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An approach to off Grid Photovoltaic System Cost optimization

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***Abstract*—Major purpose in power system is to ameliorate energy by efficiently using the available power. In this paper, a smart system is proposed that is adaptable with our existing system to make the overall home photovoltaic (PV) system better and cost emphatic. Because of low operating efficiency of most of the available solar home systems, the cost of usable power through solar is more than the power from the grid. This system will dominate the cost of energy by reducing the use of batteries and inverters, which will also reduce the overall losses. Comparative analysis is used to explain the cost effectiveness and efficiency of proposed system over current system.**

Keywords— Photovoltaic, cost, conversion efficiency.

I. INTRODUCTION (*HEADING 1*)

In recent times, the solar energy is growing and gaining much popularity, as it has become a source of generation of the energy in different forms. Nowadays two configurations of PV systems are being used in the world, that are grid linked system and Solar Home System (SHS). The operating system of SHS is easy to handle, reliable and also cheap in cost thus it is more popular in remote areas. A low cost and reliable electricity service can be utilized by using solar energy [1-2]. It is a wrong notion that as the solar energy is totally free thus the price of Solar Home System will also be negligible always. We need to decrease the price of the solar system to improve it and increase the efficiency of overall solar system by improving it so that it can become compatible with the energy of the grid [3]. To optimize overall system the interconnectivity of components can be improved and this will reduce the cost of the system [4-5].

An effective and simple model is presented here in this paper that shows how SHS can be optimized by decreasing the amount of components being used in the present system. The technology used will not be overdone and our new Smart Grid System (SGS) will also be able to compare with the present Grid System. A comparative analysis of efficiency and energy cost calculations are also done according to the present SHS components. The calculations done in literature shows that for a SGS the parameters like efficiency and cost are much better [6-7].

II. EXISTING SOLAR HOME SYSTEM

The classic SHS is composed of battery for the storage of energy, load for the consumption of power and solar panel as a source. The most common schematic view of SHS that has been accepted though out the world and especially in South Asian Countries is shown in Fig.1.

Figure 1. Schematic diagram of a typical Solar Home System.

The size and cost of the components of SHS depend on each other and also on the power consumed by the loads used like glowing lamps and small TV. Development in power is being restricted due to lack of primary fuels like natural gas etc. A rapid growth of SHS is seen by such developments including the awareness about smart grid. Regrettably there is a negligible result seen in the effort of the study of real cost of SHS [8-9]. Some notable calculations and concerns must be done by our new policy makers, so that required steps can be taken for the growth of SHS.

III. PROPOSED SMART GRID SYSTEM

Separate components of SHS will be used by neighboring homes for the generation of power. Supposing if in a colony 10 homes are having SHS or solar panels then the total quantity of batteries, solar panels and inverters will also be 10 for each home separately. Thus a cost effective interpretation could be made by detaching unneeded components and minimizing the system to just required components. This will help to increase the efficiency and also the cost of the system all together, also the needed components will be working near to the rated values on which they were developed [10-11]. Such suggested Smart Grid System for each colony is shown in the Fig 2.

The minimization of batteries and an ordinary inverter are the main aim. The houses have already been connected in parallel to AC supply. Using a distinct DC wire they all are to be connected to SGS. This might cost initially but in the huge scale the cost of installation would not affect much. Using a usual DC wire, the isolated DC will be conducted to inverter. During the day time solar will give its maximum efficiency [12-13]. When the power inflow is larger than the power outflow then the rest of the power is conducted back to the grid for usage in other things. To communicate the important information and for storage and for the control of fuses and switches, microcontrollers will be used.

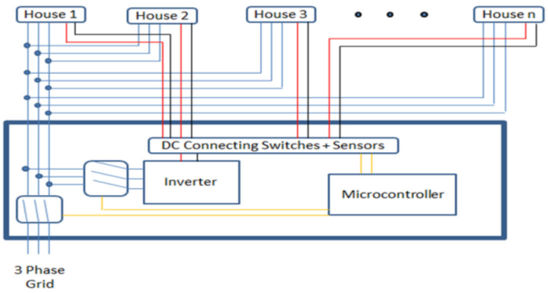

Figure 2. New Proposed Smart Grid System.

The benefits of the Solar Grid System over Solar Home System are

- Less cost
- More efficiency
- The system is in control of supplier who can now control the colony by accumulation more program to the system.
- Encouraging for the user to buy solar because of lowest cost of installation for user.
- No destruction of the grid.
- No power is lost even if a single home is not using it, someone else will use it.
- The preference of power is given to the same colony instead of giving it to grid.

IV. COMPONENTS TO CONSIDER

A. *Solar energy in South Asia*

Moreover, a massive amount of solar radiation exists in Pakistan. "Central and western" regions of the country that are established in equator, they are subjected to higher intensities of solar radiations as related to northern and southern coastal regions. Monthly average data of sun brightness hours (1992-2012) of Bahawalpur (District of South Punjab) from this Climatological station is shown in Fig. 3 and Fig. 4 [14]. Monthly and annual sunshine hours of Bahawalpur are shown in Fig.3 and Fig.4. "Metronome software" has been used to get data of solar radiation of Bahawalpur District that presented in Table I, For Bahawalpur District, amount of solar radiation is 6,40MJ/m^2 and annual average hours of sunshine are 3,201.

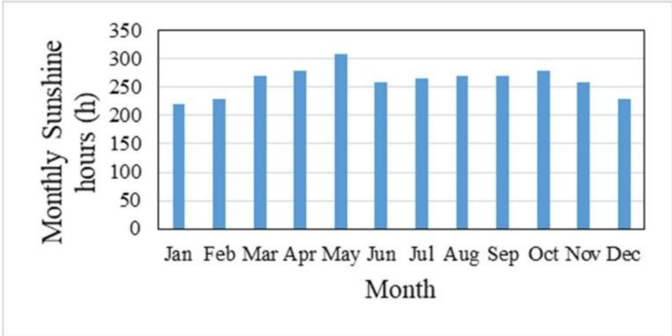

Figure 3. Monthly Average Sun Brightness hours (1992-2012) of Bahawalpur.

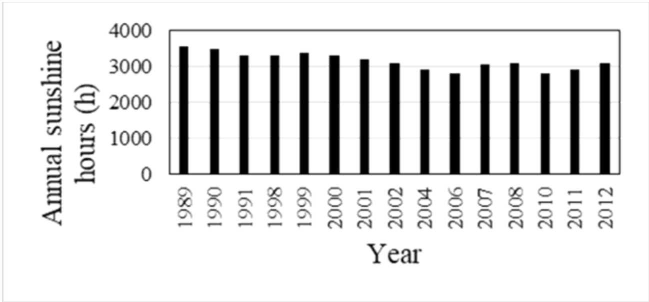

Figure 4 Annual Sunshine hours of Bahawalpur.

TABLE I. SOLAR RADIATION DATA OF BAHAWALPUR.

Month	Monthly Average Radiation Quantity(KJ/m^2)	Monthly Average Sunshine Hours
January	354000	223
February	441000	224
March	536000	271
April	638000	288
May	686000	308
June	664000	262
July	651000	276
August	637000	282
September	606000	285
October	496000	293
November	386000	263
December	343000	226

B. *Inverters*

The AC power which electric utility company grid will use, will get through the inversion of the DC power by using inverters. The frequency of GTI (grid tie inverter), by the usage of the local oscillator should get harmonized with the grid's frequency which is e.g. 50 or 60 Hz. Also it regulates the voltage level of the inverter to not exceed the voltage level of the grid. An elementary circuit of an inverter comprises DC power and a transformer is connected by the center tap of primary windings. Due to swift switching of the current between two distinct paths it reverses to DC source i.e. by one extreme of primary winding and the through other [15]. Due to the fluctuation of current of different route in the transformer's primary windings alternating current is produced, in the secondary current.

A three-phase inverter is connected to one of the three load terminals. It consists of three single-phase inverter switches, as shown in Fig.6.

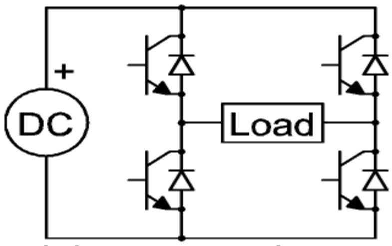

Figure 5. Single phase inverter circuit with transistor switches.

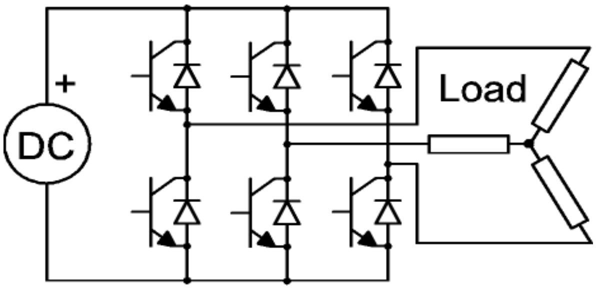

Figure 6. Three phase inverter with wye connected load.

C. *Batteries*

Battery is used for the storage of the output of solar PV and this battery is known to be the essential part of the SHS. At the day time the battery stores the PV energy and after the sun has set this stored energy is provided to the appliances. Mainly it is a notable parameter for the altogether cost of energy. The process of the charging and the discharging of the battery are also going on the same time which reduces the energy of the battery up to 15% [16]. This loss of the energy of the battery is the reason of the reduction in the efficiency of the SHS and also the reason for the costly energy, this issue enforces to use less number of batteries in the system [17]. The arrangement of the installation of the AC system in a solar house is described in the Fig. 7, the arrows represent the power flow.

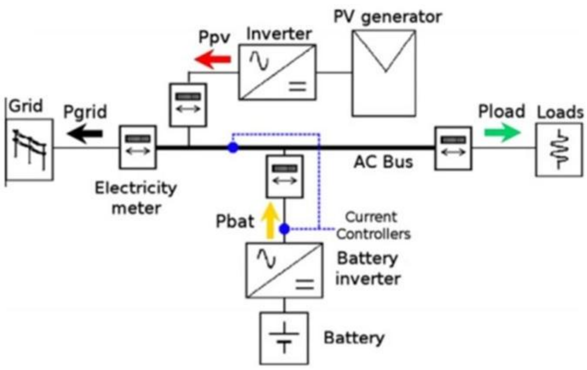

Figure 7. Topology of the AC system installed in the solar house.

V. COST ANALYSIS

Cost of Energy model calculation is based on the solar panel prospect cost and the storage battery prospect cost. The "price of solar PV in the international market determines the energy cost in a SHS which is the only most significant factor [17-18]. Effective solar protection includes cost per watt-peak (C_{solar}) price and solar protection (S) kW-hr/day in the physical location on a one meter square surface where the solar panel is used. The weather data is taken form Meteorological NASA Surface data sheet [19]. A solar PV panel watt peak is defined with intensity of radiation at $1000W/m^2$ and 11.5AM atmospheric circumstance. Annual creation of energy per Watt-peak of a panel is [20-21]

$$E_{solar} = \text{"}S.365 \text{ "W-hr /year} \quad (1)$$

Depreciation is Csolar/15 per W-peak. The sum of the depreciation of the panel and bank interest are total opportunity cost Csolar, that is

$$C_{solar} = C_{solar}\times(1+0.0667) \text{ per "W-peak/year"} \quad (2)$$

For the solar panel, energy cost component is

$$C_{solar\ energy} = C_{solar} \times(1+0.0667)/ E \text{ per kW-hr} \quad (3)$$

The solar PV output is stored in the storage battery which is an important section of SHS as energy saved during the day time and it provide energy to lamps after sunset.

$$C_{Bnergy}=\text{Cost of Battery per kW-hr} \quad (4)$$

Another essential component which is used to convert the DC generated power from panels to required electrical AC power. The cost of this DC to AC converter will be accumulated as

$$C_{EnergyI}= \text{Cost of Inverter per kW-hr} \quad (5)$$

The entire energy cost (C_{EE}) includes the cost of battery, inverter and panel cost (other less expensive components is ignored).

$$C_{EE} = C_{solar\ energy} + C_{Energy} + C_{Energy\ I} \text{ per kW-hr} \quad (6)$$

VI. EFFICIENCY

The model for energy efficiency of the entire SHS is based on the efficiency of solar panel, battery and inverter's efficiency.

$$\eta_{system}=\eta_{solar}\times\eta_{battery}\times\eta_{inverter} \quad (7)$$

The charging and discharging of batteries decreases the overall efficiency by 15% and thus the remaining efficiency of battery is 85%.

$$\eta_{battery}=85\% \quad (8)$$

As we know the efficiency of an inverter increases with the increase in load, as shown in Fig. 8. For a single solar cell (of specified power), efficiency of inverter increases as the load is increased. Thus we can increase the efficiency of inverter by operating it at rated power instead of minimal loads [22-23].

VII. RESULTS AND DISCUSSION

A. *Calculations*

In order to compare the energy cost of a SHS, the following assumptions need to be considered. These assumptions are taken on their previous studies and minimum values in practical conditions are considered. The slight variation in assumptions would not change the results, because they are same for both scenarios. Following points are considered:

1. No Sun tracking is considered, however in the best possible way panel position is expected.
2. Life of a solar cell is considered to be fifteen years [24].
3. Life of a battery is considered to be five years [25].
4. The calculations and analysis are done for a period of fifteen years.
5. The calculations are done in consideration of ten houses under a new smart system.
6. Assuming 5kW solar panel for a home [26].

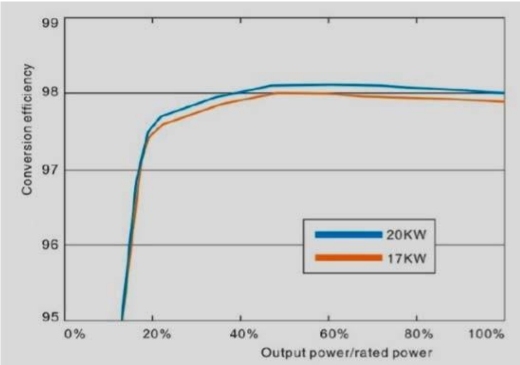

Figure 8. Conversion Efficiency and Output power of an Inverter.

Table II shows the number of desired components in order to calculate the total cost of both existing Solar Home System and the proposed Solar Grid System for the duration of fifteen years.

TABLE II. NUMBER OF DESIRED COMPONENTS BOTH IN EXISTING SYSTEM AND IN PROPOSED SYSTEM.

Components	**Existing System**	**Proposed System**
Number of inverters	10×1=10	One
Number of batteries	10×3=30	Zero
Number of solar panels	10×1=10	10×1=10

Where Cost of Solar PV= 10,000 USD, Cost of Battery = USD 1.5/AH, Cost of System $=C_{Solar}$ =100 USD, Cost of Inverter = USD 300, Cost of Solar Energy= 2100 kW-hr per year

$$\text{Cost of Existing System}=\text{CES} \quad (9)$$

$$C_{EE} = C_{solar\ energy} + C_{EB} + C_{Energy\ I} \quad (10)$$

$$\text{CES} = (10\times C_{ES}) + (30\times C_{EB}) + (10\times C_{EI}) \quad (11)$$

$$\text{Cost of Proposed System}=(10\times C_{solar\ energy})+C_{Energy\ I} \quad (12)$$

Efficiency can be calculated as

$$\eta_{system}=\eta_{solar}\times\eta_{battery}\times\eta_{inverter} \quad (13)$$

$$\text{Efficiency of Existing System}=\eta_{solar}\times 0.85\times\eta_{inverter} \quad (14)$$

$$\text{Efficiency of Proposed System}=\eta_{solar}\times\eta_{inverter} \quad (15)$$

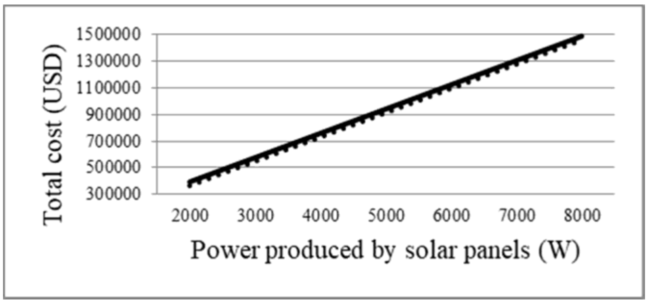

Figure 9. Total Cost and Power of Solar Panel, where black line represents existing and dotted line represents purposed system.

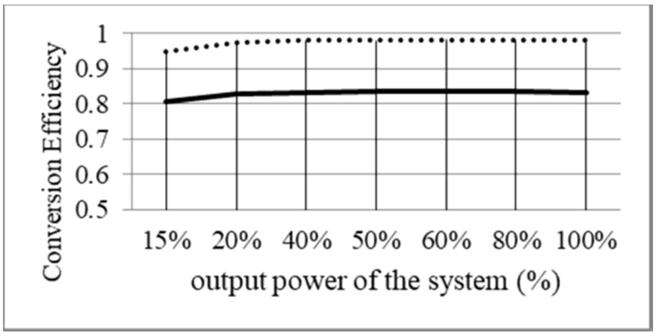

Figure 10. Conversion Efficiency and output power of the system, Panel, where black line represents existing and dotted line represents purposed system.

When we increase output power of existing system and purposed system then purposed system gives better efficiency. It is shown in Fig. 10. Efficiency of purposed system is better than existing system at same output power of system.

As inverter is operated at maximum load that is maximum efficiency of about 98%, the efficiency of Solar Grid System is

$$\text{Efficiency of Proposed System}=\eta_{solar}\times 0.98 \quad (16)$$

From Fig. 9, it shows that there is a less difference in price because of a small initial price of few components that is divided over a long period. But from Fig. 11 we can clearly observe that the total available power in both the cases is different. Thus same price results in various output power [27]. And same output power will result in value difference. This could also be shown from Fig. 11 where the wasted or loss of price in the existing SHS is much more than the loss of price of proposed system [28].

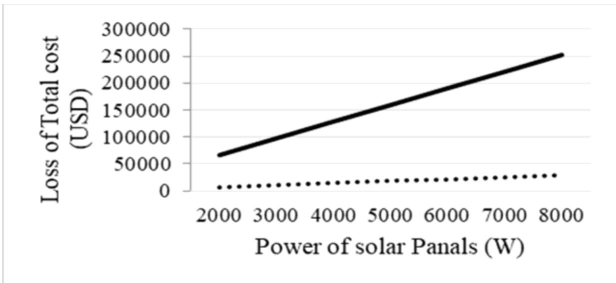

Figure 11. Loss of Total Cost and Energy of Solar Panel , where black line represents existing and dotted line shows purposed system.

Figs. 9, 10, 11 and 12 shows that the initial cost of system is almost the system, however, new purposed system will have more efficiency. This way there will more available power to use in same price.

VIII. CONCLUSION

For the end user appliances and the generation of the variety of energy required for those appliances, Smart Grid is an up-to-date form of the power system. It encompasses communication and intelligence technology, power transformation technology, system control technology. It progresses the level of utilization of the solar energy, and thus it becomes much more safe, stable, efficient and economic. In this paper a new system is purposed which can reduce the cost and increase the conversion efficiency at the same time. In this system a number of houses are connected to a single battery bank and a single inverter. Since the process of the charging and the discharging of the battery reduces the energy of the battery up to 15% of a specified power of a single solar cell, using a combined battery will increase its life. And using a single inverter will increase load on it, hence the efficiency of invertor will improve. Combining battery bank and inverter will reduce its initial cost by a small amount, however, improvement in conversion efficiency will increase available power. This way we will have more power in less cost. Cost analysis is carried out to on the basis of solar panel cost, the storage battery cost, solar insulation cost, cost of DC to AC converter and cost of energy losses.

IX. FUTURE ENHANCEMENT

A numbers of possibilities may be added to this system. If such a system is established in every colony and the control of system is in the hand of distributor, then he could use it for several other aspects. Limited of them are given below

- Damages of transformer can be decrease by swapping it off .
- Three phase observing system.
- DC source to the home using current cables.
- Voltage distinctions in grid system.

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