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A New Algorithm Based Charge Controller for Global MPPT of Si Solar Cell

Sajal Debbarma, Shivaji Debbarma, Saptadip Saha

Abstract*: *This work illustrates the development of a new hybrid MPPT algorithm and the construction of an efficient charge controller based on this algorithm. The existing perturb & observe (P&O) methodology and incremental conductance (IC) method are unable to trace the global maximum power point (GMPP) once there's a frequent modification in solar irradiance. These algorithms stick to local maxima in such scenario so the controller efficiency drops. Here a new hybrid MPPT algorithm was designed to track the GMPP efficiently, which involves the concept of Savitzky Golay digital filter technique. This filter is employed to swish a collection of digital information points that additional will increase the S/N of the signal while not greatly distorting it. The substitute sub-sets of niggardly observations fact are passable about a low-degree polynomial by the come nigh of neat least squares by means of convolution. This algorithm first smoothens the output of photovoltaic using the described technique and removes the local maxima and then further applies the P&O method to find out the GMPP. The circuit was simulated using Proteus and later on, an experimental setup was built using Arduino UNO (ATMEGA328P) to run the algorithm in real-time environment. The controller successfully tracked the GMPP voltages for variable irradiance both in simulation and real-time environment.

Index Terms*: *maximum power point trackers, Photovoltaic systems, perturbation methods, solar panels, microcontrollers.

I. INTRODUCTION

Out of different types of solar cells, Si solar cells are most widely used in the world due to their stability and higher efficiency reported till date. In general, the output power of a solar cell is far less as compared to its price, and secondly, the power is varying at every instant due to constantly changing solar irradiance and temperature [1-2]. Due to the nonlinearity of a solar cell, when the irradiance (G) changes the maximum power point (MPP) also changes. By chasing the maximum point of the operating PV cells at an explicit instant by implementing varied maximum power point tracking (MPPT) algorithms [3-8], we will increase the potency of the PV system by extracting the utmost obtainable power from the module. Although there are several MPPT algorithms, such as P&O method [9-12], IC method [13-15], voltage based peak power tracking method [16], current based peak power tracking method [17] and many more, they have some short comes too. Out of them, perturb & observe technique is generally adopted as a result of, despite oscillation round the most electric receptacle, it's one in all the foremost economical MPPT algorithms because it will even increase the system potency up to 97% [18-21]. However, in practical cases, for partial shading condition the output power-voltage (P-V) curve of a PV array contain a huge number of ripples and complex multiple peaks which are known as local maxima, thus reducing the efficiency and stability of the system. Apart from the conventional MPPT techniques new methods for global maximum power point (GMPP) tracking were reported like hybrid MPPT methods using an augmented state feedback precise linearization (AFL) controller combined with an artificial neuron network (ANN) [22], Radial Movement Optimization (RMO) [23] and so on. To extract the utmost power, GMPP must be tracked with quick and reliable technique. The conventional MPPT algorithms like perturb and observe (P&O) and incremental conductance methods are inadequate to trace the GMPP because of the presence of native maxima. This work proposed the development of a fast, reliable and efficient technique based on Savitzky Golay filter [24]. The filter is widely used for digital signal smoothing. But this is the first time the filter is implemented along with the existing P&O method to build a unique hybrid algorithm in the proposed work to track the GMPP of Si solar cell very efficiently. The algorithm was implemented in association with the microcontroller-based programmable MPPT charge controller. Apart from tracking the GMPP, the controller also efficiently converts photovoltaic energy to electrical energy in the form of DC and charges a 12-volt battery.

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* Correspondence Author

Sajal Debbarma*, Department of Electrical Engineering, Tripura Institute of Technology, Narsingarh, Agartala-799009, West Tripura, India.

Shivaji Debbarma, Department of Electrical Engineering, Tripura Institute of Technology, Narsingarh, Agartala-799009, West Tripura, India.

Saptadip Saha, Department of Electrical Engineering, National Institute of Technology Agartala, Jirania, Agartala-799046, West Tripura, India.

II. PERTURB AND OBSERVE METHOD

In this method arrangement for measuring parameters and feedback system are made. The maximum output voltage that can be delivered by solar cells is open-circuit voltage (V_{oc}). In this process, the module voltage is periodically perturbed and corresponding power is measured. The change in power (ΔP) is calculated concerning change in the voltage (ΔV) at every instant [9]. Theoretically, this value is zero at MPP. The value of $\Delta P/\Delta V$ is positive on the right side and negative on the left side the slope of the MPP in the P-V graph.

The current value of change in power to voltage is compared to the instance of the previous perturbation cycle. If this factor ($\Delta P/\Delta V$) increases, further perturbation continues in the same direction unless and until the value of $\Delta P/\Delta V$ becomes zero. The zero value of the factor signifies that MPP is reached, so the cells are operated for that particular value of voltage known as V_{mp}.

$\Delta P/\Delta V > 0$, $V > V_{mp}$, the right side of the MPP

$\Delta P/\Delta V = 0$, $V = V_{mp}$, at MPP and

$\Delta P/\Delta V < 0$, $V < V_{mp}$, the left side of the MPP

Fig. 1 illustrates the determination of MPP on PV curve using P&O method. The logical flowchart of this method is described by Fig. 2. The main disadvantage is, it takes much time to reach to the MPP and after reaching oscillates around the MPP.

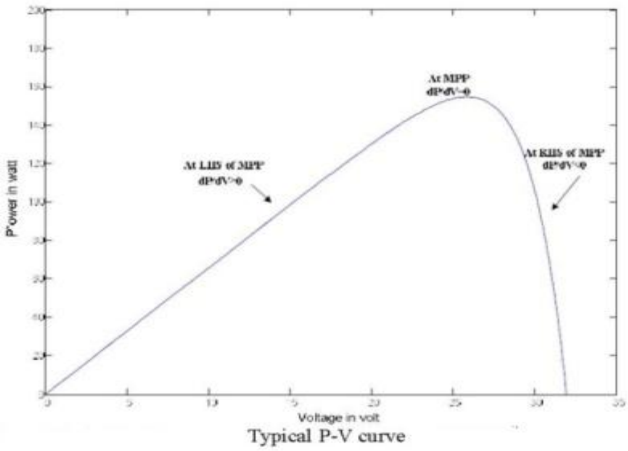

Fig. 1. MPP tracking with perturb and observe method.

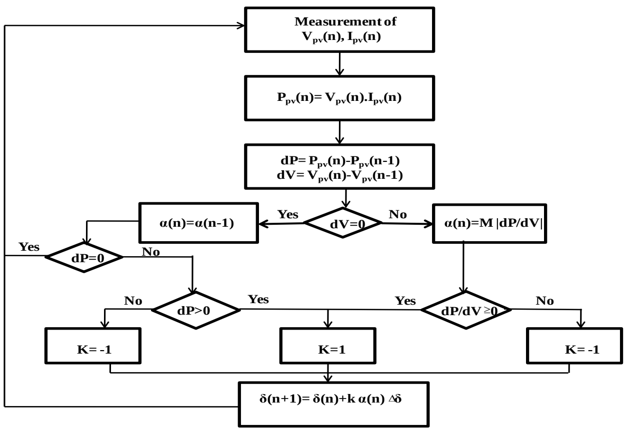

Fig. 2. Flowchart of perturb and observe methodText in Indents

III. INCREMENTAL CONDUCTANCE METHOD

In this method, the positive change in PV current to voltage is measured and predicts the outcome of change in voltage. Though it can track MPP rapidly than perturb & observe method, it involves the more complex calculation. The factor $\Delta I/\Delta V$ which is a ratio of PV current to voltage is inductance derived from the PV cell. In this method, perturbation is stopped while reaching MPP. The relationship between $\Delta I/\Delta V$ and $-I/V$ decides the further perturbation of the operating point is MPP is not met. When the value of $\Delta I/\Delta V$ becomes equal to $-I/V$, the algorithm decides that MPP and reached (Fig. 3). This method involves some more calculations, but faster tracking is achieved than perturb and observe method.

$\Delta I/\Delta V > -I/V$, $V < V_{mp}$, the left side of the MPP

$\Delta I/\Delta V = -I/V$, $V = V_{mp}$, at MPP and

$\Delta I/\Delta V < -I/V$, $V > V_{mp}$, the right side of the MPP

The flowchart of the algorithm is depicted by Fig. 4.

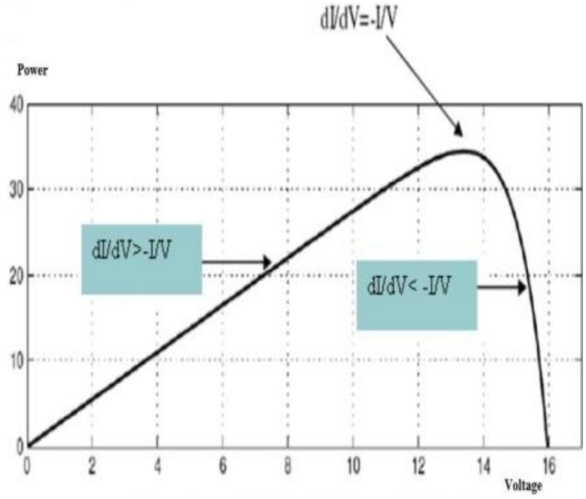

Fig. 3. MPP tracking with incremental conductance method.

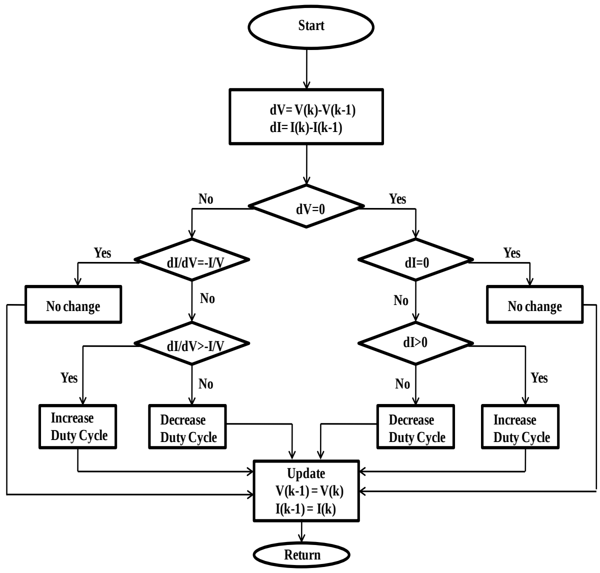

Fig. 4. Flowchart of incremental conductance method.

IV. SAVITZKY GOLAY FILTER

A Savitzky–Golay filter is a digital filter which employed to swish a collection of digital information points that additional will increase the S/N of the signal while not greatly distorting it (Fig. 5). In 1964, Abraham Savitzky and Marcel J. E. Golay suggested convolution coefficients for various polynomials. The substitute sub-sets of niggardly observations fact are passable about a low-degree polynomial by the come nigh of neat least squares by means of convolution.

An analytical resolution to the least-squares equations could also be found if the data points are equally spaced inside the variability of one set of "convolution coefficients", that be applied to all or any data subsets. This provides an estimation of the smoothed signal (or derivatives of the smoothed signal) at the central point of every subset.

If an information consists of a collection of n{xj, yj} points (j = 1, 2, 3, …., n), where x is independent quantity and Yj is an discovered worth, this will be processed by a collection of m convolution coefficients, Ci, and may be expressed as,

$$Y_j = \sum_{i=-\frac{m-1}{2}}^{\frac{m-1}{2}} C_i y_{j+1}$$

Where, Y_j = smoothed and discrete value of n data points.

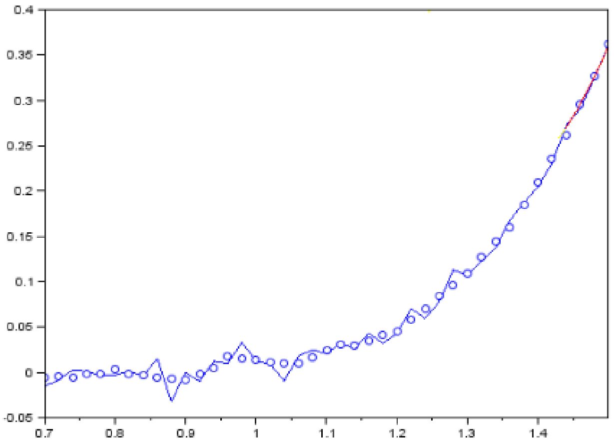

Fig. 5. Smoothening of a signal with Savitzky- Golay filter having multiple peaks

V. PROPOSED ALGORITHM

This work has suggested a new algorithm which hybridized of perturb and observe (P&O) method and Savitzky–Golay filter. In this work, the Savitzky- Golay filter was applied for smoothing the PV output of experimental result by a 3-point, 4-point and 5-point quadratic polynomials, but a better and optimized result was obtained in case of 5-point quadratic polynomials (Fig. 20). Hence, the algorithm was designed based on the 5th order polynomials. So, for m = 5 and i = −2, −1, 0, 1, 2, the j_{th} smoothed data point, Y_j, can be expressed as,

$$Y_j = \frac{1}{35}(-3y_{j-2} + 12y_{j-1} + 17y_j + 12y_{j+1} - 3y_{j+2})$$

Where, C−2 = −3/35, C−1 = 12 / 35, etc.

The PV output voltage was perturbed in a regular interval (few µs) starting from the open circuit voltage (V_{oc}) using the microcontroller (Arduino UNO) based GMPP tracker and corresponding instantaneous values of the voltage (V_n) and current (I_n) were recorded. The controller then calculated the instantaneous values of the power (P_n) and saved in an array of the internal memory of UNO. Thus, the consequent data points of V_n, In and Pn were discretized and saved as digital data sets. Hence, this step involved the conversion of analog data to equal spaced digital data points. The process initiated with the measurement of the PV output and generating a set of five equally spaced data points of Pn (P1, P2, P3, P4 and P5) with corresponding values of Vn (V1, V2, V3, V4 and V5) (where, n is the position of the data) using perturbation and these values were stored in an array in the memory. During the whole process always a set of 5 data points was maintained. Subsequently, these data points were smoothed by Savitzky-Golay filtering algorithm using 5th order polynomial which gave single data points of both the P and V out of this set of 5 data points. Theses smoothed data formed another array inside the controller. Further, using the same method and maintaining the identical time interval the next data points of both P and V were logged. During the execution of the algorithm the immediate next data points Pn+i and Vn+i (where, i= 1, 2, 3,…,m) continued to occupy the 5th position (last entry) of the data set saved in the arrays eliminating the i_{th} data (1st entry) considering total m number of data points were logged. The process is the same as the FIFO (first in first out) mechanism. In the end, a PV spectrum was formed containing the smoothed data sets, eliminating all the local maxima (bad data points) as depicted in Fig 20. Further, the conventional P & O method was applied to find the GMPP.

VI. MODELLING AND SIMULATION

The modelling of the controller in association with the proposed algorithm was done in Proteus 8.3 and the circuit was simulated (Fig. 13). The proposed algorithm was coded in Arduino UNO using Arduino 1.6.8 (open source software). The UNO was used as a main controlling unit where the control signals were generated following the algorithm and control signals were generated to operate the circuit components. UNO also monitored the operations and all necessary calculations were carried out digitally. After successful simulation, a real-time circuit built to realize the results. The schematic diagram of the proposed method was depicted by Fig. 14. During the simulations, the following circuit components were used and some of them were designed also.

A. Configuration of PV Panel

A solar panel (250 W) with 36 series-connected solar cells (each of 8.28 A, shunt and series resistances of 100 kΩ & 0.5 mΩ respectively) was designed in simulation (similar to the specifications of Sun module Pvt. Ltd.). This entire configuration of 250-watt solar panel with I_{sc} and V_{oc} of 8.28 ampere and 37.8 volts respectively at Standard Testing Conditions (STC), i.e. temperature= 25^{o}C & irradiance= 1000 W/m2, was designed as per the data sheet and is encapsulated within a module-like structure (Fig. 8). A potentiometer is connected, varying which the different irradiance conditions on the 250-watt solar PV modules was calibrated.

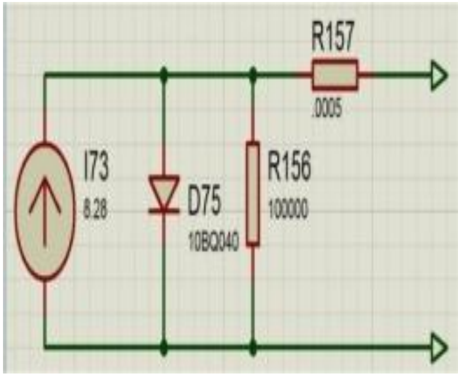

Fig. 6. Configuration of a solar cell represented by a single diode.

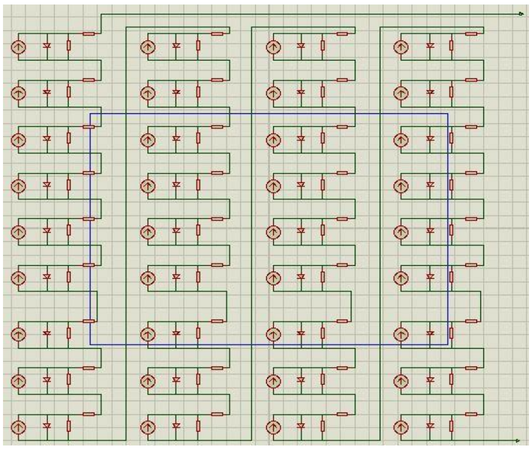

Fig. 7. Simulated Model of a 250-watt solar panel.

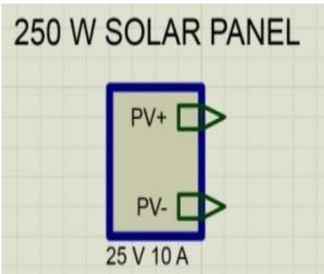

Fig. 8. 250-watt solar panel encapsulated in a subsystem.

B. Buck and buck-boost circuit

The output of solar panel is fed to a storage battery followed by the converters. The buck circuit was used to buck the PV voltage gradually and when V_{mp} was reached decided by the algorithm, the buck operation stopped and a constant voltage was reached. The buck-boost converter either bucked or boosted the output voltage of the buck converter as per the state-of-charge (SOC) of the battery that was being charged. Two power electronics switches of buck and buck-boost circuits, MOSFETS IRF9520, which are P-channel power MOSFETs, were triggered by two separated and dedicated PWM pins of Arduino UNO.

C. Arduino UNO

Arduino is a family of multitasking programmable platform based on AVR microcontroller (ATMEGA 328P, clock frequency:16 MHz). Here, it was tuned to 50 kHz. UNO (Fig. 9) has 6 input pins (analog) and 14 I/O pins (digital). Out of them 6 are dedicatedly PWM pins.

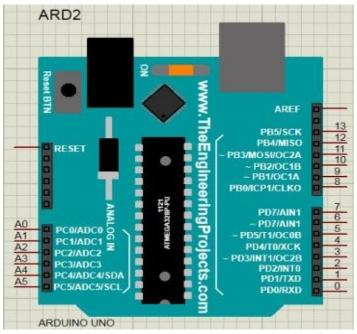

Fig. 9. Arduino UNO.

D. Gate Triggering Circuit

A Gate triggering circuit (Fig. 10) was used to amplify the PWM signal to turn on the MOSFET.

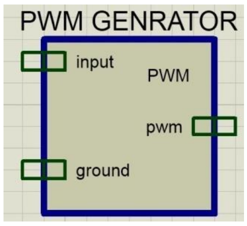

Fig. 10. Circuit used for MOSFET triggering.

An optocoupler PC817 was used in gate triggering circuit (Fig 11).

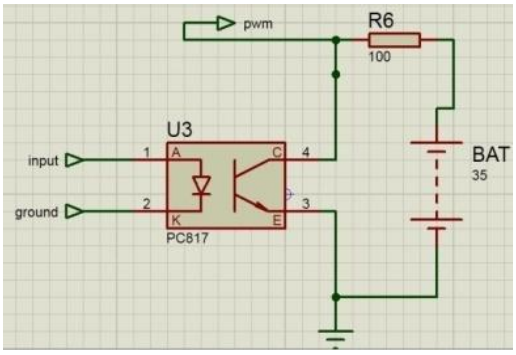

Fig. 11. Gate Triggering Circuit consisting of PC817.

E. Current Sensor

A Hall current sensor (ACS712) was used to measure the PV current efficiently (Fig. 12) through Arduino UNO followed by a LC filter.

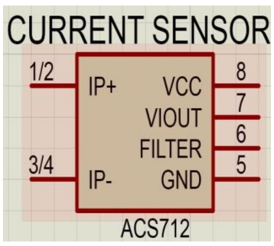

Fig. 12. Current Sensor ACS712.

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VII. RESULTS AND DISCUSSION

Arduino UNO can accept a maximum value of 5 V as input. So, a voltage divider was used to step down the PV voltage and sensed through the analog pin A0 of the UNO. The PV current was sensed through a Hall sensor and after filtration by LC filter, the current was fed through A1 pin. The UNO calculated the power using the inbuilt microcontroller and stored in memory. The UNO has sufficient memory space to log the output parameters and to store calculated values. The algorithm present in the UNO automatically eliminated local maxima for partial shading condition and filtered the sets of data to generate a smooth PV graph. A buck converter in series was connected. The duty cycle of the firing pulse (PWM signal) of the MOSFET present in the buck converter was controlled automatically for both perturbation and to find the GMPP. The buck-boost converter connected in next was used to follow the constant charging voltage of 12 V to charge the 12 V batteries. As irradiance changed and partial shading was imposed, the V_{mp} was also changed in accordance. So, the algorithm in association with the controller successfully tracked the GMPPs for different cases. Somehow these values of V_{mp} may be different than the battery charging voltage. The PWM signal of the MOSFET associated with the buck-boost controller was changed accordingly by the algorithm to follow a constant voltage depending upon the SOC of the battery.

A. Simulation Results

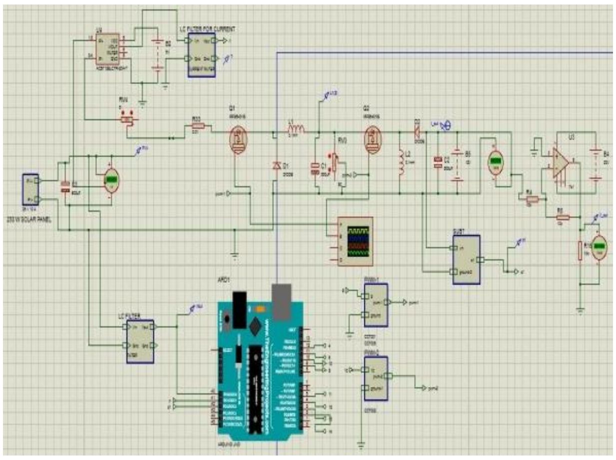

Fig. 13. Simulation model of the proposed charge controller.

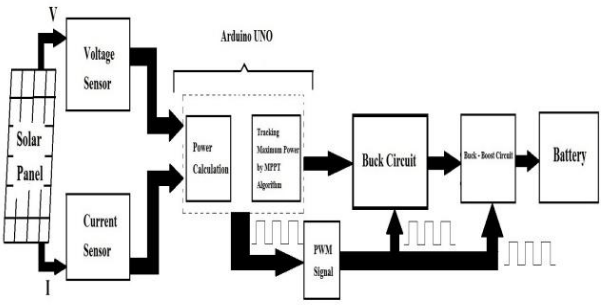

Fig. 14. Workflow of the operation of the proposed controller.

After successful compilation and validation of the MPPT algorithm, a hardware model was designed to realize the algorithm. The hardware circuit worked as per the expected results retrieved from the simulation.

Since there is no inbuilt option in Proteus 8.3 Professional to vary the irradiance and temperature incident on the solar panel, a potentiometer was connected in the circuit at the output of the panel and was calibrated in such a manner so that PV voltage can be varied abruptly assuming the effect of different irradiance including the partial shading and temperature conditions. For different values of the potentiometer, the solar panel operating wattage was taken. As the potentiometer resistance gradually increased, i.e., incident irradiance decreased, the wattage of the panel reduced. These three potentiometer values, at 0% (Fig. 15), 25% (Fig. 16) and 50% (Fig. 17).

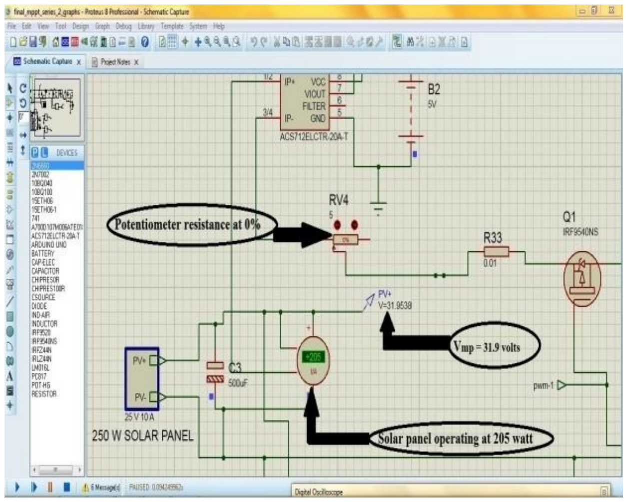

Fig. 15. When the resistance of the potentiometer was 0%.

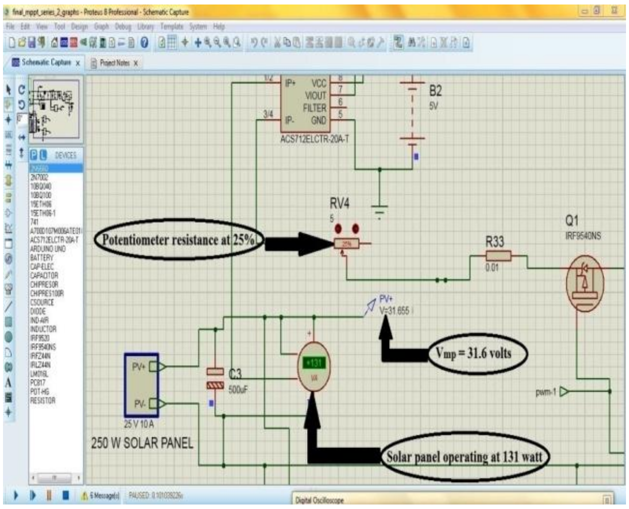

Fig. 16. When the resistance of the potentiometer was 25%.

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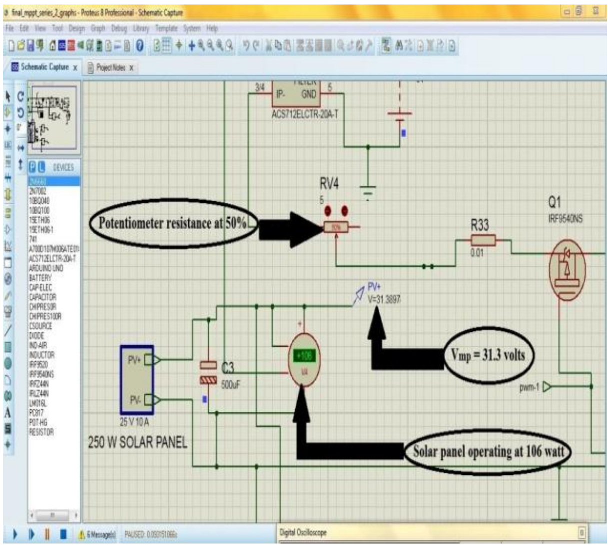

Fig. 17. When the resistance of the potentiometer was 50%.

V_{mp} was tracked successfully for different configurations.

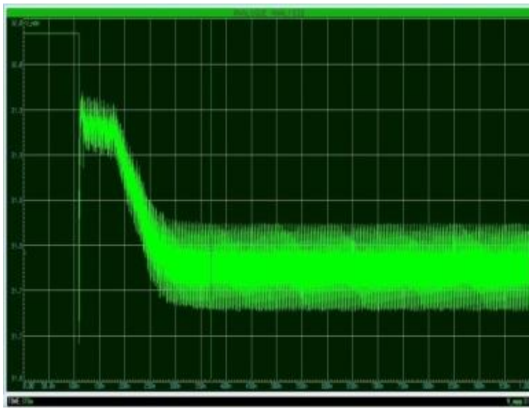

Fig. 18. Vmpp curve.

The converter fixed the voltage on an average at 12.1 volts. .

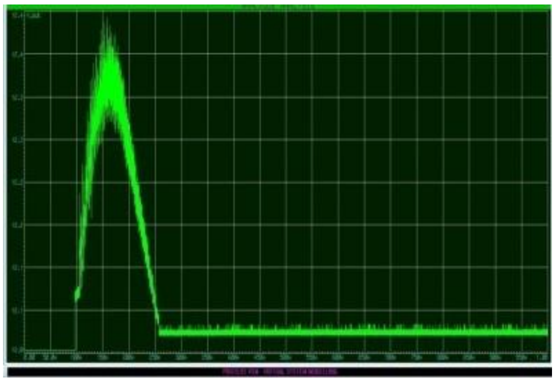

Fig. 19. output voltage of the controller.

B. Experimental Results

An experiment was carried out in real-time environment with a 250W PV panel of Si solar cells in partial shading conditions also. Fig. 21 depicts the experimental setup. Table 6.1 shows that the algorithm successfully tracked the GMPP for different values of irradiance and in partial shading conditions. The controller output voltage was stable in the range 12.10~ 12.45 V, which is acceptable. Despite multiple peaks present in the P-V graph the controller successfully tracked the GMPP.

Fig 20 describes the implementation of the proposed algorithm for eliminating the local maxima and finding the GMPP during partial shading with G=1000 W/m2. The algorithm was tested with 3rd, 4th and 5th order polynomials. The 5th order polynomial delivered the best result and eliminated the local maxima and the tracking time was also too short. The V_{mp} was calculated as 32 V and P_{mp}= 198 W.

Table 6.1 Summary table of the measured experimental results.

SL No.	Irradiance (W/m^2)	GMPP Voltage (V)	Extracted power (W)	Controller output voltage (V)	Controller output current (A)
1	1000	31.9	205	12.45	5.67
2	750	31.6	131	12.23	4.18
3	500	31.3	106	12.10	2.12
4	250	30.9	90	12.10	1.29

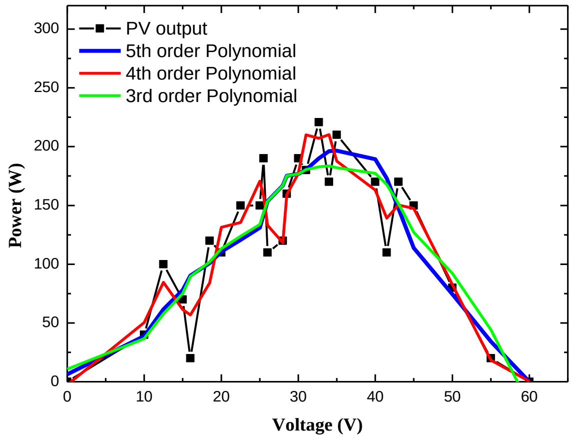

Fig. 20. Elimination of local maximas from the PV graph (G= 1000 W/m2) using the proposed algorithm in partial shading condition and finding the GMPP.

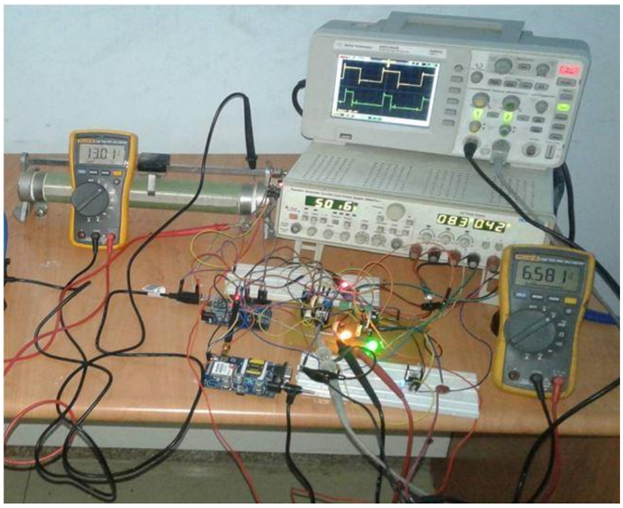

Fig. 21. Experimental setup of the GMPP tracking controller.

VIII. CONCLUSION

Si Solar cells connected to PV panel may suffer from full shading or partial shading. During partial shading the P-V graph is not obtained as expected, it contains multiple unwanted small peaks or better known as maxima. During MPP tracking the existing algorithm-based controllers may stick at any of these peaks considering as MPP. So to eliminate these peaks and to find a global maximum power point (GMPP) fast and precisely, a new hybrid MPPT algorithm was proposed in this work. The algorithm was modelled based on the Savitzky-Golay filter and Perturb & Observe (P&O) method. The algorithm was successfully simulated and later implemented in association with a hardware circuit (controller) in real-time experiment. In both the cases, the algorithm delivered the output as expected.

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AUTHORS PROFILE

Sajal Debbarma was born in Agartala, India. He received his M.Tech. from National Institute of Technology Agartala, Agartala, India in 2018. He received his B.Tech from Tripura University. Presently he is pursuing his PhD from NIT Nagaland. He is working as Assistant Professor in the department of Electrical Engineering, Tripura Institute of Technology, Govt. of Tripura. His research interests include Power System, Solar and Renewable Energies.

Shivaji Debbarma was born in Agartala, India. He received his M.Tech. from National Institute of Technology Agartala, Agartala, India in 2017. Presently he is pursuing his PhD from NIT Silchar. He is working as Assistant Professor in the department of Electrical Engineering, Tripura Institute of Technology, Govt. of Tripura. His research interests include Power Electronics, Solar and Renewable Energies.

Saptadip Saha was born in Agartala, India. He received his PhD and M. Tech from National Institute of Technology Agartala, Agartala, India. He was working as Assistant Professor in the department of Electrical Engineering, NIT Agartala for 4.5 years. Before that he has worked as Systems Engineer in Tata Consultancy Services for 2.5 years. His research interests include Solar Photovoltaics, Renewable Energies, Power Electronics.