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An experimental study of DC motor application based on MPPT DC-DC buck-boost converter powered by Photovoltaic Generators using Akbaba model

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Abstract

Photovoltaic generators (PVGs) are a kind of renewable energy technology that transforms solar radiation into electrical power. The Maximum Power Point Tracker (MPPT) optimizes power generation on a small scale for independent PVG systems. This study aims to develop, evaluate, and use an innovative MPPT circuit for small-scale PVGs. The control circuit utilizes a microcontroller, while the Akbaba Model represents the I-V characteristics of the PVG. The suggested system utilizes a DC/DC buck-boost converter. The microcontroller calculates the converter's duty cycle by using feedback from the output voltage and converts the intensity of solar radiation into a reference value for control. A prototype is created to empirically verify the suggested methodology.

Keywords: *Akbaba model, DC motor, MPPT, Photovoltaic generators, Renewable energy*

1. Introduction

In recent years, the global energy scene has changed significantly, with an increasing focus on renewable energy sources and technological developments allowing their integration into the power system. The desire to solve environmental issues, lower greenhouse gas emissions, and improve energy security drives this change. Solar photovoltaic (PV) systems have become crucial among the many renewable energy sources because they can use plenty of solar energy and transform it into electrical power. Particularly in industrialized nations, research on renewable energy use and how it affects economic development has been thorough. For example, Balcilar et al. [1] used a historical decomposition approach to investigate the link between renewable energy usage and growth in the G-7 nations. Their results stress the importance of ongoing investment in renewable technology as they show the positive contribution of renewable energy to economic development.

Utilizing maximum power point tracking (MPPT) techniques is essential for optimizing solar energy conversion efficiency, making it a crucial component of PV systems. Researchers have developed numerous MPPT techniques to adapt to load fluctuations and changing environmental conditions. For instance, Goksenli and Akbaba [2] presented a novel microcontroller-based MPPT technique based on the Akbaba model, proving its efficiency via simulation and application. Likewise, Xu et al. [3] suggested a quick and effective MPPT method for changing solar irradiance and load resistance conditions. Developed for fast-changing partial shade situations, Kermadi et al. [4] developed a high-performance global MPPT tracker for fast-changing partial shade situations, demonstrating its excellence in preserving optimum power output

Berrezzek et al. [5] also explored the potential of neural networks for effective MPPT, observing significant improvements in speed and tracking accuracy.Priyanka and Dash [6] closely examined clever MPPT techniques, stressing developments in artificial intelligence (AI) uses. Emphasizing artificial intelligence's role in recent developments, Boubaker [7] methodically examined present trends in MPPT approaches. Offering a thorough overview of MPPT methods, Katche et al. [8] underlined the need for sophisticated algorithms for improving PV system performance. Kumar et al. [9] presented a novel wide-input voltage DC-DC converter for solar PV systems using a hybrid MPPT controller, and demonstrated its performance through experimental data.

Researchers have carefully investigated the financial factors of PV systems, in addition to MPPT approaches. Bazilian et al. [10] reviewed the economics of solar electricity, addressing elements such as cost reductions, technical developments, and legislative frameworks that contribute to the general acceptance of PV systems. Reviewing photovoltaic solar cells holistically, Al-Ezzi and Ansari [11] discussed their technical development, efficiency gains, and economic feasibility.

Researchers also investigate the integration of solar PV systems with motor-driven applications, particularly in water pumping. While Appelbaum and Sari [13] examined the behavior of permanent magnet DC motors run by solar cells, Akbaba [12] examined the matching of induction motors to PV generators for optimal power transmission. Saied and Monji [14] investigated ideal solar array layouts and DC motor field characteristics for the highest yearly mechanical energy output. For dynamic matching of a solar-electrical/photovoltaic system, Zinger and Braunstein [15] approximated the minimal Z requirements on the matching system. Akbaba and Akbaba [16] examined a DC motor pump system driven by a photovoltaic-boost converter. Akbaba [17] has investigated the ideal matching characteristics of an MPPT unit used for a PVG-powered water pumping system. Presenting an FPGA-based active disturbance rejection control method for a DC motor drive driven by solar photovoltaic energy, Guerrero-Ramirez et al. [18] for water-pumping uses, Shukla and Nikolovski [19] looked at a solar photovoltaic array with a brushless DC motor drive supplied from a grid. Using solar cells and an MPPT technique via the incremental conductance approach, Mahmmoud et al. [20] created an induction motor speed control method.

Thus, with its financial advantages and pragmatic uses, the continuous developments in renewable energy technologies, especially solar PV systems, and MPPT methods, highlight the essential function renewable energy plays in determining a sustainable energy future.

This research concentrates on developing, testing, and implementing a unique Maximum Power Point Tracking (MPPT) circuit, primarily for small-scale solar generators (PVG). A microcontroller-based control circuit is employed, with the Akbaba Model utilized to simulate the I-V characteristics of the PVG. The system integrates a DC/DC buck-boost converter, where the microcontroller computes the duty cycle based on feedback from the output voltage and converts the solar radiation intensity into a reference value for optimal control. A prototype of the system is constructed to empirically validate the proposed methodology.

2. Materials and Methods

This paper presents the development and experimental implementation of an MPPT method using permanent magnet DC motors as the load. The photovoltaic generator (PVG) characteristics are modeled using the Akbaba model, which accurately captures the I-V relationship of the PVG. The Akbaba model is defined by Equation (1) [4].

$$I = \frac{V_{oc} - V}{A + BV^2 - CV} \qquad (1)$$

Where A is given by Equation (2),

$$A = \frac{V_{oc}}{I_{sc}} \qquad (2)$$

In these equations, V_{oc} represents the open-circuit voltage, and I_{sc} is the short-circuit current of the PV panel.

The power output of the PVG can be expressed as in Equation (3):

$$P = I \cdot V = \frac{V(V_{oc} - V)}{A + BV^2 - CV} \qquad (3)$$

The parameters A, B, C, V_{oc}, and I_{sc} are derived for different values of solar irradiance (S). The detailed parameter extraction process is described in [2]. A sample of measured solar irradiance values is provided in Table 1.

Table 1. V_{oc}, I_{sc}, A, B, and C values at selected % solar radiation values

%S	Voc	Isc	A	B	C
50	18.3	0.35	51.8	0.0257	3.10
75	19.16	0.51	37.7	0.022	2.275
85	19.6	0.58	32.7	0.0167	1.915
100	19.8	0.68	28.94	0.008528	1.574

By performing further mathematical processes, the voltage at the maximum power point V_{max} can be stated as shown in Equation (4).

$$V_{max} = \left[\frac{V_{oc}}{I_{sc}}(C - BV_{oc})\right]\left[\frac{1}{1-\sqrt{1-I_{sc}(C-BV_{oc})}}\right] \tag{4}$$

Equations (3) and (4) determine the current and power at the maximum power point I_{max} and P_{max}, respectively, as given in Equations (5) and (6).

$$I_{max} = \frac{V_{oc}-V_{max}}{A+BV_{max}^2-CV_{max}} \tag{5}$$

$$P_{max} = V_{max} \cdot I_{max} \tag{6}$$

The accuracy of the I-V characteristics defined by parameters A, B, and C are validated through comparison with conventional I-V data, as referenced in [4]. The derived model parameters for the PVG, based on solar irradiance (S), are presented as given in Equation (7).

$$\begin{aligned} A &= 0.005347S^2 - 1.258S + 101.3 \\ B &= -6.832 \times 10^{-6}S^2 + 0.00068S + 0.0088 \\ C &= 0.0001788S^2 - 0.05736S + 5.523 \end{aligned} \tag{7}$$

In the proposed method, system performance is primarily influenced by the levels of solar radiation and the output load voltage. The control circuit measures solar radiation, converting it into a voltage signal for the microcontroller. The microcontroller then calculates the model parameters A, B, C, V_{out}, I_{sc}, V_{max}, and the duty cycle (*dc*).

The duty cycle is determined by Equation (8):

$$dc = 1 - \frac{V_{max}}{V_{out}} \tag{8}$$

where V_{max} is the maximum power voltage of the PVG, and V_{out} is the instantaneous measured output voltage.

The microcontroller, programmed with embedded software, generates the required duty cycle to maximize the output power. Solar radiation is detected by the voltage drop across a resistor (R), providing an input voltage (V_R) to the microcontroller for the duty cycle. Figure 1 illustrates the system's block diagram.

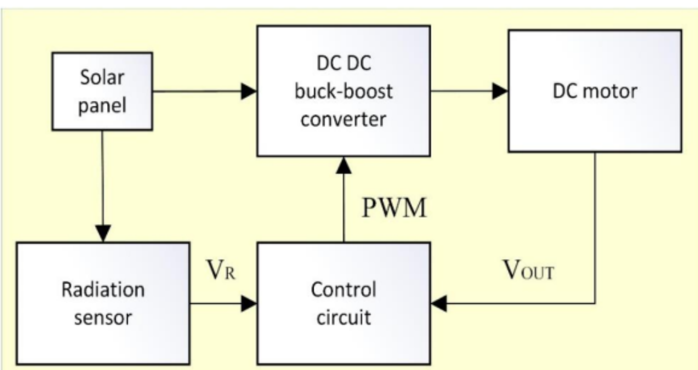


Figure 1. Block diagram of the system

The microcontroller is programmed to apply the V_{max} = f(S) relationship to determine the required duty cycle based on Equation (10), enabling the PVG to operate at maximum power. The system requires only two inputs: solar radiation (S) and output load voltage (Vout) with other parameters depending on S and embedded within the microcontroller program. The MPPT circuit output aligns with the output of the DC-DC buck-boost converter.

3. Experimental Application and Results

The experimental study is conducted using the application circuit depicted in Figure 2, specifically under varying solar radiation conditions, represented as S = 74% and 93%.Many variables like voltage, current, and power output are carefully monitored and noted throughout the experiment. These tests gave important new perspectives on the operating qualities and efficiency of the system components, including the DC-DC buck-boost converter, microcontroller, and sensor.

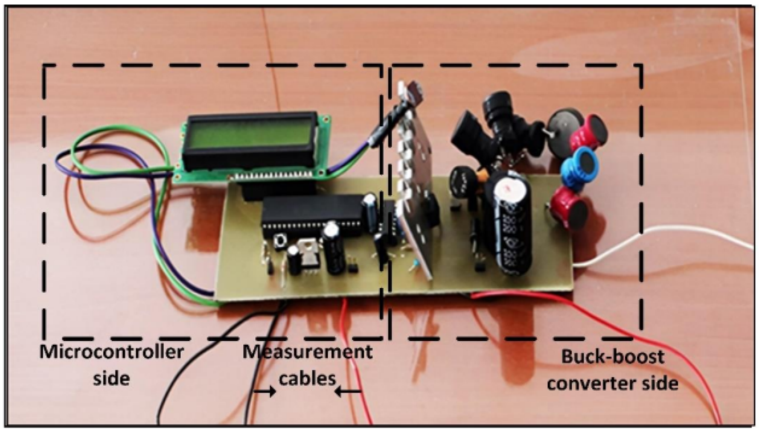
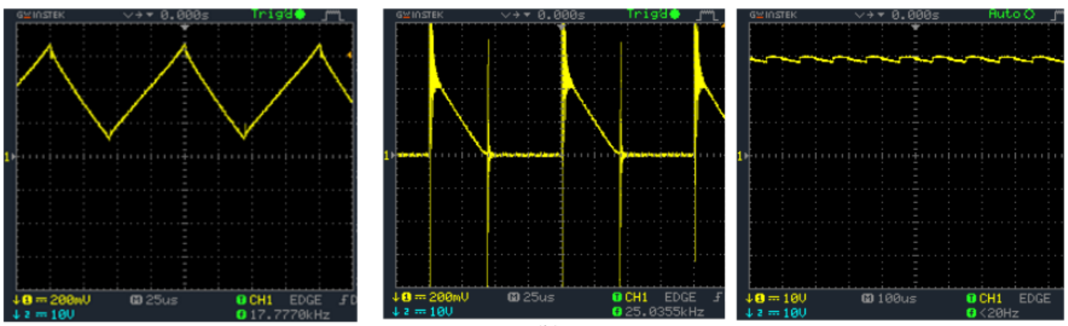


Figure 2. Application circuit of the system

For the boost converter, inductance and capacitor are determined as 6mH and 140uF. With these values, the converter operates with a 20% inductance current ripple and a 1% voltage ripple. Consequently, the oscilloscope graphics and DC-DC buck-boost converter design process are acquired and are given in Figure 3. Here, altering the L and C variables can provide various outcomes. Finding the best suitable value to achieve better outcomes is essential in practice.



(a) (b) (c)

Figure 3. Experimental results a) Inductance current, b) Diode current, c) Output voltage of converter (capacitor voltage)

To determine the conditions for the DC load operating at maximum power, permanent magnet motor combinations that can operate at 24 V and 0.5 W-2W output are used. For different S values (74% and 93%) input/output voltages of the converter, currents of the panel, and load are measured as in Tables 2-3.

Table. 2 Measured system parameters for parallel connection at S=74%

Number of motors	V_{Load}	I_{Load}	P_{Load}	V_{Panel}	I_{Panel}	P_{Panel}
1	18.24	0.068	1.24	14.9	0.2	2.98
2	17.87	0.137	2.459	14.85	0.258	3.83
3	17.42	0.196	3.41	14.8	0.311	4.6
4	17.22	0.240	4.133	14.75	0.353	5.21

Table 3. Measured system parameters for parallel connection at S=93%

Number of motors	V_{Load}	I_{Load}	P_{Load}	V_{Panel}	I_{Panel}	P_{Panel}
1	18.8	0.105	1.974	16	0.24	3.84
2	18.5	0.17	3.145	15.9	0.3	4.77
6	15.4	0.54	8.316	15.6	0.612	9.54
7	15.3	0.567	8.675	15.5	0.623	9.66
8	15.1	0.584	8,818	15.3	0.635	9.72

By connecting DC motors in parallel, the resistance of the load decreases. It can be concluded that as the load resistance decreases, the Solar Panel approaches the appropriate load resistance and the losses decrease. It can be assumed that the solar panel is producing power that is nearly at its maximum when S is 93%. In this instance, the proposed algorithm follows the V-I curve produced by the Akbaba method to modify the converter voltage. As a result, the expected maximum power is obtained and minimum loss is realized.

4. Conclusion

In this study, the I-V characteristics of the PVG are simulated using the Akbaba Model in a microcontroller-based control circuit. A DC/DC buck-boost converter is part of the system. The microcontroller figures out the duty cycle by using feedback from the output voltage and turns the amount of solar radiation into a reference value for the best MPPT control. The system aims to draw more power from the PV panel as the number of parallel-connected DC motors increases. At 74% solar irradiance, the panel voltage fluctuates between 14.9 and 14.75 V, with the converter output set to 17-18 V. However, at 93% solar radiation, the proposed MPPT control technique effectively reduces the load voltage to 15 V. Consequently, the system achieves a loss of approximately 0.5 W and a power transfer of 9.5 W.

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