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Performance Analysis of Solar inverter

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Abstract

In this paper, the performance analysis of solar inverter has been carried out. For this analysis, the experiment has been conducted over two different input and different capacity of solar inverter. This Inverter was connected with the PV system of 1.8 kWp and the storage battery bank for supplying the domestic load. Battery storage is used here for supplying the electricity when PV power is insufficient or supplying power in night time and also used for storage of extra PV power when load is insufficient or not matched with supply. The result of these experiments shows that the efficiency of inverter is very less when it works under load condition. And it also conclude about necessity of battery in domestic load for maximum PV power utilization and reducing the cost of PV system. And experiment also shows the performance of inverter in different climate condition as load varies with conditions. This paper also discusses about the different types of inverter and their techniques, which are used in PV systems. In this thesis, Simulation of inverter has been also carried out with the SPWM technique

Keywords: ***Solar inverter, Solar photovoltaic, Battery storage***

1. **Introduction**

For every country in the world, Energy supply has very vital role. Energy is practically desired for all the activities of human being and it is essential to improve our quality of life. Due to higher prices and limited energy resources of conventional fuels, energy requirement is increasing day by day, so for fulfill the increasing requirements of energy for elementary need and other development activities, some efforts are made in the recent years. So some new options are required for this energy requirement. The options shouldbe eco-friendly as well as plentiful in nature. Among all the available renewable energy options, solar energy is ecofriendly, pollution free, abundant in nature and freely available. Thus, the solar energy based systems can fulfill energy demand to some extent and keep the environment pollution free. Solar energy is a renewable energy, it refers to the direct conversion and use. Direct conversion of solar radiation into electrical energy by the conversion device is called solar photovoltaic power generation. In order to boost the development and utilization of solar power, governments dynamically develop various kinds of concessions to encourage the development of solar photovoltaic power generation, Along with increases of demand for the new energy sources, and the key technologies of use new energy is how to incorporate new energy into electrical energy**.** Due to high installation cost and low conversion efficiency of solar photovoltaic, it is required to obtain as much power generated as possible from photovoltaic systems. There are several factors which affect the generated power, such as efficiencies of the system components, solar radiation, shading, cell temperature, etc. The operating point of the photovoltaic array determined by the load, is an additional important factor. Therefore solar inverter research has also become important topics for a sensible use of new energy. The photovoltaic array can deliver its maximum power only if load matching achieved. So, we need a device which transform the load impedance to its optimum value for maximum power point (MPP) operation. Unfortunately, the maximum power point is also depends on different external factors mentioned above. Therefore, in present scenario, a reliable, efficient and inexpensive inverter has become an urgent necessity **[1-2]**. In this project, SPWM technology is used as the control circuit in simulation, for improving the inverter efficiency.

Ismail et al. [3] has discussed that Sinusoidal pulse width modulation (SPWM) is widely used in power electronics for digitizing the power, so that a sequence of voltage pulses can be generated by the ON and OFF of the power switches. The pulse width modulation (PWM) inverter has been the main choice in power electronic for years, because of its circuit simplicity and rough control scheme. SPWM switching technique is commonly used in industrial applications but in now a days, it is also used in domestic applications. SPWM techniques are described by constant amplitude pulses with different duty cycle for each period. The width of these pulses are modulated to achieve inverter output voltage control and to decrease its harmonic content. Sinusoidal pulse width modulation is the mostly used method in motor control and inverter applications. In this project a unipolar SPWM voltage modulation is selected because this method leads to effectively doubling the switching frequency of the inverter voltage, as a result making the output filter smaller, cheaper and easier to implement. Usually, to generate this signal, triangle wave is used as a carrier signal, and it is compared with the sinusoidal wave, whose frequency is the desired frequency. This method has low cost and a small size of control circuit for the single phase full bridge inverter.

To better understanding of this implications in inverter based PV generation, some experiments were conducted on two types of inverters, one is 48V/ 2.5kVA and other one is of 24V/2 kVA, so that numerical model could be built and validated. The additional determined of this testing was to find out the performance of inverter in domestic use with different load and different climate conditions. These experiments were also given the idea of different type of arrangement of inverter in PV system and use of different capacity of inverter in domestic used PV system.

2. Literature survey

Norton el al. [4] discussed that PV array size is defined by the PV generated DC power required to supply a given AC load.

Some other factors also influence the PV array size like Efficiency of an inverter in converting PV generated DC power into AC power, Efficiency of charge controller, battery storage, efficiency of PV array in converting solar radiation into electrical power. The performance of an inverter depends on, inverter output waveform, harmonic distortion, transformer, its point of work, threshold of operation and maximum power point tracker (MPPT). The main functions of an inverter are wave shaping, output voltage regulation and operation near peak power point.

Norton el al. [4] also discussed that an inverter uses a MPPT algorithm, extracts maximum power from the PV array by varying the input voltage to maintain maximum power point voltage on the *IV* curve as PV output varies with solar radiation and module temperature. An inverter efficiency depends on the fraction of its rated power at which inverter operates. A PV system operates at higher efficiency either when it has an inverter operating with a large enough load to maintain peak efficiency or it has an interconnection of module-integrated inverters, multiple string inverters, or master-slave configurations.

Norton el al. [4] discussed here some facts about efficiency of solar inverter and factor which causes the losses in inverter. When input power level of inverter reaches 30% to 50% of its rated capacity then inverter works on its maximum efficiency which is usually 90%. If the input power level of inverter is below 10% then the efficiency falls to its lower level. When PV module is shaded, the PV module current decreases significantly because of this not only that particular module power is dropped but also the series connected PV module string power also drops, which affects inverter performance. This occurs when inverter used without batteries storage. For this inverters have been developed specifically for PV applications with improved maximum power point tracking (MPPT), reliability and low solar radiation performance. This type of solar inverter mainly used for grid connected PV system, these are not suitable for domestic uses because losses are very high. In these type of PV Inverter output or stand-by losses occur due to

(i) Threshold energy loss due to inverter Operation under low input power

(ii) DC/AC conversion loss occurs due to the protective cut off being activated when inverter operates under high input power.

(iii) Coupling of a number of inverters.

(iv) Increase in inverter temperatures.

(v) Use of inverter with low operating efficiency.

(vi) Operation with partially load conditions

3. Sine wave generation

Sine wave inverter provides sine wave output voltage waveform which is very similar waveform as received from the Grid. The sine wave inverter has very less harmonic distortion, resulting in very clean supply and makes this inverter ideal for handling electronic systems such as computers and other sensitive equipment without causing noise or any other problems.

Advantage of using Sine Wave Inverters: **[3, 6]**

- Most of the electronic and electrical equipment are designed for the sine wave supply.

- Some appliances such as refrigerator, microwave, variable motor, will not be able to deliver rated output without sine wave supply.
- Electronic clocks are mainly designed for the sine wave supply.
- Harmonic content is less in sine wave.

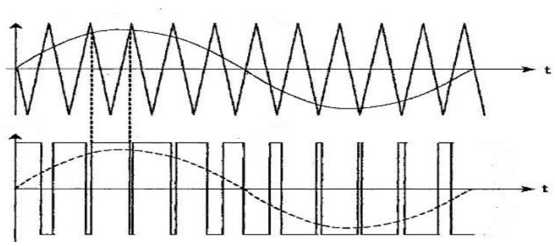

Figure 2.1: SPWM signal

Pulse width modulation is most popular and common technique for generating sine wave, in which sinusoidal pulse width modulation is more suitable. SPWM technique involves generation of a digital waveform by modulation of duty cycle in such a way so that average voltage waveform corresponds to a sine wave.

Let amplitude of the sinusoidal modulating signal is Am, and amplitude of triangular carrier signal is *Ac*, then the ratio modulating signal and carrier signal is called modulation index (*m*).

3.1 SPWM harmonic elimination:

There are several application which may allowed harmonic contents of 5% of its fundamental component of input voltage when inverter is used. But actually, the inverter output voltage may have much higher harmonic content than 5% of its fundamental components. For bring these harmonic content in a reasonable limit as per application required, one method is to insert a filter between the load and inverter. If output voltage contains high frequency harmonics, these harmonics can be reduced by low size filter. But for low frequency harmonics larger size of filter is required, this makes the inverter costly, weighty and bulky, and in addition the transition response of these circuit becomes sluggish. So that lower frequency harmonics should be reduced by some means other than filter. But high frequency components of harmonics can be easily removed by small size, low cost filter.

3.1.1 Advantages of SPWM:

- Low power consumption.
- High power handling capability
- High energy efficient up to 90%.
- Compatible with today's digital microprocessors.
- Easy to implement and control

3.2 LC Filter Design:

A low pass filter is placed at the output of full bridge voltage source inverter for reducing the harmonic content generated by the pulsating modulating waveform. Selection of the cut-off frequency in designing LC filter, depends on the lower order harmonics elimination. To operate as an ideal voltage source, i.e. under the nonlinear load or load variation there is no additional voltage distortion, Inverter's output impedance must be kept zero, therefore, the value of capacitance should be maximized and the value of inductance should be minimized at the selected cut-off frequency of the LC low-pass filter. But, as the value of capacitor increases, the power rating of inverter will be increased due to the reactive power increment of the filter. So that the capacitor value should be limited to particular value and the value of inductance should be increased as much the decrement in capacitance value. So it is difficult to develop the zero output impedance for the L-C filter is used. **[6, 10-11]**

4. Inverter simulation

For the better performance of PV system, it is require to design a solar inverter with the small losses, so that the efficiency of PV based electricity generation is increased. The use of SPWM Technique in this inverter provides the flexibility in control algorithms. ORCAD PSPICE software is used for this inverter simulation. The block diagram of the inverter system is shown in Fig. 4.1.

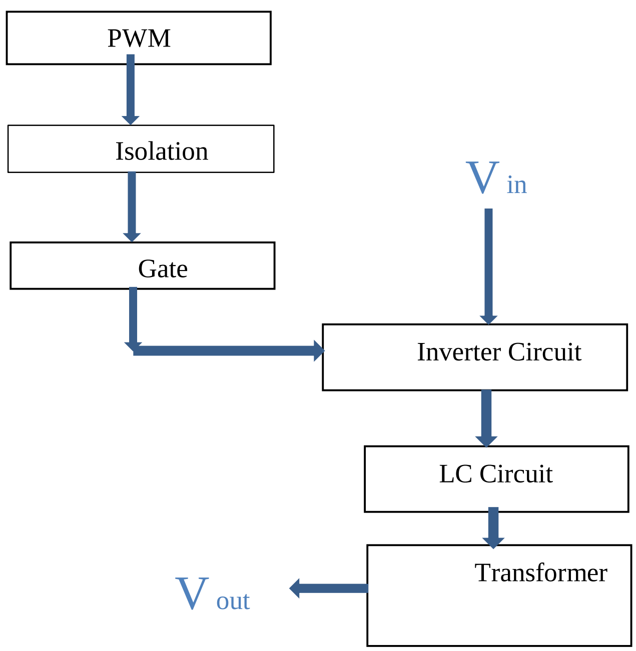

Figure 4.1: Block diagram of inverter

For generation of SPWM pulses, PWM Generator is used, there after isolation circuit and gate drivers provides the conditioning output to the switches of full bridge inverter as a gate control. The output of full bridge inverter goes to LC filter to reduction of harmonics. LC filter provides filtered sine wave output which is less in amplitude as per desired to load so a step up transformer is used for the step up the amplitude of LC filter output.

SPWM signal generated by PWM Generator needs to be isolated for protection and safety between a safe and a potentially hazardous environment. The outputs are then fed to gate drivers which contains four independent electrically-isolated MOSFET drivers. The outputs of the gate drivers are then distributed to power switches in full bridge arrangement. The output of the inverter has square waveform due to the switching pattern. In order to get a sine wave signal the LC filter was used to reduce harmonic content. The output then fed to step up transformer to get the required output level.

5. Simulation Results

PSpice tool of Orcade 9.2 is used to simulate the circuits. The reference signal which is a sinusoidal signal and the carrier signal which is a triangular signal, is given to comparator circuit shown in figure 5.1 to generate the SPWM pulses.

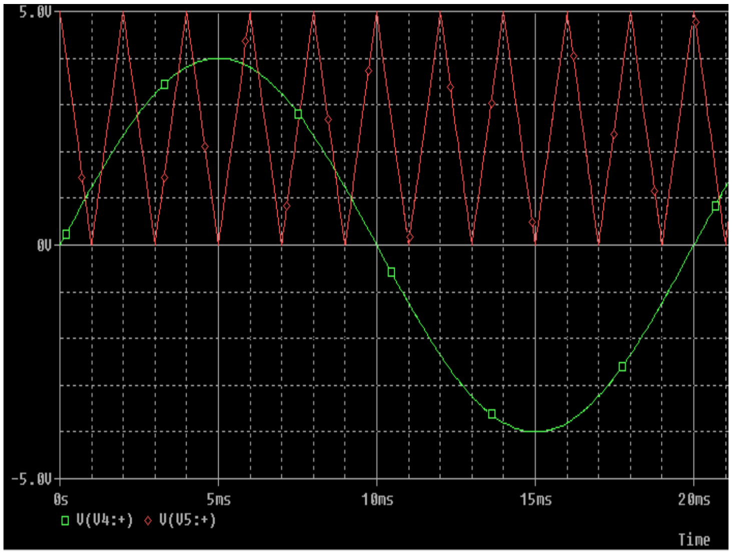

Figure 5.1: SPWM waveform generating from SPWM circuit

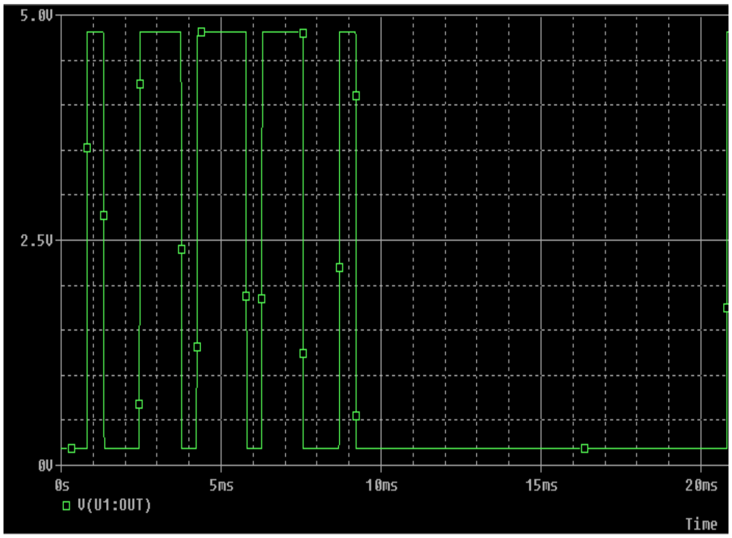

Figure 5.2: SPWM 1 output

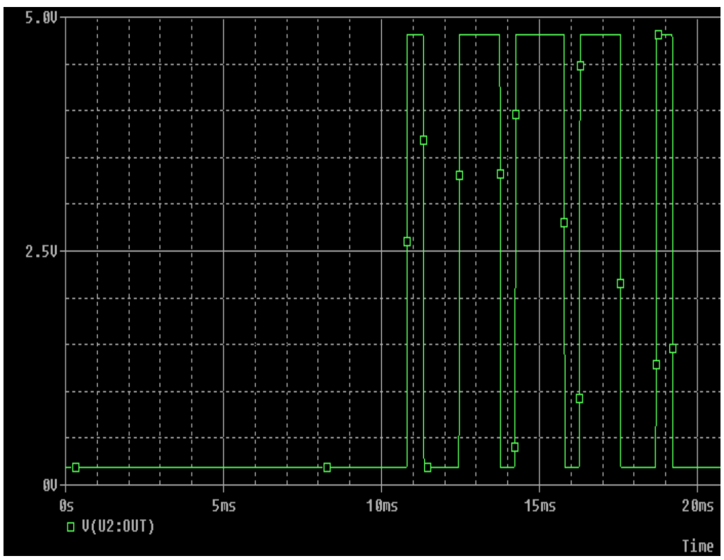

Figure 5.3: SPWM 2 output

There are two SPWM signal of 180 degree phase difference is generated for switching the full bridge topology of the inverter. SPWM1 signal shown in figure 5.2 and SPWM2 signal shown in figure 5.3.

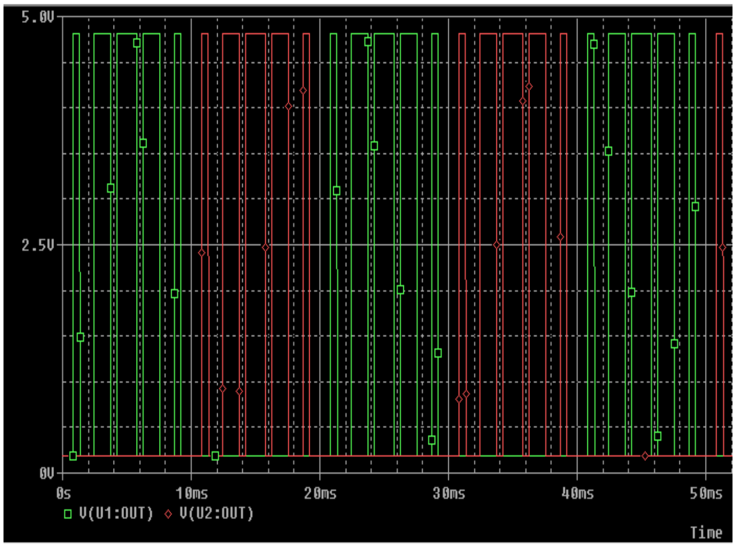

Figure 5.4: SPWM 1 and SPWM 2 output

The switching output of full wave inverter shown in figure 5.5. This output goes to LC filter, which is required for reducing the harmonic content and to make the signal become sinusoidal. This sinusoidal output signal then goes to step-up transformer to amplify this voltage to proper level as required to the load. The output voltage wave form at the load is shown in Figure 5.6.

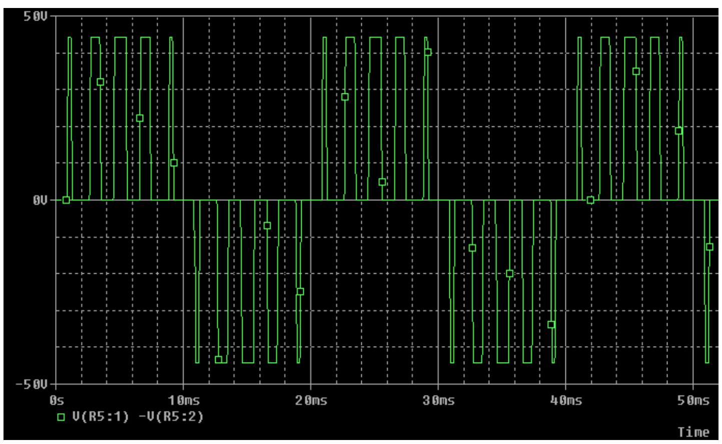

Figure 5.5: Switching output of full bridge inverter

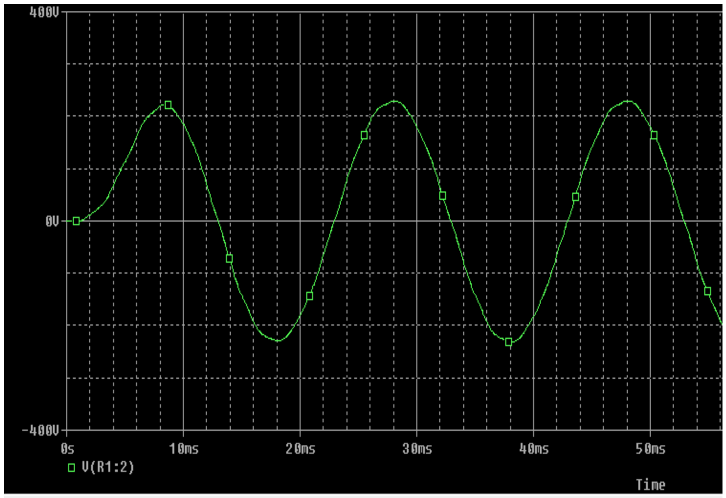

Figure. 5.6: Voltage output at load

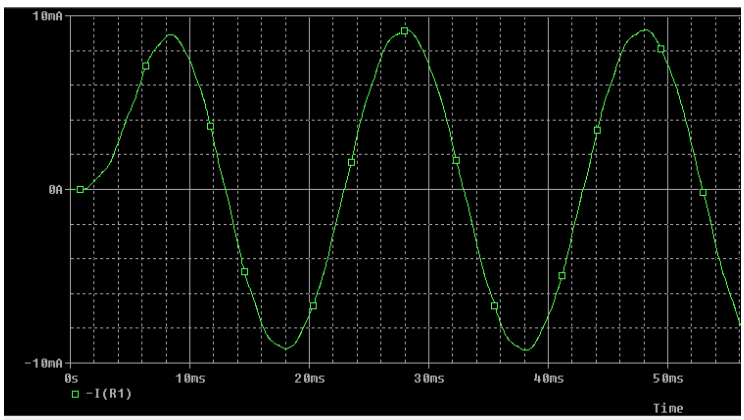

Figure 5.7: Current output at load

6 Experimental set-up

A rooftop PV system is installed at Ghaziabad (UP.) for supplying electricity to the domestic load. This PV system can generate maximum electricity of 1.8 kWp.

In case, due to some fault in the system or in the cloudy weather condition, if the rooftop PV system is not able to supply the required load then grid connected supply can be given to load by using the change-over switch.

A complete Rooftop PV System includes:

- 24 PV modules (which are opaque type).
- A PWM Charge Controller, to regulate the power into the battery bank.
- A power storage system (Battery Bank).

- An Inverter to convert the PV modules DC output to AC.
- Grid supply (220 V, 50 Hz, Single phase).

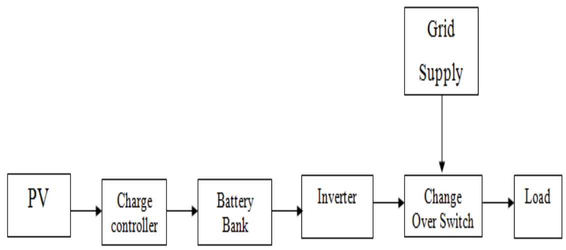

Figure 6.1: Block diagram of rooftop PV system

6.1 Description of different components of rooftop PV system:

6.1.1 PV array:

In this PV system, 24 PV modules constructed by CEL(Central Electronics Limited) having effective area of 0.66 m^2 each are connected in a combination, where 4 modules are connected in series and 6 such series combinations are connected in parallel and mounted on an inclined iron structure. The inclination of this iron structure is kept at latitude of Delhi (28.6°) to receive maximum annual insolation.

The specifications of each PV module are as follows:

- Electrical Parameters:
- Model PM75
- Maximum Power rating Pmax (Wp) 75.0
- Rated Current IMPP (A) 4.40
- Rated Voltage VMPP (V) 17.0
- Short Circuit Current Isc (A) 5.00
- Open Circuit Voltage Voc (V) 21.4

Figure 6.2: Photograph of PV array

6.1.2 Charge controller:

This device regulates rates of flow of electricity from the PV array to the battery and the load. This controller keeps the battery full charged without over charging it. When the load is drawing power, the controller allows the charge to flow from the PV array into the battery, the load or both. When the controller senses that the battery is fully charged, it reduces or stops the flow of electricity from the PV array.

Figure 6.3: Photograph of Charge controller

A charge controller can also be used to power DC equipment directly through solar panels. Charge controller provides a regulated DC output and stores excess energy in a battery as well as monitors the battery voltage to prevent under / overcharging. 3 stage charging by the charge controller could be shown as below:

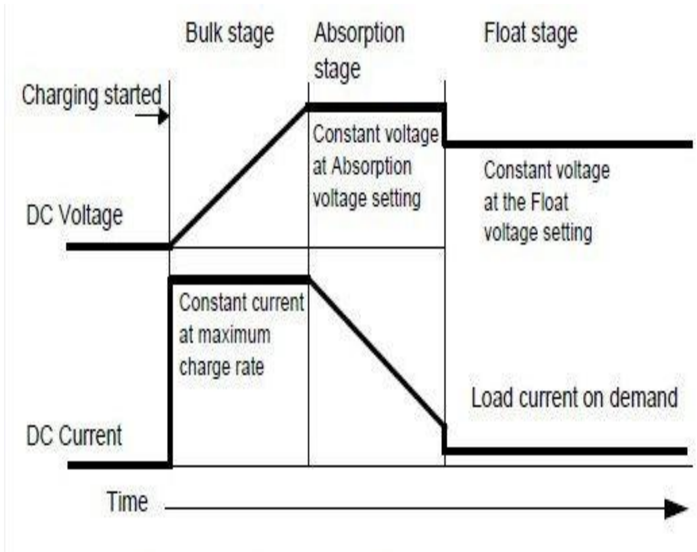

Figure 6.4: 3-Stage battery charging [12]

6.1.3 Inverter:

An inverter is a device which converts the DC electricity coming from sources such as battery or PV array to AC electricity. The electricity coming from an inverter could be at any required voltage and particularly it is used to operate AC equipment designed for mains operation, or voltage could be rectified to produce DC at any desired voltage.

A solar inverter is a critical component in a photovoltaic system as it converts the variable DC output of the solar panel into a utility frequency alternating current that can be fed into the used by a local, off-grid electrical network or commercial electrical grid. Here electricity is only required for domestic load. So for maximum utilization of PV generated electricity battery storage is used.

Here two inverters with different specifications are used for experiment for different condition, one is used for 48V input, 2.5kVA rated capacity and other one is used for 24V input, 2kVA rated capacity.

Figure 6.5: Photograph of 48V input inverter

Battery capacity of up to 200Ah is recommended for better performance even though lower capacity battery can also be used.

6.1.4 Battery:

A battery stores electricity produced by a solar PV system. The capacity of a battery is often given in amp-hours, which is the number of amps drawn for how many hours.

Figure 6.6: Photograph of 24V inverter

Figure 6.7: Photograph of batteries

Specification:

- Model – Exide Invared 500+
- 12 volt, 150 amp-hour, Storage capacity of 1800 Watt-hours.
- Deep Cycle Design (600-700 cycles at 80% DOD)
- Weight – Dry (34.9 kg) & Filled (52.5kg)

6.1.5 Grid connected supply:

220 Volt, 50 Hz, 1 Phase AC supply

6.2 Instrumentation:

6.2.1 Solarimeter:

The intensity of solar radiation is measured by Solarimeter having a least count of 20 W/m2, manufactured by CEL, India Ltd, Sahibabad (UP), India. Solarimeter has been calibrated with standard Pyranometer.

6.2.2 Clamp meter:

It is used for measurement of current and voltage**.**

6.2.3 Thermometer:

The thermometer is used to measure top surface temperature of PV module and the ambient temperature.

6.3 Working of rooftop PV system:

PV Modules use light energy (photons) from the sun to generate electricity through photovoltaic effect. The output of PV Array is given to the charge controller. Charge controller regulates rates of flow of charge from the PV Array to the battery and load. This charge controller desires to keep the battery full charged without over charging it. The output of charge controller is given to the battery bank. Battery bank is connected to the inverter which is connected to the load. During sunshine hours battery is charged via PV array and this stored energy is used during non-sunshine hours. The current being supplied to the battery bank changes during the day as the state of charge of the battery changes. This is due to the fact that the charge controller provides 3-stage charging. During sunshine hours if the load current increases more than being generated by the PV then extra current is supplied by the battery bank and thus keeps the system working.
When there is no sunshine and the battery as well is not sufficiently charged to supply the loads, Grid connected supply is used for supplying the loads

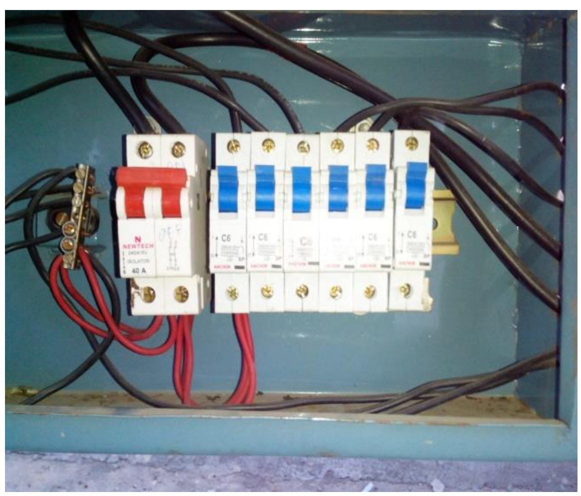

Figure 6.8: Photograph of electrical connections of system

7.Observations

Observations on PV System were taken on different days of different months and these observations are listed in the tables below. These observations shows the effect of different seasonal load, different weather, and different rating of the components on the PV generated electricity utilization in domestic load. Here power factor for calculation of output power of inverter is taken as 0.8, and fill factor for calculation of PV generated maximum power is taken as 0.7. Equations used in calculation for these table are given as follow:

$$P_{in}=V_{in}I_{in} \quad (7.1)$$

$$P_{out} = V_{out}I_{out}\cos\Phi \quad (7.2)$$

$$P_{out} = \frac{VoutIoutcos\Phi}{VinIin} \quad (7.3)$$

$$P_m=V_{oc}I_{sc}FF \quad (7.4)$$

$$P_{ex}=P_m-P_i \quad (7.5)$$

Table 7-1: Observations of PV system parameters on November 15, 2013

Time	*I(t)*	V_{oc}	I_{sc}	T_a	T_g	P_m
8:00 AM	260	80.5	7.2	19	23	405.72
9:00 AM	380	80.6	9.1	20	29	513.42
10:00 AM	560	80	13.7	24	34	767.2
11:00 AM	760	79.2	18.8	26	38	1042.27
12:00 PM	780	78.6	17.5	26	39	962.85
1:00 PM	780	78.3	17.2	27	41	942.73
2:00 PM	640	78.3	15.3	27	40	838.59
3:00 PM	420	77.5	9.1	26	33	493.67
4:00 PM	220	76.3	5	26	29	267.05
5:00 PM	80	73.2	2.1	25	27	107.61

Table 7-2: Observations of PV system parameters on November 20, 2013

Time	*I(t)*	V_{oc}	I_{sc}	T_a	T_g	P_m
8:00 AM	260	81.5	8.2	19	23	467.81
9:00 AM	480	82.1	13	20.5	28	752.86
10:00 AM	620	80	19	24	34	1080.8
11:00 AM	780	79.5	22	28	41	1235.4
12:00 PM	840	79	24	28.5	43	1299.6
1:00 PM	880	79	24	29	44	1305.1
2:00 PM	700	79	18	27	40	995.4
3:00 PM	440	78.9	12	27	37	684.85
4:00 PM	300	78.2	8.1	27	33	443.39
5:00 PM	100	73.8	3	26	27	154.98

Table 7-3: Observations of inverter (48V, 2.5kVA) on February 9, 2014

Time	V_{in}	I_{in}	P_{in}	V_{out}	I_{out}	P_{out}	η
9:00 AM	52.2	6.5	339	220	1	176	51.87
10:00 AM	55.4	6.7	371	220	1.1	193.6	52.15
11:00 AM	60.1	6	361	220	0.9	158.4	43.92
12:00 PM	60	5.9	354	220	0.9	158.4	44.74
1:00 PM	60	5.8	348	220	0.9	158.4	45.51
2:00 PM	59.6	4.9	292	220	0.8	140.8	48.21
3:00 PM	59.5	4.9	292	220	0.7	123.2	42.25
4:00 PM	57.6	5.2	300	220	0.7	123.2	41.13
5:00 PM	54	5	270	220	0.7	123.2	45.63

Table 7-4: Observations of inverter (48V, 2.5 kVA) on February 11, 2014

Time	V_{in}	I_{in}	P_{in}	V_{out}	I_{out}	P_{out}	η
9:00 AM	59.4	8	475	220	1.4	246.4	51.85
10:00 AM	59.5	8	476	220	1.4	246.4	51.76
11:00 AM	59.6	5.2	310	220	0.7	123.2	39.75
12:00 PM	59.2	5.1	302	220	0.7	123.2	40.8
1:00 PM	59.4	5.1	303	220	0.7	123.2	40.66
2:00 PM	58	4.5	261	220	0.7	123.2	47.2
3:00 PM	56.3	3.5	199	220	0.4	70.4	35.67
4:00 PM	56.4	3.5	197	220	0.4	70.4	35.66
5:00 PM	56.6	3.5	198	220	0.4	70.4	35.53

Table 7-5: Observations of inverter (24V, 2kVA) on February 18, 2014

Time	V_{in}	I_{in}	P_{in}	V_{out}	I_{out}	P_{out}	η
9:00 AM	25.1	20	502	220	1.7	299.2	59.6
10:00 AM	25.3	15.7	397	220	1.2	211.2	53.17
11:00 AM	25.8	15.5	400	220	1.2	211.2	52.81
12:00 PM	26.4	16.5	436	220	1.2	211.2	48.48
1:00 PM	26.5	17	451	220	1.2	211.2	46.88
2:00 PM	27.1	17	461	220	1.2	211.2	45.84
3:00 PM	27.1	9.6	260	220	0.7	123.2	47.35
4:00 PM	26.3	10.7	281	220	0.8	140.8	50.03
5:00 PM	24.9	13.3	331	220	0.9	158.4	47.83

Table 7-6: Observations of inverter (48V, 2.5kVA) on March 31, 2014

Time	V_{in}	I_{in}	P_{in}	V_{out}	I_{out}	P_{out}	η
9:00 AM	51.7	2.8	144.76	220	0.3	52.8	36.47
10:00 AM	52.2	3	156.6	220	0.3	52.8	33.72
11:00 AM	54.3	3.3	179.19	220	0.4	70.4	39.29
12:00 PM	56.2	5.3	297.86	220	0.6	105.6	35.45
1:00 PM	57.9	3.5	202.65	220	0.4	70.4	34.73
2:00 PM	58	2.8	162.4	220	0.3	52.8	32.51
3:00 PM	58	3.7	214.6	220	0.5	88	41.01
4:00 PM	55.3	3.7	204.61	220	0.5	88	43.01
5:00 PM	55.5	1.1	61.05	220	0	0	0

Table 7-7: Comparison between PV generated power and inverter input power on March 31, 2014

Time	$I(t)$	V_{oc}	I_{sc}	P_m	P_{in}	P_{ex}
9:00 AM	600	80.8	16.3	921.92	144.76	777.16
10:00 AM	860	80.5	23.8	1341.13	156.6	1184.53
11:00 AM	1040	81	29.3	1661.31	179.19	1482.12
12:00 PM	1020	80.6	29	1636.18	297.86	1338.32
1:00 PM	960	79.3	27.5	1526.52	202.65	1323.87
2:00 PM	880	79.4	24.1	1339.47	162.4	1177.07
3:00 PM	760	78.8	19.9	1097.68	214.6	883.08
4:00 PM	480	78.8	13.2	728.11	204.61	523.50
5:00 PM	180	77	6.7	361.13	61.05	300.08

Table 7-8: Observations of inverter (48V, 2.5kVA) on April 3, 2014

Time	V_{in}	I_{in}	P_{in}	V_{out}	I_{out}	P_{out}	η
9:00 AM	51.4	4.5	231.3	220	0.6	105.6	45.65
10:00 AM	53.4	3.8	202.92	220	0.3	52.8	26.02
11:00 AM	56.5	3.5	197.75	220	0.3	52.8	26.70
12:00 PM	58	4.7	272.6	220	0.4	70.4	25.82
1:00 PM	57.8	3.2	184.96	220	0.3	52.8	28.54
2:00 PM	55	4.2	231	220	0.4	70.4	30.47
3:00 PM	55.3	3.5	193.55	220	0.2	35.2	18.19
4:00 PM	55	5	275	220	0.6	105.6	38.4
5:00 PM	50.5	4.4	222.2	220	0.4	70.4	31.68

Table 7-9: Comparison between PV generated power and inverter input power on April 3, 2014

Time	$I(t)$	V_{oc}	I_{sc}	P_m	P_{in}	P_{ex}
9:00 AM	480	78.5	6.5	357.175	**231.3**	125.875
10:00 AM	700	77.7	9.2	500.388	**202.92**	297.468
11:00 AM	840	78	12.3	671.58	**197.75**	473.83
12:00 PM	920	78	13.5	737.1	**272.6**	464.5
1:00 PM	920	78	12.6	687.96	**184.96**	503
2:00 PM	840	78.2	11.8	645.932	**231**	414.932
3:00 PM	660	78.4	9.8	537.824	**193.55**	344.274
4:00 PM	460	77.8	6.2	337.652	**275**	62.652
5:00 PM	180	76.1	3.3	175.791	**222.2**	-46.409

Table 7-10: Observations of inverter (48V, 2.5kVA) on April 12, 2014

Time	V_{in}	I_{in}	P_{in}	V_{out}	I_{out}	P_{out}	η
9:00 AM	50.1	1.2	60.12	220	0	0	0
10:00 AM	51.5	1.4	72.1	220	0	0	0
11:00 AM	52.5	1.4	73.5	220	0	0	0
12:00 PM	52.7	6.8	358.36	220	0.7	123.2	34.37
1:00 PM	53.3	7.2	383.76	220	0.9	158.4	41.27
2:00 PM	53.8	6.1	328.18	220	0.7	123.2	37.54
3:00 PM	54.4	1.4	76.16	220	0	0	0
4:00 PM	51	8.8	448.8	220	1.1	193.6	43.13
5:00 PM	50	8	400	220	1	176	44

Table 7-11: Observations of inverter (48V, 2.5kVA) on April 20, 2014

Time	V_{in}	I_{in}	P_{in}	V_{out}	I_{out}	P_{out}	η
9:00 AM	55	10.7	588.5	220	1.8	316.8	53.83
10:00 AM	52.9	11.7	618.93	220	1.8	316.8	51.18
11:00 AM	52.7	10.5	553.35	220	1.6	281.6	50.89
12:00 PM	57.2	10.3	589.16	220	1.4	246.4	41.82
1:00 PM	57.2	10.2	583.44	220	1.5	264	45.25
2:00 PM	57.2	11.7	669.24	220	1.6	281.6	42.08
3:00 PM	57	11.3	644.1	220	1.1	193.6	30.06
4:00 PM	54.3	13.3	722.19	220	1.7	299.2	41.43
5:00 PM	48.9	11.6	567.24	220	1.5	264	46.54

Table 7-12: Observations of inverter (24V, 2kVA) by load variation

Type of Load	V_{out}	I_{out}	P_{out}	V_{in}	I_{in}	P_{in}	η
F1	220	0.2	35.2	26.2	6.4	167.68	20.99
F1 + F2	220	0.4	70.4	26.2	8.5	222.7	31.61
F1 + F2 + CF1	220	0.5	88	26.2	8.6	225.32	39.06
F1 + F2 + CF1+ T1	220	0.6	105.6	26.2	10.1	264.62	39.91
F1 + F2 + CF1 + T1 + T2	220	0.8	140.8	26.2	11.6	303.92	46.33
F1 + F2 + CF1 + T1 + T2 + CF2	220	0.9	158.4	26.2	12.3	322.26	49.15
F1 + F2 + CF1 + T1 + T2 + CF2 + M	220	2.7	475.2	26.2	28.8	754.56	62.98

Table 7-13: Observations of inverter (48V, 2.5kVA) by load variation

Type of Load	V_{out}	I_{out}	P_{out}	V_{in}	I_{in}	P_{in}	η
T1	220	0.1	17.6	55.3	2.9	160.37	10.97
T1 + CF1	220	0.1	17.6	55.3	3.1	171.43	10.27
T1 + CF1 + CF2	220	0.2	35.2	55.3	3.4	188.02	18.72
T1 + CF1 + CF2+ T2	220	0.3	52.8	55.3	4.2	232.26	22.73
T1 + CF1 + CF2+ T2 + F1	220	0.5	88	55.3	5.6	309.68	28.41
T1 + CF1 + CF2+ T2 + F1 + F2	220	0.8	140.8	55.3	7.3	403.69	34.88
T1 + CF1 + CF2+ T2 + F1 + F2 + M	220	2.4	422.4	55.3	16.1	890.33	47.44

Where

Short forms used in Table 7-10 & Table 7-11 are
F1 & F2 → Fans (55W each)
T1 & T2 → Tube lights (36W each)
CF1 → CFL (5W)
CF2 → CFL (14W)
M → Motor (373W)

8. Results

The observations on November 15, 2013 were taken with the dust, and observation on November 20, 2013 were taken without dust. The comparison of these two observation shown in figure 8.1 and figure 8.2, by these figure can be conclude that with the effect of dust, the open circuit voltage of PV system is decreased. The short circuit current of PV system also decreased with the dust effect, this can be seen in figure 8.3. So it can be conclude that the dusting has significant effect on performance of solar PV system. So it is require to keep the PV panels clean. The variation of Open circuit voltage V_{oc} with Glass Temperature T_g is shown in figure 8.4. It is observed that with increment in glass temperature the open circuit voltage is decreases. So it can be concluded that with the increment in solar intensity the glass temperature increases and efficiency of solar PV system decreases.

With the help of Table 7-7 and Table 7-9, it is observe that in the domestic load the PV generated power is not matched with the domestic load. The domestic load is some time high compare to the power generated by the PV system and some time is less. Because of this, losses will take place so battery use in the domestic PV system is to be necessity for maximum utilization of PV system. With the maximum utilization of PV generated electricity, PV array size can be reduced and cost of PV system will also be reduced.

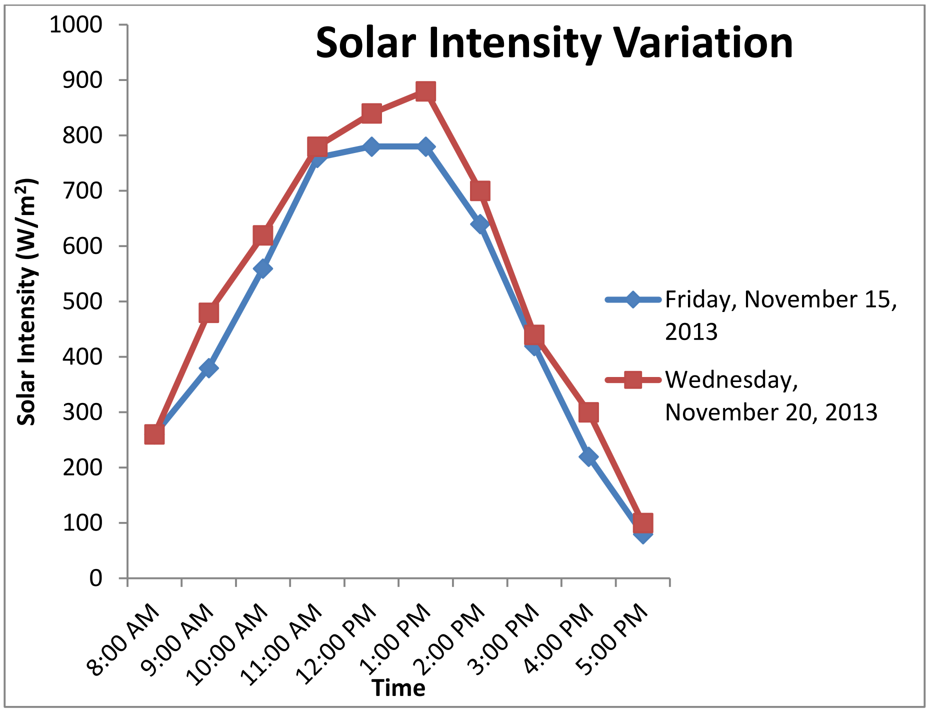

Figure8.1: Solar Intensity variation

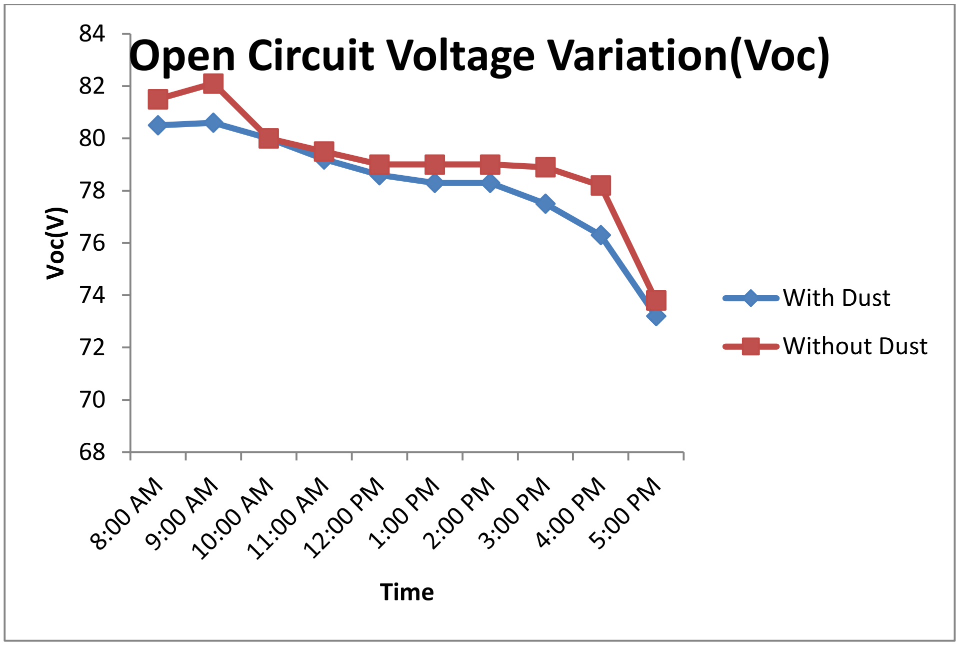

Figure 8.2: Open Circuit voltage Variation (Voc)

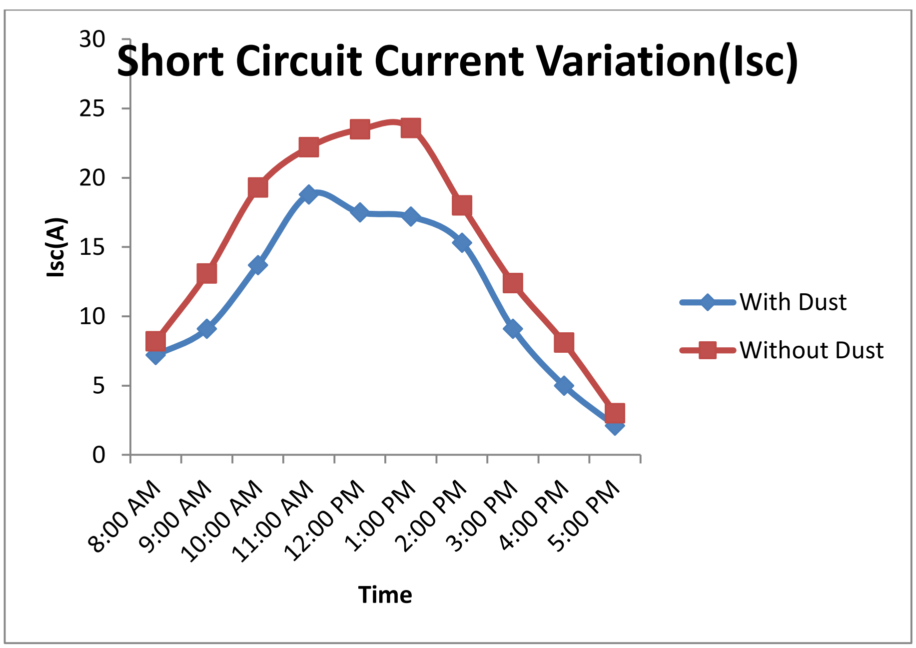

Figure 8.3: Short circuit variation (Isc)

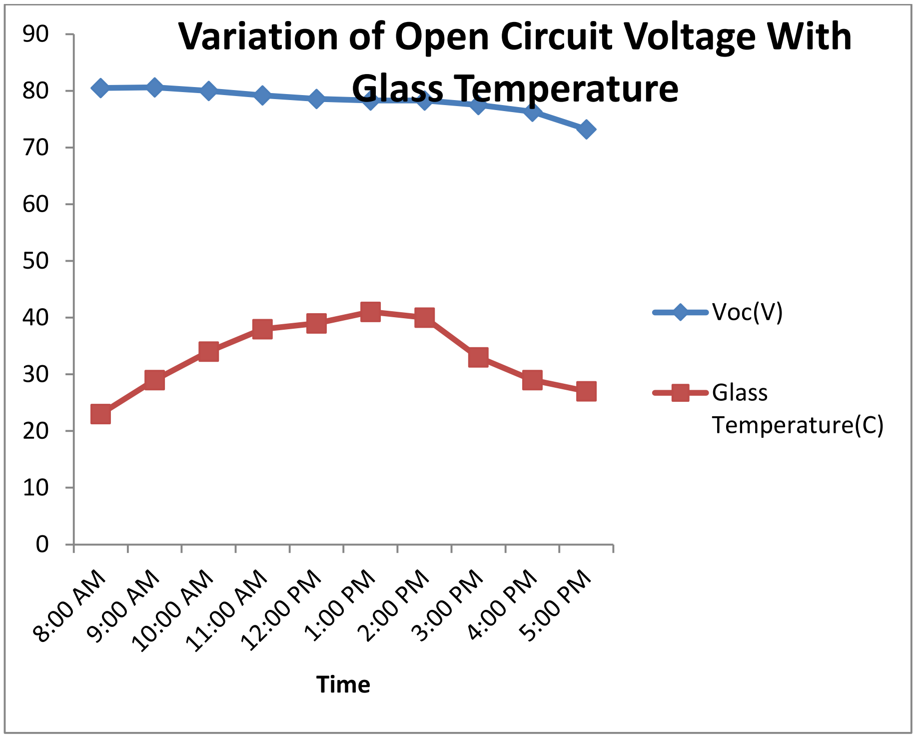

Figure 8.4: Variation of open circuit voltage with glass temperature

It can be observe from Table 7-6 and Table 7-10 that the study state losses of inverter is about 60-80W which is about 2-4 % of inverter rated capacity. Table 7-1, 7-2, 7-7, 7-9 shows that the power generated in month of November (winter) is less as compare to month of April (summer). But the efficiency of PV system is less in summer as compare to winter

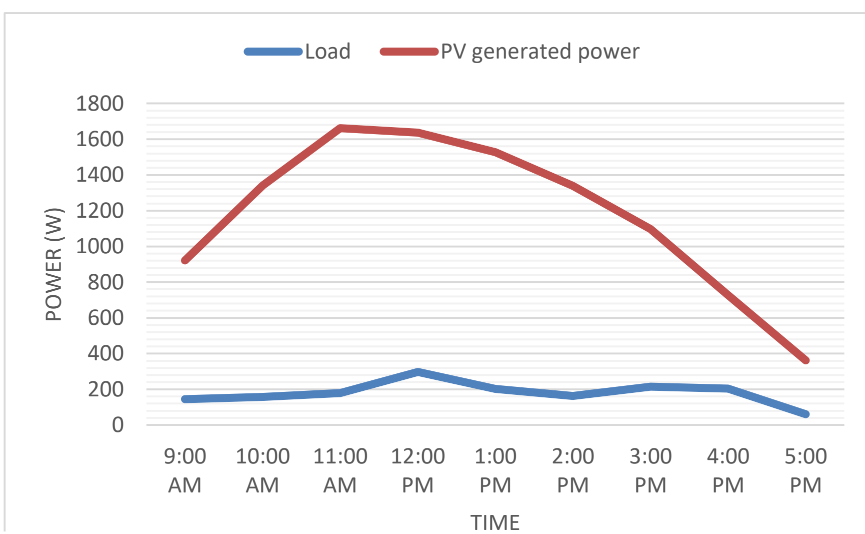

Figure 8.5: Comparison between PV generated power and load variation on March 31, 2014

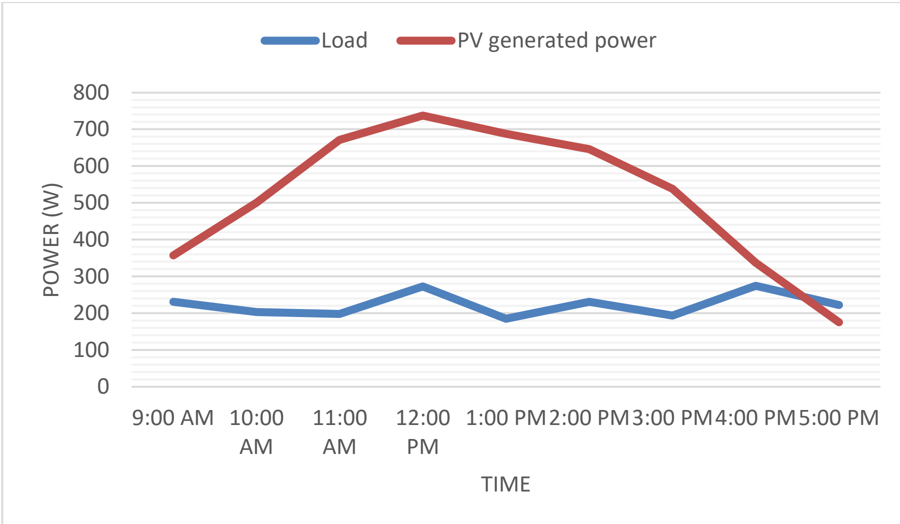

Figure 8.6: Comparison between PV generated power and load variation on April 3, 2014

Observations on 48V inverter were taken on different day with the domestic load variation of whole day. The observation are listed in table 7-3, 7-4, 7-5, 7-6, 7-8, 7-10, 7-11, by taking these observations in consideration, here power factor of AC power is considered as 0.8. It is concluded that the efficiency of the inverter is very low under the condition of partial load, shown in figure 8.7 and figure 8.8. Figure 8.7 is the graph of variation in efficiency with load varying as battery is charging. And figure 8.8 shows the graph of efficiency variation with the load variation as input voltage of inverter is constant. This figure shows that if the load is under 10% of its rated capacity then the efficiency of the inverter is below 50%.

Observations on 24V inverter were taken on different day with the domestic load variation of whole day. The observation are listed in table 7-5, 7-10, by taking these observations in consideration, here power factor of AC power is considered as 0.8. It can be seen that same conclusion are made here as 48V inverter that the efficiency of the inverter is very low under the condition of partial load, shown in figure 8.9 and figure 8.10.

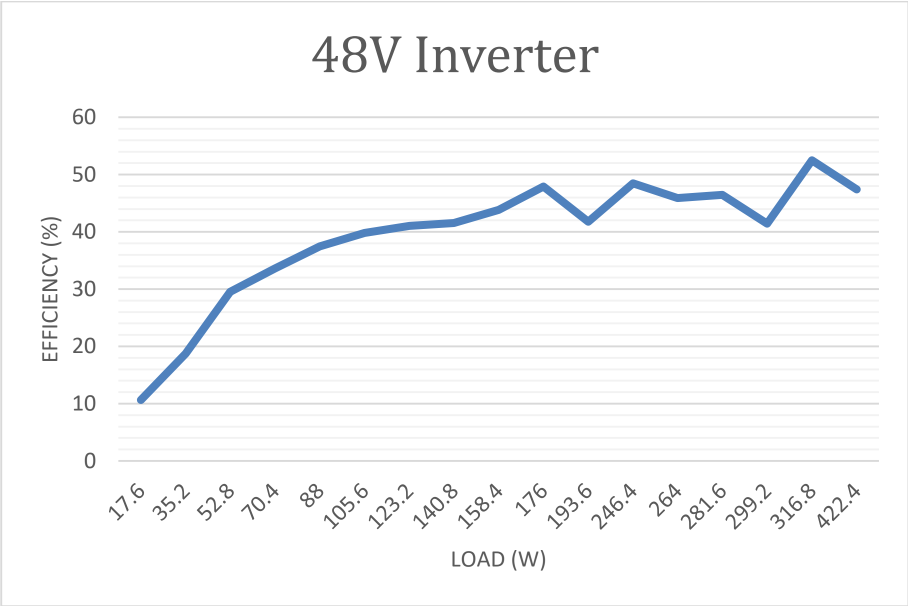

Figure 8.7: Efficiency Vs Load Variation of 48 V Inverter

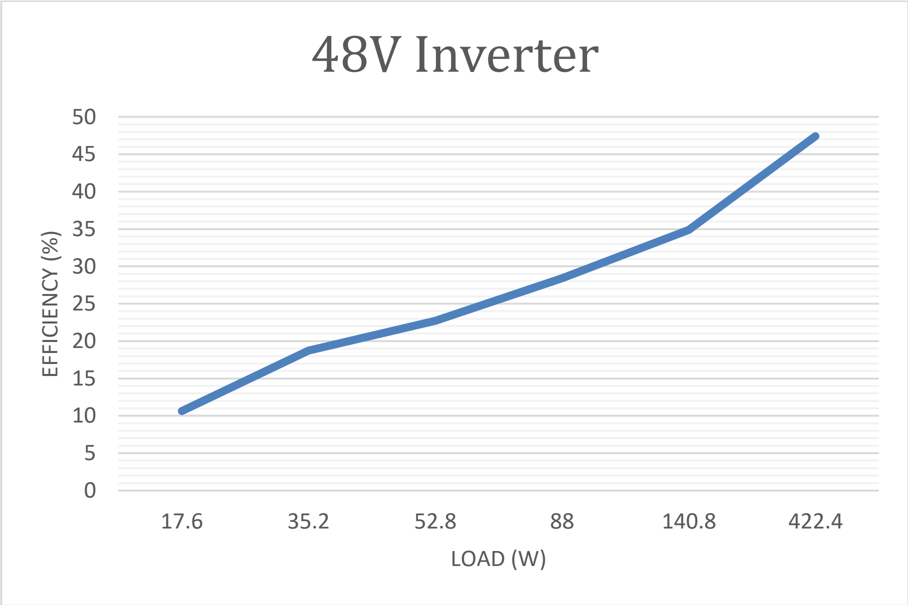

Figure 8.8: Efficiency Vs Load Variation of 48 V Inverter with constant input voltage

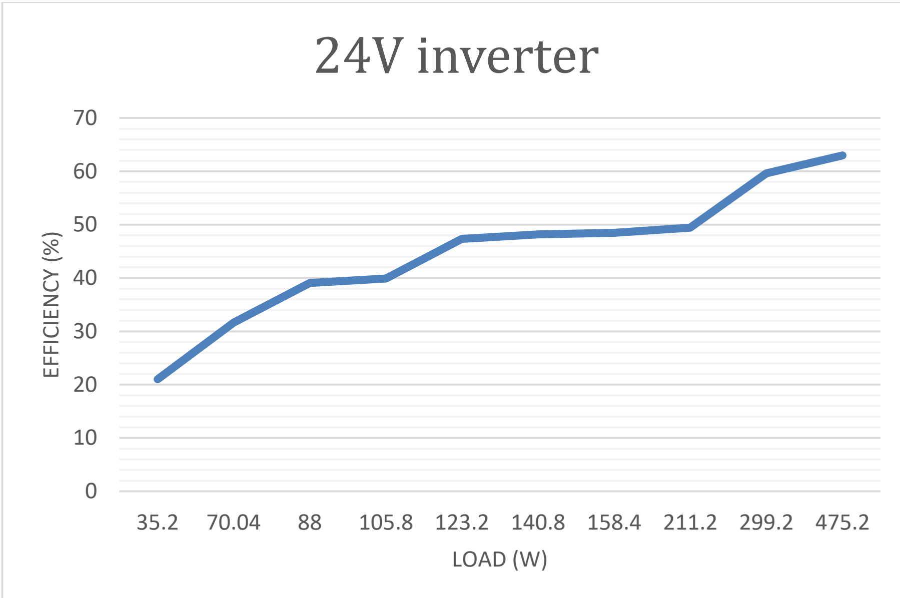

Figure 8.9: Efficiency Vs Load Variation of 24V Inverter

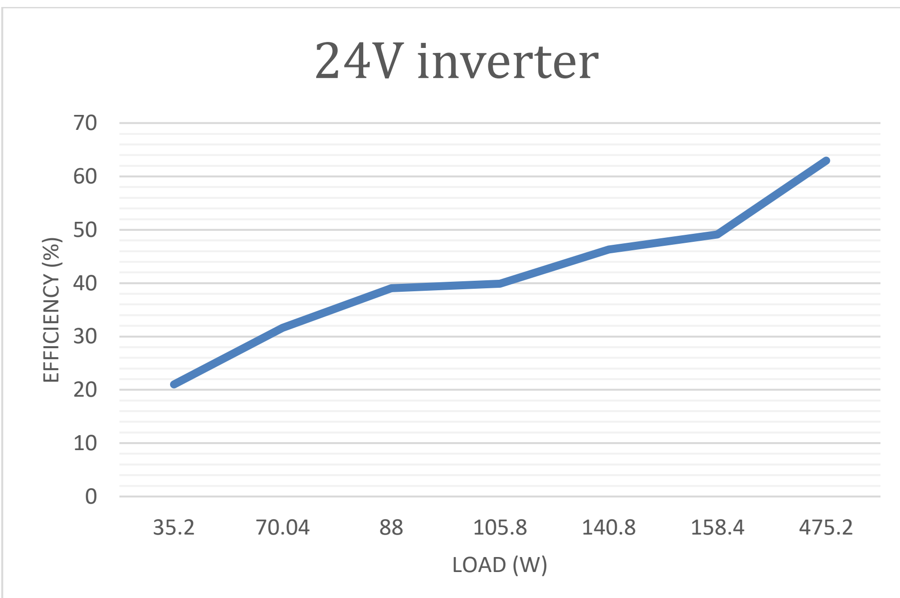

Figure 8.10: Efficiency Vs Load Variation of 24V Inverter with constant voltage

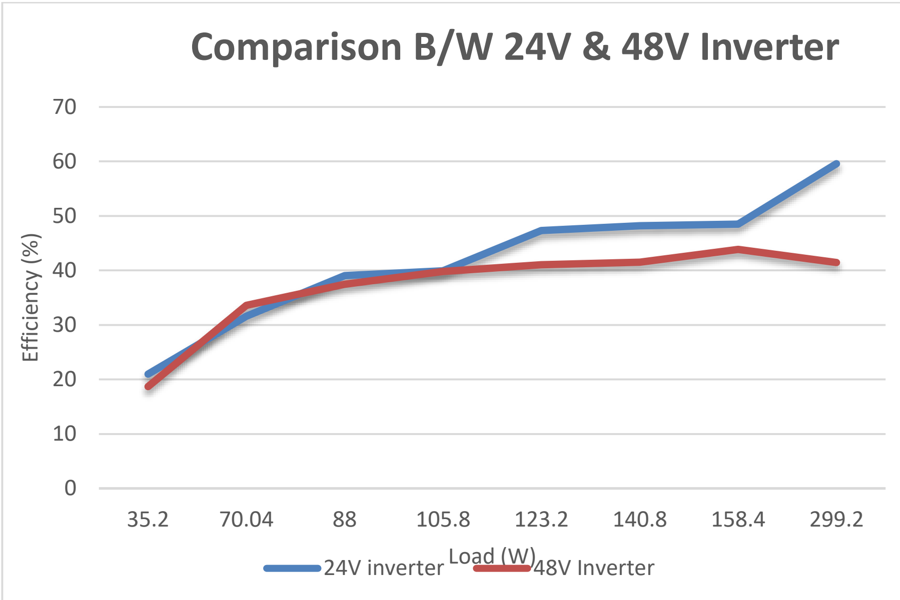

Figure 8.11: Comparison between 24V inverter and 48V Inverter

By comparison of 24V/2kVA inverter and 48V/2.5kVA inverter, it can be concluded that at lower load, low rated capacity inverter has high efficiency comparison to high rated capacity inverter. It also can be concluded that losses by the inverter in winter is large as comparison to summer because the domestic load in winter is less. By using the battery storage, the efficiency of PV system increases because the domestic load is variable, so load matching is difficult in domestic without battery storage. There are more cut-off losses when PV power is more as comparison to load when inverter connected to PV system without storage.

9. Conclusions

- The dusting has significant effect on performance of solar PV system. By the dusting open circuit voltage and short circuit current has decreased. Because of this, efficiency of PV system has decreased. So it is required to keep the PV panels clean.
- With increase in glass temperature of PV module the open circuit voltage decreases. Because of this efficiency of PV panel decreases. So efficiency of PV system in winter is high as compare to summer. Glass temperature can be reduced by the use of transparent PV module and this heat energy can be used in other purpose.
- Power generated by PV system in winter is less as compare to power generated in summer.
- If PV array directly connected with the inverter in domestic use than large amount of PV generated power not utilized. Because of this efficiency of solar system reduces, size and cost of PV array will also increase. So battery storage is necessary in domestic use of PV system. Battery storage also provides the power in night time for domestic use.
- Steady state losses in inverter are about 2-4% of its rated capacity.

- When load is under 10% of its rated capacity then efficiency of inverter goes under 50%
- When load is small, low rated capacity inverter gives good performance on the basis of efficiency.
- In the winter the performance of inverter decreases because of percentage load of its rated capacity is small as compare to the summer.

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