HYBRID RENEWABLE ENERGY DEVICE – LOW SPEED CURRENT TURBINE AND SOLAR CELL

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ABSTRACT

Malaysia has rivers and surrounding seas that can be a good source for obtaining environmentally friendly water/marine renewable energy. Their importance is as a source of energy for rural and remote areas, islands and isolated regions that have no access to the electrical grid for electricity supply. Due to the low flow velocities of Malaysian waters which are between 0.5 to 1.5 m/s, one solution to the energy problems is to have a balance of the current (tidal) and solar power sources to sustain the energy for a long period of time and to reduce the charging time of the batteries. The paper presents a standalone hybrid system consisting of a Low Speed Vertical Axis Current Turbine (LS-VACT) and solar panels. A computer simulation program is developed using Math lab-Simulink software to investigate the performance and the efficiency of the hybrid system. This simulation model was mainly designed for the operations analysis of LS-VACT-electric generator system that is upgraded to include solar cell, battery, charger and inverter as a hybrid standalone renewable energy system. A study is conducted to identify the problems that may occur due to the upgrading of the LS-VACT system in real-time operations and power quality analysis. This paper is useful as an example in modelling and presenting a current turbine-solar cell standalone energy system.

Keywords: Renewable Energy, low speed current turbine, solar cell, hybrid system, and Math Lab/Simulink

1.0 INTRODUCTION

The concerns and fears of climate change and the worries of diminishing natural resources has created a worldwide great interest in clean renewable energy that can meet the world needs of power. Long time ago, researchers started their journey of exploring potential renewable energy resources in order to create a sustainable environment to support the needs and of trying to harvest the energy from those sources by the development of new technologies. Presently, the recognized sources of renewable energy include solar power energy, hydropower, wind power energy, geothermal energy, biomass energy and ocean energy [1]. The renewable energy sources are free natural sources. The investments on these sources are economically effective and could be recovered in measured time period. The research and development of renewable energy production techniques is of great importance to overcome the environmental issue due to

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burning the fossil fuels to generate electrical energy. An increased awareness of air pollution, carbon dioxide emissions, the issues regarding storage of various waste products and the greenhouse effect has also contributed to this research and development.

In line with Malaysia’s rapid economic development and growing energy demand [2, 3], more alternative energy sources are needed to fulfil its demand for energy. In 2009, Malaysia formulated the National Green Technology Policy [4] to promote green technology usage for economic growth as in reference [2]. Malaysia has rivers and ocean energy which can be the best source of environment friendly water/marine renewable energy. Generation of the electricity by burning of fossil fuels produces undesired greenhouse gases which has harm impact [5] and on the other hand the reserves of fossil fuels are limited [6] and being depleted [7] and there is no accurate way to determine how much remains. Renewable energy sources such as wind, solar and hydro power are the cleanest from of other sources such as nuclear and fossil fuels and are the only few types that can generate power without producing carbon dioxide. It becomes interesting and excellent choice to use them for isolated regions, inlands and remote areas due to the lack of network installation (for example the cost of the grid extension) that enables access to electricity.

Many researchers and experts have focused on feasibility and system performance of the hybrid renewable energy systems, mainly concentrating only on solar/wind [8-10], solar (PV)/wind/diesel [11,12], PV/fuel cells [13] and geothermal energy options. However, the study on water/marine current turbine-solar cell hybrid system has been neglected. Clean and renewable production systems are becoming profitable, especially sun and hydraulic energies. There for, this paper presents a hybrid combination of water current/solar cell/battery as a standalone hybrid system and provides a study and analyse the performance of the system using Mat Lab Simulink environment.

2.0 HYBRID WATER CURRENT-SOLAR CELL SYSTEMS

Integration of the water current and solar resources into a combination makes the system more reliable and can overcome the variable nature of two resources. This solution can be an attractive hybrid standalone system to supply continuous power for different applications at rural and remote areas. Referring to the solar –wind hybrid systems, there are two types of the hybrid systems: grid connected and stand-alone systems. So, water current-solar hybrid systems can be classified into two types as well: grid connected and stand-alone systems. The standalone system is considered as a target system in this study and it is illustrated in the Figure 1.
Understanding each component of the system to simulate it probably and knowing the type, size and length of time of use of loads are important factors for better system design and determining the cost with including and considering the location and the system maintenance factors.

The advantage of the hybrid system with a water current turbine is when sustained currents driving the turbine to run and then turning the generator during non-daylight hours, one battery-bank can be charged, or DC appliances can be energized if both of the battery banks are fully charged. Moreover, this combination of both resources can reduce the number of the batteries of the standalone system and decrease the charge time of the batteries as well. In addition, this energy storage system can be designed where the current turbine and/or solar panels are disengaged until the battery banks state of charge reaches a certain level. Simulation of the system requires the current turbine performance data, current speed and solar radiation data (for the intended geographical location of the site) and household load demand. Also, requires manufacturing data for the following equipment: generator, gearbox, solar panels, charge controller, battery and inverter and their operational efficiencies. The system contains the following units; one LS-VACT turbine, one PMSG generator of 2 KW, four solar panels (each 230 W) in two groups, eight deep cycle batteries (250 AH each battery) divided in two groups or banks (4 batteries in each bank), one charger-controller and one invertor.

3.0 SIMULATION MODELS

The simulation model was primarily designed for the opportunity analysis of the LS-VACT and its performance and validated using experimental tests to increase the accuracy results. Then, this computer program was upgraded to simulate the standalone LS-VACT- electric generator system as renewable energy system for the study of problems that may occur due to the adopted solution. In addition to the previous, now the model is improved and developed for the study of real-time system operation and for power quality analysis of the hybrid water current/solar/battery system. The diagram of the simulation models of the standalone hybrid system is shown in Figure 2. Moreover the interface of the simulation program developed to simulate the hybrid system and to predict the performance of the system is shown in Figure 3.
3.1 The water current turbine model (LS-VACT model)

The LS-VACT is a vertical axis current turbine drag type like the conventional Savonius turbine. The conventional Savonius turbine is suitable for the Malaysia's waters requirements; low speed current and low water depth as stated in reference [14] however, this turbine has a main drawback which is the low torque and difficult to integrate it with a generator or not enough torque to rotate the generator to generate energy or power output [15]. Consequently the LS-VACT as novel desgin which has four buckets and arms to increase the torque is one of the best solutions to overcome the low speed problems and difficulties to match it with suitable generator. Also, this concept of LS-VACT by having four blades and arms leads to enhance the power output. The main particulars and Functional and dimensional principal sketch and Schematic drawing of the LS-VACT are shown in Table 1 and Figures 4 & 5 respectively. The summary of the performance results of the turbine conducted at MTC of FKM –UTM at the different flow velocities are illustrated in Table 2 and Figures 6 &7:
Table 1: The principal particular of the LS-VACT

<table>
<thead>
<tr>
<th>No</th>
<th>Specification</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Height of Rotor, H (m)</td>
<td>1.5</td>
</tr>
<tr>
<td>2</td>
<td>Diameter of the bucket, d (m)</td>
<td>0.35</td>
</tr>
<tr>
<td>3</td>
<td>Blade Area $A_s$ ($m^2$)</td>
<td>0.525</td>
</tr>
<tr>
<td>4</td>
<td>Diameter of Turbine, $D_p$ (m)</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Arm length, $r'$ (m)</td>
<td>0.15</td>
</tr>
<tr>
<td>6</td>
<td>Current speed, $U_{\infty}$ (m/s)</td>
<td>0.5 to 2</td>
</tr>
</tbody>
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Table 2: Performance Results of LS-VACT at several velocities

<table>
<thead>
<tr>
<th>Current Speed $U_{\infty}$ (m/s)</th>
<th>Tip Speed Ratio (TSR) $\lambda$</th>
<th>Torque Coefficient $C_t$</th>
<th>Power coefficient $C_{P_{\text{max}}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>0.259</td>
<td>0.22</td>
<td>0.06</td>
</tr>
<tr>
<td>1</td>
<td>0.29</td>
<td>0.52</td>
<td>0.19</td>
</tr>
<tr>
<td>2</td>
<td>0.55</td>
<td>0.25</td>
<td>0.119</td>
</tr>
</tbody>
</table>

Figure 4: A functional and dimensional principal sketch of the LS-VACT

Figure 5: Schematic drawing of the LS-VACT
The turbine in this system is a low speed vertical axis current turbine and simulated using its efficiency performance (power coefficient curve) which is power coefficient ($C_p$) as function of tip speed ratio ($\lambda$). The curve can be defined by a third-order polynomial as illustrated in the simulation turbine model and are shown in Figures 8, 9, 10:
Figure 8: Simulation model of the water current turbine (LS-VACT model)

Figure 9: LS-VACT power coefficient vs. TSR at current speed = 1 m/s

\[ C_p = 4.7146\lambda^3 - 6.0603\lambda^2 + 1.9457\lambda + 0.001 \]
The current speed was simulated using the lockup table and part of the data was measured using current meter at the site. The data collected is based on tide changes and the other data is random values just to simulate the change in current velocities. The current turbine is connected through a gear to a generator which produces 12 volts across the charger controller to charge the batteries.

3.2 The gearbox model

Gear box: Simple gear of base and follower wheels with adjustable gear ratio and friction losses and simulated using Simscape model as illustrated in Figure 11.

3.3 The generator model with dc/dc converter model

Low RPM Permanent Magnet Synchronous Generator (PMSG) of 2 KW power has been used and simulated using a MATLAB, Simulink. Simscape electric model library (as illustrated in Figure 12) is used to model a synchronous generator and the load on it.
The Generator Simulation Model and the following equations 1 and 2 which are used to simulate the generator and its operation as mentioned in mat lab in references [15-16]. Also, assumed that the Generator Load Ratio = 0.9.

\[
\text{Gear\_ratio} = \frac{\text{Turbine RPM}}{\text{generator RPM}}
\]

\[
\text{Generator Power Output} = \frac{\text{Generator\_voltage\_out}}{\text{Generator Load Ratio}} \div \left( \frac{\text{Turbine RPM} \times \text{Gear\_ratio}}{} \right)
\]

3.4 The ac/dc inverter model

It should be considered that the inverter capacity must correspond to the required energy consumption. The inverter model was simulated using the Simscape block as shown in Figure 13 and the common DC/AC inverter will control the DC bus voltage.

3.5 The battery model with dc/dc converter model

The battery bank is charged by both LS-VACT and Solar panel power resources. The battery bank is supplying the power to the user load with other sources and when there is an extra power will be used to charge the battery. The battery will supply the power with when there is shortage of power from the renewable energy sources. The number of
batteries is four to supply electrical power for a household with autonomy time of 2 days as mentioned in reference [19] and following stand-alone system design procedure. In addition, the total number of the battery banks is two and each bank with the dc/dc unit is simulated using battery blocks from Simscape library as illustrated in Figure 14.

![Figure 14: Simulation model of the battery with dc/dc converter unit](image)

3.6 The solar panel with dc/dc converter model

The DC electricity produced by the solar panel module(s) is used to supply the user loads with power through the inventor and charge batteries via a charge controller. The solar panels were simulated using Simscape model and dc/dc converter was simulated using electric model library as illustrated in Figure 15.

![Figure 15: Simulation model of Solar panel with dc/dc converter unit](image)

4.0 SIMULATION RESULTS AND DISCUSSIONS

Simulation scenario adopted in these performance predictions of the LS-VACT-Solar-Battery hybrid system is based on one day of operation time. First simulation scenario the control will allow the solar and one battery bank together feeding the user loads with power for seven hours while the LS-VACT generator charging the other battery bank. Then the 2nd simulation scenarios where the solar power will be cut-off while the LS-
VACT- generator still charging the other battery bank and the power to the user load will be supplied using the other battery bank. So these scenarios can be managed properly using a management system. The signals of managing 3 AC appliances, battery banks, turbine generator and the solar panels are shown in Figure 16.

![Figure 16: Management system signals for the standalone LS-VACT/solar hybrid system](image)

The results of simulation of the system operations are shown in Figures 17, 18 and 19 and the summary of operation results of the LS-VACT and generator is illustrated in Table 3.

<table>
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<tbody>
<tr>
<td>2.5</td>
<td>12.79</td>
<td>1051.56</td>
<td>972.33</td>
<td>16.57</td>
<td>11.72</td>
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<td>2</td>
<td>11.55</td>
<td>538.398</td>
<td>504.88</td>
<td>15.67</td>
<td>11.67</td>
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<tr>
<td>1.5</td>
<td>10.89</td>
<td>298.7</td>
<td>258.66</td>
<td>14.37</td>
<td>11.64</td>
</tr>
<tr>
<td>1</td>
<td>10.24</td>
<td>88.5</td>
<td>55.406</td>
<td>13.62</td>
<td>11.61</td>
</tr>
<tr>
<td>0.5</td>
<td>3.053</td>
<td>3</td>
<td>-</td>
<td>4.07</td>
<td>-</td>
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Figure 17: RPM and angular velocity of LS-VACT during current speed changes

Figure 18: Voltage and current of the generator during the changes of turbine RPM

Figure 19: Nominal current discharge characteristics
The results indicate that the system running smooth and stable and the control system working accurately. Also, the results shows that the LS-VACT is providing a power and charging the battery but the power is not permanent and fluctuates due to the change in the current speed. The power output is higher when the speed > 2 m/s (even low $C_p$) and the power is lower when the current speed values are from 1 to 2 m/s even in this range the $C_p$ is higher. In other hand, the solar power also supplying a power to the user load and charging the battery as there is an extra power. All in all, the state of charge (SOC) decrease not much in one battery bank and increases in other bank and the system is operating well and can supply the power of 3 KW/h per day to the user loads.

5.0 CONCLUSION

- This paper presents a hybrid Water Current/Solar/Battery energy device for standalone renewable system by utilising LS-VACT and solar panels using Matlab/Simulink environment and predicting its performance and efficiency.
- The results of simulation indicate that the LS-VACT and solar panel can supply the power and charge the battery. Also, show the superior stable control system and high efficiency.
- Discontinuous energy from solar and water current has impact on the power quality such as voltage and current fluctuation. One way to overcome this problem by having battery banks; one bank under charging and the other one to provide the loads with continuous power supply.
- The adoption of water current turbine-solar hybrid energy systems requires an understanding of the individual components within the system. The hybrid device can increase the length of time of use of loads with quality power by having two battery banks to achieve permanent power supply and autonomy.
- The simulation of hybrid system developed in this paper can be upgraded for further performance analysis of the system including other resources such as the diesel-generator (genset) or fuel cells. For future work, a hybrid standalone system of current turbine/solar panel/battery can be built and tested using laboratory and field experiments to validate the results of the simulations and increase the accuracy of the simulations.

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