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Evaluation and Implementation of Maximum Power Point Tracking (MPPT) on a Stand-Alone Power Based Solar Panel

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ABSTRACT: The work seeks to evaluate and implement the Maximum Power Point Tracking (MMPT) on a standalone power based solar panel. The entire system in this work has been modeled on MATLABTM R2017a and SimulinkTM. It focuses on the development, evaluation and implementation of a circuit simulation model for Maximum Power Point Tracking (MPPT) of a solar power that involves using buck-boost power converter topology (buck-boost DC/DC converters). A simulation model to extract maximum obtainable solar power from a PV module and using the energy for a DC application was implemented. The simulation model mainly includes three subsystems: a PV model; a buck-boost converter-based MPPT system; and a fuzzy logic MPPT controller. Dynamic analyses of the current-fed buck-boost converter systems are conducted, and results presented. The inputs of the solar PV panel modeled in the study were temperature, solar irradiation, number of solar cells in series and number of rows of solar cells in parallel. The findings of the study revealed that the main hindrance for the penetration and reach of solar PV systems is in their low efficiency and high capital cost. Results from the modeling also show that using the Perturb & Observe MPPT technique increased the efficiency of the photovoltaic system by approximately 111% from an earlier output power of around 90Watts to an obtained output power of around 190Watts. Maximum Power Point Tracking (MPPT) significantly increases the efficiency of the solar photovoltaic system.

Keywords- Maximum Power Point Tracking; buck-boost DC/DC converters; Perturb & Observe MPPT technique

I. INTRODUCTION

Before industrialization, energy was predominately provided by man and animal power and to a limited extent from the burning of wood for heating, cooking and smelting of metals. Industrial revolution was due to the discovery of abundant coal, and the concurrent technological advances and its uses. Steam engines, mechanized production and improved transportation, all fueled directly by coal, rapidly followed [1]. For so many years, energy sources depend on conventional sources such as fossil fuel, hydro, coal, radioactive decay, etc. But all these have their peculiar problems of scarcity, rapidly depleting, causing pollution, greenhouse effect and harmful to both man and other living organisms in the environment. Global climate change is a change in the long-term weather patterns, in view of this, the Intergovernmental Panel on Climate reported that by the year 2050 earth surface's temperature will rise by 28° C while the amount of CO₂ emissions must have reduced by 85% [2].

This could happen due to a commeasurable change in the number of natural climate changes or, as well, by a number of human induced climate events. The increased awareness of the environmental impact, the carbon trail of all energy sources, and electric power production have given stimulus to the growth and adopting of renewable as an alternative energy. Renewable energy sources (RES) such as solar, wind, and tidal were considered as the solution to the aforementioned problems, of which solar might cost more than its counterpart renewable energy sources but is preferred more than others due its abundant in nature.

For the fact that renewable energy sources are clean, pollution-free, harmless, recyclable, distributed throughout the earth and inexhaustible that makes it a better substitute. Moreover, global climatic change, world-wide increase in energy demand, uncertainty in price and availability of non-renewable energy and world energy policies on using environmentally friendly source of energy have made PV systems suitable for energy generation in recent time. Consequently, the feed-in tariffs policies adopted by many countries, especially in Europe, have supported the spread of photovoltaic (PV) energy resources. Although, PV cells still show some technological limitations in terms of efficiency in power output, thus more research work requiring significant improvements in the exploitation of PV systems were still going on. Nigeria is not left out in such policy, by signing the Electricity Power Reform Act into law in 2005, provided impetus for long term investment and turn-around in the electricity sector, with improved generation and stable power supply delivery [3-4].

A major component of the law is the provision made for renewable energy investment and allowance in electricity generation to boost rural access to electricity and meet the needs of about 70% of the country's rural communities [5]. Unfortunately, the policy did not see the light of the day; even as at that, many private sectors and individuals have embarked upon stand-alone PV power as a remedy for frequent power failures in Nigeria. One of the main challenges of designing MPPT schemes is to the need to quickly detect global MPPs (GMPPs) instead of searching for other local MPPs (LMPPs) under partial shading conditions (PSCs). Numerous MPPT techniques for investigating the performance of an overall PV system were reviewed, and their advantages and drawbacks identified. Based on their implementation complexity, flexibility, reliability, and cost, the MPPT methods can be evaluated on the basis of the speed and accuracy of GMPP tracking under PSCs. The performance evaluation of MPPT schemes is imperative because of their sensitivity to various dynamics [6-8].

II. RELATED WORKS

Many methods to track Maximum Power Point (MPP) for PV collections have been discussed by many authors. It comprises of all the procedures implied in this field. It was shown that at least 19 distinct methods have been already introduced. A high-frequency photovoltaic pulse charger (PV-PC) for lead-acid battery (LAB) guided by a power-increment-aided incremental-conductance maximum power point tracking (PI-INCMPPT) had been implemented [9-10]. The PV-PC implemented by a boost current converter (BCC) to eliminate sulphating crystallization on the electrode plates of the LAB and to prolong the battery life. The BCC associated with the PV module is modeled to maximize the energy charging to battery under maximum power transfer. A duty-control

guided by the PI-INC MPPT is blue printed to drive the BCC operating at MPP against the random insulation. A blue-print example of a PV-PC system for a four-in-series LAB battery (48 VDC) had been examined. The charging behavior of the PV-PC system in comparison with that of CC-CV charger was studied. Four scenarios of solar insulation changes to describe tracking behavior of PI-INC MPPT in PV-PC system were investigated in earlier works, which is also compared with that of INC MPPT. K.H. [11].

The modelling and control blue-print of the PV charger system using Buck-Boost converter was presented in [12]. The controller was blue printed to balance the power flow from PV module to the battery and the load such that PV power was utilized effectively and the battery was charged in three charging steps. The latest progress of inverters for photovoltaic AC-modules outperformed the past technology which was based on Centralized Inverters, present on String Inverters and future on AC-Modules and AC-Cells[13-16]. In [17], focused was on a DC to AC Inverter; power switching system; ability to generate the drive voltage and switching the power supply among the city electrical system and the solar power system. The main aim is to construct a stabled, completed and low cost of solar energy conversion systems. Novel photovoltaic converter system was in [18], implementing a new maximum power point tracking procedure. The three roles, battery regulation, inverting and maximum-power-point tracking, needed for photovoltaic systems with battery back-up, were integrated in a single cost-effective converter. This converter charges the battery, operates close to the maximum power point of the photovoltaic collection and forms a DC to AC inverter for a complex power load. The step-down charger allows the combination of high-voltage PV collections with low voltage batteries. A full description of the circuit and practical measured output with efficiencies were presented.

III. METHODOLOGY

This section shows the detailed modeling of various components of stand-alone system presented. Extensive simulation results using Matlab/SIMULINK will be used to establish that the performance of the controllers is quite satisfactory under balanced as well as unbalanced load conditions. Moreover, results with real time digital simulator (RTDS) will be presented.

Maximum Power Point Tracking Algorithms

Typically,PV solar panel converts only 25 to 40 percent of the incidented solar irradiation into electrical energy. Maximum power point tracking technique is used to improve the efficiency of the PV solar panel.

According to Maximum Power Transfer theorem, 'the power output of a circuit is maximum when the Thevenin impedance of the circuit (source impedance) matches with the load impedance'. Hence our problem of tracking the maximum power point reduces to an impedance matching problem. In the source side we are using a boost convertor connected to a solar panel in order to enhance the output voltage so that it can be used for different applications like DC or AC load. By changing the duty cycle of the boost converter appropriately we can match the source impedance with that of the load impedance.

MPPT Interfacing

The controlled voltage source and the current source inverter have been used to interface the modeled panel with the rest of the system and the boost converter which are built using the Sim Power Systems module of MATLAB. The block diagram for the model shown in the figure is a simulation for the case where we obtain a varying voltage output. This model is used to show the difference between the PV power obtained on using an MPPT algorithm and the PV power obtained without the MPPT algorithm.

In order to compare the PV power outputs stated above, a manual switch is used to couple the model. When the switch is thrown to the left the circuit bypasses the MPPT algorithm and we obtain the desired PV power, the voltage and current outputs are shown through the respective scopes. Then when the switch is thrown to the right, the circuit now includes the MPPT function block and we obtained the desired current and voltage outputs through the respective scopes.

Parameter	Value taken for simulation
Rated Power (VMP)	200W
Voltage at Maximum Power (VMP)	26.4V
Current at Maximum Power (IMP)	7.58A
Current at Maximum Power (IMP) Open Circuit Voltage (VOC) Short Circuit Current (ISC) Shunt Resistance Series Resistance Band Gap Energy of Semiconductor (Eg0) Boltzmann's Constant (K) Ideality Factor (n) Electronic Charge (q) Solar Module Temperature (T) Total Number of Solar Cells in Series (N _S) Total Number of Solar Cells in Parallel (N _P) Resistance of load (R)	7.58A 32.9V 8.21A 415.405ohms 0.221ohms 1.1 1.38e-23 1.3 1.6e-19 25°C 54 1 1 300
Capacitance of boost converter (C)	0.611µF
Inductance of boost converter (L)	0.763mH
Switching frequency of PWM	100 KHz
Proportional gain of PI controller (K _P)	0.006
Integral gain of PI controller (K ₁)	7
Short Circuit Current of Cell at 25OC (Ki)	0.0032

Table 1: The Parameters of a Stand-Alone PV System

The proposed block diagram of a solar off-grid PV system that provides the required electricity for the proposed system is shown below. The main components of the system are namely PV array, controller, battery, inverter and load. The solar PV system is simulated such that the PV module charge the battery through the controller and battery also provides the power to the load when the solar radiation is insufficient. DC/AC inverter provides AC electricity to the required residential AC loads.

IV.

The simulation results for a solar PV cells are as shownin Figs.4.14 and 4.15. The V-I characteristics and V-P characteristics for different temperatures such as 25^- , 50^- and 75^- are presented. It is observed that as the temperature increases, the open circuit voltage decreases without any significant change in the short circuit current. As a result, the maximum power from the cell is decreasing.

4.1 Modelling of the PV Mathematical Equations using Matlab

The Mathematical modelling of the Solar PV Arrays in Simulink (MATLAB 2017a) cells or modules are shown below;



Fig 4.1 Block the Photo Current

Diagram of Simulink



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Fig 4.2 Subsystem Block Diagram of the Photo Current

Reverse Saturation Current (IRS)





Fig 4.4 Subsystem Block Diagram of the Reverse Saturation Current

Saturation Current (IO)

 $IO = IRS * (T/Tn)^{3} * exp\{[q*Eg0*(1/T-1/Tn)] / n*K\}$ (4.3)



Fig 4.5 Block Diagram of the Saturation Current Simulink



Fig 4.6 Subsystem Block Diagram of the Saturation Current

Shunt Resistor Current (ISH) ISH = {(V+I*R)/RSH}

(4.4)



Fig 4.7 Block Diagram of the Shunt Resistor Current



Fig 4.8 Subsystem Block Diagram of the Shunt Resistor Current

PV Output Current I = IPH – IO *{exp[(q*(V+I*RSH) / (n*K*NS*T)] – 1} – ISH

(4.5)



Fig 4.9 Block Diagram of the PV Output Current Simulink



Fig 4.10 Subsystem Block Diagram of the PV Output Current

PV Module



Fig 4.11 Block Diagram of the PV Module Simulink



Fig 4.12 Subsystem Block Diagram of the PV Module



Fig 4.13 Block Diagram of PV Module



Fig 4.14 V-I and V-P Characteristics with Constant Irradiation

As Temperature increases with a constant Irradiation, the short circuit current ISC increases, because the Band Gap Energy decrease and more photons have enough energy to create Electron-Hole pairs. The increase in Temperature have an obvious reduction in the PV panel output power due to drop in the open circuit voltage VOC, thereby reduces the PV module efficiency.



Fig 4.15 V-I and V-P Characteristics with Constant Temperature

As the Irradiation (V-I and V-P characteristics for radiations 200, 400, 600, 800, and 1000 W/m² are given) increases with a constant Temperature, the PV output voltage and current increases, thereby increasing the PV output power. Also, for the low values of solar radiations, the short circuit current ISC is reducing considerably but the change in open circuit voltage VOC is very less, thus proving that the maximum power from the module is dropping.

V. CONCLSUION

From the simulation it observed that the power obtained at the load side was 90Watts for a solar radiation of 80Watts per square meter when the switch was on No MPPT mode which bypasses the MPPT algorithm block in the

circuit. Also, the conversion efficiency was very low as the PV panel power generated was 200Watts with the same solar radiation of 80Watts per square meter.

When the simulation was switched on to MPPT mode, which includes the MPPT block and the PI controller, the PV panel continued to generate 200Watts power, and it was observed that the obtained power at the load side is 190Watts, which shows that there is an increase in power in conversion efficiency of the PV system using the solar irradiation of 80Watts per square meter of 200Watts power.

Therefore, it was observed from the Simulation that using the Perturb & Observe MPPT technique increased the efficiency of the photovoltaic system by 111% from an earlier output power of around 90Watts to an obtained output power of around 190Watts.

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