conditions (e.g., rapidly and gradually changing weather), efficiency and stability concerns (oscillations around the maximum power point and convergence time), and the trade-offs between tracking speed and complexity. To overcome these shortcomings, a modified duty cycle sweeping (MDCS) algorithm which is formulated based on a hill-climbing algorithm is proposed in this work. The goal is to alleviate the limitations of the conventional perturb and observe (P&O) algorithm, specifically (1) the diverging direction of tracking during the dynamic change in irradiance and (2) failure to follow the global peak ( $GP_{MPP}$ ) when a rapid increase in irradiance occurs. This failure occurs due to incorrect decisions taken and trapped at the local peak power (LP). MDCS algorithm is proposed to avoid the diverging direction by incorporating the information of change in duty cycle in the tracking process, change in global peak ( $GP_{MPP}$ ), and the change in output power ( $P_O$ ). To verify the performance, the proposed method was compared to the conventional P&O and particle swarm optimization (PSO) method under various environmental conditions using MATLAB/Simulink<sup>®</sup> software for simulation verification. A DC-DC single-ended primary inductance converter (SEPIC) converter was constructed for experimental validation and the proposed MPPT algorithm is implemented into TMS320F28335 DSP controller board. Both simulation and experimental validations were performed under similar irradiance conditions. The results demonstrate that the proposed MDCS algorithm effectively adapts to changing weather conditions by automatically directing the operating point of the system towards the optimal or nearest MPP position. The MDCS algorithm is regarded as optimal in various aspects, with each verification measurement demonstrating outstanding tracking accuracy and efficiency exceeding 95% across the majority of tested scenarios.

## CHAPTER 1: INTRODUCTION

### 1.1 Research Background

Energy demand refers to the amount of energy used by human activities. It encompasses the total quantity of energy consumed by people and businesses for purposes like transportation, heating, cooling, lighting, and production. Numerous factors, such as population growth, economic expansion, and lifestyle changes, influence energy demand. The surge in energy demand is exerting pressure on the world's energy resources. Oil, coal, and natural gas are the primary energy resources. However, fossil fuels are limited resources, and their use contributes to climate change. The growing concerns about climate change have pushed researchers and their developments towards cleaner, renewable, and less environmentally damaging energy sources (Kandemir, Cetin, & Borekci, 2017). To address the increased need for energy, alternative energy (renewable energy) sources must be explored. However, renewable energy sources are not yet capable of meeting the entire energy demand.

Renewable energy sources such as solar, wind, hydropower, geothermal, and biomass are gaining importance to reduce dependency on fossil fuels and combat climate change. Renewable energy resources have several advantages over conventional fossil fuels. They are environmentally friendly, long-lasting, and becoming more affordable. Solar power, which is eco-friendly, clean, and noiseless, is readily available and one of the most used alternative energies (Kandemir et al., 2017). Today, the use of solar power, especially solar photovoltaic (PV) systems, has increased dramatically (Bahrami et al.,

2019)(Chiu, Cheng, Liu, Wang, & Yang, 2014). This trend highlights the global shift towards reducing reliance on non-renewable resources and recognizes solar power's significant role in fostering a sustainable future.

Solar PV system growth is likely to continue in the next few years, owing to factors such as lowering costs, government initiatives, and increased awareness. There are three types of PV systems that can be categorized as (1) standalone, (2) hybrid, and (3) grid-connected systems. However, many small businesses and homes still hesitate to invest in PV systems due to their low efficiency. The efficiency of a PV system is the percentage of solar energy converted into electricity. The electricity produced from a PV system is based on solar irradiation, the temperature of the cell, and the load (Sharma & Agarwal, 2014). The low efficiency of the PV system has attracted attention from interdisciplinary research groups to improve the conversion efficiency of solar power into electricity. One method for increasing the efficiency of a PV system is to maximise the energy harvested from the PV array by guaranteeing high conversion efficiency of the DC-DC converter and improving the tracking efficiency of the maximum power point tracking (MPPT) algorithm.

For all types of PV systems (standalone, hybrid, and grid-connected), the DC-DC converter carries out two important functions. The first function automates power transfer from the PV unit to the load or battery. The second function involves correctly tracking the maximum output power ( $P_{MPP}$ ) in a uniform irradiance condition and the global peak maximum output power ( $GP_{MPP}$ ) under partial shading (PS) conditions, irrespective of how fast atmospheric conditions change (Cho, 2017)(Gholami, Khazaei, Eslami, Zandi,

& Akrami, 2018)(Nag & Sarkar, 2018)(P. Sivakumar & Arutchelvi, 2017)(Zandi et al., 2017). There are two categories of DC-DC converters available: (1) isolated and (2) non-isolated DC-DC converters. Various topologies (isolated and non-isolated) for DC-DC converters are designed for higher efficiency, stable control switching techniques, fault-tolerant configurations, and primarily for renewable energy-based applications (S. Sivakumar, Sathik, Manoj, & Sundararajan, 2016). These DC-DC converters are integrated with MPPT algorithms to perform better in extracting the maximum output power from the PV system.

The MPPT algorithm tries to extract the highest power produced by the PV system under varying environmental conditions. Several MPPT techniques for a PV system have been developed over the past ten years and can be classified into two (2) main groups: conventional and soft computing (SC) algorithms. Conventional algorithms are based on an examination of the  $I-V$  curve of a PV module or array. The  $I-V$  curve depicts the relationship between PV current ( $I_{PV}$ ) and PV voltage ( $V_{PV}$ ). A variety of factors influence the  $I-V$  curve of a PV system, including irradiance, temperature, and the type of solar cells employed in the PV module. The MPP is the point on the  $I-V$  curve where the PV output power is greatest. The most common conventional MPPT algorithms are perturb and observe (P&O), hill climbing (HC) and incremental conductance (Inc. Cond).

The operating principle of P&O is based on voltage and current perturbation. This algorithm operates by perturbing (changing) the operating point of the solar panel and observing the resulting change in output power. It continuously adjusts the operating point in the direction that increases power until it detects a decrease in output power, at

which point it changes the direction of perturbation. The HC algorithm employs direct perturbation of the power converter duty cycle. The algorithm starts at an initial (duty cycle) operating point and evaluates the output power. The algorithm then makes a small adjustment to the operating point and compares the new output power with the previous one. If the power increases, the algorithm continues in the same direction; otherwise, it changes direction. This process is repeated until the MPP is reached. Inc. Cond will compare the derivative conductance with instantaneous conductance and goes towards MPP when the derivative is zero.

The conventional MPPT algorithms are excellent for tracking the MPP under uniform conditions with fluctuations near the MPP peak. However, the conventional algorithms will face difficulties during low irradiance conditions, such as difficulty in tracking MPP, the potential for incorrect tracking, overshooting, and oscillations. Additionally, such algorithms may have issues identifying the MPP when irradiation conditions rapidly change, either in uniform or PS conditions. For example, PS could induce such a change in a short period of time. When a PV array is subjected to PS, the  $P$ - $V$  characteristic curve will show several peaks. During PS, conventional MPPT algorithms frequently trap at a false power peak (local peak, LP), resulting in MPP tracking failure. Furthermore, it oscillates near LP and will remain there permanently, resulting in severe power loss. The divergence problem in the context of conventional MPPT algorithms refers to a situation where the algorithm fails to converge to the true MPP or exhibits unstable behaviour, leading to oscillations or continuous adjustments that do not result in reaching a stable operating point. To address this issue,

improvements, and enhancements to the working principles of the conventional algorithms and SC algorithms are proposed.

SC MPPT algorithms are a subset of MPPT algorithms that track the MPP of a PV system using artificial intelligence techniques like fuzzy logic control (FLC), artificial neural networks (ANN), and particle swarm optimization (PSO). SC MPPT algorithms are more sophisticated than conventional MPPT algorithms but can achieve higher power efficiency and faster convergence times. The MPP during PS conditions can be successfully tracked using artificial intelligence and metaheuristics techniques, but their implementation requires extensive parameter calibration to ensure that the PV array operates at the MPP, necessitating the use of a high-cost microcontroller (Camilo et al., 2019)(Kong, Wang, Liu, Yu, & Wang, 2017)(Abu Eldahab, Saad, & Zekry, 2016a). However, as irradiance gradually changes, artificial intelligence algorithms tend to lose tracking performance and deviate significantly from the MPP direction. These issues contribute to the loss of power and a decrease in tracking efficiency and accuracy. In contrast, traditional MPPTs like HC show good MPPT performance, especially when contrasted with SC MPPT approaches, which deviate significantly from MPP during gradual irradiance change.

To deal with challenging environmental conditions, this work proposes a modified HC algorithm that implements an adaptive mechanism to modify the duty cycle based on the algorithm's performance and system conditions. The proposed approach is known as modified duty cycle sweeping (MDCS). The goal of this MDCS method is to combine various features such as adaptive duty cycle step size, variable sweeping range,

and real-time performance monitoring to increase the algorithm's performance. Since the MDCS is modified to be adaptive, the algorithm can use the stored duty cycle after convergence to tackle the re-initialization problem. This is important because the conventional HC may have difficulty converging to the true MPP, especially when irradiance changes are small if the initial conditions are far from the MPP. In addition, in the case of large irradiance changes, if the HC fixed step size is too small, it can result in slow convergence in the PV system. The MDCS algorithm offers the advantage of being flexible and adaptable to different problem landscapes. It significantly improves the tracking accuracy and efficiency of the MPPT during sudden, gradual and PS irradiance conditions.

## 1.2 Problem Statement

In a PV system, voltage ( $V$ ), current ( $A$ ), and power ( $P$ ) are nonlinear parameters that are fully dependent on solar irradiation and temperature. Tracking the MPP with nonlinear parameters is a complex operation since the environmental conditions are continually changing. The task is further complicated in PS conditions, which can be caused by different obstructions, such as buildings, trees, clouds, and more. To overcome these problems, many MPPT algorithms have been developed for PV systems. The primary objective of these MPPT algorithms is to continuously optimize the operating point of the PV system, ensuring it aligns with the specific point on the  $I-V$  or  $P-V$  curves where the PV array yields maximum output power. The conventional HC algorithm can effectively track the maximum output power under uniform irradiance conditions but is not always able to accurately track the MPP during non-uniform conditions. This results