Economic evaluation of grid connected and standalone photovoltaic systems using PVSyst

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Abstract. Nowadays, the consumption of household electricity has increased with the cost per unit of energy. Due to this, the consumers are pushed in seeking an alternate source of energy such as renewable energy. Thus, solar photovoltaic (PV) systems being small and economically viable modules are coming into action. Even though designing a PV system is has been proven to be a tedious work, not due to the complexity but due to various options that are laid down. Basically, PV systems are divided to standalone, hybrid and grid-connected systems. Solar PV panels are considered as the only source in generating the electricity. Using the simulation software PVSyst, the economic viability of a typical household backup system connected to grid and as a standalone system are analysed. The reliability, performance and financial values of both the systems are compared and presented here.

1. Introduction
In today’s situation, it is not possible to run a better life without the availability of electricity. People gets disturbed if the power is shut even for a few minutes. Also, a lot of residential homes have inverters as a mandatory source to provide power to few electrical appliances. So that, they can stay inside their comfort zone even if the power supplied from the grid is interrupted. The power interruption is occurred mainly due to some maintenance work at the power stations in developed countries [1]. In developing countries like India, the power generated from the substations through various conventional sources is not enough to completely fulfil the countries’ energy demand. Thus, the government provides some subsidy for those who reduce the use of power during peak hours based on the tariff amounts paid as electricity bill. Also, various private companies are coming forward in investing their money on the solar power plants for generating power and directly injecting to the grid but a lot of land area is required to do so [2]. Several types of PV panel performance enhancement has been discussed to improve the PV panel output under variable ambient conditions [3, 4]. Bioinspired and pervskite solar cells are researched recently [5, 6]. In this paper, the comparison of a standalone and grid-connected PV systems based on the household requirement that has an inverter backup facility. Further, the work provides details about the amount of energy that can be injected to grid after meeting the household load needs throughout the day. A comparison between standalone and grid-connected system is done based on the aspects such as the energy production, energy supplied to grid and energy obtained from grid, payback period, etc [7].

Sharma et al. [8] studied the 190 kWp grid interactive PV performance with PVSyst simulation. An off-grid solar PV system is simulated to study the effect of shading conditions on the system performance by Bouzguenda [9]. Meriem et al. [10] simulated 909 kWp PV system using PVSyst by
considering the inclination and direction of PV generator. Performance ratio, loss parameters and energy generated were estimated. Several researchers investigated grid connected PV plants using PVSyst and found that the results were significantly matching with the real time performance [11-13]. Thus, the PVSyst has been found to be in-line with the real time studies. The procedures are followed as per the PVSyst manual [14]. MPPT tracking is beneficial to produce maximum power [15].

2. Materials and Methods

The main aim of this analysis is to determine annual energy yield, cost estimation, payback period amount of energy that could be injected to grid from rooftop of the residential buildings. Equal load is provided to both grid as well as standalone system. Both the systems are provided with battery in order to supply energy during the absence of sunlight. The test site is Kattankulathur, Chennai, India. At the operational site, with tilt angle of 13° based on the latitude of the area. Also, the solar azimuth angle is zero for fixed axis and one axis and 0 to 180° for two axis tracking.

2.1. Description of Standalone system

The standalone systems are the ones which do not depend on grid connection for their operation i.e. a standalone photovoltaic system obtains the power produced from the panels and stored in the battery. They don’t consume any power from the grid for their operation and stops working once the power stored in the battery gets exhausted. A typical layout for a standalone system is shown in figure 1. It consists of PV array, system and user load. PV panel array consists of four 320W polycrystalline panels connected in series. Four panels are considered based on the area available on roof of residential buildings in an average. The total modules can occupy 8m² area approx., considering the structures in order to hold the panels the area occupied can be between 10 to 12m² which is easily available on the rooftops of residential buildings. System consist of inverters, charge controller, and batteries.

A 1.2 kW AC inverter with an operating voltage of 90-580V had been considered. The inverter is chosen based on the output voltage that can be obtained from the panels when connected in series. A 26 V Lithium Ion battery with 180 Ah is chosen as the storage option in order to provide power during the absence of sunlight. The Battery can store up to 3.6 kWh energy with max. 2.7 kW DC as charging power and 0.3 kW AC as maximum discharging power. The system is provided with Maximum Power point tracking in order to control charging/discharging of battery. Also, the user load with 4 tube lights, 2 fans, and a laptop is considered with total daily energy need of 3936 Wh/day.

![Figure 1. Typical Standalone Photovoltaic System.](image-url)
2.2. Description of Grid Connected System
In this work both the grid and standalone systems are provided with same PV array and user load. In grid connected the energy produced from PV array is stored in the battery for use after sunset as well as the excess energy obtained from the array is injected to grid. A typical layout of Grid connected system is shown in figure 2. In grid connected systems the power obtained from PV array is injected to inverter so that the generated direct current can be switched to alternating current and supplied to the grid. The inverter is provided with a charge controller to charge and discharge the battery.

![Typical Grid Connected System](image)

**Figure 2. Typical Grid Connected System.**

3. System Performance Evaluation
In this work, both the standalone and grid-connected systems are simulated using PVSyst software. The metronome data for the location Kattankulathur, Chennai is obtained through the data collection from the weather station kept at the test site. The weather station data logger stores the hourly weather data such as wind speed, global radiation, diffused radiation, ambient temperature, humidity. The data is collected for the year of 2019 and is fed to the PVSyst software by editing the already available metronome data in the software. The hourly data obtained each day is entered in Microsoft Excel data sheet and the average value for direct, diffused radiation, wind speed, ambient temperature is determined. This average value is fed in the PVSyst software for the determination of output power from the PV array. Figure 3 shows the hourly load distribution, tilt angle and few aspects that are provided as input to the software. The simulation is carried with fixed axis, one axis tracking and two axis tracking for both the standalone and grid connected systems.

4. Results and Discussion
After running the simulation using the software the overall average output that can be obtained from the PV array is determined for three different tracking system and for standalone and grid connected system.

4.1. Grid-connected output
In this the output obtained for the simulated grid connected system is determined. The obtained results for fixed axis system, one axis tracking and two axis tracking is represented in the figure 4. Also the figure 4 displays the amount of energy produced by PV array for the respective months from January to December, energy supplied to the user, Energy injected to grid per month, and energy used from the grid with respect to the load provided to the system.
4.2. Standalone system output

Here the output obtained by standalone system is determined. Figure 5 represents the data obtained from the three different tracking system similar to grid connected systems. In standalone we can notice a column mentioning unused energy. This is the amount of energy that is wasted per year on average. 2205.9 kWh energy is wasted without using it. Thus, this energy can be injected to grid from each household. Also, we can see that the output obtained from single axis tracking is greater than fixed and two axis tracking system. Thus, one axis tracking is considered in calculating payback period. Also the payback is calculated with respect to the same load connected to grid connected and standalone systems. Both the grid and standalone systems are provided with equal number of panels.
Figure 4. Output obtained from grid Connected Systems with different tracking.

Figure 5. Output obtained from standalone Systems with different tracking.
4.3. Cost estimation for grid-connected system
- PV panels Rs.25/Watt, 4 Panels at 320W = Rs. 32,000 approx.
- Battery 12V 180Ah, 2 in series = Rs. 24,800 approx.
- MPPT Tracker, 4 numbers = Rs. 44,800 approx.
- Solar Inverter ABB Inverter 1.2 kWAC = Rs. 50,000 approx.
- Luminous Charge Controller = Rs. 800 approx.

Total amount = Rs. 1,51,600 approx.

4.4. Cost estimation for standalone system
- PV panels Rs.25/Watt, 1 Panels at 320W = Rs. 8,000 approx.
- Battery 12V 180Ah, 2 in series = Rs. 24,800 approx.
- MPPT Tracker, 1 number = Rs. 11,200 approx.
- Charge controller = Rs. 800 approx.
- Inverter Luminous = Rs. 4000 approx.

Total amount = Rs. 48,000 approx.

4.5. Payback period for grid-connected system
Total amount invested: Rs. 1,51,600
Amount after 30% subsidy = Rs. 1,06,120
Amount of energy consumed from Grid/year = 12 units = zero due to government subsidy.

Amount obtained per year due to energy injected to grid @ Rs. 6.63/unit = Rs. 6.63*1893.7= Rs. 12,555 approx./year
Amount saved per year in electricity bill = Rs. 1,932/year
Amount Remaining = Rs. 1,06,120 – (12,555 + 1,932) = Rs. 91,633
Payback = Rs. 91,633/14,487 = 6.32 years.
Return on investment = Rs. 14,487/year. (after 6 years 4 months)
Amount obtained = Rs. 2,70,424/18 years 8 months (after 6 years 4 months) as Panel Life span is 25 years.

4.6. Payback period for standalone system
Total Amount Invested: Rs. 48,000
Amount after 30% subsidy = Rs. 33,600
Amount of Energy consumed from Grid/year = 12units = Rs.0 due to government Subsidy.
Amount saved per year in Electricity bill = Rs. 1,932/year
Amount remaining = Rs. 33,600 – Rs. 1932 = Rs. 31,668
Payback = Rs. 31,668/1,932 = 16.3years.
Return on investment = Rs.1,932/year. (after 16 years 3 months)
Amount obtained = Rs. 18,837/9 years 9 months (after 16 years 3 months) 25 years life

PVSyst is used to effectively compare the economic performance of the selected standalone and grid-connected PV systems. A single axis tracking on standalone systems found to be effective. The payback period of standalone PV systems is lesser when compared to the grid-connected PV systems. Since both the systems are provided with equal number of panels for comparison purpose, the power produced by standalone is excess and also recharges the battery required to supply for the load at after sunshine hours with in two to three hours in a day. And the power produced by panels are wasted as it is not stored in the battery. The unused energy from standalone can be supplied to grid so that the subsidy from government due to power injection can be obtained that is Rs. 6.63 per unit. Thus
drastically reduces the payback period of standalone by converting standalone systems at residential
to grid connected systems.

5. Conclusions
From the results obtained from PV SySyst for the standalone and grid-connected PV systems, the
following conclusion were drawn.
On annual basis, considering single axis tracking on standalone systems a total of 2205.9 kWh energy
generated is neither not used to charge the battery nor supplied to the load.
Thus, Combining the standalone system with just grid connected inverter, the unused energy can be
injected to grid.
By injecting the unused energy per year, obtained from standalone systems that is 2205.9kWh the
payback period is gradually reduced through the subsidy provided by the government which is Rs 6.63
per unit.
We can also conclude that if each household opts to solar inverters and starts injecting to grid the
overall energy crisis of our country can be easily reduced.

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