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Development of a Simulation for a Solar Powered Engine Using Matlab/Simulink

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Authors' contributions

This work was carried out in collaboration between both authors. Author BOA identified the criterion to be measured, develop the models required while author SAA carried out the literature searches and the software development. Both authors read and approved the final manuscript. Authors do acknowledge our student J. P. Eche for his help in area of data collection and development of some required interface.

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ABSTRACT

This research focused on converting Solar energy into electrical and mechanical energy for the development of transmission system of a Solar Powered Vehicle (SPV) with the use of a DC motor, thereby eliminating the use of fuel and air. A computer simulation model was developed and tested to achieve this goal. The research identified the components for solar powered engine configuration, parameters required for the configuration, developed the required mathematics models, developed the flow chart for the simulation and computer software using Graphics User Interface (GUI) and MATLAB/SIMULINK interface model for the implementation of the mathematical model identified and adopted. This makes it easy to carry – out design and it reduces time consumption. The simulation results for Powered Vehicle (PV) model are: photo – current (Iph) 75800A, cells reverse saturation current (Irs) 7.2626e – 40A, reverse saturation current (Is) 5,17577e109, diode saturation current 1 mf voltage – resistor current Iv 5.5875A, model current Im – inf and model power Pm – inf. The Simulink gave the values of combined DC motor and battery as: voltage 0.2929 V, system on chip SOC 0.7624, angular speed (ω_m) 838.9 rad/s and armature

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current Ia -3.645 A. Solar MSX60 specifications (1000 W/m^2, 25℃ was used as case study. As seen from the motion curves of the parts (battery), the model starts to operate very quickly. This is to confirm the behavioural aspect of the system and it shows that the model gives better accuracy in the process of computation of data's GUI under MATLAB and Simulation process in SIMULINK.

Keywords: Solar energy; simulation; solar engine; designed (models; software development).

1. INTRODUCTION

The achievement of Solar Powered Car capable of continuous motion for a specified or long distance was still a dream years ago, but this great challenges have been realized in the domains of transportation aids, security systems, refrigeration services, villages industrial power hybrid cars and corrosion protective instrument. The background of this study covers the simulation model for solar powered vehicle (SPV) in providing the needed rotational motion for the wheel of the solar car. Only with emphasis on renewable energy, will people be able to look confidently to a future that is healthier more secure and economically feasible?

Solar energy produces clean and virtually unlimited power [1,2]. This provides an existing solution to the problems encountered in the depletion of fossil fuels. In addition to the public uses of this petroleum base energy such as personal transportation in business and light generations (generations at home and individual companies); combustion of carbon based petroleum derivative generates the infamous green – house effect (carbon dioxide; CO_2), which continually leads to global warming and the main source of air pollution in the cities. This has led to the researches made in the provision of programs such as to design low emission (LEV) and zero emission (ZEV) vehicle [3,4]. The search for alternative energy coming from the sun has led to the development of building of a solar powered vehicle using the energy gotten from the sun. Solar power is a form of energy derived from the sun using photovoltaic (PV) or solar panels [5,6]. Solar panels are the major component of a solar power system, which aid the conversion of light energy from the sun to direct current (DC) electric voltage [7]. Photovoltaic panel seen as a semi – conductor is static, free of moving parts, and these responsible for its low operation and maintenance cost [8].

It was revealed through literature that [9], developed an optimal decision and dynamic simulation of a hybrid solar vehicle. The paper deals with a detailed study on the optimal sizing of a solar hybrid car, based on a longitudinal vehicle dynamic model and considering energy flows, weight and cost. [10] showed in their research that stirling engines working with relatively low temperature air are potentially attractive engines of the future, especially solar – powered low temperature differential Stirling engines with vertical, double – acting and gamma – configuration. This was also confirmed by [11,12].

Considering the facts that the cost posed to PV system in terms of fabricating is high and the conversion efficiency is low, the skyrocketing oil prices make potentially long – term benefits [13]. Photovoltic module represents the fundamental power conversion unit of a PV generators system [14]. The output characteristics of PV module depend on the solar insolation, the cell temperature and output voltage of the PV module [15-17]. Since PV module has non – linear characteristics, it is necessary to model it for design and simulation of maximum power point tracking (MPPT) for PV system applications.

The light from the sun being reflected on the solar panel provides, a rotational motion to the motor which acts as a machine in the conversion of electrical energy to mechanical energy thereby powering the wheel of the solar car [18].

This research involves the background study of the energy being generated of light to electrical energy and then to mechanical energy in the transmission system of the SPV with the use of a DC motor, eliminating the use of fuel and air and a computer simulation to back the study.

The simulation model designed makes it possible to experiment with a wide set of variations in order to determine the optimum solution, since changes on the design can be made easily in a simulated system. The solar vehicle is a step in saving this non – renewable source of energy.

2. METHODOLOGY

The component for the configuration of the solar powered engine, parameters required, the mathematical model were identified. The logic chart and computer model for the implementation of the software were also developed.

2.1 Design Procedure

The design procedure of the solar powered vehicle involved: chassis building, connection of the rotational motion gotten from the solar energy generation, integration of the solar panel and motor, transmission of the power derived from the solar panel from the motor to the wheels of the vehicle and how to make the shell effects car performance.

Generally, all the force generated is transmitted through the driven wheels, so the weight increased the traction where it is needed. Hence, weight distribution is very important, since traction can be increased by moving existing weight from one part of the car to the other.

The functional flow required in this simulation for a solar car is from the sun to the solar panel to the batteries to the DC motor to the belt and chain drives and finally to the wheel of the vehicle.

2.2 The Solar Powered Vehicle Simulation Model Design Procedure

The procedure for solar powered vehicle simulation model involves: strategic decisions identification, model development (mathematical equations), software development and data collection. These were integrated as shown in Fig. 2.1.

2.2.1 Strategic decisions considerations

These are the positioning of the solar panel, type of panel to be used, storage tank (the lead-acid accumulator which stored energy using a reversible chemical reaction) and its capacity, the power required to drive the solar powered vehicle, total weight which the SPV can carry, solar tracking devices and how to transfer the derived power from the solar panel and from the motor to the wheel of the vehicle.

2.2.2 Solar panel model

Double exponential model was adopted from [5] for a PV panel shown in Fig. 2.2.

From Kirchhoff Current law,

$$I = I_{ph} - I_{D1} - I_{D2} - I_V \qquad (2.1)$$

$$I = I_{ph} - I_{S1}\left(e^{q\left(\frac{V+IZR_S}{KT}\right)} - 1\right) - I_{S2}\left(e^{q\left(\frac{V+IZR_S}{KT}\right)} - 1\right) - \left(\frac{V+IZR_S}{R_{sh}}\right) \qquad (2.2)$$

Where:

I_{ph} = Panel Current (A)

I_{D1} & I_{D2} = Diodes Current (A)

I_{S1} & I_{S2} = Reverse Saturation Currents (A)

V = Input Cell Voltage (V)
I = Input Cell in Current (A)
Z = number of cell in series.
q = Charge (1.602 x 10^{-19} C)
R_s = Series Resistance (Ω)
R_p (R_{sh}) = Shunt Resistance (Ω)
K = Boltmann Constant (1.38066 x 10^{-23}) J/Kg

$$I_{RS} = I_{SC} / \left(\exp(qVoc / N_S KAT_C) - 1\right) \qquad (2.3)$$

$$I_{ph} = I_{SC} + K_i\left(T_C - T_{ref}\right)S \qquad (2.4)$$

$$I_S = I_{RS}\left(\frac{T_C}{T_{ref}}\right)^3 = \left(e^{qE} G\left(\frac{1}{T_{ref}} - \frac{1}{T_C}\right)\right) \Big/ K_i A \qquad (2.5)$$

Where:

T_c and T_{ref} = Cell temperature and reference temperature respectively (Celsius)
S = Solar Irradiance (W/m)
A = Ideal Factor
I_{RS} = Cells reverse saturation current at a reference temperature and a solar irradiance (A)
K_i = Cell Short Circuit Current Coefficient
E_G = Band gap energy of a semi – conductor used in the cell
I_{SC} = Short circuit current

2.2.3 Battery model

The most popular equivalent circuit model used by researcher as the improved battery model (Casacca and Salameh 1992; Salameh, Casacca et al. 1992). This model is simple but meets most requirements for good battery model.

This is as shown in Fig. 2.3, in which C_1, R_1 and R_o are the elements of the internal impedance Z_m

R_2

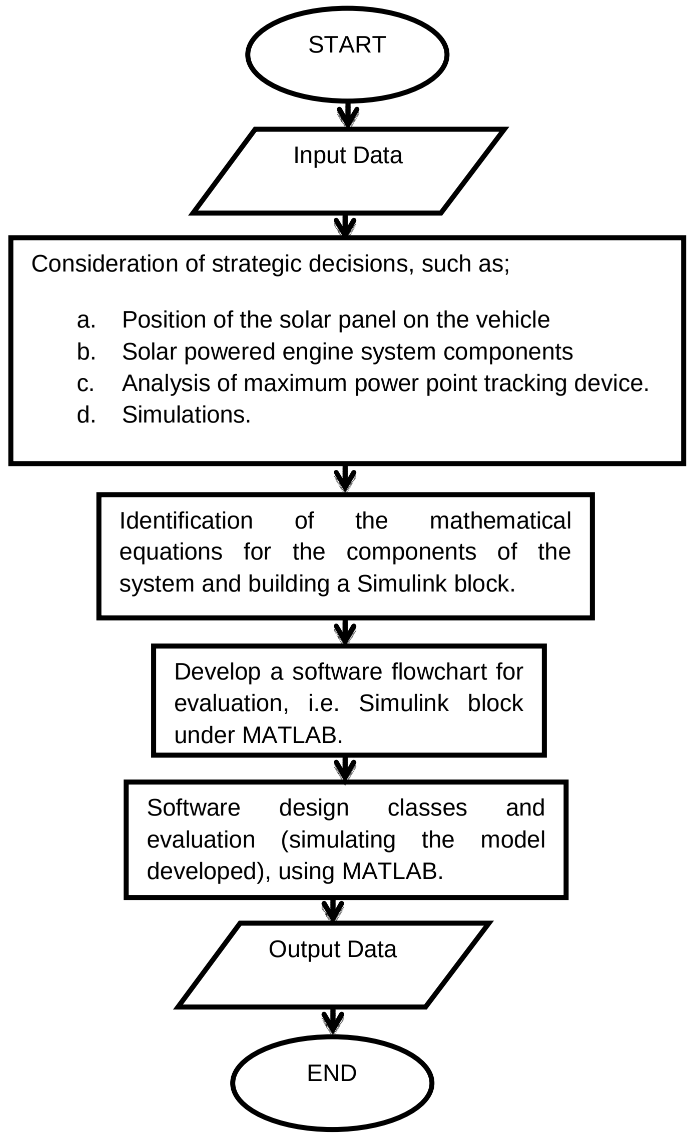

Fig. 2.1. Solar powered engine simulation model design procedure

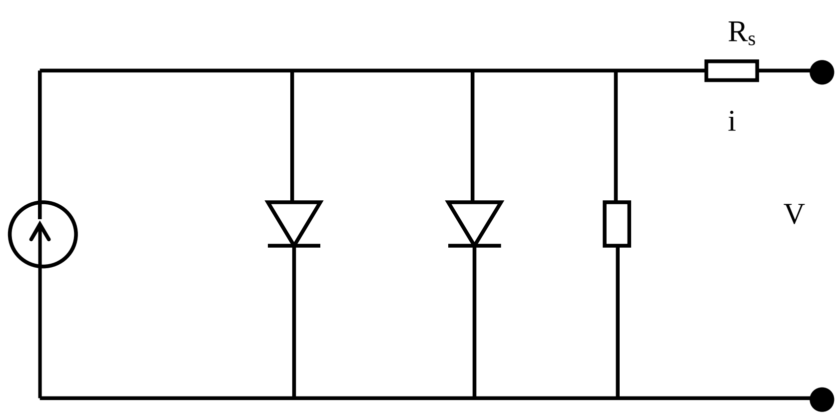

Fig. 2.2. Equivalent circuit for a double exponential model for a PV Panel

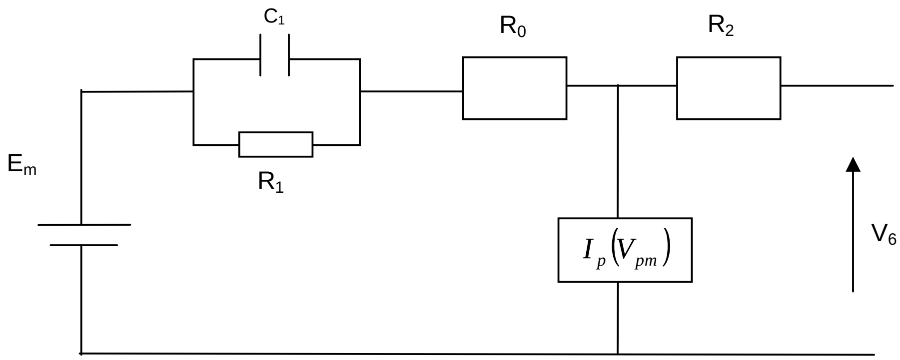

Fig. 2.3. Equivalent circuit for a lead and battery

Considering the behavior of capacity, state of charge and depth of discharge, electromotive force and internal resistance, an improved battery model based on the equivalent circuit shown in Fig. 2.3 was introduced.

The battery model for the complete discharging progress was derived by [19,20] and written in the research work of [21] as follows:

$$C(I,\theta)=\frac{K_c C_o\left(1+\frac{\theta}{\theta_f}\right)^{\varepsilon}}{1+(K_c-1)(I/I*)^m} \tag{2.6}$$

$$Q_e(t)=\int_0^1 I(\sigma)d\sigma \tag{2.7}$$

$$SOC=1-Q_e/C(0,\theta) \tag{2.8}$$

$$DOC=1-Q_e/C(I_{avg},\theta) \tag{2.9}$$

$$E_m=E_{mo}-K_E(273+\theta)(1-SOC) \tag{2.10}$$

$$R_0=R_{00}[1+A_0(1-SOC)] \tag{2.11}$$

$$R_1=-R_{10}In(DOC) \tag{2.12}$$

$$C_1=\frac{\tau}{R_1} \tag{2.13}$$

$$V_{R1}(t)=R_i\left(1-e^{\frac{t}{\tau}}\right).I \tag{2.14}$$

$$P_s=V_{RI}^2/R_1+I^2..R_o \tag{2.15}$$

$$C_\theta\frac{d\theta}{dt}=\frac{\theta-Q_a}{R_\theta}+P_s \tag{2.16}$$

Where:

C(I, θ) = Capacity of battery when discharging (F) at a particular discharge current and temperature

I = Discharge Current (A)
θ = Temperature (^{o}C)
C_{o*} = Capacitance when discharging (F)
I* = Dispated discharged current (A)
θ_f and ε = Constraints in the model
$\theta_e(t)$ = Charge already consumed
E_m = Electromotive force corresponding to the SOC and the cell temperature (V)
E_{mo}, K_E = Constants for a battery
R_{oo}, R_{10} = Parameters related to the SOH
τ = Time constant of the R – C circuit which represents the time at takes it takes the system's step response to reach (1 – 1/e = 63%) of its (sec) asymptotic value
DOC = Depth of Discharge
SOC = State of charge of the battery

The last two equations 2.15 and 2.16 represent. The thermal dynamic of battery, in which

P_s = Joule heat generated by internal resistant (D)
C_θ = Thermal Capacity (J)
R_θ = Thermal resistance between the battery and the environment (Ω)

The improved battery model based on the electric equivalent circuit satisfied the requirements to serve these research objectives.

And the energy stored E_c is given by:

$$E_C = \frac{1}{2} C V_C^2 \quad (2.17)$$

Dc motor model equation

$$Vt = Rala + La \frac{d1a}{dt} + Ea \quad (2.18)$$

$$T = J \frac{d\omega}{dt} + B\omega - T_1 \quad (2.19)$$

$$Ea = Ka\omega \quad (2.20)$$

$$\frac{d\omega}{dt} = \phi$$

With the following physical parameters:

Ea = Input terminal voltage (source) (v)
Ra = Armature resistance (Ω)
1a = Armature current (A)
La = Armature inductance (H)
J = The moment of inertia of the motor rotor and load (Kg.m^2)
T = Motor torque (Nm)
ω = The speed of the shaft and the load (rad/s) (angular velocity)
ϕ = The shaft position (rad)

2.2.4 Dc motor model

The equations required for DC motor modeling were as stated in equation 2.18 and 2.19 i.e [$Vt = Rala + La \frac{d1a}{dt} + Ea$ and $T = J \frac{d\omega}{dt} + B\omega - T_1$] respectively.

2.2.5 Logic of the model

The integration of the mathematical model for solar panel batteries and DC motor is as shown in Fig. 2.4.

2.2.6 Building the simulink block diagram

Simulink block diagram are tool use for building a model before simulating it whether the model will work or not. After identification of the mathematical equations that describe each system, the next stage was to begin building a block diagram, of the desired model in Simulink.

During the process of building each component to reduce bulkiness, the block diagram was subdivided into subcomponents which are: solar panel model, current model, diode current model, solar car battery model, and solar powered engine model. These are shown in Figs. 2.6 to 2.12 on the appendices.

The graphic user interface of the PV panel is as shown in Fig. 2.5.

The GUI was used in the development of the computer software for the computations of the various components that makes up the system SPV based on the manufacturers specifications on each components.

2.2.7 Simulation

The simulation step developed for the designed powered vehicle is shown in Fig. 2.6.

The model of the solar panel for the system was built into four subsystems: generated panel current model, generated voltage current model, diode current model, and solar car battery model.

2.2.8 Software development

The Graphics User Interface (GUI) was used in the development of the computer software for the computations of the various component that makes up the system (SPV). GUI seen as a user friendly environment aid in the computation of the model parameters based on the manufacturers specification on each component. Above all, SIMULINK under MATLAB was used as the computer model to Simulate the abstract model and behaviour of the system (SPV).

Table 2.1 Identified parameters identified by the genetic algorithms in the model of 12V – 1.3Ah Lead – acid battery

Parameter	Value	Parameter	Value
C_0	4819.8 (Amp – sec)	E_{mo}	2.1465 (v)
K_E	0.001109 (V)	A_o	2.9895
R_{oo}	0.01038 (Ohm)	R_{10}	0.12196 (ohm)
Y_1	210.52 (s)	Y_2	12.564 (S)

Source: [20] and [21]

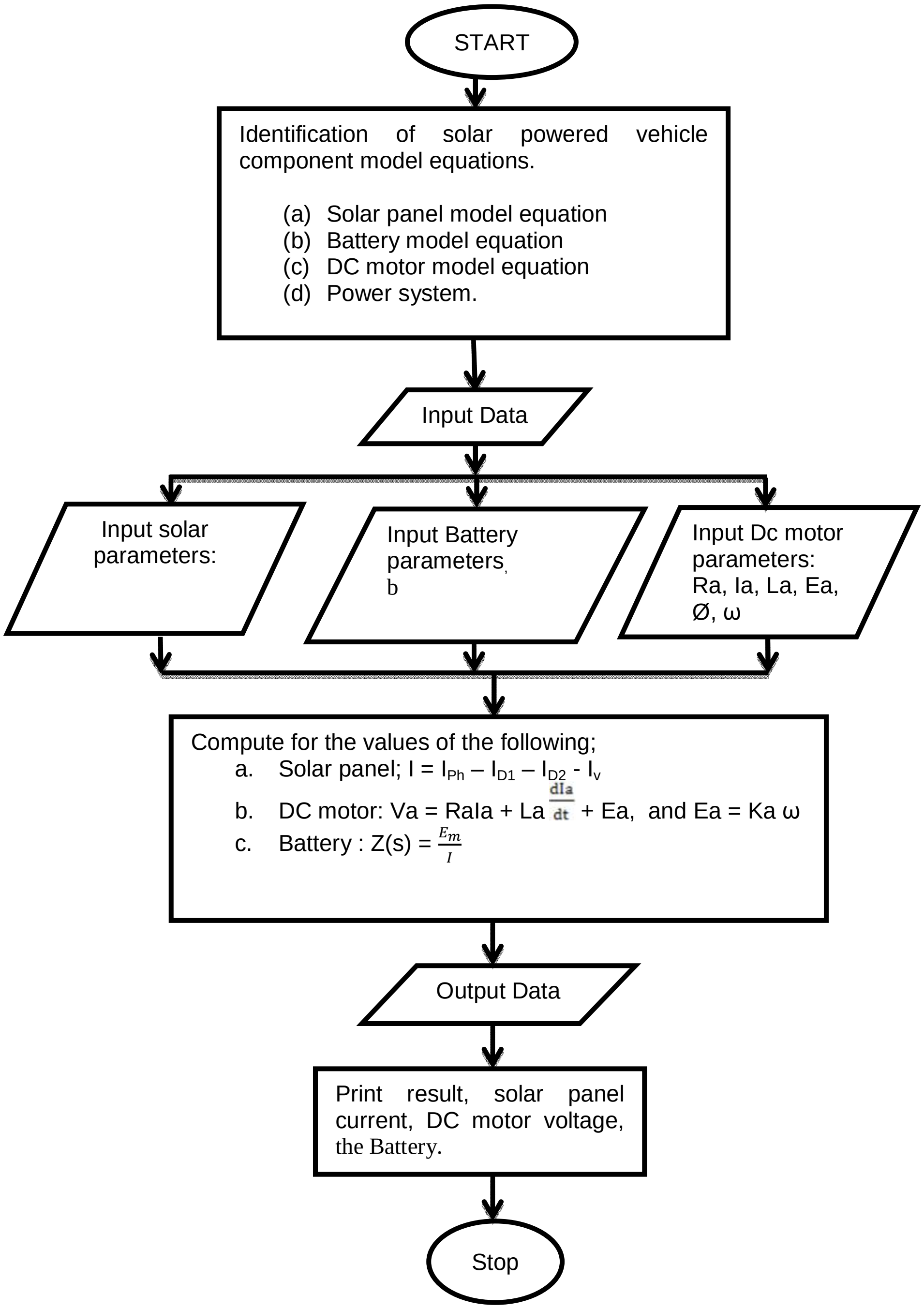

Fig. 2.4. Flow chart showing the relationship of the mathematical model of SPC

3. RESULTS AND DISCUSSION

The software and model developed in the GUI and model both interface of MATLAB/SIMULINK makes it easy to carry – out design and it reduced both design time consumption and error.

The mathematical models for the designed components were as shown in the Table 3.1.

The model of the solar panel for the system was built with three stages subsystem, thereby integrating them to single model. These subsystem models are the solar panel, generated voltage and diode current.

The models shown in Table 3.1 were used to build the solar panel shown in Fig. 3.1.

The Simulink implementation of the solar panel as the major component of PV system is shown in the Fig. 3.1. Parameters gotten from Table 3.1 (solar MS X 60 specifications) was used in testing the model developed. During the purchase of a desired power rating of a solar panel for a SPV, parameters such as the ones listed in Table 3.1 were given. These values were used to test the model developed in Fig. 3.1. The result obtained for the solar panel current was equal to infinity. For the purpose of accuracy and user friendly environment, the graphics user interface was developed as shown in Fig. 3.2. These represent the computer software of the solar panel configurations. The full results obtained during the process of computation in the graphic user interface are shown in Table 3.2. The value of the model current was found to be the same, which describes the accuracy of the model.

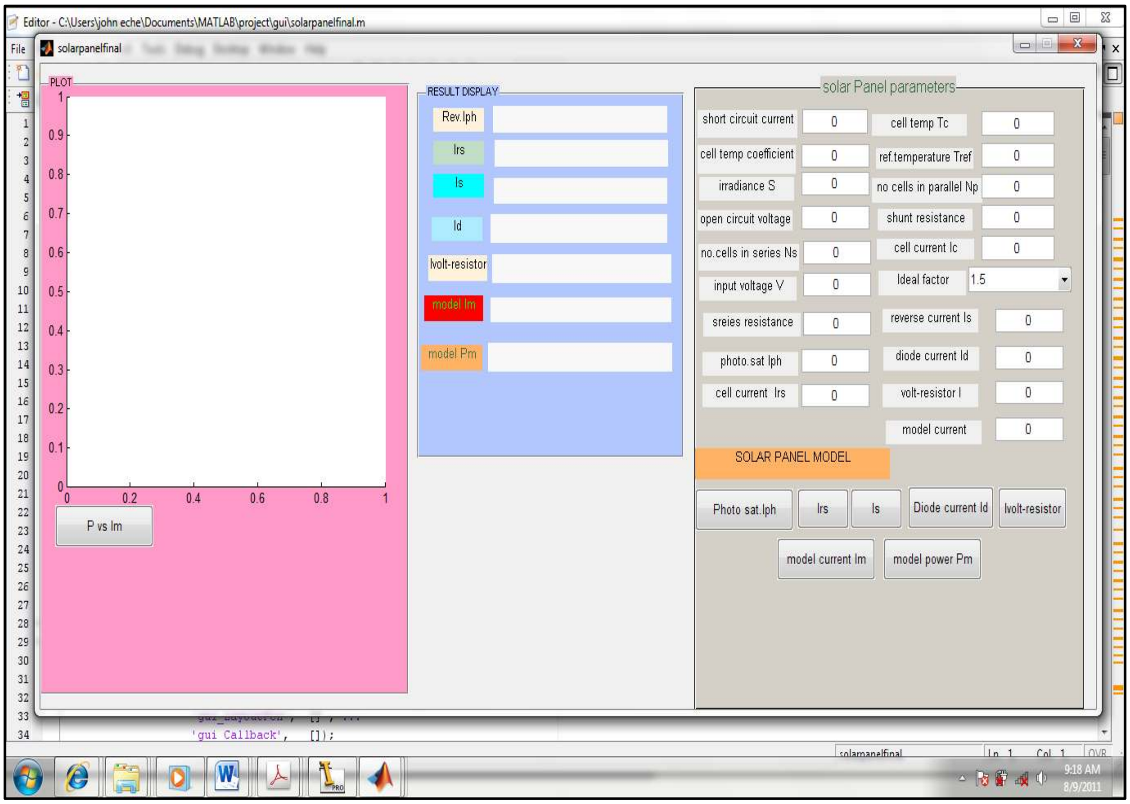

Fig. 2.5. Graphic user interface (GUI) of PV panel

Table 3.1 Components and models used for design

S/N	Component	Model
1.	Solar Panel	$I = I_{ph} - I_{S1}\left(e^{q}\left(\frac{V + IZRS}{KT}\right) - 1\right) - I_{S2}\left(e^{q}\left(\frac{V + IZRS}{KT}\right) - 1\right) - \frac{V + IZRS}{R_{sh}}$
2.	Battery Energy Stored	$E_C = \frac{1}{2} CV_C^2$
3.	Motor Direct Current	$Vt = Rala + La\frac{d1a}{dt} + Ea$
4.	Motor Torque	$T = J\frac{d\omega}{dt} + B\omega - T_1$

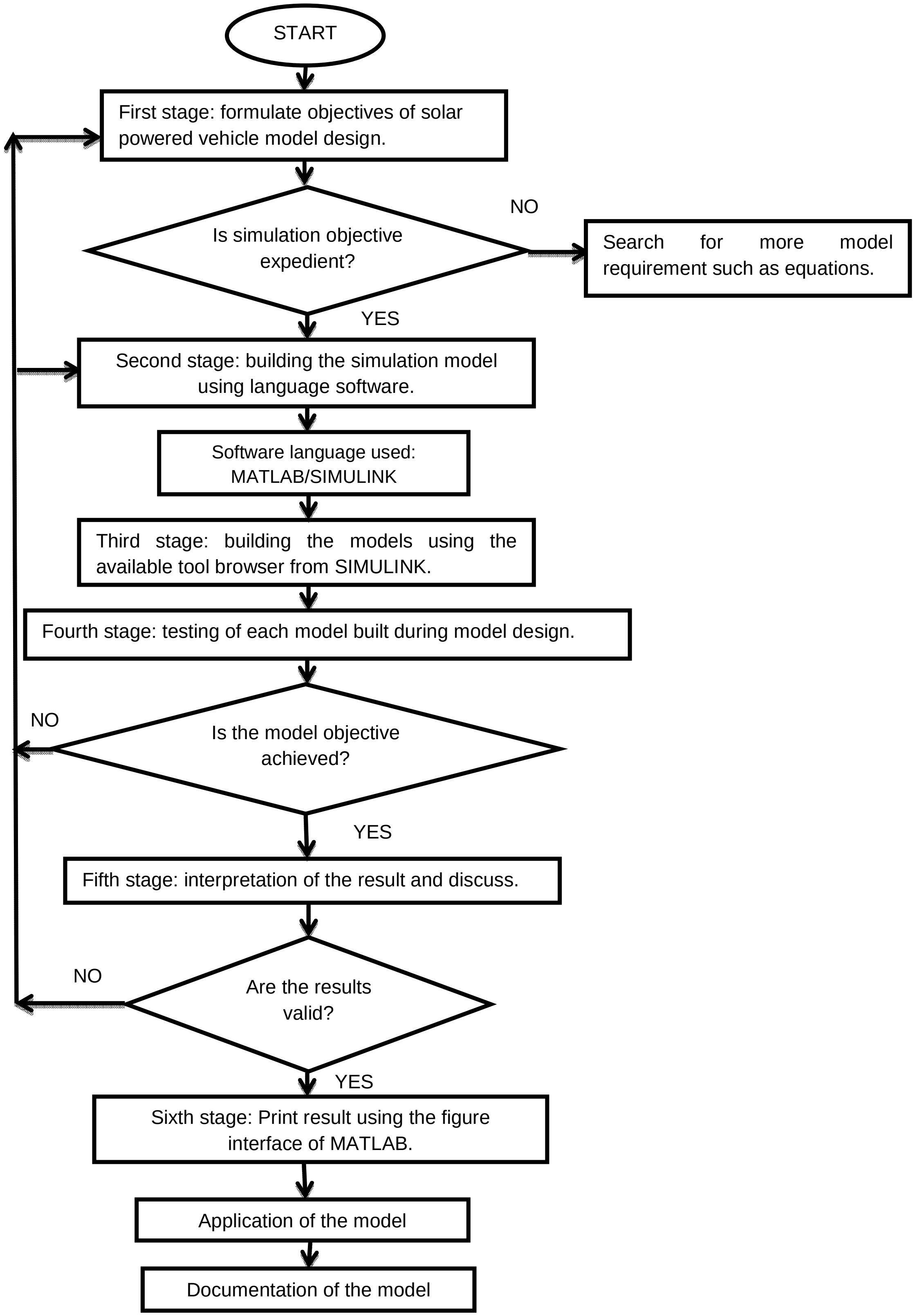

Fig. 2.6. Solar powered vehicle simulation model flowchart

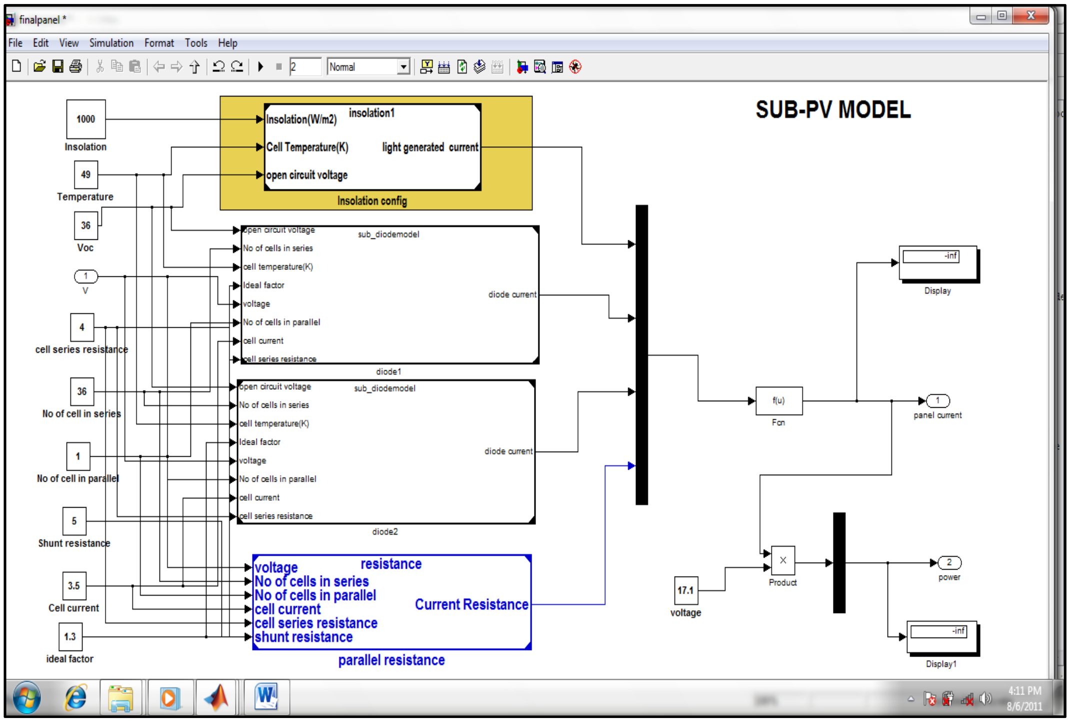

Fig. 3.1. Simulink implementation of the expression of PV panel

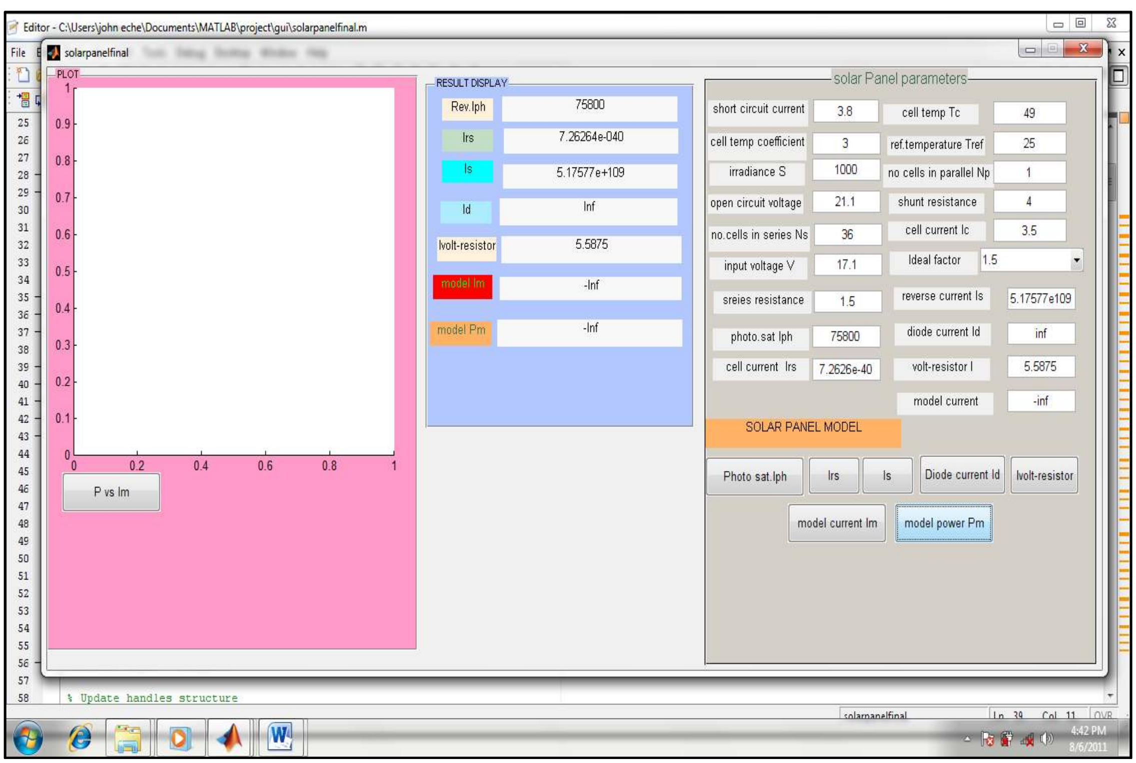

Fig. 3.2. GUI implementation of the expression of PV panel

3.1 Battery and DC Model

The Fig. 3.3, shows the Simulink implementation of the battery. Parameters from Table 3.3 were used in testing the model.

Similarly, the Simulink implementation of the combined model of Dc motor and battery is as shown in Fig. 3.3. Values from the Table 3.2 were used for application of the model developed and the result obtained from of simulation is displayed on the graph in Fig. 3.3 (scope dialog box). The model panel current used as the input variable was 50A (the value of current at which the model is stable, during simulation). This is a result of the model stoppage caused by the infinity value of the current.

The graph shown in Fig. 3.4 proved the behaviour of the SPV model can be seen to be stabled at 50 amperes and above it, it begins to experience instability. Values of the output parameters calculated during simulation are as shown in Table 3.5.

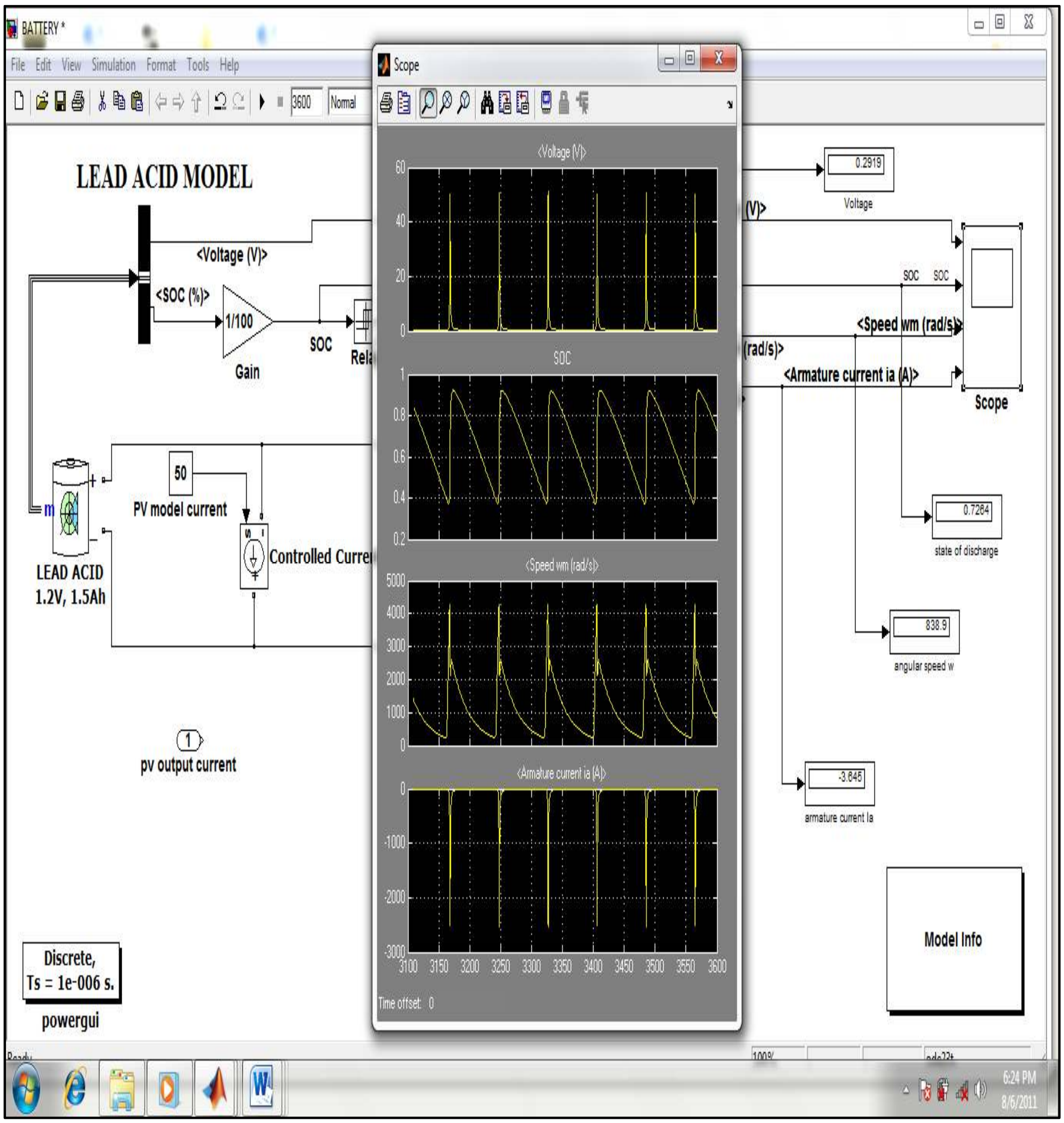

Fig. 3.3. Simulink implementation of the expression of battery and Dc motor

From the simulation results shown graphically on the scope dialog box of Simulink in Fig. 3.3, the values of each output V, SOC, ω_m, I_a, was found to be stable at I_m equals 50A. The summary of the maximum and minimum value are as shown in Table 3.6.

Table 3.2. Summary of simulation result for PV model

Parameters calculated (simulation)	Results
I_{ph} (photo-current)	75800A
I_{rs} (cells reverse saturation current)	7.26264e-40A
I_s (reverse saturation current)	5.17577e109
I_d (diode saturation current)	inf
I_v (voltage-resistor current)	5.5875A
I_m (model current)	-inf
P_m (model power)	-inf

Table 3.3. Solar MS X 60 specifications (1000 W/m^2, 25℃)

Characteristics	Specifications
Typical peak power (PP)	60W
Voltage at peak power (Vp)	17.1V
Current at peak power (Ipp)	3.5A
Short circuit current (Isc)	3.8A
Open circuit voltage (Voc)	21.1V
Temperature coefficient of open circuit voltage (Kp)	-73mV/℃
Temperature coefficient of short circuit current (Ki)	3mA/℃
Approximate effect of temperature on power	-0.38/℃
Nominal operating cell temperature (NOCT)	49℃
Reference temperature Tref	25℃

Source: [16]

3.2 Discussion

The core aim of the simulations was to show, that the model actually runs and that the behaviour is based on the execution of a solar powered vehicle, which corresponds to the behaviour described in the literature. As seen from the motion curves of the parts (battery), the model starts to operate very quickly. This is to confirm the behavioural aspect of the system and it shows that the model gives better accuracy in the process of computation of data in GUI interface under MATLAB and the simulation process in the Simulink.

The model and computer software developed makes it easy to carry-out design and reduce time wastage in designing. Simulations are powerful tool used for evaluating the theoretical performance of different systems, which is of great importance and contribution to the automobile industry.

The math works software package (MATLAB) includes the simulation tool gotten from Simulink library browser used in building the model. Above all, the objective of this research work was achieved by the algorithms, flowcharts, and the procedures mentioned under methodology of this research.

Table 3.4. Parameters specification for DC motor

Characteristics	Specifications
Armature resistance (Ra)	0.4832Ω
Armature inductance (La)	0.006763H
Moment of the rotor and load (Kg.m^2)	0.2053
K_b	0.015
K_f	0.2

Source: [17]

Table 3.5. Summary of simulation result for combined model of DC motor and battery

Parameters calculated (simulation)	Results
Voltage	0.2919V
SOC	0.7624
Angular speed (ω_m)	838.9rad/s
I_a (armature current)	-3.645A

Table 3.6. Description of the simulation graph of DC motor

Parameters calculated (simulation)	Maximum	Minimum
Voltage	50 V	0 V
SOC	0.9	0.39
Angular speed (ω_m)	4200	200
I_a (armature current)	0	-2500

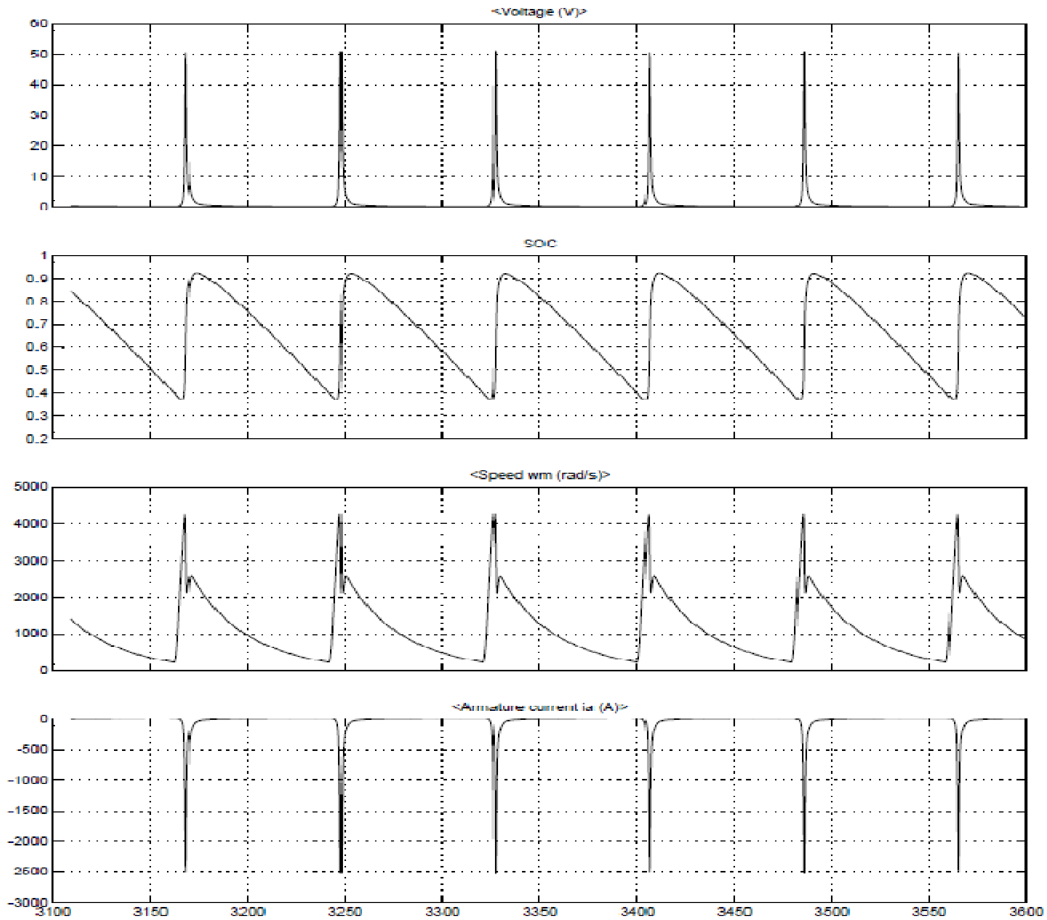

Fig. 3.4. Result of simulation (Scope)

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

The aim of this research work was to develop a simulation model for a solar powered vehicle. A library of mathematical models were identify for each component of the solar powered vehicle system, namely solar panels, battery, and dc motor. The developed models were done in the SIMULINK environment of MATLAB (Simulink-version 2008a), which is a suitable tool for further development and investigation of the dynamic behaviour of the SPV system.

A flow chart representing the relationships between the tasks involved in the development of the simulation model for solar powered vehicle were developed, in order to identify the require computer sequence of operation to be used in modelling and translate the logical set of programs. The evaluation of the model was performed through the testing of standard values of each component gotten from journals and the internet (standard). This in turn gives the value of the results shown in Table 3.1 and Table 3.5 for PV panel and battery – Dc motor model respectively. With the result obtained, by varying the amount of current used in the simulation of battery-Dc motor model, it shows that at 50 amperes, the system begin to experience stability.

Above all, the sets of programs and model developed were carried-out within the set objectives of this study by developing a simulation model for a solar powered vehicle and examining the behaviour of the system.

4.2 Recommendation

Concerning the future frame work in the field of automobile industry, this study revealed that there is need for:

a. More experiment to be carried-out on theoretical part of the model based on the result obtained in the process of simulating the model.
b. Due to ambiguous nature of PV panel produce, the need for size reduction should also be considered, and still gives the desirable objectives required.
c. A rheoretic approach was used to carry-out the simulation model for the DC motor. A DC machine component was used in place of Dc motor. Further implementation of the model due to the availability of the library browser during modelling.

In the area of usage of solar panels, though the efficiency is not at it optimum point, however it is necessary to consider the long-term approach of ensuring that as we embrace this part of the system into our economy, we must proceed with caution in accomplishing our goals. Furthermore, since the power supply using photovoltaic is still a fresh project in our system, we recommend that:

a. It should be applied not only to large scale but also small scale projects (most especially in Africa), since the sector is endorse with domestic and commercial areas.
b. The government should not be left only, this project should be proposed to the banking sector and engineering companies so that a good work may be accomplished.
c. Finally, the world has regarded Africa as the land with the highest possibilities of generating very large scale electricity from sunlight; we should take the information as an opportunity of a break through.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDICES FOR THE BLOCK DIAGRAMS

Appendix 1. Sola Panel Model

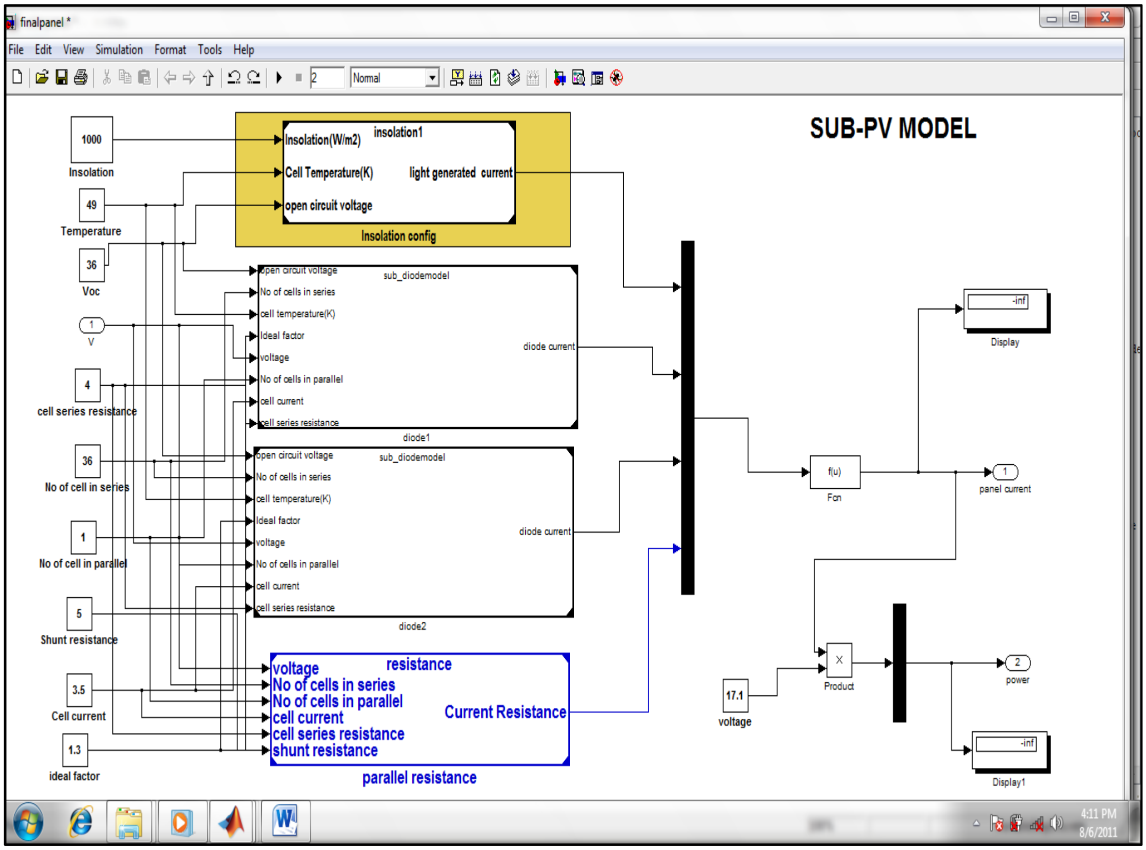

Fig. 2.6. Subsystem of the solar panel model

Appendix 2. Generated Panel Current Model

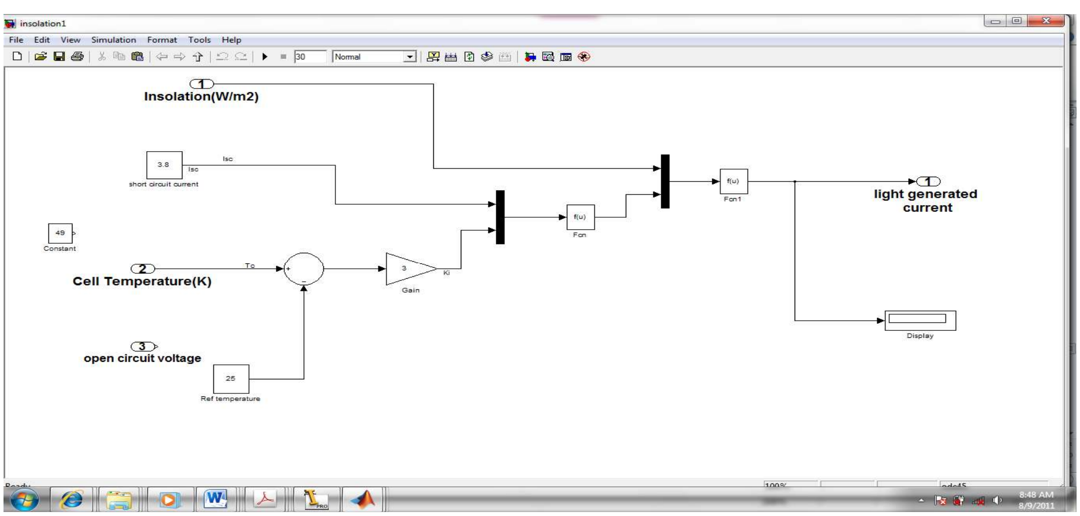

Fig. 2.7. Subsystem of the generated panel current model

Appendix 3. Generated Voltage Current Model

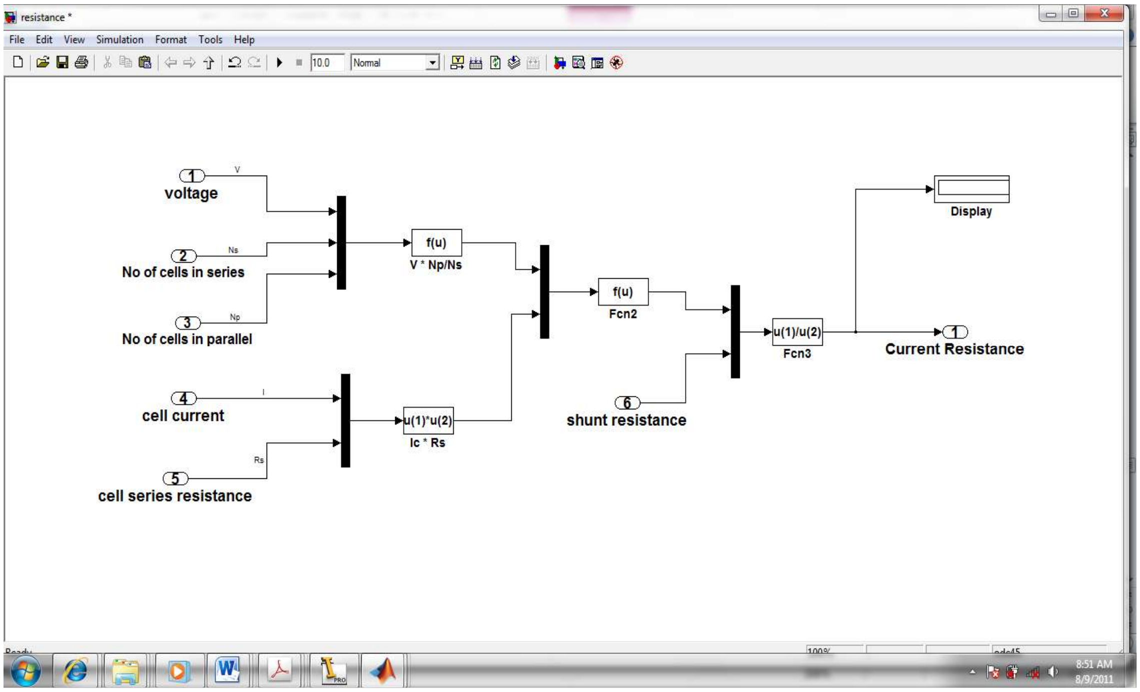

Fig. 2.8. Subsystem of the generated voltage current model

Appendix 4. Diode Current Model

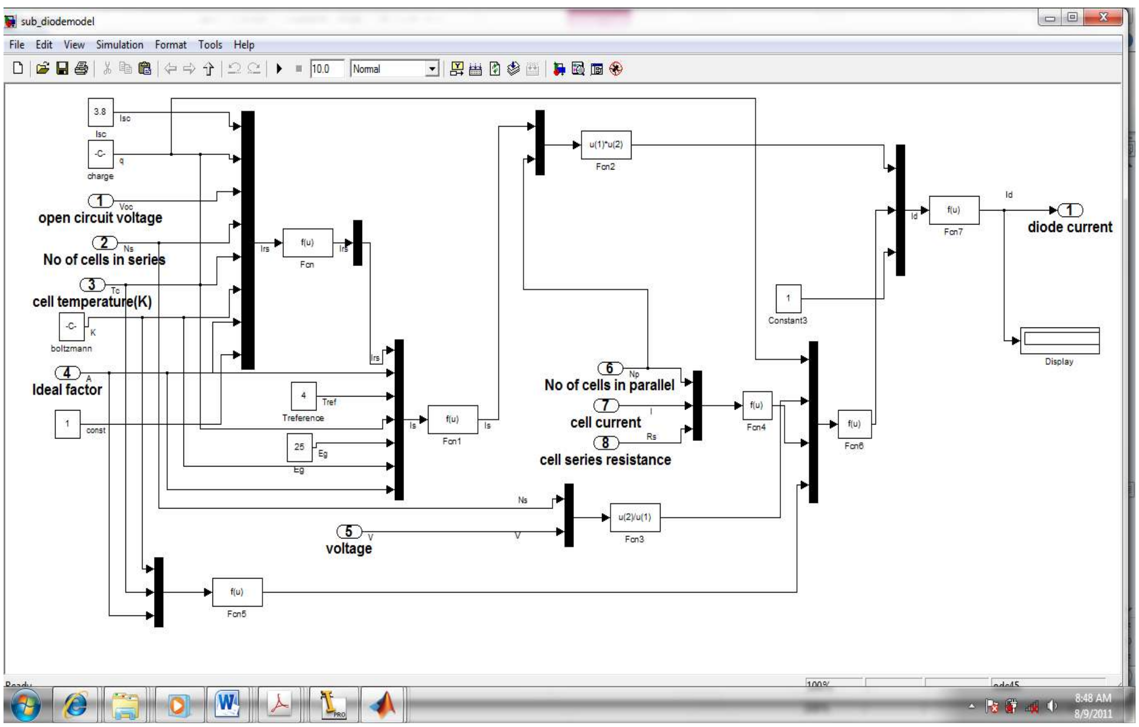

Fig. 2.9. Subsystem of the diode current model

Appendix 5. Sola Car Battery model
(a)Battery model

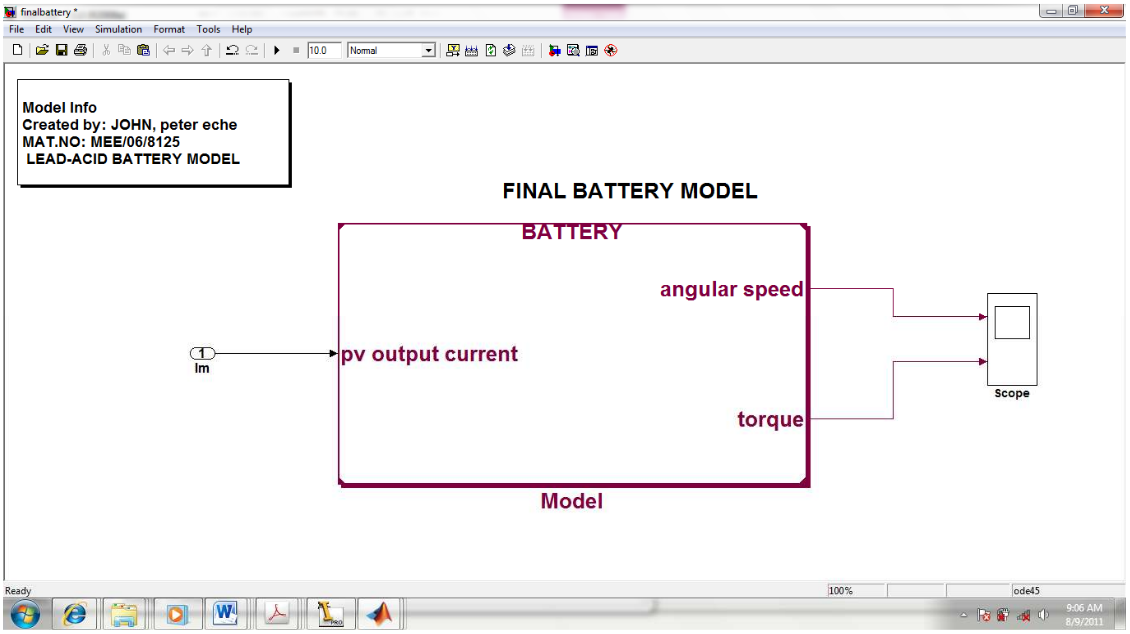

Fig. 2.10. Model of the solar car battery

Appendix 6. Solar Car Battery Subsystem Model

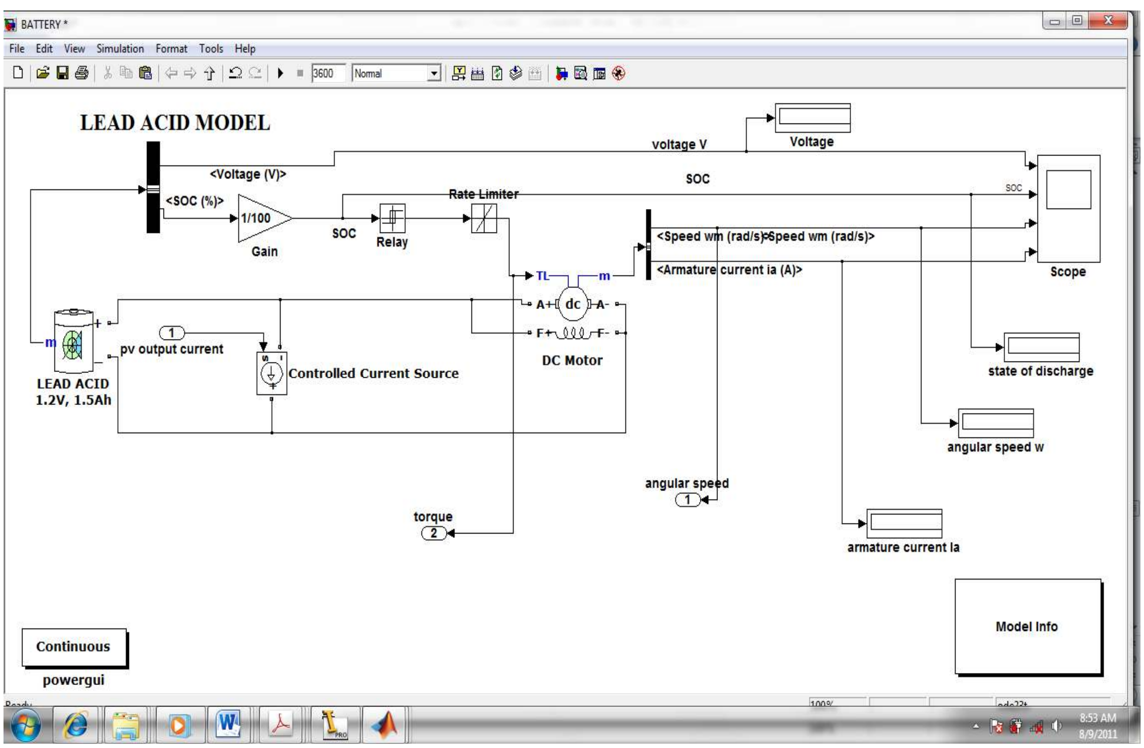

Fig. 2.11. Subsystem of the solar car battery model

Appendix 7. Solar Powered Engine Model

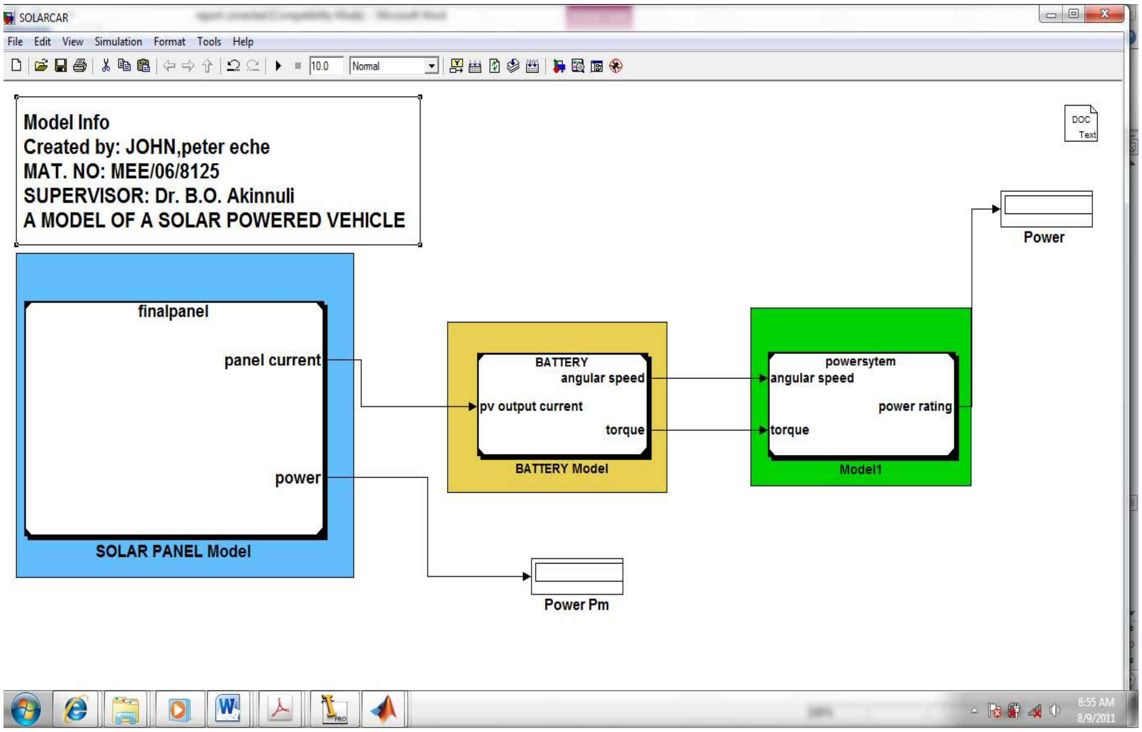

Fig. 2.12. Solar powered engine model

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