Performance Investigation of Improved High Step-up MPPT using Fuzzy Logic Controller for BLDC Motor Drives

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Abstract : *In this paper, the conventional DC-DC converter is replaced with a High Step-up Converter for the Maximum Power Point Tracking (MPPT) in solar power applications. The performance of converter-inverter technology to drive a brushless DC motor is analysed. The converter switching power losses is eliminated by zero-voltage method in this proposed converter. The fuzzy controlled high step-up converter increases the output voltage from the panel compared to the conventional type. The DC to DC converter is operated at an adjustable duty cycle by the fuzzy logic controller. The advantage of the proposed high step-up converter for the MPPT compared to the conventional type are, the output is efficiently increased and regulated by the boost operation. This avoids the parallel buck operation. The ZVS technique further reduces the power loss due to frequent switching. The proposed fuzzy controlled unidirectional operation of the high-step up MPPT converter is analysed. The experimental results are compared for different inputs and analysed.*

Keywords:*Brushless DC Motor, Fuzzy Logic Controller, High Step-up Converter, Maximum Power Point Tracking, Zero-voltage switching.*

I. Introduction

The years of research in solar power applications have reached to a greater extent in the field of power generation and utilization. Problems caused due to non-renewable resources are being explained for years which introduced the renewable energy resources using wind, solar, tidal, water as its major source of power generation. The influence of these renewable resources requires a higher power generation compared to the non-renewable resources. This is being a major problem for years, in comparison to the existing non-renewable energy units. In developed counties, the problem is solved by introducing the advanced control units for the renewable energy resources to compete the production capacity of the non-renewable energy resources.

However the research and developments have a challenging environment in producing high power generation units using renewable energy. The use of the solar is widely seen in many applications. However the power conversion from the renewable energy is the challenging task. It is well known that the power extraction from the renewable energy is not possible for 100% extraction. This challenging task over years has developed various power electronics techniques to extract the maximum power from the renewable source. In solar, the solar panels require the maximum power point tracing system (MPPT) to obtain the maximum power. In conventional methods the MPPT is performed using the DC-DC converter through the controllers. This DC-DC converter is operated both in buck and boost operation to obtain the wide range of voltage values. There are various methods to obtaining the maximum power from the solar energy. Each method has its own significance. The solar energy form the solar power is converted to electrical form using the solar PV panel. The solar radiations are not the constant source so the output of the solar panel is also variable [4]. The power constancy is obtained by using the DC-DC converters. The different DC-DC converters are the buck, boost and cuk converters are used based on the application requirements. The implementation of cuk converter for the power constancy which is also referred to maximum power tracking method is used in direct control of power extraction [1]. The MPPT techniques have various advantages which is discussed and compared and the significance are studied [2]. The implementation of boost converter is more common among the MPPT technique. The boost converter output is comparatively efficient however; the extraction of power from the panel is considerable limited [3]. In some applications it is necessary to have the buck and the boost converter to obtain the various level of the power output, but the cost of two converters in a single system is not much efficient for the power generation [5]. Further discussions have turned another new method of MPPT for the lower power solar PV panels [6]. In the proposed method, the MPPT involved uses the boost converter which is controlled using the fuzzy logic controller. This fuzzy logic controller efficiently controls the boost converter operation in obtaining the maximum power from the solar PV panel.

II. Modeling of Solar PV Panel

The solar PV can be modeled by a current source acting as the PV panel current (I_{pv}) connected to the parallel diode. The equivalent structure implies the photo-diode operation producing the current (I). The combination of the series resistance (R_s) and the parallel resistance (R_p) refers to the solar array consisting of the

solar cells connected in series and parallel combination. The modeling of the PV cells describes the I-V characteristics of an ideal PV cell. The equivalent circuit of the PV cell is shown in Figure 1.
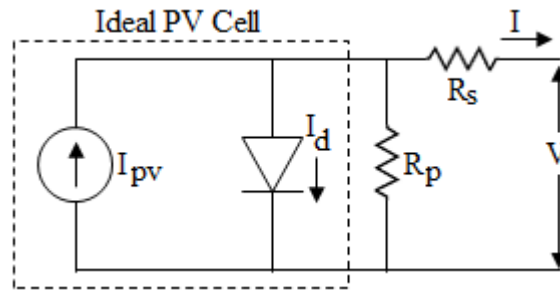

Fig.1. Equivalent Circuit of PV Cell

The output of the current from the PV cells is given as,

$$I = I_{pv,cell} - I_d \qquad (1)$$

Where,

$$I_d = I_{0,cell} \left[\exp\left(\frac{qV}{akT}\right) - 1 \right] \qquad (2)$$

Therefore,

$$I = I_{pv,cell} - I_{0,cell} \left[\exp\left(\frac{qV}{akT}\right) - 1 \right] \qquad (3)$$

Where,

$I_{pv,cell}$ is the current generated by the incident light (it is directly proportional to the Sun irradiation),
I_d is the Shockley diode equation,
$I_{0,cell}$ is the reverse saturation or leakage current of the diode,
q is the electron charge (1.60217646 × 10−19 C),
kis the Boltzmann constant (1.3806503 × 10−23 J/K),
T (in Kelvin) is the temperature of the p–n junction, and
ais the diode ideality constant.

The figure 2 shows the origination of the I − V curve for the equation (2). Practical arrays are composed of several connected PV cells and the observation of the PV array requires the inclusion of additional parameters to the basic equation.

Hence,

$$I = I_{pv} - I_0 \left[\exp\left(\frac{V+R_s I}{V_t \alpha}\right) - 1 \right] - \frac{V+R_s I}{R_p} \qquad (4)$$

Where,

$V = N_s kT/q$ is the thermal voltage of the array with N_s cells connected in series.

The output voltage is increased by increasing the number of the series cells because the voltage gets added up in series combination. Similarly, the current is increased on parallel connection of the solar cells as the current gets added up in parallel combination under same direction. If the array is composed of N_p parallel connections of cells the photovoltaic and saturated currents may be written as,

$I_{pv} = I_{pv,cell} * N_p$, and
$I_0 = I_{0,cell} * N_p$.

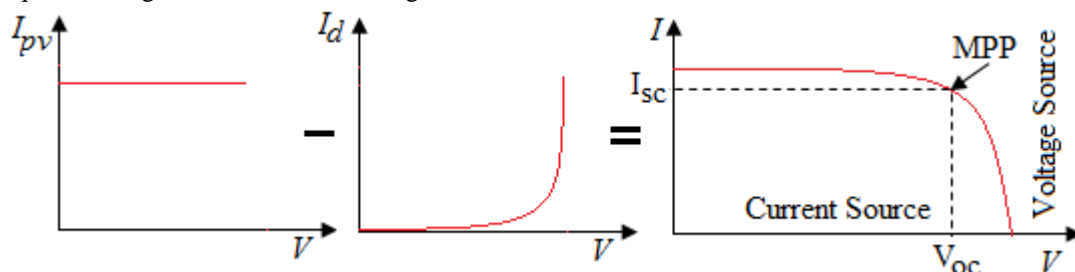This equations originate the I-V curve in figure 2.

Fig.2. Origin of I-V equation of an Ideal PV cell curve of a practical PV module and Characteristic I-V curve of a practical PV module

The mathematical modeling equations of the PV panel are modeled using suitable equations programmed in the MATALB. This simulation is done for standard test condition (STC) when temperature is 35ºC and Irradiation is 3000 W/m². The modeling is done for a 500W solar panel.

TABLE I PARAMETERS OF THE PV PANEL – TATA BP1235

Open Circuit Voltage V_{oc}	500 V
Short circuit Current I_{sc}	10.9 A
Maximum Voltage V_m	487.5V
Maximum Current I_m	10.35A

III. Modeling of MPPT using High Step Up Converter

DC-DC Converters are prominently used to obtain the Maximum Power output from the PV panel. The conventional DC-DC are operated both in buck and boost condition. The optimized output value is set such that if the output from the panel when comparatively less to that of the desired out is boosted and when comparatively greater than the desired output it is bucked. This double operation minimizes the output level due to the frequent operation of the converter both in buck and boost operation. In the proposed method, a high step up converter is used such that for any output obtained from the panel can be boosted to a maximum constant value to attain the maximum power. This can be done by selecting the duty cycle of the converter such that the voltage is boosted to a constant value. This can be performed using a controller to convert feedback signals to a desired output pulse for the converter. In this proposed technique fuzzy logic controller is used to select the desired duty cycle. Due to this the limitation in the linear voltage output is eliminated. The switching losses are reduced as the converter operates only in boost condition. The figure 3shows that high step-up converter for the MPPT technique. The circuit diagram consists of the Solar PV Panel connected to the proposed converter. The output of the panel is controlled by the step-up DC-DC boost converter. The converter produces a constant boosted output for the load. The stepped voltage is inverted using an inverter to supply the brushless DC Motor. The power drop during the inversion process is compensated by stepping up to a higher value at the input level so as the losses is reduced during the power conversion and drive operation.
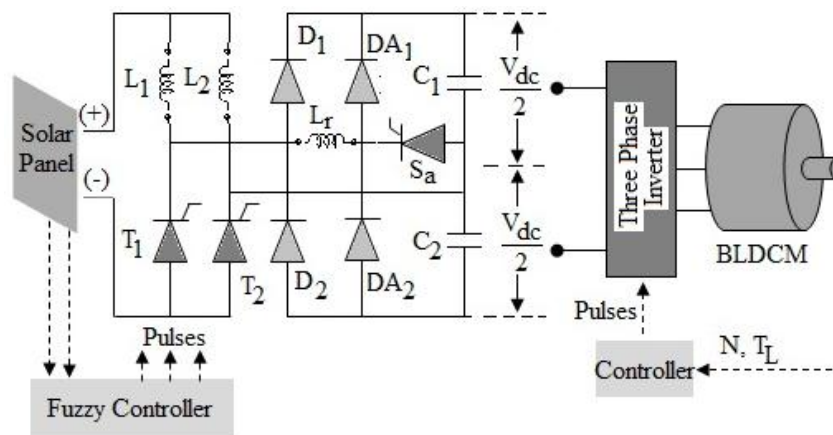

Fig.3. Proposed High Step-up Converter Driven BLDC Motor

The proposed high step up DC-DC boost converter is constructed using two thyristor switches T_1 and T_2 connected in series to the inductor L_1 and L_2 respectively. The gate pulses are signaled to switch ON and OFF the thyristor switch T_1 and T_2. A resonant inductor is connected to this boost circuit which consists of the series combination of diodes D_1 and $D_2$and additionally a parallel combination of auxiliary diodes DA_1 and DA_2. The stress in the switching of the thysistor is reduced by soft switching using the Auxiliary thyristor switch S_a which is turned ON and OFF using separate gate pulses. This is due to the zero voltage switching (ZVS) technique followed in the proposed converter circuit. The output of the converter is maintained constant by the capacitors C_1 and C_2. The output is maintained constant thereby to supply as a source to the three phase inverter. The boosting nature of the circuit produces the voltage step up level at the motor rated voltage thus driving the motor.

The figure 3 shows the proposed circuit diagram with power stage. The proposed circuit is divided into three stages: first is the boost power factor pre-regulator for the continuous conduction mode (CCM) for the PWM. This involves the power factor correction in the AC/DC boost conversion. The boost power factor pre-regulator operating at fixed frequency and variable duty ratio is dependent on the amplitude of the voltage. When the rectifier operates at higher line input, the sinusoidal duty ratio is lower. Thus, the line voltage is zero so as the maximum duty ratio is located. The minimum duty ratio is located on that the line input voltage is equal to its peak value. Using the input inductor this can be controlled and thereby reducing the total harmonic distortion to get high power factor. Second stage provides soft-switching on the thyristor switches. This is rated

for small power when compared to the power output. The positive half voltage region is specified for the simplicity of the analysis. Also, it is assumed that the proposed dc power supply system is operating in steady state and the following assumptions are made during one switching cycle.

The input current is constant and is greater than the resonant inductor is observed during the cycle and a large value is assumed for the power factor pre-regulator inductor L_1 and L_2. The constant and ripple free values are obtained in the voltage V_{dc} by the capacitor C_1 and C_2.

The lossless switching operation is obtained using the zero voltage switching of the proposed converter. The inductor and capacitor values and the switching pulses for both the thyristor switches are mathematically calculated. During the ON and OFF condition the auxiliary switches perform the ZVS operation.

IV.   Modeling of Fuzzy Controlled MPPT

The maximum power point tracking is a technique that involves the voltage and current peak values. This electrical method applied, tracks the power which is maximum available with respect to the temperature and radiations of the solar. This method of tracking the power is more efficient compared to that of the mechanical tracking which requires additional power to the drives operating the panels.This control technique can be implemented using the fuzzy controller which is comparatively more efficient in MPPT technique.The functional block diagram of the fuzzy logic based MPPT system is shown in the figure 4.
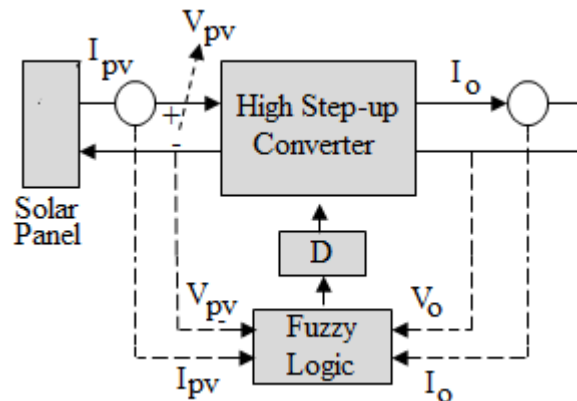

Fig.4. Fuzzy Logic Controller for Solar Panelc.

TABLE IIIFUZZY RULE TABLE

ΔVpv/ΔPpv	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NS	NS	NS	Z	Z
Z	Z	Z	Z	PS	PS
PS	Z	Z	PS	PS	PS
PB	Z	PS	PB	PB	PB

V.   Simulation Modeling and Results

The proposed system is mathematically modeled in MATLAB. The solar panel is modeled using the equivalent circuit programmed in MATLAB. The output of the solar panel is tracked by the maximum power point tracker using High step–up DC-DC converter controlled by fuzzy logic controller. The figure 5 shows the power generated from the solar panel and the power tracked using various techniques. The solar power obtained in the panel is subjected to the solar irradiation and the temperature. The solar energy converted is tracked using a reference voltage. By using conventional DC-DC converter operating both in buck and boost operation the output voltage is constant but limited to the maximum values. In proposed method, the high DC-DC converter acts only as a boost converter, thereby stepping up the voltage to maximum value. This enables the maximum power output under any input conditions.

The power developed in the PV panel is connected to the high step up DC-DC converter for tracking the maximum power. This input voltage is controlled effectively by the fuzzy logic controller (FLC).
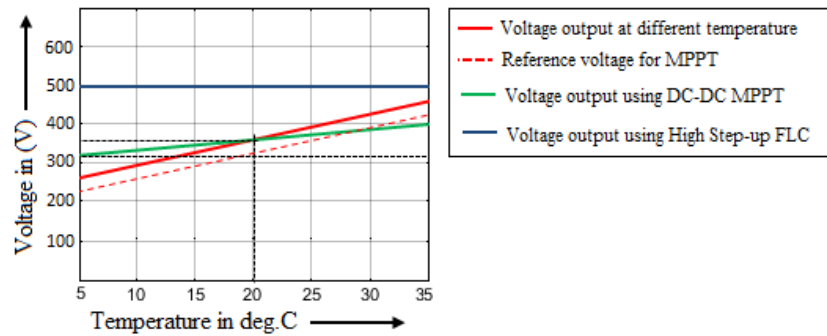
Fig.5 Voltage generated by solar panel using proposed MPPT

The voltage output variations are limited to very small range and are neglected in practical applications. The figure 6 shows the output of the high step up converter.
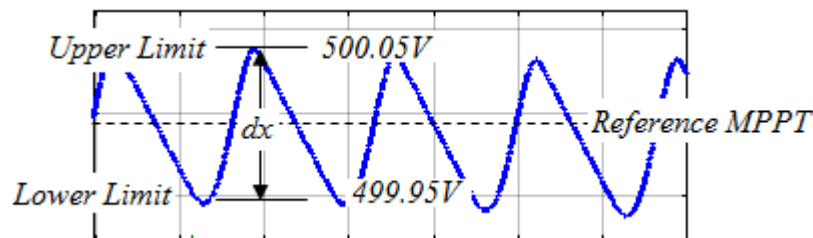

Fig.6 Effective voltage output using FLC

The figure 7 shows the voltage vs. incidence/deg.C graph. The incidence / deg.Care 0.6 for the maximum voltage to be obtained close to 480V. The region at which the voltage curves drifts along the incidence angle is referred to drifting region.
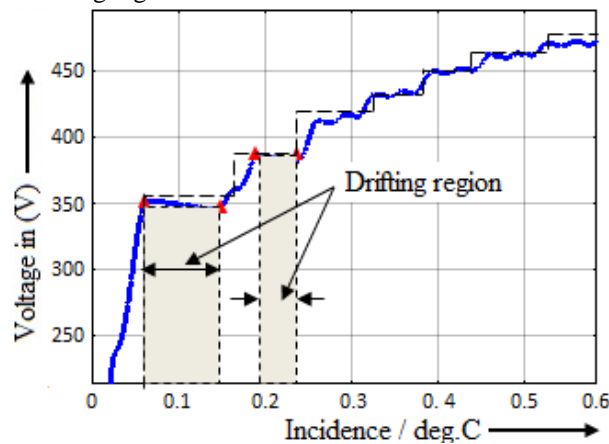

Fig. 7Voltage vs. Incidence/deg.C

The output from the high step-up converter is fed to a three phase inverter. The input to the three phase inverter is divided into two dc voltages ($+\frac{V_{dc}}{2}$ and $-\frac{V_{dc}}{2}$). The input is inverted using space vector PWM technique to obtain maximum inverted output. Though the inverter operation provides buck operation, the strategic control by SVPWM inverts the voltage with minimum losses. The voltage output simulated is shown in the figure 8. The voltage output from the inverter is used to power the input to the BLDC motor. The speed of the BLDC motor is sensed using the hall sensor and it is fedback to the SVPM controlled with the error signal. The error signal is corrected and it is converted into gate signal to the power converter. The figure 9 shows the modeling of the speed controller of BLDC motor.
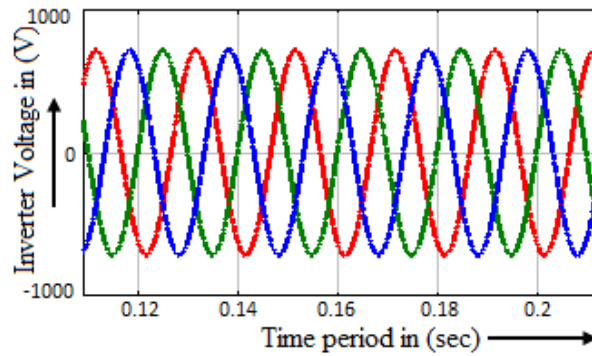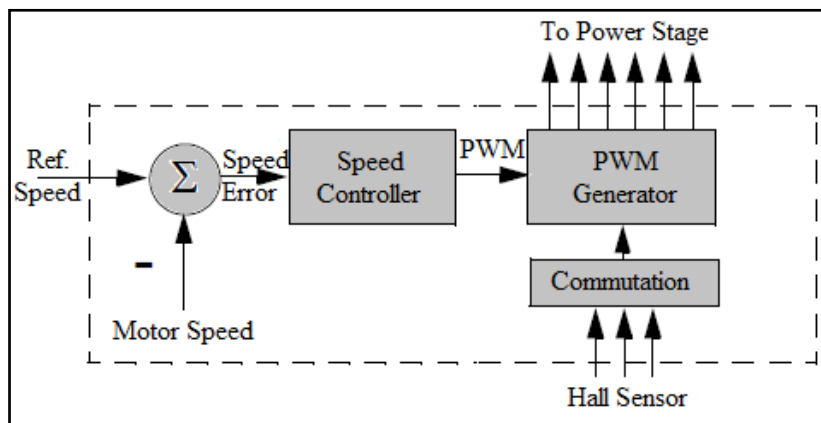
Fig. 8 Three phase inverter output

Fig. 9 Speed Controller of BLDC Motor

VI. Hardware Model and Results

The prototype model of the proposed method is developed for a 500W solar panel. The solar panel is regulated using fuzzy logic controlled to track the maximum power using high step up DC-DC converter. The high DC-DC step up converter acts as the MPPT controller to track the solar power.
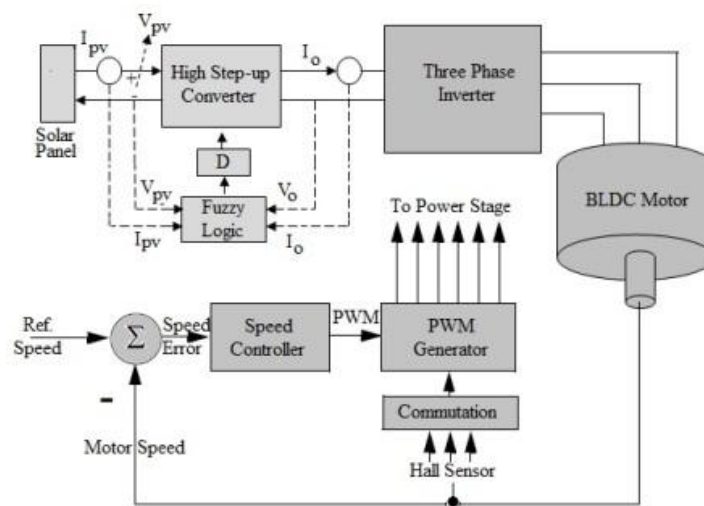

Fig. 10 Hardware prototype model

The SVM is programmed using ATMEL 32-bit AVR Microcontroller using six channels. The AVR32UC3 is widely used in the speed control of BLDC motor.The hardware model is modeled in the laboratory for a closed loop speed control of the BLDC motor. The figure 10 shows the hardware model of the proposed system.

The figure 11 (a) shows the DC output obtained from the solar panel through the high step up DC-DC converter. The DC voltage of 373V is obtained from a 400V panel. The voltage obtained is inverted using three

phase inverter controlled using space vector pulse width modulation. The inverted output voltage is shown in the figure 11 (b). The inverted three phase output obtained is 338V.

<table>
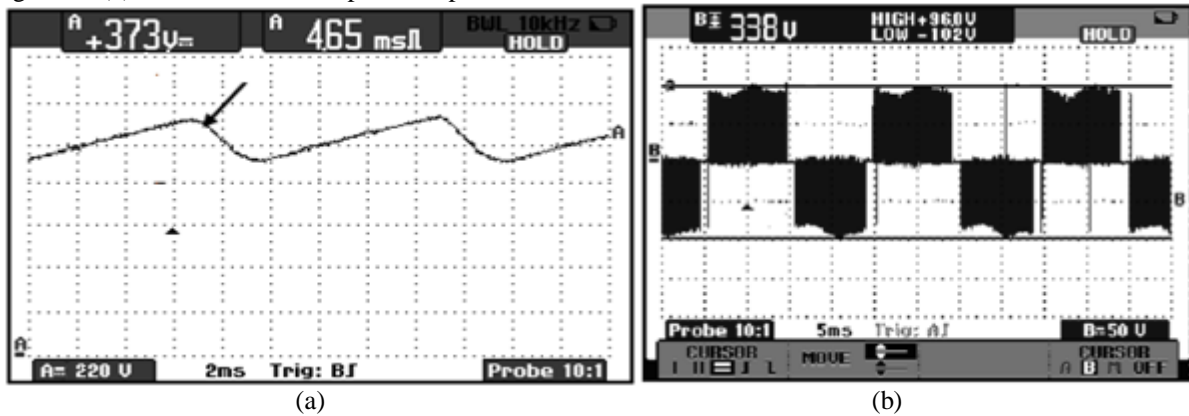<tr><td>(a)</td><td>(b)</td></tr>
</table>

Fig. 11 Voltage output (a) from the panel (b) from the inverter

The output power is measured using the power quality meter. It is observed that the current RMS value to be 1.3A. The output power obtained is 391.29W with 0.9 power factor. The screenshot of the power quality meter while measuring the parameters is shown in the figure 12.
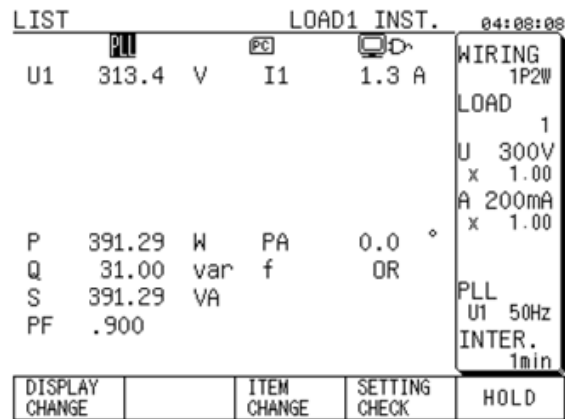

Fig.12 Output measurement using power quality meter

VII.   Conclusion
The proposed high step-up DC-DC converter replaces the conventional DC-DC converter for the MPPT technique. The proposed technique involves boost conversion of the input power produced by the solar panel. The high step up converter steps up to the maximum value and regulates the value of the voltage to a constant value irrespective to the change in the input voltage. The conventional MPPT using the DC-DC converter involves the buck boost conversion which is limits the voltage output. The power extracted from the panel is inverted using the space vector controlled three phase inverter with minimum power loss. The proposed method provides a high step up power output for the drive application. Here the BLDC motor drive is used to study the performance. Extending its scope, the proposed method can be implemented in hybrid power generation.

Acknowledgements

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