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An Analysis of Small Scale Grid Connected Rooftop Solar Power Generation-A Pilot Scheme

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Abstract

Energy demand in India and especially in Karnataka state is continuously increasing, however the electric utilities failed to meet this load demand. Photovoltaic (PV) solar power plant is used for larger development of solar power generation. In a solar roof top system, the solar panels are installed on the roof of any residential, commercial, institution and industrial building. The solar roof top system may come up with storage facility using battery or grid connected. In grid connected roof top solar PV system, available roof top area on the buildings is used for setting up solar power plant and the DC power generated from solar photovoltaic panel is converted to AC power using solar grid inverter and is fed to grid during day time and in night when solar power is not sufficient, loads are served by drawing power from grid. In this research paper, real time and Simulation analysis of 8KW grid connected photovoltaic solar roof top power plant at Davangere city is carried out using PV syst. The real time meter readings on both export and import side are recorded and simulation results of energy output of inverter, energy injected into the grid and energy supplied to the user are presented.

Keywords: Grid, Roof top system, solar photovoltaic panel, solar radiation, Solar grid inverter.

I. INTRODUCTION

Solar energy is a clean, pollution free renewable source of energy. Karnataka state being located between 11° 40′ and 18° 27′ North latitude and the geographical location favors the harvesting and development of solar energy. Karnataka state is having 300 sunny days with good solar radiation of 5.4 to 6.2 KWh / square-meter

/day. Davangere city comes under Karnataka state in India which is 250KM from the Bangalore, the capital city of Karnataka state. The yearly average solar radiation on horizontal surface in Avaragere village of Davangere city is 5.24 $KWh/m^2/day$ at latitude of 14.4384 ^{0}N and longitude of 75.956082 ^{0}E [8].

In Oct 2013, Karnataka Electricity Regulatory Commission (KERC) has fixed tariff of Rs 9.56 per unit (without subsidy) and Rs 7.20 per unit (with subsidy) to the roof top solar Photovoltaic (PV) plants for the energy generated exceeding the energy consumed during a billing period. The above approved tariff is applicable to solar power generator entering into power purchase agreement (PPA) after Apr 2013 and up to Mar 2018. KERC revised again fixed tariff to Rs 7.08 per unit (without subsidy) in Apr 2016. The government of Karnataka has announced solar policy 2014-21 in May 2014 for grid connected rooftop PV systems. It is proposed to achieve a minimum of 400MW's of grid connected rooftop solar power plants in Karnataka state by 2018.

Electric utilities are finding it difficult to meet rise in peak demand and as a result, most of cities and towns are facing severe electricity shortages. Most of commercial establishments use one or more diesel generator for back-up power. In order to utilize the existing roof space of buildings, the scheme proposes to promote rooftop solar PV systems on buildings to replace diesel generator sets.

II. GRID CONNECTED ROOF TOP SOLAR POWER PLANTS

Solar PV cells converts sunlight to generate electricity through a photovoltaic process. There are two types of solar PV systems: standalone and grid connected. Standalone solar PV systems work with batteries [6]. The solar energy is stored in the battery and used to feed building loads after conversion from DC to AC power with a standalone inverter. These systems used in remote areas without grid supply. The disadvantage of these systems is that the batteries require replacement once in every 3-5 years.

In Grid connected rooftop solar power plant, the DC power generated from solar photovoltaic (SPV) panel is converted to AC power using power conditioning unit and is fed to the grid either of 11KV lines or of 415/240V, three / single phase lines and if any shortfall of solar energy is imported from grid. A schematic sketch of a typical grid connected solar rooftop photovoltaic power plant is shown in Fig1.

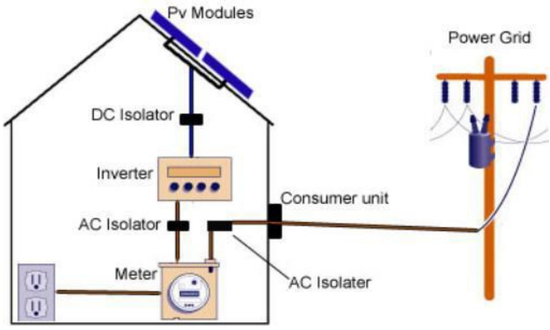

Fig1. A Schematic sketch of a Typical Grid connected Solar Roof Top Photo Voltaic Power Plant.

Solar PV cells generate power during the day time which is utilized fully by powering captive loads and feed excess power to grid [3]. In case solar power is not sufficient due to cloud cover, the captive loads are served by drawing power from grid. The grid-interactive roof top system can work on net-metering basis where in utility pays to the power plant owner on net metering basis only. Two meters can also be installed to measure the export and import of power separately. Grid interactive systems do not require battery backup as utility grid acts as the backup to feed excess solar power and vice-versa [4]. To enhance the reliability of overall systems, a minimum battery backup of one hour of load capacity is recommended.

III COMPONENTS OF SOLAR PV SYSTEM

A Grid-connected solar PV system consists of following main components [1]:

A. Solar photovoltaic (PV) modules

Solar PV modules are mounted on the roof of buildings and convert sunlight into direct current. The size of a solar PV system depends on the 90% energy consumption of the building and the shade-free rooftop area available. To achieve a required voltage and current, a group of PV modules are wired into large array called PV array.

B. Solar PV array support structure

These are galvanized steel structures secure the solar PV modules on the roof of building. The mounting structures require roof to be penetrated and mounting solar panels correctly is part of maximizing power generation.

C. Solar grid inverter

Solar grid inverter converts generated direct current into alternating current which is required for all electrical appliances through a charge controller. It also regulates battery charging if required.

D. Balance of system

All other components considered for solar rooftop power plant are cables, junction boxes, fuses etc.

The size of solar plant require depends on requirement of electrical load, number of KWh consumption and how much money would we like to earn etc. The size of solar plant is limited by the extent of shaded free rooftop space available. The expected life of solar PV plant is 25 years.

IV REAL TIME SYSTEM DESIGN

The main target is to design and install 8KW solar rooftop solar power plant.

A. Key facts of solar rooftop power plant

Plant capacity in KWp : 8KWp Rooftop Solar power plant

PV Technology/Module: Polycrystalline modules

Power conditioning unit: 8 KVA

Power evacuation : 415/240V, three/single-phase, 50HZ

A typical Design of 8KW Solar Roof Top Power Plant of Avaragere village in Davangere city is shown in Fig 2.

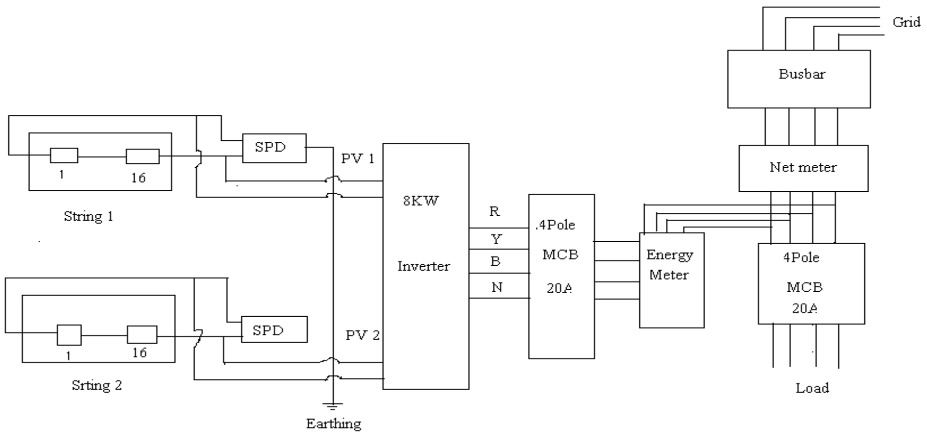

Fig 2 A typical Design of 8 KW Roof Top Solar Power Plant at Avaragere,Davangere City.

Actual on-site 8KW Solar Roof Top Power Plant of Avaragere village in Davangere city is shown in Fig 3.

Fig 3. Actual onsite of 8KW solar roof top plant at Avaragere, Davangere city

B. System capacity based on rooftop area

Total Power output = Total area × Solar irradiance x Conversion efficiency

$$8000 = \text{Total area x } 1000 \text{ Watts/m}^2 \text{ x } 0.1537$$

Total area required for 8KWp = 52 Sq.m = 560sq.feet

The rooftop area required to install 8KWp is around 600 sq.feet.

C. Number of PV panels for the system

Divide the total watt-hours per day needed from PV panels by the rated output watt-peak of PV modules.

Capacity of each module: 250Wp

Number of PV panels or modules required = 8000Wp / 250WP = 32

Number of strings as per system Design = 02 Numbers

Number of solar panels in each string = 16

The maximum power of this module is 250Wp; hence it requires 32 modules to design 8KW PV system. The selected PV is manufactured by Emvee Solar and onsite arrangement of solar PV modules at Avaragere, Davangere is shown in Fig 4.

Fig 4. Actual onsite of 8KW solar roof top PV modules at Avaragere, Davangere city

The PV module parameters and ratings [2] are given in Table 1 and more specifications of PV module and dimension [7] are given in Table 2.

Table 1. PV module parameters and ratings

Electrical Characteristics	
Rated Maximum power (Pmax)	250Wp
Maximum power voltage (Vmp)	30.84 V
Maximum power current (Imp)	8.15A
Open circuit voltage (Voc)	37.26V
Short circuit current (Isc)	8.907A
Module efficiency	15.37%
Operating temperature	- 40°C to +85°C

Table 2. PV module specifications and dimension

Specifications and Dimensions of PV module	
Solar cells	Multi crystalline solar cells
Solar cell size	156 mmx156 mm(6 inx6 in)
Number of cells(pieces)	60 (6x10)
Module dimensions	1644 mm x994 mm x50 mm
Weight	18.8 kg
Front glass	3.2 mm tempered glass
Frame	Anodized aluminum alloy
Protection degree	IP 65
High efficiency	17.4%
Grid connection	ON/OFF grid
No. of PV modules/panels	20

D. Solar Grid Inverter rating

The recommended solar grid inverter capacity is in the range of 95% to 110% of solar PV array capacity. The solar array PV capacity is 8KW. The solar grid inverter requires will be in range of 7.6KW to 8.8KW. For grid connected, input rating of inverter should be same as PV array rating [5]. For this system, solar grid inverter used is 8KVA of ABB make is shown in Fig 5.

The inverter parameters are given in Table 3

Table 3. Inverter parameters

Inverter specifications	
3-phase inverter chosen	8KVA on grid inverter
Maximum efficiency	98%
Maximum ac output current	35A
Maximum ac output power	8000W
Rated ac power	7360W
Rated ac grid voltage	415V

Fig 5. Actual onsite 8KVA solar grid inverter at Avaragere, Davangere city

E. Distribution Transformer rating

The details of distribution transformer used in this analysis are

Summarized as follows:

Location of Distributing Transformer: Kudli Ranga Rao DTC, Davangere city

Capacity of Distribution Transformer: 100KVA

Total connected load in KW: 53 KW

Tong Tester reading at current in all 3-phases and

Neutral: 62A, 60A, 60A

The rating of SRTPV capacity = 8KWp

Total generating capacity in KWp = 8KWp

F. Feeder rating

The details of feeder are summarized as follows:

Name of 11KV Feeder: Avaragere, Davangere city.

Feeder Number: F-7

Name of 66 / 11 KV substation: Avaragere, Davangere city

Type of conductor / cable (Size): Rabbit

Total connected load on feeder in KVA: 2731KVA

Total capacity (KWp) of SRTPV system: 800KWp connected on feeder.

Peak load on feeder in Amperes: 60 Amps

G. Meter specifications

The meter specifications are given below:

Meter Number (RR Number) : AVAEH 27317

Tariff: LT – 2(A)

Phase: 1- phase LT or 3-Phase LT/HT: BSRTPV-13 /31.12.15

Sanctioned Load: 1 KW

Make: Secure sprint 350, 3-phase, 10-60A (Bidirectional)

L and G, 3-phase, 5-30A, solar grid side

V. REAL TIME TEST RESULTS

A. Meter output readings on Import and Export side

The output meter readings of energy meters on import side and export side at the time of installation are tabulated in Table 4.

Table 4 Meter reading on Import and Export side at the time of installation.

Import side			
C KWh	C KVArh (lag)	C KVArh(lead)	C KVAh
0.899908	0.328637	0.178941	1.087422
Export side			
C KWh	C KVArh (lag)	C KVArh(lead)	C KVAh
0.703373	0.277700	0.210893	0.863453

The output meter readings of energy meters on import side and export side after 15 days of installation on 21.05.2016 are tabulated in Table 5.

Table 5 Meter reading on Import and Export side after 15 days of installation on 21.05.2016.

Import side			
C KWh	C KVArh (lag)	C KVArh(lead)	C KVAh
390	6.07	5.3	391.7
Export side			
C KWh	C KVArh (lag)	C KVArh(lead)	C KVAh
387	3.8	3.0	389

The Energy generated from the actual site of 8KW solar roof top plant at Avaragere, Davangere on 21.05.2016 is 38.6 Kwh.

A perfectly efficient 8KW Solar system would generate about (4.8 peak sun hours x 8KW=) 38.4 KWh of power per day.

Table 6 shows the residential solar PV index of pricing, electricity yield and returns of 8KWp Solar PV systems.

Table 6 The residential solar PV index [9].

Solar Choice
Residential Solar System Payback Estimator

Inputs	Solar							Electricity usage	
	System size (kW)	Average daily sun hours*	Solar system out-of-pocket cost	Feed-in tariff rate ($/kWh)	Cost of retail electricity ($/kWh)	Self consumption ratio¥	Solar system efficiency factor†	Average daily household energy usage (kWh)	Quarterly household energy usage (kWh, based on daily usage)
(Enter values only in cells with white backgrounds)	8	6.2	$12,280	$0.08	$0.25	0.6	0.7	30	2737.5

Outputs	Solar power produced (kWh)	Solar power consumed (kWh)	Solar power exported to grid (kWh)	Total power purchased from grid (kWh)	Value of solar power consumed	Value of solar exported to grid	Total savings from solar	Total electricity usage charges with solar	Total electricity usage charges without solar
Daily^	34.7	20.8	13.9	9.2	$5.21	$1.11	$6.32	$1.18	$7.50
Quarterly^	3168.2	1900.9	1267.3	836.6	$475.23	$101.38	$577	$108	$684

Number of years to pay off	Annual internal rate of return (IRR)	Annual savings (Year 1)	System net present value (NPV)ø
5.19	20%	$2,288	$24,249

Additional inputs	
Assumed electricity inflation rate (%)	2.50%
Assumed discount rate (%)	5.00%
Assumed FiT annual increase rate (%)	1.20%

VI. SIMULATION ANALYSIS RESULTS

The global system configuration of the PV array is shown in Fig.6

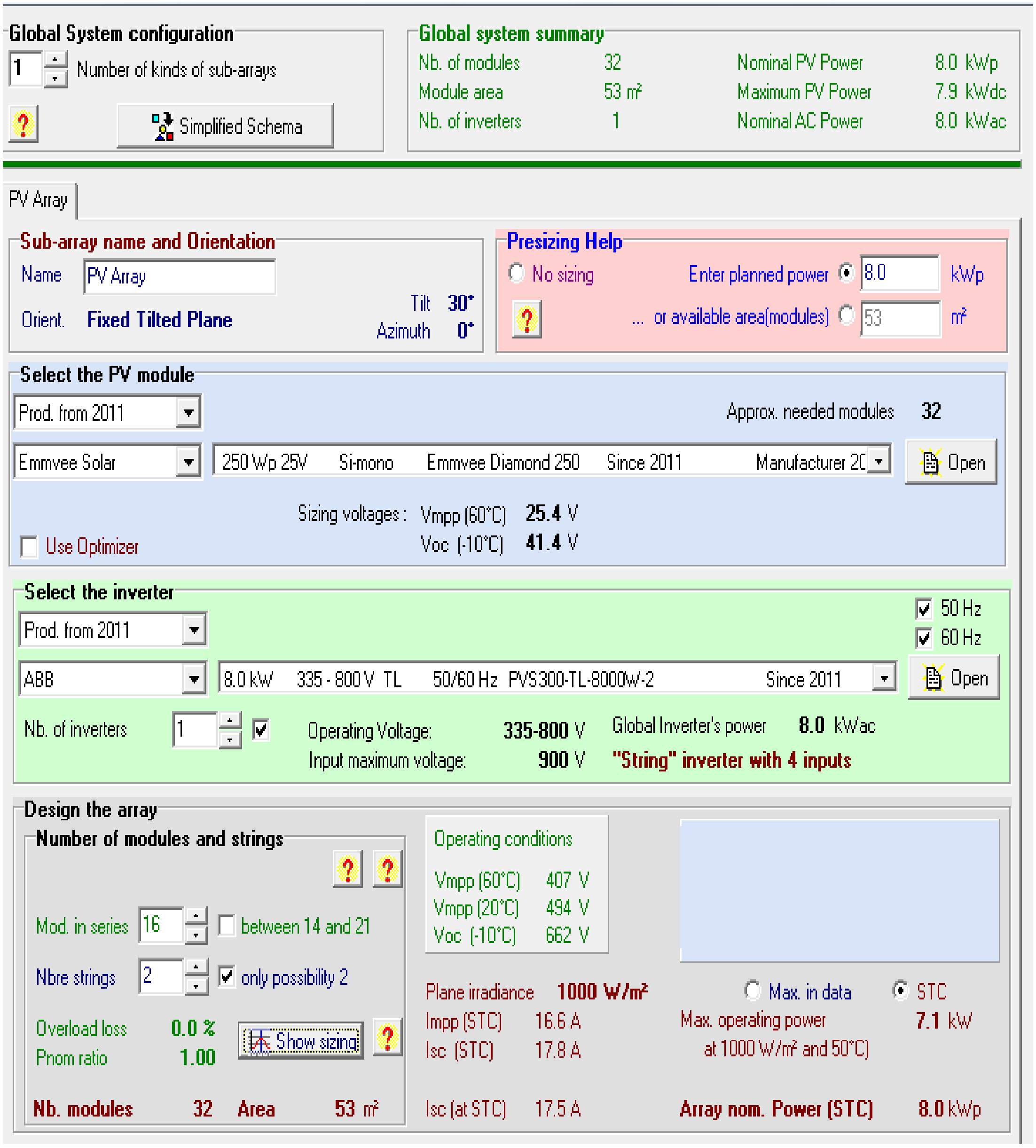

Fig.6 The global system configuration of the PV array

The main Simulation results of 8KW simulation project are presented in Table7

Table 7. Main Simulation results

New simulation variant

Energy use and User's needs

	E Avail kWh	E Load kWh	E User kWh	E_Grid kWh	SolFrac
January	1382	79.15	37.73	1344	0.477
February	1246	71.49	37.72	1208	0.528
March	1342	72.64	39.39	1302	0.542
April	1125	70.30	37.99	1087	0.540
May	1019	72.64	39.36	979	0.542
June	810	60.25	33.99	776	0.564
July	770	62.25	35.32	735	0.567
August	822	62.25	35.11	787	0.564
September	970	70.30	37.75	932	0.537
October	1182	72.64	38.38	1143	0.528
November	1234	70.30	36.80	1197	0.524
December	1370	79.15	37.51	1333	0.474
Year	13272	843.35	447.05	12825	0.530

The available energy at inverter output/day is shown in Fig.7

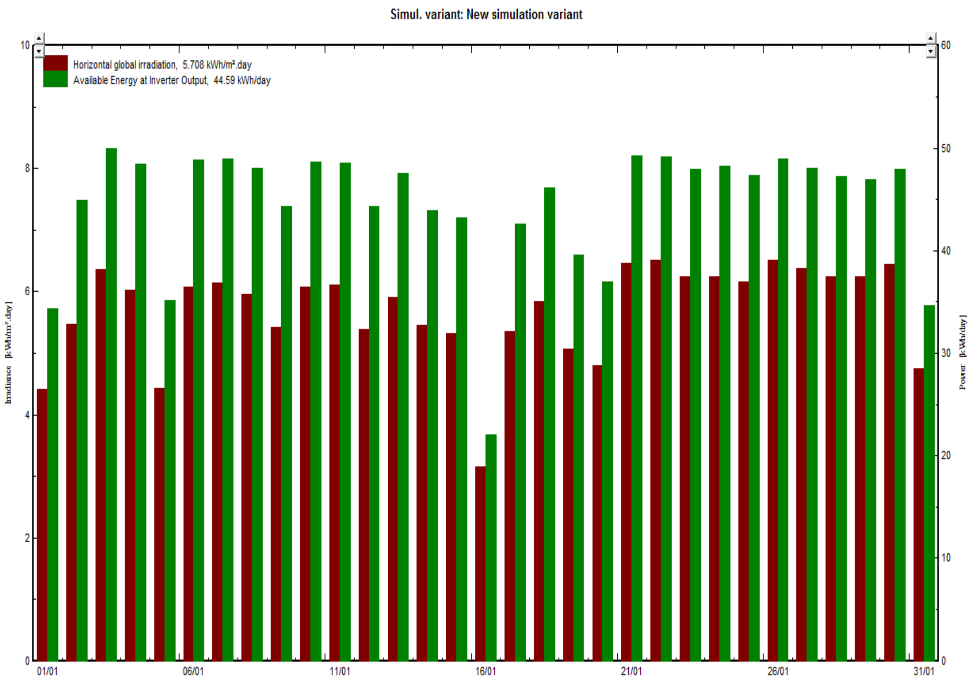

Fig7. The available energy at inverter output /day

The energy injected into grid is shown in Fig.8

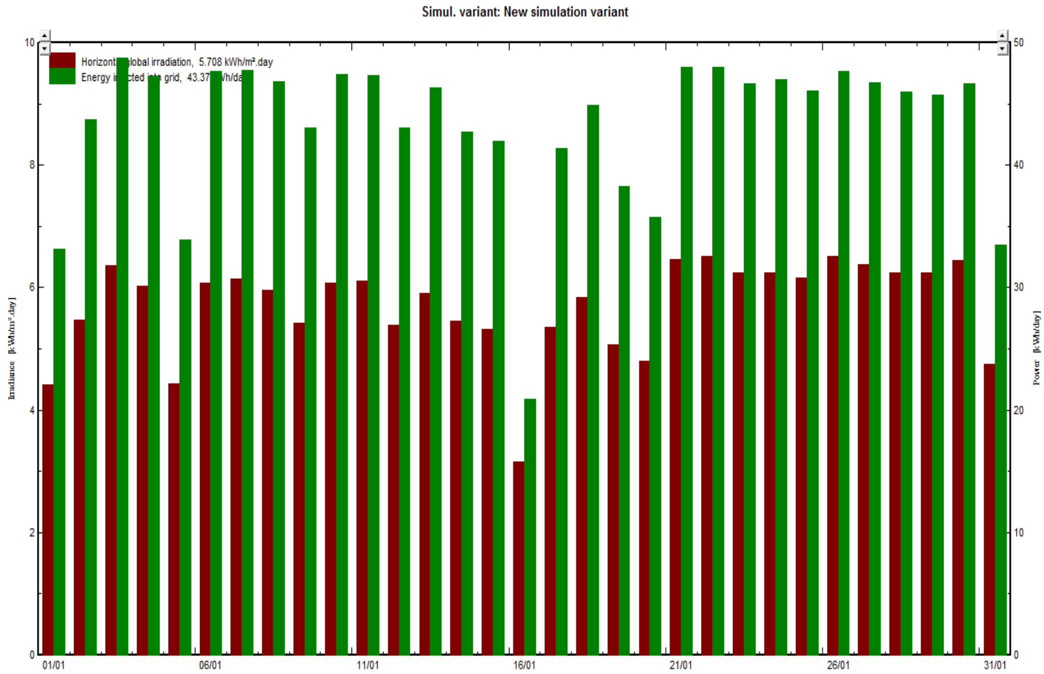

Fig.8 Energy injected into grid

The energy supplied to the user is shown in Fig.9

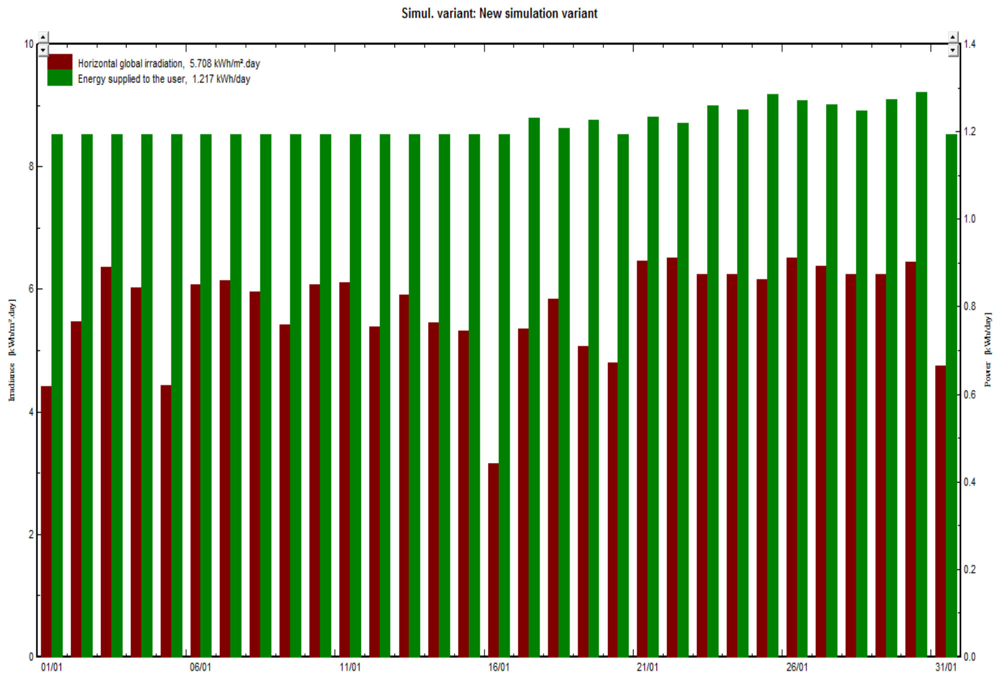

Fig.9 Energy supplied to the user

VII. CONCLUSIONS

The real time design of an 8KW solar PV power plant located on the roof of a residential building in Davangere city is carried out by means of determining the engineering standards and realistic constraints of design. The required shaded free roof top area for installing such plant is found to 600 sft. We study how to establish a real time design of 8KW photovoltaic solar roof top power plant and installation of the 8KW roof top plant and the meter output reading on both import and export side are recorded and it is observed that the available energy at inverter output is 38.6 KWh/day. The available energy at the inverter output is indicated by import side meter and the energy injected into the grid is indicated by meter on export side. The energy supplied to user is the difference of these two meters after meeting losses. The Simulation analysis of 8KW solar PV power plant located on the roof of a residential building in Davangere city is also carried out by the software PV syst. From the simulation results, the horizontal global irradiation is 5.708 Kwh/m^2.day and the available energy at inverter output is 44.59KWh/day. The energy injected into grid is 43.37 KWh/day. The energy supplied to the user is 1.217KWh/day. The duration of PV production of the considered array is 10.52Hour. These outputs reading vary with respect to irradiation. The opportunity to build and design large scale PV roof top Power plants is a future growth.

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