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AN INVESTIGATION ON THE CHARACTERISTICS AND PERFORMANCE OF A PV-DIESEL HYBRID ENERGY SYSTEM FOR TEACHING AND RESEARCH

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Abstract: This paper presents an investigation of the characteristics and performance of a Photovoltaic (PV)-diesel Hybrid Energy System for teaching and research purposes. The system was developed at the Centre for Renewable Energy and Sustainable Technologies Australia (CRESTA) at Curtin University, Australia. It is intended that the system will be introduced to remote areas where the main electricity grids are not available. The system comprises of PV module of 1.2kWp, a 5 kVA diesel generator, a 5 kVA bi-directional inverter and a 13 kWh battery bank. It also incorporates a weather station which measures the horizontal and tilt (32°) irradiation, ambient temperature and barometer pressure. Data from the site have been recorded continuously. The average global radiation is 5.17 kWh/day and the tilt radiation is 5.62 kWh/day. The performance ratio of the PV-array has been calculated approximately as 0.6. The average fuel efficiency of the motor generator is 1.67 kWh/ltr based on a predictive control strategy.. The battery efficiency is 0.96 while and the overall system efficiency is found to be 0.64. The system runs in synchronism with a diesel generator and a predictive control strategy, which is based on the theoretical control principles for optimum supply side management.

1. Introduction

Electricity is one of the fundamental necessities for every day's life. We have now got used to electric appliances which improve our quality of life and make daily living more convenient. However, about 2 billion people in remote areas around the world are still living without electricity because utility grids are not available. Renewable energy have become viable alternative energy sources for electrical power production in remote areas. Although the initial cost of engine generators may be comparatively low, the long term cost can be high due to problems associated with fuel cost, storage sites and maintenance costs. The high maintenance cost is due to the frequent start and stop cycles of the engine, cost of skilled technicians to be sent to the site, spare parts, and the noise and pollution issues.

Although the initial cost of a renewable generators is generally higher than a engine generator of compatible size, the operating and maintenance costs of the renewable generator are however lower. This is mainly due to the fact that the renewable sources are free. So, it is advantageous to look for ways to combine both generators into one and get the best of both systems. This configuration is called a Hybrid Energy System (HES) [1].

By integrating renewable energy technologies with diesel generators, batteries and inverters, the hybrid energy system can provide high quality AC power to remote communities. Such systems are important sources of electricity for resort islands, schools, clinics, and village communities. In addition, they can provide essential supply for national parks, wild life research centres, farms and tourist facilities which are far from the mains grids [4].

The main advantage of hybridizing a renewable energy system is to reduce reliance on expensive renewable generators. It also enable a reduction in the rated capacities of the motor generator, battery, inverter, and the size of the PV array while meeting the peak loads.

2. Studies of PV-Diesel Hybrid system at CRESTA

CRESTA has been involved in the research and development of hybrid power systems for more than a decade. Previous research projects have included identifying the advantages and disadvantages of various HES configurations (series, switched and parallel) [1], and the development of bi-directional inverters which may run in synchronism with a diesel generator and control system topologies. In addition to the bi-directional inverter performance analysis, an optimum control strategy based on set points for a PV/Diesel hybrid system have also been studied. Other work included a fuzzy logic and genetic algorithm method to determine the dispatch strategy of single generator in remote area power supply (RAPS) systems, and, the problem of unit commitment of multiple generators system. Recent work also included the development of control strategy which schedules the operation of a single diesel generator. The strategy is based on the predicted solar photovoltaic resource, the load

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demand, and the measured state-of-charge of the batteries. The developed strategy includes predictive energy management system as part of the control objectives. This is not possible with conventional control strategies. The strategy aims to increase the fraction of directly supplied energy from the photovoltaic array and the diesel generator thereby reducing the associated power conversion losses and minimizing the number of charge/discharge cycles of the battery bank.

3. System components

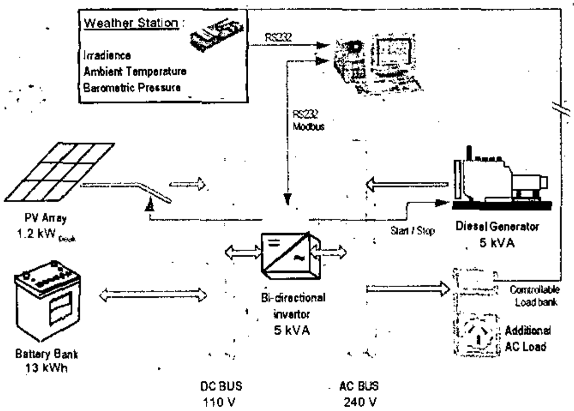

Figure 1. Schematic Diagram of Photovoltaic Diesel Hybrid Energy system

Figure 1 presents an overview of a PV-diesel hybrid system, which has been developed for the analysis of the system performance. Those components of the Hybrid system are as followed.

3.1 Photovoltaic array

The photovoltaic array consists of two parallel strings of BP280 panels rated at 8*80W_{peak}. They generate a maximum power of 1.2 kW_{peak} under standard test condition (STC). The nominal operating voltage is 110 V_{DC}. From previous results while considering medium to high temperatures and a low average inverter efficiency, the performance ratio (P_R) of the PV array is [3,5,6]:

$$P_R = \frac{E_{PVuse}}{\eta_{PV,STC} \times G \times A_{PV}} = \frac{E_{PV,direct} \times \bar{\eta}_{INV} + E_{PV,stored} \times \bar{\eta}_{BB} \times \bar{\eta}_{INV}}{\eta_{PV,STC} \times G \times A_{PV}}$$

$$= \frac{1008kWh \times 0.665 + 176kWh \times 0.96 \times 0.665}{0.127 \times 987 kWh/m^2 \times 10.1m^2} = 0.619$$

when

A_{PV} = Area of photovoltaic array (m^2)
E_{PVuse} = Photovoltaic energy supply to the load (kWh)
$E_{PVdirect}$ = Directly supplied photovoltaic energy on DC side (kWh)
$E_{PVstored}$ = Stored photovoltaic energy on DC side (kWh)
G = Global solar radiation (kWh/m^2)
$\bar{\eta}_{BB}$ = Average energy efficiency of battery bank
$\bar{\eta}_{INV}$ = Average energy efficiency of inverter
$\eta_{PV,STC}$ = Conversion efficiency of PV array under STC

3.2 Diesel generator

The diesel genset is a Honda GD410 with $P_{mechanical}$ = 5 kW. The diesel engine drives a Sincro 6 kVA alternator. The voltage varies from 250V AC under no load to 220 VAC at an output power rate of 4 kVA. Figure 2 shows the fuel consumption characteristics.

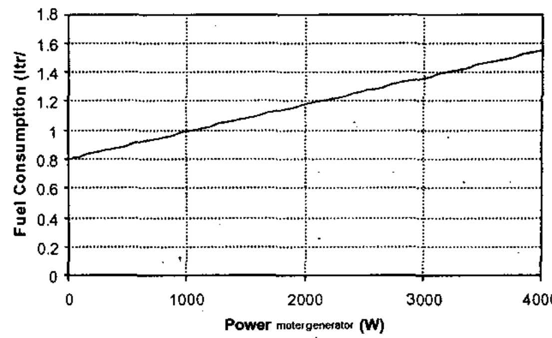

Figure 2. Fuel consumption of Honda GD 410 diesel generator

The average fuel efficiency using the predictive control strategy of the motor generator can be calculated as [2]:

$$FE_{PCS} = \frac{E_{MG}}{MFC} = \frac{459\ kWh}{288\ ltr} = 1.67 kWh/ltr$$

where

FE_{PCS} = Fuel efficiency using the predictive control strategy (kWh/ltr)
E_{MG} = Energy generated by motor (kWh)
MFC = Motor generator fuel consumption (ltr)

3.3 Battery bank

The battery bank consists of one string of 18*6V *SunGel200* gelled electrolyte cells connected in series. Individual battery is rated at C_{120} = 200 Ah and C_{10} = 125 Ah. Selecting the 10-hr rating as representative for the system, the available energy storage capacity can be calculated as [2]:

$$E_{BB} = C_{10} \times V_{BB,nom} = 125\ Ah \times 110\ V = 13.75\ kWh$$

where

E_{BB} = Energy storage capacity of battery bank
C_{10} = 10-hour battery discharge capacity
$V_{BB,nom}$ = Normal DC voltage of battery bank

Assuming a minimum state-of-charge (SOC) at 40% and a subsequent recharge of the battery bank to 90% SOC, the useable energy storage capacity is limited to:

$$E_{BB,use} = 0.5 \times E_{BB} = 6.9 \text{ kWh}$$

where

$E_{BB,use}$ = Useable energy storage capacity of battery bank

When the average daily load E_{load} is 8.14 kWh/day, then the battery bank provides approximately 0.68 days of storage:

$$NDS = \frac{E_{BB,use} \times \bar{\eta}_{INV}}{E_{LOAD}} = \frac{6.9\ kWh \times 0.8}{8.14\ kWh/day} = 0.68\ day$$

where

NDS = Nominal days of storage of the battery bank (days)
E_{LOAD} = Average daily load demand (kWh/day)
$\bar{\eta}_{INV}$ = Average energy efficiency of inverter (Typically 0.75 ...0.85)

Battery efficiency can be calculated as [2]:

$$\bar{\eta}_{BB} = \frac{E_{BB,out}}{E_{BB,in}} = \frac{E_{BB,out}}{E_{PV,stored} + E_{MG,stored}} = \frac{538 kWh}{560 kWh} = 0.96$$

3.4 Bi-directional inverter

The single-phase, 5 kVA bi-directional inverter converts electrical power from DC to a sinusoidal AC waveform. The inverter also rectifies the AC voltage from the diesel generator to DV voltage. The DC energy is then used to charges the battery bank.

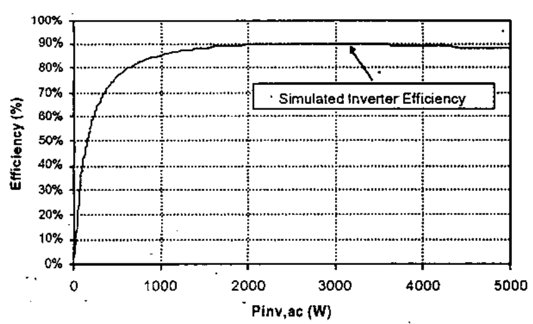

Figure 3. Efficiency of Inverter

3.5 Computer control

This hybrid energy system is controlled using Lab VIEW. An optimum control strategy based on set points for a PV/Diesel hybrid system has been deployed. The program displays the system performance and implements the data acquisition tasks of the test system.

3.6 Controllable load bank

A Controllable load bank (CLB) has been built. It which can be switched automatically to provide the required load demand. The maximum power consumption of the system is 9.76 kW. The voltage supply is 240 VAC at maximum load with a maximum current of 40.7 A.

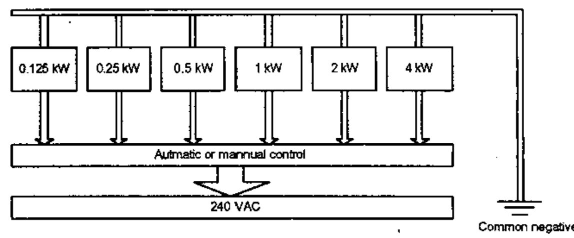

Figure 4. Controllable load bank

3.7 Weather station

A weather station has been installed to record the environmental conditions at the test site. The data is recorded continuously as 5-minute average values with a scan rate of 5 seconds. The following data are recorded:

a) Horizontal irradiance
b) Tilted Irradiance (32°)
c) Ambient temperature
d) Barometric Pressure

CRESTA situates at Perth, Western Australia. The exact latitude and longitude are 31.56 °S and 115.50 °E respectively [7]. The irradiation varies with the time of day and an average of global radiation about 2051 kWh/m² per year. The amount of irradiation in May is at its lowest which January is the highest. The set of data were recorded during 1999. The irradiation is measured horizontal and tilt (32°) of plane.

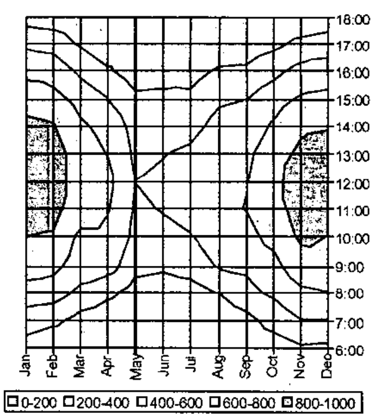

Figure 5. Annual Global Irradiation at CRESTA

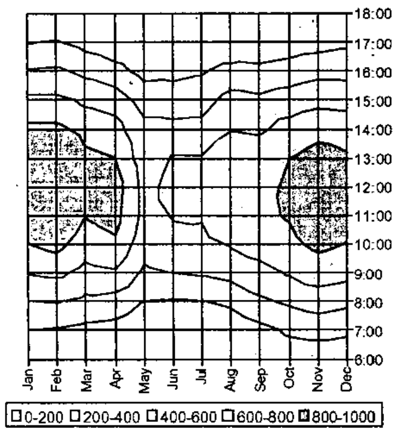

Figure 6. Annual tilt (32°) Irradiation at CRESTA

The radiations of the average per day for each month, and the average for the year are shown in Table 1.

Table 1. Average Irradiation

Month	Irradiance	
	Horizontal kWh/day	Tilted (32°) KWh/day
January	7.70	6.91
February	7.28	7.35
March	5.35	6.07
April	4.44	5.85
May	2.58	3.54
June	2.58	3.95
July	2.80	4.00
August	3.83	4.91
September	4.38	5.25
October	5.79	6.12
November	7.54	6.90
December	7.78	6.56
Average/year	5.17	5.62

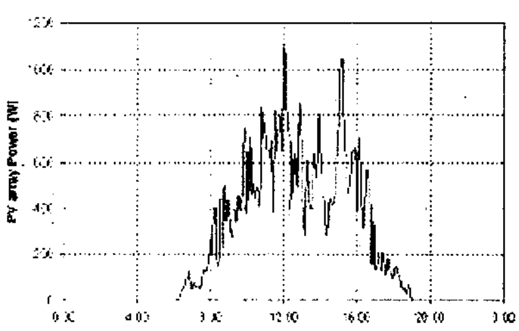

Figure 7. A Typical Power Profile from PV-generator (9/1/1999)

Figure 7 shows a typical profile of power generated from the PV-module with an average power of 5.2 kW/day. The efficiency of the hybrid energy system can be deduced as [2]:

$$\bar{\eta}_{HES} = \frac{E_{HES,out}}{E_{HES,in}} = \frac{E_{LOAD}}{E_{PV} + E_{MG}} = \frac{770kWh}{1198kWh} = 0.64$$

4. Conclusion

A Hybrid Energy system for teaching and research has been described in this paper. The system can run in synchronism with a diesel generator and new control system topologies. It has a predictive control strategy based on the theoretical control principles for optimum supply side management of PV-diesel hybrid energy systems. Based on recorded data and calculations, the performance ratio of PV-array has been found to be approximately 0.6. The average efficiency of the motor generator is 1.67 kWh/ltr. The battery efficiency is 0.96, and the system efficiency is 0.64. This study has provided groundwork and information for future study on optimal control and intelligent control strategies.

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