MODELING AND CONTROL OF PHOTOVOLTAIC CONNECTED TO GRID BASED ON ADVANCED EVOLUTIONARY TECHNIQUES

By

Dima Omar Fadel El-Hassan

A Thesis Submitted to the
Faculty of Engineering at Cairo University
In Partial Fulfillment of the
Requirements for the Degree
of

MASTER OF SCIENCE

in

ELECTRICAL POWER AND MACHINES ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
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Title of Thesis: Modeling and Control of Photovoltaic Connected to Grid Based on Advanced Evolutionary Techniques

Key Words:
Grid Connected PV; Maximum Power Point Tracking techniques (MPPT); (PID) and (PI); Computational Evolutionary Techniques.

Summary:
Grid interconnection of Photovoltaic power generation system has the advantage of more effective utilization of generated power. Power quality issues are one of the challenges associated with increasing photovoltaic power generation. The Maximum Power Point Tracking Techniques (MPPT) are adopted to obtain maximum power during all-day irradiance. Conventional MPPT techniques (P&O, INC) are presented and detailed with an overall approach. This Thesis discusses the advantages and the drawbacks of the conventional algorithm and proposes a Variable-Step Incremental Conductance algorithm (VS-IC) and a Modified Variable-Step Incremental Conductance algorithm (MVS-IC) that responds more accurately to the changes in the solar irradiation. The PI controller is used to improve the performance of the DC voltage controller in the inverter. Combined with the evolutionary computational techniques, each technique is used to set optimal and tune PI parameters. Finally, the Total Harmonic Distortion (THD) of the voltage and the current prior to connection to grid shall be computed.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have approprialy acknowledged all sources used and have cited them in the references section.

Name: Dima Omar Fadel El Hassan Date : .11.2019

Signature:

Dedication

I dedicate this thesis to my small family for their understanding, passion, and for being a great motivation to success in my life.

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Last, but not least, I would like to extend my thanks and gratitude to my small family and especially my husband for his unconditional support and understanding

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Nomenclature

A	: An ideality factor (= 1.6)
AACPSO	: Adapted Accelerated Coefficient Particle Swarm Optimization
AC	: Alternating Current
ANFIS	: Adaptive Neuro-Fuzzy Inference System
ANN	: Artificial Neural Network
AWPSO	: Adapted Weighted Particles Swarm Optimization
CS	: Cuckoo Search
D	: Duty Cycle
DC	: Direct Current
E (k)	: Error Signal
Ego	: Band Gap for Silicon (= 1.1 eV)
I	: Current
IAE	: Integral of Absolute Error
IC	: Incremental–Conductance
IGBT	: Insulated-gate Bipolar Transistor
I_o	: PV Module Saturation Current
Iph	: Light-generated Current in PV Module
Ipv	: Output current of a PV module (A)
I_{SCr}	: PV module short-circuit current at 25^{o}C and 1000W/m^2 (= 2.55A)
ISE	: Integral of Squared Error
ITAE	: Integral of Time Weighted Absolute Error
ITSE	: Integral of Time Weighted Squared Error
k	: Boltzman Constant (=1.3805 x 10^{-23} J/K)
K_i	: Short-circuit Current Temperature Coefficient at I_{SCr} (=0.0017 A/^{o}C)
MAACPSO	: Modified Adapted Accelerated Coefficient Particle Swarm Optimization
Ma	: Modulation Index
MHA	: Meta-heuristic Algorithms
MVS-IC	: Modified Variable Step Incremental Conductance
MPP	: Maximum Power Point

MPPT : Maximum Power Point Tracking

Np : Number of Cells connected in parallel

Ns : Number of Cells connected in series

O : Overshoot

P : Power

P&O : Perturb and Observe

PE : Power Electronic

PI : Proportional-integral

$P_{pv}(k)$: Instantaneous Output Power

PSO : Particle Swarm Optimization

PV : PhotoVoltaic

PWM : Pulse Width Modulation

q : Electron Charge (=$1.6x10^{-19}$ Coulomb)

Rs : Series Resistance of PV Module

RT : Rise Time

SPVS : Stand-alone Photovoltaic System

SSE : Steady State Error

ST : Settling Time

STC : Standard Test Condition

T : Module Operating Temperature (in degree Kelvin)

Temp : Temperature

Tr : Reference Temperature (= $298^{o}K$)

V : Voltage

Vpv : Output Voltage of PV module

$V_{pv}(k)$: Instantaneous Output Voltage

VS-IC : Variable Step-Size Incremental Conductance

λ : PV Module Irradiation

Abstract

Photovoltaic energy systems have grown over the past period as one of the most favorable renewable energy sources due to the probable high costs, and negative environmental effects of conventional energy sources, whereas Photovoltaic remains a pollution-free and everlasting energy source. PV has been extensively used in numerous applications in remote and isolated regions all around the world.

Photovoltaic arrays should be arranged in such a way that their exposure to the sun is maximized, and their performance needs to be addressed and approached from several engineering perspective so as to ensure optimum conditions are reached. Accordingly, this thesis discusses the modeling of a standard 33 kW power of photovoltaic connected to grid.

This thesis addresses the concept of Maximum Power Point Tracking (MPPT), which rises the efficiency of the solar photovoltaic System. In order to acquire maximum power from the solar panels, they have to function at their maximum power point (MPP) regardless any variations in the environment conditions. The purpose of MPPT is to guarantee that the system can always exploit the maximum power generated by the Photovoltaic (PV) arrays. Solar panels have a non-linear voltage-current characteristic, which counts on the environmental factors, such as temperature and insolation.

This Thesis analyses the conventional MPPT techniques “Perturb and Observe” (P&O), “Incremental Conductance” (IC), discusses the Variable Step-size Incremental Conductance (VS-IC) and proposes an improved maximum power point tracking for solar photovoltaic system using “Modified Variable Step Incremental Conductance”(MVS-IC) algorithm. Results of the modified, conventional algorithms are duly presented and compared.

This Thesis also presents voltage regulation of Photovoltaic Generation (PVG) system connected to 3-phase grid for any situation of solar radiation using PI controller. The “Integral Square of Error” (ISE) performance index is one of four performance indices to be investigated for the objective function. Using the best MPPT technique, a comparison between the “Proportional Integral Derivative” (PID) controller and the “Proportional Integral controller” (PI) is performed by checking the ISE with aim to minimize errors. This is done by means of the evolutionary computational techniques: Particle Swarm Optimization (PSO), Adapted Weighted Particle Swarm Optimization (AWPSO), Adapted Accelerated Coefficient Particle Swarm Optimization (AACPSO), Modified Adapted Accelerated Coefficient PSO (MAACPSO), in addition to Cuckoo Search (CS). All such techniques are based upon PI gains so as to minimize the objective function, and hence reaching optimal solution that ensures minimum Overshoot (O), Rise Time (RT), Steady-State Error (SSE) and Settling Time (ST).

Moreover, the Total Harmonic Distortion “THD” at the output of the inverter shall be computed.

All studied techniques were implemented in Matlab/Simulink and resulted in satisfactory output consistent with the objective and conclusions of this Thesis.

Chapter One: Introduction and Solar Energy

1.1 Introduction

Photovoltaic power into utility grids is acquiring more and more credibility seeing the rather problematic situation of the traditional world power sources (oil and natural gas for instance) owing to its unconditional availability and environmental friendliness. Nonetheless, yet the efficiency and control still represent significant disadvantages for the photovoltaic systems, especially when combined with the strict requirements often imposed by the utility grid operators in terms of the control philosophy and controller types so as to ensure power stability as much as possible. Consequently, research efforts are nowadays being focused onto the enhancement of the PV systems control and efficiency.

1.2 Advantages and Disadvantages of Photovoltaic Systems

Table (1.1) presents the advantages and disadvantages of PV systems, as discussed in [1].

Table (1.1): Advantages and Disadvantage of PV Systems

Advantages of PV Systems	Disadvantages of PV Systems
▪ PV systems require no costly fuel and convert freely available daylight into electricity. ▪ PV systems produce "quiet" electricity without emitting exhaust gases or pollutants. ▪ PV systems require small amount of maintenance. ▪ Solar modules have no moving parts and last for more than 20 years. ▪ Cost saving and earnings when connected the grid.	▪ Sun is not present all day long. ▪ PV systems higher initial costs. ▪ Most off-grid PV systems require batteries to store electric power.

1.3 Problem Diagnosis

The non-linearity of the PV systems and output dependency on the terminal voltage and prevailing environmental conditions impose more complications and challenges on the widespread use of PV systems.

The main challenges are the PV efficiency, intensity of source radiation and storage techniques, knowing that the PV cells efficiency is still bound by the industry materials used in their manufacture.

Besides the obvious problematic variation of the Sun irradiance and temperature during the day (which results in fluctuating output voltage), the low efficiency and high cost of solar cells represent another considerable hurdle, even though the efficiency of the PV systems has increased significantly in the last decade owing to innovative "maximum power point tracking" (MPPT) approaches.

Another problematic characteristic of the PV systems is the DC/AC conversion, which often requires some sophisticated filters to reduce the induced ripples almost always associated with such systems.