

Design considerations for a sustainable hybrid energy system

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This paper outlines the design considerations needed to produce a sustainable energy system for night-time lighting of footpaths. The factors to be incorporated in a computer modelling system are described.

Keywords: renewable energy system, engineering design, systems approach, sustainability, modelling, computer applications, engineering education.

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1. Introduction

Commonly hybrid energy systems use solar, wind, and hydro energy sources, although most of the renewable energy available on earth consists of different forms of solar energy. A system using a combination of these different sources has the advantage of balance and stability. For instance, winds are usually relatively strong in winter and solar radiation is higher in summer. A balanced system provides stable outputs from sources such as these and minimises the dependence of the output upon seasonal changes; furthermore, it optimises utilisation of the different renewable sources of energy available.

Numerous publications describe optimisation of individual renewable energy sources. Adebiuyi et al. (1977) demonstrated the optimisation of a class of latent thermal energy storage systems with multiple phase-change material. De Vries & Francken (1980) used electrical resistance to simulate a solar energy system. For a complex hybrid energy system, however, optimisation by computer simulation has become popular only recently with the advancement of computer technology.

Computer modelling permits optimisation of the various engineering and economic parameters that have to be considered in order to plan, design and construct a hybrid energy system. In particular, computer simulations can be used to perform a feasibility study on any new system. They can be used to diagnose problems that might occur in the system's operation. Recent work in using computer modelling includes Barnard & Wendell (1997), Simmons (1996), Fanney et al. (1997) and Jennings (1996).

The design and structure of a hybrid energy system obviously take into account the types of renewable energy sources available locally, and the consumption the system supports. For example, the hybrid energy system presented here is a small-scale system and the consumption

of power takes place during nights, so the wind energy component will make a more significant contribution in the hybrid system than solar energy. Although the energy produced by wind during night can be used directly without storage, a battery is needed to store solar and wind energy produced during the day.

In addition to the technical considerations, cost benefit is a factor that has to be incorporated into the process of optimising a hybrid energy system. In general, the use of wind energy is cheaper than that of solar energy. In areas where there is a limited wind source, a wind system has to be over-dimensioned in order to produce the required power, and this results in higher plant costs.

The system described here was designed to provide power for lighting pathways at nights. Renewable energy on a small scale is still a relatively expensive option compared to "conventional energy" use. In the current situation the use of renewable energy (except from large wind farms) to meet energy demand is not cost effective compared to the use of conventional fuel based energy where this energy is supplied via a mains electricity supply network. However, renewable energy has environmental appeal even though this is less quantifiable in terms of the reduced pollution compared to conventional energy. It is hoped that projects such as this will foster enthusiasm and encourage creativity in engineering students.

2. Local renewable energy sources

A typical hybrid energy system consists of solar, wind and hydro energy sources. The principle of an open loop hybrid system of this type is shown in Figure 1. The power produced by the wind and hydro generators is an AC voltage that can then be transformed into DC to charge the battery. The controller protects the battery from overcharging or deep discharging. As high voltages can be used to reduce system losses, an inverter is normally in-

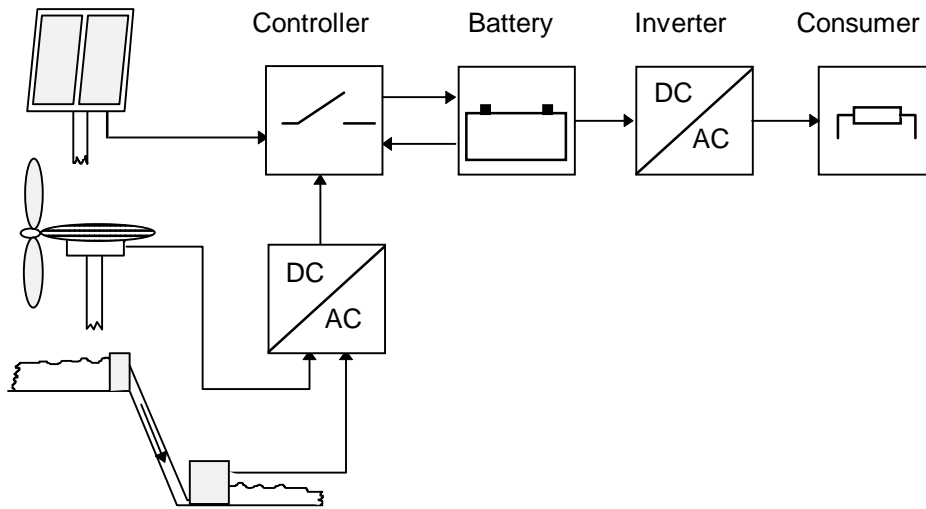


FIGURE 1: Schematic diagram of a typical hybrid energy system containing solar, wind and hydro sources.

troduced to transform the low DC voltage to an AC voltage of 110V or 230V, depending upon the power system used in the region.

2.1 The solar component

The solar resource is determined by the solar radiation received at a particular site in kWh/m². The principal feature of solar radiation is the strong seasonal dependence with a minimum in winter and maximum in summer. Solar radiation consists of direct and diffuse components. Energy captured from direct solar radiation depends on the tilt angle of the collector, and is attenuated by atmospheric effects such as cloud and pollution. Diffuse irradiance on the other hand is due to reflection and scattering and is dependent on the surroundings and atmospheric effects, and the energy captured is not dependent on the tilt angle of the collector (Cooper, 1974). Although the maximum direct irradiance can be calculated, the actual direct irradiance plus the amount of diffuse irradiance, or the global irradiance, is difficult to calculate and is usually estimated from historical records. Maximum annual energy collection can be achieved by setting the collector tilt angle to the angle of latitude of the site.

Photovoltaic generation of power is based on the principle of radiation separating positively and negatively charged carriers in an absorbing material. If an electric field is present these charges can produce a current for use in an external circuit. In junction devices (photovoltaic cells), it is the current that is produced by the radiation and not the voltage (Twidell, 1990).

The solar energy source can best be described by the air mass ratio and clearness index. The distance travelled by the direct beam through the atmosphere depends on the angle of incidence to the atmosphere (the zenith angle) and the observation height above sea level. For the direct beam at normal incidence passing through the atmosphere at normal pressure, a standard mass of atmosphere will be encountered. If the

sun's beam is at a zenith angle, then the increased path length compared with the normal path is called the air mass ratio, denoted by m .

The clearness index is a factor that indicates the degree of pollution and cloud cover in the atmosphere. It can be given by $K_T = H_h / H_{oh}$, where H_h is the radiation received on a horizontal surface during a given period of time (for example, one day) and H_{oh} is the radiation that could possibly be received on a corresponding extraterrestrial surface during the same period.

It is recommended (De Vries et al, 1980) that the performance of photovoltaic cells and modules should be measured under prescribed test conditions. In particular, the standard specifies that the temperature should be 25° Celsius and that the solar radiation should have a total power density of 1000W per m², with a spectral power distribution as at air mass of 1.5.

Figures 2 and 3 show local solar radiation data collected under standard test conditions. The information was obtained and organised with respect to different inclinations

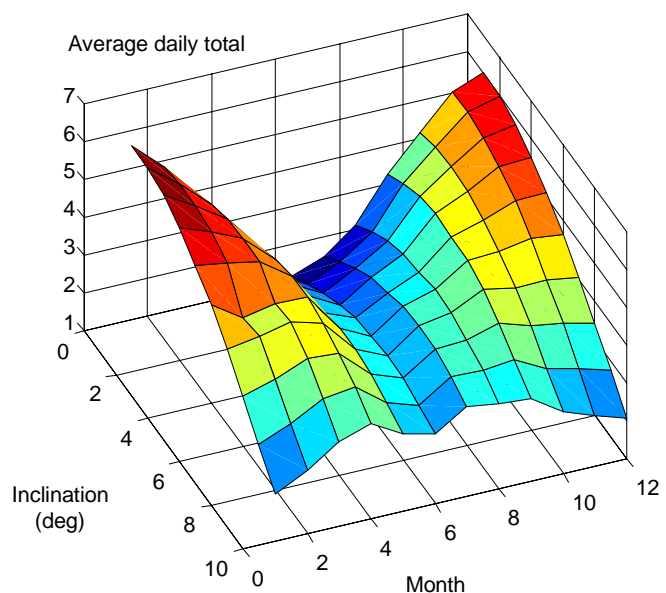


FIGURE 2: Local solar radiation information about average daily totals.

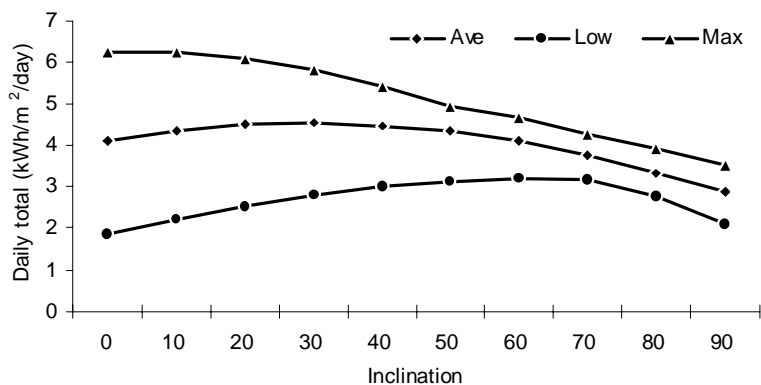
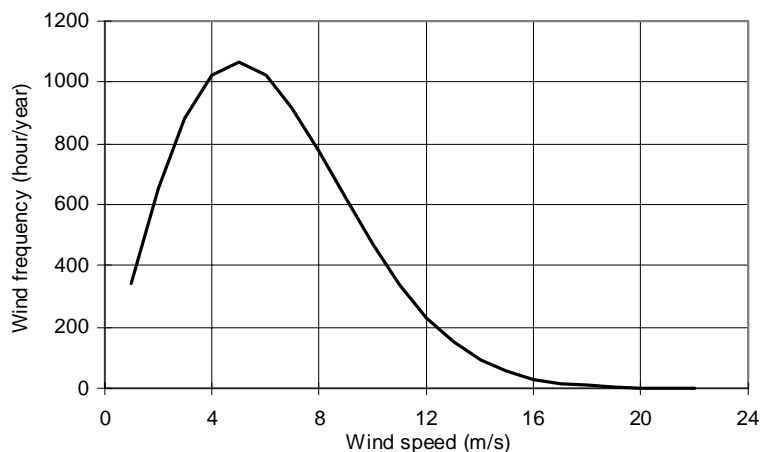


Figure 3. Local solar radiation information: high, low and average values of daily solar radiation calculated over one year

of the photovoltaic cells, as this is one of the key parameters used for applications. For example, an application that is used only in the summer has solar panels arranged at a flat angle. The smaller the inclination, the more the output depends on the seasons. In Auckland, the best output of a solar system over a year is at an inclination of 30°. For large inclinations, the total output is low. However for a hybrid energy system an inclination of 55° is a useful compromise between the system output and its dependence upon seasons. This parameter is used for the simulations of the hybrid energy system described here.

2.2 The wind component

Clearly any power output from wind turbines will vary with the wind speed. For example, a SOMA1000 wind turbine has a maximum output of 1.2 kW at wind speed of 16 m/s and this is used in this project as the wind component system. The other parameters of SOMA1000 which has two blades are a cut-in speed of 3.5 m/s, rated wind speed 10 m/s, maximum design speed 50 m/s, operating speed 250–800 revolutions per minute. Consideration was given to a loss factor of 10% to 20%. The energy that a wind turbine will produce depends on its wind speed power curve and the wind speed frequency distribution at the installation site. Figure 4 shows the wind frequency distribution measured at a height of 30 m above ground level, demonstrating that a high frequency over 800 hours per year occurs for the wind speed range of 3.2 m/s to 7.9 m/s.



Consideration also has to be given to wind turbulence. It is well known that turbulence increases with rough terrain and obstructions above ground, and the higher the wind speed, the more the wind turbulence will be. For the installation of wind turbines, a height of 10 m above ground is considered to be the minimum. However, a building of 10m high may not be an appropriate site upon which to install a wind turbine, as the building itself causes turbulence. A common practice is an installation tower, rising 5 m above any obstructions within the range

of 150 m (Twidell, 1990).

2.3 The hydro component

The power supplied by falling water is the rate at which it delivers energy, and this depends on the flow rate and water head (Fraenkel, 1991). The local water flow and head are limited at this project site, and a relatively simple hydro energy component is used in the project.

3. System characteristics

If an exchange of material, energy or information occurs between a system and its surrounding environment, the system is termed open. By its very nature, a hybrid energy system is open, too, because the inputs include the effects of the environment. Without these inputs from the environment, the system will not function properly. The inputs of an open-loop system are independent of its outputs, which are not linked to its performance. As such the system can not regulate itself. On the other hand, in a feedback system (or closed-loop system) the outputs have influence on the inputs, and feedback is generally used for control. As a result the system can control itself and is sustainable.

Although hybrid energy systems are open, they can have the characteristics of a closed system if a subsystem with the function of “monitoring” is introduced as a feedback between output (consumer) and input (controller). As inputs, the solar, wind and hydro energy sources can not be changed. However, the load may be changed. With a backup system as another energy source (for example a diesel generator), the system can be designed as a partial closed-loop feedback system.

Figure 5 shows the flow diagram of the hybrid energy system under consideration. The energy generated by the various renewable sources is used to charge the battery component system. If the battery fails, the hybrid energy system will not function, so some protection mechanism has to be introduced. This is a monitoring system centred on a component called the charger, which constantly monitors the level of the

Figure 4. Local wind speed frequency distribution.

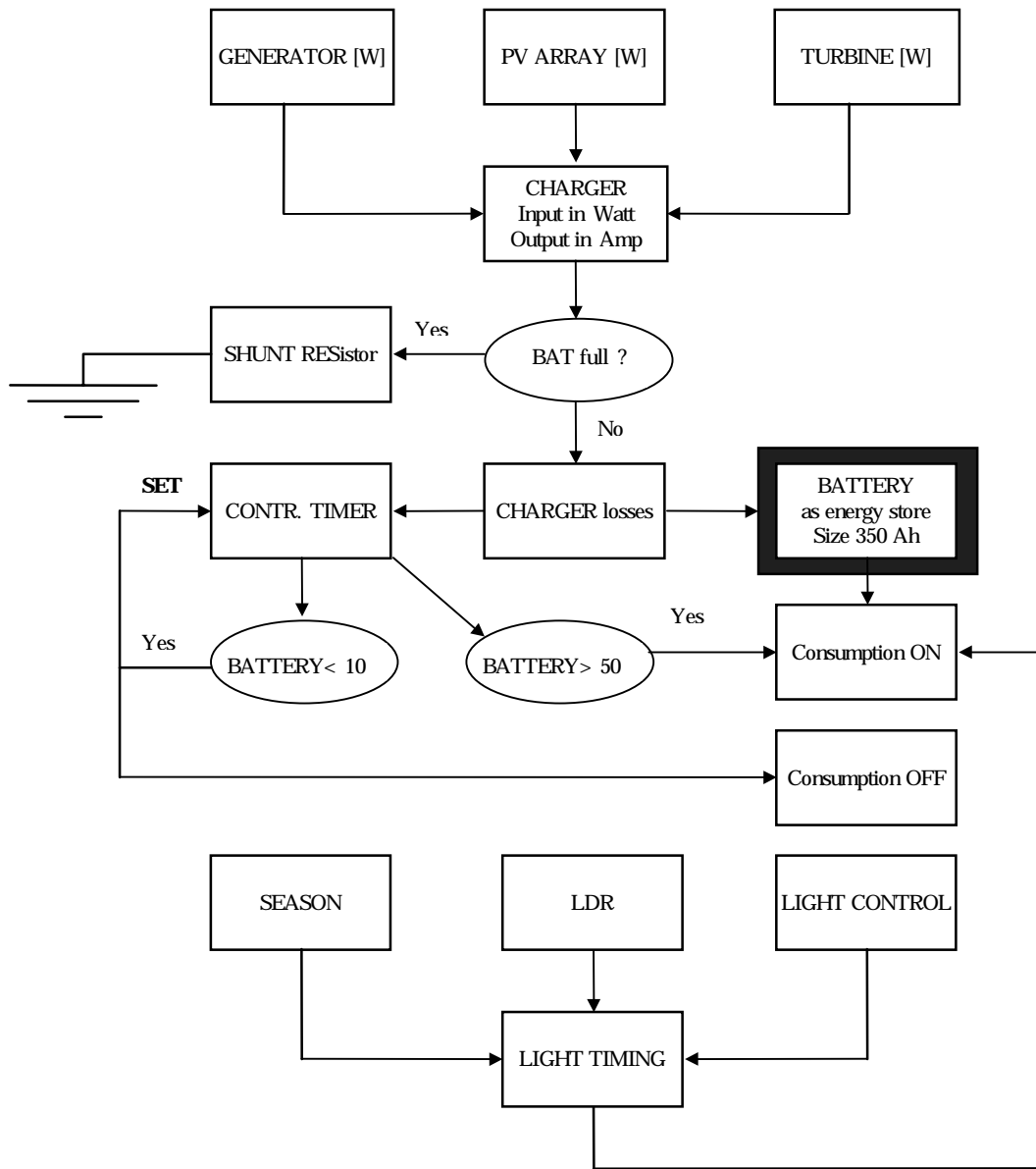


Figure 5. Flow chart of the hybrid energy model over 12 months

battery: the battery discharges at a rate greater than it charges and the level drops below a threshold, then the consumption is turned off so to protect the battery.

As the hybrid energy system is used to provide power for lighting pathways during nights, the monitor system is integrated into the system with a light-timing component as shown in Figure 5.

In practical situations, it is sometimes impossible to describe a phenomenon with explicit functions. For example, it is impossible to express wind in an explicit function because it is a random phenomenon. However, data for past wind values can be used in this situation. In the computer software used for simulation, a function is provided to generate random numbers between zero and two. When this is used to simulate the wind, the number 1 can be used to provide a datum, where 0 means that there is no wind and 2 means that the wind is blowing twice as strongly as the average. The frequency of the random generator can be determined by choosing an appropriate sampling interval which is denoted by DT.

In order to simulate a real hybrid energy system, consideration was given to the following: the type of wind generator, the number of wind generators, water heads, flow rate, the type of photovoltaic cell, the number of photovoltaic panels, consumption, the size of battery and the statistical weather data.

Simulations were carried out over a period of 12 months, allowing the statistical information about local weather to be truly representative. This model also allows an optimal capacity of the hybrid energy system to be determined. For instance, if the system is under-dimensioned the battery protection will cut off consumption, indicating that consumption is too high for the chosen inputs. In addition, protection which allows only a small amount of the produced energy to be consumed can be used to prevent the battery from overloading. An important task for the simulation is to optimise a hybrid energy system so that it is balanced, stable and cost-effective.

4. Conclusions

Given the fact that a hybrid energy system consisting two or more renewable energy sources has the advantage of stability, the objective of lighting pathway at the project site can be achieved by making use of the wind, solar and hydro energy sources. The information about local wind, solar and hydro energy sources indicates that a feasible hybrid energy system can be planned, modelled and designed for the above purpose. The collected data of the various energy sources was analysed in order to plan for the structure of the system.

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