2020 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES) | 978-1-7281-5672-9/20/$31.00 ©2020 IEEE | DOI: 10.1109/PEDES49360.2020.9379820

Solar PV Array Powered ON Board Electric Vehicle Charging with Charging Current Protection Scheme

Harshit Kumar Singh
Department of Electrical and Electronics Engineering
Dr. A.P.J Technical University, Uttar Pradesh
I.T.S Engineering College, Greater Noida – 201308
Email: Harshitkumarsingh108@gmail.com

Nishant Kumar, *Senior Member IEEE*
Department of Electrical and Computer Engineering
National University of Singapore (NUS)
Singapore- 117583
Email: nishantkumar@ieee.org

Abstract: In this paper, a three-sensors based Maximum Power Point Tracking (MPPT) scheme with charging current protection facility has been proposed for Solar PV powered ON board Electric Vehicles (EV) applications. Therefore, this scheme is capable of charging the different types of EVs with current within the rated limit of the EV. Solar PV array can be directly attached for charging the EV without any external required circuitry. Therefore, any Solar panel array can be attached to charge the EV safely. The Above strategy is Simulated and tested in MATLAB Simulink under variable irradiance of solar energy, which optimal SOC, charging current, and voltage shows satisfactory performance.

Keywords—EV Charging, Electric Vehicle, Solar PV Array, MPPT, ON Board EV, current-controlled, Rated Charging Current.

I. INTRODUCTION

Electric vehicles are currently being seen as a great alternative to gasoline-based vehicles as they don't produce any green gas. Moreover, they can be charged using grid-based electrical power or renewable energy-based power such as a solar photovoltaic panel. The electric vehicles mainly come in two charging schemes that is ON board charging and OFF Board charging. In ON Board, the charging circuit is kept within the car itself, and it can be charged using AC or DC. In the case of the OFF Board, the charging circuit is kept within the charging station, and it is charged using DC, while both have their advantages and disadvantages [1]. Charging EV using solar energy can be a challenging task as solar irradiance keeps changing as time passes [2]. Therefore, the power generated is non-uniform, to tackle this, various mathematical optimization algorithms and techniques are used this process is called Maximum power point tracking (MPPT) of solar array [3] wherein each MPPT control configuration having their pros and cons. This is used in a series connection with the circuit called DC-DC Buck/Boost converter, in which by controlling the pulse width modulated (PWM) the input signal to the converter, the power output of the solar panel can be controlled. By using this, solar panels are operated at maximum power point(V_{mp}, I_{mp}). Therefore, charging the EV with a maximum power output of the solar PV [4]. But we also know that a large solar array can output hundreds of Ampere of Direct current which when directly fed into the EV can damage it [5]. Moreover, EV has a charging current rating which is usually 10% of the maximum capacity of the EV Battery. Therefore, current needs to be controlled before it is fed into the EV [6] which can be done using sensors to monitor the output of the Solar array [7]-[11]. Most of the circuit currently being used are kept on the charging stations to charge OFF Board electric vehicles which require charging solar stations equipped with current-controlled charging MPPT circuits [12]-[16].

In this paper we are proposing, three feedback sensors based on Hill climbing optimization technique MPPT current-controlled charging scheme which is kept ON board the EV and any Solar PV array can be directly plugged into the EV for charging, wherein two sensors are monitoring the power output of the Solar array, and one sensor is used to monitor the output of the Dc-Dc converter circuit i.e. charging current which is going to charge the EV also this sensor will be used as the main feedback sensor to control the power output of the solar array using the MPPT controller and DC-DC converter circuit by varying the duty cycle as required to keep the charging current within the limit. And therefore, Charging the EV safely and securely moreover simplifying the overall charging process by providing all circuits within one single unit.

978-1-7281-5672-9/20/$31.00 ©2020 IEEE

II. SYSTEM LAYOUT

A. *Complete model setup -*

Fig. 1 shows the proposed model of the whole charging setup. The scheme is given with Solar power monitoring sensors (current and voltage sensor), DC-DC Boost converter, MPPT controller, pulse generator, and a feedback sensor for charging current connected before the EV battery. Moreover, the whole circuitry will be kept inside the vehicle. Therefore, to charge the Electric Vehicle, Solar PV can be directly connected to the EV. Charging current limit can be changed from the controller for higher Power capacity EVs. Further, an optional input capacitor can be used to reduce voltage ripple.

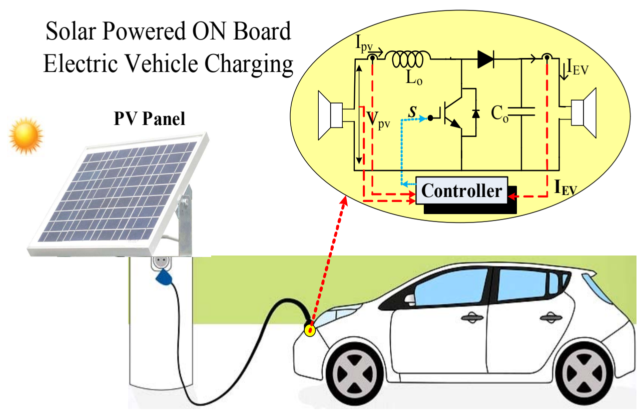

Fig. 1 Complete Layout for Proposed Model.

B. *Solar PV cell*

Fig. 2 shows the equivalent electrical circuit of a solar PV cell for

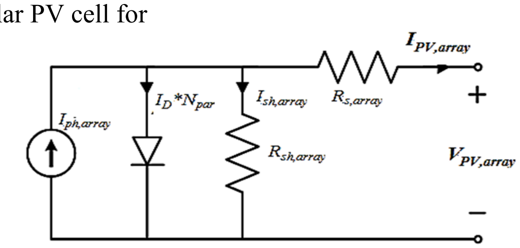

Fig. 2 Solar PV cell electrical model

$$I = I_{Ph} - I_S\left[exp\left(\frac{V + IR_S}{aV_t}\right) - 1\right] - \frac{V + R_S I}{R_p} \quad (1)$$

Equation 1 Describes the Single Diode Solar PV model as shown in Fig. 2.

Where I_{Ph} and I_S are the PV current and Saturation current of the solar cell further V_t being the Thermal voltage of the cells connected in series, $V_t = N_s kT/q$ with N_s series-connected cells while k is the Boltzmann constant ($1.3806503 \times 10^{-23} J/K$), "$T$" is the p-n junction temperature and "a" is ideality constant of Diode.

C. *DC-DC Boost Converter*

In Fig. 3 DC-DC Boost Converter is presented which is to be connected in between the Solar PV Array and EV as shown in Fig.1

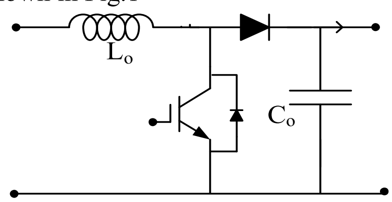

Fig. 3 DC-DC Boost Converter

The voltage equation of the Ideal converter is given by;

$$V_O = \frac{V_{IN}}{(1-S)} \quad (2)$$

In the practical converter, after taking losses of MOSFET and Diode into account. The output voltage is derived as;

$$V_O = \left(\frac{V_{IN} - V_{SW}S}{(1-S)}\right) - V_D \quad (3)$$

For EV, it can be Changed such as;

$$V_{CHARGING} = \frac{V_{PV}}{(1-S)} \quad (4)$$

$$V_{CHARGING} = \left(\frac{V_{PV} - V_{SW}S}{(1-S)}\right) - V_D \quad (5)$$

Where S is the Duty Cycle.

III. CONTROL SCHEME

Maximum Power point tracking (MPPT) of solar array-based Hill climbing algorithm is being utilized based on three sensors design out of which two are used for monitoring the power output of the Solar array, and one current sensor is used to monitor the charging current of the EV or $I_{MPPT}(t)$. Based upon the feedback from the sensors if the value of $I_{MPPT}(t)$ greater than or less than the current rated for EV the operation Mode is selected, which is MPPT mode or Protection mode, as shown in (6) and (7). Current is continuously monitored and therefore accordingly, the Small iteration is done to the duty cycle to get the desired current of 14A.

$$I_{MPPT}(t) > I_{EV\ Ratimg} \rightarrow (Protection\ Mode) \quad (6)$$

$$I_{MPPT}(t) < I_{EV\ Rating} \rightarrow (MPPT\ Mode) \quad (7)$$

A. *Protection Mode*

In this condition Equation (6) is satisfied, and it is basically, the Current $I_{MPPT}(t)$ is higher than the rated current of the EV. Therefore, in protection mode

978-1-7281-5672-9/20/$31.00 ©2020 IEEE

current is brought down to the rated current that is in our case 14A. Which is Done by either increasing the Duty-cycle or decreasing it based upon the comparisons of different parameters such as Power and Voltage, which is expanded upon in Equation 8.

$$\left.\begin{array}{l} If \\ \Delta P > 0 \;\&\; \Delta V > 0 \rightarrow \; Increment\ in\ Duty\ Cycle \\ If\ else \\ \Delta P > 0 \;\&\; \Delta V < 0 \rightarrow \; Decrement\ in\ Duty\ Cycle \\ If\ else \\ \Delta P < 0 \;\&\; \Delta V > 0 \rightarrow \; Decrement\ in\ Duty\ Cycle \\ If\ else \\ \Delta P < 0 \;\&\; \Delta V < 0 \rightarrow \; Increment\ in\ Duty\ Cycle \end{array}\right] \quad (8)$$

Equation (8) can be written as

$$\left.\begin{array}{l} If \\ \Delta P>0\&\Delta V<0\ or\ \Delta P<0\&\Delta V>0 \rightarrow Deccrement\ in\ Duty\ Cycle \\ Else \\ \Delta P>0\&\Delta V>0\ or\ \Delta P<0\&\Delta V<0 \rightarrow Increment\ in\ Duty\ Cycle \end{array}\right] \quad (9)$$

Equation (9) can be further simplified as

$$\left.\begin{array}{l} If \\ \Delta P > 0 \;\&\; \Delta V > 0 \;\; or \;\; \Delta P < 0 \;\&\; \Delta V < 0 \\ \rightarrow S(t) = S(t-1) + \delta_i \\ Else \\ \rightarrow S(t) = S(t-1) - \delta_i \end{array}\right] \quad (10)$$

where δ_i is the Step Change and $S(t-1)$ is the previous Duty-cycle.

B. *MPPT Operation*

This operation followed in the case, equation (7) is satisfied, and it is used to maximize the power output of the solar array until the charging current reached the rated limit. This is done by Varying the duty cycle of the converter to control the power output, which is going to charge the EV. Similar to the Protection.

$$\left.\begin{array}{l} If \\ \Delta P > 0 \;\&\; \Delta V > 0 \rightarrow \; Decrement\ in\ Duty\ Cycle \\ If\ else \\ \Delta P > 0 \;\&\; \Delta V < 0 \rightarrow \; Increment\ in\ Duty\ Cycle \\ If\ else \\ \Delta P < 0 \;\&\; \Delta V > 0 \rightarrow \; Increment\ in\ Duty\ Cycle \\ If\ else \\ \Delta P < 0 \;\&\; \Delta V < 0 \rightarrow \; Decrement\ in\ Duty\ Cycle \end{array}\right] \quad (11)$$

Equation (11) can be written as

$$\left.\begin{array}{l} If \\ \Delta P>0\&\Delta V>0\ or\ \Delta P<0\&\Delta V<0 \rightarrow Decrement\ in\ Duty\ Cycle \\ Else \\ \Delta P>0\&\Delta V<0\ or\ \Delta P<0\&\Delta V>0 \rightarrow Increment\ in\ Duty\ Cycle \end{array}\right] \quad (12)$$

Equation (12) can be further simplified as

$$\left.\begin{array}{l} If \\ \Delta P > 0 \;\&\; \Delta V > 0 \;\; or \;\; \Delta P < 0 \;\&\; \Delta V < 0 \\ \rightarrow S(t) = S(t-1) - \delta_i \\ Else \\ \rightarrow S(t) = S(t-1) + \delta_i \end{array}\right] \quad (13)$$

IV. RESULT AND MEASUREMENTS

A. *Output Measurements of the solar PV*

Solar PV Array is directly attached to charge in EV, Where the solar output is given to the circuitry where input voltage and current is monitored. Fig 4 shows the raw Solar PV Voltage, Current and Power generated. As clearly seen in Fig.4 the Generated current is approaching 20A, which is well above the Rated current of the EV that is 14A, and therefore if directly fed to charge the EV can damage it.

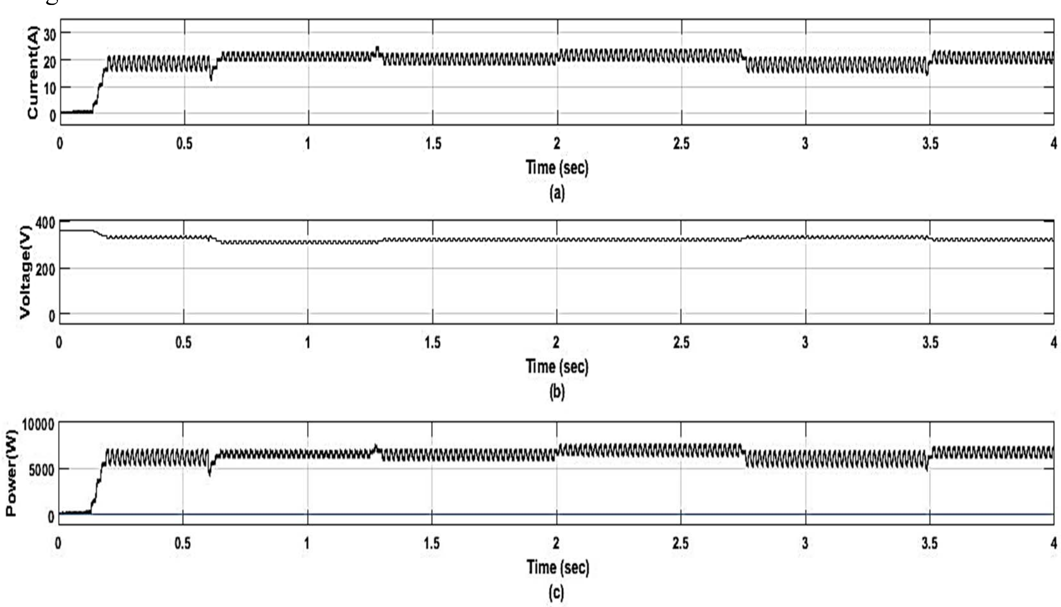

Fig 4 Output measurement of the Solar PV.

978-1-7281-5672-9/20/$31.00 ©2020 IEEE

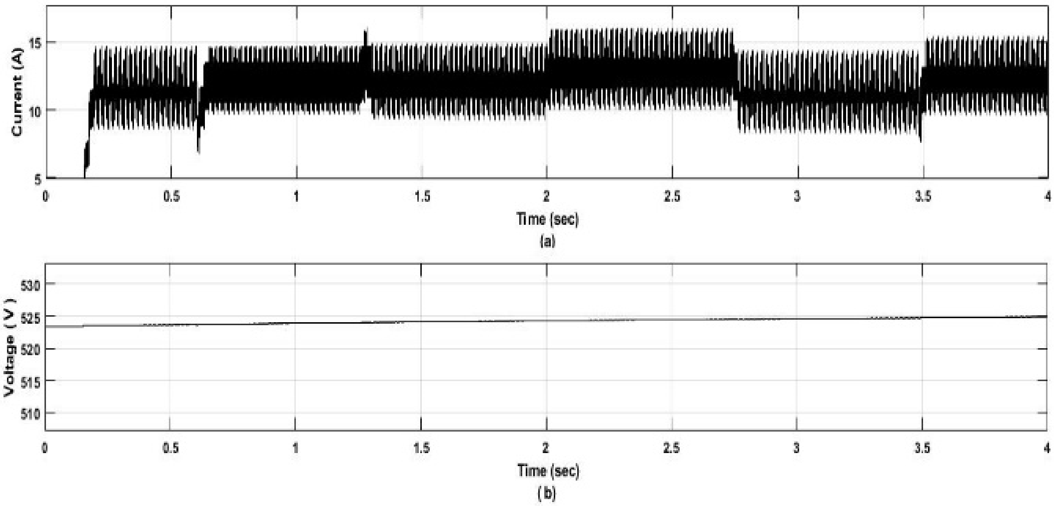

Fig 5 V-I Measurement after MPPT .

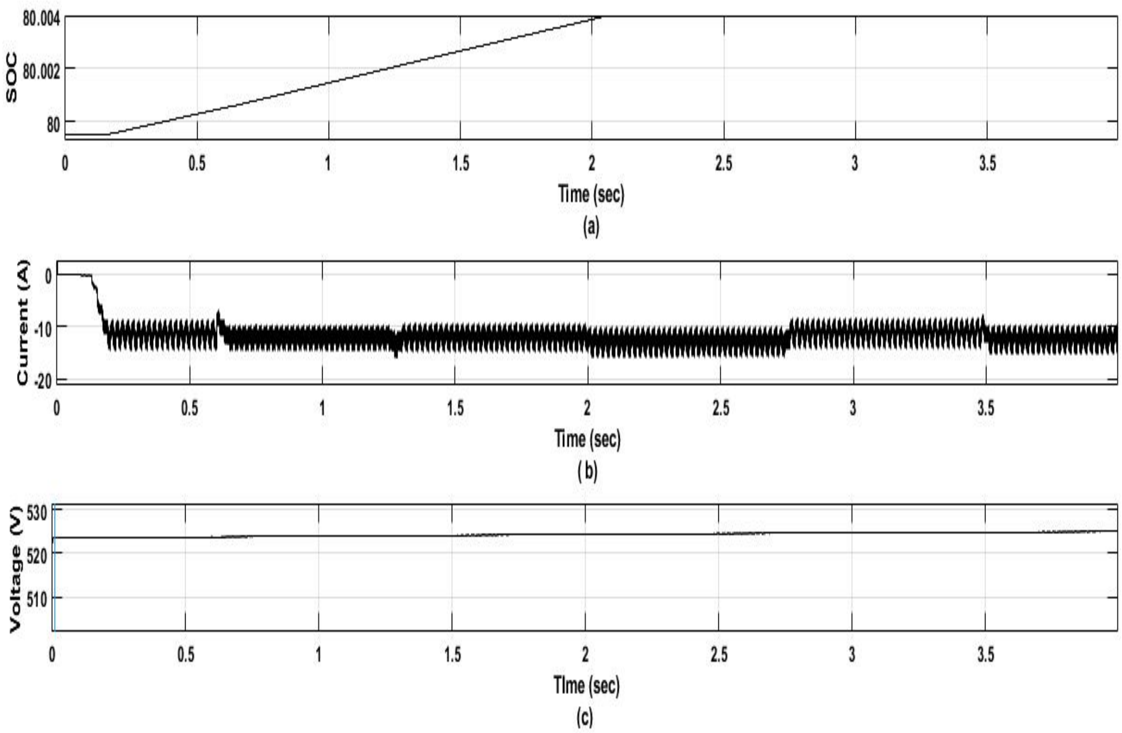

Fig. 6. Measurement of EV while getting charged.

B. V - I Measurements after MPPT

Here, in Fig. 5(a) Protection operation takes place when $I_{MPPT}(t)$ is above the rated limit of the battery, that is 14A, and MPPT operation takes place if the $I_{MPPT}(t)$ is below the rated limit. As shown in Fig 4(a) current is above the 15A and approaching 20A, which after the current control scheme, the current is maintained below 14A while the voltage remains approximately in a straight line of the curve as shown with Fig.5(b) when compared to Voltage in Fig4(b). While MPPT operation takes place when the current is below the 14A. Therefore, making it safe as well as optimal to charge the EV.

978-1-7281-5672-9/20/$31.00 ©2020 IEEE

C. Measurement of EV while being charged

Fig. 6(a) shows the state of charge (SOC) of the battery which is increasing, which means the battery is being charged. At the same time, the charging current Fig. 6(b) is maintained below the rated limit of 14A. Here the negative graph of the current indicates that the current is being given to the battery and not drawn out. While during the charging voltage remains the Battery voltage and approximately constant throughout the process.

V. Conclusion

A new three sensor-based current-controlled protection scheme for charging ON Board Electric Vehicles from solar Photovoltaic Array has been proposed, where Hill Climbing MPPT strategy has been used. Wherein Charging current was controlled with help of DC-DC Boost converter to achieve the Rated Current of the EV, which in this particular case is 14A, Here the proposed model was tested on Matlab Simulink software. And the satisfactory results were demonstrated that is charging current was maintained below the rated limit of the EV. The performance of the model is demonstrated under varied Solar Irradiance at nominal conditions (25° C and 1000W/m^2) Moreover, the need for external charging circuitry is eliminated, and solar PV array can be directly connected to the EV for charging, Therefore, making it more economical, reliable and Compact. Also, this strategy is easy to implement as well as requires less computational power. Therefore, it can be implemented with low-cost microcontrollers.

References

[1] N. Kumar, I. Hussain, B. Singh and B. K. Panigrahi, "Normal harmonic search algorithm based MPPT of solar PV system," *IICPE Conference*, Patiala, 2016, pp. 1-6.

[2] N. Kumar, B. Singh and B. K. Panigrahi, "Grid synchronisation framework for partially shaded solar PV-based microgrid using intelligent control strategy," *IET GTD*, vol. 13, no. 6, pp. 829-837, 26 3 2019.

[3] N. Kumar, B. Singh and B. K. Panigrahi, "PNKLMF-Based Neural Network Control and Learning-Based HC MPPT Technique for Multiobjective Grid Integrated Solar PV Based Distributed Generating System,"*IEEE TII*, vol. 15, no. 6, pp. 3732-3742, June 2019.

[4] N. Kumar, B. Singh, B. K. Panigrahi, C. Chakraborty, H. M. Suryawanshi and V. Verma, "Integration of Solar PV With Low-Voltage Weak Grid System: Using Normalized Laplacian Kernel Adaptive Kalman Filter and Learning Based InC Algorithm," *IEEE TPEL*, vol. 34, no. 11, pp. 10746-10758, Nov. 2019.

[5] S. S. Satapathy and N. Kumar, "Derated MPPT Scheme for Grid Integrated Solar PV Energy Conversion System," *GUCON Conference*, New Delhi, 2019, pp. 975-980.

[6] N. Kumar, B. Singh and B. K. Panigrahi, "Framework of Gradient Descent Least Squares Regression-Based NN Structure for Power Quality Improvement in PV-Integrated Low-Voltage Weak Grid System," *IEEE TIE*, vol. 66, no. 12, pp. 9724-9733, Dec. 2019.

[7] N. Kumar, T. Mulo and V. P. Verma, "Application of computer and modern automation system for protection and optimum use of High voltage power transformer," *ICCCI Conference*, Coimbatore, 2013, pp. 1-5.

[8] N. Kumar, S. Majumdar and G. M. Babu, "Automatic control of tidal power plant," *ICETEEEM Conference*, Chennai, 2012, pp. 24-28.

[9] N. Kumar, B. Singh and B. K. Panigrahi, "ANOVA Kernel Kalman Filter for Multi-Objective Grid Integrated Solar Photovoltaic-Distribution Static Compensator," *IEEE TCS I: Regular Papers*, 2019.

[10] S. S. Satapathy and N. Kumar, "Modulated Perturb and Observe Maximum Power Point Tracking Algorithm for Solar PV Energy Conversion System," ICRDCAPE *Conference*, NOIDA, 2019, pp. 345-350.

[11] S. S. Satapathy and N. Kumar, "Wavelet Mutation based JAYA Optimization Algorithm for Global Maximum Power Peak Searching for Partially Shaded Solar PV Panel Condition," *RDCAPE Conference,* NOIDA, 2019, pp. 351-356.

[12] H. K. Singh and N. Kumar, "Current Controlled Charging Scheme for off Board Electric vehicle Batteries from Solar PV Array," *SPIN Conference*, Noida, 2020, pp. 935-940.

[13] M. P. Korukonda, S. R. Mishra, K. Rajawat and L. Behera, "Hybrid adaptive framework for coordinated control of distributed generators in cyber-physical energy systems," *IET Cyber-Physical Systems: Theory & Applications*, vol. 3, no. 1, pp. 54-62, 3 2018.

[14] S. R. Mishra, M. P. Korukonda, L. Behera and A. Shukla, "Enabling cyber-physical demand response in smart grids via conjoint communication and controller design," *IET Cyber-Physical Systems: Theory & Applications*, vol. 4, no. 4, pp. 291-303, 12 2019.

[15] M. P. Korukonda, S. R. Mishra, A. Shukla and L. Behera, "Handling multi-parametric variations in distributed control of cyber-physical energy systems through optimal communication design," *IET Cyber-Physical Systems: Theory & Applications*, vol. 2, no. 2, pp. 90-100, 7 2017.

[16] K. Mathuria, I. Hussain, B. Singh and N. Kumar, "A Quadrature Oscillator-Based DT for Accurate Estimation of Fundamental Load Current for PV System in Distribution Network," *IEEE TII*, vol. 15, no. 6, pp. 3324-3333, June 2019.

978-1-7281-5672-9/20/$31.00 ©2020 IEEE