IMPROVED LAYOUT AND CENTRALIZED CONTROL FOR SMALL HYBRID POWER SYSTEMS

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1. Introduction

At present 1.4 billion people around the world do not have access to electricity. In Southeast Asia 52% of homes in rural areas have electricity, while in Africa only 25% of rural homes have electricity. Access to electricity is even lower in rural areas of Sub-Saharan Africa, at 14.3% [1]. Hybrid wind-solar systems as shown in Figure 1 with a battery bank and backup generator, have a potential to provide reliable power and thus improve the lives for millions of people. One of the major barriers to the widespread deployment of renewable energy systems is the unreliability of the wind and solar resources as well as the uncertainty in forecasting them. Thus it is very important to assess the resource availability of combined energy sources for a specific location and contribute to the understanding of the complementary nature of wind and solar energy against the electricity demand for a particular location [2]. Combining a PV and wind energy system should generally improve power availability as sunny days are often quiet in terms windiness, and strong winds more frequently occur on cloudy days or at night. Most hybrid systems have battery storage, but this is often the most unreliable component.

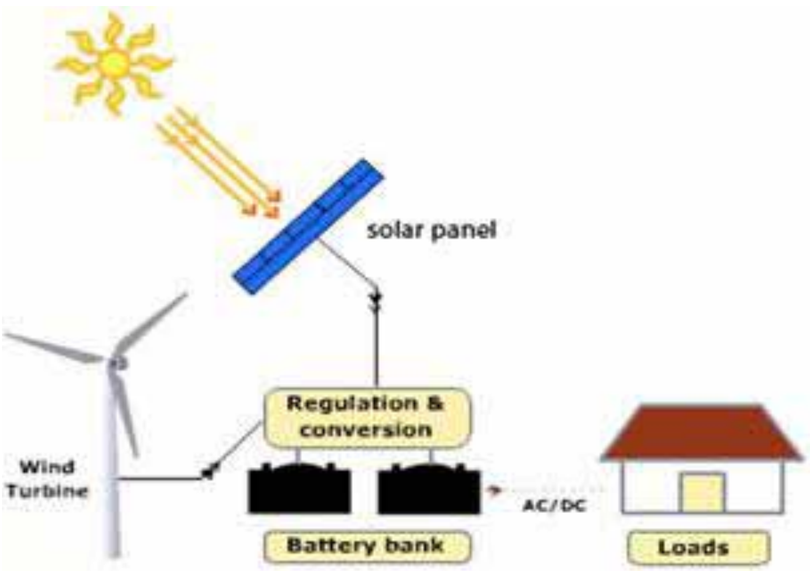

Fig. 1 Basic Diagram of Hybrid Wind-PV System. Photo Courtesy Enarch Energy Solutions

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Another major problem with current hybrid systems is the multiplicity of controllers since the power sources and their control electronics are usually supplied individually and have little or no communication between them. This adds to the system cost and reduces reliability and functionality. Thus it may be valuable to develop a centralized supervisory control which monitors the entire system and maximizes the power extracted from each renewable energy source. This paper addresses the related issues of basic system sizing, improving system layout, integrating and centralizing system control [3][4]. Actual wind speed and solar radiance data are used to design hybrid wind-solar-battery-diesel systems using Hybrid 2 software for a nominal 10 kW AC residential load. A 10 kW system is considered in this paper to be sufficient to power 15 households in Sub-Saharan Africa. Another similar-sized application is to provide an economical alternative to diesel power that is presently in use in thousands of remote cell-phone telecommunication base towers. The main aim in the layout and design is to use the diesel generator as little as possible. Another design decision is whether to have the generator feeding the batteries directly or to place it on the AC bus. We have chosen the latter as this allows the generator to be used on its own if there are faults in the remainder of the system, yet batteries can still be charged from the diesel generator when necessary.

One important issue in designing a remote power system is the tolerance to loss of power. It is well-known that the difference in cost between providing say 95% of demanded power and all demanded power can be significant [5]. However, it is a good assumption that remote communication towers require uninterruptable power and our design examples have all assumed this.

The paper is organized as follows. Section 2 explains the comparison among different topologies of the proposed hybrid power system. Section 3 presents how the sizing of the hybrid system is done using the weather data of Calgary, Canada and Hybrid 2 software. Section 4 presents the results of the economic analysis of the hybrid system and compares its benefits and Section 5 discusses the modelling of the hybrid system and explains the concept of supervisory control. And the last section evaluates the conclusion.

2. Different Topologies of Hybrid Power System

For an hybrid system consisting of a wind turbine, photo-voltaic (PV) panels, diesel generator and a battery bank, the load can be fed in three different ways:

A. AC-Bus Hybrid Power System.

B. DC-Bus Hybrid Power System.

C. Combined AC-Bus and DC-Bus Hybrid Power System.

We now discuss these possibilities in turn in a generic manner. In practice, equipment limitations may impose constraints on the possible topologies. For example, some, but not all, small wind turbines produce AC output power which can only be accommodated by rectification[6]. It is also becoming common for PV systems to use micro-inverters for each panel, rather than the single inverter assumed here.

A. AC-Bus Hybrid Power System

An AC-bus coupled system is a centralized system where all energy conversion systems are connected to the main AC-bus, which is also connected to the load. This configuration is shown in the Figure 2. Here the wind-turbine is assumed to produce AC power, so it and the diesel are directly connected to the AC-bus with or without using AC/AC converters. The PV system produces DC power so it is connected to the bus through an inverter. Due to the requirement of charging and discharging of the battery, it is connected to the AC-bus with a bi-directional power-flow inverter.

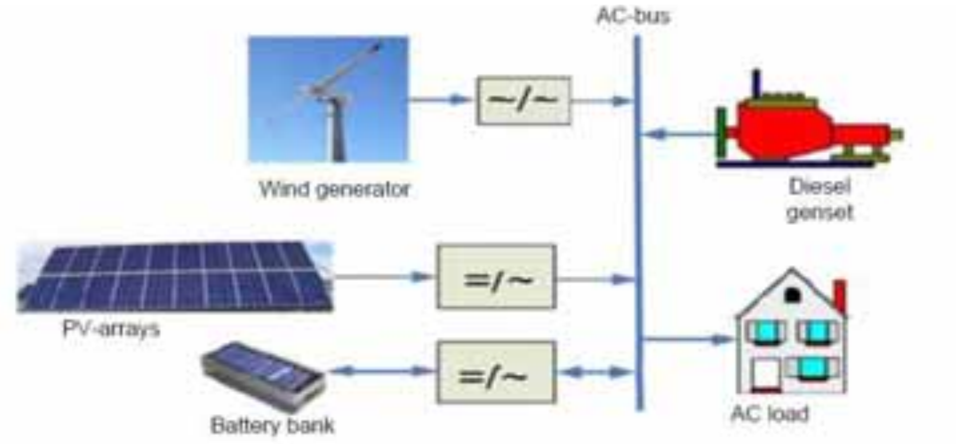


Fig. 2 Centralized AC-Bus Hybrid Power System

B. DC-Bus Hybrid Power System

In a DC-bus hybrid power system all hybrid power sources are connected to the central DC-bus as shown in Figure 3, so that the bus accepts the rectified power output from the wind turbine. The DC-bus feeds a DC/AC inverter for the household AC load and with the possibility for a DC/DC converter(s) for the telecom load. Since the sources are connected to the DC-bus, the wind turbine and diesel genset will need AC/DC rectifiers. While the battery bank and the PV systems are connected to the bus using a charge controller for better system efficiency (charge controllers are not shown in Figure 3).

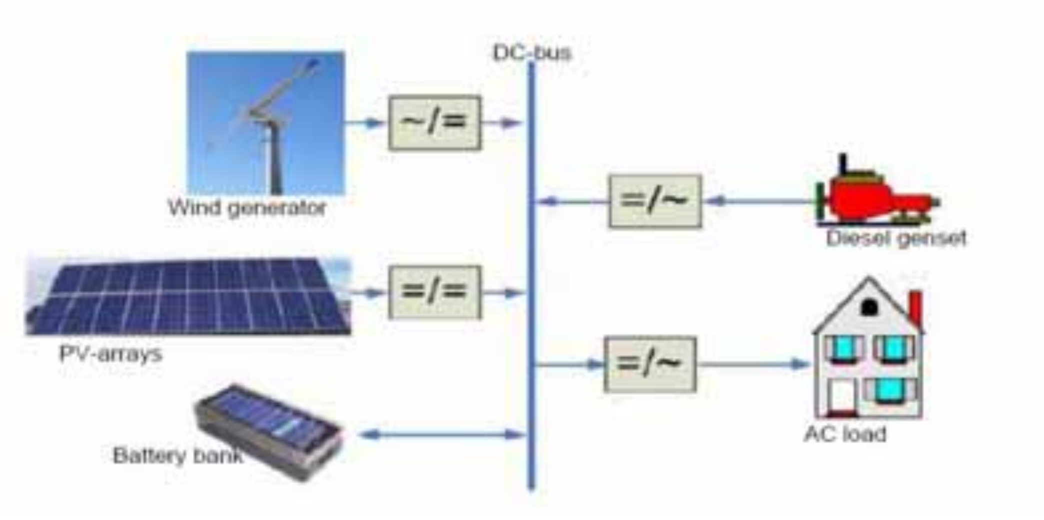


Fig. 3 Centralized DC-Bus Hybrid Power System

C. Combined AC-Bus and DC-Bus Hybrid Power System

It is possible to combine AC and DC Bus in a hybrid power system to create a mixed coupled system. Here some sources like PV and battery bank are connected to the DC-bus while the wind turbine and diesel generator are connected to the AC-bus. Figure 4 shows a typical architecture for a combined AC-bus and DC-bus hybrid power system. Here a bi-directional power-flow inverter is connected between the two buses for the transfer of power among the buses.

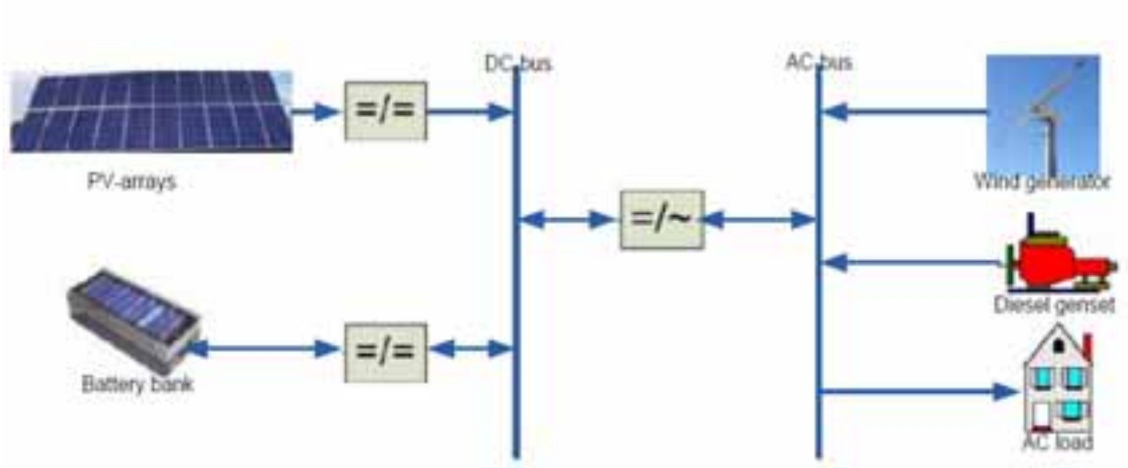


Fig. 4 Combined AC-Bus and DC-Bus Hybrid Power System

The single bus system is very simple and easy to operate. The combined AC-bus and DC-bus system also has the potential problem that an inverter failure will jeopardize the entire system. Also from the control point of view, a single bus system is beneficial as only a single bus voltage has to be maintained for the system stability, thus removing the complications that might have arisen in the two bus system. Among the single AC and DC bus systems, depending upon the functionality of household and telecommunication load, a DC-bus system is more suitable for telecom loads and an inverter connected to the DC-bus will supply the household load. Since the system is located close to the load site; the DC Bus system will not require a large cost for wiring. Thus, comparing all the parameters of installation and operation, the DC-bus hybrid power system shown in Figure 3 is preferred over other systems.

3. Sizing of the System using Hybrid 2 Software

Five-minute wind speed and solar insolation data over an entire year for Calgary, Canada, was used for a Hybrid 2 simulation of a Wind-Solar-Battery-Diesel system to optimize the size of each component of the system and reduce the consumption of diesel fuel but still provide reliable power to the load[7][8]. We decided to use Hybrid 2 software after a detailed assessment of other software tools such as Homer, Power-cad etc, as Hybrid 2 was able to create a comprehensive assessment of the system with simulation time steps as low as five minutes for a span of an entire year. The data sampling period is critical to capture the interaction between the solar and wind resources. Valuable information for supervisory control operation and system sizing would have been substantially lost if daily averages were used. Here the software uses a combined probabilistic/time series model to design and study the hybrid power system. Also the model uses a statistical approach to account for the effect of short-term fluctuations in renewable power sources and load to consider the power smoothing effect [9]. Also it uses different control strategies to minimize the diesel operation. The program is structured in three blocks. The first block is where user builds the model, sets up the power system, exporting load and resource data. The details about the load demand are the system is its sized for Max. 10 KW household load which we assume is sufficient to power 15 homes in developing countries, with an average of 7.84 KW giving a yearly consumption of 68,692 KWh. Note that the load considered here is a hypothetical situation based on the assumption that the primary electrical use is for fans and some lighting. The simulations discussed below also factors in daily and monthly variations in load. Figure 5 illustrates the typical electrical load power use over a 24 hour period, as well as variations from month to month.

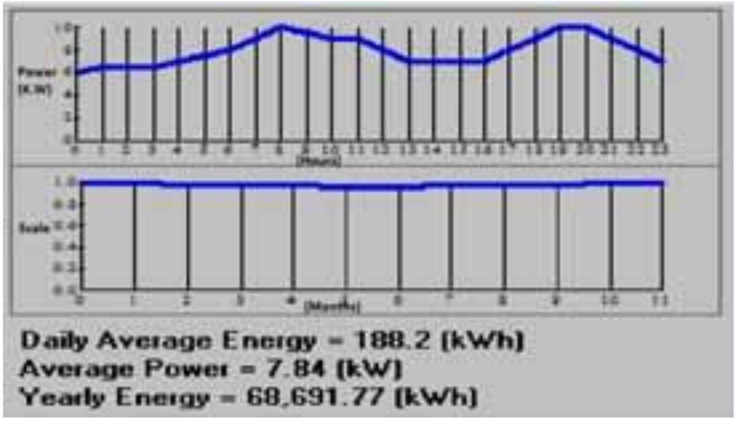


Fig 5. Load profile data; upper graph shows the variation of load over a day and the lower one shows variation over 12 months

The 10 KW hybrid system under study is sized with an installed capacity of 12.5 KW for Wind, 6 KW for solar and the battery bank is sized for 560 KWh/11,000 Ah at a nominal voltage of 48V (equivalent to 3 days of average load). Note from Figure 6 that the wind resource is uniform over the year but there is a definite summer peak in the solar radiation and this seasonal difference has a significant impact on the equipment selected.

The battery bank and renewable resources meet the load, if possible, and the diesel is operated to allow the battery to be charged at the maximum charge rate. The diesel is started when the battery goes below 80% SOC level and it continues till it charges the battery to 98% SOC level and its minimum run time requirement has been fulfilled. It is not started again until the renewable resources or the battery can meet the load. The battery only provides power directly to the load if the remainder of the system is not working. We believe this strategy simplifies the overall control and supervision of the system.

Software also performs a consistency check so that all the aspects are in order for the project. The second block consists of simulation where actual performance of hybrid power system is calculated. The economic module is the third section of the program where the performance of the system is combined with user input economic parameters to calculate economic indicators like system payback period and life time cost. Here the hybrid system is compared to base case diesel only system to give you an evaluation as to how much diesel consumption can be reduced using the hybrid system.

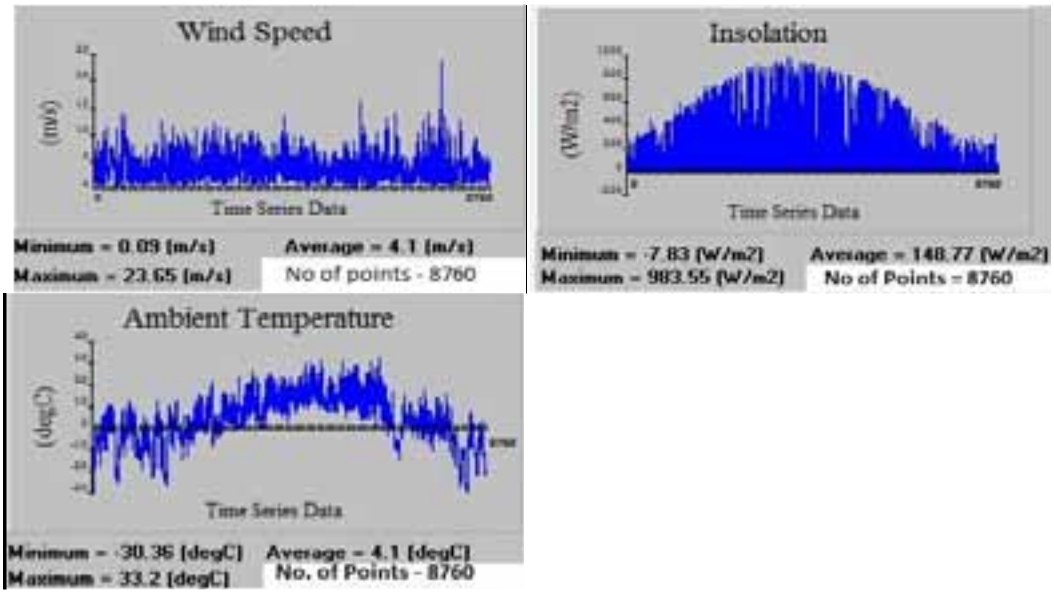


Fig 6. Wind, solar and temperature data for a location in Calgary, Alberta, Canada. The x-axis denotes hourly data for a year, hence there are 24*364 = 8760 data points.

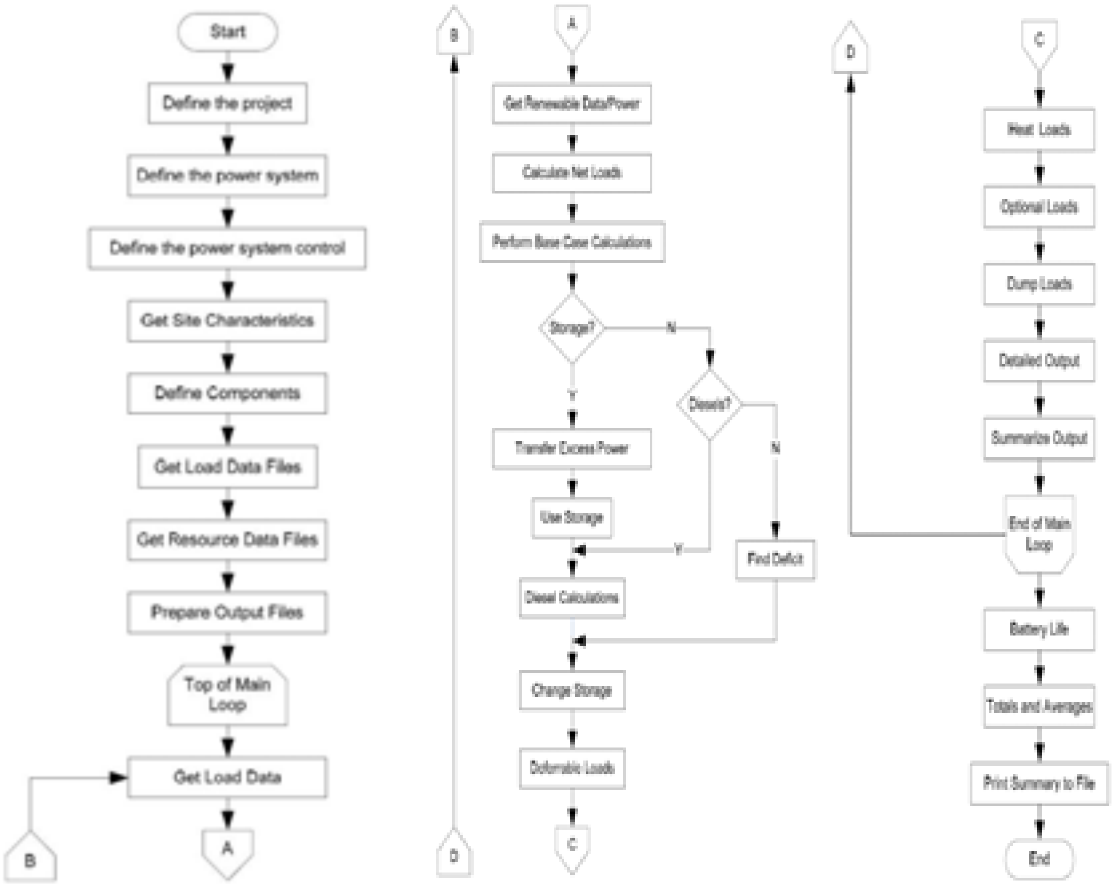
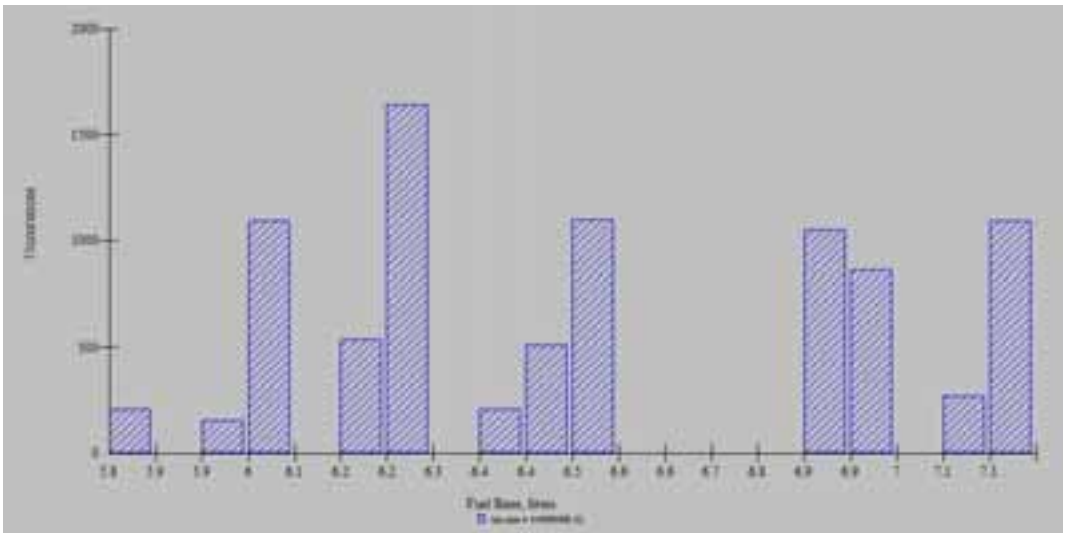


Fig 7 . Detail Flowchart of Simulation Model in Hybrid 2 Software [10]

4. Results of Hybrid Simulation

Hybrid 2 was used to simulate the hybrid system and compare it with base diesel-only system to detail the savings the hybrid system can generate in terms of less diesel usage. In addition it also calculates the yearly cash flow, the present value, system costs; income levelized annual cost, pay-back period and internal rate of return. Now since our system is a standalone application with no grid tie up, yearly cash flow, levelized annual cost can be eliminated. Figure 8 shows the hybrid diesel usage as compared to the base case of diesel only system. The vertical axis shows the occurrences of diesel consumption; for example for the base case there were approximately 1000 instances over the year where 7.1 Litres to 7.2 Litres of diesel was consumed. In contrast, most diesel consumption for the hybrid system was less than 0.4 Litres and thus the total consumption was significantly reduced (from 56,633 L of diesel fuel in the base case, diesel only system, to 13,148 L of diesel fuel for the hybrid system; see Table 1).



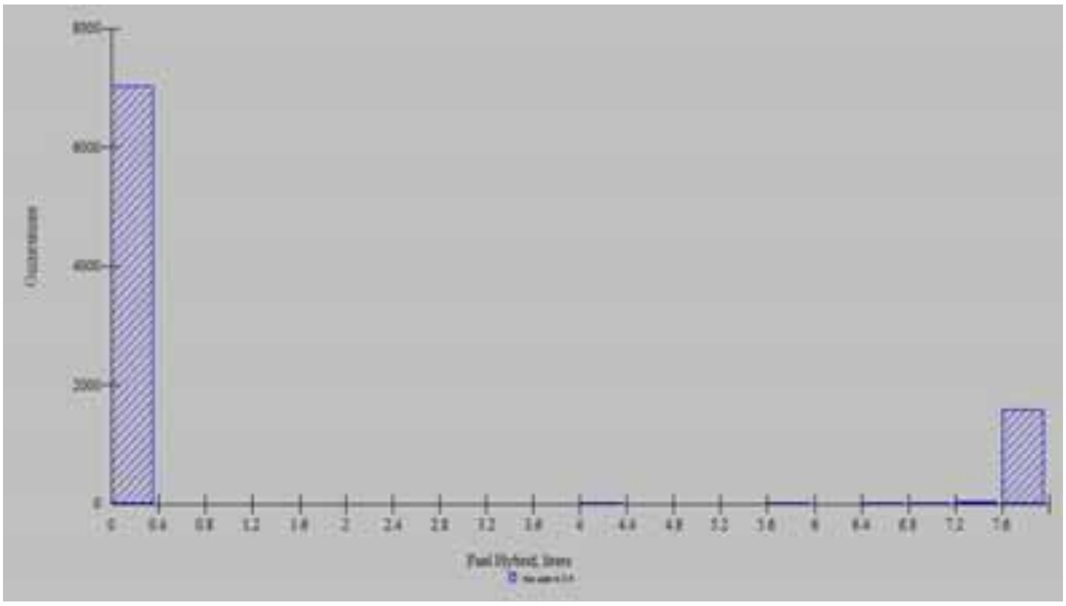


Fig. 8 Diesel Usage; Upper graph for the base case of diesel only system, and lower graph for the hybrid power system

Table 1 Base Case Diesel Only and Hybrid Power System Comparison for a 10 KW Rating

Diesel Only or Hybrid System Characteristics	Characteristic Value
Base Case: Diesel Only System Fuel Consumption/Annum	56,633 L
Hybrid System Diesel Consumption/Annum	13,148 L
Diesel Fuel Saved by Hybrid Power System/Annum	43,485 L
Percent Diesel Fuel Savings of Hybrid System/Annum	76.8%
Assumed Cost of Diesel including Transportation to Remote Location	$1.50/litre
Initial Capital Cost of Hybrid Power System	$ 262,000 CAD
Initial Capital Cost of Diesel Only System	$ 10,000 CAD
Operation and Maintenance Cost of Hybrid Power System/Annum	$ 22,000 CAD
Operation and Maintenance Cost of Diesel Only System/Annum	$ 80,000 CAD
Break Even Time for Hybrid System Total Cost to Equal Diesel System Total Cost	5 yrs

Table 2 Comparisons of Fuel Savings for Hybrid, PV Only and Wind Only Systems w.r.t to Diesel Only System

System Topology	Reduction in Diesel Fuel Use
Hybrid Wind, Solar and Diesel System	76.8%
Wind – Diesel System	59%
PV – Diesel System	52%

Table 2 shows the percentage diesel savings of hybrid, wind and PV systems with equal installed capacity of 10 KW in comparison to the diesel only 10KW system. The results clearly indicate that the hybrid system requires the least backup generation, due to the complementary nature of the wind and solar resources. The results in Table 2 could only be produced from detailed wind and solar data such as that used in this study. For example, the monthly-averaged data available in most climate databases would be unsuitable as the time scales of the interaction of the wind and solar resources are much shorter than this. Of course, this interaction (as well as the mean resource levels) can be highly site-specific.

It is clear that a key issue for remote power system design is the relationship between the renewable resources. If, for example, wind and PV power were strongly correlated, then the optimum remote power would simply use the cheaper technology. On the other hand, the ability to defray diesel usage depends on significant occurrences of high PV power when there is no wind power and vice versa. Figures 9 and 10 show simultaneous power outputs over one day (Figure 9) and one week (Figure 10). It is clear that there is significance output from one resource when the other resource is at low or zero output. It is believed that this behaviour is a major factor in the reduction in diesel usage shown in Table 2.

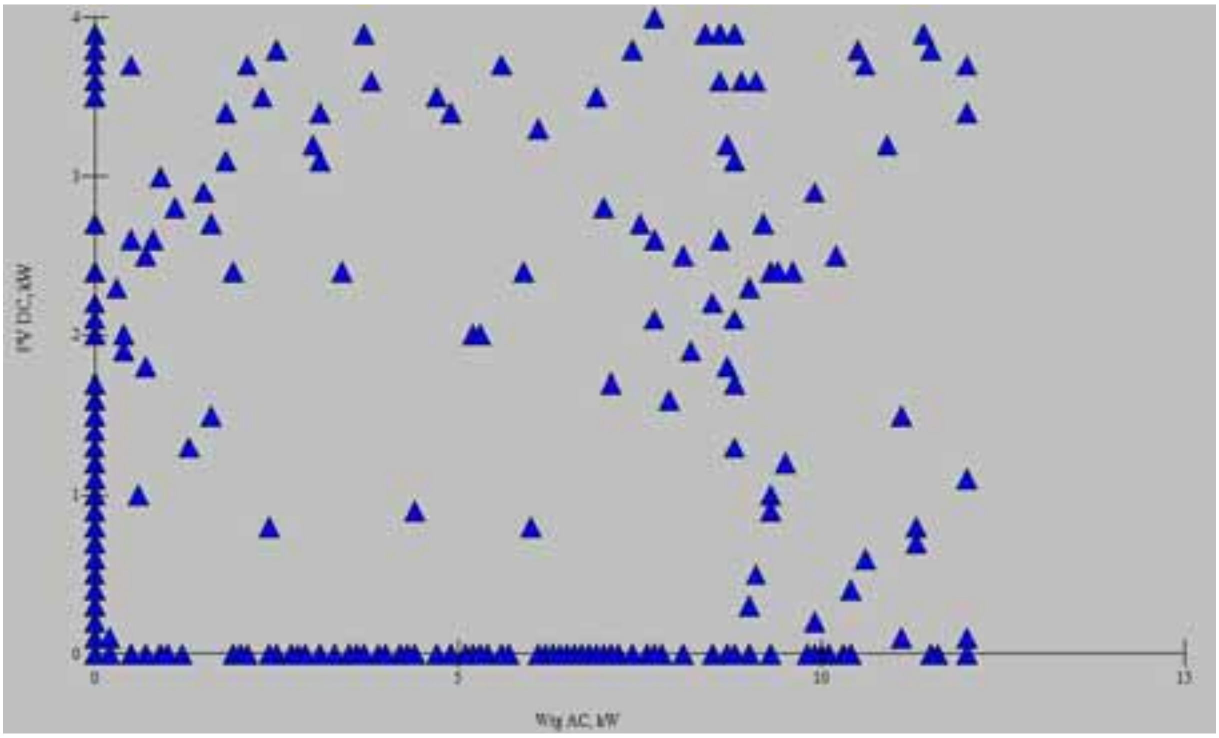


Fig. 9 Wind and PV power output averaged over 5 minutes for one day

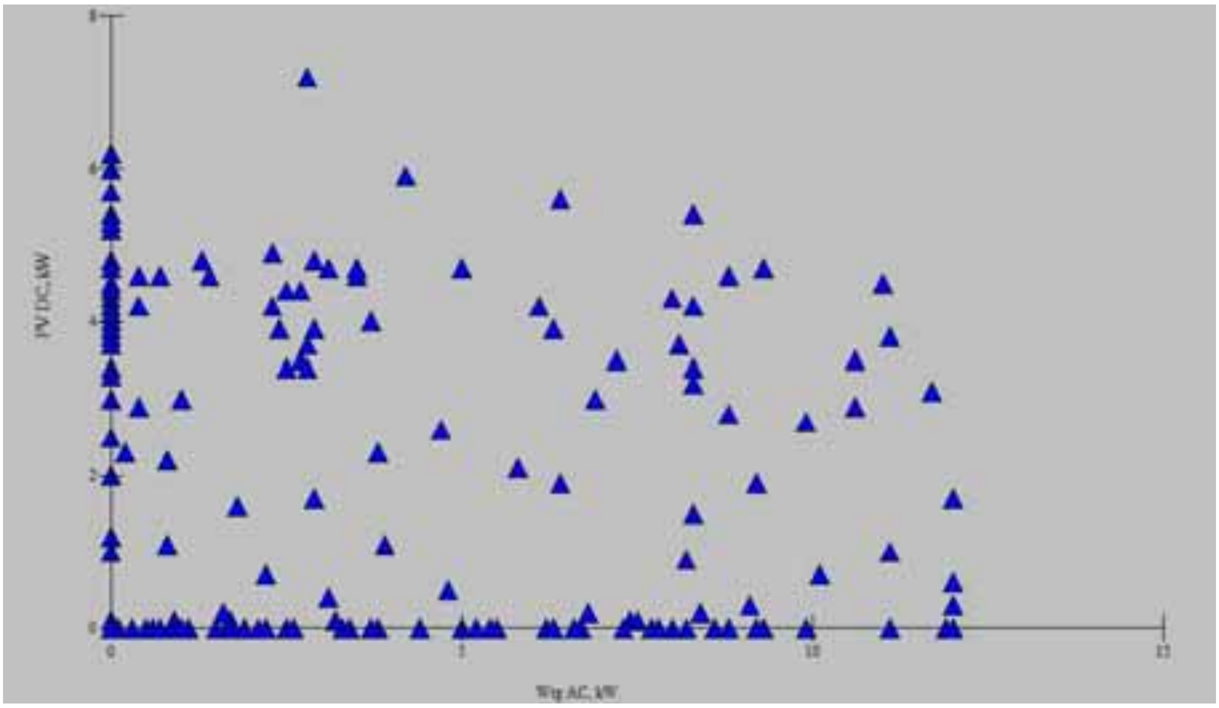


Fig. 10 Wind and PV power output averaged over 1 hour for one week

5. Design of the Hybrid System

Hybrid 2 is invaluable for system sizing and basic layout but it does not address issues such as the provision of supervisory control and maximum power point tracking for the PV array and wind turbine [11].

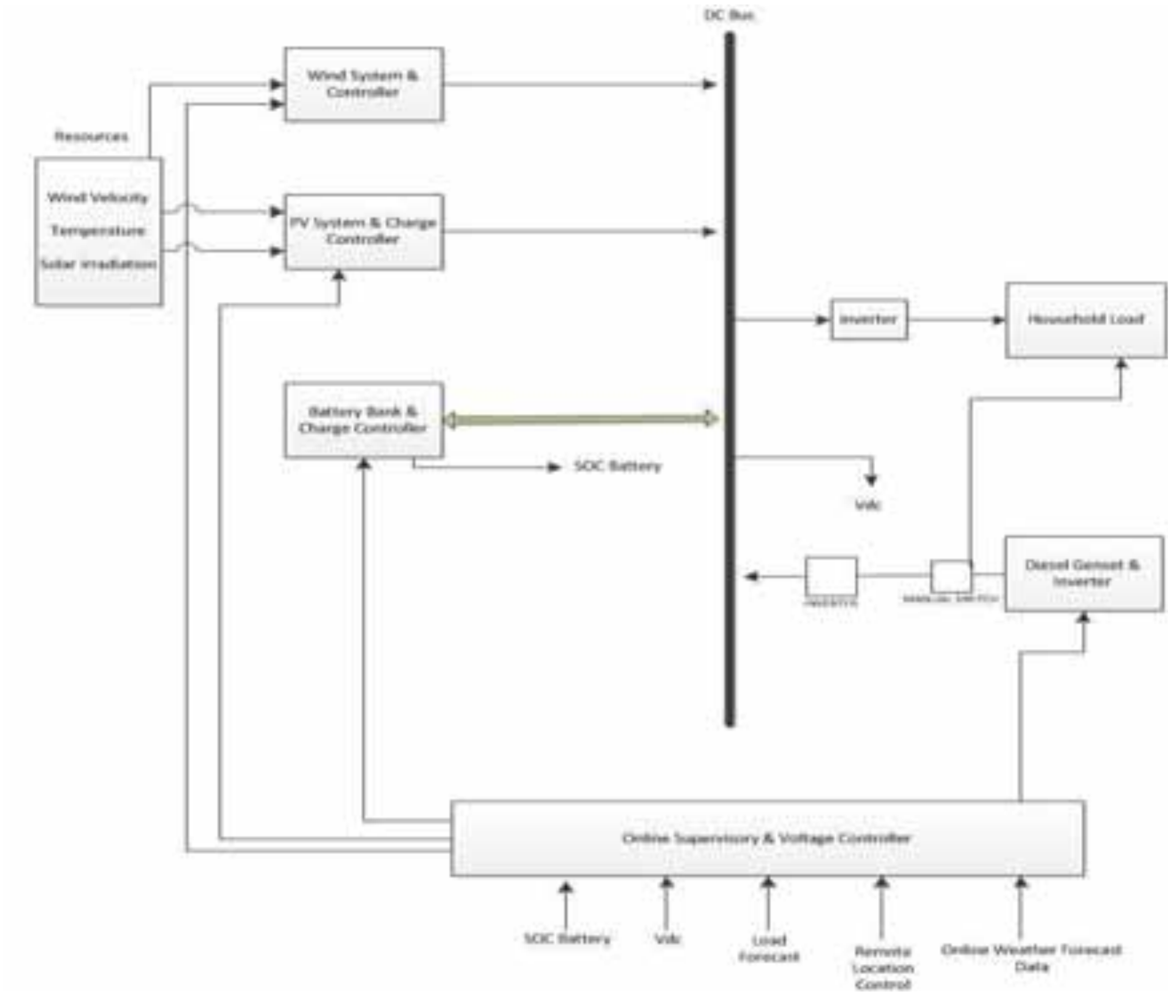


Fig. 11 Proposed Model of Supervisory Control for the Hybrid Power System

As discussed in Section 2, the proposed hybrid system illustrated in Figure 11 has a common DC bus. Note that the main difference from the basic topology in Figure 3 is the provision of a direct connection between the backup generator and the load which can be used if the renewable energy system has a fault. The load is connected to the bus with or without an inverter depending upon the AC household or DC telecom load. Here the wind turbine and PV array are connected to the Bus using their individual converters which are assumed to contain the maximum power point tracking. The battery bank is linked to the DC Bus using a charge controller. The charge controller is used so that it can monitor the charge and discharge level of the battery bank and accordingly send signals to the controller. The diesel genset is connected to the bus using an inverter. The battery charge controller also contains a dump load for those times when the renewably-generated power exceeds the load and the battery requirements. The supervisory controller has an input from battery bank charge controller so that it can monitor the State of Charge (SOC) of battery and accordingly switch on the diesel genset if necessary. Also the voltage of the DC Bus is monitored by the controller so it can perform power quality control by monitoring the voltage and frequency. Although not explored in this project, the controller has the potential for load and resource forecasting so that it can optimise the power flow of wind or solar resources so as to minimize diesel operation. Also, it may be possible for the centralized controller to be monitored in real time from a remote location for system condition monitoring and maintenance forecasting.

6. Conclusion

The data presented in this paper shows that the hybrid wind-solar system is an attractive alternative to traditional fossil-fuel-based system for small remote power systems, for example a load of 10 KW capacity which is sufficient to power 15 households of primarily fan and lighting loads. Even with only two renewable resources, a large number of system architectures are possible. The paper begins by reviewing the main candidates and selects the single DC-bus system shown in Figure 11. The well-known software package Hybrid 2 was used to size a system for an assumed daily load (Figure 5) and detailed weather data over one year (Figure 6). A key finding is that the simulations using 5-minute averaged wind and solar data exploited the complementary nature of wind and solar to reduce the dependence on diesel fuel. Further, for the data available from Alberta, Canada it is better to have a greater penetration of wind because the wind resource is more evenly distributed over the year. The paper also briefly considers how the supervisory control for the hybrid system improves the efficiency of the system in terms of reduced sizing of each component. In other words the controller helps in greater penetration of renewable resources incorporating the complementary nature of wind and solar resources. Further, the supervisory controller reduces the multiplicity of controllers to simplify the system, thus it is expected that the hybrid system with the supervisory controller will be cheaper, more reliable, and easier to operate.

Acknowledgements

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