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RESEARCH ARTICLE

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PERFORMANCE OF SOLAR PV SYSTEM WITH BATTERY BACKUP FOR UNINTERRUPTED LOADS AND COMPENSATION FOR UNBALANCED AND DISTORTED LOADS

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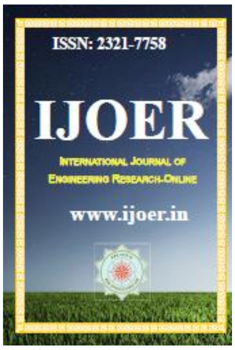

ABSTRACT

A simple and cost effective control technique has been proposed for MPPT from the photovoltaic array under varying climatic conditions (Irradiance w/m2 of the photovoltaic). This paper proposes an energy system combing solar photovoltaic with battery backup as a small-scale alternative source of electricity in rural areas. The proposed system is an attractive owing to its simplicity, ease of control and reliability. The paper also discusses about the in detail results for low and average irradiance cases are presented and analyzed in order to determine, how output power and other quantities are affected by changes in solar irradiance. In this, the solar cell is delivering power to both AC and DC loads with battery backup. The role of MPPT algorithm is to charge battery quickly, maximum utilization of solar power and also uninterrupted power supply when solar power fails. This solar PV system can be applicable to remote located industrial loads like heating, welding and small arc furnace type distorted loads and also for unbalanced loads. The PV inverter is designed such that it will maintain nearly constant voltage magnitude and can mitigate harmonics in voltage and current near the load terminals. The system performance is analyzed with and without MPPT algorithm, if failure in solar power how the system responds with and without battery backup were evaluated using MATLAB/ SIMULINK. The proposed technique shows that the inverter is effective for supplying uninterrupted load supplying, better performance during unbalanced and distorted loads. The proposed technique is having very less voltage and current harmonic content and can maintain nearly constant voltage profile for highly unbalanced system.

Keywords: Solar photovoltaic, buck-boost dc-dc converter, maximum power point tracking, solar irradiance, AC and DC loads, Lithium-ion battery.

1. INTRODUCTION

Solar power is the conversion of sunlight into electricity using photovoltaic (PV), which converts light into electric current using the photoelectric effect. India is located in the equatorial sun belt of the earth, thereby receiving abundant radiant energy from the sun [3].The India Meteorological Department maintains a nationwide network of radiation stations, which measure solar radiation, and also the daily duration of sunshine [5]. In most parts of India, clear sunny weather is experienced 250 to 300 days a year [4]. The annual global radiation varies from 1600 to 2200 kWh/m^2, which is comparable with radiation received in the tropical and sub-tropical regions. The equivalent energy potential is about 6,000 million GWh of energy per year [2,3].

So solar energy is available abundant in nature, be utilized for agriculture and low power applications where conventional energy is scares. Solar PV power system adjusts and distributes the power to ensure the safety of the load and system equipment, especially the management of the charge and discharge of the battery. Controller is the core part of the solar power systems. The efficiency, reliability, battery control of the solar power systems are up to controllers.

Solar Power Supply System is controlled by using MPPT for DC-DC Voltage-stabilization. It is not bound with the battery banks. Using MPPT function the system can freely search the max power point of solar array. It can set up the output voltages and conduct bulk & float charge and temperature compensation to the battery banks. It can make intelligent selection of energies so that the battery energy is used with appropriate proportion in due time. Compared to PWM control to optimize the power utilization, MPPT is easier, and has about 95% operational efficiency, whereas former has 60-80% efficiency, and can't conduct bulk & float charge and temperature compensation to the battery banks. The electrical energy delivered by the PV is easy converted into storage energy using battery bank or energy capacitor system (ECS) which meets the daily load fluctuations [6-9]. Several batteries can be stacked for 6kW or 12kW battery backup systems.

In this paper a PV array generating system is the major source of power to the DC load while the battery is used as back-up energy source. The DC load encompasses of RL load and DC motor. A simple and cost effective maximum power point tracking (MPPT) control with dc-dc converter is used to extract maximum power from the PV array.

2. PROPOSED SYSTEM

The PV module with 280Vdc under normal conditions with 34KW is designed to supply constant AC and DC loads, DC series RL load of 10KW and 100Var at 220Vdc, AC parallel RL (sensitive) load of 16KW and 800Var at 400Vph-ph ac. The battery bank is Lithium-Ion of 150V 8000mAh, used as power backup when solar cell fails. The MPPT algorithm adopted in this paper is a high efficiency DC to DC converter which functions as an optimal electrical load for a photovoltaic (PV) cell, most commonly for a solar panel or array, and converts the power to a voltage or current level which is more suitable to whatever load the system is designed to drive. The block diagram of the system is shown in the figure 1.

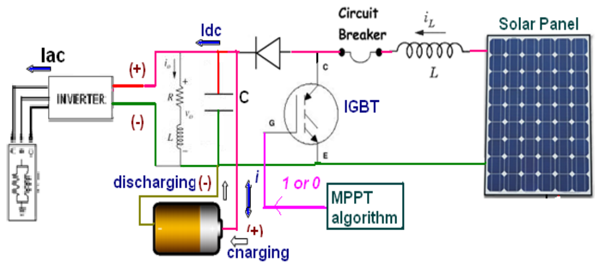

Fig 1: Block diagram representation of PV-battery system with AC and DC Loads

In any applications with PV module is energy source, MPPT solar charge controller is used to correct for detecting the variations in the current-voltage characteristics of solar cell and shown by P-V and I-V curve (Fig 3a & 3b).

The diode allows only unidirectional current flow from PV source to load. The inductor near the source is used to provide smooth direct current, IGBT with desired gate pulse is provided to operate the system as per the requirement. In the case if there is no load or lesser load, the total power from PV cell is used to charge the battery. The batter bank consists of a battery charger; diode which is to prevent the battery from being charged when the charger is opened after a full charge. A dump load may be required, if excessive power is still available after fully charging the battery.

Solar cell with MPPT algorithm: The photovoltaic (PV) power technology uses semiconductor cells (wafers), generally several square centimeters in size [1]. From the solid-state physics point of view, the cell is basically a large area p-n diode with the junction positioned close to the top surface. The cell converts the sunlight into direct current electricity. Numerous cells are assembled in a module to generate required power. Unlike the dynamic wind turbine, the pv instal- MPPT solar charge controller is necessary for any solar power systems need to extract maximum power from PV module; it forces PV module to operate at voltage close to maximum power point to draw maximum available power.

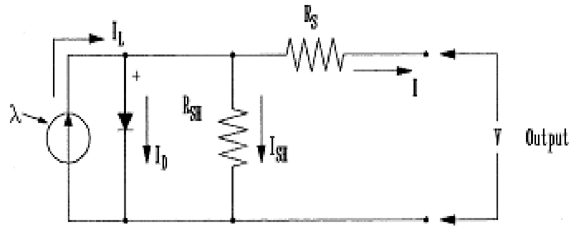

Fig 2. Equivalent electrical circuit of pv module, showing the diode and ground leakage currents.

The open circuit voltage of the equivalent pv module is given by the equation

$$V_{oc} = V + I\,R_{sh}$$

The diode current is given by the classical diode current expression:

$$I_d = I_D\left[\frac{QV_{oc}}{AKT} - 1\right]$$

Where I_d = the saturation current of the diode

Q = electron charge = 1.6 · 10–19 Coulombs

A = curve fitting constant

K = Boltzmann constant = 1.38 · 10–23 Joule/°K

T = temperature on absolute scale °K

The load current is therefore given by the expression:

$$I = I_L - I_D\left[e^{\frac{QV_{oc}}{AKT}} - 1\right] - \frac{Voc}{R_{sh}}$$

The last term, the ground-leakage current, in practical cells is small compared to I_L and I_D, and can be ignored. The diode-saturation current can, therefore, be determined experimentally by applying voltage Voc in the dark and measuring the current going into the cell. This current is often called the dark current or the reverse diode-saturation current.

If the 'i-v' characteristic of a 22-watts panel under two solar illumination intensities, 1,000 watts/m2 and 500 watts/m2. These curves are at AM1.5 (air mass 1.5). The air mass zero (AM0) represents the condition in outer space, where the solar radiation is 1,350 watts/m^2 [2, 3]. The AM1 represents the ideal earth condition in pure air on a clear dry noon when the sunlight experiences the least resistance to reach earth. The air on a typical day with average humidity and pollution is AM1.5, which is taken as the reference value. The solar power impinging a normal surface on a bright day with AM1.5 is about 1,000 watts/m^2. On a cloudy day, it would be low. The 500 watts/m^2 solar intensity is another reference condition the industry uses to report the i-v curves.

The photo conversion efficiency of the PV cell is defined as the following [1]:

$$\eta = \frac{\text{electrical power output}}{\text{solar power impinging the cell}}$$

Obviously, the higher the efficiency, the higher the output power we get under a given illumination.

MPPT solar charge controller allows users to use PV module with a higher voltage output than operating voltage of battery system.

Traditional Solar Inverters perform MPPT for an entire array as a whole. In such systems the same current, dictated by the inverter, flows though all panels in the string. But because different panels have different IV curves, i.e. different MPPs this architecture means some panels will be performing below their MPPT, resulting in the loss of energy.

Normal Solar Charge Controller: Solar Panel working voltage is a little higher than battery voltage. If Solar Charge Voltage: U_{ch}=280V, Charge Current I_{ch}= 60A, then Charge Power: P_{ch}=34*KW.

Solar Panel working voltage is a much higher than battery voltage. Battery Charge Voltage: Ub=150V with 50% charging and 8000mAH.

The power solar cell (Ps) is more than power of battery output (Pb)=12.07kW under normal conditions.

△P/ Ps = （Ps— Pb） / Ps＝64.5%

As a result of different manufacture of solar panels, different solar illumination intensity, different temperature, different efficiency of solar charge controller and so on. The effective power increase rate is 64.5%.

More research and development in the design and technological innovations could also decrease the cost of components, and in particular of energy storage systems, inverter (DC-AC) systems represent a major fraction of the total installation cost of systems where storage and conversion is required. New techniques have to be developed which integrate performance of larger system that delivers either electrical or thermal energy to a demand isolated solar collectors, along with energy storage for uninterrupted or future use.

3. Simulation Analysis

The physical of PV cell is very similar to that of the classical diode with a pn junction formed by semiconductor material. When the junction absorbs light, the energy of absorbed photon is transferred to the electron-proton system of the material, creating charge carriers that are separated at the junction. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field, and circulate as current through an external circuit. The solar cell is the basic building of the PV power system it produces about 1 W of power. To obtain high power, numerous such cell are connected in series and parallel circuits on a panel (module), The solar array or panel is a group of a several modules electrically connected in series-parallel combination to generate the required current and voltage. The electrical characteristics of the PV module are generally represented by the current vs. voltage (I-V) and the current vs. power (P-V) curves. Figs. and show the (I- V) and (P-V) characteristics of the used photovoltaic module at different solar illumination intensities.

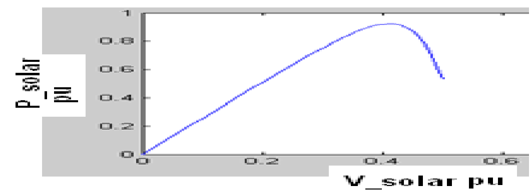

Fig3a: Shows P-V characteristics of solar cell with constant irradiation

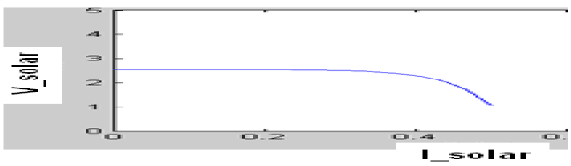

Fig3b: Shows I-V characteristics of solar cell with constant irradiation

The variation in electric power and voltage from solar cell with time variation in solar irradiance is studied using MATLAB. The power produced by the system, shown in Fig.4, is strongly dependent on solar irradiance. Fluctuations of solar irradiance lead to fluctuations of active power supplied to the distribution network. The unpredictable response of the system, assuming high densities of photovoltaic systems connected to the distribution network, can be troublesome for the producer of energy that has already scheduled the load for the time of peak demand. In the case of unpredictable variations of power quantities in distribution networks prediction algorithms must be utilized as described in [15].

Solar irradiation varies with time in seconds as [0 0.5 1 1.5 2 2.5 3] and magnitude as [13.75 27.5 41.25 55.00 41.25 27.50 13.75] is shown in figure 4. The variation in the form of increasing and decreasing can be considered as disparity of solar ray's intensity from morning to evening. Due to this, the solar cell output also changes accordingly, but we are using MPPT algorithm and capacitor at load, makes the output voltage and/ or power nearly constant.

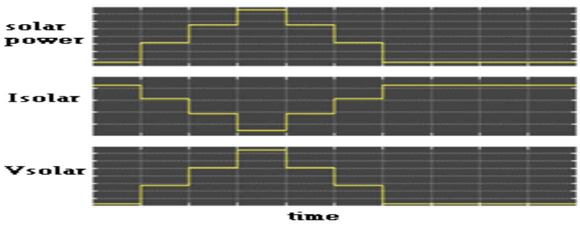

Fig4: Shows solar output power, current and voltage with varying solar irradiation considered in this paper

With the changes in the irradiation, the output power (top), current (middle) and voltage (bottom) are as shown in the figure4.

The proposed MPPT algorithm is simple and easy to implement is as shown in fig5. The multimeter reads the voltage output from PV cell. This voltage is compared with a reference saw tooth waveform voltage of 250V. The MPPT technique proposed in this work makes use of a predetermined relationship between the operating voltage or current and the open circuit voltage/short circuit current to obtain MPPT at any operating conditions.

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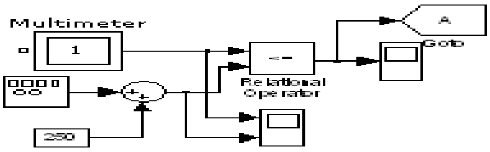

Fig5: MPPT algorithm proposed in the paper

The PV module with 280Vdc under normal conditions with 34Kw is designed to supply a constant loads, DC series RL load of 10Kw and 100Var at 220Vdc, AC parallel RL (sensitive) load of 16Kw and 800Var at 400Vph-ph ac. Solar energy is never constant in a day, varies with climate, pollution and many factors. Therefore PV source voltage, current, thereby power is varying with irradiation of sunlight Fig 4. Initially the solar irradiation is 13.75kWh/m^2 and is increasing and decreased to same value at 3 seconds then after maintained constant for remaining simulation time. The construction of the system using MATLAB is as shown in Fig 6.

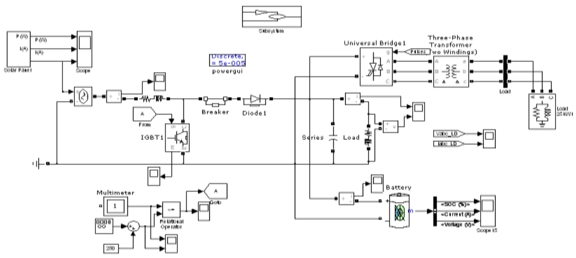

Fig 6: PV module with battery backup for AC and DC load

Case 1a: In this case influence of the system without applying MPPT algorithm is studied. The current flowing though the circuit is increasing and decreasing at regular intervals, due to the fact that solar irradiance is varying the same way, thereby, the output power is also varying.

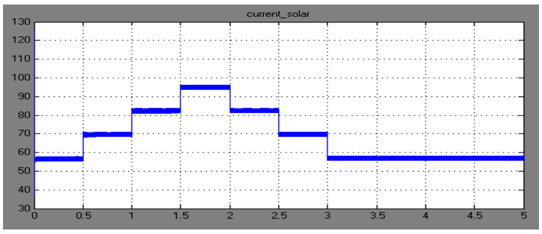

Fig 7: shows the current through the solar power, variation is due to disparity in solar irradiation without MPPT algorithm.

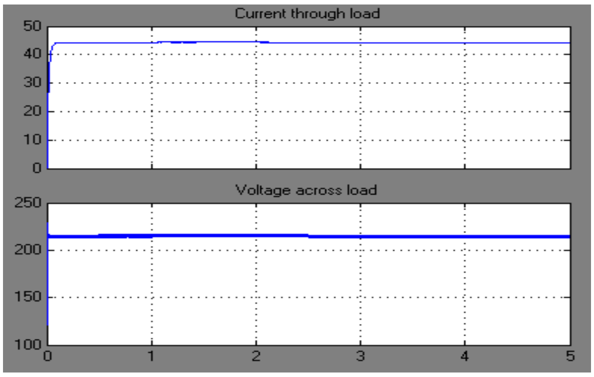

Fig 8: current and voltage near DC load without MPPT algorithm

In this the DC load is getting nearly 45A with 230V dc supply. The variation in solar irradiation is having very diminutive impact on both DC and AC loads as in Fig 8. Therefore power to both DC and AC loads are nearly constant.

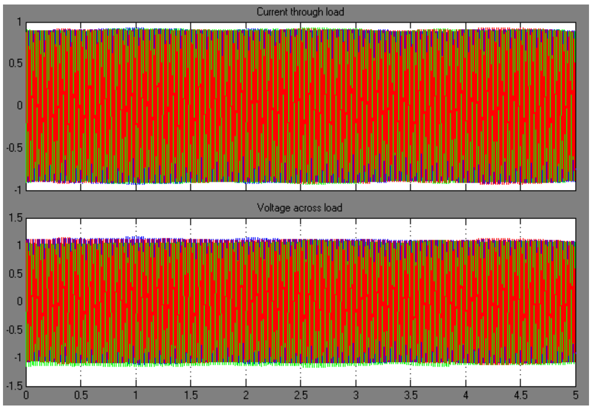

Fig 9: current and voltage at AC load without MPPT algorithm

The waveform for AC load was shown in Fig 9, current (pu) on the top and voltage (pu) on bottom with 400Vph-ph and 16Kw base values which are almost constant, even with variation in input. The zoomed current and voltage waveforms of Fig 9 at AC load without MPPT algorithm taken at 3.9 seconds till 8 cycles, is shown in Fig 10.

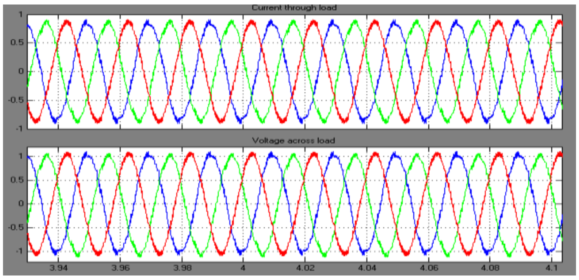

Fig 9: Zoomed view of current and voltage at AC load without MPPT algorithm

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The AC load wave form is maintained nearly constant of 400Vph-ph at 50Hz supply.

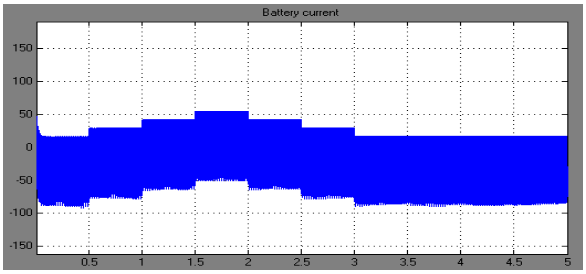

Fig 10: Battery current without MPPT algorithm

The Lithium-Ion battery current flow is shown in Fig 10. In this case, we did not apply MPPT algorithm. The current from battery varies from -90A to 50A. The waveform is having both positive and negative waveforms, which implies rapid charging and discharging.

Also we can say that the solar cell output is not effectively utilized, battery is also delivering supply.

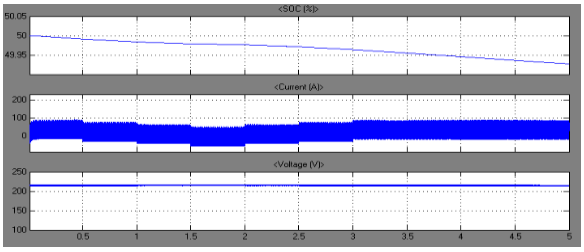

Fig 11: Battery SOC %, current and voltage without MPPT algorithm

The output of battery is shown in Fig 11, % SOC (top) indicates charging and discharging rate, In this case without MPPT algorithm, battery is also getting discharged (negative slope) to supply constant power to DC and AC load. The current (middle) is decreasing as solar current is increasing and vice-versa after 2s and nearly constant current after 3s and voltage (bottom) is nearly constant at 230Vdc.

Case 1b: In the system considered, the solar irradiation and other parameters were as is taken as in previous case, but circuit power flow is constrained with MPPT algorithm as in Fig 5.

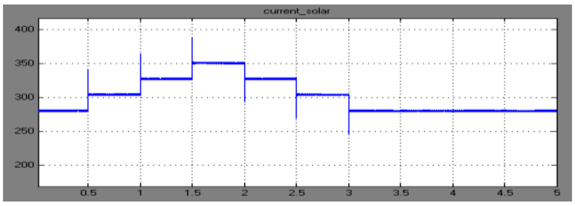

Fig 12: current output from solar cell with MPPT algorithm

With MPPT technique, the current through the solar cell has changed from 56A (Fig 7) to 280A (Fig 12). This shows that current extraction from solar cell has improved 5times.

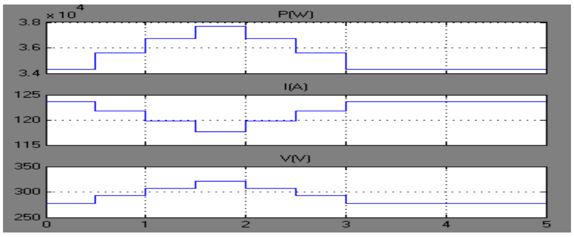

Fig 13: solar cell output power, current and voltage under normal conditions with MPPT algorithm

The solar irradiation is increasing insteps and reduced the same way as is shown in the Fig 13 with MPPT. So solar voltage (volts) is increasing, output power (watts) also increasing. As load is a constant power load, therefore current (amps) is decreasing in steps.

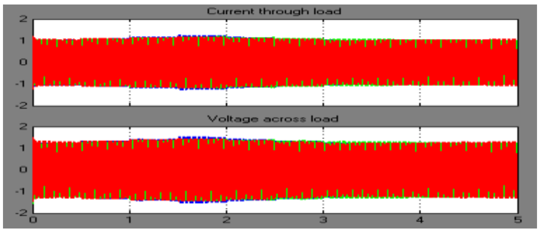

Fig 14: current and voltage near AC load under normal conditions with MPPT algorithm

The output AC load current(top) and voltage in pu. With MPPT algorithm is shown in Fig 14. The small increase in voltage and current from 1.05 to 1.15 pu is due to increase in solar cell power.

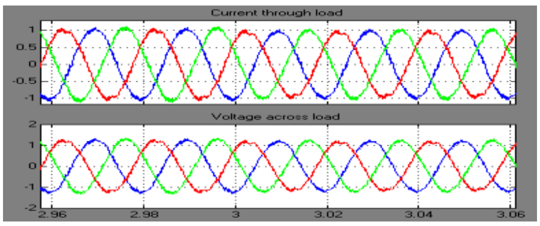

Fig 15: Zoomed view of current and voltage near AC load under normal conditions with MPPT algorithm

The close-up view of output AC loads current (top) and voltage in pu. With MPPT algorithm is shown in Fig 15.

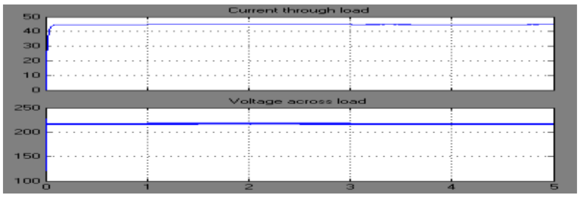

Fig 16: current and voltage at DC load with MPPT algorithm

The output DC load current (top) and voltage with MPPT algorithm is shown in Fig 16. It can seen that current(A) and voltage (V) arte constant, even though there is discrepancy in input supply.

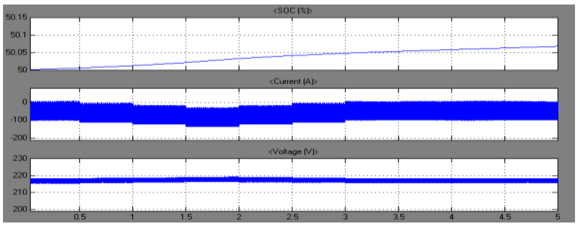

Fig 17: Battery SOC %, current and voltage with MPPT algorithm

In this paper, the battery is having 50% charge initially. Comparing Fig 11 to Fig 17, the %SOC (top) is decreasing in former figure, whereas increasing in later figures. The %SOC reveals the fact about charging (positive slope) and discharging (negative slope) rate. So with proposed MPPT algorithm, the battery is charging with excess power from PV cell. This implies better utilization of natural resources (solar power) and battery as backup when this solar cell fails to deliver part or full power to the loads. We can also observe that the battery charging rate is also changing with time. The current waveform is also below 0Amps in Fig 17, but in Fig 11. the current is oscillating above and below 0Amps axis.

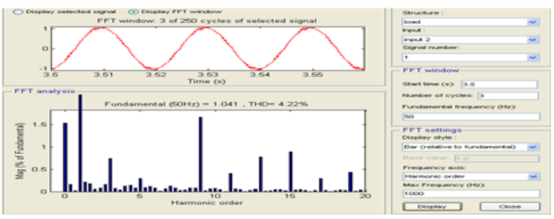

Fig 18: voltage THD with MPPT algorithm for 3 cycles taken at 3.5 seconds

he voltage harmonics are less than 5% THD as is shown in Fig 18. In this scheme we did not even used any filter circuits to reduce lower or higher order harmonics. The proposed scheme itself will reduce the harmonics naturally.

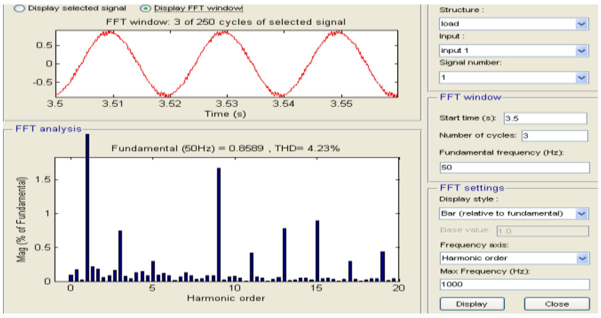

Fig 19: current THD with MPPT algorithm for 3 cycles taken at 3.5 seconds

The current harmonics taken from 3.5s till 3 cycles are less than 5% THD as is shown in Fig 19 which is said to be delivering power as per IEEE standards. In the proposed scheme, both voltage and current harmonics are very less.

Case 2a: In this case, PV module alone is delivering load, a circuit breaker is used which opens the circuit from 3 to 4 seconds. During this time, as there is no power supply to the loads from PV cell, the current from the PV cell became zero as shown in Fig 20.

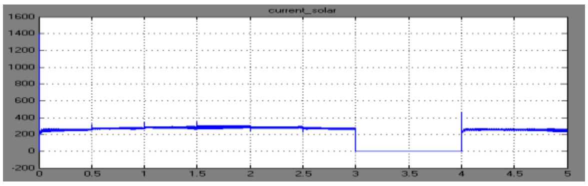

Fig 20: current through solar cell with its interruption between 3 to 4 seconds without battery backup

The PV cell current which is about 200A became zero due to the DC circuit breaker operation, because of which no power flows to the loads.

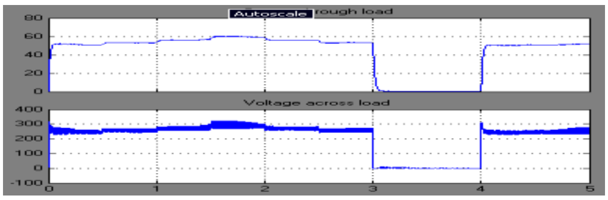

Fig 21: current and voltage near DC load with PV cell interruption between 3 to 4 seconds without battery backup

The DC load current amps (top) and voltage (volts) were made zero, as solar cell output was interrupted by DC circuit breaker as in Fig 21. So a complete load shed has taken place. The same current and voltage zero also holds for AC load Fig 22.

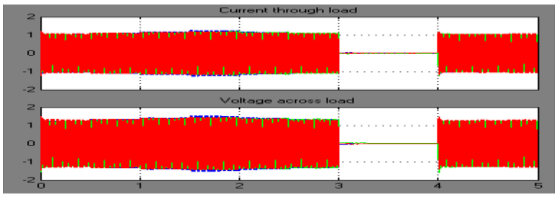

Fig 22: current and voltage near AC load with PV cell interruption between 3 to 4 seconds without battery backup.

As there is no backup power like battery or other power sources DG set etc, there is no way we can deliver power. Hence complete load shed has taken place.

Case 2b: PV cell with battery backup

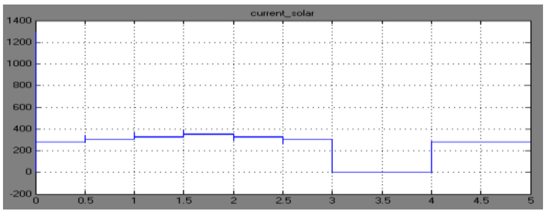

Fig 23: current through solar cell with its interruption between 3 to 4 seconds with battery backup

The PV cell current which is nearly 280A became zero due to the DC circuit breaker operation is as shown in Fig 23 with battery backup. In Fig 20, the PV cell output current is nearly 220A has risen to 280A is because of battery charging. After delivering load required current, excess current is diverted for battery charging. So, battery backup with MPPT algorithm better holds good.

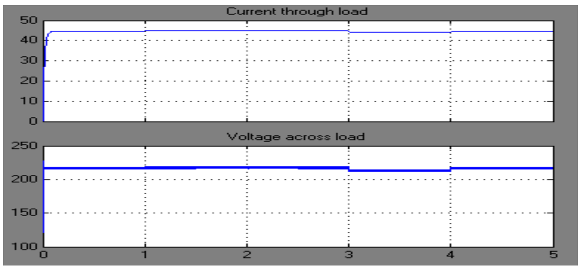

Fig 24: current and voltage near DC load with PV cell interruption between 3 to 4 seconds without battery backup

The DC current and voltage of the system with battery backup when PV cell was interrupted by DC CB between 3 to 4seconds was shown in Fig 24. There is very small dip in current from 44.6 to 44A and voltage from 216 to 212V, because the battery is supplying power to the load during this time interval.

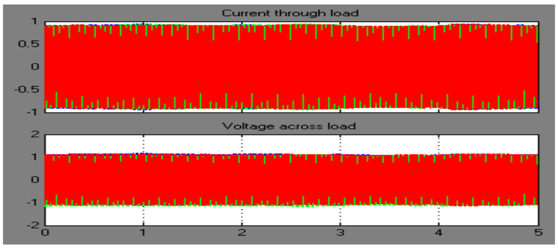

Fig 25: current and voltage near AC load with PV cell interruption between 3 to 4 seconds with battery backup

The AC current and voltage of the system with battery backup when PV cell was interrupted by DC CB between 3 to 4seconds was shown in Fig 25. The p.u. current (top) and per unit voltage were almost constant even after interruption of PV cell is because of battery power delivering required load.

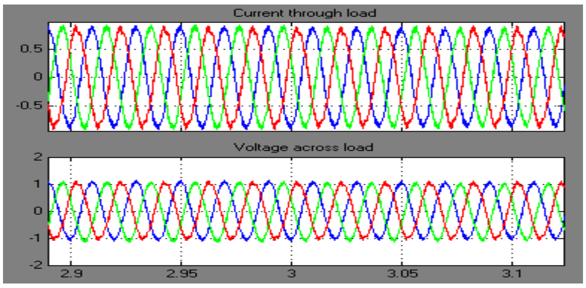

Fig 26: Zoomed view of current and voltage near AC load with PV cell interruption between 3 to 4 seconds without battery backup

The zoomed picture of AC current and voltage for Fig 24 is shown in Fig 25.

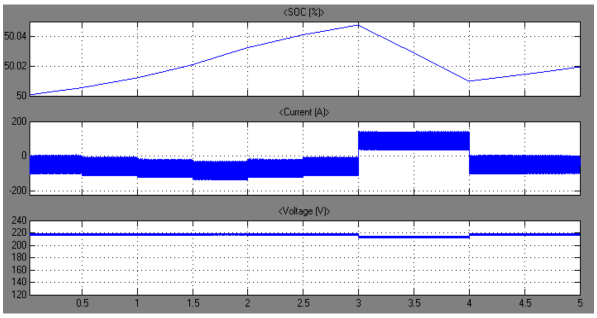

Fig 27: %SOC, Current and Voltage of battery when PV cell fails between 3 to 4 seconds

The Li- ion battery is getting charged (positive slope) till 3seconds, as solar cell is delivering power to the loads, when solar cell failed to deliver load because of the circuit breaker action, battery is delivering load, thereby getting discharged (negative slope) till 4s, then again increasing as in Fig 27. Under normal conditions, the excess current from PV cell flows to battery, but when the PV cell fails (at 3s), the battery power is discharged to deliver the respective load. We can observe from the fig, the current direction was reversed (-ve to +ve) and battery voltage has decreased, %SOC is decreasing during this time between 3 to 4seconds.

Case 3: The implemantation of MATLAB/ SIMULINK for grid connected and PV inverter for distorted and unbalanced load is shown in Fig.28 and 5. Now comparison is made between these two circuits for same rated load in case-A and case-B, case-A is grid connected and case-B is with inverter type load. The ratings of the parameters are given in Appendix.

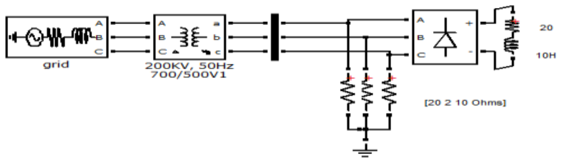

Fig.28 Simulink diagram of grid circuit for distorted and unbalanced load.

Case 3a: The load voltage and current waveforms for grid connected distorted and unbalanced loads are shown in Fig.29. It can be observed that all the three phases' voltages are not same, the red color waveform is having 650V, blue is having 300 volts and green is having 550 volts. Similarly red color current waveform is 50A, blue color current wave is 165A and green color phase current is 65A. Both voltage and current are unbalanced

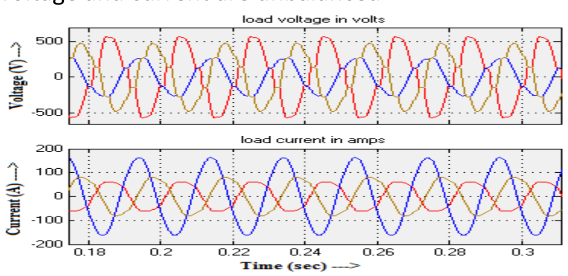

Fig.29 Load voltage and current waveforms for grid supply circuit

The total harmonic distortion (THD) of voltage and current waveform for blue color phase for grid connected non-linear and linear loads are shown in Fig 30 and 31.

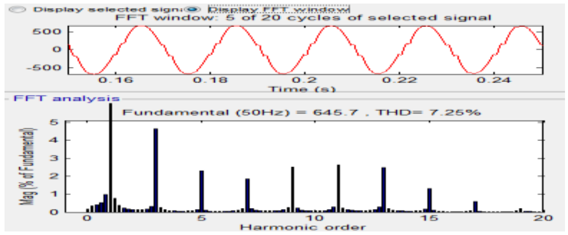

Fig. 30 THD of blue color waveform for grid connected load voltage

It can be observed that voltage THD is 7.25% and current THD is 1.17% for blue phase. For red color phase voltage and current THDs are 4.80 and 6.77%, green color phase is having 6.34 and 3.43%. However it can be observed that power factor is almost unity as resistive load is more dominating than inductive load.

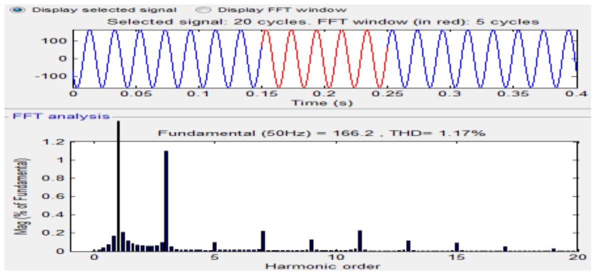

Fig. 31 THD of blue color waveform for grid connected load current

Case-3B: *The PV cell based inverter for same linear and non-linear loads is given in Fig.32.*

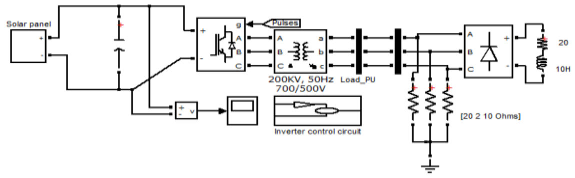

Fig.32 Simulink diagram of PV inverter for distorted and unbalanced load.

It can be observed that all the three phase voltages are nearly same and have 650V as peak-to-peak value and current in red phase is 52A, blue phase is 290A and green phase is 82A respectively as shown in Fig.33. The three phase's voltages are 650, 625 and 550 Volts respectively.

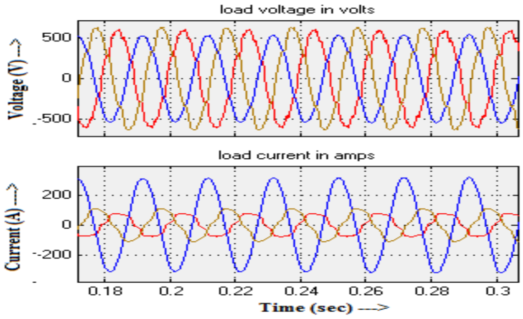

Fig.33 Load voltage and current waveforms for PV inverter circuit

The difference in three phase currents for grid connected and inverter fed loads are different simply due to the fact of voltage unbalance and balance in these cases. The output voltage, current and power waveforms for solar PV system is shown in Fig.34. In this analysis, the sun irradiation is constant solar cell is working in normal conditions with good cooling and appropriate MPPT algorithm. The output of solar cell is maintained at 900 volts and current varying between 100 and 150Amps. The output power is about 135KW.

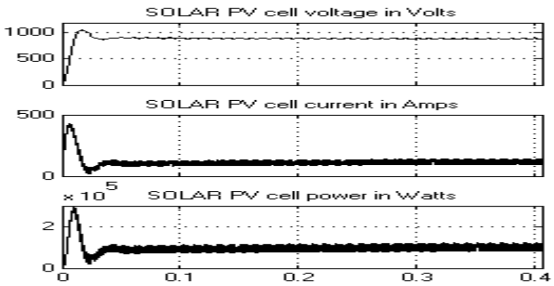

Fig.34 solar PV cell output voltage, current and power waveforms

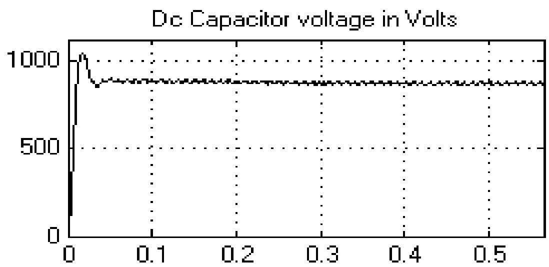

Fig.35 DC link capacitance voltage in volts.

The output voltage waveform of DC link capacitor is given in Fig.35 and its value is nearly constant at 850V and the ripples are also minimum. The THD of voltage and current waveform for blue phase is shown in Fig.36 and 37. The load voltage THD is 2.06% and current THD is 1.80% for blue color waveform. The red color wave is having 3.36% and 2.80%, while green color wave is having 4.8% and 1.25% THD. Table 1 shows the output voltage and current with THD values for grid and PV Inverter.

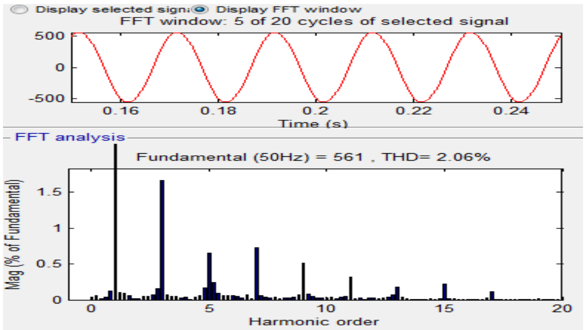

Fig. 36 THD of blue color waveform for inverter connected load voltage

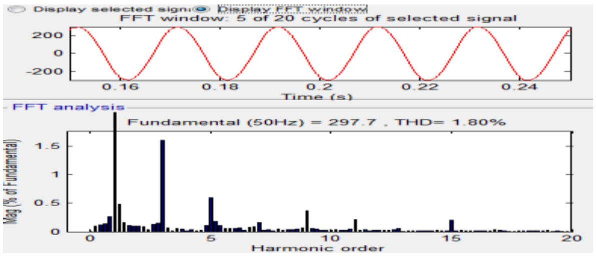

Fig. 37 THD of blue color waveform for inverter connected load current

4 Conclusions

Maximum Power Point Tracking (MPPT) charge controller is better way to extract maximum power (fig 11 & 17) from a renewable energy source (typically a solar array) with battery backup in rural areas. The system can be more reliable (fig 21 & 24), easily controllable (fig 5), can be used anywhere (fig 6) for small scale loads like agriculture etc. The output power can be distributed to load centers or utilized as an isolated load. Even with variation in solar irradiation (input), output power was maintained constant (fig 13 & 16). Because of this technique, rate of battery charging can be improved (fig 27). The AC load is having V and I harmonics less than 5% THD (fig 18 & 19). However, the battery energy system continues to operate during a PV cell outage. The BESS system provide quiet, uninterrupted back-up power for sub-panel loads such as refrigerators, lights, pumps, and computers, while PV array continues to produce power and charge the batteries during the day. When the PV output is restored, the batteries can be charged to their full state of charge while the PV cell powers all DC and AC loads. Once the batteries are recharged, the system returns to normal operation. So, the system efficiency, reliability was intensified using the proposed system.

For normal grid connected supply, the three phase voltages are different due to unbalanced loads and their voltages are 650, 550 and 300 volts respectively and their voltage THDs are 4.8, 6.34 and 7.16% and current THDs are 6.77, 4.43 and 1.17% from figures 29 to 31. The source or load voltages are unbalanced and have THD in two phases more than 5%, which may not be acceptable. So an additional passive filter is required to mitigate harmonics and active filter to compensate decreased voltage due to load. With the proposed control strategy, the voltage in the three phases is 650, 625 and 550 volts and current is 82, 290 and 52Amps respectively. The same phase's voltage THDs are 2.06, 3.36 and 4.8% while current THDs are 1.8, 2.8 and 1.25%. Hence in all the three phases, maintained nearly constant voltage profile and is also having THD less than 3%. But compared to grid source, current THD is high and in two phases it is more than 3% and however is acceptable to keep a passive filter to decrease this content from figures 32 to 37. The proposed scheme will have 5, 7 and 11 order harmonics in voltage and current waveforms and has to be minimized by using a band pass filter. Therefore our proposed scheme can suppress voltage harmonics due to load and also do not produce much destructive harmonics and is highly capable to maintain load voltage almost constant. DC voltage ripples are minimum and control scheme is easy to implement compared to Park's transformation or phase sequential methodologies.

APPENDIX

PARAMETERS OF THE SYSTEM CONSIDERED

Three phase grid supply: 700V, 50Hz, 200kVA, X/R value is 7.

PV cell inverter supply: 1000V, 180kW at 36 degrees temperature

Transformer rating: 200KV, 50Hz, 700/500V delta/ star connection

Distorted load parameters: Diode rectifier with 20Ω and 10H

Unbalanced load resistance: A Ph-20, B Ph-2 and C ph-10 Ohms.

Inverter control circuit: PWM pulse generator switching frequency is 2250Hz, PI controller- 3 and 75.

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