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Sustainable Solar-wind Hybrid Power Plant for Implementation in Malaysia

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Abstract: Solar and wind energy are renewable sources of energy that can be used for renewable electricity generation. Solar and wind energy sources are intermittent sources of energy. They are not available on demand and backup systems are needed to obtain a reliable supply. By implementing a hybrid system where both the solar and wind plants supplement each other can further enhance their energy harvesting capability, thus improving the supply reliability and overall performance. The aim of this project is to study the feasibility of using a hybrid plant as compared to standalone solar and wind power plants in areas pertaining to the reliability and sustainability of our energy sources. In addition to combining both power sources, the efficiency factors of solar powered systems were studied to further improve the overall performance of the hybrid system. The modeling equations were formulated for sizing simulations at the theoretical development stage. Results obtained from this study includes data indicating factors, such as solar positioning, PV operating temperatures, PV efficiency, solar irradiance and operating locations that affect solar power output of PV arrays and comprehensive sizing data for local implementation, while at the same time, addressing issues pertaining to reliability and sustainability of existing standalone solar power plants.

Key words: Electricity generation, solar ,wind energy, hybrid system

INTRODUCTION

The main concern over utilizing renewable energy resources such as solar and wind energy are the reliability, sustainability and economical feasibility factors, that must be given due consideration, in setting up and maintaining electrical power plants. Photo Voltaic (PV) is used to harness solar energy and convert it directly to electricity and wind generators will convert mechanical energy to electricity with the aid of a electricity generator. Solar power is challenged by the fact that Photo Voltaic (PV) cells rely heavily on the availability of sunlight. Electrical output can be predicted to rise in the morning, reaching the peak during mid-day and decreases towards the evening. Since wind is also an intermittent source of energy, a solar-wind hybrid system is studied to improve reliability and sustainability of the overall system (Razak *et al*., 2009).

Solar power output is often affected by solar positioning, PV operating temperatures, PV efficiency, solar irradiance and operating locations. All these factors must be taken into consideration, whereby appropriate measures can be implemented in the hybrid power plant to improve its overall efficiency. Proper plant sizing allows for a reliable system to be implemented and thus, reducing overall cost. For a standalone solar power plant, large numbers of PV arrays and battery systems are required to ensure reliability and cost effectiveness (Shen, 2009). Some of the key areas studied under system sizing are the optimal number of components: PV arrays, auxiliary wind turbines, battery systems and energy converters. All the parameters that have been described heavily rely on the operating condition of the load demand, operating conditions and operating location of the power plant (Amin *et al*., 2009). The preliminary steps and planning are to be carried before the completion of the project with the construction of a working prototype.

THEORETICAL DEVELOPMENT

A detailed theoretical development describing the implementation of a functional solar-wind power plant was established. Further modifications were made to hybridize the default system and to implement a wind generator to form the proposed solar-wind hybrid power plant. The process to hybridize the system must be carefully planned and the approach used is as illustrated in Fig. 1 and 2.

In approaching the theoretical development, the solar geometry element was first studied to understand the relationship between declinations of the sun, the solar h angles and altitude angle. This was followed by the study of the meteorological conditions such as

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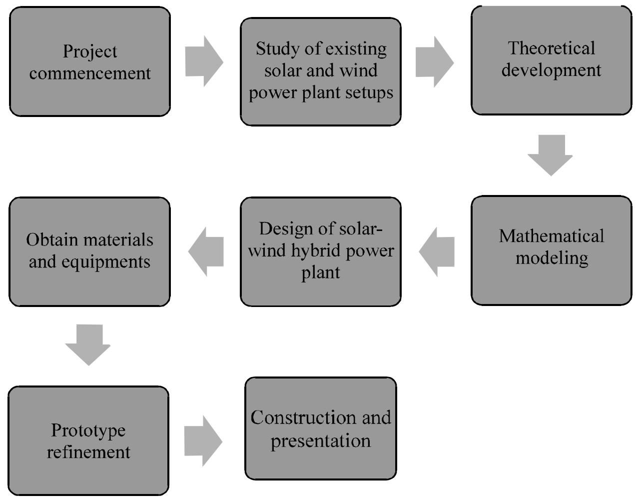

Fig. 1: Flow chart indicating the approach used in this project

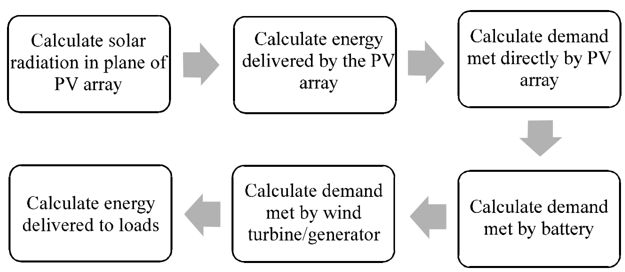

Fig. 2: Theoretical development flowchart

extraterrestrial radiation and clearness index, to carry out calculations to identify the relationship between the amount of radiation and overall PV system output. Additionally, the tilted irradiance calculations were made using the set of formulas introduced in to help estimate the effects of tilting a PV panel to face the direction of the sun (Cheng *et al*., 2009). The information obtained from the solar study was then applied to the PV array model where the efficiencies and parameters were linked to obtained output information for array-sizing purposes based on the meteorological conditions.

An off-grid model was chosen for the study of this project, as the Solar-Wind Hybrid System will mainly focus on supplying electricity to suburban residences (Salameh and Davis, 2003). A general number of 20 homes using 60 kWh^{-1} were used as an estimate for the load calculations. The analysis of the energy distribution system was separated into matched demand, continuous demand and battery demand components. The energy breakdown analysis allowed the estimation and sizing of the battery system in terms of capacity whereby an estimated amount of standby time by the battery bank was estimated to last 3 days when there is poor or nonexistent sunlight for electricity production. A modification to the model was made in this section to implement a wind generator in place of a conventional diesel generator. The generator rating was obtained based on the identified scope that it will only be used to charge the battery bank when needed. Additional information allowed further estimations on the meteorological factors that affect the wind power generators. Mathematical models were compiled to allow quick and comprehensive computation of these relationships.

The hybrid system optimization process was conducted to study the energy economics feasibility of implementing a hybrid power plant in Malaysia. Simulations were carried out by using HOMER software that incorporated the detailed analysis of the commercial factors, together with overall operation factors that were involved in determining the feasibility of the project. The simulation study was also carried out on a scaled-down standalone hybrid where a setup requiring the supply of uninterrupted electricity to 20 modern homes in the Malay sian climate, particularly in suburban Kuala Lumpur, Malaysia was used. The hybrid configure ration setup was introduced in the simulation process where the

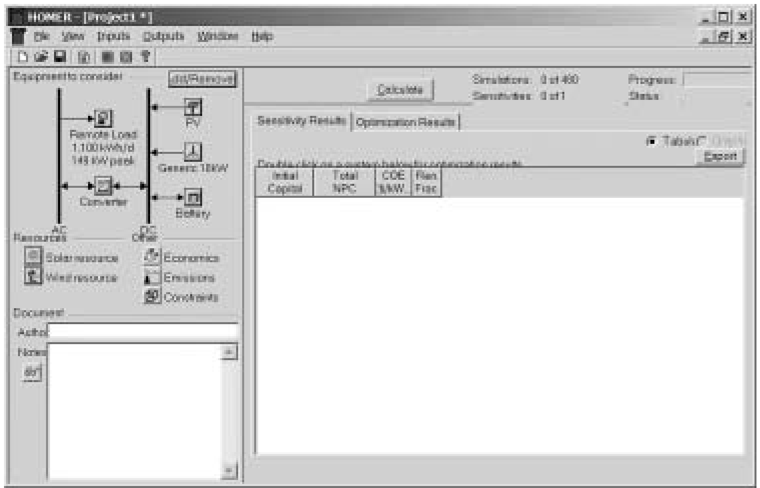

Fig. 3: Screenshot of HOMER sizing simulation software

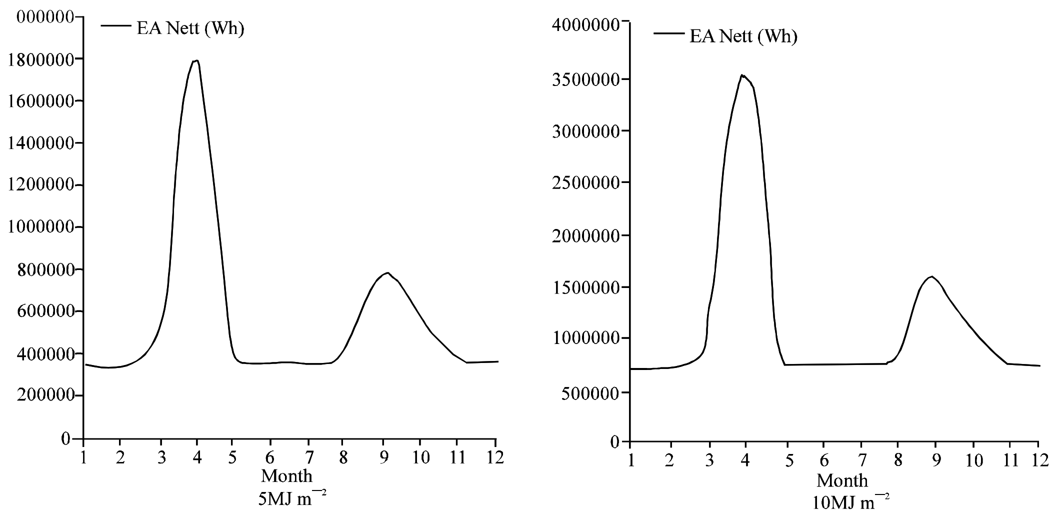

Fig. 4: Comparison between EA for different levels of irradiance

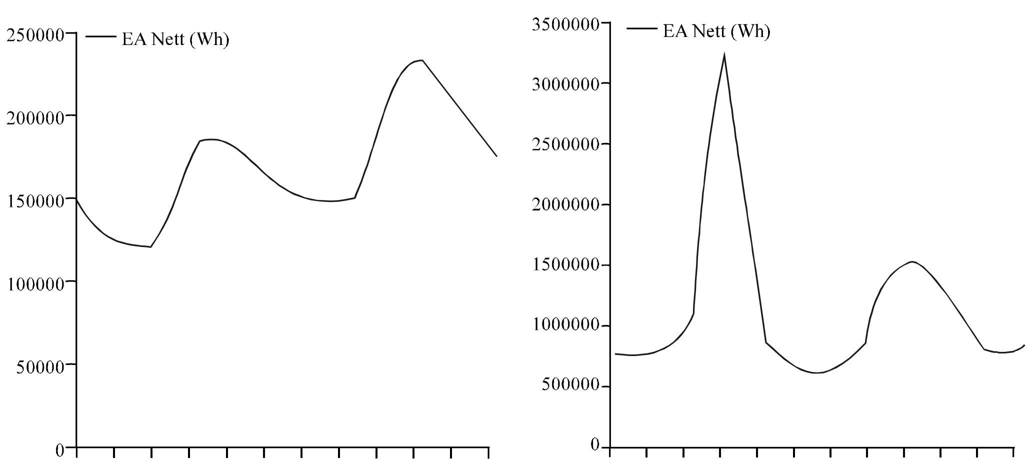

Fig. 5: Comparison between EA for different position of the sun in the sky

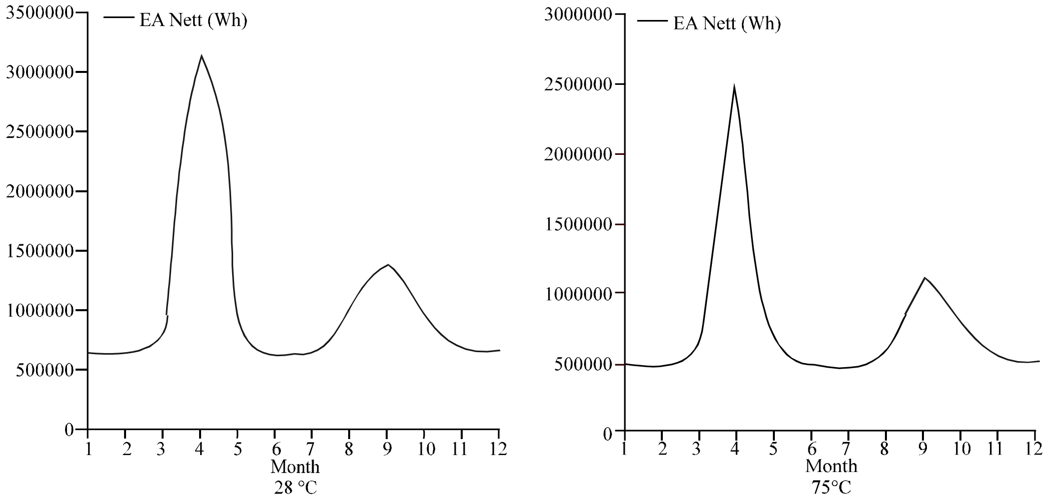

Fig. 6: Comparison between EA for different operating temperatures

main network involved the primary load, solar panels, wind turbines, converters and battery banks. Figure 3 illustrates the user interface of the HOMER software and the methodology elaborated is used to obtain the optimized setup for the most practical and cost effective hybrid system.

The main aspects studied for optimizing the hybrid system in terms of sizing and cost as given below:

- Primary load PV panels
  - Capacity per unit
  - Operation and maintenance
  - Solar radiation in location of operation
- Wind turbines
  - Capacity per unit
  - Operation and maintenance
  - Wind profile for location of implementation
- Converters and battery banks
  - Capacity per unit

RESULTS AND DISCUSSION

In this section, simulation results by using specifically developed mathematical models shows that the average energy output is greatly affected by the level of daily irradiance, as mentioned in Fig. 4. A comparison between the average Energy Outputs (EA) is obtained based on input of daily average irradiance of 5 and 10 MJ m^{-2}, respectively.

The significant effect on PV output variation due to position of the Sun in the sky is as illustrated in Fig. 5, where the difference in average output energy, EA at different times of the day, at 8 and 11 am is illustrated. A similar trend is observed for the same time of the day but different months of the year.

The EA from PVs decreases with increasing levels of operating temperature. Figure 6 illustrates how EA varies for given temperatures of 28 and 75°C.

The experimental analysis of the electrical output of PV panel with regards to the changing position of the sun was conducted using a standard a-Si PV module. The module was placed horizontally across the workbench, connected to the computerized data acquisition system to obtain the readings as a light source is passed over the PV module from 0 to 180° with respect to the horizontal. The aim is to observe the results of having the sun's irradiance applied to the PV module at an angle of incident and results are mentioned in Fig .7. The output obtained shows fairly consistent readings when a light source passes over the solar cell. This applies to situations where the Sun rises and sets across a predictable path every day, and the real-time effect of the level of irradiance and the output voltage clearly shows that by pointing the solar cell towards the direction of the Sun will definitely provide a constant output voltage regardless of the position of the Sun in the sky.

In order to test the wind turbine design, 5 different configure rations were examined using DC fans operated in reverse. The fans were exposed to a constant wind speed and the electrical outputs were recorded using the same data acquisition system. Figure 8 to 12 illustrates the various DC outputs generated from the different fan configure rations.

From the results obtained, it can be concluded that the single rotor configuration remains the most reliable and efficient method for implementation of a wind turbine. Upon setting up the hybrid system components, a number of simulations were conducted using multiple sensitivity values to estimate the most efficient and cost effective configuration. A few sets of results were obtained from

Fig. 7: Voltage output curves from PV module

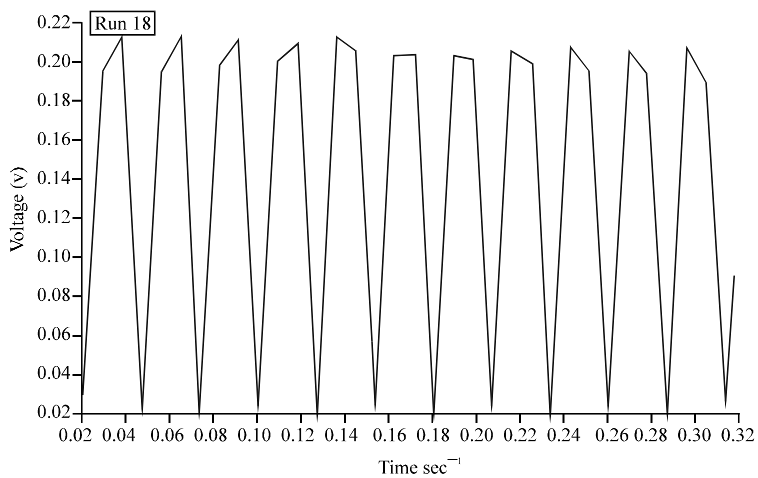

Fig. 8: Single turbine configuration

the simulations with a combination of solar radiation values of 4.95, 5.00 and 6.00 kWh m^{-1} day, respectively against wind speeds velocities of 2.86, 3.00 and 4.00 m sec^{-1}. A total of 720 simulations were conducted, out of which, 9 outputs were chosen to be further refined for system optimization. It can be concluded that should the global solar radiation exceeds a consistently high wind speed; it is more practical to just maintain a standalone power plant. However should wind speeds exceed 3.6 m sec^{-1} with global solar radiation below 5.1 kWh m day^{-1}, it is more feasible to implement a hybrid system.

Another important factor that must be acknowledged in this simulation is the fact that fuel used in the back-up diesel generator for a standalone solar power plant will fluctuate in the long run and may influence the cost analysis from HOMER and ultimately our decision on the system comparison. Hence an assumption is made where the cost analysis of fuel is omitted and the system is analyzed entirely based on the typical components of a standalone solar power plant and typical outputs are mentioned in Fig. 13 and 14. From the sizing study, the most efficient and cost effective system configuration was obtained. The conditions provided a best fit for Malaysia's weather conditions, based on the average solar irradiance of 4.95 kWh m^{-2} and average wind speeds of 3 m sec^{-1}.

The following table summarizes the sizing simulation output and compares the hybrid system and a standalone solar power system should it be implemented on the same given operating conditions.

It is observed from Table 1 that a hybrid system is more practical as compared to a standalone solar power plant that is of similar capacity. One of the reasons is that

PV modules are costly to manufacture and implement, in addition to their low energy output rating. However, wind turbines on the other hand are rather matured technology and they are capable of generating larger amounts of electricity per session. Hence by using the right sizing method, the number of PV modules required is reduced, reducing the overall cost while maintaining the overall system capacity.

A working prototype was built successfully through this research project, whereby some of the major components required to implement a hybrid system were identified through the simulation studies. Three major components designed in the prototype are the solar panel to convert solar energy to electricity, a wind turbine

Table 1: Sizing simulation outcomes from HOMER

Requirements	Standalone	Hybrid
PV panels	450 KW	400 KW
Wind generators	-	50 kw
Batteries	2000 units	2000units
Converters	200 kw	200 kw

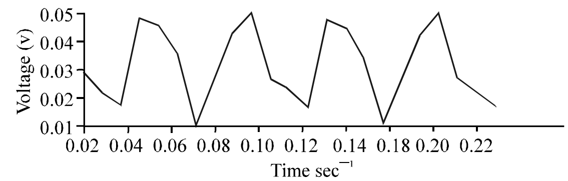

Fig. 9: Single turbine with attached wind tunnel configuration

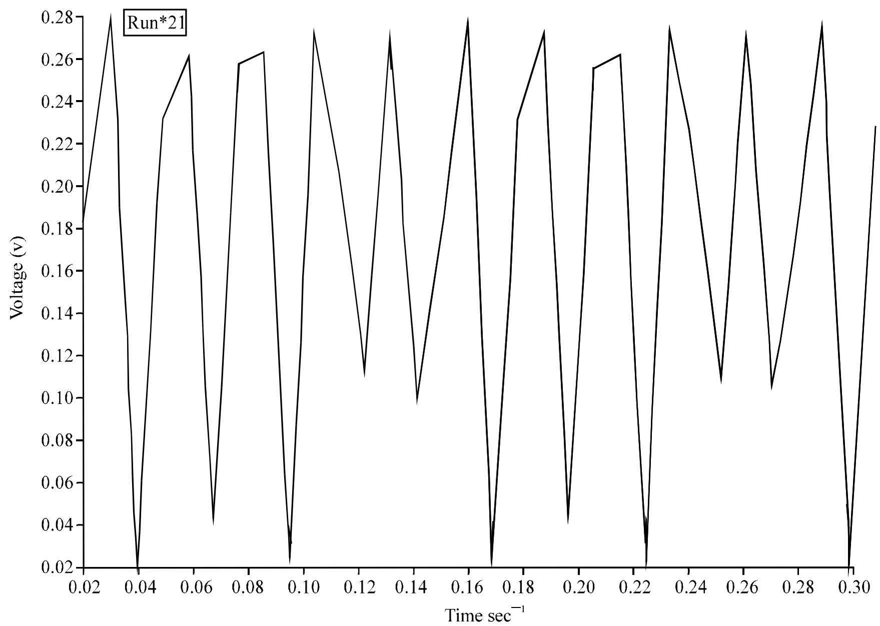

Fig. 10: Double turbine back-to-back configuration

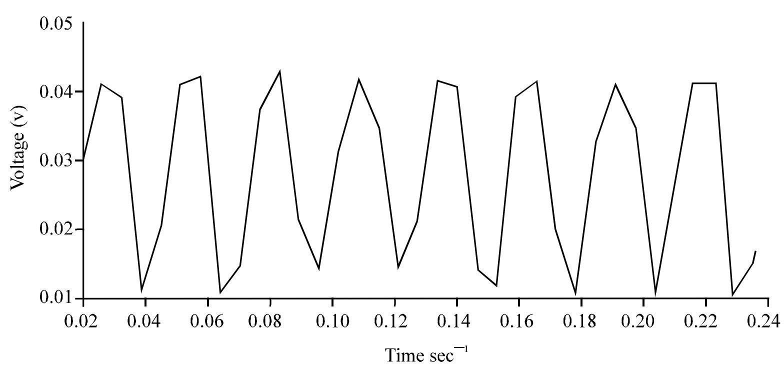

Fig. 11: Single turbine with attached funnel configuration

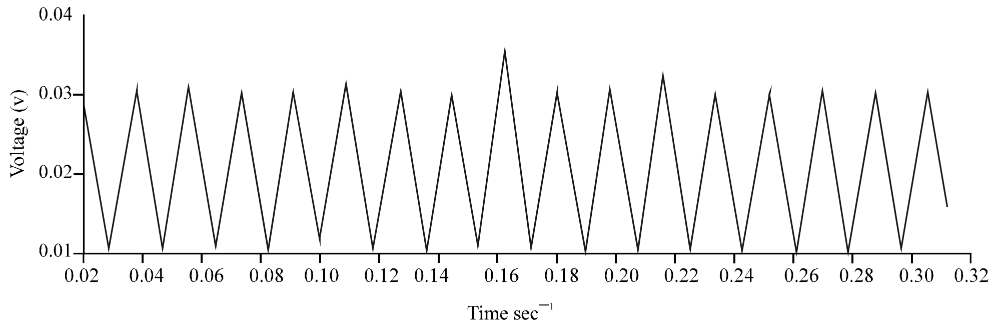

Fig. 12: Single turbine with reduced blades

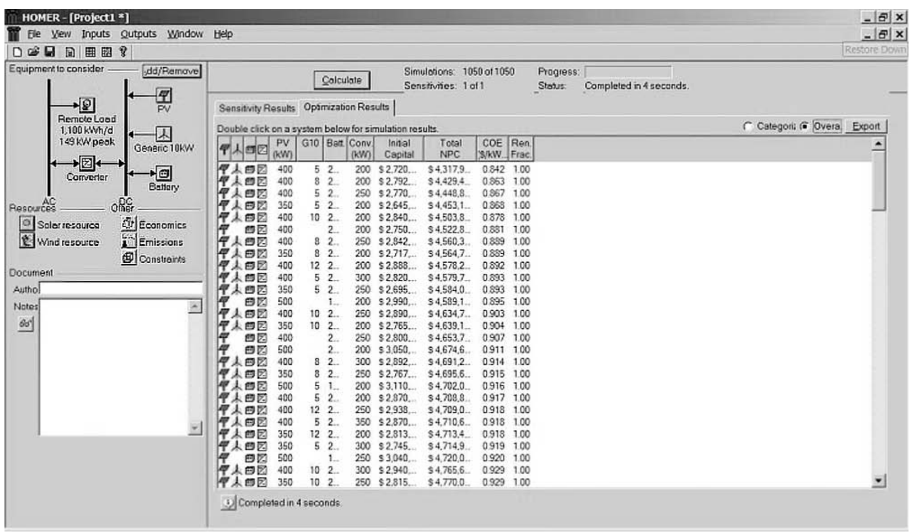

Fig. 13: HOMER sizing simulation results

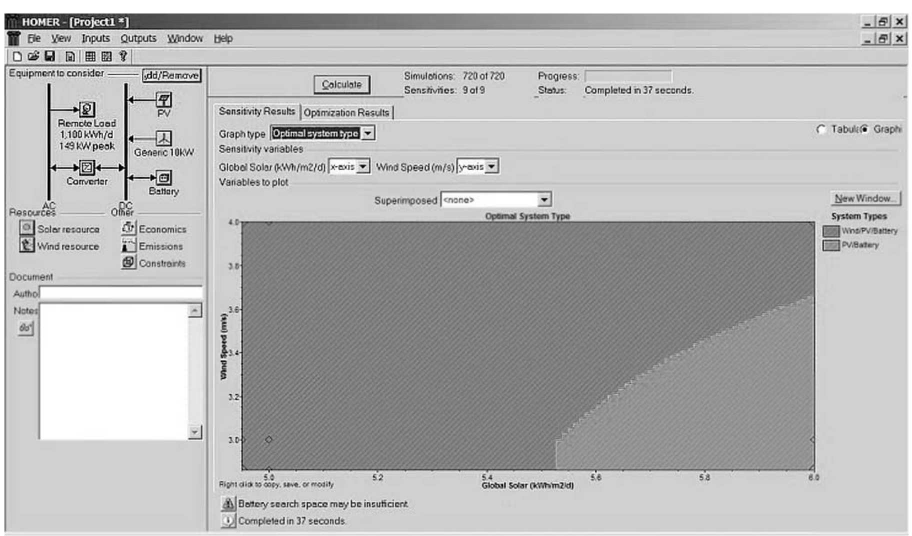

Fig. 14: Graphical representation of optimized simulation results

connected to a generator to convert kinetic energy to electricity, a battery system to store electricity for future use and charge controller to regulate the charging and discharging of the system to protect the battery bank. Among some of the core components analyzed in detail were PV panel and tracking devices, wind turbine and DC generator, wind turbine gear ratio, battery storage system and charge controllers.

CONCLUSION

This study involved the detail analysis of the technical and economical feasibility of implementing a solar-wind hybrid power plant in Malaysia. A theoretical development was successfully formed to obtain the mathematical models required to define the various factors and relationships that represent the system. These factors were taken into account in determining the best possible location, operating conditions for optimal electricity generation for the solar and wind hybrid power plant. Among some of the key factors identified through this project that significantly affected solar power output were solar positioning, average daily irradiance, PV efficiency, and PV operating temperature. Sizing simulations were conducted to determine the feasibility of the hybrid power plant in Malaysia. A comparison was made between the hybrid system and a conventional standalone PV based system where the results favored the hybrid system for a small system consisting of only 20 conventional homes. From the analysis, a solar-wind hybrid power plant is highly feasible and will improve the reliability and sustainability of existing standalone solar power plants. Further studies can be conducted to improve and build upon the current hybrid system studied in this project. The that can be further developed to complement this project work are the incorporation of an automated solar tracker/positioning system, supervisory or monitoring system and the use of distributed system approach.

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