CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

This research aims to introduce a new hybrid power source system between proton exchange membrane fuel cell and gasoline generator, and to design the optimal operation technique of the hybrid system. It studies the behavior and the performance of the hybrid power sources system, conducts an experiment on the hybrid power source system, and determines an operation strategy for optimal performance of the hybrid system. In order to understand the behavior and the performance of the hybrid system, a mathematical model of the hybrid system with two sub models was developed. The first sub model is stack fuel cell model with maximum power 1200 kW which is based on conservations of energy, mass, and electrochemical equation and the second sub model is gasoline generator model which is based on experimental data. And a dynamic model of fuel consumption is developed based on experimental data. The fuel cell model can be used to predict the effects of various parameters on PEM fuel cell performance.

5.1 Conclusions

5.1.1 The Simulation Model of the Fuel Cell and Hybrid System

The mathematical model of the hybrid system consists of two sub models, stack fuel cell and gasoline generator model. The models are developed in order to study behavior and the performance of the hybrid system under various load conditions. The fuel cell model can predict the effect of parameters, which is affected to PEM fuel cell performance, such as hydrogen pressure. Increasing the operating pressure of hydrogen from 1 to 3 bars will increase the average output voltage 0.02V. Increasing the operating temperature from 40°C to 80°C will result in the decrease of the average output voltage by 0.04V. Increasing the transfer coefficient which lowers the activation losses of the fuel cell potential results in the increase of average output voltage by 0.26V. Decreasing an exchange current density from $3x10^{-4}$ to $3x10^{-8}$ A/cm^2, which in effect lowers the activation losses, results in the increase of average output voltage by 0.05V. The increase of internal resistance from 0.1 to 0.2 Ω/cm^2 results in the decrease of average output voltage by 0.03V. Increasing the limiting current density from 1.4 to 1.7A/cm^2, which affects concentration losses of the fuel cell potential, results in the increase of average output voltage by 0.10V. The hybrid model can predict the behavior of the fuel cell, gasoline generator and hybrid system under various load conditions. The operating concept of the hybrid model has been studied in 3 cases. First, switching operation with fuel cell works as the main power. Second case is switching operation with gasoline generator operates as main power and the third case model, the fuel cell works as the main power source and gasoline generator works as an add-on power source. This operation shows that fuel cell power source can supply load power from zero to its maximum capacity while the higher demand is supplied by gasoline generator.

5.1.2 The Experimental of the Hybrid System

The set up experiment composes of the use of the Nexa^{TM} 1200 watts stack fuel cell with maximum current at 45A and a gasoline generator with 2.7kW at maximum rate power, 3600 rpm. The tests are conducted for various load conditions. The experiment was designed to study the behavior of hybrid system which is classified into 3 cases with the same as in the model. It found that the hybrid models can predict the behavior of the fuel cell, gasoline generator and hybrid system under various load conditions. First, switching case, fuel cell operates as the main power source and the results show that the system can work appropriate and supply the load power condition as well. The time response to initiate gasoline generator average is 4 seconds to start and ready to supply load power. And, the time response to initiate fuel cell to power the load is 3 seconds in average. Second case, gasoline generator works as the main power source and fuel cell works as the back up power source. Third case, both of fuel cell and gasoline generator work and supply load power. The first test of hybrid power source, fuel cell work as main power source and supply load power. Whenever, load power is higher than set point power, the system will connect gasoline generator to the system and power to the load power. At this point, fuel cell will supply load power about 46.59% of full load power. Second test, gasoline generator is the main power source and fuel cell is the add-on power source. During the operation, at the hybrid power, fuel cell also supply 45.97% of full load power. The comparison result of model and experiment show that the response of power supply to load conditions is very well. There is maximum error of the system is 13% of fuel cell and 20.51% of gasoline generator at the low load condition. At high load power, the error of model to experiment of fuel cell is 6.98% and 2.51% of gasoline generator.

The Experimentat results of hydrogen fuel and gasoline consumptions have been tested under load conditions. The empirical models of the hydrogen and gasoline fuel consumptions are developed in order to predict the fuel consumptions of both hydrogen and gasoline. *RMSE* of hydrogen fuel consumption is 0.2. Then, the empirical model of fuel consumption will be used to determine the operation strategy for optimal performance of the hybrid system.

5.1.3 Operation strategy for optimal performance of the hybrid system

Operation strategy for optimal performance of the hybrid system in the point of fuel consumption rate and cost shown in Table 4.2, it shows that the operation of the first case switching, second case switching and third case of hybrid system can be shown by the operation procedure which respect to the percentage of fuel cell operation to percentage of gasoline generator operation. The results of the operation procedure at 0:100 (only gasoline generator operated), the operation cost is about 34.08 baht per hour and the operation of 100:0 (only fuel cell operated), the operation cost is about 383.13 baht per hour. At 50:50 (both power sources are sharing load power), the operation cost is about 265.52 baht per hour. By the way, at 90:10 (fuel cell operated 90% and gasoline generator operated 10%) and 10:90 (fuel cell operated 10% and gasoline generator operated 90%) of the operation procedure, it found that the operation cost is about 380.65 baht per hour, and 106.14 baht per hour, respectively. From these results, the conclusion of the operation of the system in with fuel cell at 10% of operation and 90% operation of gasoline generator is the best operation for hybrid case with low cost operation.

5.2 Recommendation for future works

The following paragraphs give a few suggestions for further research and provide some suggestions to improve a hybrid system in high performance

- The control unit cannot operate at the equally sharing load power because difference of overall resistance of each power source. The resistance of each system needs to check and make it equally in order to share load power at any operation procedure

- The concept of hybrid system between fuel cell and internal combustion engine generator is a newly ideal in this work. It has a significant in this research. However, this concept still needs much more development for consistent with the phenomena inside of both stack fuel cell and gasoline generator.

- Hybrid system of fuel cell and internal combustion engine generator configuration has more advantage in fuel consumption management, and simple control strategy of operation. Therefore, it is another hybrid system configuration, which can be developed and studied in the future.