High Efficient Proposed MPPT Algorithm Applied to PV Integrated UPS

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Abstract: With the rise in power demand and depletion of conventional energy resources, the cost of conventional energy has gone up in recent times. In this regard a promising alternative Solar energy has emerged today. Since environmental condition changes PV array's maximum power changes accordingly, to get peak power various "Maximum Power Point Tracking (MPPT)" techniques are available. Presently various methods are available to maintain the PV system to operate at peak power point. among various techniques, techniques which are simple and less cost are fractional short-circuit current and fractional open-circuit voltage schemes. In order to measure a Isc and Voc for reference, disconnection of PV cells or short circuit of the PV cells are required periodically. resulting in degradation of utilized power. Perturb & Observe (P&O) MPPT algorithm is a much better technique which avoids this problem and has a better tracking profile. Even though this method has limitations in conditions where the variation in solar irradiation and temperature is fast, this method is quite popular due to the simplicity in its implementation and low resource requirement. This method works on the principle of perturbing and fixing the operating point based on the change in transferred power. Thus present paper focuses on developing a simple, effective new proposed MPPT algorithm for charge controller, to charge Lead acid batteries from a photovoltaic panel and to integrate it into the Online UPS. Thus power consumption from the grid reduces, with the use of renewable energy source which is available plenty. The paper involves design and simulation of the hardware controller circuit along with the development of new proposed MPPT algorithm for the charge controller and effective current sharing technique for effective utilization of grid power.

Keywords: DC-DC Converter;Maximum Power Point Tracking (MPPT);Solar energy; regulator.

Introduction

Demand for electrical energy has increased drastically over the last few decades. Hence alternative source of energy became more important, among all renewable energy source solar energy source provide a biggest contribution towards to the generation electric power. Solar energy to electrical energy conversion is of two types: solar thermal and solar photovoltaic. But under low solar Insolation, conversion efficiency is very less for electrical power generation (around (9 - 14%)).Weather variation varies the power generated by solar arrays. PV panel non-linear characteristic as shown in Fig.1.power at each point varies due to irradiation and temperature, peak power obtained from the solar panel only when voltage is at the global maximum of the p-v curve, this global maximum point is known as Maximum power point (MPP). though there are many algorithm to track maximum power point[1], proposed P and O algorithm proved simple and best algorithm to track maximum power point. Since storage technologies like Super capacitors, pumped hydro, superconducting magnetic, compressed air and thermal storages are there for storage on a large scale, but the most cost efficient and best technology for storage on a small scale is battery storage, power management by using the state machine and set operating point on the basis of sensed conditions[2]-[5],using programmed algorithm and control algorithm for PV or battery standalone system[6]-[9],[3].[7]-[9].if battery is connected to the load directly rather than connecting through the DC-DC converter have some drawback [4],[5], and [10] Interfacing the battery through DC-DC boost converter to the DC-link will be discussed in further section.

Multiple loop strategy to control DC-DC converters operation including constraints like charging current and limit in their capacity, system structure, power management, modeling approach, control design, experimental results for different modes of operation of implemented system followed by concluding remarks is explained in this paper.

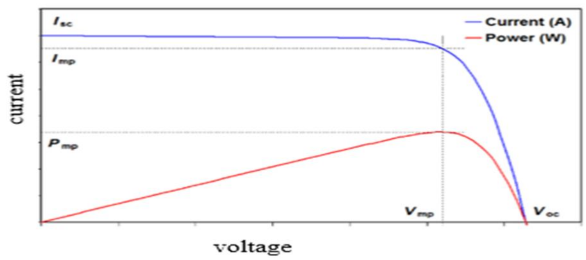

Fig .1. Non-linear characteristic of PV panel

Proposed MPPT algorithm

The proposed algorithm is shown in fig.2 since voltage around peak power point is changes linearly with open circuit voltage, at initial start the algorithm voltage around maximum power point is assumed to be 0.7 times the open-circuit voltage i.e.Vmpp=0.7 *Voc, so soft start is done until Vpv reaches 0.7 times the Voc by varying duty accordingly now it reaches to MPP, when it reaches to MPP, upper and lower limit of current reference are set . new power calculated at new instant and then compare the new power with the previous power, new power is greater or less than the previous power than decrease or increase the reference current with in the limit, if new current reference is greater or less than the set limit then maintains the old reference current. Depending on the power variation and voltage variation current reference is varied.
Benefits:

- Easy for implementation
- Accurate tracking of Maximum power point
- Less spikes in output voltage and output current due to soft - start
- Computational time is less
- Trade-off between accuracy and speed of algorithm can be achieved

Draw backs:

- Step size need to be evaluated and changed constantly during rapid changing weather condition

MPPT implementation uses the factor that the system can either regulate the output or track the panel maximum power point, but not both at the same time. While tracking the panel MPP in order to reduce the noise, samples of input current and voltages are averaged and fed to MPPT algorithm, depending on the averaged values the input reference is modified by the algorithm, PI control loop as to control the movement of panel current to that of reference, speed of PI control loop update rate must be faster than the MPPT controller algorithm update rate, so that there is a sufficient time for PV voltage to maintain steady state. PI control loop start regulating the output only when output voltage and current above the set limit, this means PV can supply greater power than battery or more power than the load can draw. When tracking ends duty cycle of boost converter is memorised. output voltage is maintained constant even though the panel voltage decreases or increase due to some environmental changes, In order to maintain the constant output the duty can be increased, if duty exceeds the previous memorized value then the PV voltage dropped below the MPP, this indicates that main loop has to track the MPPT, If in regulation mode if MPP impotent to meet the set current or voltage then that indicates that the panel is impotent to supply required power than the main loop as to return back to the MPPT tracking. Output regulation loop can be updated only by battery charging/discharging state machine, In MPPT tracking if current or voltage reached to their limit, charge termination protocol will not work properly, if the constant voltage stage of battery reached than the charge will be terminated as the current drops below the threshold even in slow charging condition. As in case of Li- ion battery chemistry to avoid maintaining the battery at high voltage for long run their must be another termination condition to abort the charge if voltage is more and current is less than the certain voltage threshold but in case of lead acid batteries it can be neglected since lead acid are more tolerant and cheaper than Li-ion batteries.

Operation and control strategy

Connecting battery directly to the DC-link through Boost converter is presented Fig.3 which provides following Benefits

- Selecting a Nominal voltage for battery is more flexible in this configuration
- Controllable Discharging is allowed
- In order to balance the system and to provides peak power to the load, and It stores excess PV energy in battery

Regulation of voltage in DC-bus link is by controlling the duty of boost converter that interface the battery, the peak power point is achieved by regulating the PV input terminal by controlling PV boost converter, average current control is preferred [12] than the peak current control mode since it provides immunity towards noise and more efficient control of voltage, In order to reduce measurement noise, switching noise and ripple second order low pass filter is used

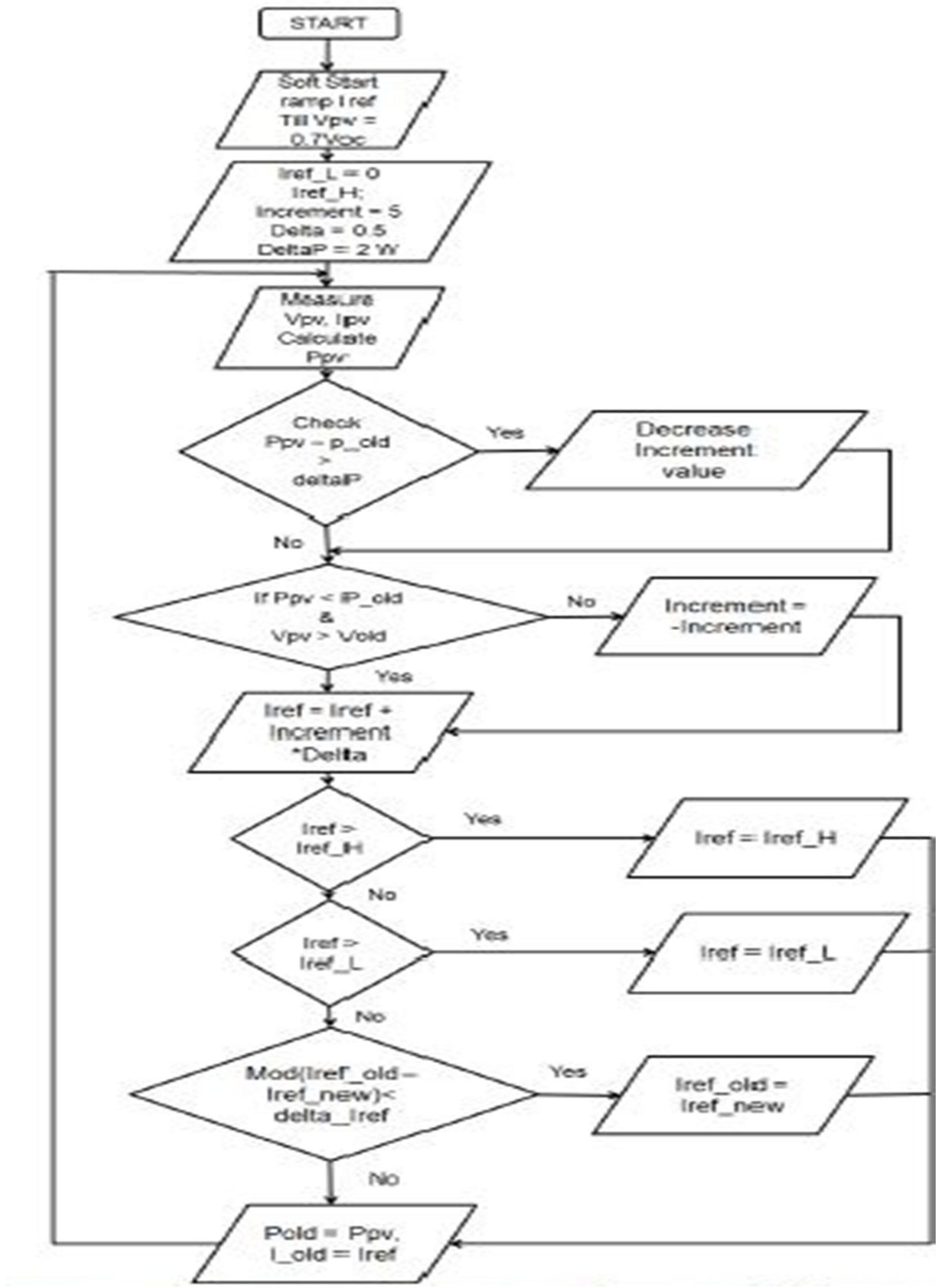

Fig.2. proposed MPPT algorithm

Operation

Based on battery SOC, PV power availability and grid state, system can be operated in three modes.

- Charging the battery with PV power and/or utility supply Fig.4
- Supplying load with PV power and/or utility supply
- Supplying the load with PV power and/or battery

Mode1: Battery is charged by PV power and/or by utility supply

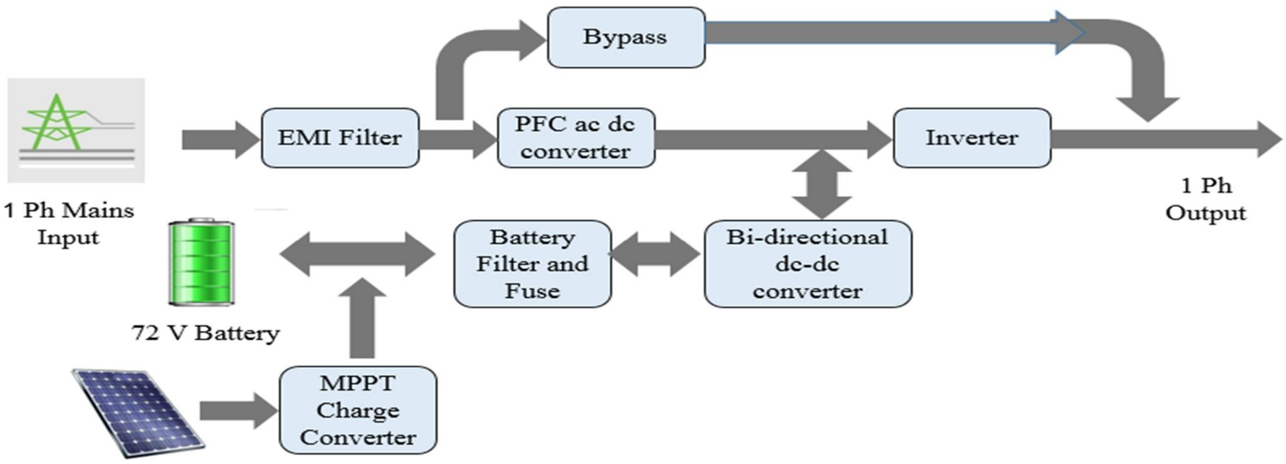

Fig.3. Block diagram of PV integrated UPS

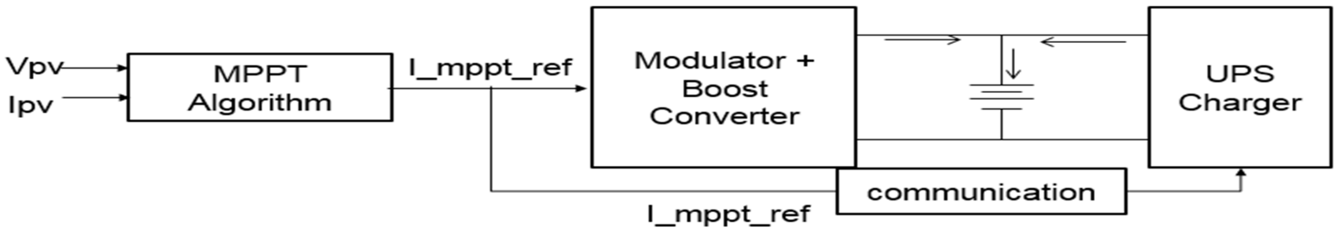

Fig .4. PV power and/or utility supply charging the battery

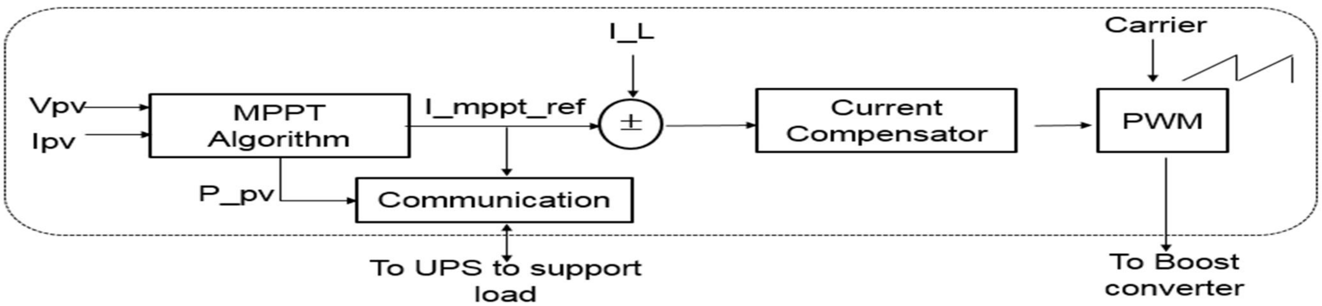

Fig .5. PV power and/or utility supply charging the battery with CC mode

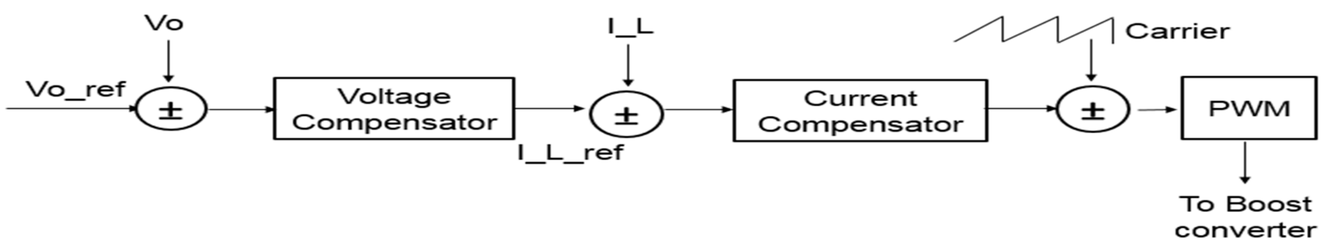

Fig .6. PV power and/or utility supply charging the battery with CV mode

Mode 1 mainly concerns about charging the battery. depending the SOC of the battery constant voltage/constant current mode is regulated by battery state machine. The battery is charged with defined maximum current, when converter reaches to constant voltage the battery state machine starts controlling the output current, when output current meets minimum threshold or if the current does not reduce for long time, then constant current mode begins. most of the case PV current charges the battery if the current required to charge than battery than the utility grid pumps remaining part of the current than the PV along with utility supply supports the battery. During Night time/No PV power available then the utility alone supports the battery.

Mode 2: Supplying load with PV power and/or utility supply

If the battery is full, PV power capable of supporting the load then PV power alone can support the load, If the battery and PV power is not available then Utility support the load.

Mode 3: Supplying the load with PV power and/or battery

If the battery is full, PV power capable of supporting the load then PV power alone can support the load, if battery is full PV power is not capable of supporting the load then both PV and battery support the load.

Design procedure

PV models, control design and boost converter designs are explained. Designing procedure follows the steps as shown below

- Design of 300W DC-DC boost converter for control and conditioning of power from PV panel
- Implementation perturb and Observe algorithm to achieve MPP
- To integrate the converter with 3kVA online UPS with optimal power sharing between the PV panel and utility supply such that the power delivered by the grid is minimum
- Different modes of operation are controlled depending on the SOC of battery
- Maintain the smooth transition between different operating modes
- Achieving communication between the UPS and solar charge converter, output current changes on the basis of AH of a battery, maximum Iavg is 12A

Two controllers are used one is the TMS320F2xx, DSP processor for UPS controlling operation and STM micro-controller for MPPT charge controller converter. State machine for complete system is represented in Fig.7.

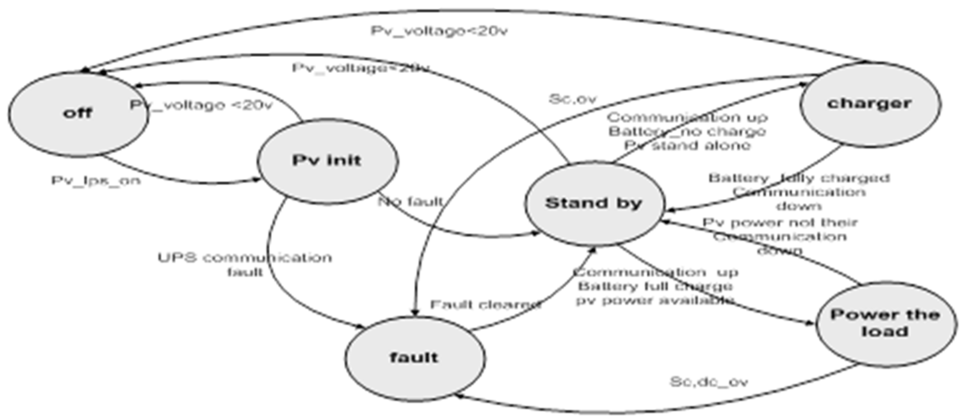

Fig 7. Complete system state machine

PV Boost converter control design

PV boost converter parameter as shown in TABLE I and PV boost converter as shown in Fig.8.

Table 1. Pv Boost Converter Parameter

Parameter	Values
Power	300W
Input voltage	25-45V
Input current	8.35A
Output voltage	88V
Output Current	3.253A
Efficiency	95.88%

The converter used to boost the voltage, the voltage which required to charge the batteries, higher voltage than the output of solar panel voltage, Duty of PWM gives the ratio between input and output voltages. D represents the duty of PWM, thus by varying the D MPP is maintained.

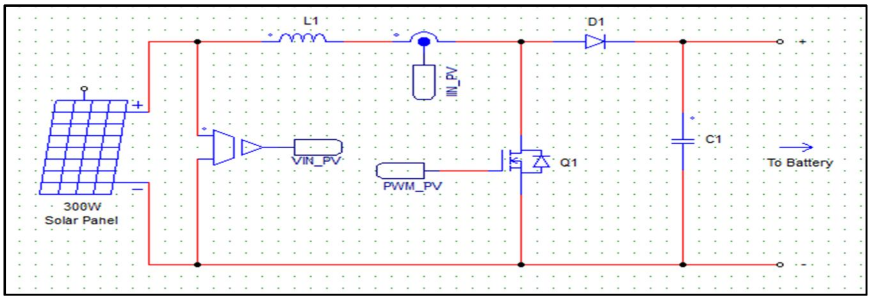

Fig 8. PV boost converter

$$Vout = \frac{Vin}{1 - D}$$

Voltage control loop around an average current mode controlled converter is designed with Type II PI compensator. transfer function for type II compensator having one pole at origin, one high frequency pole and one zero is given by H(s)

$$H(s) = \frac{1 + C_1 R_2 s}{(C_3 + C_1) R_1 s + R_1 C_1 C_3 R_2 s^2}$$

Inner current loop *cross* over frequency must be much greater than outer voltage loop cross over frequency

$$f_{ci} = 10 f_{cv}$$

C_3, C_1, R_1, R_2, are required for finding the poles and zero

Consider R_1 = 10kΩ

$$C_1 = \frac{1}{2\pi \times R_1 \times f_{p0}}$$

$$R_2 = \frac{f_{p0} \times R_1}{f_{z1}}$$

$$C_3 = \frac{f_{z1}}{2\pi \times R_1 \times f_{p0} \times f_{p1}}$$

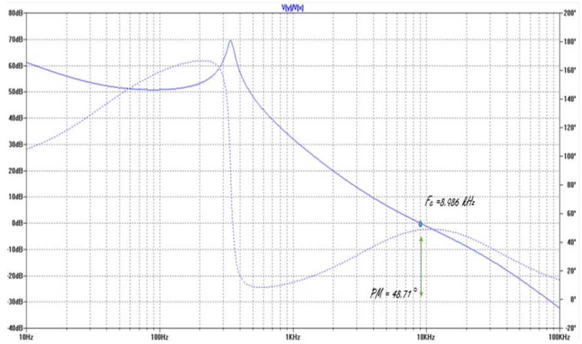

Fig 9. Average current mode cross over frequency and phase margin

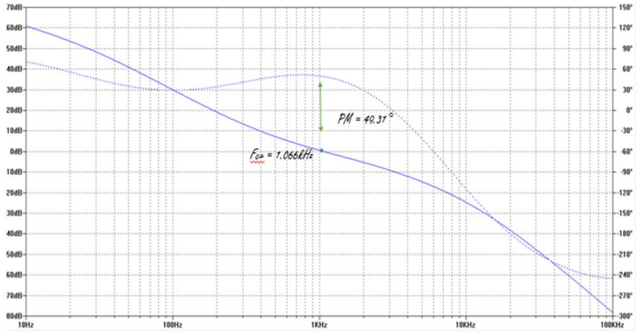

Fig 10. Voltage control cross over frequency and phase margin

PV modelling

PV array's I-V characteristic is described by single diode model as in equation (1), The voltage current relationship for PV array is described in [14]

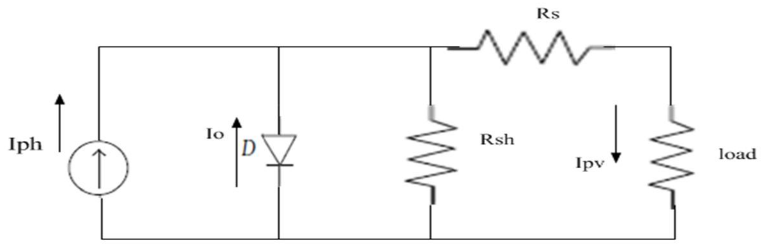

Fig 11. Single diode model of PV panel

$$Ipv = Np\left[Iph - Is\left\{\exp\left(\left(\frac{q}{AkT}\right)\left(\frac{V}{Ns}+\frac{IRs}{Np}\right)\right)-1\right\} - \frac{\frac{V}{Ns}+\frac{IRs}{Np}}{Rp}\right] \quad (1)$$

Where Ipv : PV panel array current, Is : Saturation current of diode, Vpv : PV panel array voltage, Iph : Photo-generated current, T : Cell operating Temperature in kelvin, Ns : Number of cells connected in series, Voc : Open circuit voltage, k : Boltzmann's constant($1.38 \times 10^{-23} J/C$), Rs : Cell series resistance, A : Diode quality factor, Rp : Cell parallel resistance ,Isc : Short-circuit current, q : Electron charge($1.6 \times 10^{-19} C$),Np : Number of cells connected in parallel

For more convenient equation (2) in [15] to calculate Is, series and parallel resistances is estimated by equating Pmax with experimental value maximum power [15], for all experimental condition A is 1.5

$$Is = \frac{Isc}{\exp\left(\frac{qVoc}{kTANs}\right)-1} \quad (2)$$

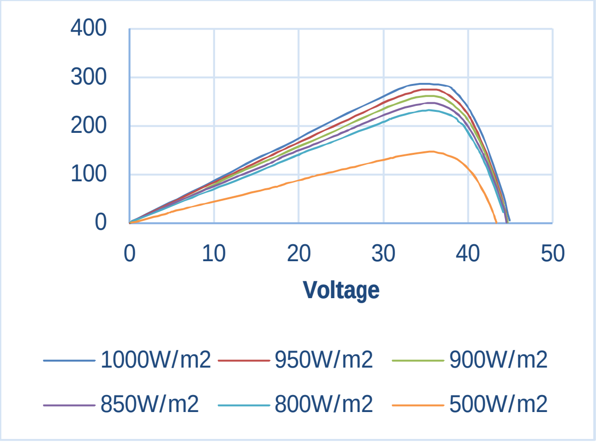

Fig 12. P-V curve depending on different Irradiation

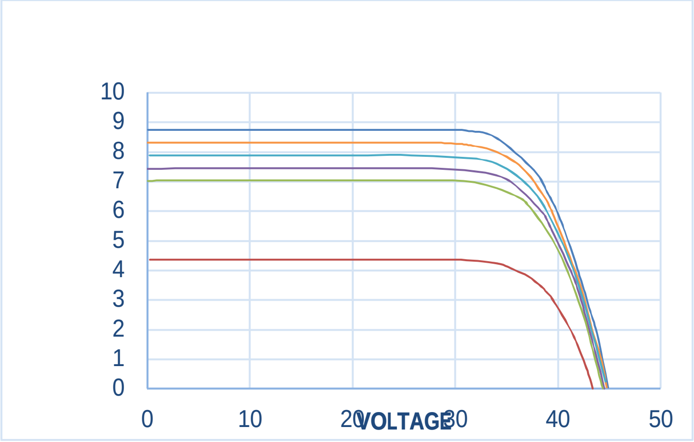

Fig 13. I-V curve depending on different Irradiation

Design challenges

Running the MPPT controller and running the charger on a same board is a great challenge because device must consider following issues:

- Output current regulation
- Output voltage regulation
- Tracking the peak power point of the panel
- Run battery charging state machine
- Run only one regulation loop at one instance.

Update rate of MPPT is restricted by various factors most important is update rate of PI loop must be faster than the update rate of MPPT.PI loop runs at least 25 times faster than MPPT update rate.

Accuracy of MPPT during low illumination is contributed by Input capacitance. Input capacitance limits current ripple, slow down the panel voltage variation, and Input capacitance is important for tracking maximum power point at the low power level, if capacitance is very less than that causes stress on the component and if the capacitance is more than MPPT track point cannot reach the set point. Interrupt timing for different modes of operation as shown in Fig 14.

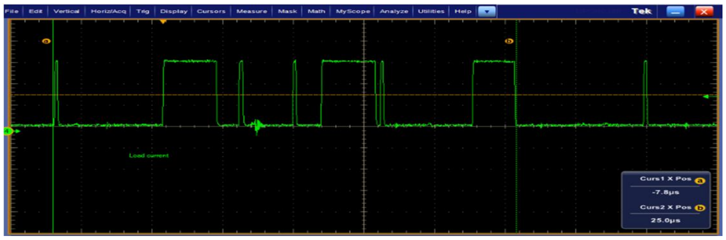

Fig.14 Interrupt timing result

Simulation

Simulation results for parameters shown below are discussed.

	Boost Converter	
Power	285	W
Input Voltage	25 – 35.93	V
Input Current	8.35	A
Output Voltage	87.6	V
Output Current	3.253	A

Components	Rating
Inductor (L1)	104 uH
Capacitor (C1)	330 uF, 160V
Diode (D1)	150 V, 8 Amp
Mosfet (Q1)	150V, 8 A

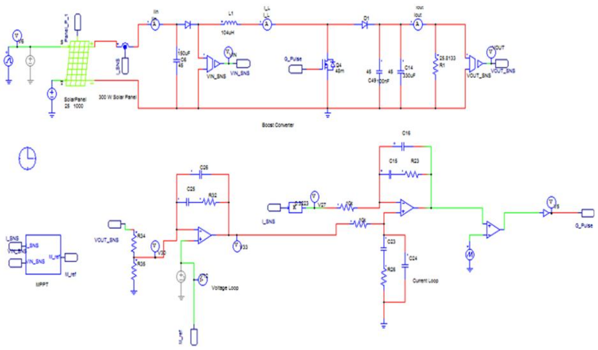

Fig.15. Simulation of MPPT charge controller

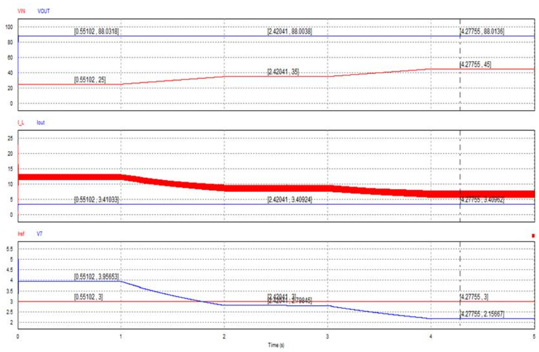

Fig.16.Output voltage, current and reference current of MPPT boost converter

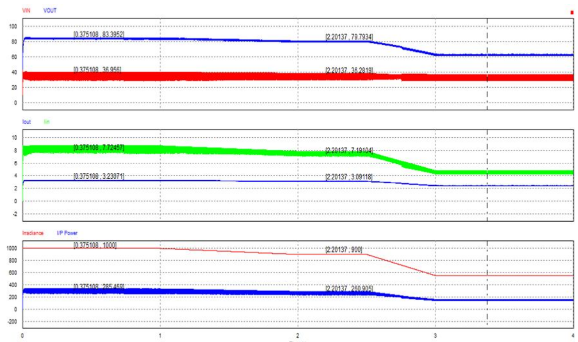

Fig .17. Output voltage and current MPPT charge controller for different irradiation

Experimental results

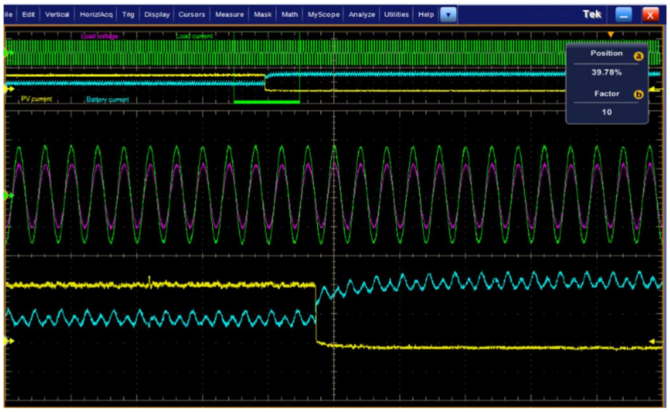

Fig.18. PV supporting the Load, if PV power reduces the battery start supporting the load

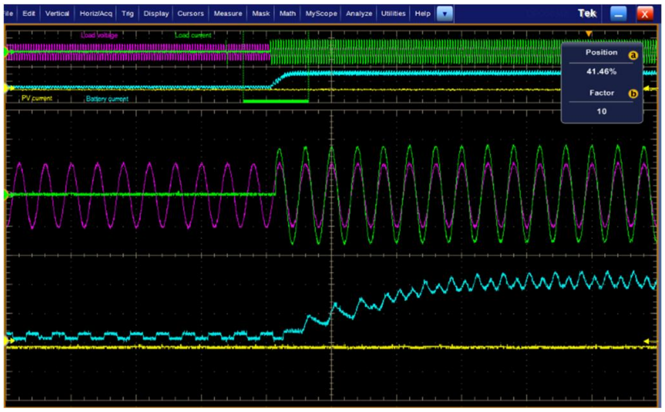

Fig.19.No PV, battery alone supporting the Load

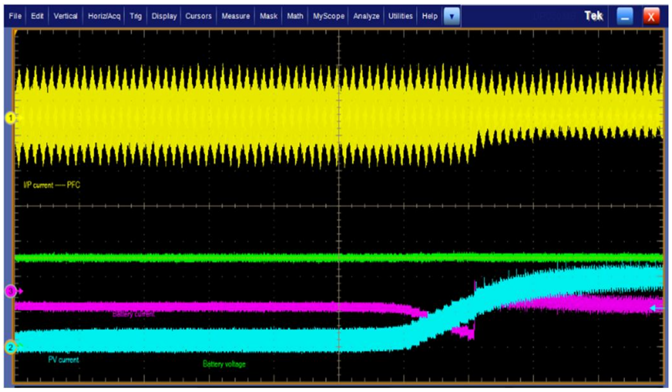

Fig.20. PV and utility charging battery for a period of time, then PV supporting the Load along with battery charging

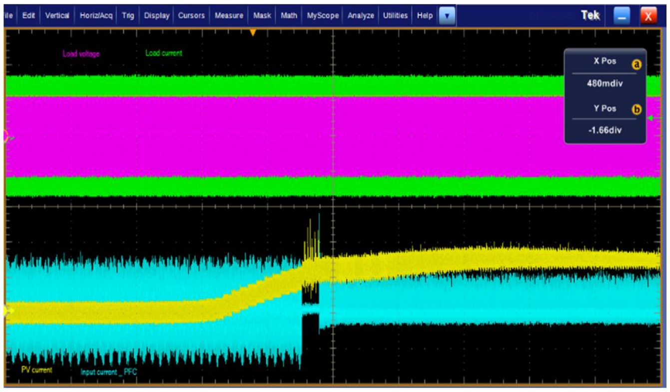

Fig.21. PV and utility supporting the Load

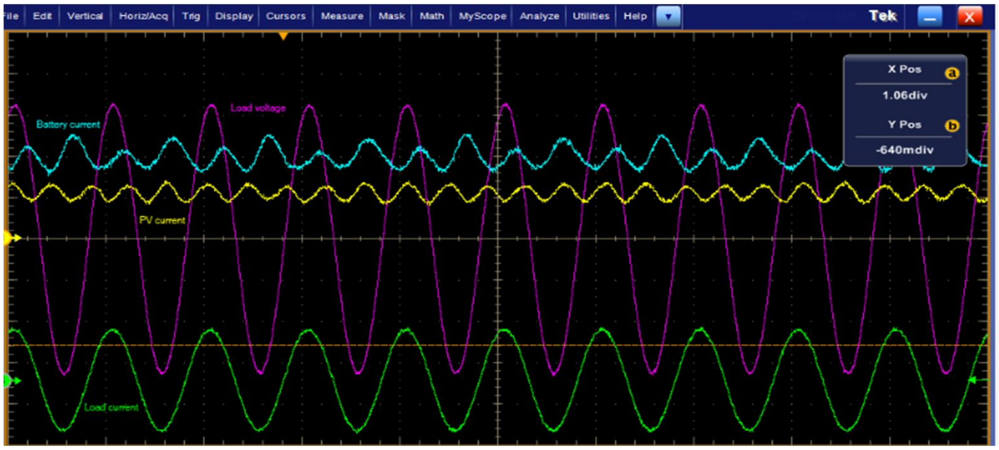

Fig.22. PV and battery supporting the Load

Conclusion

Maximum use of solar power with minimum utilization of grid power to charge the battery and support the load with high efficient proposed MPPT algorithm and current sharing techniques,which provides a attractive return on investment,smooth transition between different modes are expalined.experimental results for 3kVA UPS system integrated with MPPT charge controller is presented.

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