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Application of modified particle swarm optimization for maximum power point tracking under partial shading condition

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Abstract

Solar PV cells usually operate at efficiency less than 20%, never generates maximum power due to change in environmental conditions such as irradiation, temperature, partial shading etc. Maximum power can be generated from PV cell with suitable tracking techniques. A modified Particle Swarm Optimization (MPSO) technique is proposed in this paper for tracking maximum power. This proposed evolutionary computation technique assures nearly zero steady state oscillation and faster convergence while tracking maximum power. The proposed PSO algorithm is tested on a CUK converter due to its higher efficiency and ripple free output. Simulations are carried out in MATLAB/SIMULINK and the computed results are validated in an experimental setup.

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Keywords: Maximum Power Point Tracking (MPPT); Modified Particle Swarm Optimization (MPSO); CUK Converter.

1. Introduction

The power sector has been reeling from proper utilization of limited conventional energy sources, which never helps in the growing energy demand. The abundance and risk-free nature of renewable energy has augmented its use in large scale. Solar energy has emerged as the most recognized renewable energy source due to its zero maintenance, inexhaustibility, reliability and zero noise. Reports by International Energy Agency (IEA) envisage that the solar power by 2050 accounts for 11% of global electricity

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production. Suitable tracking techniques, such as an appropriate MPPT algorithm, can be helpful in maximizing the power output from a PV cell. Among the various MPPT algorithms available in literature, the best commonly used MPPT methods are Perturb and Observe [2], Incremental Conductance [3] and Hill Climbing algorithm [4]. These methods suffer from various disadvantages like slow tracking, steady state oscillations at MPP and poor efficiency. To overcome this above drawbacks researchers worked at applying various Artificial Intelligence techniques like Neural Network (NN) [6] and Fuzzy Logic Control (FLC) [7]. However, these methods need periodic training, more memory requirement and computationally complex. Recently Bio inspired techniques were applied for the problem of MPP tracking, some of the techniques used are PSO [8], GA [9], and ACO [10], authors in their earlier work Bacterial Foraging Algorithm (BFA) [12] implemented for solar PV parameter extraction. However, in PSO, random initial guess may lead to momentary power loss, larger computational time and steady state oscillations. In order to overcome the above problems modified PSO (MPSO) algorithm is proposed in this paper to determine the initial values closer to MPP. This new formulation assures faster convergence and avoids steady state oscillations.

In this paper, a CUK converter is designed to implement modified PSO algorithm. The advantages of CUK converter are: it eliminates the necessity of a filter at input and output side and efficiency is high. The proposed algorithm is implemented in hardware via Arduino based digital controller. Simulation and experimental results are taken at different operating conditions.

2. Proposed PSO method and its implementation with cuk converter

The proposed method is named as Modified PSO (MPSO) algorithm and it differs from conventional method in parameter initialization. For initial duty cycle computation equation (1) is used and the value of R_{in} is based on voltage to current ratio at maximum power. Hence, it starts with an initial value closer to MPP. The expression for initial duty cycle of the MPSO algorithm is:

$$d = 1/\left(1+\sqrt{R_{in}/R_0}\right) \tag{1}$$

Where,

$R_{in} = \left(\dfrac{V_{mpp}}{I_{mpp}}\right)$ is the internal resistance of the PV module, and

R_0 is the output load resistance

The equation for voltage at maximum power point is given by:

$$V_{mpp} = k_1 * V_{oc} \tag{2}$$

The equation for current at maximum power point is given by:

$$I_{mpp} = k_2 * I_{sc} \tag{3}$$

Where,

k_1 and k_2 are the constant of proportionalities that changes with the change in irradiation and temperature.

The equation corresponding to k_1 and k_2 can be derived for a particular panel as:

$$\mathrm{k}_1 = \left(\frac{V_{mppn}}{V_{ocn}}\right) * \left[1 + \left(\alpha * \ln\left(\frac{G}{G_n}\right)\right) + \beta * \left(T - T_n\right)\right] \tag{4}$$

$$\mathrm{k}_2 = \left(\frac{I_{mppn}}{I_{scn}}\right) * \left[1 + \left(\gamma * \ln\left(\frac{G}{G_n}\right)\right)\right] \tag{5}$$

The values of α, β and γ are 0.03, 0.004, and 0.014 respectively.

MPSO method starts with initial set of particles (duty cycles) and are defined as:

$$x_i^t = d_i^t = \left\lfloor d_1, d_2, d_3, \ldots\ldots.., d_{N_p} \right\rfloor \tag{6}$$

where,

N_p is the number of particles ($N_p = 3$), and

t is the number of iteration.

$$d_1 = d_2 - M$$

$$d_1 = d_2 + M$$

M = correction factor added to initial duty d_2 for duty cycle initialization.

$$d_i^t(new) = \left[d - M,\, d,\, d + M\right] \tag{7}$$

The objective function [8, 11] to be solved using MPSO method is given below:

$$P\left(d_i^t\right) > P\left(d_i^{t-1}\right) \tag{8}$$

The search process begins by sending three initial duty cycles to the power converter and is treated as the *pbest* value. During the next iteration, the particle position and velocity are update applying PSO algorithm. This process continues till the best results are converged. The advantage with this approach every time the search process is initialized with a set of duty cycles closer to MPPT. New set of initial duty cycles formed applying above procedure is : if a sudden change in irradiation or temperature occurs, the duty cycle needs to be re-initialized using the Equation (1) and Equation (7) in order to track the new MPP accurately.

3. Simulation and experimental results

The DC-DC CUK converter system configuration with digital controller converter is shown in Fig. 1. The MPSO algorithm is tested using this system. An Arduino microcontroller is programmed to function as a digital controller. Further, for implementation of MPSO algorithm, temperature and irradiance inputs are required for initial duty cycle computation.

3.1. Simulation Results

The model comprises of a DC-DC CUK converter operated at switching frequency of 10 kHz. According to design the inductors L1 and L2 values are 1.5mH and 5mH respectively. C1 and C2 values are found out to be 24 μF and 1.38 μF respectively. The CUK converter is operated in continuous conduction mode and the algorithms are tested for two different conditions: 1) Uniform irradiation 2) Change in irradiation. Under uniform irradiation; the irradiation and temperature are kept constant. While, during change in irradiation; the irradiation is changed by keeping temperature constant. The initial parameters of MPSO chosen for simulation are: c_1 = 1.6, c_2 = 1.8, and w = 0.4. The value for error M is taken as M = 0.02 for the accurate tracking of MPP without any fluctuation.

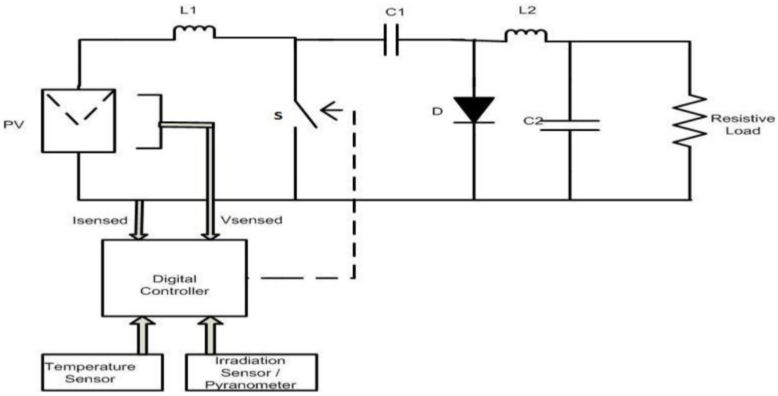

Fig 1. System Configuration

Simulation and experimental results showing voltage, current and power tracked waveform under uniform irradiation using MPSO is presented in Fig. 2. A step size of 0.02 is provided at every 0.1 sec. The step size is chosen considering the factor of tradeoff between the steady state oscillations and the tracking speed. In MPSO algorithm, initially, three duty cycles are computed using Equation (1) and Equation (2) and sent to CUK converter to read the corresponding power. From the computed power, the duty cycles are updated according to the proposed MPSO algorithm. Fig. 2 clearly shows that after two iterations the MPSO algorithm settles at MPP with zero steady state oscillations. Change in irradiation is attained by changing the irradiation from 1000 W/m^{2}to 750W/m^2 at time t = 0.6 sec and maintained till time reaches 1.5 sec and finally returned to initial irradiation of 1000W/m^2. This setting ensures irradiation change occurs from higher to lower value and vice versa.

The MPSO algorithm provides better dynamic response by initializing with three duty cycles and settles to MPP without any oscillations. It can be also noted that, MPSO method provides no oscillations in duty cycle as well and it initializes three new duty cycles when there is any change in irradiation and temperature occurs. It provides good tracking both during increase as well as decrease in irradiation.

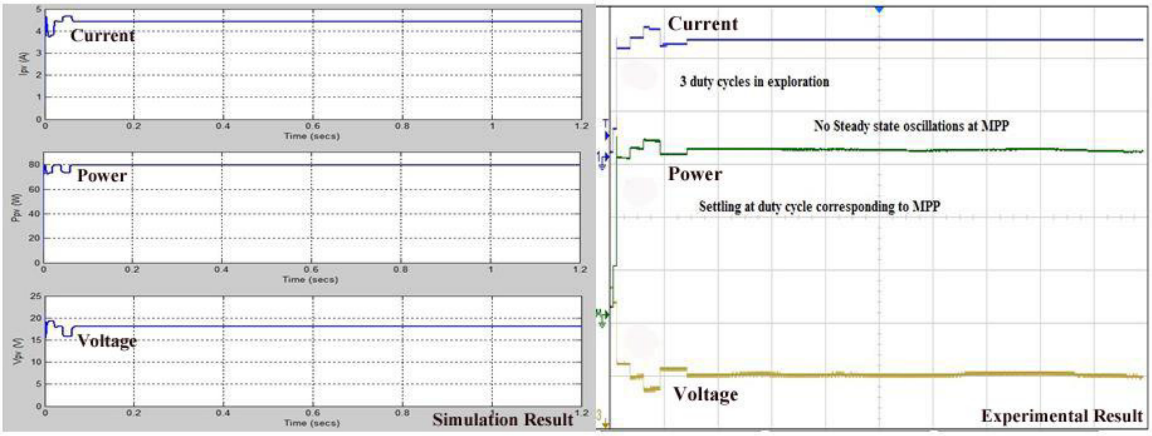

Fig. 2 Simulated and experimental results of voltage, current, and power tracked for modified PSO algorithm under constant irradiation condition

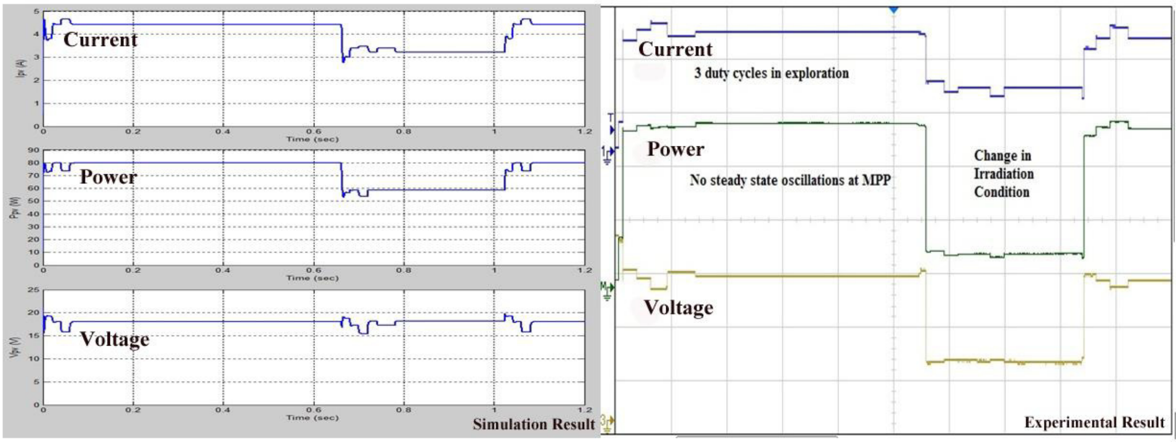

Fig. 3 Simulated and experimental results of voltage, current, and power tracked using modified PSO algorithm for variation in irradiation condition

3.2. Experimental Results

To validate the simulation findings a hardware prototype is built in the laboratory. The hardware set up comprises of a Kotak solar module, a CUK converter set-up with designed values of inductors (1.5mHand 5mH) and capacitor's (24 μ F and 1.38 μ F), a load of 50 ohm resistance. To drive the MOSFET, triggering pulses are generated using low-cost Arduino microcontroller. The complete hardware set-up is shown in Fig.4. The MPPT algorithms are programmed using low cost Arduino microcontroller board and the required pulses are generated. Sensors (LV20P and LA55P) are used for sensing voltage and current from the PV panel. A reference panel is calibrated with a pyranometer for measuring irradiation in terms of voltage. With the developed hardware circuit; testing is done for proposed MPSO algorithm.

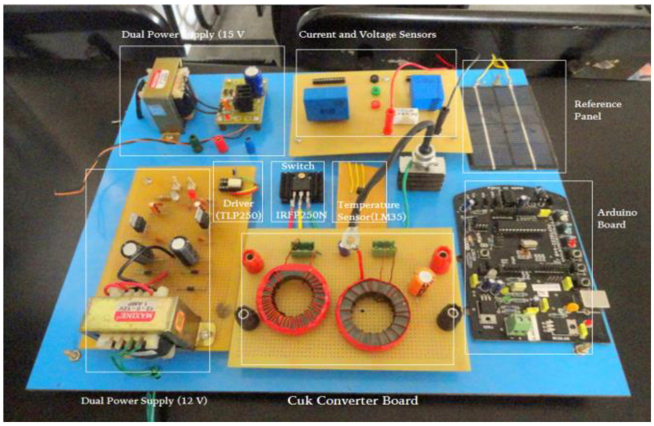

Fig.4. Experimental set-up of the systems configuration

The experimental waveforms of PV module voltage, current and power tracked using MPSO algorithm under uniform irradiation condition are shown in Fig. 2. From the results, it is clear that there is a good agreement between the simulated and experimental results with MPSO algorithm, three duty cycles are initialized and present operating power is computed with the help of voltage and current sensor values. Apart from sensor reading, the measurement of environmental factors such as irradiation and temperature becomes essential for the proposed method and hence they are sensed subsequently. To further illustrate the capability of MPSO algorithm; shading is done in order to reduce irradiation and the results are obtained. The experimental waveforms for MPSO algorithm under change in irradiation condition is shown in Fig. 3. From the experimental results of MPSO method, it can be inferred that like in the uniform atmospheric condition, three initial duty cycles are computed and are given to CUK converter, finally reaching the MPP. These three duty cycles are converging to a single point at MPP in the second iteration with no steady state oscillations at the region of MPP. When change in irradiation condition occurs, the three duty cycles get re-initialized and the process continues till final MPP is reached. It is important to mention that the proposed method successfully attains MPP with zero steady state oscillations even under change in irradiation conditions attributing to good dynamic and steady state performance. Based on the above results presented in Fig. 2 and 3. The performance of proposed MPSO method is found to be outstanding, especially in terms of tracking speed, steady state oscillations.

4. Conclusion

In this paper, a modified Particle Swarm Optimization technique with an effective way of calculating duty cycle was presented. The electrical specifications of Kotak solar module were used to implement the PV model in simulation with CUK converter as an interface between PV module and load. From the above observed results MPSO was found to be the best method due to following advantages: 1) almost zero steady state oscillations, 2) good tracking speed 3) ability to track MPP under varying environmental conditions, and 4) easy implementation using low cost microcontroller.

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