



AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Electronics Engineering and Electrical Communications

Design and Experimental Investigation of Maximum Power Point Tracking For Photovoltaic Generation Energy System

A Thesis submitted in partial fulfilment of the requirements of the degree of

Master of Science in Electrical Engineering

(Electronics Engineering and Electrical Communications)

By

Hazem Hossam EL-din Mostafa

Bachelor of Science in Electrical Engineering

(Electronics Engineering and Electrical Communications)

Faculty of Engineering, Higher institute of engineering and technology fifth
settlement, 2012

Supervised By

Prof. Wagdi Refaat Anis

Dr. Amr Mohamed Ibrahim

Cairo - (2019)



**AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
ELECTRONICS & COMMUNICATION ENGINEERING
Department**

**Thesis Title: Design and Experimental Investigation of Maximum
Power Point Tracking For Photovoltaic Generation Energy System**

Submitted By: Hazem Hossam El-din Mostafa.

.Degree: Master of Science in Electronics and Communication Engineering.

Examiners' Committee

Name and Affiliation

Signature

Prof. Abdelmoneim Mohammed El-Mahdy

National Authority for Remote Sensing and Space Sciences

Prof. Abdelhalim Abdelnaby Zekry

Faculty of Engineering, Ain Shams University

Prof. Wagdy Refaat Anis

Faculty of Engineering, Ain Shams University

Ass.Prof. Amr Mohamed Ibrahim

Faculty of Engineering, Ain Shams University

Date: 12/10/2019



**AIN SHAMS UNIVERSITY
FACULTY OF ENGINEERING
ELECTRONICS & COMMUNICATION ENGINEERING
Department**

Thesis Title: Design and Experimental Investigation of Maximum Power Point Tracking For Photovoltaic Generation Energy System

Submitted By: Hazem Hossam El-din Mostafa.

.Degree: Master of Science in Electronics and Communication Engineering.

Supervisory Committee

Name and Affiliation

Signature

Prof. Wagdy Refaat Anis

Faculty of Engineering, Ain Shams University

Ass.Prof. Amr Mohamed Ibrahim

Faculty of Engineering, Ain Shams University

Date: 12/10/2019

RESEARCHER DATA

Name	: Hazem Hossam El-din Mostafa
Date of birth	: 21/12/1990
Place of birth	: Cairo/ Egypt
Last academic degree	: Bachelor Science
Field of specialization	: Electronics and Communication
University issued the degree	: Higher Institute of Engineering and Technology Fifth Settlement
Date of issued degree	: 7/2012
Current job	: Teacher Assistant at Egyptian Chinese University

STATEMENT

This thesis is submitted as a partial fulfilment of Master of Science in Electrical Engineering Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

Hazem Hossam El-din Mostafa

Signature:

Date: 12/10/2019

ABSTRACT

The use of new renewable energy sources has extended rapidly for many reasons, including the dwindling conventional sources, environmental problems, and soaring fuel price dispersion. PV System (PVS) represents a promising sustainable energy source. An MPPT extracts the highest power from the PVS and transfers it to the load. Many developments are done trying to advance the drawback efficiency of the PVS. Many algorithms to track the MPP of PVS have been introduced to resolve the drawback of efficiency. Typical PVS consists of PVM, DC-DC Converter (DDC) and an MPPTC. MPPTC controls the DDC that acts as a coupling stage between PVM and load. A DDC is a device that transfers a DC supply's voltage from a level to another. The power electronics engineers face many challenges in designing converters with maximum efficiency, small size, reduced cost, and minimize switching losses. For the PVS applications, a conservative step-up (boost converter) can be used. This converter has a simple structure. The step-up (boost) converter is pulse controlled, when the duty cycle is near to hundred percent, the gain approaches infinity. But, practically, the static gain is restricted because of losses associated with the inductor, switch, diode, and capacitor. This thesis pursues a complete analysis of the DDC (buck and boost), involving the parasitic elements effect. Simulation model & experimental examination are utilized confirming the recommended analysis.

In this thesis, four MPPT algorithms are written in MATLAB m-files and investigated by simulations. Oscillation-Less P&O (OLPO), Golden Section Search assisted P&O (GSS-PO), Grey Wolf Optimization (GWO), and Multi-Verse Optimization Algorithm (MVOA) are tested under load variation and under environmental (irradiance) condition variation. Also for more validation a hardware experimental investigation for OLPO & GSS-PO is done to validate the efficiency and tracking performance of the proposed MPPTCs.

The simulated results & practical investigation of the complete PV system show that the performances of the PV panel using the GSS-PO MPPT algorithm provides better steady state and fast transient characteristics when compared with the other three methods. It yields not only a reduction in convergence time to track the maximum power point MPP, but also a significant reduction in power fluctuations around the MPP due to its very small step-size.

Keywords:

Photovoltaic; MPPT; DC-DC Converters

ACKNOWLEDGMENT

I would like to express my deepest gratitude and appreciation to **Prof. Wagdi Anis & Dr. Amr Ibrahim**, for their kind supervision, continuous encouragement, help, and continuous guidance and for giving me generously of their time.

Also I would like to thank them for their valuable advices that guided me throughout this work.

Table of Contents

RESEARCHER DATA	III
STATEMENT	IV
ABSTRACT	V
ACKNOWLEDGMENT	VI
Table of Contents	VII
List of Figures	X
List of Symbols	XIII
Chapter 1 INTRODUCTION	1
1.1 Photovoltaic systems	1
1.1 Background and Motivation	2
1.2 Thesis Organization	3
Chapter 2 LITERATURE REVIEW	4
2.1 Introduction	4
2.2 MPPTC Algorithms Performance Criterion	6
2.2.1 Dynamic Response of MPPTC Algorithms	6
2.2.2 Steady- State Operation of MPPTC Algorithm	7
2.2.3 Tracking Efficiency of MPPTC Algorithm	7
2.3 MPPT control algorithms classification	7
2.3.1 PO MPPT Algorithm	9
2.3.2 IC MPPT Algorithm	11
2.3.3 Golden Section Search (GSS) algorithm	13
2.3.4 Fuzzy Logic control (FL)	14
2.3.5 Artificial Neural Network (ANN)	15
Chapter 3 PHOTOVOLTAIC MODELS	17
3.1 Introduction	17
3.2 Mathematical Model of PV cell	17
Chapter 4 MODELLING OF BUCK AND BOOST CONVERTERS	20
4.1 Introduction	20
4.2 State-Space Averaging	21

4.3	Buck DDC Operation	22
4.3.1	State-Space Averaging.....	22
4.4	Boost DDC Operation	27
4.5	Experimental Verification of the Derived Models	30
4.6	DDC Simulation Results	37
Chapter 5	MPPT CONTROLLER	44
5.1	Introduction	44
5.2	Conventional PO (PO)	45
5.3	Oscillation-Less PO (OLPO)	46
5.4	Golden Section Search assisted PO (GSS-PO)	47
5.5	Grey Wolf Optimization (GWO)	48
5.6	Multi-Verse Optimization Algorithm (MVOA).....	51
Chapter 6	SYSTEM SIMULATION AND ANALYSIS.....	54
6.1	OLPO Simulation and Experimental Results.....	55
6.2	GWO Simulation Results	60
6.3	GSS-PO Simulation and Experimental Results	65
6.4	MVOA Simulation Results	69
6.5	Overall results	71
6.6	Algorithms Rating.....	72
Chapter 7	CONCLUSION AND FUTURE WORK.....	74
REFERENCES		76

List of Tables

Table 1 P&O algorithm desicion	10
Table 2 buck converter elements	31
Table 3 boost converter elements	31
Table 4 buck converter results	40
Table 5 boost converter results	40
Table 6 Qualitative comparison of the mppt techniques	72
Table 7 Algorithms Overall Rating.....	73

List of Figures

Fig. 1-1 PV System Configurations	2
Fig. 2-1 PV module characteristics	4
Fig. 2-2 PV and load characteristics curve	5
Fig. 2-3 PV characteristics under irradiance and temprature variation	5
Fig. 2-4 MPPT system	6
Fig. 2-5 P&O tracking characteristics	9
Fig. 2-6 PO flowchart	10
Fig. 2-7 IC flowchart	12
Fig. 2-8 GSS illustration	13
Fig. 2-9 GSS flowchart	14
Fig. 2-10 FL block diagram	15
Fig. 3-1 PV cell model	18
Fig. 3-2 I_{sc} and V_{oc} of PV module	18
Fig. 4-1 Non-ideal Buck converter	22
Fig. 4-2 State Space Averaging Steps	23
Fig. 4-3 Buck converter ON state	25
Fig. 4-4 Buck converter OFF state	25
Fig. 4-5 Non-ideal Boost converter	27
Fig. 4-6 Boost converter ON state	29
Fig. 4-7 Boost converter OFF state	29
Fig. 4-8 ideal and non-ideal boost converter gain	32
Fig. 4-9 ideal and non-ideal buck converter gain	33
Fig. 4-10 Inductance effect on damping factor of buck converter	34
Fig. 4-11 capacitance effect on daping factor of buck converter	34
Fig. 4-12 inductor resistance effect on output voltage of buck converter	35
Fig. 4-13 Inductance effect on damping factor of boost converter	35
Fig. 4-14 capacitance effect on damping factor of boost converter	36
Fig. 4-15 inductor resistance effect on output voltage of boost converter....	36
Fig. 4-16 boost converter simulink model	37
Fig. 4-17 buck converter simulink model	37
Fig. 4-18 buck converter simulation output at 50% dutycycle	38
Fig. 4-19 buck converter simulation output at 90% dutycycle	38
Fig. 4-20 boost converter simulation output at 50% dutycycle	39
Fig. 4-21 boost converter simulation output at 90% dutycycle	39
Fig. 4-22 buck converter output voltage vs dutycycle	41
Fig. 4-23 boost converter output voltage vs dutycycle	41
Fig. 4-24 r_l variation effect on efficiency of buck converter	42
Fig. 4-25 r_l variation effect on efficiency of boost converter	42
Fig. 5-1 PO flowchart	45
Fig. 5-2 OLPO flowchart	46

Fig. 5-3 PV characteristics under uniform irradiance	47
Fig. 5-4 GSS-PO flowchart.....	47
Fig. 5-5 GWO position update.....	49
Fig. 5-6 GWO flowchart	50
Fig. 5-7 MVOA illustration diagram	52
Fig. 5-8 MVOA flowchart	53
Fig. 6-1 PV module I-V characteristics	54
Fig. 6-2 PV module P-V characteristics	55
Fig. 6-3 configuration used in simulations	55
Fig. 6-4 PV module characteristics under irradiance variation.....	56
Fig. 6-5 PV module characteristics under temprature variation	56
Fig. 6-6 OLPO output under 1KW/m ²	57
Fig. 6-7 OLPO ripples under 1KW/m ²	57
Fig. 6-8 OLPO output under 0.8KW/m ²	58
Fig. 6-9 OLPO ripples under 0.8KW/m ²	58
Fig. 6-10 OLPO Experimental test output	59
Fig. 6-11 OLPO output under irradiance sudden change from 1 KW/m ² to 0.8KW/m ²	60
Fig. 6-12 GWO output for 18 Ohm load.....	61
Fig. 6-13 GWO output for 28 Ohm load.....	61
Fig. 6-14 GWO search agents n=1.....	62
Fig. 6-15 GWO search agents n=2.....	62
Fig. 6-16 GWO search agents n=4.....	63
Fig. 6-17 GWO search agents n=8.....	63
Fig. 6-18 GWO search agents n=16.....	64
Fig. 6-19 GWO search agents movments toward convergence	64
Fig. 6-20 GWO output under irradiance sudden change from 1 KW/m ² to 0.5 KW/m ²	65
Fig. 6-21 GSS-PO output for 18 Ohm load	66
Fig. 6-22 GSS-PO output for 28 Ohm load	66
Fig. 6-23 GSS-PO steady state oscillations	67
Fig. 6-24 GSS-PO under irradiance sudden change from 1 KW/m ² to 0.5 KW/m ²	68
Fig. 6-25 GSS-PO Experimentale test output	68
Fig. 6-26 MVOA output for 18 Ohm load.....	69
Fig. 6-27 MVOA output for 28 Ohm load.....	70
Fig. 6-28 MVOA under irradiance sudden change from 1 KW/m ² to 0.5 KW/m ²	70
Fig. 6-29 Comparison of the proposed algorithms	71

List of Abbreviations

ACO: Ant Colony Optimization	8
ANN: Artificial Neural Networks	7, 8
CCM: Continuous Conduction Mode	16
CV : Constant Voltage	3
CVT : Constant Voltage Tracking	7
DCM: Discontinuous Conduction Mode	16
DDC: DC-DC Converter	3
FL : Fuzzy Logic	3
FPO : Fuzzy based Perturb and Observe	8
GA: Genetic Algorithm	8
GMPP: Global MPP	8
GSS: Golden Section Search	13
GSS-PO: Golden Section Search assisted PO	44
GWO: Grey Wolf Optimization	8
HC: Hill Climbing	9
IC: Incremental Conductance	3
MPPT : Maximum Power Point Tracking	3
MPPTC: MPPT Controller	6
MVOA: Multi-Verse Optimization Algorithm	51
OLPO: Oscillation-Less PO	44
PO : Perturb and Observe	3
PVC: PV Cell	17
PVM : PV Module	4
PVS: PV System	2
PWM: Pulse Width Modulation	15
SC : Short Circuit	7
SOFLC : Self-Organized Fuzzy Logic Controller	7
SPTLE : Solar Powered Traffic Light Equipment	8
SSA: State-Space Averaging	21

List of Symbols

ΔV_e : Change in error voltage	14
A.M: Air mass	19
A: coefficient vector of GWO.....	48
C: coefficient vector of GWO.....	48
d: Duty cycle	20
Dg: Coefficient vector of GWO.....	48
dmax: Maximum duty cycle	50
d _{min} : Minimum duty cycle.....	50
dP: Change in Power.....	10
dV: Change in Voltage.....	10
G: Irradiance	19
G _{nom} : Standard test irradiance	19
h 13	
h:Golden ratio	13
I: Current	11
IMPP: Maximum Power Current	5
I _{rev} : Reverse saturation current	19
I _{sat} : Saturation current	17
I _{sc} : Short Circuit Current	8
I _{TK} : Current generated by photons	17
K _s : Stefan Boltzmann's constant	19
n: Search agent numbers	61
P _d : Conduction loss of the diode	26
P _{rl} : Loss of the inductor series resistance.....	26
P _{sw} : Conduction loss of the switch.....	26
q: Charge of an electron.....	19
r ₁ : Random number	48
r ₂ : Random number	48
r _d : Diode resistance	24, 27
r _l : Inductor series resistance	24, 27
R _{opt} :Optimum Resistance	5
R _p : Shunt resistance of PV cell	17
R _{se} : Series resistance of PV cell	17
r _{sw} :Switch resistance	24, 27
T _d : Damped time response period.....	26
toff: Off time	20
ton: On time	20
Ts: Total period	20

V: Voltage	11
V_d : Diode voltage.....	19
V_e :Error voltage	14
V_m : Maximum array voltage.....	14
VMPP: Maximum Power Voltage.....	5
V_o : Output voltage	24, 27
V_{oc} : Open Circuit Voltage.....	8
V_{pv} :PV array voltage.....	14
V_{ref} : Reference voltage.....	14
V_{sw} : Switch voltage drop	26
X: Wolf position	48
$\dot{X}_1$: State vector.....	22
X_p : Prey Position	48
δ : Overshoot step response	26
ζ : Damping factor	26
η : Efficiency	27
ω_o : Un-damped frequency.....	26