

Hybrid Power System Model Component Development

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Abstract-In recent years, the various concept of hybrid power systems have been received and models. This paper presents a hybrid power system model component development using MATLAB® Simulink®. This hybrid model comprises of the system of a diesel electric generator (DEG), a heat exchanger, a boiler, a wind turbine generator (WTG) and a Photovoltaic array (PV). The system was designed and built in a simulink to fulfill the objective of this study. This modeling is very important to form the different system components are integrated in a hybrid power system. Simulation studies were conducted in order to realize the functionality of the development models.

Keyword-Hybrid Power System, Diesel Electric Generator, Heat Exchanger, Boiler, Wind Turbine Generator, Photovoltaic Array

I. INTRODUCTION

Electric energy is the most popular form of energy. It can be easily transported at high efficiency and reasonable cost. In 1882, the first electric network in United States was established at the Pearl Street Station in New York City by Thomas Edison. The station supplied dc power for lighting. Come up with the new invention of transformer by William Stanley in 1885 to raise the level of ac voltage for transmission and distribution and invention of the induction motor by Nikola Tesla in 1888 to replace the dc motors [3]. From this invention, the system became apparent and more power can be produced conveniently at higher voltages [4].

Nowadays, the need for power system has been increasingly acute. Due to the unstable oil prices and increase of green house gases (GHG) have forced many utilities to explore hybrid power systems. Hybrid power system is served by two or more different power sources. In general, a hybrid system might contain AC diesel generators, DC diesel generators, an AC distribution system, a DC distribution system, loads, renewable power sources like wind turbines or photovoltaic power

sources, energy storage, power converters or a supervisory control system [1]. All this can be modeled with the matlab simulink.

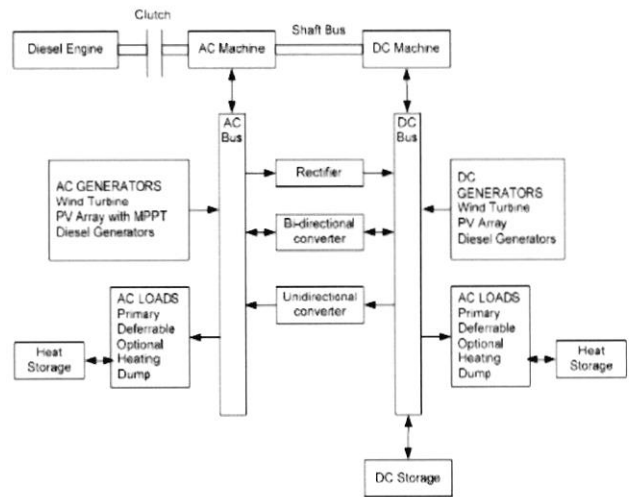


Figure 1: Hybrid Power System Configuration

II. COMPONENT OF POWER SYSTEM

The system including of five major subsystems: a diesel electric generator model, a heat exchanger model, a boiler model, a wind turbine generator model and a photovoltaic model.

A DEG can be represented as a prime mover and a generator. The prime mover is capable to supply any power demand up to rated power at constant frequency. To keep frequency constant, the diesel engine maintains the rotor speed constant by governor. The synchronous generator must be able to keep voltage constant at any load condition.

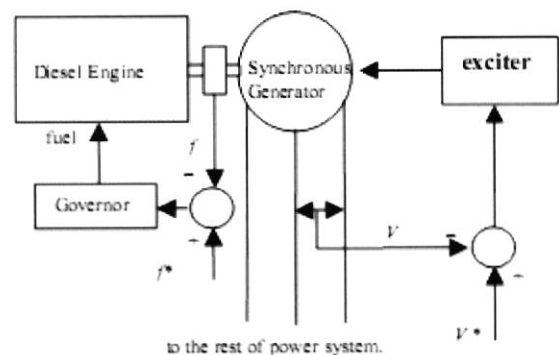


Figure 2: Diesel Generator Control Block Diagram

In hybrid power system, a DEG is used as a back-up generator in order to supply the electricity demand. Without battery bank, a DEG still kept spinning but an extra power from the WTGs and the PV array must be less than 20% of the load demand. The battery bank will take over to supplies the AC loads if the power available from the PV array and WTG is not enough to supply the AC load on the system. In this system, the heat exchanger functions as heat energy to supply the heating load. The boiler will combine with the heat exchanger to supply the heating load.

A WTG and PV array are the renewable energy in the hybrid power system. This renewable energy has the priority to supply the load. Wind energy is the fastest growing source of electricity around the world. In 2020, it is expected that the wind will supply about 12% of the world's electricity demand. For the solar energy, it uses radiation from the sun to provide heat, light, electricity and air conditioning for homes, offices and factories. This solar energy can be economical in applications. A WTG and a PV array supplies AC load through a DC/AC inverter and DC load through DC/DC converter.

This paper presents the modeling of various components of hybrid power system. A Simulink® model are used to evaluate the long term economic and environmental performance of stand-alone hybrid power system.

III. METHODOLOGY

The flow charts on developing the simulink model of the hybrid power system are listed below:

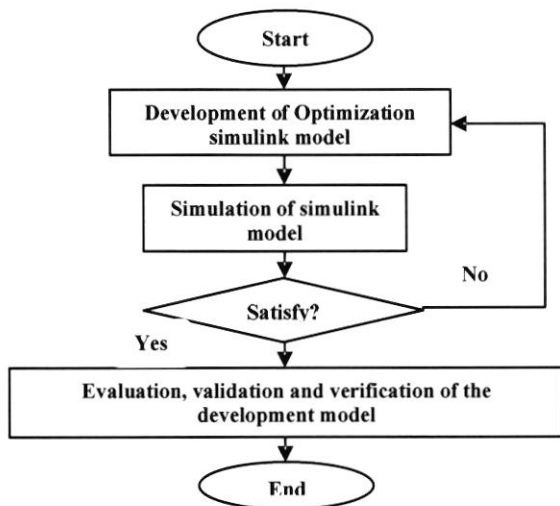


Figure 1.0: Flow chart of the optimization model.

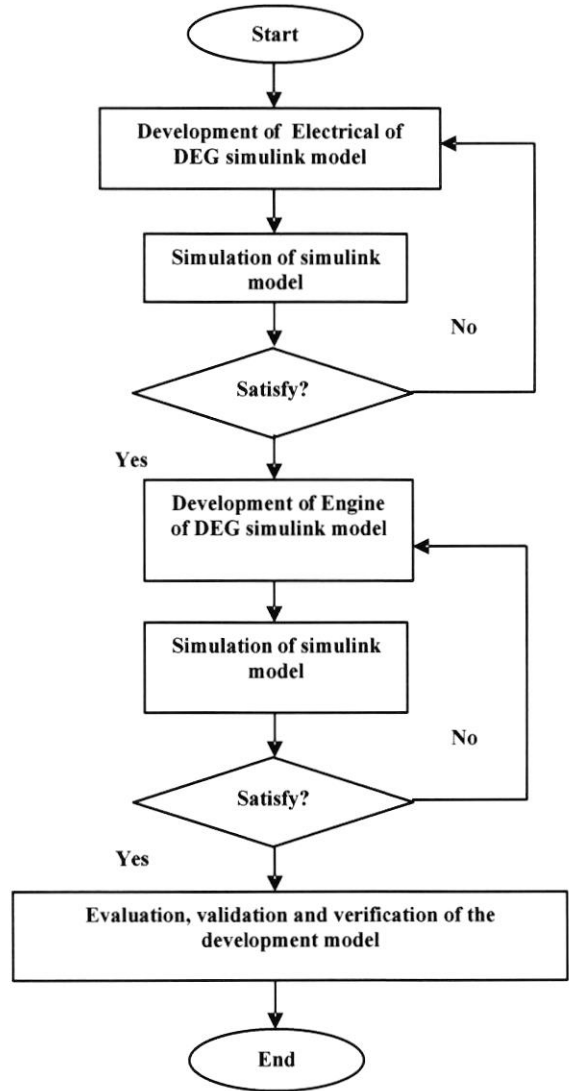


Figure 2.0: Flow chart of the DEG model.

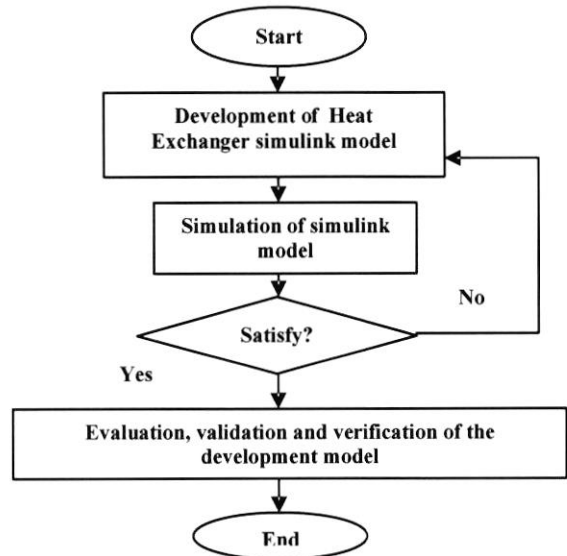


Figure 3.0: Flow chart of the Heat Exchanger model

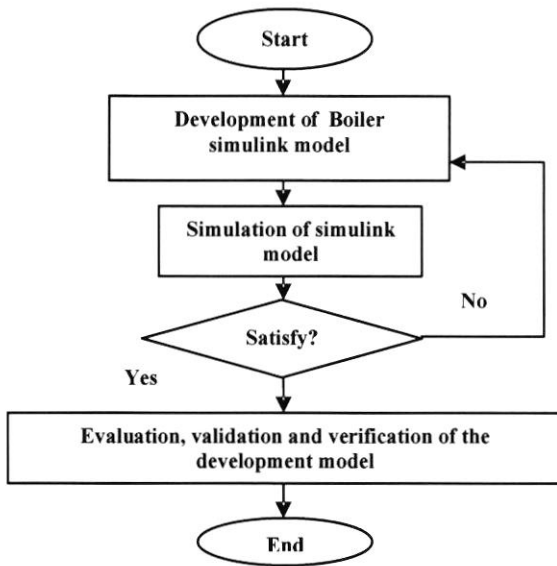


Figure 4.0: Flow chart of the Boiler model

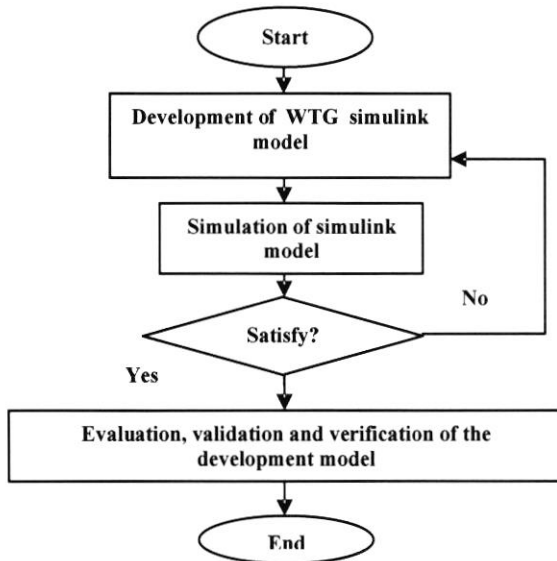


Figure 5.0: Flow chart of the WTG model

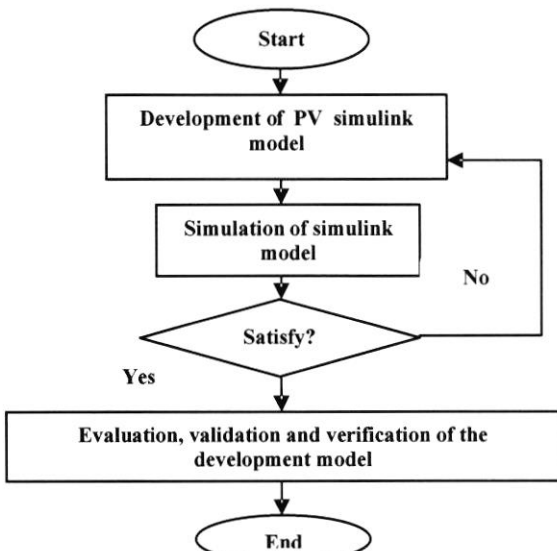


Figure 6.0: Flow chart of the PV model

IV. PROJECT DESIGN

A.1 Simulink Model

In this section, the dynamic simulation model consists of a DEG, a heat exchanger, a boiler, a WTG and a PV array are built using Matlab Simulink.

B. Design Parameter Values

The design parameter values of the system were as follow:

B.1 DEG input value

Load (kW)	Load (%)	Power Factor
8	38.095	0.9

B.2 Optimization input value

Input	Value
DEG load	50
kW_A	21000
kW_B	24000
Optimization point	10

B.3 Heat Exchanger input value

Input	Value
Mdot (g/m)	8400
T _{out} (F)	373.15 K
T _{in} (F)	293.15 K
Eta_HE	0.85

B.4 Boiler input value

Input	Value
Recovered kWh	1324387.3739
Boiler efficiency	0.82

B.5 WTG input value

Input	Value
Miles / hour	9

B.6 PV input value

Input	value
Insolation (kWh/m ² /day)	4

A.1 DEG Model

Figure below depicts the simulink model for Diesel Electric Generator. This model consists of electrical model and engine model

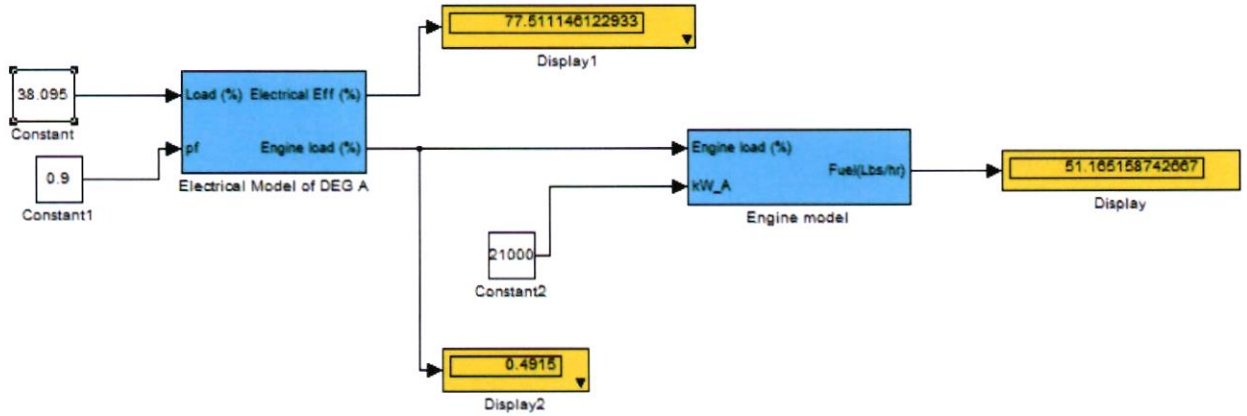


Figure 7.0: Detail of the Diesel Electric Generator Model Block

A.2 Optimization Model

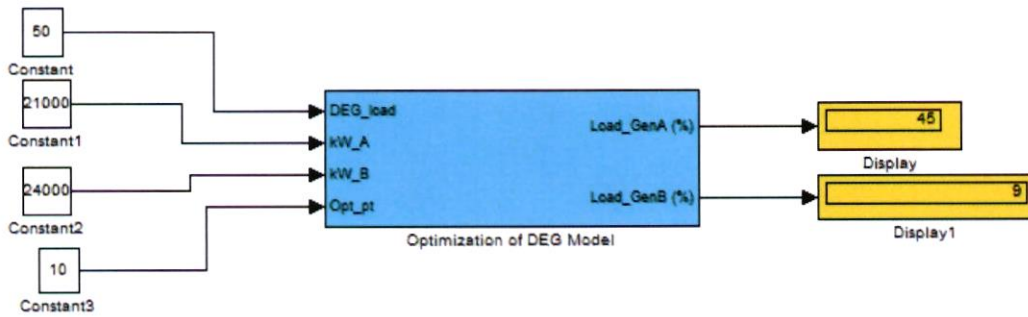


Figure 8.0: Subsystem for the Optimization Model Block

A.3 Heat Exchanger Model

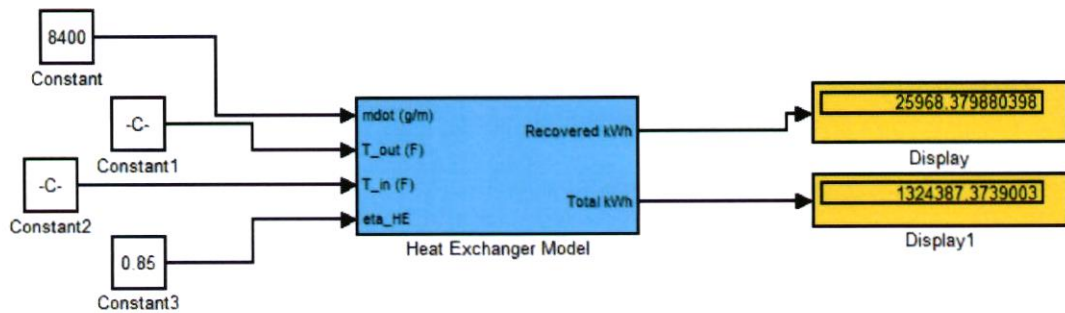


Figure 9.0: Subsystem of a Heat Exchanger Model Block

A.4 Boiler Model

Figure below depicts the simulink model for Diesel Electric Generator. This model consists of electrical model and engine model

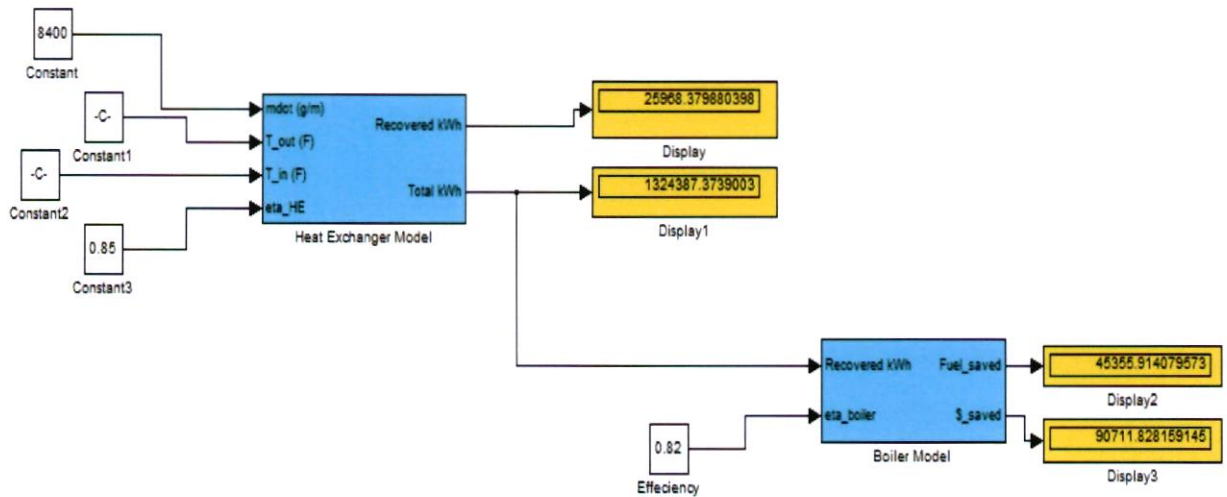


Figure 10.0: Detail of a Boiler Model Block

A.5 WTG Model

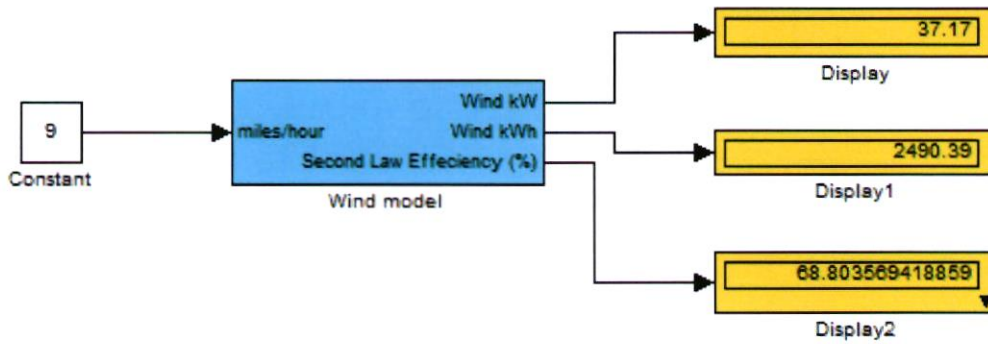


Figure 11.0: Detail of a Wind Model Block

A.6 PV Model

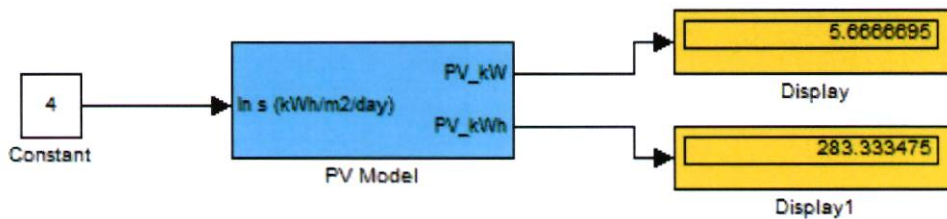


Figure 12.0: Detail of a PV Model Block

C. Theoretical Analysis

C.1 Diesel electric generator (DEG)

In this hybrid power system, the load demand falls below zero when the amount of power needed from the diesel generators are required to supply.

The algebraic equation of fourth polynomial fit for electrical efficiency curve at unity and 0.8 power factor are [1]:

$$\eta_{el1} = -6.953e - 9 * L^4 + 2.932e - 7 * L^3 - 9.858e - 4 * L^2 + 0.201 * L + 81.372 \quad (1)$$

$$\eta_{el2} = 1.540e - 7 * L^4 + 4.424 - 5 * L^3 + 2.996e - 3 * L^2 + 0.034 * L + 81.652 \quad (2)$$

Where 'L' is the load on the electric generator (%) Rating of the electric generator as given:

$$\text{Percentage load} = \frac{\text{actual load}}{\text{Generator rating}} * 100 \quad (3)$$

The electrical efficiency of generator for any given power factor (pf) by means of linear interpolations

$$\eta_{el} = \eta_{el2} + \left(\frac{(\eta_{el1} - \eta_{el2})}{0.2} * (pf - 0.8) \right) \quad (4)$$

The diesel engine load is obtained as follows:

$$L_{eng} = \frac{L_{gen}}{\eta_{el}} \quad (5)$$

' L_{eng} ' is the load engine, ' L_{gen} ' is the load generator and ' η_{el} ' is the electrical efficiency.

For the equation of linear curve engine fuel is given as:

$$\dot{F}c = 0.5 * \left(L_{eng} * \frac{kW - A}{100} \right) - 0.44 \quad (6)$$

$$\text{Total } Fc = \int_0^T \dot{F}c \cdot dt \quad (7)$$

' $\dot{F}c$ ' is the fuel consumption rate in kg/hr (lbs/hr), ' L_{eng} ' is the percentage load on engine, ' kW_A ' is the rating of electric generator, ' Fc ' is the total fuel consumed in kg (lbs), ' dt ' is the simulation step and ' T ' is the simulation period

C.3 Heat exchanger

The formula for the heat flux recovered from the jacket water of DEG using heat exchanger as below [1]:

$$\dot{Q} = \eta_{HE} * m * Cp * \Delta T \quad (8)$$

Where ' \dot{Q} ' is the rate at heat is transferred, ' η_{HE} ' is the efficiency of the heat exchanger, ' m ' is the mass flow rate of coolant, ' Cp ' is the specific heat of the coolant and ' ΔT ' is the different temperature of the coolant in and out of the jacket. While the formula of total heat recovered ' Q ' as below:

$$Q = \int_0^T \dot{Q} \cdot dt \quad (9)$$

This model also calculate the avoided pollutant including CO₂, PM₁₀, and NO_x.

C.4 Boiler

The boiler model block relate to the heat exchanger model block. The output from heat exchanger is supplied to a boiler. The fuel saved using the below equation:

$$Fs = \frac{Q}{HV * \eta_b} \quad (10)$$

Where 'Fs' is the total fuel saved due to heat recovery, 'Q' is the total heat exchanger, 'HV' is the heating value of the boiler fuel and ' η_b ' is the efficiency of the boiler.

C.5 Wind turbine generator (WTG)

In the designing of the wind turbine model, a couple of factor that important are the availability of the wind and the power curve of the wind turbine itself. The equation for a fifth order polynomial as below [1]:

$$P_{WTG} = -4.12e - 6 * S^5 + 7.58e - 4 * S^4 - 5.22e - 2 * S^3 + 1.59 * S^2 - 17.8 * S + 63.12 \quad (11)$$

$$E_{WTG} = \int_0^T P_{WTG} \cdot dt \quad (12)$$

Where the ' P_{WTG} ' is the power output from WTG, ' S ' is the wind speed, ' E_{WTG} ' is the energy obtained

from the WTG, 'T' is the simulation time and 'dt' is the simulation time-step.

For the second law efficiency of WTG calculate as below [1]:

$$\eta_{second_law} = \frac{actual_power}{max_possible_power} \quad (13)$$

Where ' η_{second_law} ' is the second law efficiency of WTG, 'actual_power' is the actual power output and 'max_possible_power' is the maximum possible power output from the WTG.

In wind turbine, the actual power is obtained from the power curve and the maximum possible power is obtained as follows:

$$P_{max} = \frac{1}{2} \rho . A . V^3 . 0.59 \quad (14)$$

Whereby Pmax is the maximum possible power, 'ρ' is the density of air taken as 1.225 kg/m³ at sea level, 1 atmospheric pressure = 101.325kPa, and temperature of 15.15°C, 'A' is the rotor swept area, 'V' is the velocity of wind and the factor '0.59' is the theoretical maximum value of power coefficient of the rotor.

$$\rho = \frac{p}{RT} \quad (15)$$

Where 'ρ' is the density of air, 'p' is the air pressure, 'R' is the gas constant and 'T' is the temperature.

C.6 PV model

The PV model used to calculates the PV power and the PV array using equation below:

$$P_{pv} = \eta_{pv} * ins * A * PV \quad (16)$$

$$E_{pv} = \int_0^T P_{pv} . dt \quad (17)$$

Where 'P_{pv}' is the power obtained from the pv array, 'η_{pv}' is the efficiency of the solar collector, 'ins' is the solar insolation, 'A' is the area of the solar collector, 'PV' is the rating of the PV array and 'E_{pv}' is the total energy obtained from pv array.

V. RESULTS AND DISCUSSIONS

In this section, the results of the various component from the simulation of the matlab simulink software was analysed and tabulated

DEG output value

TABLE VII
VALUE OF DEG USING MATLAB SIMULINK

Load (%)	Electrical Efficiency (%)	Fuel (lbs/hr)
38.095	79.52	78.88

VALUE OF DEG BY CALCULATION

Load (%)	Electrical Efficiency (%)	Fuel (lbs/hr)
38.095	84.291	66.96

Optimization output value

TABLE VIII
VALUE OF OPTIMIZATION USING MATLAB SIMULINK

Output	Value
Load Generator A	45
Load Generator B	9

Heat exchanger output value

TABLE IX
VALUE OF HE USING MATLAB SIMULINK

Output	Value
Recovered kWh	25968.3798
Total kWh	1324387.3739

VALUE OF HE BY CALCULATION

Output	Value
Recovered kWh	25160
Total kWh	1283160

Boiler output value

TABLE X
VALUE OF BOILER USING MATLAB SIMULINK

Output	Value
Fuel saved	45355.9141
\$_saved	90711.8281

VALUE OF BOILER BY CALCULATION

Output	Value
Fuel saved	43944.01
\$_saved	87888.02

WTG output value

TABLE XI
VALUE OF WTG USING MATLAB SIMULINK

Output	Value
Wind kW	37.17
Wind kWh	2490.04
Second law efficiency	68.80

VALUE OF WTG BY CALCULATION

Output	Value
Wind kW	31.72
Wind kWh	2125.24
Second law efficiency	69.12

PV output value

TABLE XII
VALUE OF PV USING MATLAB SIMULINK

Output	Value
PV kW	5.6667
PV kWh	283.3335

VALUE OF PV BY CALCULATION

Output	Value
PV kW	5.6667
PV kWh	283.333475

Each device was simulated individually. From the observation, it can be seen that values of the system using simulink and by calculation are totally different except for the PV model.

Table VII shows the efficiency of DEG model by calculation is 84.29% and by simulation 79.52%. These values show that the simulation value using matlab simulink is less efficient. When the DEGs is less efficient, the saving in fuel consumption also not as save as theoretical. The efficiency for diesel generator will drop extremely when it operates less than 40% of full load. In addition, when diesel generator is operating less than 40% of full load, the frequency maintenance increased.

Table IX tabulate the rate heat is transferred, 25968.3798 kWh and total heat recovered, 1324387.3739 kWh is greater than calculation values.

From the table X, the input of the boiler model is an output from the heat exchanger model. When the output of the heat exchanger model is high, the output of the boiler will also high.

The preliminary results of this project can be approached by develop both component more efficient so that the fuel consumption can be reduced. Furthermore, it will reduce the growing of pollutant.

7.0 Future Development

Future work in developing the hybrid components using simulink model includes the testing and updating of all equipment. Upon completion of the hybrid components, the overall model can be simulated to verify its accuracy. It is suggested to explore data for all the actual corresponding equipment for future development.

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