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# DESIGN AND OPERATION OF SOLAR PHOTOVOLTAIC VAPOUR COMPRESSION AIR-CONDITIONING SYSTEM

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**Abstract:** Energy is a crucial input in the process of economic, social and industrial development. Energy consumption in the developing countries is increasing at a faster rate. With the increasing human demand for energy, fossil energy reserves are getting exhausted. The use of fossil fuels has brought serious consequences to the human environment. As conventional energy sources are depleting day by day in a faster rate, utilization of alternative (renewable) sources is the only solution. Amongst the renewable sources of energy, solar energy is freely available, pollution free and inexhaustible. Photovoltaic systems use solar energy which presents various environmental benefits. Air conditioning system is almost a must in every building if we want to have a good indoor comfort inside the building. In recent years, progress on solar-powered air conditioning has increased. With increasing power tariffs, power cuts and decreasing solar panel prices, there is a lot of interest in people to adopt solar PV technologies. Air Conditioners are high wattage appliances. When a compressor of an air conditioner is running it needs high current. Conventional air conditioners running at the hottest points of the day contribute to power grid demands that often lead to outages. A photo-voltaic air-conditioning system consists of PV cells providing electrical energy to run a vapor compression system. Solar air conditioning units offer environmental benefits including lower grid demand and load shifting during peak usage, reduced electricity costs, fewer power outages, off-the-grid capabilities and reduced greenhouse gas emissions. The work involves designing, assembling and studying the PV power generation and Air conditioner load behavior, the feasibility of solar PV application to domestic air-conditioning. Although Solar Air Conditioners have some limitations in working during nights, but reducing electricity bill is our main motive, then Solar Air Conditioners provide much more value for money by using Solar PV for air conditioning.
**Key words:** Energy, Solar, Photovoltaic (PV), Renewable energy, Air-conditioning

## 1. INTRODUCTION

Harnessing of non-polluting renewable energy resources to control green house gases is receiving impetus from the government of India. The solar mission, which is part of the National Action Plan on climate change has been set up to promote the development and use of solar energy in for power generation and other uses with the objective of making solar energy competitive with fossil fuel-based energy options[1]. A significant part of the large potential solar energy in the country could be developed by promoting grid connected solar photovoltaic systems of varying sizes as per the need and affordability coupled with ensuring adequate return on investment. Solar energy integration into the energy mix at rural/urban level requires proper planning that spans across social, political, policy, technical and economic dimensions. Up to know, throughout world to run air-conditioning on solar, everybody thinks about solar vapor absorption system. Solar vapour absorption system was suitable with higher tons of refrigeration capacity (100TR and above) for industrial/commercial organizations where boilers steam will be available [3, 4]. A part of the steam will be supplied for operation of Aqua-Ammonia vapor absorption system. But whereas for domestic air-conditioning (small scale of TR) is concerned, it is not possible to run domestic air-conditioners on solar vapour absorption system.

### 1.1OBJECTIVE & SCOPE OF WORK

This paper focuses on the design and operation of SPV based split air-conditioning of 1 Ton capacity, 2005 year Voltas manufactured. The air-conditioner was not BEE rated. The compressor and fan motor of the air-conditioner are alternating current operated. Hence inverter is must for converting DC source from solar PV to AC source of 230v, 50 Hz.Chukwuneke et al explained [2] about a mathematical model of a solar DC vapour compression refrigeration system. The air-conditioner comes under inductive load. Many inductive loads draw 4 to 5 time's normal running power for few seconds during starting. This is called surge power. Inverter should be able to supply the surge power required by the inductive load [3]. The challenging task with solar PV and battery is to provide the surge power required by the air-conditioner during starting time [5].

**1.2NOMENCLATURE**

TR-Tons of refrigeration
SPV-Solar Photovoltaic
STC Standard Test Condition
AM Air Mass
Area, $m^2$
$W_P$, Watt Peak
$V_{max}$ - Maximum voltage
$V_{oc}$ - Open-circuit voltage
$I_{max}$, Maximum current
$I_{sc}$, Short-circuit current
MPPT- Maximum power point tracking
AC - Alternating current
DC - Direct current
VAC-Volts AC power
VDC-Volts DC power
LMLA- Low maintenance lead acid
FRP- Fiber reinforced plastic
BEE- Bureau of Energy Efficiency
PSC - Permanent Split Capacitor
CSR - Capacitor Start and Run
C- Common
S- Starting winding
R- Running winding
Hz- Hertz
USB-Universal serial bus
$I_b$ - Direct (or) Beam radiation
$I_d$ - Diffused radiation
$I_g$ - Global radiation
A/C- Air-conditioner
AJB - Array Junction Box
DCDB- Direct current distribution box
ACDB- Alternating current distribution box
MC-Multi-Contact
R.P.M-Revolutions per minute
VFD- Variable frequency drive

## 2. DESIGN METHODOLOGY FOR SOLAR PV AIR-CONDITIONING SYSTEM

**2.1STEP:** Determine the connected load and their energy estimation (Watts, and Wh)Energy consumed by the air-conditioner load in a given day is obtained by simply multiplying its power rating by the number of hours of operation.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| S.No | Name of appliance | No | Watts(W) | Total watts | No. of hours operation | Energy = Total watts×No. of hours operation |
| 1 | Split air-conditioner1 Ton, 2005 made, Rotary type compressor. | 1 | 1650 | 1650 | 5 | 8250Wh |

Table: Air-conditioner load calculation

**2.2 STEP: 2SIZING AND CHOICE OF ELECTRONICS COMPONENTS.**

The electronic components include an Inverter (DC-AC converter) and MPPT/Charge controllers (for optimal generation of electricity).

Inverter selection: The inverter should be selected in such a way that it should supply desired power to the load. In practice, it is good to choose an inverter having power capacity higher than the total connected load.

High DC voltage means less current: Generally, it is good to choose an inverter which can take high input DC voltage. High voltage will require less current in the system for the same power flow. Power is the product of current and voltage. Thus, for the same power flow, if voltage increases, current decreases. Lower current flow in the system has many advantages. Less current means less power loss and thinner wires, this also means less cost of the system.

**2.2.1 SOLAR HYBRID INVERTER SPECIFICATIONS:**

Rated power-3000 Watts.

**PV Input (DC):**

Nominal DC Voltage: 360VDC
Maximum DC voltage: 500VDC
Start-up voltage/Initial feeding voltage: 116VDC/150VDC
MPPT Voltage range: 250VDC~450VDC
Maximum Input Current: 13A

**Battery & Charger:**

Nominal DC voltage: 48VDC
Maximum charging current: 25A

**Grid/utility output(A/C):**

Nominal output voltage: 208/220/230/240VAC
Output voltage range: 184-265VAC
Output frequency range: 47.5~50.2 Hz (or) 59.3~60.5 Hz
Nominal output current: 13.6A
Power Factor; >0.99

**Battery mode output A/C:**

Nominal output voltage: 208/220/230/240 VAC
Output Frequency: 50Hz/60Hz (Auto sensing)
Output waveform: Pure Sine Wave
Efficiency (DC to AC): 92%

**AC input:**

AC start-up voltage: 120-140 VAC
Auto restart voltage: 194VAC
Acceptable input voltage range: 184-265VAC
Maximum AC input current: 20A

**Interface:**

Communication port: RS-232/USB

**2.3 2KW SOLAR PV POWER PLANT SPECIFICATIONS**

| S.No | Description | Specification | Quantity |
|---|---|---|---|
| 1 | Solar Panels (Multi or poly crystalline) | 250 $W_p$ | 8 No |
| 2 | Power Conditioning unit (PCU) | 3KVA Solar Hybrid Inverter, 1Ph output, 230V, 50 Hz. | 1 No |
| 3 | Array Junction Box (AJB) | FRP/Thermoplastic, suitable for 3Kw | 1No |
| 4 | Battery Bank | LMLA, 12V, 200Ah (Deep Cycle) | 4 No |
| 5 | Lightening arrestor | Class ‘C’ | 1No |

**2.3.1SOLAR PV MODULE DESIGN CALCULATION FOR 3KVA SOLAR HYBRID INVERTER.**

| | Module design calculation for Solar hybrid inverter - 3KVA | | | | |
|---|---|---|---|---|---|
| | $W_P$ | $V_{max}$ | $V_{oc}$ | $I_{max}$ | $I_{sc}$ |
| Module capacity | 250 | 36 | 42 | 6.98 | 7.32 |
| Series | 8 | | | | |
| Array Capacity | 2000 | 288 | 336 | 6.98 | 7.32 |
| Parallel | 1 | | | | |
| System Capacity | 2000 | 288 | 336 | 6.98 | 7.32 |

**2.3 STEP: 3 BATTERY SELECTION**

Batteries are important because without energy storage, a solar PV system will not be able to deliver the energy to the load when there is no sunlight.
Individual Battery Terminal voltage: 12V
Battery capacity: 200Ah
No. of batteries connected in series: 4
Battery ‘C’ rating: C/10
In a solar PV system, batteries are connected together in series when the required PV system voltage is higher than the individual battery terminal voltage. In series connection, the negative terminal of one battery is connected to the positive terminal of other battery. The positive terminal of the first battery in the series and the negative terminal of the last battery are used to obtain high voltage. When the batteries are series connected, same current will flow in all the batteries. But the voltage gets added. It is desired that the terminal voltage of all the series connected batteries is same.
Battery voltage: Manufacturers specify the range of voltages, called DC input window that can be applied to the input of inverter. In this case, the nominal DC voltage to the inverter input is 48V. Hence 4 nos. of 200Ah, 12V batteries are connected in series in order to make 48V system.

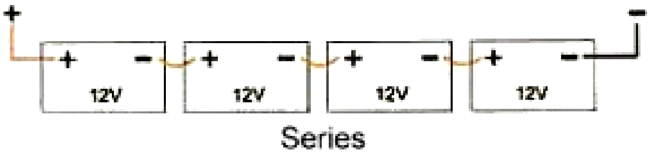

Fig.(a) 12V, 200Ah batteries in series connection

Power of the array of 4 batteries connected in series= No. of batteries × Voltage × Current delivered by a battery= 4×12×20 = 960W= 0.96KW
Energy stored in the battery array connected in series= 48×200= 9600Wh =9.6Kwh

**ELECTRICAL CABLES**

AC side:4 Sq.mm copper flexible
DC side:10 Sq.mm copper flexible
Interconnections for solar panels:MC-4 Connectors
Solar Radiation Data:
The following formula was used for converting solar radiation measured in millivolts by multimeter into W/m$^2$.

$$I_g = [(154.5 \times mv) - 3.2] W/m^2$$

| S.NO | Time | Insolation(in mv) | | | Insolation (in W/m$^{2}$) | | |
|---|---|---|---|---|---|---|---|
| | | $I_g$ | $I_d$ | $I_b=I_g-I_d$ | $I_g$ | $I_d$ | $I_b=I_g-I_d$ |
| 1 | 12:00 | 5.9 | 1.8 | 4.1 | 908.35 | 274.9 | 633.45 |
| 2 | 12:30 | 6.2 | 1.2 | 5.0 | 954.7 | 182.2 | 772.5 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 3 | 13:00 | 5.6 | 1.7 | 3.9 | 862.0 | 259.45 | 602.55 |
| 4 | 13:30 | 5.4 | 1.6 | 3.8 | 831.1 | 244 | 587.1 |
| 5 | 14:00 | 4.7 | 1.3 | 3.4 | 722.95 | 197.65 | 525.3 |
| 6 | 14:30 | 4.5 | 1.0 | 3.5 | 692.05 | 151.3 | 540.75 |
| 7 | 15:00 | 3.6 | 1.0 | 2.6 | 553 | 151.3 | 401.7 |
| 8 | 15:30 | 2.6 | 0.08 | 2.52 | 398.5 | 9.16 | 389.34 |
| 9 | 16:00 | 2.2 | 0.07 | 2.13 | 336.7 | 7.615 | 329 |
| 10 | 16:30 | 1.3 | 0.06 | 1.24 | 197.65 | 6.07 | 191.58 |

Table: Pyranometer (Radiation) Readings on 24-08-2016

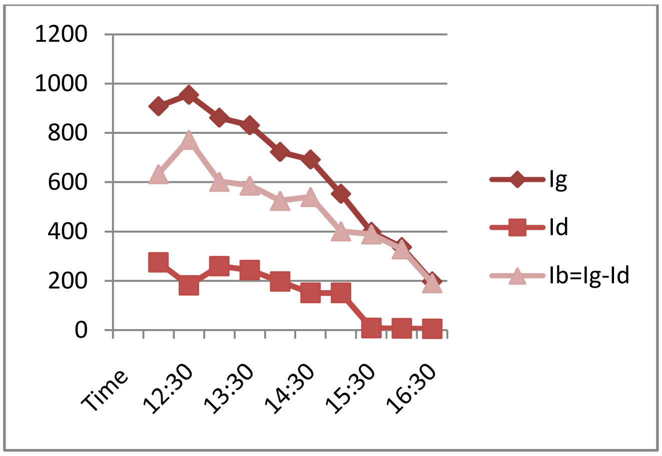


Fig.(b) Solar Radiation 2-D line chart

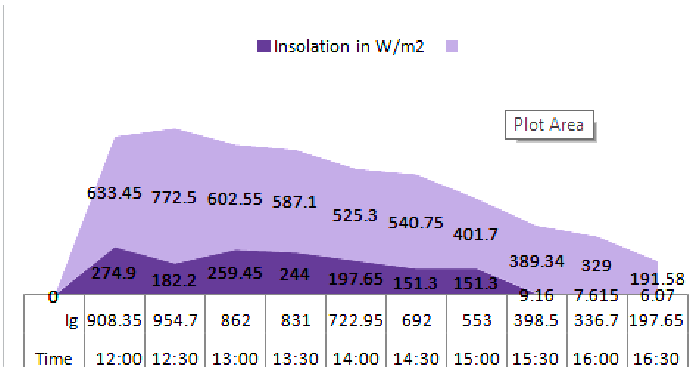


Fig.(c) Solar Radiation Data

**SOLAR PV PLANT, EARTHING & LIGHTNING ARRESTOR DIAGRAMS**

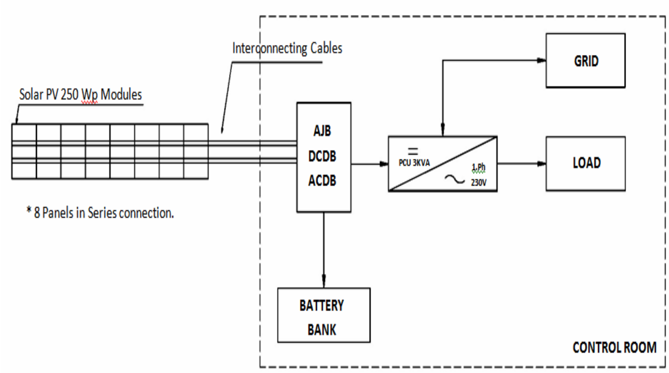


Fig.(d)Solar PV power plant

In the above diagram the ‘Load’ refers to air-conditioner.
Grid connection was not provided for the air-conditioner. Air-conditioner was operated with only solar PV and battery source.

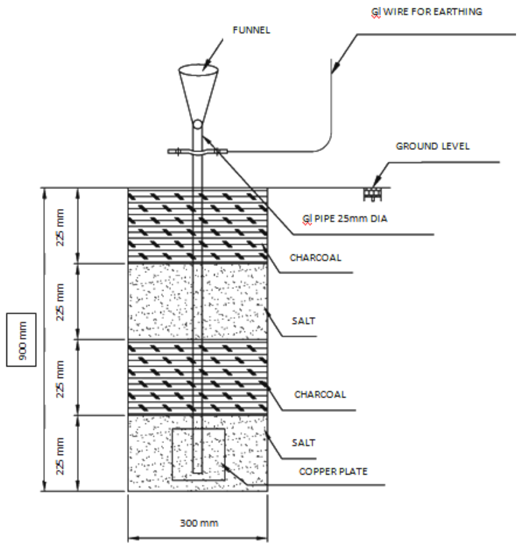


Fig.(e) Earthing Pit for PV panels

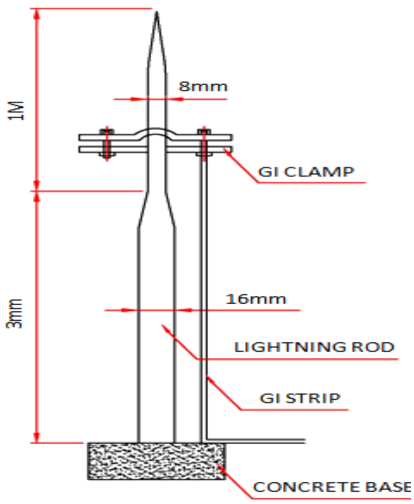


Fig.(f)Lightning arrestor (class ‘C’)

Dedicated earthing was provided for the lightning arrestor and separate earthing was given to solar panels.

**Operation of split air-conditioner:**
Site co-ordinates:
Latitude:17$^0$49$^'$.
Longitude:78$^0$39$^'$
Tilt Angle:18$^0$
Averaged solar radiation: 5.02 KW-hours/m$^2$/day
Number of full production days per year: 330

The electrical circuit of 1 ton capacity split air-conditioner is of permanent split capacitor (PSC) type, which is given by the Voltas manufacturer. Before testing on solar PV, the air-conditioner was successfully operated with grid/utility without any starting problem. Since Grid/Utility will be capable to supply the required initial inrush current. But when trying to operate on solar PV source and battery backup, the compressor was not started, and the inverter output A.C supply was tripping and showing overload error.

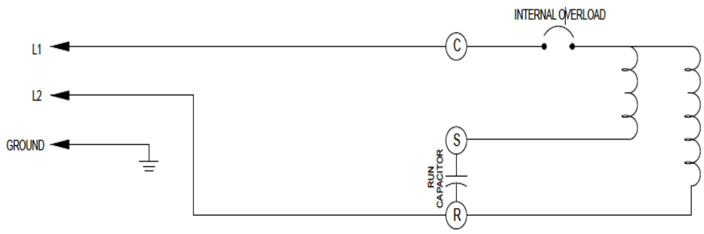


Fig. (d) The electrical circuit of PSC operated air-conditioner

'C' 'S' 'R' denote compressor glass terminal pins.
$L_1$ - Phase or Line, $L_2$ - Neutral.
Then we have concluded that the PSC circuit was not providing the required torque to the compressor shaft and it requires high initial surge current which will damage the compressor windings. The inverter was unable to supply the starting inrush current (Surge) and A.C output supply is tripping by its internal relay.
The initial inrush current will be 4 to 5 times more than the normal running current. In the PSC circuit, starting and running windings both will be in the circuit after starting of the compressor also. To resolve this initial starting problem of the PSC circuit based compressor, by modifying into capacitor start and run (CSR) circuit.

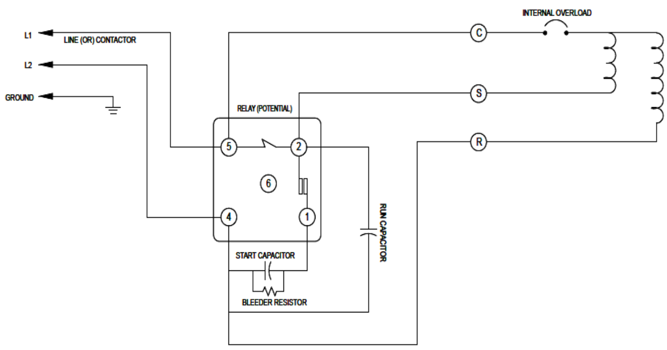


Fig.(e) After Modification, the electrical circuit of CSR operated Air-conditioner

'C' 'S' 'R' denote compressor glass terminal pins.
#4 and #6 on relay are dummy terminals.
$L_1$ - Phase or Line, $L_2$ - Neutral

In the CSR circuit, the compressor is equipped with internal over load protector, run capacitor, start capacitor and potential relay. The relay and start capacitor will provide additional starting torque. Potential relay consists of a coil and a plunger. Relay coil is in parallel with start winding. Before power is applied, the relay contacts are closed. When power is applied, the motor comes up to the speed and a high voltage is induced in the start winding. This voltage is sensed by potential relay coil and it causes the relay contacts to open through magnetic action. As soon as contacts are opened, start capacitor is cutout from the circuit. Contacts open in less than 1 second as motor starts. Since dropping action is gravity assisted, positioning the relay with 'TOP' side up is important.

Now the split air-conditioner was able to start with only battery backup of 48v, 200Ah capacity and also with solar PV and battery backup and only with grid supply also. Smooth starting in all above cases was observed. Current drawing is also within the limits (8Amps).

The air-conditioner was operated for continuously from 11.45a.m to 16.45p.m.

Graphs are drawn between No. of hours for A/C operation and with different parameters are given below.

a. Solar PV input power, W
b. Solar PV input voltage, V
c. A/C load power, W
d. A/C load level, %
e. Battery voltage, V
f. Battery capacity, %
g. Charging current, A
h. Inverter internal temperature, $^{0}C$

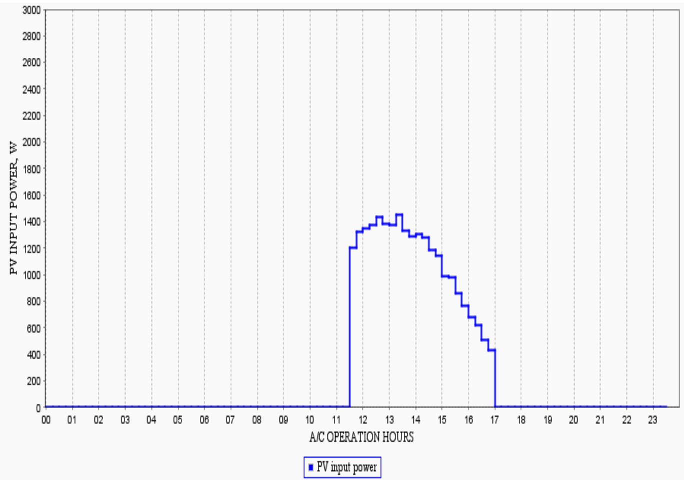


Fig. (a) PV input power Vs A/C operation in hours

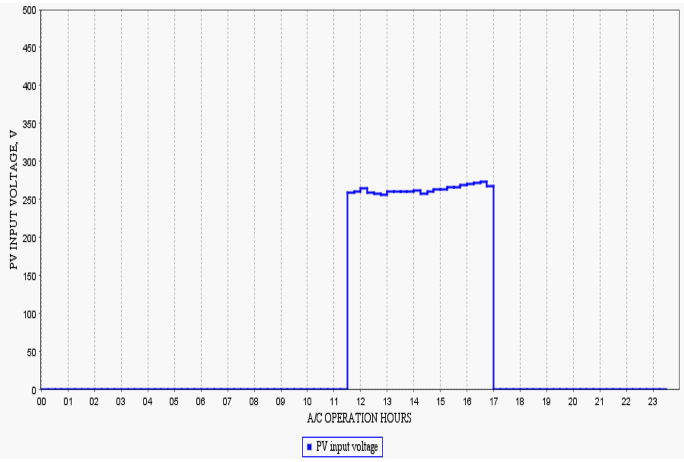


Fig. (b) PV input voltage Vs A/C operation in hours

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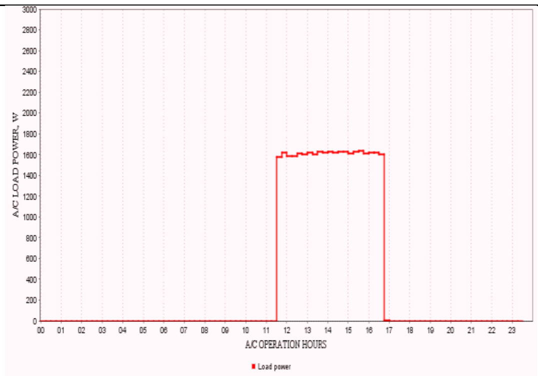


Fig. (c) A/C load power Vs A/C operation in hours

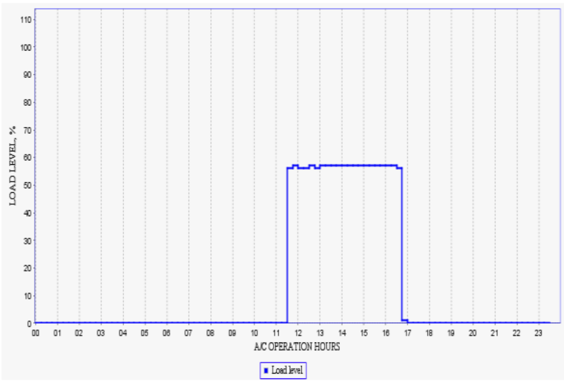


Fig.(d) Load level Vs A/C operation in hours

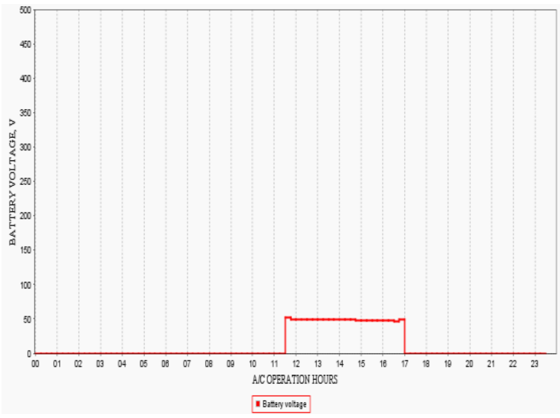


Fig. (e) Battery Voltage Vs A/C operation in hours

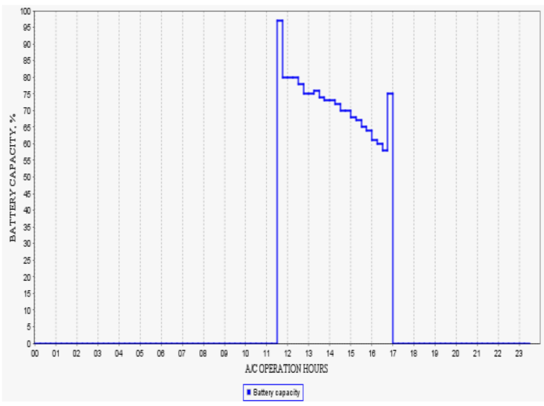


Fig. (f) Battery capacity Vs A/C operation in hours

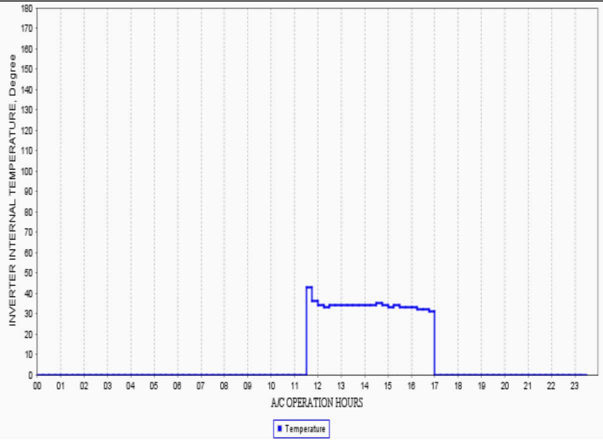


Fig. (g) Inverter internal temperature Vs A/C operation in hours

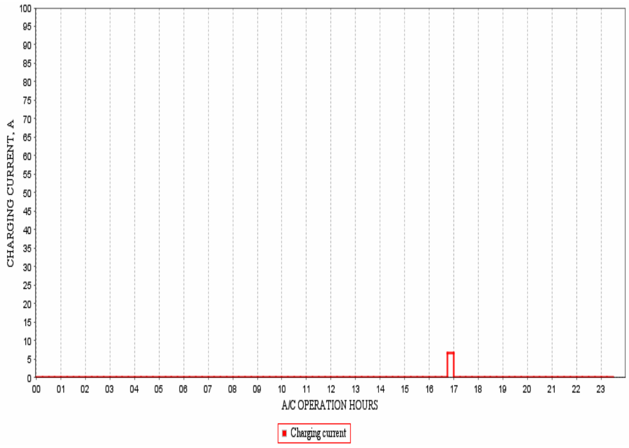


Fig. (h) Charging current Vs A/C operation in hours

## CONCLUSION

The experimental setup of 2 kW solar PV plant generating maximum 1448W power at maximum radiation of 772.5 W/m$^2$after all losses on the experiment conducted day. The initial starting problem in air-conditioner was solved by changing the electrical circuit from 'PSC' to 'CSR' operated. The starting current (or) initial inrush current required for the A/C Compressor was provided by the battery bank and solar PV simultaneously.In order to know the behavior of surge load under peak solar radiation, the air-conditioner electrical supply was directed (without thermostat) and operated in an open environment continuously for 5 hours. Hence there is no question of putting off the compressor by the thermostat.

During the peak solar radiation, the maximum energy was supported by the solar PV source and remaining energy was supplied by the battery bank. If this experiment will be conducted in closed room, the thermostat will cut-off the compressor, after attaining the required room temperature. During this compressor off-cycle time, the energy generated by solar panels will be stored in the batteries and that energy will be used for the air-conditioner during on-cycle time.

In the sunset conditions (or) during night time also, the air-conditioner was able to start and operated for 5hours continuously only with battery back-up, without any grid connection.

We can operate the air-conditioner with different energy mix with solar hybrid inverter was as given below:

a. The solar PV and grid connection
b. Solar PV and battery backup if there is no grid
c. Grid and battery backup in absence of solar PV

First the solar hybrid inverter gives preference for solar PV and if there is no radiation, then checks for grid supply. If grid will also fail, then finally, checks for battery source. If the demand from load side is less, the inverter checks for battery demand. If battery was not fully charged, it will supply the current to batteries. If there is no load demand, no battery demand, the energy will be exported to grid if it is grid connected. Hence we can generate revenue from excess power export to grid as and when air-conditioning was not required.

**FUTURE SCOPE OF WORK**

With the above mentioned experimental setup, we have operated the split air-conditioner (old one) of 1ton capacity (1650watts) which is drawing 8 amps of current. In case of Inverter based technology air-conditioner we can very easily operate and save energy as the air-conditionerscompressor isof rotary type and itsoperationwas based on variable frequency drive (VFD). Depending on the load condition i.e. external temperature/ambient conditions, the compressor and fan motor R.P.M varies. Hence once desired temperature occurs, the compressor and fan motor runs with lesser R.P.M and consumes less energy. With inverter technology, we can save a lot of energy.

We can also design an air-conditioner operates only with pure DC source of power. In this case of study we have to use DC compressor and DC fan motor. The required DC voltage for the compressor and fan motor can be provided by the DC-DC converter. In this case, we cannot require an inverter and also we can reduce the energy conversion losses as we found in pure A.C power source operated air-conditioner. With pure (DC) solar air-conditioner we can save energy and environment.

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