



Ain Shams University
Faculty of Engineering
Electric Power and Machines Department

Design of MPPT controller for on-grid PV systems

Ph.D. thesis

By:

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M.Sc. in electrical power engineering

A thesis submitted to the Faculty of Engineering, Ain Shams University in
partial fulfillment of the requirements for the Ph.D. degree in Electrical
Power and Machines Engineering

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STATEMENT

This thesis is submitted to Ain Shams University in partial fulfillment of the requirement for the Ph.D. degree in Electrical Engineering. The work included in this thesis has been carried out by the author at the Electrical Power and machines department, Ain-Shams University. No Part of this thesis has been submitted for a degree or a qualification at other university or institute.

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ABSTRACT

Maximum energy utilization using tracking, search, and optimization algorithms are considered an integral design requirement of PV system. The photovoltaic (PV) array output power is variable based on insolation/irradiation and junction temperature. The maximum power point tracking (MPPT) controller is added to the PV array, in order to increase an energy efficient operation of installed PV array. Conventional control methods of MPPT are perturbation and observation (P&O) method and incremental conductance(IC) method, etc. Regardless the simplicity of the used search algorithms, all suffer from two drawbacks. Firstly, as the search approaches the MPP operating zone, the controller forced the operating point to chatter and keep oscillating around the MPP. Secondly, any changes in irradiation level cause loss of tracking and a severe change in MPP search direction. The solar cell is affected by its surroundings, such as shadowing from nearby buildings and scattered clouds. The result is that operating P–V curve for the PV array has multiple operating PowerPoint-peaks, different from the assumed single peak curve in normal irradiation. Conventional MPPT methods (such as P&O & IC) are possibly ineffective to severe shadowing and partial clouding conditions.

This research presents MPPT controller based on the modification of the P&O algorithm through using variable perturbation steps. A three-level perturbation step approach is proposed to P&O method. Results show that the newly proposed algorithm enhancement the system performance. The proposed algorithm was compared with the conventional P&O under different conditions such as changing the irradiation level and partial shadowing . In all tests the proposed controller provides better performance through racking MPP and less oscillations. Control of real & reactive powers in PV system connected to the grid was achieved by using the PI controller for active power control and fuzzy logic control (FLC) for reactive power control. The control scheme is based on controlling the direct and quadrature components (I_d , I_q).

An augmented FLC-PI MPPT control scheme is used for a standalone PV-Battery hybrid system. The FLC-PI augmented controller is compared with classical PI-MPPT controller. PV array power is used to

charge the battery through a double functional regulation of the buck DC-DC converter which also used for maximum power point tracking. The new augmented FLC-PI is compared with conventional MPPT PI controller and validated under different operating conditions. Digital simulation results validated its dynamic effectiveness in tracking, battery charging with less ripple, inrush, and transient voltage conditions. The proposed structure of the FLC-PI is now being extended to multi array PV farms with DC and AC type loads. In addition interface to the grid with restrictions on total harmonic distortion and requirements for improved power quality using modified PWM switching strategies.

A hybrid standalone PV-Battery utilization scheme uses an efficient modified search and optimization controller for maximum power point operation, as well as continuous fast Li-ion battery charging. Novel modified MPPT controller is used to regulate the duty cycle ratio for optimized energy efficient operation with maximum power minimal chattering and oscillatory behavior. The modified P&O achieves MPPT with minimum excursions. PI controller combined with feed forward battery current (I_b). This combination is used to control the charging state of the battery. The proposed control scheme for hybrid PV-Battery system is validated for fast dynamic performance and continuous tracking of MPP with minimal oscillations. The common DC bus voltage was regulated, in addition to fast battery charging with limited transients and inrush current conditions.

This thesis also presents a unified, integrated PV-Battery-Inverter interface to Grid energy using DC-AC interface. A multi regulation PWM is switching control scheme using a modified P&O maximum PV-power tracking. The search is used to ensure energy efficient operation. The Modified P & O algorithm is based on multi-zonal prespecified power change to update duty cycle. The new search algorithm is used to control battery charging with minimal current ripple content using battery current dynamic feedback signal. This is done using a PI controller combined with feed forward of battery current (I_b). The multi-regulator control scheme for integrated PV-Battery-Inverter fed the grid with DC and AC side load is validated for variations in Irradiation Levels. Load changes as well as fault conditions. The integrated scheme with the controller is validated and assessed for fast dynamic performance, efficient PV solar

energy utilization, reduced current ripples as well as fast Li-ion Battery continuous charging. An additional LC filter is added to reduce harmonic content and smooth VSI-inverter waveforms at the grid interface bus. Inverter control is done using Park's transformation with PLL. Phase Locked Loop synchronization with AC grid. The PI controller is used to controlling the amount of power that delivered to the AC side from the VSI-inverter to the grid.

Keywords: Photovoltaic (PV), Maximum power point tracking (MPPT), Perturb and Observer (P&O), Hybrid system, battery system, and Power flow Management.

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List of Main Symbols

A	Transformation factor
B	Transformation factor
C	Current capacity
D	Duty factor
$e(s)$	Error
$\Delta e(s)$	Change in error
F_s	Grid system frequency
I_b	Battery current
I_d	Direct current component
I_q	Quadratic current component
I_{sc}	Short circuit current
K_d	Derivative signal gain
K_p	Proportional signal gain
K_i	Integral signal gain
N_p	Number of parallel cell
N_s	Number of series cell
P	power
PL	Load power
P_{inv}	Power from inverter
R.M.S	Root mean square value
R.P.M	Rev per minute
Rsh	Shunt resistance
S	Irradiation
V_{oc}	Open circuit voltage

Δu	Change in output control signal
η	Efficiency
β	Minimum discharging value of voltage

List of Main Abbreviations

AI	Artificial Intelligence
CS	Cuckoo Search
DC	Direct Current
FC	Fuel Cell
FF	Feed forward
FLC	Fuzzy Logic Control
GA	Genetic Algorithm
IC	Incremental Conductance
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
PID	Proportional Integral Derivative
P&O	Perturb and Observe
PSO	Particle Swarm Optimization
PV	Photovoltaic
PWM	Pulse Width modulation
SMES	Super-Capacitors and Superconductive Magnetic Energy Storage
SOC	State of Charge
T-S	Takagi – Sugeno
TW	Terra Watt
VSC	Voltage Source Control
VSI	Voltage Source Inverter
W-H	Watt-Hour