International Journal of Research and Reviews in Applied Sciences
ISSN: 2076-734X, EISSN: 2076-7366
Volume 2, Issue 1(January 2010)

OPTIMAL DESIGN OF A COST EFFECTIVE SOLAR HOME POWER SYSTEM - AN ALTERNATIVE SOLUTION TO DG FOR GRID DEPRIVED RURAL INDIA

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ABSTRACT

In the present study, a solar (PV) home power system integrating with conventional DG sets has been proposed for a grid deprived areas for rural India. The main objective of this scheme is optimal design of a solar (PV) powered power supply system to produce green power and reduce the use of conventional DG sets resulting in reduced cost of operation and maintenance. The cost of logistic by minimizing diesel runtime and fuel consumption thus will have a better impact on environment. The prototype unit for daily load energy requirement varying from 1200 - 1800Wh of a rural home has been developed. Performance tests were carried out for quality of power and efficiency of the converter system.

KEYWORDS: *Off-grid power supply; Photovoltaic (PV); Solar Hybrid System; Sinusoidal Pulse Width Modulation (SPWM) ; Diesel Generator(DG); State of Charge (SOC).*

1. INTRODUCTION

Energy is the basic need of human life and with the rapid growth of population; its demand is increasing day by day in urban as well as in rural sectors of the country. The people living in the remote rural area of Indian villages are still deprived of electrical supply from the conventional grid source. The Diesel Generator (DG) sets are being used by rural masses as an alternative source of power but its operation is limited due to high cost of fuel and high maintenance. This forces the scientist and engineers to look for non conventional sources of energy which can easily be made available free of cost or at negligible cost and at the same time its conversion technology to produce electricity must be simple and cost effective. Many stand- alone and hybrid devices using renewable energy sources like solar photovoltaic, wind, biomass, biogas and / or mini /micro hydro has been developed in the past and reported by many authors [1, 2, 3, 5, 6] but their availability, complexity in design & operational feature, difficulty in getting the system or its spare parts and scarcity of trained manpower have resulted in less popularity among rural masses.

In the present study, a solar (PV) power system has been proposed with simple technology which can work as a standalone device or as a primary source of hybrid power supply system (i.e. integrating PV system with DG set). The simple technology of hybrid power supply system offers the following benefits:

- Adaptability of technology by rural masses
- Improved reliability
- Reduced emissions of hazardous gasses and pollution
- Provide continuous power supply
- Increased operational life
- Reduced cost and more efficient use of power

2. SYSTEM CONFIGURATION AND OPERATION

The solar (PV) home power system (Figure 1) consists of the following :

- PV module
- Battery
- Bi-directional Power Converter
- Controller unit
- DG set as a standby source

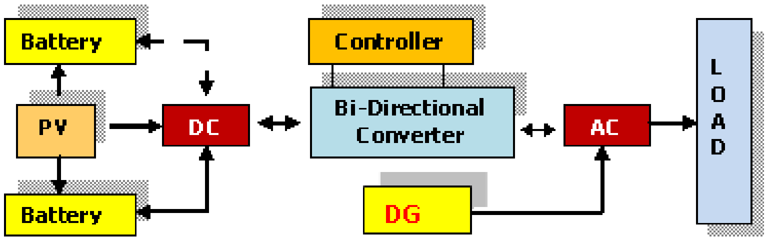

Figure 1. Block schematic of a solar power converter with a standby DG Set

The primary source of power supply to rural houses is the PV power. Load power is managed either by PV system or stand by alternative DG source. The power converter unit of the PV system takes the low 12V DC voltage input from PV energy source, stored in battery, as shown in Figure 2 and convert it into usable 220VAC, 50Hz output with the help of a centre tapped transformer (Tr) based push-pull configured BJT/MOSFET bi- directional converter(inverter) circuit. The controller circuit generates PWM pulses to activate transistors T1 and T2 alternatively, producing AC voltage across the load. DG set is connected to load only when the battery reaches a discharge level of 10.4V and remain on till battery become fully /sufficiently recharged at a level in the range of 12.8V to 13.8V. The intelligent, adaptive control action of the controller performs load power and energy management and thus monitor and manage to deliver continuous power to load. The charging operation is performed by PV source and /or DG Source through converter circuit comprising of diodes D1 and D2 while transistor T1 and T2 remain off. Due to this bi-directional feature AC power is transferred to DC power which charges the battery under low charged condition.

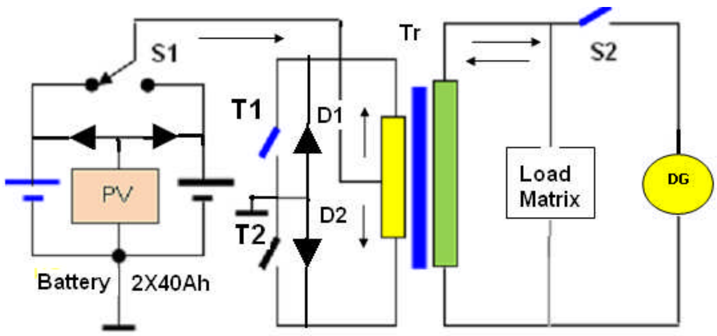

Figure 2. Circuit diagram of PV System integrated with DG Set

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3. OPTIMAL DESIGN OF PV SYSTEM COMPONENTS [4]

3.1. PV Sizing

The empirical formula based on energy balance equation has been used to compute the optimal size of PV module for critical load(s) as stated below:

$$\text{PV Cell Rating } (P_{PV}) = \{(P_{TL} * S.F) / \text{sun hour}\} \quad \text{watt} \qquad (1)$$

Where,

Sun hour = 6.2 hours for adopted area

Safety Factor (S.F) = 1.5 for cloudy weather/low sun radiation

P_{TL} is total load energy in watt- hours (i.e. total load power over a period of 24 hours assuming hourly load power (P_L) as constant)

$$P_{TL}(Wh) = \sum_{0h}^{24h} (P_L) \quad \text{Watt-Hours} \qquad (2)$$

$$\text{The optimal number of PV module} = P_{PV} / \text{Standard PV module rating} \qquad (3)$$

The design of components of solar (PV) hybrid system for PV is computed using Eq.1 – Eq.3 for different varying daily load energy requirement of rural houses as depicted in Table 1.

Table 1. Number of standard PV module

Load Energy (Watt-Hours)	No. of 75 Wp PV module
300 Wh	1
500 Wh	2
1000 Wh	3
2000Wh	6

3.2. Battery Sizing

The battery stores the energy to a maximum value as per average load energy requirement.

$$\text{Battery capacity (Ah)} = P_{TL} / (12V * SOC) \qquad (4)$$

Where,

SOC (State of Charge) of Battery = 50%

The design of Battery sizing is computed using Eq.4 for different varying daily load power i.e. energy requirement of rural houses as depicted in Table 2 respectively.

Table 2. Battery capacity

Load Energy (Watt-hour)	Battery Capacity (Ampere-hour)
300 - 500 Wh	80 Ah
1000 Wh	150 Ah
2000Wh	300 Ah

4. PROTOTYPE DEVELOPMENT OF SYSTEM MODULE

Load energy profile recorded day to day basis and monitored over a period of one month to compute the average daily energy requirement of house. A typical load power profile of a day has been shown in Figure 3.

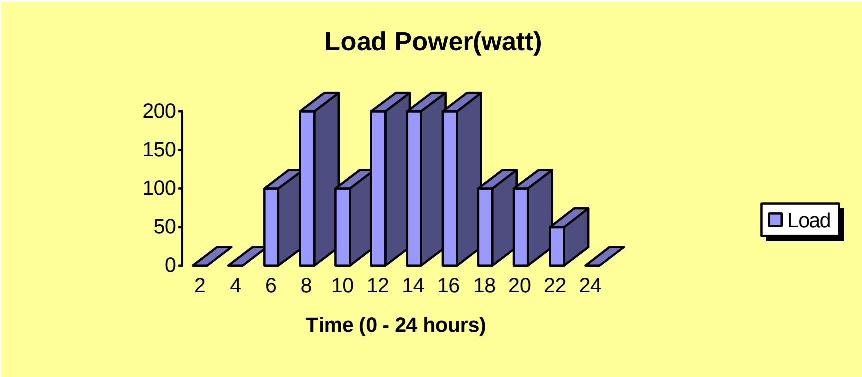

Figure 3. Load Power profile of a Rural House on a Typical Day

A prototype system module has been developed to meet the load energy requirement with the following design specifications .The system was installed at tribal village in the remote area of Patamda village of Jamshedpur (India):

Load Energy	=	1200 - 1800 watt-hours over a period of 24 hour, computed over a period of a month
PV size	=	2 X 75 Wp, 12 V
Battery Size	=	2 X 80Ah, 12 V low self discharge inverter grade lead acid battery
Load(s)	=	CFL lamps , Fans, TV and Rural Industrial/household equipment etc
Converter	=	300 VA, 12VDC ~ 220 V SPWM AC , 50Hz
Mobility	=	Portable

5. MODE OF SYSTEM OPERATION

5.1. During Day Time

In Figure 4 (a), solar is the first choice and only source of energy while the generator is off. Solar (PV) DC power, sharing with one of the pre stored charged battery, is converted into AC power by converter for the load (s) and simultaneously charges the other battery.

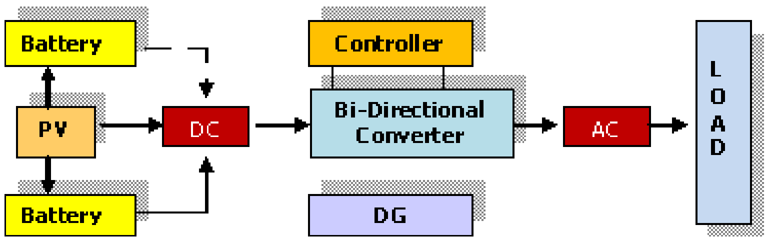

Figure 4 (a). Operation of System during daytime

5.2. During Night Time

In Figure 4 (b), solar energy stored during daytime in battery is the only source of energy while the generator is off. The converter converts DC power, selecting either pre stored charged battery or the day stored battery, to AC power for the load. The battery will supply the load to its maximum discharge level.

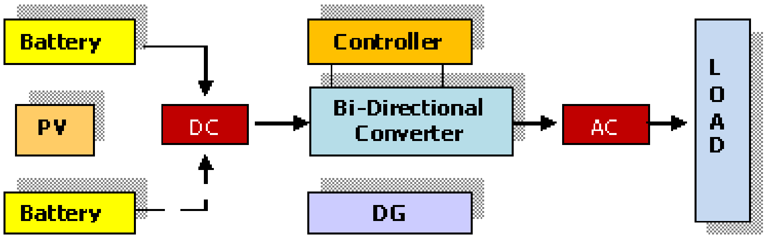

Figure 4 (b). Operation of System during night time

5.3. During Shortfall period

Shortfall can occur on any low sun - radiation day or on excess load demand resulting in low charging of battery and thus system may encounter a problem during end of day or night period to meet the balance load power requirement of the day. During shortfall, the battery reaches its maximum discharge level and therefore, the generator is made on, as shown in Figure 4 (c). During this period DG set serves the load as well as charges both the batteries , one at a time or simultaneously , till they resume full /sufficient voltage in the range of 12.8V - 13.4V.

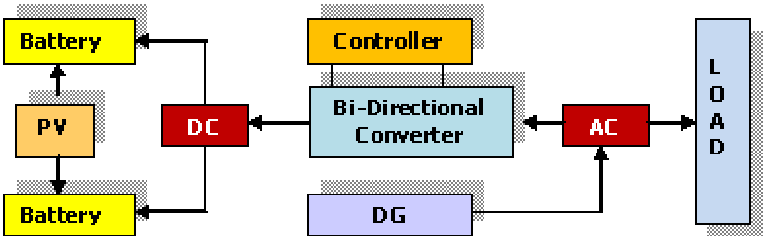

Figure 4 (c). Operation of System during shortfall

The battery charge rate (i.e. Trickle/Boost (C4/C8/C10)) is adjusted to maintain the generator at full output. The operations, which activate or deactivate Gen-set and charging or discharging battery are managed and done by controller unit. The built in DC and AC switching module of controller unit monitors and manages the load demand and energy supplied.

6. PERFORMANCE AND COST EVALUATION OF SYSTEM

6.1. Quality of Power

The qualitative analysis of output waveform simulated by the MATLAB program show low (less than 5%) THD sine wave (Figure 5).

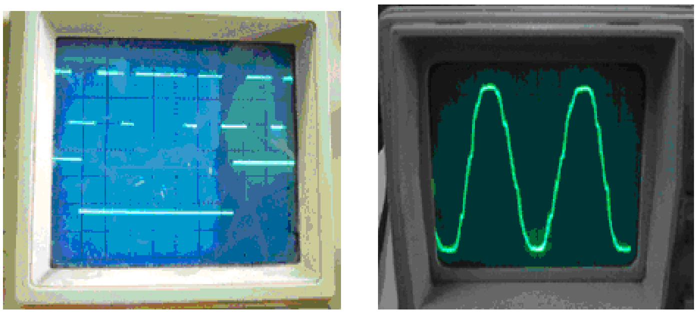

Figure 5. Control PWM pulses (Left) and Output waveform of converter (Right)

6.2. Efficiency of Converter system

The efficiency of the converter system was found to be almost constant value in the range of 96% or more under varying load conditions as shown in Figure 6 leading to an indication of low loss and maximum utilization of energy resources.

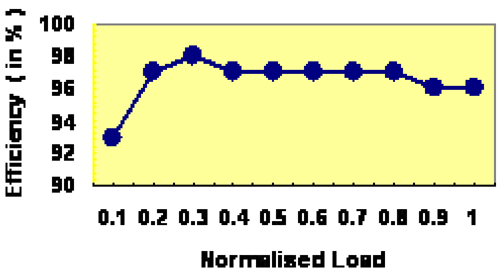

Figure 6. Efficiency of Converter System

6.3. Cost Evaluation

The cost of fuel consumption was evaluated for a period of one year (Table 3) and compared with cost of PV system. It is apparent from the table that the payback period the PV system introduced in the scheme is less than two years only as against the fuel consumption and maintenance of DG sets.

Table 3. Cost evaluation of PV system and comparison with cost of fuel consumption and operational maintenance of DG set

DG Fuel Consumption and Maintenance Cost		Cost of PV System	
Fuel Cost X Month Rs 1000 X 8 = Rs 8000 Rs 1500 X 4 = Rs 6000	Rs 14000	PV 4 X 75Wp	Rs 30000
		Inverter 300VA	Rs 5000
		Battery 2 X 80Ah	Rs 10000
Operational Maintenance Rs 1000 X 12 = Rs 12000	Rs 12000	Maintenance	Rs 500
		Misc. Expenses	Rs 4000
Total	**Rs 26,000**	Total	**Rs 49,500**

Pay back Period = Total Cost of PV system / (Fuel consumption +Maintenance) (5)
= 2 years (Maximum)

7. CONCLUSIONS

Solar (PV) power system has a great potential in future as one of renewable energy technologies for off-grid power generation. The hybrid technology, integrating PV with DG, offers solution to off-grid power generation. The easy installation and maintenance free operational feature of the hybrid system created more popularity among the rural masses. The successful implementation of system has following outcomes:

- Generating electricity and meeting load(s) demand of a rural house in a grid deprived area by reducing consumption of fuel etc in DG set
- Reducing CO_2 emission and noise due to minimum use of DG and thus preserving the environment from being polluted
- Cost effective (i.e. the minimum running hours of DG set also reduces the maintenance cost of a diesel generator).

REFERENCES

1. Baharuddin Ali et al, “Hybrid photovoltaic diesel system in a cable car resort facility”, European journal of scientific research, Vol 26, No1 (2009), pp 13-19.
2. Sopitpan . S, “PV System with / without GRID Backup for Housing Applications”, IEEE (2000), pp 1687-1690.
3. Saha et al, “Grid interfaced Urban Domestic Power pack”, Proceeding of 29th IEEE photovoltaic specialist, May 19-24 Neworlians Louiana , pp 1625-1629.
4. S.N.Singh, A.K.Singh**,** “Modeling and dynamics of a PWM sinusoidal Inverter for water pumping system for use in agriculture and household applications”, Journal of ieema, Jan (2008), pp 114-122.
5. Lindgrin, “A 110W inverter for photovoltaic application”, Published in International Journal of Renewable Energy Engineering, April 2002.
6. M.H .Rashid, “Power Electronics: Circuits, devices and applications”, Pearson Education (2004).