Impact of Energy Efficient Technologies Combined with Solar Roof Top MPPT Control Towards Achieving Sustainable Development in Indian Household

K. Mohan, Sujatha Balaraman

Abstract*: *The primary energy demand in India is expected to increase about 1250 to 1500 million toe (tone of oil equivalent) in 2030.As a result of increasing incomes and growth in economy, energy demand increases electric energy utility services in lighting, space cooling, industrial production, office automation etc. In 2011, annual average supply was only 0.6 toe per capita; whereas the world average was 1.88 toe per capita. To cater the energy demand with minimum CO2 emissions, two prolonged approach is employed. In the generation side, use of renewable such as solar and wind are promoted. In the customer end, a number of policy measures innovatively taken under Energy Conservation Act 2001.This paper analysis the impact of energy conservation technologies and along with the implementation of Solar Photovoltaic MPPT on the roof top of the Indian household. This combined approach will reduce grid dependency of Indian household and thereby minimizing the peak demand on utility.

Keywords: Energy, MPPT, Solar Rooftop, Sustainable Development.

I. INTRODUCTION

An average of 300 sunny days in a year, India has selected solar photovoltaic (PV) energy as main source of renewable energy to achieve its target of 175 GW by 2022. India achieved 521 MW of rooftop solar energy generation capacity in the second quarter of the calendar year 2021.This target presents challenges in deploying and integrating moderately expensive renewable energy, at the same time to ensure universal access of energy for all Indian citizens. Large-scale utility solar and conducive policy environment with adequate capital will achieve grid parity in the recent times. The rooftop segment is a new area in India and lag in capacity addition. It necessitates innovation to reach the target goal of 40 GW [1]. For a successful rooftop solar, the India's buildings sector needs a robust net metering framework which is critical. India achieved the installed capacity of 100 GW of renewable power recently. The majority of these additions about 78% is because of large-scale wind and solar power projects [2]. Scientists and conservationists have often stressed the need of rooftop solar as an alternative to large-scale renewable energy projects. Large scale projects in renewable result in ecological and social costs. Large solar farms require a lot of water to clean the panels. Through ground mounted solar panels, existing vegetation can be lost, endanger for local wildlife.

In 2009, National Solar Mission (NSM) launched to address India's energy security challenges together promoting ecologically sustainable growth. The NSM will be a major contribution to India's commitment to meet its climate change mitigation and adaptation activities agreed within the United Nations Framework Convention on Climate Change (UNFCCC) [3].

Some of the Schemes implemented to promote energy efficiency for household in India are:

1. Standards and Labelling

Standards and Labelling are given to equipments and appliances. It is used to decrease the energy consumption of appliances. Household appliances labelled are room Air Conditioners, Fluorescent Lamps, Frost Free Refrigerators and Washing machine etc.

2. National Mission for Enhanced Energy Efficiency (NMEEE)

NMEEE strengthen the market by creating conducive regulatory and policy. It motivates new sustainable business models. Under Market Transformation for Energy Efficiency (MTEE), People use cheaper energy efficient appliances through energy efficient measures.

(i)Bachat Lamp Yojana (BLY): A public-private partnership program with stake holders of Bureau of Energy Efficiency (BEE), Distribution Companies (DISCOMs) and private investors. It changed the lighting market more energy efficient. More than 29 million incandescent bulbs have been replaced by CFLs in first phase.

Promotion of LED lights covered under second phase, Rural Electrification Corporation (REC) frame the technical specification, monitor and verify the energy savings from the LED.REC distributes LED bulbs to Below Poverty Line (BPL) households. BEE does activities to adopt large scale LEDs.

Manuscript received on 27 March 2022 | Revised Manuscript received on 06 April 2022 | Manuscript Accepted on 15 May 2022 | Manuscript published on 30 May 2022.

* Correspondence Author
K. Mohan, Assistant Professor, Department of Electrical and Electronics Engineering, Government College of Engineering, Bargur, Krishnagiri (Tamil Nadu), India. Email: kmohangcebargur@gmail.com
Dr. Sujatha Balaraman, Professor, Department of Electrical and Electronics Engineering, Government College of Technology, Coimbatore (Tamil Nadu), India. Email: sujaengg@gmail.com

Super-Efficient Equipment Programme (SEEP): It accelerates market transformation for super-efficient appliances by providing financial aid at critical points of requirement. Under this program, ceiling fan has been earmarked as the first appliance to adopt. SEEP for ceiling fans target of about 50% more efficient than conventional fan. A time bound incentive given to fan manufacturers to manufacture super-efficient (SE) fans and sell them at a reduced price. The aim is to deploy super-efficient 35W ceiling fans, against the current induction motor based ceiling fan of 70W rating [4].

II. SYSTEM MODEL

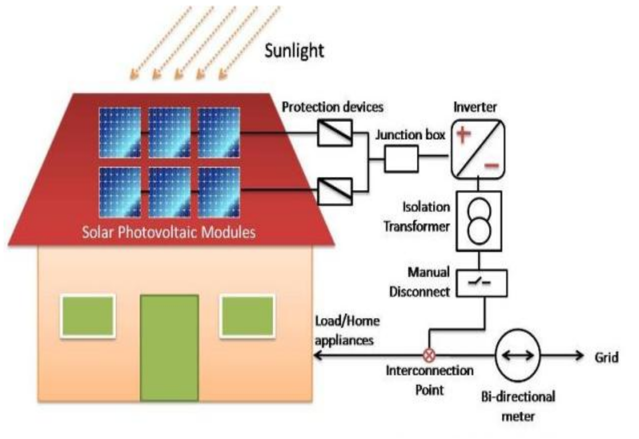

Fig.1 Schematic of Grid interactive rooftop solar system

Solar PV rooftop system uses very less space compared to large scale PV projects and cost effective. Availability of land is the major issue for utility scale solar PV projects. For 1MW of solar PV plant installation, it requires 5 acres of land. Enormous growing populace, sizeable land area is needed for cultivating food grains to support the population. Use of fertile agricultural land for solar project is not a viable option. Availability of grid is another issue. Due to grid inaccessibility, in India rural population is still struggling enormously for electricity. In addition, there is huge shortage of electricity generation due to inadequate availability of coal which result in frequent power cuts [5]. Solar PV rooftop system is a mini power plant at house rooftop. The Grid interactive Roof Top Solar PV consists of three major components: PV modules, mounting structure and the inverter or power conditioning units. Solar PV array requires a mounting structure to hold PV modules at the required angle for maximized generation. The solar panels convert light energy into electricity in Direct Current (DC). The DC energy is converted to Alternate Current (AC) power by the inverter/power conditioning unit which is connected to the power grid through AC distribution board. The AC power output can be recorded through net metering. The single phase 230V AC output of the system can be synchronized with the grid. Electricity can be exported to the grid depending upon solar power generation and local load consumption. Electrical inverters convert DC from solar PV modules to AC. Grid-interactive inverters can produce AC power that synchronise with voltage and frequency of the grid. Electrical power from the inverter to the connected load transferred by an Isolation transformer. It isolates the load from the power source. Also, avoid DC power injection into the grid. Solar rooftop system power during the daytime utilized fully by powering the building loads and feeding excess power to the grid when grid is available. When solar power is not available due to shadow, rainy or a cloudy day, the building loads can be served through the grid. A Smart inverter automatically understands the power situation and gives preference to power generated from solar modules [6].

Table1 shows the conventional load appliances in typical Indian households. These appliances are conventional, have no star rating and consumes large amount of power for the same output. Average energy consumed per day by these appliances is approximately 8.1KWh

Table 1: Conventional appliances-based Loads

S. No	Appliance Name	Power (W)	Hours of Usage (Hr)	Energy Consumption per day (Wh)
1	Florescent lamp 1	40	8	320
2	Florescent lamp 2	40	4	160
3	Florescent lamp 3	40	4	160
4	Florescent lamp 4	40	12	480
5	Florescent lamp 5	40	6	240
6	Induction Fan 1	70	12	840
7	Induction Fan 2	70	8	560
8	Induction Fan 3	70	4	280
10	Single phase induction motor	750	0.5	375
11	Fridge	350	24	700
12	Air Conditioning	1000	4	4000
			Total	8115

Table 2 shows the some of the conventional appliances (Lights and Fans) are replaced with 5 star rating appliances. It reduces significantly average energy consumption per day to 6.1KWh.

Table 2: Energy saving appliances based Loads

S. No	Appliance Name	Power (W)	Hours of Usage (Hr)	Energy Consumption per day (Wh)
1	LED Lamp 1	9	8	72
2	LED Lamp 2	9	4	36
3	LED Lamp 3	9	4	36
4	LED Lamp 4	9	12	108
5	LED Lamp 5	9	6	54
6	BLDC Fan 1	35	12	370
7	BKDC Fan 2	35	8	280
8	BLDC Fan 3	35	4	140
10	Single phase induction motor	750	0.5	375
11	Fridge	350	24	700
12	Air Conditioning	1000	4	4000
			Total	6171

III. SOLAR ROOF TOP DESIGN

After energy saving appliances, the demand on load energy requirement significantly reduced. The peak energy requirement during the summer changed from 700 KWh to 490 KWh whereas during the winter demand reduced from 460 KWh to 190 KWh. With an average sunshine of 300 days in India and per KW solar PV can produce up to 5.5KWh per day. The peak demand of loads after installing the energy conservation appliances=490KWh.

Retrieval Number: 100.1/ijrte.A69140511122
DOI: 10.35940/ijrte.A6914.0511122
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

Allowing 10% higher capacity for any changes in future load=(490*1.10)=540 KWh (Approx.) Daily energy consumption as per billing cycle (60 days) =540/60=9 KWh. As per Indian Condition, 1KWp solar plant can generate an average of 5.5 Units/day.
Solar plant capacity required = 9/5.5 =1.64 KWp
Each solar panel rated for 300W.
No. of solar panels required =1640/300=5.45=6 Panels.

Table 3: Specifications of Solar Panel

Description	Value
Maximum Power(Pm)	300W
Maximum operating voltage(Vmp)	37.5V
Maximum operating current(Vmp)	7.99A
Open Circuit Voltage(Voc)	45.7V
Short Circuit Current(Isc)	8.55A

IV. MPPT CONTROL

P&O algorithm is widely used to operate the PV panel at the optimized operating point due to its simple structure. This MPPT algorithm operates periodically by comparing the PV output power with that of the previous perturbation cycle. Based on the change in power (DP), the PV array voltage is incremented or decremented to reach MPP.P&O algorithm obeys for the instantaneous value of PV array voltage and current, if sampling occurs only once in each switching cycle. The MPPT process is recurring periodically until the optimal operating point is reached. The system then oscillates near the MPP. The oscillation is minimized by reducing the perturbation step size. However, a smaller perturbation size slows down the MPPT [8-9] .Fig. 2 shows the flow chart of conventional P&O technique.

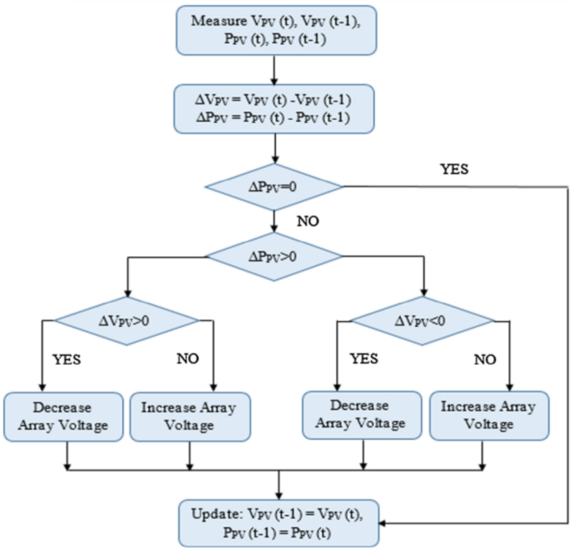

Fig.2 Flow chart of conventional P&O technique

V. RESULTS AND DISCUSSION

Fig.3 shows the bar chart comparison of energy consumption of loads before and after installing the star rated appliances. In the year 2020 July month conventional Fluorescent lighting and Induction motor based fans were replaced with energy saving Light Emitting Diode (LED) lights and Brushless Direct Current Motors (BLDC) based fans respectively. From the chart, there is a significant amount of energy saving in each billing month by the star rated appliances.

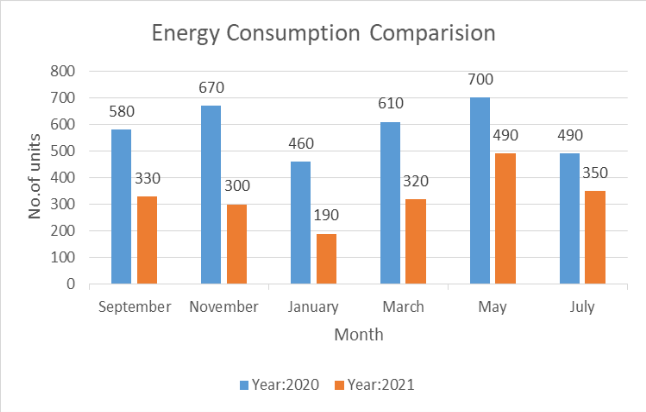

Fig.3 Energy consumption of load with and without star rated appliances

Fig.4 shows the bar chart of comparison of electricity billing before and after installing the star rated appliances. The billing was computed based on prevailing slab rate and after applying the subsidy of Tamil Nadu Generation and Distribution Company (TANGEDCO). From the chart, there is a huge amount of cost saving potential by the star rated appliances.

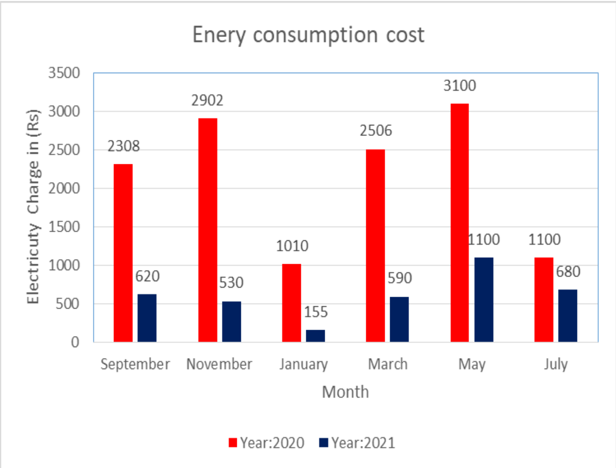

Fig.4 Energy cost with and without star rated appliances

Fig. 5 shows the energy consumption of the load before and after implementing the energy conservation technologies. After July 2020, the peak demand for the energy significantly reduced to 490 KWh based on bi monthly billing process by TANGEDCO

Fig.5 Energy consumption of household loads from September 2019 to November 2021

Retrieval Number: 100.1/ijrte.A69140511122
DOI: 10.35940/ijrte.A6914.0511122
Journal Website: www.ijrte.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Fig.6 shows energy cost reduction after implementing the energy conservation technologies. The energy cost reduced from Rs 3100 in July 2020 to Rs 1100 in July 2021.

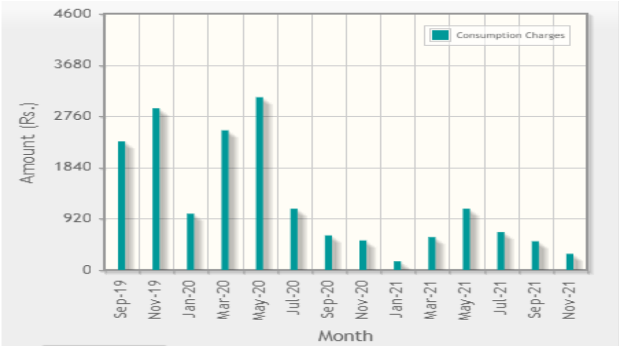

Fig.6 Energy cost from September 2019 to November 2021

Table 4 shows the effect of solar power plant on the energy consumption in the household. After installing solar plant, the household can not only consume its own power from solar energy also, export power to the grid thereby getting additional revenue. This exporting energy will be maximum during winter as 157 KWh in January Month and minimum during summer as 12 KWh in May Month

Table 4: Energy details after solar plant installation

Month	Total Energy consumption by Loads (KWh)	Average insolation in KWh/m^2/ day	Average insolation in W/m^2	Total Energy produced by solar plant (KWh)	Total Energy supply to grid (KWh)
(1)	(2)	(3)	(4)	(5)	(5)-(2)
March-21	320	5.25	750	405	85
May -21	490	6.50	929	502	12
July -21	350	5.50	786	424	74
September-21	330	5.0	714	386	56
November -21	300	4.3	679	367	67
January-21	190	4.5	643	347	157

A. Cost Analysis:

Table 5: Cost of Energy savings after installing Energy Conservation Technologies

Month/Year	Year: 2020 Energy Cost (Rs)	Year: 2021 Energy cost (Rs)	Cost of Energy saving per year in (Rs)
	(1)	(2)	(1)-(2)
March	2506	590	1916
May	3100	1100	2000
July	1100	680	420
September	2308	620	1688
November	2902	530	2372
January	1010	155	855
		Total	9,251

Table 5 shows cost of the energy savings due to energy conservation technologies. A total of Rs 9,251/- saved annually while the capital cost of the energy saving equipment is Rs 10,200/- as shown in Table 6.

Table 6: Cost of Energy conservation Appliances

Appliance Name	No. of appliances	Average Cost per appliance (Rs)	Total Cost (Rs)
LED lamps	5	120	600
BLDC Fans	3	3200	9600
		Total	10,200

Simulation work was carried out in PV*SOL simulation software to show the effect of PV power on grid power import and export.

For the simulation, the following climate date is taken

Location: Krishnagiri, India

Latitude: 12°32'59"

Longitude: 78°13'16"

Annual some of global irradiation: 1914 kWh/m2

Annual average temperature: 24.4° C.

PV power production and energy consumption by loads is shown in Fig.7. PV power production have maximum of 300 kWh in January month while minimum of 170 kWh in July month. The maximum grid feed in from solar takes place during December month to March month (150 kWh) and minimum energy export during the month of June to August (70 kWh) due to internal load consumption as shown in fig.8.

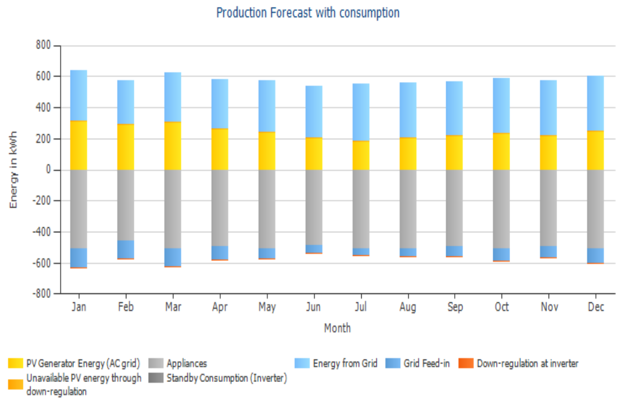

Fig.7 PV production forecast and energy consumption by loads

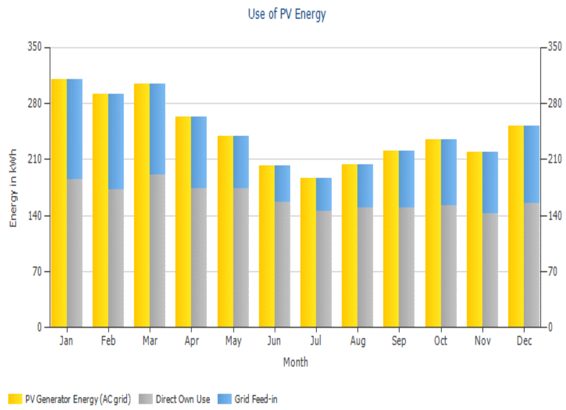

Fig.8 Uses of PV energy

Fig.9 shows the pattern of energy consumption by loads and sharing of PV and Grid energy for monthly basis. PV energy contribute significantly to meet the demand of load ranging from 180kWh during the month of January and 180kWh during 140kWh during July month

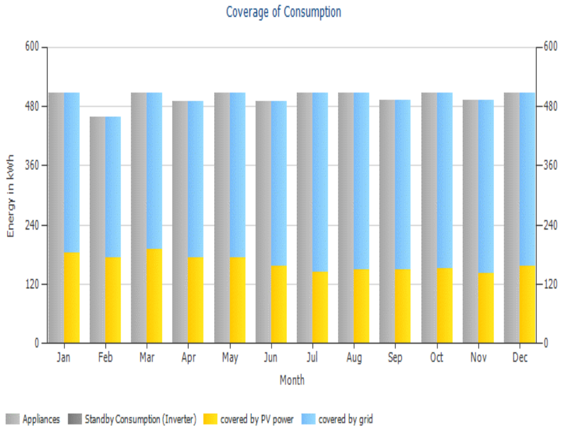

Fig.9 Coverage of consumption

Fig.10 shows the energy production forecast in the inverter. The energy will be higher in the month of January 310 kWh and July month at 190 kWh.

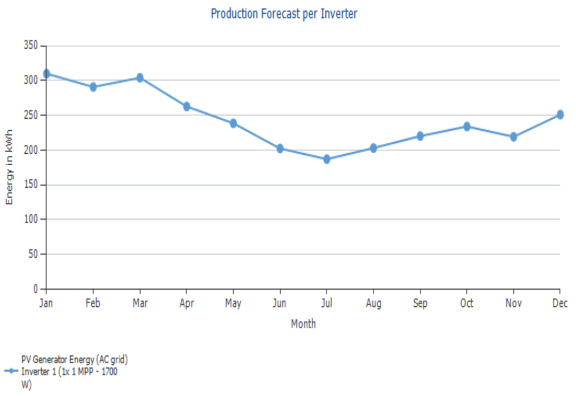

Fig.10 Production forecast in the inverter

Fig.11 shows the variation of solar irradiation on the module over the years. Irradiation on a tilted module surface has higher capture of solar energy 240 kWh/m^2 than horizontal plane modules 160 kWh/m^2.

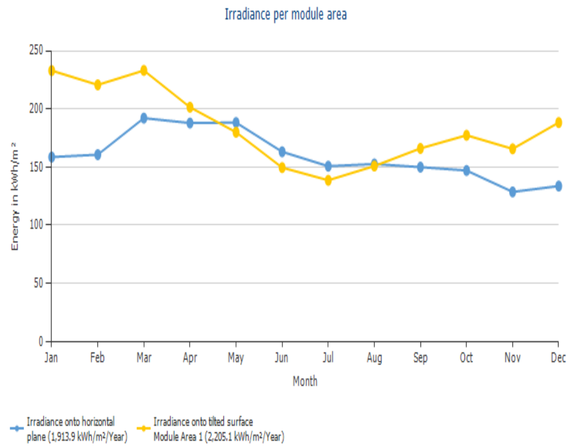

Fig.11 Irradiance on the modules

Fig.12 shows the variation of module temperature with respect to outside environmental temperature. The module temperature and environmental temperature are minimum during the winter-December month 27°C and 22°C respectively. It is maximum for module in March month as 34°C and outside environment as 27 °C.

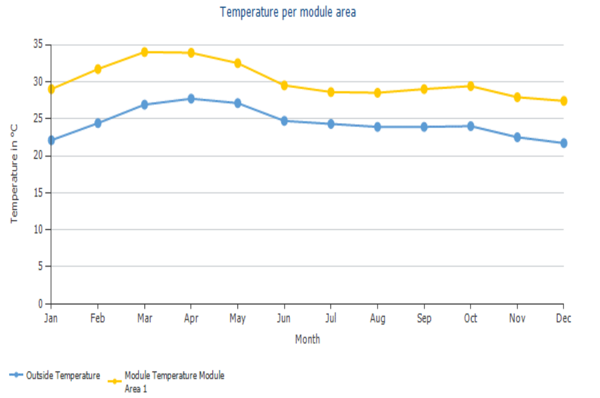

Fig.12 Module temperature versus outside temperature

Fig. 13 shows the Capital cost recovery for the solar PV. From the figure, it is understood that solar roof top capital can be recovered by exporting the energy from the PV to grid. For the life span of 21 years for the solar panel, it is evident that the capital cost can be recovered from 5th years onwards. The recovery of cost steadily increases for every year and maximum of Rs 10,000/- in the 21st year.

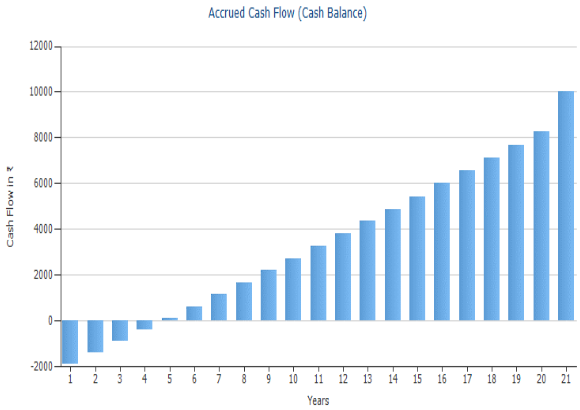

Fig.13 Cash balance

VI. CONCLUSION

The future of Indian energy security depends from renewable sources. Among the different renewables, solar roof top is a promising option. It will produce power and consume locally and thereby reducing the transmission line losses and minimizing the dependency on the utility grid. Energy efficient technologies in Fan and Lighting will significantly reduce the peak energy demand in household. This will intern minimize the cost of solar power plant. The combined energy efficient technology and solar roof top will have energy security for the household and sustainable development.

REFERENCES

1. Ministry of New and Renewable Energy Source India, Government of India. Available: http://mnre.gov.in/mission-andvision-2/achievements/
2. Siva Reddy V, Kaushik SC, Panwar NL. Review on power generation scenario of India. Renew Sustain Energy Rev. 2013; 18:43–8. [CrossRef]

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

3. Kapoor Karan, Pandey Krishan K, Jain AK, Nandan Ashish. Evolution of solar energy in India: A review. Renew Sustain Energy Rev. 2014;40:475–87. [CrossRef]
4. Sharma Naveen Kumar, Tiwari Prashant Kumar, Sood Yog Raj. Solar energy in India: Strategies, policies, perspectives and future potential. Renew Sustain Energy Rev. 2012; 16(1):933–41. [CrossRef]
5. Adaramola, M.S., 2015. Techno-economic analysis of a 2.1 kW rooftop photovoltaic-grid-tied system based on actual performance. Energy Convers. Manag. 101, 85–93. [CrossRef]
6. Dondariya, C., Porwal, D., Awasthi, A., Shukla, A.K., Sudhakar, K., Murali, M.M.,Bhimte, A., 2018. Performance simulation of grid-connected rooftop solar PVsystem for small households: case study of Ujjain, India. Energy Rep. 4, 546–553 [CrossRef]
7. Sharma, R., Goel, S., 2017. Performance analysis of a 11.2 kWp roof top grid-connected PV system in Eastern India. Energy Rep. 3, 76–84. [CrossRef]
8. Ram JP, Babu TS, Rajasekar N. A comprehensive review on solar PV maximum power point tracking techniques. Renew. and Sust. Energy Rev., Vol.67, pp. 826-47,Jan 2017. [CrossRef]
9. B. Subudhi and R. Pradhan, ―A comparative study on maximum power point tracking techniques for photovoltaic power systems,‖ IEEE Trans.Sust. Energy, vol. 4, no. 1, pp. 89–98, Jan. 2013. [CrossRef]
10. Ahmed, Jubaer, and Zainal Salam. "An Accurate Method for MPPT to Detect the Partial Shading Occurrence in a PV System." IEEE Transactions on Industrial Informatics 13, no. 5 (2017): 2151-2161. [CrossRef]

AUTHORS PROFILE

Mohan Kuppusamy received B.E. degree in Electrical and Electronics Engineering from Arunai Engineering College, affiliated to University of Madras, Chennai, Tamil Nadu, India in 2001.M.E, Degree in Instrumentation Engineering from Madras Institute of Technology, Anna University, Chennai, Tamil Nadu, India in 2004. He is currently working toward the Ph.D. degree at the Department of Electrical and Electronics Engineering, Government College of Engineering, Bargur, Tamil Nadu, India. His research interests include Solar Photovoltaic, Electric Vehicles and Power Electronic Applications.

Dr. Sujatha Balaraman received B.E., in Electrical and Electronics Engineering and M.E. degree in Power System from Thiagarajar College of Engineering, Madurai, India. She received her Ph.D. degree from Anna University, Chennai. She is currently working as Professor in Government College of Technology, Coimbatore, India. Her research interests include Application of Intelligent techniques to Power System Operation & Control and Selective Harmonic Elimination.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)