Low emission and sustainable power supply for remote communities

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Abstract:

There are a large number of un-electrified remotely located communities and villages almost everywhere around the world including China & Australia. Most of these villages are located in forest, hilly, desert, islands and difficult-to-access regions. Because of technical and economical reasons most of these villages and communities are unlikely to be electrified by extension of national electricity grid.

At present, the real question is how we should cover the growing energy demand of these villages in a sustainable and reliable manner. While the answers to this question are many and varied, one certain fact is that in future some of the electric power for these communities will be produced by decentralized power system facilities using renewable sources of energy such as solar photovoltaic, micro-hydro, fuel cells, biomass and wind power.

The objective of this paper is to present the results of a study conducted to analyze the technical issues related to decentralized power supply for the purpose of villages' electrification. A further objective is to discuss the design aspects of a technologically suitable and economically acceptable power system for remote regions by small scale hybrid energy system. The hybrid system in this study is designed based on renewable sources of energy. And finally, this paper presents results of a simulation program conducted to predict the performance of such a hybrid electricity system.

Introduction

According to the World Energy Outlook, there are still 1.6 billion people in the world without electricity [1]. On present policies, that number would fall by only 200 million by 2030. As these people usually live in remote locations, so distributed generation technologies using natural resources available at the locations would be technically possible and environmentally acceptable to bring electricity to these people.

Distributed energy systems include various renewable energy technologies using natural resources such as solar, wind, micro hydropower, as well as some non-renewable technologies such as gas technologies. Because of diversity of resources, distributed power systems can supply a reliable electricity system, provided the system is properly designed and correctly sized.

Because of the intermittency nature of renewable energy sources, including an energy storage technology to support the system during the period that renewable energies are not available is essential.

Intermittency Issues and role of energy storage technology

Intermittent power sources are sources of energy that may be variable or intermittent, such as wind and solar. The variable nature of power generation from intermittent sources has raised concerns about the ability of providing a reliable power supply. By integration of an energy storage technology, using intermittent power sources has little effect on the system's operation. The fact is that electricity demand is never constant and also energy generation from renewable energy is seldom constant over time. Therefore, including an energy storage technology into renewable energy generating system is important.

Energy storage technologies provide opportunity for the generation side to meeting the level of power quality as well as reliability required by the demand side. Energy storage can also provide emergency power and peak shaving opportunity. Energy storage is especially important for decentralized power supply system by giving the more load-following capability, which is an important factor from generation side management.

Description of the system in this study

The hybrid system of this study is shown in Figure 1. The main components of this system are solar PV array, wind turbine, and an energy storage unit. As a result of unpredictability of sun and wind, the output power from PV array and wind turbine is unpredictable. The storage unit is there to ensure a reliable power is supplied to the load. The energy storage unit would be absorbing the excess generating capacity available during periods of low demand. Therefore, this excess energy is stored in the storage unit for later use. The stored energy can then be used to provide electricity during periods of high demand, helping to reduce power system loads during these times.

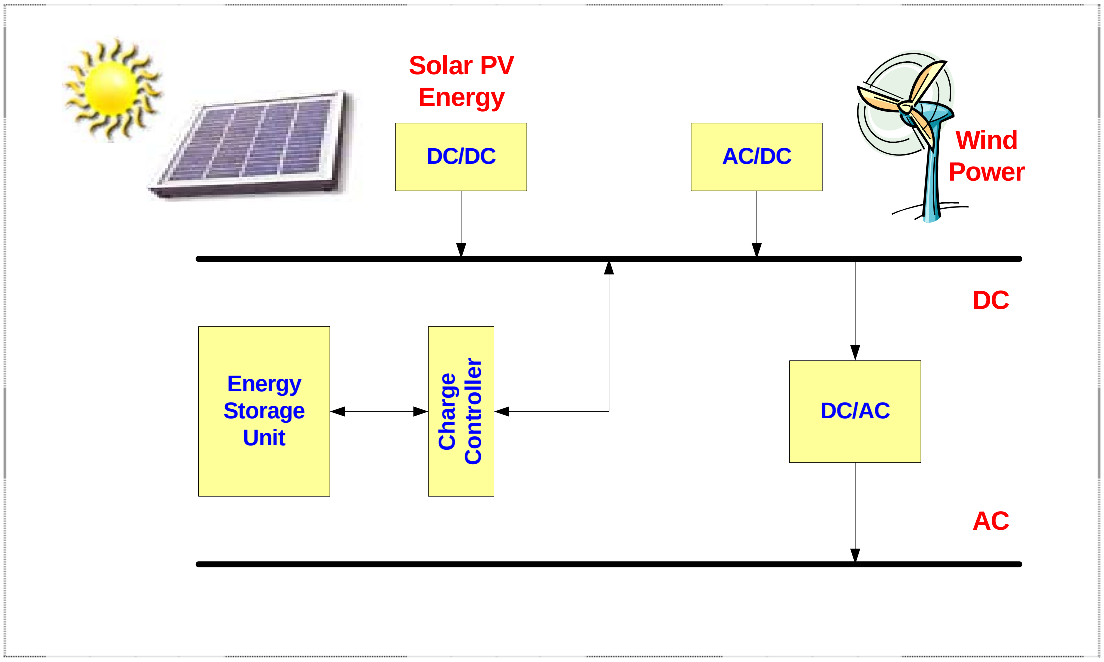

Figure 1

Optimum sizing of the PV & WT sub-systems

Optimum sizing is important part of any engineering design. Optimum sizing results in minimum system's cost. The optimum size of the two components in this system, i.e. PV & WT is determined based on the annual energy requirement of the load. It has been chosen that these components be able to produce about 50% (each generator) of the energy required by the load. This allows supplying the load with reliable electricity as well as covering the power loss within the system. Size of the PV system depends on energy requirement by the load as well as the sun radiation data of power generation site. Average value of monthly sun radiation data to test the simulation program is shown in Table 1, obtained from Australian Solar Radiation Data Handbook.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6.5	6.4	5.5	4.2	3.2	2.8	3.2	3.7	4.6	5.4	5.8	6.2

Table 1 monthly average values of the PSH used in this study

For size optimization of wind turbine we used the relationship between the power in the wind and speed of the wind, which is given by equation 1, [5].

$$P_{wind} \text{ (in Watts)} = ½ \rho * A * U^3 \qquad [1]$$

Where, ρ (rho) is Air density in kg/m^3 and A is the cross sectional area through which the wind passes. This relationship tells us that we can not determine the average power in the wind by simply substituting average wind speed into this equation. We need to use this nonlinear characteristic of wind to determine the average power in the wind. For this purpose we need to re-write this equation in terms of average values:

$P_{wind\ (Ave)} = ½ \rho * A * (U^3)_{Ave}$.

So we need to find the average value of the cube of velocity ($(U^3)_{Ave}$). The average of wind speed is used to determine the average power in the wind [5]. This has been shown below:

$$v_{ave} = \frac{\sum_{i=1}^{n}(v_i * hrs@v_i)}{\sum hours(8760)} \text{ or } v_{ave} = \sum_{i=1}^{n}(v_i * fractionofhrs@v_i) \text{ or}$$

$$v_{ave} = \sum_{i=1}^{n}(v_i * probability(v = v_i)$$

$$(v^3)_{ave} = \frac{\sum_{i=1}^{n}((v_i)^3 * hrs@v_i)}{\sum hours(8760)} \text{ or}$$

$$(v)^3{}_{ave} = \sum_{i=1}^{n}((v_i)^3 * fractionofhrs@v_i) \text{ or}$$

$$(v)^3{}_{ave} = \sum_{i=1}^{n}((v_i)^3 * probability(v = v_i)$$

According to Gilbert M. Masters [6], the probability of wind density can be modeled by equation 2.

$$f(v) = \frac{2v}{c^2}(\exp(-(\frac{v}{c})^2)) \qquad [2]$$

The average power of the wind based on Rayleigh statistics is calculated by using the equation 3.

$$P_{wind} = 0.5\rho A((v)^3_{ave})$$

$$P_{wind} = 0.5(\frac{6}{\pi})\rho A(v_{ave})^3 \qquad [3]$$

Average value of monthly wind speed is shown in Table 2.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
6.3	5.3	5.4	5.9	7.0	8.3	7.5	6.7	6.1	6.7	6.3	6.9

Table 2 monthly average values of the wind speed

System simulation

In order to analyze the operation as well as to optimize performance of the system a simulation software tool has been used, taking into account the characteristics and efficiencies of all devices involved. The simulation tool uses as input both average wind speed data and sun radiation data over a year and calculates the energy flux between the different segments. Depending on the size and efficiency of the devices selected (solar array, wind turbine), it is possible to predict the system's performance over the whole year. And also the overall system efficiency, the percentage of energy generated by solar array and wind turbine are determined. Figure 2 shows the flow chart used for system's performance prediction.

The energy storage technology for this system can be of any type. It can be a battery bank, pump storage or electrolyzer to store energy in form of hydrogen. In our calculations and simulation we used energy flow to and from storage unit in kWh and energy conversion efficiency.

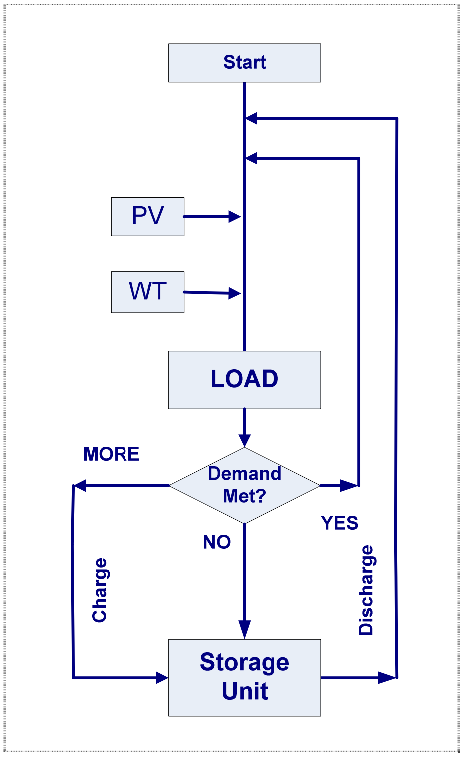

Figure 2

Simulation Results

MATLAB was used to simulate the system to: Optimize the size of components; to predict the performance of he energy flow; to determine: The amount electricity produced by each power generators; the excess or deficit of electric power. Simulation results are shown in Figure 3 to 8.

In this study we assumed that a remote located community consisting of 15 families using 20 kWh of electricity in average every day. To simplify the calculations we have assumed that the daily consumption of electricity remains constant.

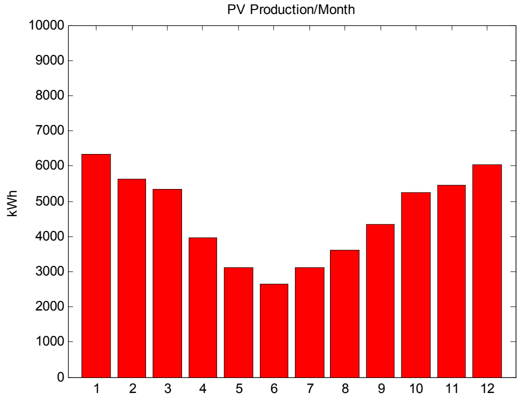

Figure 3 Monthly production, PV

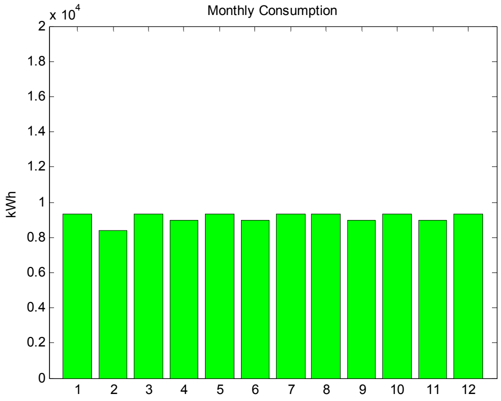

Figure 6 Monthly consumption

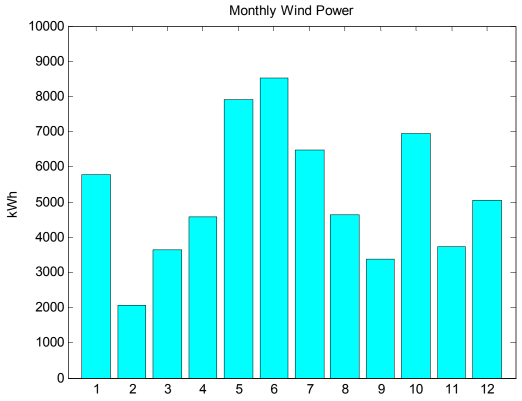

Figure 4 Monthly production, wind

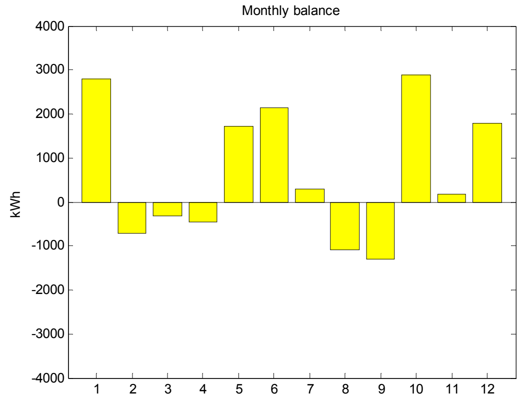

Figure 7 Balance of electricity each month

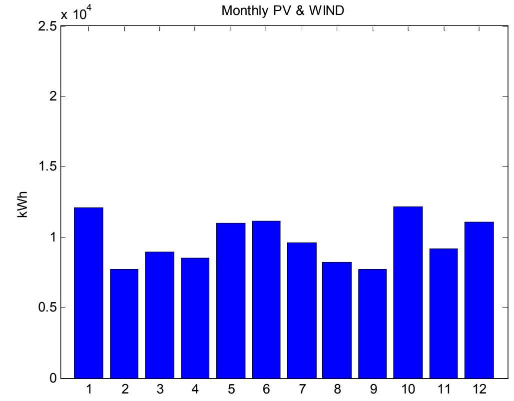

Figure 5 Monthly production, PV & wind

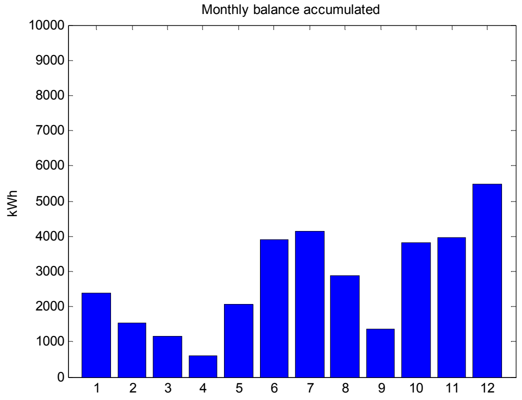

Figure 8 Accumulated reserve

Following assumptions were made in this simulation process. For solar PV subsystem: PV's Performance Ratio = 0.75; for wind energy subsystem: efficiency=0.45; height at which the wind data were collected is 10m. Radius=2.5m; the value of (ρ) =1.225 kg/m^3; number of wind turbines: 3 but the simulation results tell us that there is no need for all three to be operation all the time; roughness factor is 0.15.

Conclusions

Technical analysis of a stand-alone power supply system consisting of intermittent energy sources combined with energy storage devices have been presented here. The system is to supply a reliable energy for an off grid load, using intermittent renewable sources of energy such as solar and wind. Energy storage helps improving the efficiency and reliability of the power generating system by reducing the requirements for considering energy reserves to meet peak power demands. This paper has also presented the results of a computer simulation program developed in MATLAB environment for modeling the entire power generation and storage system. This program allows us i) to find a near-ideal size of system's components, ii) to predict the system's performance and iii) proving that a renewable energy system based on solar, wind and an energy storage unit is able to supply a reliable.

Future work

In order to maximize the reliability of the system, a diesel generator unit will be included into the system. The role of this unit is to generate electricity to the load in case that none of the generators are supplying energy and the storage unit does not have sufficient charge. Figure 9 shows the location of this unit in the system. This is controlled by the energy management unit. This has been shown in Figure 10.

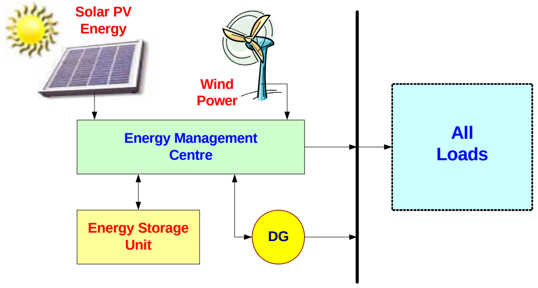

Figure 9

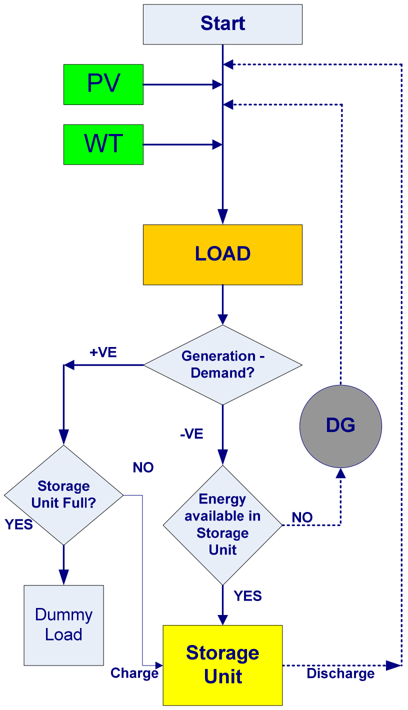

Figure 10

References

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[2] Zahedi, A. “Engineering and economical aspects of solar photovoltaic energy systems” The new world publishing, Australia, 2004

[3] US Department of Energy Website: http://www.eere.energy.gov/consumerinfo/heatcool.html

[4] Electricity Australia 2003, published by Electricity Supply Association of Australia Limited (ESAA), website: http://www.esaa.com.au/

[5] Gilbert M. Masters, “Renewable and Efficient Electric Power Systems”, Wiley and Interscience, 2004