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OPTIMAL SIZING OF A GRID INDEPENDENT STANDALONE PHOTOVOLTAIC SYSTEM WITH BATTERY ENERGY STORAGE

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Abstract**—**This paper presents the optimum number of PV panels and size of battery storage system of a proposed standalone PV system. An iterative optimization algorithm has been developed for the generation unit sizing. It has been used to determine the optimum generation capacity and storage needed for a standalone PV system for an experimental site symbiosis campus Pune with its typical load curve. In addition, analysis of net metering has been done in case of existing grid connected PV system. Thus it increases the reliability and independency on grid. To optimize, the hourly values of load demand, insolation have been used.

Keywords—Battery storage system; PV system; Iterative search method; Battery Sizing; Net Metering

I. INTRODUCTION

Recent developments in renewable generation technologies allows the use of natural resources (wind, hydro, or photovoltaic (PV)) as alternative energy sources, but their intermittency typically results in inadequate energy supply for a substantial proportion of the year. However, combining renewable energy sources (RES) with energy storage systems in so called ''hybrid renewable energy systems" may provide reliable electricity supply with reduced battery storage and/or diesel requirements [1].

Renewable energy sources like solar and wind are present in abundant quantity in nature. Energy crisis, increased costs of coal, oil, global warming, greenhouse gases emission etc. have seek people's attention towards use of renewable sources. Battery energy storage systems are used to store energy which can be used to fulfill additional load demand and also as a backup power supply. Today modern fossil fuel based systems are becoming more and more flexible. i.e. fuel cell are also suitable options to meet additional power demand. They can provide a reliable and flexible power.

This paper discusses the iterative optimization technique for the design of a grid independent PV generating system which is based on the energy balance concept. The algorithm is then used for the design of a PV generating system for a symbiosis campus Pune in India. A data acquisition system is used to record the information every 5 minutes.

The load profile of symbiosis campus Pune has been used in this paper. Based on the available hourly average data of insolation and the load demand, the generating capacity is determined to match the load demand that is the minimize the difference between generation and load (ΔP) over a 24-hour period. The capacity of the storage needed to make the system operate independently as grid independent standalone PV system is determined from hourly information obtained from ΔP [3].

The rest of this paper is organized as follows: The section II system configuration explains the existing system components and proposed system components; in the section III mathematical modeling of PV system and battery as well as the battery storage calculations and its operation like charging and discharging; next section IV methodology to solve the problem definition that is iterative optimization method; And section V shows the results and analysis

II. SYSTEM CONFIGURATION

Fig.1 shows the configuration of the existing grid connected PV generating system. The system consist of the photovoltaic(PV) panels as a renewable energy source and grid is used to improve the reliability of system by importing power. However the proposed system configuration is shown in fig.2 which is standalone in nature. The standalone system consist of a photovoltaic (PV) panels as a renewable energy source and battery is to store excess energy at the day time and discharge it at night when PV power is not available.

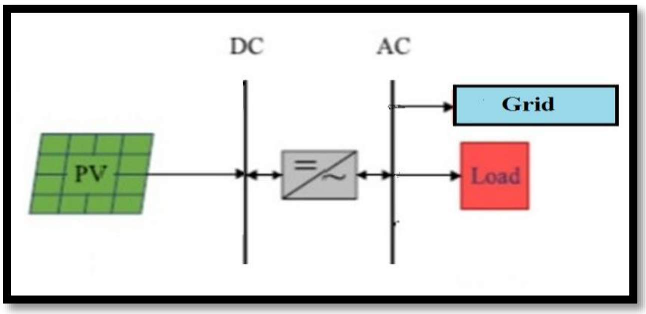

Fig.1 Existing Grid Connected PV System

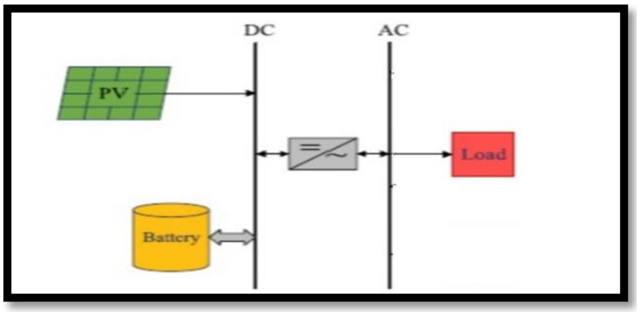

Fig.2 Proposed Standalone PV System Configuration

III. MATHEMATIAL MODELING OF THE SYSTEM CONFIGURATION

PV SYSTEM

The output power generation of each PV panel (p_{pv}) at time t can be calculated from the solar radiation using following formula [4]

$$p_{pv}(t) = I(t) * A * n_{pv}$$

Where, I is the solar radiation in w/sq-m, A is the PV panel area in sq-m, n_{pv} is the PV panel efficiency. The assumptions is that PV panels have maximum power point tracking (MPPT). The temperature effect on the PV panels is ignored.[3]

If the number of PV panels are N_{pv} then the total power produced is by following equation

$$P_{pv} = N_{pv} * p_{pv}(t)$$

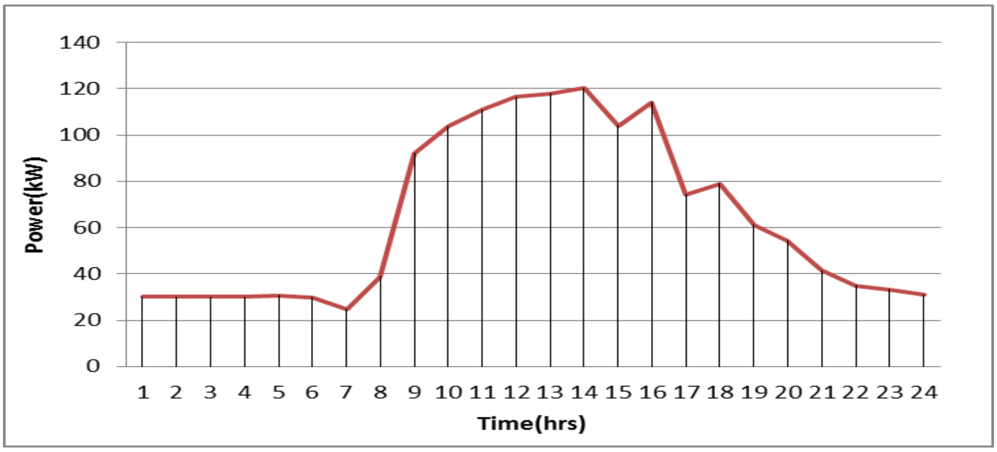

Fig.3 Hourly average demand of a symbiosis campus Pune

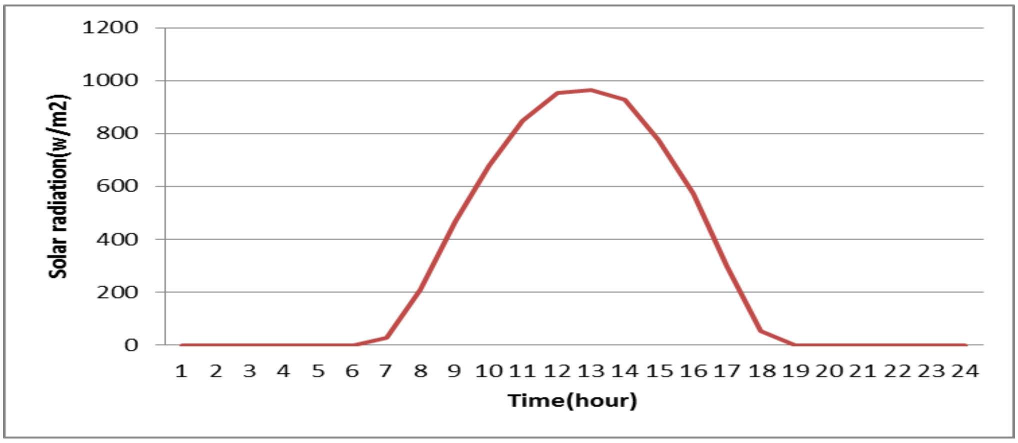

Fig.4 Hourly average radiation

Battery Storage Calculations and It's Operation

In a existing system, the grid power has been used to balance the system. The import of the required power has been done in the existing system. But in proposed system the required power is not imported from the grid , the reliability is achieved through the battery energy storage system.

The battery serves a reliable platform to the system by stores the renewable energy whenever the supply from the PV panels exceeds the load demand and discharges when load demand exceeds the PV generation. So need to optimize properly sized battery bank [1].

The following constraint must be satisfied , when determining the state of charge (SOC) of battery energy storage system.

$$SOC_{min} \leq SOC \leq SOC_{max}$$

Where, SOC_{min} and SOC_{max} are the minimum and maximum state of charge respectively. For this case SOC_{min} and SOC_{max}
Are equal to the 20% and 100% respectively.

The adopted approach to sizing the battery is laid out in [3]. The magnitude difference between PV generated power and demand over a given period of time is given by following equation

$$\Delta P = P_{gen} - P_{dem}$$

The power equation can be translated in to the energy equation that is energy generated (W_{gen}) and energy demanded (W_{dem})
Over a period of one day which is given by following equation

$$W_{gen} = \sum_{t=1}^{24} (\Delta T)[N_{pv} * P_{pv}(t)]$$

$$W_{dem} = \sum_{t=1}^{24} (\Delta T)[P_{dem}(t)]$$

Where, N_{pv} represents the number of PV panels used, t is sampling time which is hours of day and ΔT is the time between the samples (in this case in hour).

In order to get the balance between the generation and demand over a period of time, the curve ΔP verses time must have an average zero over the same time period. Note that the positive values of ΔP indicates the availability of generation and negative values of ΔP indicated generation deficiency.

Table1. System component sizes

Components	Rating
PV panel	0.315 kWp
Battery	3 kWh (250Ah,12V)

By integrating the ΔP the energy curve obtained,

$$\Delta W = \int \Delta P dt = W_{gen} - W_{dem}$$

The energy curve equation ΔW can be used to find the required energy storage capacity of the standalone system. On an average day the battery is required to cycle between the positive and negative peaks of the energy curve shown in figure. Therefore the number of batteries required for the needed storage capacity can be find by following,

$$Required\ Storage\ capacity = max \int \Delta P dt - min \int \Delta P dt$$

As before mentioned the batteries are limited between minimum SOC and maximum SOC that is 20% and 100% respectively [3]. Hence the number of batteries obtained follows,

$$Number\ \ of\ batteries \geq \frac{Required\ Storage\ \ Capacity}{0.8 \times Rated\ Capacity\ of\ Each\ Battery}$$

Because of the PV is intermittent renewable source in nature the battery bank capacity constantly changes in the system the SOC of the battery acquired as follows [4],

When the total output generation of PV panels is greater than the demand, the battery bank is in charging mode. The charge quantity of the battery bank at time t can be obtained by following equation,

$$E_{Batt}(t) = E_{Batt}(t-1) \times (1-\sigma) + [E_{pv}(t) - \frac{E_{load}(t)}{n_{inv}}]n_{Batt}$$

Where, $E_{Batt}(t)$ and $E_{Batt}(t-1)$ is the charge quantity of battery bank at time t and t-1, σ is the hourly self-discharge rate, n_{inv} is the inverter efficiency, E_{load} represents load demand and n_{Batt} is the charge efficiency of battery bank.

When the total output generation of PV panels is less than the demand, the battery bank is in discharging mode. In this case the discharging efficiency is assumed to be 1.Hence the charge quantity of the battery bank at time t can be obtained by following equation,

$$E_{Batt}(t) = E_{Batt}(t-1) \times (1-\sigma) - [\frac{E_{load}(t)}{n_{inv}} - E_{pv}(t)]$$

When the total output generation of PV panels is equal to the load demand, then the battery bank is discharges with its self- discharge rate only. The charge quantity of the battery bank at time t can be obtained by,

$$E_{Batt}(t) = E_{Batt}(t-1) \times (1-\sigma)$$

IV. METHODOLOGY

The iterative optimization procedure is adopted for the selecting the number of PV panels need for a proposed standalone system to meet a specific load is as follows [3],

1. Select commercially available unit size for PV panel and battery storage
2. Increase the number of PV panel until the system becomes balance that is the curve of the ΔP verses time for the system has an average of zero over a given period of time
3. Stop when the reliability criteria meets that is PV generation equal to the load demand
4. Obtain the required storage capacity and number of batteries.

V. RESULTS AND DISCUSSION

The iterative optimization procedure has been used for component sizing of standalone PV system to supply the electrical power to Symbiosis Campus located at a Pune in India. Plant have the coordinates of latitude at 18.575598 and longitudinal at 73.908371.

The existing system which is grid connected PV system, having 397 PV panels, one day PV generation is 854.7 kWh, the import power from the grid 678.6 kWh shown in Fig.5, and the total load demand of one day is 1533.4 kWh. From analysis the existing nature of PV generation is not sufficient

to satisfy the total load demand of one day. To balance the existing system the deficit power has been imported from the grid and to measure how much energy is imported from the grid the net metering is exist.

Fig.6 shows graphically the iterative optimization procedure for sizing a standalone PV generating system for the house under study. The number of PV panels (315Wp) was increased from zero and in each iteration the difference between generation and load demand is calculated over a 24-hour period. The number of PV panels (N_{pv}) is required to meet the load demand at a point where the average of ΔP over the period under study is zero. For the standalone configuration the number of PV panels (N_{pv}) obtained from iterative optimization procedure is 719.

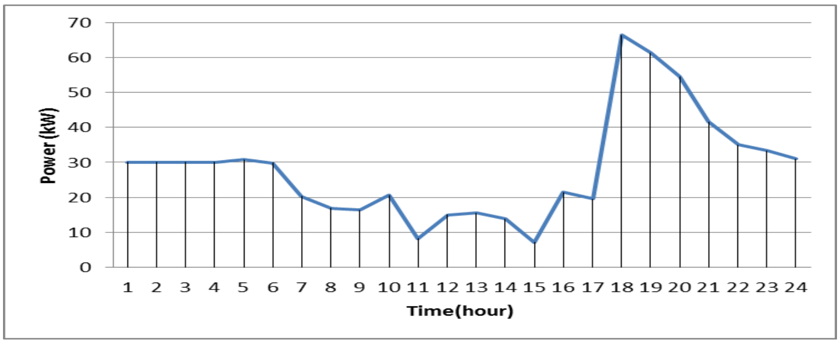

Fig.5 Grid power import to system

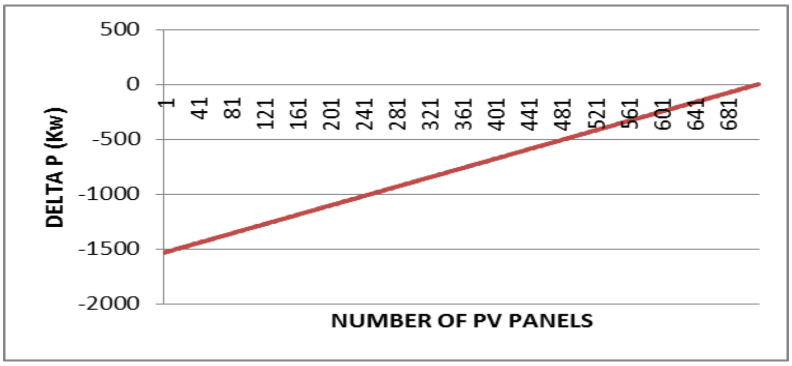

Fig.6 Average daily ΔP versus number of PV panels

The number of batteries needed for the proposed configuration is calculated by using the required storage capacity and number batteries formula and the energy curve is shown in fig.8 as described below:

Fig.7 shows the obtained ΔP versus time for the system configuration. Fig.8 shows the obtained energy curve ΔW versus time. from this curve the energy balanced over a 24hoursThe average of the energy curve is positive means the generation is greater than the load demand.

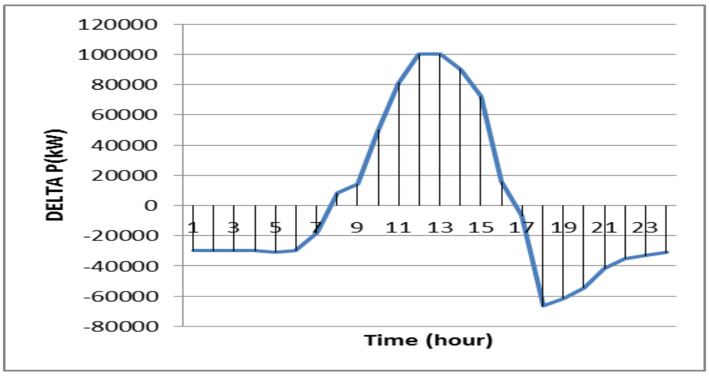

Fig.7 Average daily ΔP

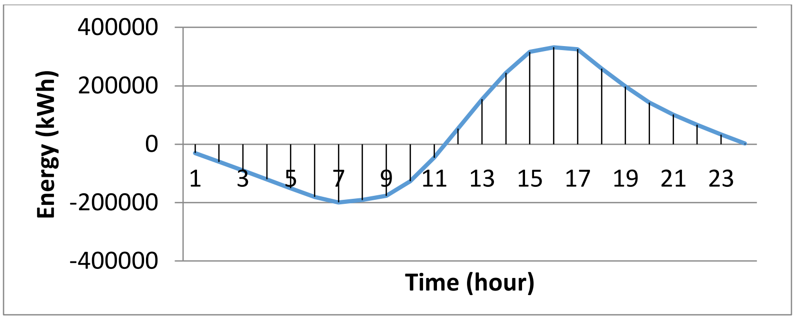

Fig.8 Average daily ΔW

Finally, obtain the storage capacity required by the battery by taking a peak to peak difference of the energy curve which results in to the 663.88 kWh and the number of batteries are 663.88/3≅221.

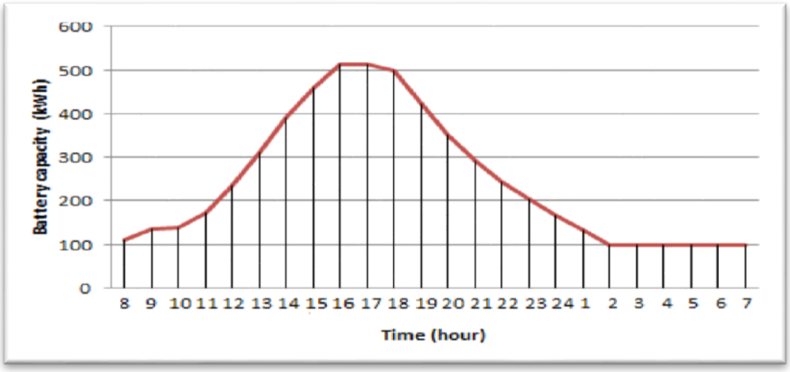

Fig.9 Operation of Battery storage system

Fig.9 shows that the operation of battery where the battery is in charging state from 08.00am to 16.00pm and the battery is discharges from 16.00pm to 08.00am.

Table 2. Optimized parameters by iterative method

Parameters	**Existing System**	**Proposed System**
Load (kWh)	1535.4	1535.4
PV power (kWh)	854.7	1535.5
Grid power (kWh)	678.6	0
Battery Capacity (kWh)	0	663.88
Number of batteries	0	221
PV panels	397	719

VI. CONCLUSION

The iterative optimization technique is successfully resulted the optimum number of PV panels and the size of the storage capacity for a proposed standalone PV system for symbiosis campus Pune. In case of existing system , the power generation of PV is less hence the deficit power is imported from the grid. But in case of proposed standalone PV system, the PV generation is increased and the excess energy is stored via storage and it used to balance the system. Thus it increases reliability of supply and independency on grid.

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