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Series Hybrid Configuration Based Proposed Architecture Model for Hybrid Electric Aircraft Using Simulink\Matlab

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ABSTRACT

Due to demand for optimization of various aircraft performance parameters, decrease in operating and maintenance cost and to reduce gas emission Hybrid Electric Aircraft (HEA) concept has been put forward.
Rapid growth in the field of power electronics, electric motor and conversion system has made Hybrid Electric Aircraft possible. Being more advantageous series hybrid configuration is used to build basic architecture model. Architecture consists of two power sources one is engine driven generator other is the battery. Electric motor drive plays an very important role in series hybrid configuration as it is the only torque source to meet the aircraft performance such as acceleration. The proposed system presents groundwork of the hybrid electric system architecture and reduced fuel consumption compared to existing convention aircraft system.
MATLAB software is used to design the basic structure of hybrid electric aircraft architecture and the simulation results shown and analysis of overall system performance is done accordingly.
Keywords: Hybrid Electric Aircraft.

I. INTRODUCTION

THE increase of petrol consumption causes the problem of greenhouse effect and the energy crises. The transport burns most of the world's petrol and is a major source of pollution. A strategy for energy economy is to use alternative propulsions in order to reduce the petrol consumption and the emissions of greenhouse gas. Increasing the energy efficiency of transport and recycling the energy which have been dissipated are the feasible solutions.
In this context, Hybrid Electric Aircraft (HEA) have been put forward.

The flight controls of the conventional aircraft are moved by multiple redundant hydraulic actuators that are heavy and consume large amounts of power. For the HEV, one or several electric motors have been installed to participate in the propulsion force with the Internal Combustion Engine (ICE). This alternative propulsion configuration makes it possible to recycle the energy and control the ICE in optimal operation points in order to increase the global efficiency [1][2][5].

The objective of this paper is to design the basic model of HEA architecture using Simulink\Matlab. In section II, comparisons of conventional aircraft and hybrid electrical aircraft is presented. In section III, components used to build architecture and there parameter calculations are discussed. The components include generator, rectifier, converter, storage system and electric motor. The simulation results and conclusions will be discussed respectively in sections IV and V.

Comparison of conventional and HEA

(a) Comparison

In a conventional vehicle, the internal combustion engine (ICE) drives an electric machine to charge the battery and supply the electrical loads of the vehicle. In most cases, this electric machine only starts the ICE but does not participate in the propulsion. Figure 1 shows the architecture of conventional aircraft.

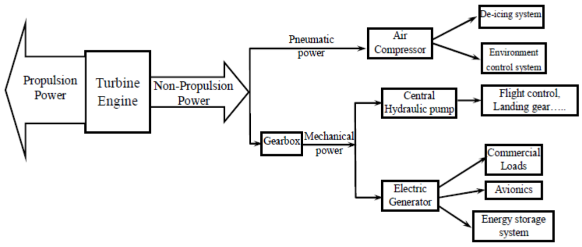


Figure 1. Conventional aircraft power distribution system [1]

An HEA is a vehicle which involves multiple sources of propulsions. A traditional vehicle has propulsion by ICE or diesel engine. Energy source can be battery, fuel cells, fly wheel, solar panel etc. As compared to ICE vehicles, HEVs have low energy consumption:

resources, independent of foreign oil, low emission, air pollution, global warming, low maintenance cost & environmental hazards & less noisy. Environmental Impacts of HEVs are Reduced air pollution including nitrogen oxides, Carbon monoxide, Unburned hydrocarbons, and Sulfur oxides due to less fuel needed in HEVs, reduce global warming effect by burning less fuel and emitting less carbon oxides & reduce oil dependence on foreign oil and leave room for the future. Key advantage of HEA's is low initial cost & wide driving range.

The revolution of HEV is mainly based on this electric machine. Thanks to the development of energy storage, power electronic and electric machine, the electric machine joins in the propulsion of the vehicle. According to the drive train configuration, the HEV can be classified in series-hybrid, parallel-hybrid or series parallel hybrid [4][5][6]. Figure 2 shows the power distribution architecture of Series Hybrid Electric aircraft.

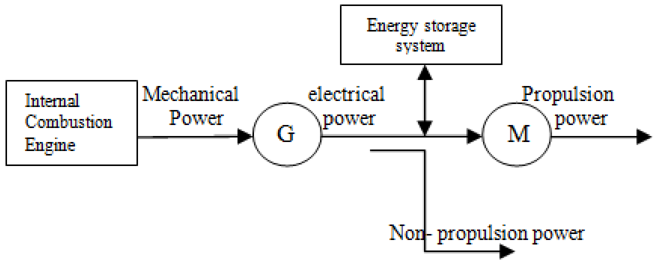


Figure 2. Power distribution architecture of Series Hybrid Electric aircraft.

In HEA, the propulsion power can be distributed by DC network. The electric propulsion motor is connected with DC bus by power electronic equipments. The propulsion power can also be distributed by a power split device in mechanical or electromagnetic form. The typical mechanical power split device is planetary gear unit.[7]

The secondary source should be bidirectional to recover the returned power and supply the electrical loads in order to reach optimum energy efficiency. The techniques of energy storage system which exist as battery, super capacitor and flywheel can be used in aircraft.

In HEV, the main electric load is the propulsion force. The electric energy is transformed to kinetic energy of vehicle via the electric motor. In the conventional vehicle, when it is braking, the kinetic energy is dissipated on the brake disk.

(a) Operation Mode of Series Architecture

* Battery alone mode: engine is off; vehicle is powered by the battery only.

* Engine alone mode: power from ICE/G

*Combined mode: both ICE/G set and battery provides power to the traction motor.

* Power split mode: ICE/G power split to drive the vehicle and charge the battery.

(b) Phases of aircraft operation

1. Taxiing: Taxiing refers to the movement of an aircraft on the ground, under its own power. The aircraft moves on wheels. An airplane uses taxiways to taxi from one place on an airport to another; for example, when moving from a terminal to the runway.

2. Takeoff: Takeoff is the phase of flight in which an aircraft goes through a transition from moving along the ground (taxiing) to flying in the air, usually starting on a runway.

3. Cruise: Cruise is the level portion of aircraft travel where flight is most fuel efficient. It occurs between ascent and descent phases and is usually the majority of a journey. It ends as the aircraft approaches the destination where the descent phase of flight commences in preparation for landing. This phase of flight consumes the majority of fuel.

4. Descent: A descent during air travel is any portion where an aircraft decreases altitude.

5. Landing: Landing is the last part of a flight, where the aircraft returns to the ground.

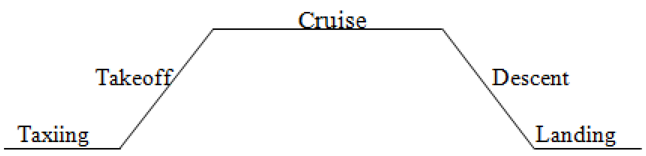


Figure 3. Flight phases

II. SYSTEM DESCRIPTION

As mentioned earlier in this paper, the main advantage of hybrid electric aircraft is reduction in the consumption of fuel. Batteries have a high specific power and their power output has a rapid dynamic response time. These complimentary advantages make hybrid systems very attractive. A block diagram of HEA architecture proposed in this study is presented in Figure 4.

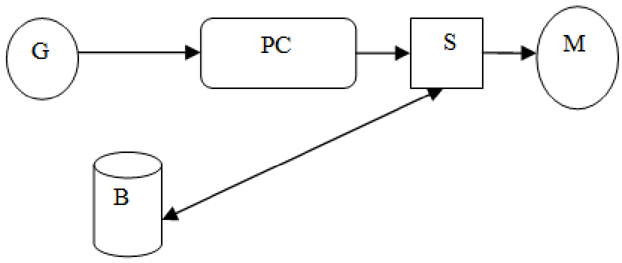


Figure 4. Block diagram of the proposed hybrid electric aircraft architecture power supply

As said earlier it consist of two power source, primary source is an engine driven generator and secondary source is a battery. It consist of a rectifier which is a AC to DC converter, a boost converter and an electric motor.

A. Design and modeling of a Generator

The primary electric sources in both MEA and HEV are the engines – either turbine engine or internal combustion engine. These sources are unidirectional. However, for the sustainable development, some energy can be recycled and reused and a bidirectional energy storage system should then be introduced in this system as secondary source.[1]

An alternator is an electrical machine which converts mechanical energy into alternating electric energy. They are also known as synchronous generators.

TECHNICAL DATA OF GENERATOR MODELED IN MATLAB\SIMULINK

Table 1

ATTRIBUTES	VALUE
V(rms)	115-118 v
Frequency (Hz)	400Hz

B. Design and modeling of a Rectifier

Power electronics are the link between electric power generation and electric power consumers; power converters therefore cannot be viewed outside their interface with power sources (generators, batteries, fuel cell) and loads [2]. Power electronics in general, and power converters in particular, are integral parts of the whole electrical system.

TECHNICAL DATA OF RECTIFIER MODELED IN MATLAB\SIMULINK

Table 2

ATTRIBUTES	VALUE
V(rms)	118v(rms)
Switching frequency(fs)	25000Hz
A	45◦
Vdc	165.3v

$$Vdc = 6/2\pi \int_{\pi/3}^{2/3\pi} \sqrt{3}\,Vs.\sin\omega t\,dt$$

$$Vdc = \frac{3\sqrt{3}}{\pi}.Vs$$

$$Vdc = 1.645Vs$$

C. Design and modeling of a Battery

The lithium-ion battery has been proven to have excellent performance in portable electronics and medical devices. The lithium-ion battery has high energy density, has good high temperature performance, and is recyclable. A lithium-ion type battery was simulated. The battery output voltage is given by [6].

$$Vbatt = Eo - k\frac{Q}{Q - \int i\,di} - R.i + Aexp(-B\int i\,dt)$$

where: Vbatt is battery no load voltage [V]; Eo is battery constant voltage [V]; the k is polarization voltage in [V]; the Q is the battery capacity in [Ah];$\int i\,dt$ is the actual battery charge [Ah]; A is the exponential zone amplitude [V]; B is the exponential zone time constant inverse [Ahrl; R is the internal resistance [Ω]; and i is the battery current [A].[6] The state-of-charge (SOC) of the battery is between 0 and 100%.

TECHNICAL DATA OF LITHIUM-ION BATTERY MODELED IN SIMULINK

Table 3

ATTRIBUTES	VALUE
Nominal voltage V	200v
Rated capacity	105AH
Initial state of charge	90%

Required AH of the battery is given by,

$$A.Hr = \frac{watt.Hr}{V}$$

C. Design and modeling of a DC motor

Electric powered aircraft has gained popularity, mainly because the electric motors are more quiet, clean and often easier to start and operate than the combustion motors. A DC motor converts the electric current into Torque and the voltage into rotations per minute (RPM). Torque is a twisting force measured at a certain radial distance from the shaft's centre line.

$$\text{Motors o\textbackslash p power(W)} = \text{Torque(Nm)} * 2\pi * \text{RPM}\backslash 60$$

The power consumption of a DC motor (Input Power) is equal to the voltage at its terminals times the current.

$$Pi = Vin * Io$$

However, every motor has losses, which means that the motor consumes more power than it delivers at its shaft.

The motor's Output Power is equal to the Input Power minus the Power Loss. Most of Power Loss is equal to the sum of the Copper Loss plus Iron Loss.

$$\text{Copper loss} = \text{coil resistance Rm} * \text{Current Iin}^2$$

$$\text{Iron loss} = Vin * Io$$

The following equation can also be used to calculate the motor's Output Power:

$$Pout = (Vin - Iin * Rm) * (Iin - Io)$$

The motor's Efficiency is the ratio of the Output Power to the Input Power .Efficiency is a measure of how much of the Input Power is actually used to turn the propeller (Output Power) and how much is wasted as heat.

$$\text{Efficiency(\%)} = 100 * \frac{Pout}{Pin}$$

Input to the motor is given through a speed control drive.[5]

TECHNICAL DATA OF DC MOTOR MODELED IN SIMULINK

Table 4

ATTRIBUTES	VALUE
DC voltage	240V
Armature resistance	2.4Ω
Load torque	0.001(Nm)

III. SIMULATION RESULTS

Overall HEA architecture is shown in the fig below

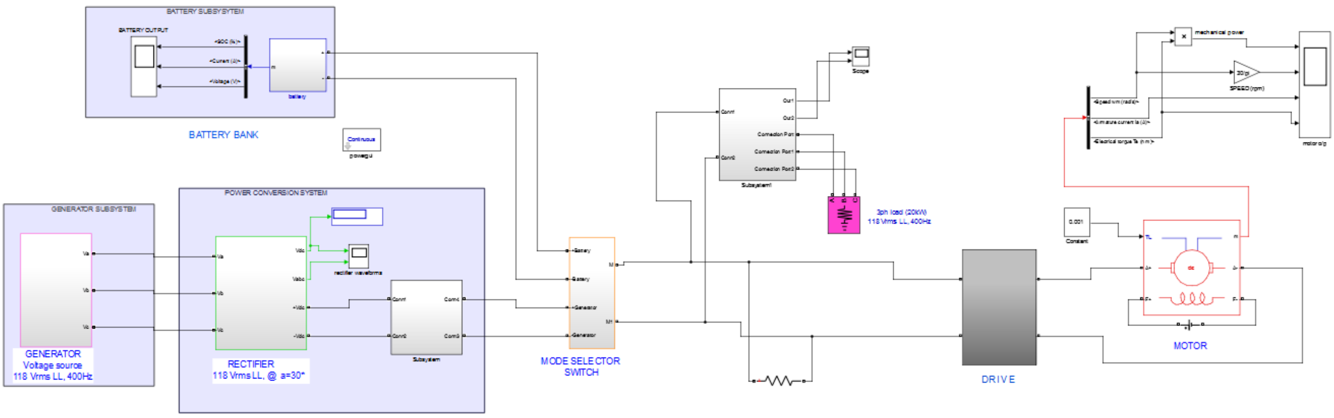
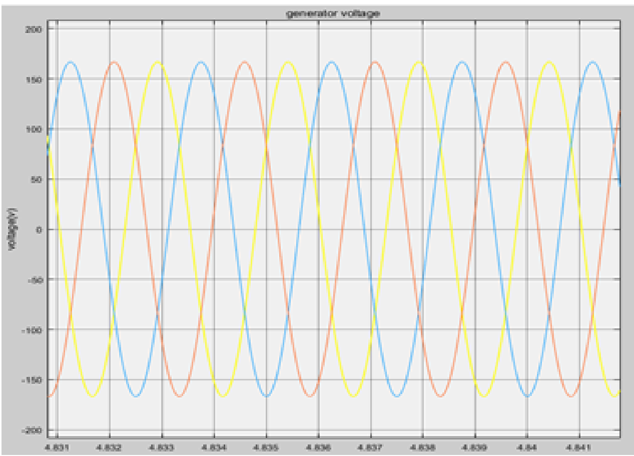
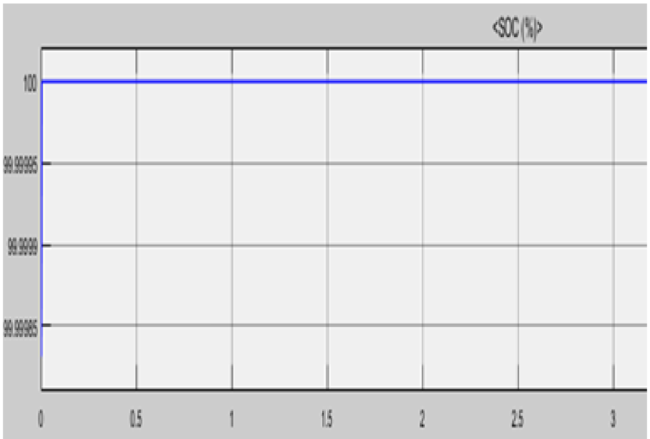


Figure 5. Overall system of HEA architecture



(a)



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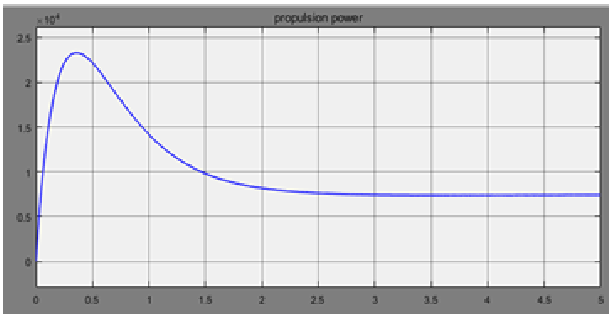

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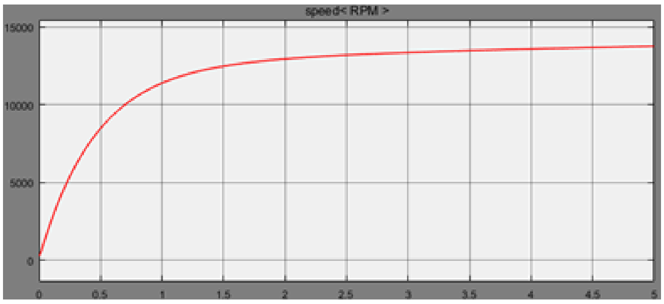
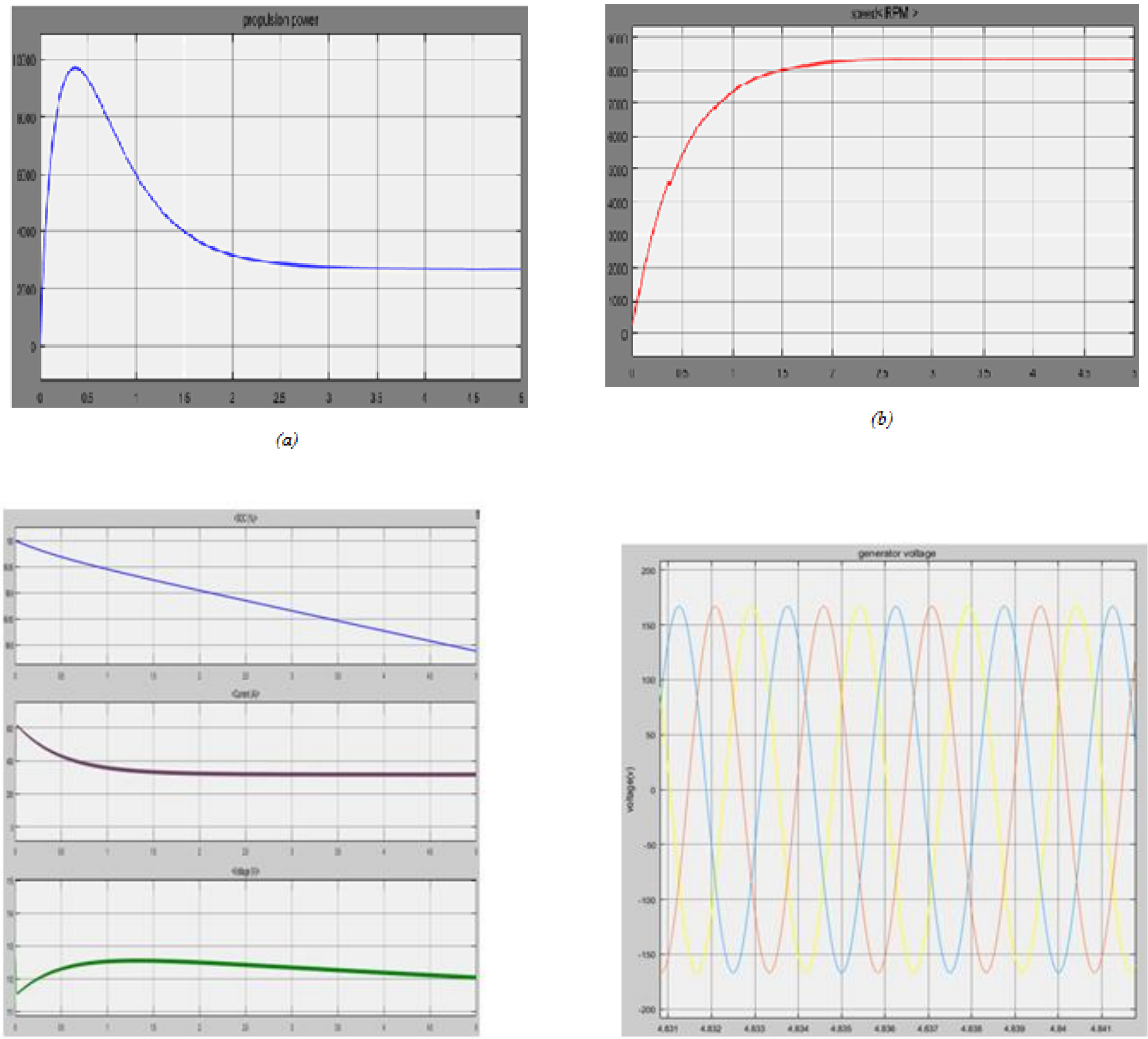


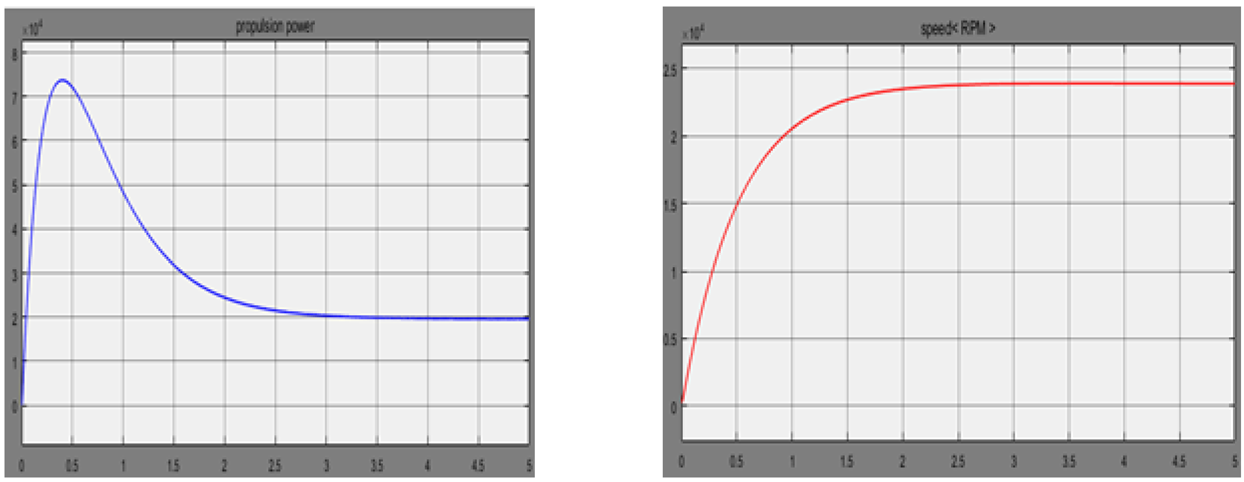
(d)

Figure 6. Battery, motor and generator o\p during engine alone mode

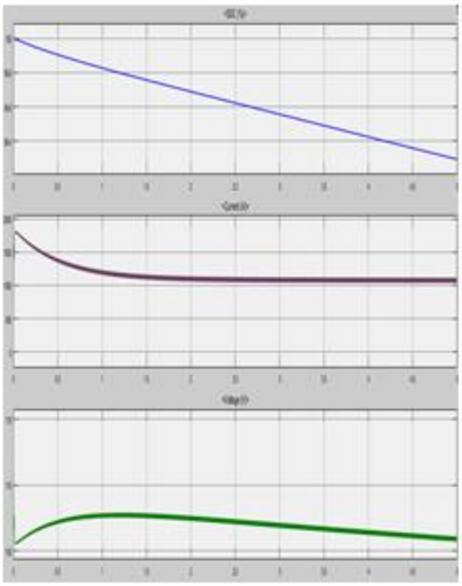


(a) (b) (c) (d)

Figure 7. Battery, motor and generator o\p during battery alone mode



(a) (b)



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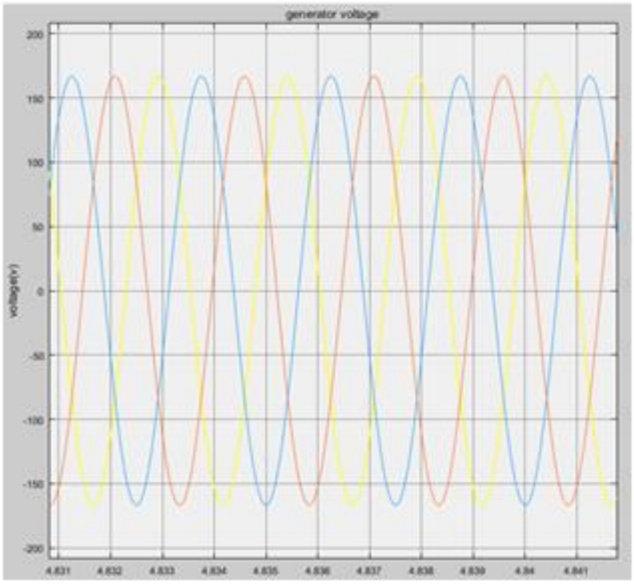

(d)

Figure 8. Battery, motor and generator o\p during combined mode

IV. CONCLUSION

The paper presented the simulation and analysis of series hybrid electric aircraft architecture. This topology uses a two power sources i.e. a generator and a battery. The advantage we have most fully exploited is reduction in fuel consumption during cruise mode. Simulation was conducted using Matlab/Simulink-based models. The simulation results show the overall system performance during engine alone mode, battery alone mode, and combined mode.

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