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Performance and Cost Optimised MPPT for Solar Powered Vehicle

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***Abstract* — These days we are emphasizing more on the need and methods to utilize the photovoltaic sources of energy in the best possible ways. Solar power is available in abundance to the Earth. With proper matching of solar irradiance and load on the solar panel , extraction of huge amount of electric energy is possible. So using such circuits which can match the load with the solar panel become an essential part for PV generation technique to improve the overall system efficiency. Maximum Power Point trackers are becoming famous and are widely available in market but only few of them are fast enough to perform well in badly varying solar intensity and load such as in solar powered/assisted electric vehicles. This paper presents the low cost and high performance technique that works effectively in such worst conditions. This technique can be used for automotive applications in Hybrid vehicles. Speed and precision of such circuits can both improve battery backup and battery life.**

***Keywords*— MPPT(Maximum Power Point Tracking), solar powered vehicle, variable step size , Incremental conductance, PID(Proportional Integral Derivative), buck/boost converter .**

I. INTRODUCTION

Mankind in last few decades have understood the necessity and need of fulfilling the energy requirements by use of renewable resources of energy. Solar being one of the most easily and abundantly available resource gets most of the attention. However utilizing and harvesting solar electricity in efficient way is one of the biggest technical challenges. This is due to the fact that power output of a solar cell is not only dependent on solar intensity but also upon load applied to it. So for extracting maximum power available at all possible conditions we use MPPT i.e. Maximum Power Point Tracking techniques. MPPT is a technique which changes the load appearance to solar panel such that solar panel can run on maximum power point [2][3]. Typical Solar panel characteristics are shown in figure below.

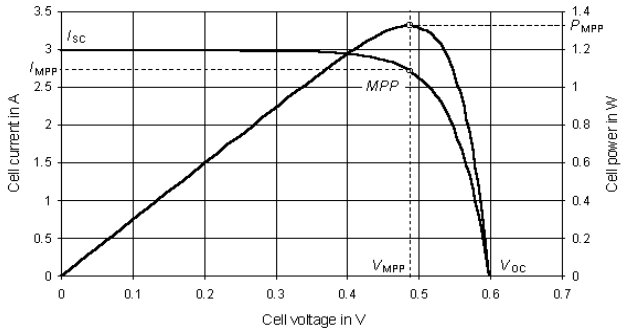

Fig: 1 Typical Solar panel characteristics

It is very clear from Fig 1 that maximum power is obtained only if Appeared Load Resistance Lr' is equal to the ratio of Vmpp to Impp, for a particular solar irradiance.

Most common Algorithms for MPPT are.

- Fractional Open Circuit Voltage
- Fractional Short Circuit Current
- Perturb and Observe (P&O)
- Incremental Conductance(IC)

All the above mentioned algorithms are widely used in commercial MPPT controllers but there always exists some trade off with performance. Both P&0 and IC are hill climbing method which means that output will always oscillate around maximum power point. The best suited algorithm for varying load and solar intensity is IC. However this technique fails when rate of change of one of the factor increases as in solar powered vehicles. In such cases the control loop may go out of lock very frequently and fails to serve its purpose. Varying step size according to the change in power is one of the possible solutions for this problem. This technique does not only improve the system performance significantly but also reduces the power oscillations at the output of system.

II. SOLUTION PROPOSED

To achieve goal of high performance and low cost as required in solar powered vehicles , the step varying Incremental Conductance(IC) algorithm along with a Proportional Integral Derivative(PID) enforced operating voltage driving loop is implemented in this project. This loop forces the operating voltage of solar panels to achieve a particular level where MPPT loop wants operating voltage level to be. PID loop changes the step size in accordance with the total error available to it at time of its initiation.

III. SYSTEM ARCHITECTURE

The whole system can be explained in detail using four major blocks as described:

1. Current and voltage sensing stage.
2. Processing and Control Unit.
3. PWM generator.
4. DC-DC converter.

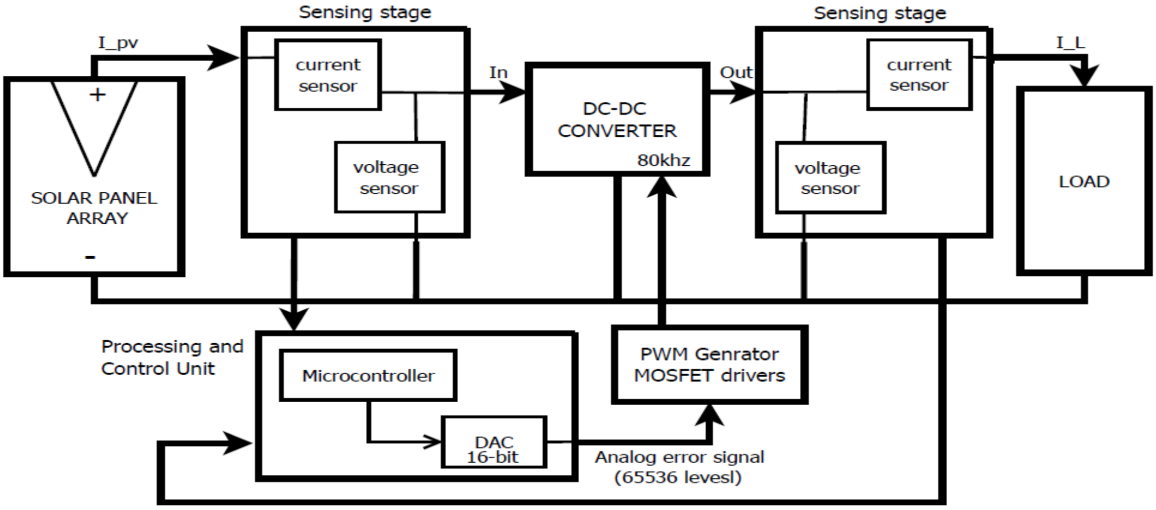

Fig. 2 High Level block diagram

1. *Current and Voltage sensors*:

Current sensor used here is a shunt type current monitor (Fig. 3) which is based upon low noise and low offset difference amplifier with configurable gain upto 60db. Shunt resistance is as low as .00006 ohms. Previously increased conductance MPPT algorithm also applied without current sensor [4][5] with a number of low efficiency problems. Here current sensor produces voltage output between 0V to 2.40V when maximum of 30A current flows through it. This allows us to read high current levels without any significant drop across shunt resistance.

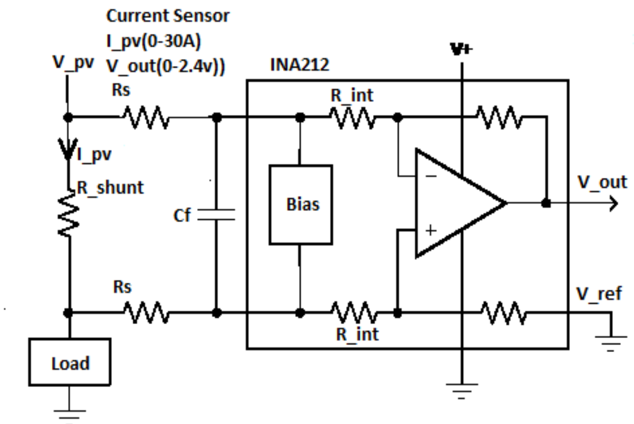

Fig. 3 Current sensor using INA212

Voltage Sensor includes a potential divider resistor network followed by a low pass filter. This network attenuate the input voltage to an optimum level between 0.0V to 2.4V when it has maximum of 70Volts across it.

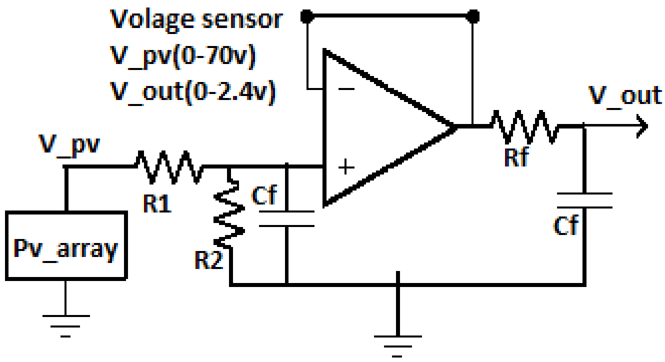

Fig. 4 Voltage sensor and LPF

2. *Processing and control unit*:

After taking continuous real point values from sensors, it is required to be fed into processing unit with adequate conversion. This section is based upon MSP430G2553 controller with mixed signal processing [1][7][10]. It has 10-bit ADC, two 16-bit timers and a serial interface peripheral.
This controller reads the analog signals produced by voltage and current sensors and then runs the algorithm to estimate the correct operating condition for solar panel.

The Algorithm stated in Fig. 5 is Incremental Conductance besides that it has variable step increment and decrement. This loop estimates MPP quickly and precisely. Variable step size of this loop also minimises the possibility of oscillations around MPP. This algorithm is highly sensitive to both variations in solar irradiance and load changes due its sensitivity to both Voltage and Current variations.

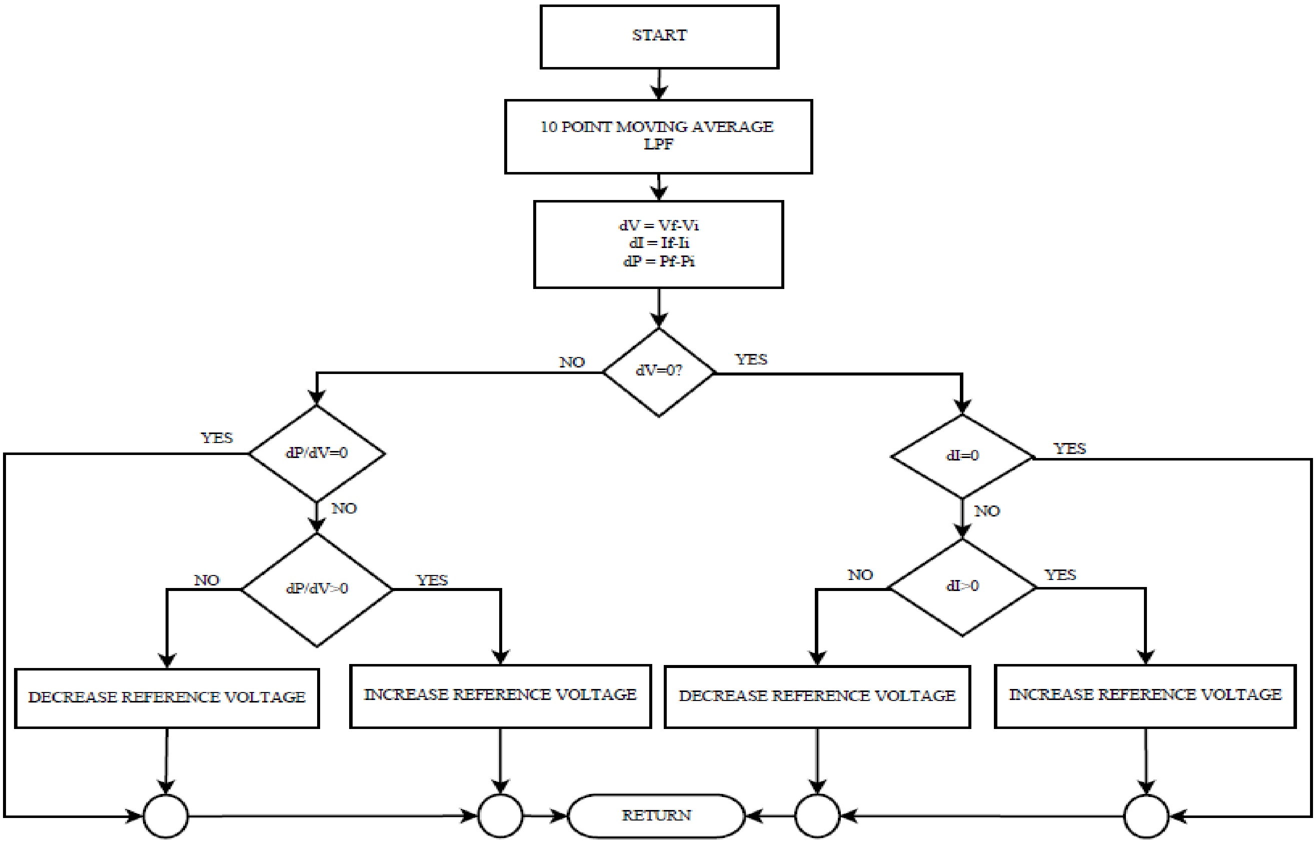

Fig. 5 Flow chart of MPPT control Loop

However it should be kept in mind that this loop should not directly control the DC-DC converter due to the fact that the DC-DC converter takes its own time to change the operating voltage of panel. So to handle this task i.e. to drive operating voltage of solar panel to reference generated by MPPT loop we have to employ another loop which should be fast and precise enough to track reference level. In our case this PID loop runs 25 times faster then MPPT loop this decreases the possibility of MPPT loop going out of lock.

Flowchart in Fig. 6 is showing the detailed information regarding the working of PID loop which has step variable error reduction. This is a generic loop and basically controls the DC-DC converter output. It takes 2 arguments from calling loop. One tells about present state and another tells about the target state. This state can be either of voltage or current.

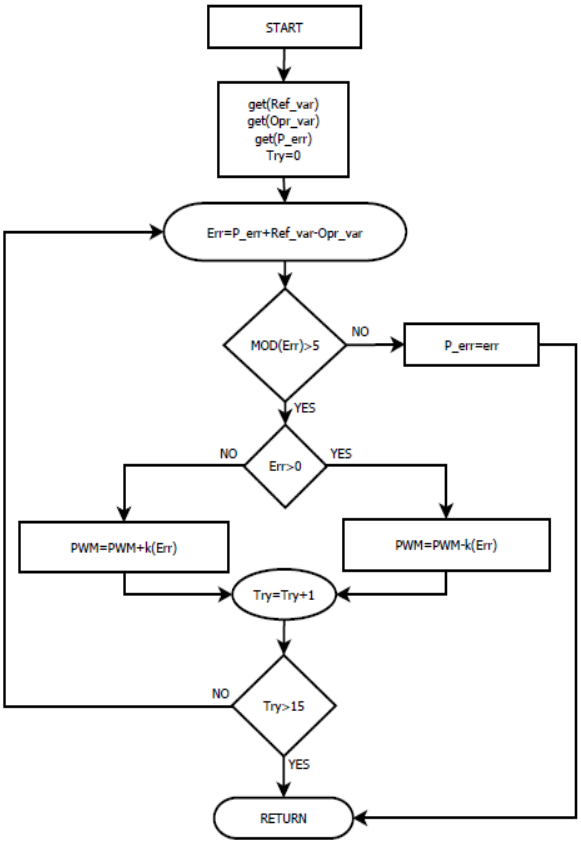

Fig. 6 Flowchart of Error correction loop

Using this loop system can run in following ways:

- Input Voltage Control
- Input Current Control
- Output Voltage Control
- Output Current Control

3. *PWM Generator*

TL494 is used as PWM generator. It has two error control amplifiers which has configurable gain setting[12]. However in our application we are using only one error amplifier. Error amplifier is configured in such a way that output PWM is directly proportional to input potential across its terminals. This error analog signal is generated by 16-Bit DAC [11]. Frequency of PWM is kept at 60KHz for having effective switching of MOSFET devices.

4. *DC-DC converter*:

This module takes care about the adequate operating voltage of solar panel to the point where controller wants it to be driven.

DC-DC converter employed here is an isolated buck/boost converter (Fig. 7). It has dedicated PWM generator whose output is controlled by a 16-bit DAC. DC-DC converter is capable of handling 1KilloWATT of power. This is designed in such a way that on 35% duty cycle output voltage is exactly equal to input voltage. Relationship between Output and input voltage depending upon Duty Cycle is given below

V_out = (2.8* V_in*D/100) - D_v.

'D' is duty cycle in percentage

'D_v' is drop across rectifying diode

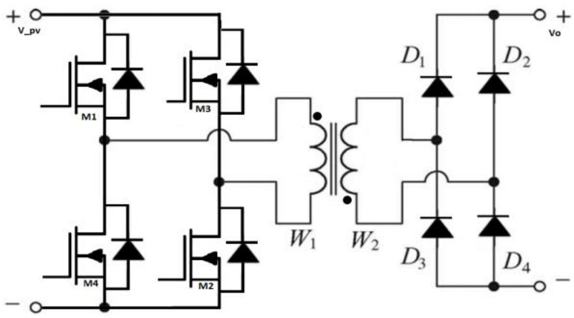

Fig. 7 Topology of Isolated DC-DC converter

IV. Experimental Set-up

Our first experimental setup was designed which aimed in finding out various areas of improvement. We started with 100W solar panel with (Fig. 8) a non isolated buck type asynchronous DC-DC converter.[6] PWM for this was generated with same MSP430 controller which was also running MPPT algorithm. This limited the PWM frequency as well as steps. With this maximum of 400 steps for PWM at 40Khz were attained.

Fig. 8 Prototype of isolated buck-boost Converter

TABLE I

Testing of DC-DC converter

Input Voltage	Input Current	Output Voltage	Output Current	Input Power	Output Power	Efficiency
12.69	3.56	3.62	12	45.176	43.44	96.76
12.21	2.34	3.11	8.89	28.57	27.64	89.95
12.93	1.85	2.85	7.55	23.92	21.51	75.79
14.87	1.37	2.55	6.07	20.371	15.47	71.22
14.99	0.88	2.16	4.35	13.19	9.39	72.013

0

Fig. 9 Simulation Model of DC-DC Converter

After implementation we realized that System works very efficiently and effectively till the point we have some passive load (example LEDs, bulb). However System fails to operate solar panel at maximum power in some cases when load is a battery. This is because the absorption charge of battery is not at optimum level which can derive solar panel to its peak level. Problem can be solved by using boost converter.

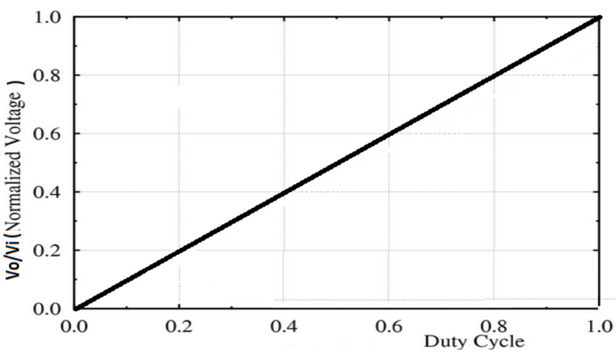

Fig. 10 Transfer characteristics of Buck Converter

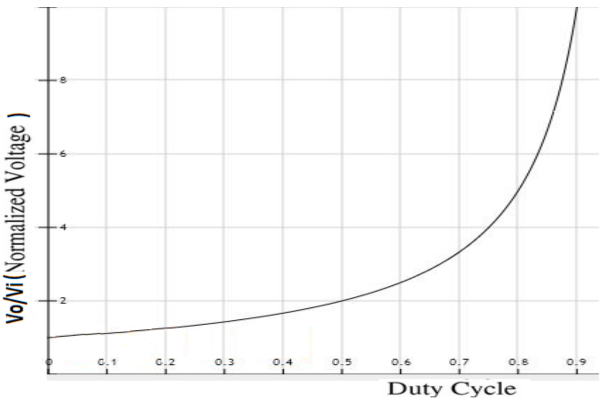

Fig. 11 Transfer characteristics of Boost Converter

It is very clear that non-isolated buck converters have linear relationship of duty cycle and output voltage whereas boost converter is non linear in nature and hence are little more complicated to control using step varying technique.
So it is desirable that system has linear characteristics and should work as both buck and boost converter.

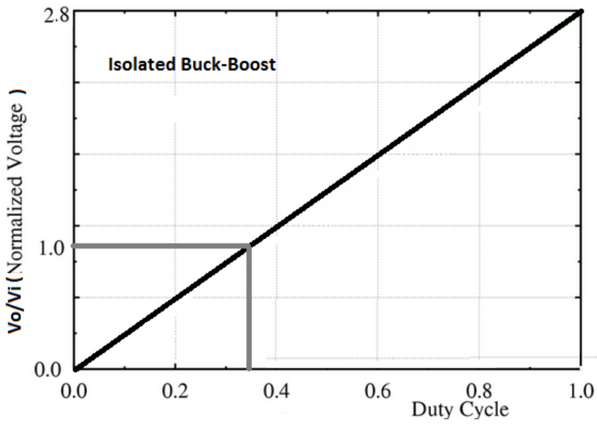

Fig.12 Transfer characteristics of isolated Buck-Boost Converter

So an isolated buck-boost converter (Fig. 12) is designed to have transformation ratio of about 2.85.At duty cycle of 35% we will have output to be equal to input voltage. Hence this converter can provide us better control over variations in load and can force solar panel to be driven to maximum limits.

Figure 10 depicts the variation in normalised voltage with change in duty cycle i.e. transfer characteristics of Buck converter showing linear behaviour. But the transfer characteristics of boost converter in non linear as in Figure 11. The simulation of full- Bridge DC-DC converter (Figure 13) is performed with high/low side MOSFET driver.

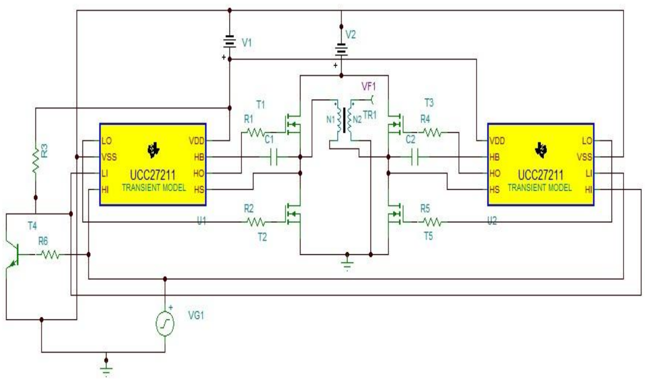

Fig.13 Simulation Modal of Full-Bridge DC-DC converter

Fig.14 LCD showing present state of System

V. CONCLUSION

Overall it is realised that MPPT technique is one of the most important factor that may considerable affect the whole system performance. Existing MPPT algorithms are liable to lose the track of maximum power point whenever used in fast changing conditions. Most of the MPPT controllers available for such applications have comparatively higher cost because the employ higher cost DSP's.
Solution purposed in this paper has been experimentally tested and performed with widely varying load and solar intensity such as in solar powered vehicle.
Since system uses double step size varying technique and has a dedicated PWM generation circuit, it has response time of tracking MPP with value of about 250ms which is sufficient for such conditions. However the cost of system is not compromised and kept a way below then commercially available high performance MPPT controllers.

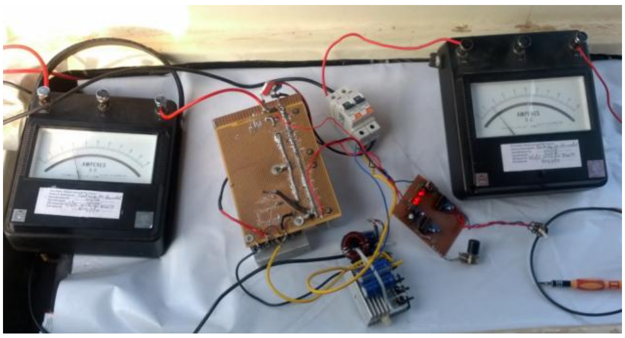

Fig.15 setup at the field testing stage

VI. FUTURE SCOPE

Here we are implementing the high performance incremental conductance algorithm based MPPT control. We are planning to have an embedded software solution for load type sensing and battery charging techniques. With this our system will have compatibility with almost every type of load. This will not only ensure the longer life time of battery charged using this controller but will also maximise the average running hours of solar power on daily basis.

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