MODELING AND CONTROL OF STAND-ALONE PV SYSTEM BASED ON FRACTIONAL-ORDER PID CONTROLLER

By

Ahmed Mohsin Betti Alrikabi

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

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Under the Supervision

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Key Words:

PV stand-alone system, Maximum Power Point Tracking (MPPT), Fractional Order (FOPID), Particle Swarm Optimization (PSO), genetic algorithm (GA).

Summary:

This thesis presents modeling and control of a standalone photovoltaic (PV) system in which a battery is used as a backup source for controlling power between the source and the load. Study of the propose Configuration for Design of stand-alone PV system to provide electricity for the purposes required. An efficient energy management scheme for stand-alone PV system is elaborated. The proposed fractional order (FO) PID and PI based energy management in battery control system; scheme comprises of two control loops namely inner and outer loops to outperform a standalone PV system with satisfactory response. The main task of the inner control loop is to extract and track maximum power from a standalone PV system. Moreover, the outer control loop is equipped with the battery for controlling the power between the source and the load smoothly. Various scenarios include sun irradiance variations and load fluctuations are presented to demonstrate the theoretical analysis, effectiveness, and feasibility of the proposed energy management strategy. Comparison between FOPID and PID control, optimization techniques is employed to fine tune the proposed control loops by generating their optimal settings. The simulation results discover the feasibility of the system. Using A software simulation model developed in Matlab/Simulink

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Nomenclature

List of symbols and Abbreviations:-

AWPSO : Adapted Weighted Particles Swarm Optimization.
AACPSO : Adapted Accelerated Coefficient Particle Swarm Optimization.
BESS : Battery Energy Storage System.
CF : Capacity Factor
C : Capacity of Battery
$c1$: Self-Confidence (Cognitive) Factor
$c2$: Swarm Confidence (Social) Factor.
CS : Cuckoo Search (CS)
D : Duty cycle
DOD : Depth of Discharge
Ed : Average daily electricity production from the given System
Em : Average monthly electricity production from the given System
ED : Daily electricity requirement
FOPID : Fractional-Order PID Controller
GA : Genetic Algorithm
GAOT : Genetic Algorithms Optimization Toolbox
$gbest_k^i$: The Best Particle Position Based on Swarm's Experience.
HD : Average daily sum of global irradiation (KWh/m^2)
HM : Average Monthly sum of global irradiation (KWh/m^2)
Io : The PV module saturation current (A).
Isc : Short-circuit current
Iph : the light generated current in a PV module (A)
Ipv : output current of a PV module (A)
INC : Incremental–Conductance
ISE : Integral of square error
IAE : Integral of Absolute error
ITAE : Integral of Time Weighted Absolute Error
IGBT : insulated-gate bipolar transistor
i : Iteration Index
Kp : Proportional gain
Ki : Integral gain
Kd : Derivative gain
MOSFET :Metal Oxide Semiconductor Field Effect Transistor
MAACPSO : Modified Adaptive Accelerated Coefficient particle swarm Optimization
MPPT : Maximum power point tracking.
MPP : Maximum power point
MATLAB : Matrix Laboratory

Np	: the number of cells connected in parallel
Ns	: the number of cells connected in series
O.S%	: The Percentage of Overshoot
$pbest_k^i$	: The Best Particle Position Based on its Experience
PVGIS	: Photovoltaic Geographical Information Survey
P pv	: Rated Peak Power
PID	: Proportional-Integral-Derivative controller
PSO	: Particle Swarm Optimization
PV	: Photovoltaic
P&O	: Perturb and Observe
Q	: Electron charge = 1.6 × 10-19 C
RAPs	: Remote Area Power Supply
Rs	: The Series Resistance of a PV Module
r1 and r2	: Random Numbers Generated between Zero and One
SHS	: Solar Home System
S	: Switch
SOC	: State of Charge
Temp	: temperature
Tr	: the reference temperature = 298 K
Ts	: Settling Time
Tr	: Rise Time
VSI	: Voltage source inverter
Voc	: Open-circuit voltage
V_K^i	: Velocity of $i^{th} ith$ particle at k^{th} iteration
x_k^i	: Current Position of the i^th Particle
λ	: Order of s in integral
μ	: Order of s in derivative

Abstract

At present the main source of energy for our needs come from fossil fuel, but unfortunately these materials are of limited existence in our planet. Solar-powered photovoltaic system provides a clean energy solution to this problem. This thesis discusses modeling and controlling of a Stand-Alone Photovoltaic (SAPV) system. The design of a stand-alone photovoltaic (PV) system is to provide electricity for the required purposes. The system is based on the data from a solar radiation site as well as electric load data from one of the houses in the same site. A Photovoltaic Geographical Information Survey (PVGIS) website is used as an estimation of the average daily sum of global irradiation depending on the latitude and longitude of the Iraqi site.

Independent Control Loops are proposed where an efficient energy management for stand-alone PV system is elaborated. The scheme comprises of two control loops namely inner and outer loops to manage a standalone PV system with a satisfactory response. The main task of the inner control loop is to extract and track maximum power from a standalone PV system, through the implementation of a Maximum Power Point Tracking (MPPT) control loop and using the best techniques of Incremental Conductance (INC) and Perturb and Observe (P&O) Algorithm which extracts the maximum power from PV module under different solar irradiation. Moreover, the outer control loop is equipped with a battery for a smooth control of the power between the source and the load. Several optimization algorithms had been used to tune FOPI control loops by generating their optimal settings where the same “Particle Swarm Optimization” (PSO), “Adapted Weighted Particles Swarm Optimization” (AWPS), “Adapted Accelerated Coefficient Particle Swarm Optimization” (AACPSO), “Modified Adapted Accelerated Coefficient Particle Swarm Optimization” (MAACPSO) and "Genetic algorithm "(GA) "Cuckoo Search "(CS). The effectiveness of FOPI controller is ensured in comparison with the classic controller. In this comparison the optimization PSO Toolbox and GA toolbox are used to get the parameters of the proposed controller to obtain the desired response to control the process of charging and discharging the battery to keep the input dc voltage constant at steady state. The integral of the square error is utilized to define the proposed system objective function.

Various scenarios include sun irradiance variations and load fluctuations are presented to demonstrate the theoretical analysis, effectiveness, and feasibility of the proposed energy management strategy. The simulation results of the entire standalone PV system are described along with a comprehensive simulation results that discover the feasibility of the system.

Keywords:

PV stand-alone system, System sizing, battery bank, Maximum Power Point Tracking (MPPT), Fractional Order (FOPID), Particle Swarm Optimization (PSO), genetic optimization (GA), MATLAB.

Chapter One: Introduction

1.1. Overview

Most of the energy comes from fossil fuels such as coal, diesel, petrol and gas, which is 80% of our current energy production. The demand for this type of energy is expected to rise by almost a half over the next two decades which may causes some fear that our energy resources are starting to run down which in turn has a very serious disturbing consequences on the global quality of life and on the global economy. Lack of electricity is one of the main hurdles in the development of rural areas in many countries. On other hand, the increasing demand for energy has two major impacts that is energy crisis and climate change where the world suffers from numerous environmental troubles due to the harmful gases emitted from burning fossil fuels. These gases destruct the ozone layer and cause a negative climatic changes [1] where all of these issues encourage the investigation of using solar, wind and other renewable types of energies for the generation of electrical power as given in [2],[3]. The greenhouse gas mitigation efforts in the electricity sector have emphasized the accelerated deployment of Energy Efficiency (EE) measures and renewable energy (RE) resources as presented in [4].

These above-stated reasons drove researchers towards the development of renewable energy sources including the solar system, and make them more reliable and beneficial. Renewable Energy is defined as the energy that comes from naturally generated resources like sunlight, wind, and rain. In recent years, applications that use Photovoltaic (PV) systems are growing continuously. The current trend is to optimize these systems by ensuring their functionality with maximum efficiency as given in [5]. The word “Photovoltaic” is composed of two terms: Photo means light and Voltaic means voltage. Solar Energy is directly converted into electrical energy by using solar cells. Simply, we can say that PV systems are just like any other electrical power generating systems but the equipment used for a PV system is different than that used for the conventional generating systems. The principles of operation and method of interfacing with other surrounding electrical systems remain the same. Solar energy has become a promising, popular and alternative source of energy because of its advantages such as its abundance, pollution free.

A PV system requires less maintenance compared with wind, hydroelectric and tidal systems because all these systems require a rotating instrument for energy conversion which is not required for conversion of the solar energy to electrical energy. In late 1950s the first conventional PV cells were produced and throughout the next ten years PV cells were mainly used for providing electrical power for earth-orbiting satellites. In the 1970s the cost of PV modules went down due to the improvements in its manufacturing, quality and performance. The reduction in their costs opened up various opportunities for powering remote terrestrial applications which includes battery charging for navigational systems and other critical low-power requirements which are isolated from utility grid where the standalone operation is the best option. Due to the dramatic increase of international applications for PV systems to power the rural health clinics, refrigeration, water pumping, telecommunications, and other off-grid households,
It remains portion of the present world market for the photovoltaic products. Nowadays, production of PV modules is growing at approximately 25% per year, and the implementation of PV systems on buildings and interconnection to utility networks are increasing rapidly, become of major programs in the developed countries, total global capacity installed from PV systems shown in Table (1.1).