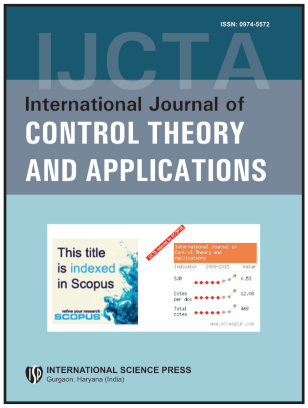

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Biogas Electricity Generation from Biomass using IC Engine

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Abstract: Biogas is a fuel which has promising characteristic of replacing conventional fossil fuels. Because of this more and more ways of effectively utilizing biogas should be implemented. This paper proposes the simulation study of a biogas fed internal combustion engine that is capable of producing electricity by running a permanent magnet synchronous generator. The engine is being controlled to a set speed by a speed controller. For providing continuous supply of biogas a storage tank at the outlet of an anaerobic digester is proposed. The proposed storage tank will have monitoring mechanism so that whenever the tank is being depleted the IC engine is shut off and when there is sufficient concentration of biogas it will provide an availability indication. Together with this a supervisory controller will monitor the system and control of the PMSG generation into a dc bus through power electronic interface.

Keywords: Biogas, PMSG, Storage tank, IC Engine, Anaerobic digester.

1. INTRODUCTION

Since man first discovered how to light fire, it started the advent of using energy for aiding our lives. The transition from producing fire to driving our daily needs through technology has resulted with various ways of generating energy. Now we have availability of not only conventional polluting fuels like coal, petrol, and diesel but also fuels providing an environmental benefit. Biogas promises to be a fuel that can replace fossil fuels. It has the characteristic of being a domestic as well as an industrial fuel. Biogas is a result of the decomposition carried out by microorganisms inside an anaerobic digester, a process carried out in the order hydrolysis, acidogenisis, acetogenisis and methanogenisis. The organic wastes or an input to the anaerobic digester is calculated in organic loading rates (OLR) and this OLR should have a balance with hydraulic retention time so that microorganisms have sufficient time in breaking down the biomass [1]-[3]. The different kinds of biogas engines are: biogas-diesel, dual fuel engine generators and spark-ignition biogas engine generators, their performance comparison is done in [4]. [5],[6] Describes about the performance of an internal combustion engine running on different fuels.[6] Gives the performance of a generator set (genset) by using gasoline, LPG, and biogas as the fuel and from this study it is clear that biogas has lower specific fuel consumption and higher thermal efficiency. The modelling of salient pole synchronous generator is introduced in [7]-[11]. The PMSG is described to have large torque density than switched reluctance machines and induction generators. The classification design and study of wind turbine generators is described in [10].

The block schematic of the proposed IC engine PMSG system is given in Figure 1. This paper is organized into seven chapters. The first chapter gives an introduction to biogas electricity generation system . The literature review is also presented in this chapter. The second chapter gives a description about anaerobic digester, biogas, storage tank and its operation. The calculations related to IC engine and its model validation is described in the third chapter. The equivalent circuit and characteristics for the study of PMSG is discussed in the fourth chapter. The system validation and Simulink simulation results are explained in chapter five. The chapter six describes the dc bus integration system. The study is concluded in chapter seven.

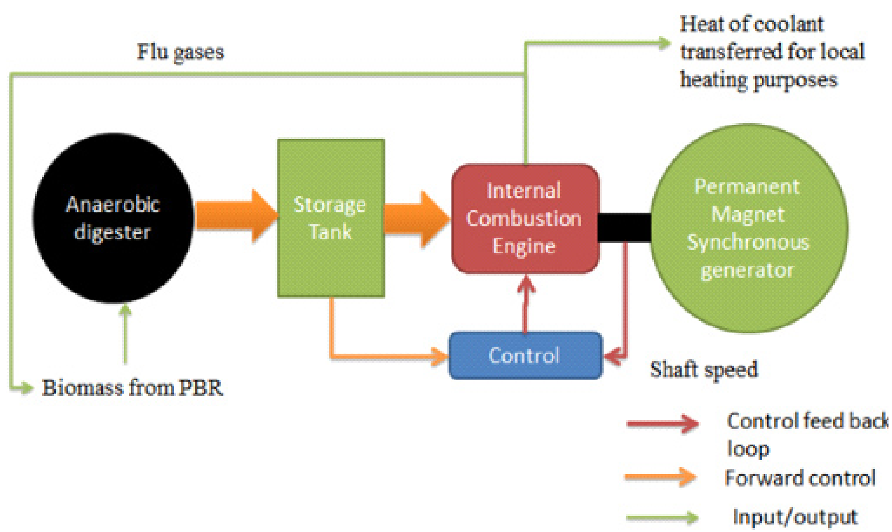


Figure 1: Block schematic of the proposed system

2. ANAEROBIC DIGESTER

Anaerobic digestion is a biochemical process which retrieves products like energy, nutrients from organic wastes. Biogas is produced inside the anaerobic digester with a composition of 50-70% CH_4, 25-45% CO_2, 2-7% water, 2% oxygen, 2% nitrogen, 1% ammonia, less than 1% of hydrogen sulphide and hydrogen. The energy content in biogas is dependent on the concentration of methane (CH_4). The calorific value of methane at 1Nm^3 is 20MJ/kg and density is 1.22kg/Nm^3 [12]. The sizing of anaerobic digester is done on the basis of organic loading rate (OLR) and hydraulic retention time (HRT). OLR is obtained by multiplying mass of substrate being fed into AD per unit time (m kg/d) to concentration of organic matter in that mass (c %) and dividing it by digester volume (VR m^3).

$$\text{OLR} = \frac{m \times c}{\text{V}_\text{R}} \tag{1}$$

The HRT is obtained by dividing digester volume (VR m^3) by volume of substrate fed per unit time (m^3/d).

$$\text{HRT} = \frac{\text{V}_\text{R}}{\text{V}} \tag{2}$$

The usual multiplication rate of algae is 10 days along with this knowing the decomposition rate of algae will help to calculate a required HRT and size the AD.

A. Storage Tank

The biogas production inside the digester is not in a uniform rate it is dependent on variety of factors like microbe concentration, temperature, ammonia content etc. In order to provide the biogas at a constant rate during demand period, storage can be implemented. The sizing of the storage tank is done on the basis of the volume of AD and the rate at which the biogas is needed.

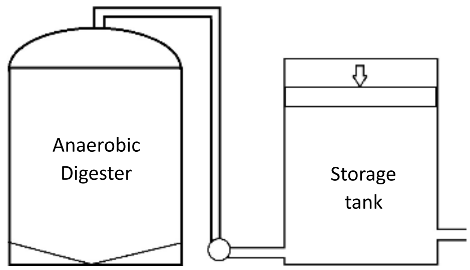


Figure 2: Anaerobic digester and storage tank interconnection

B. Storage Tank Control

The tank control logic is shown in Figure 3. The tank control comes into play when there is less concentration of biogas inside the tank. The lower threshold of CH_4 is determined based on the air fuel ratio requirement of an engine.

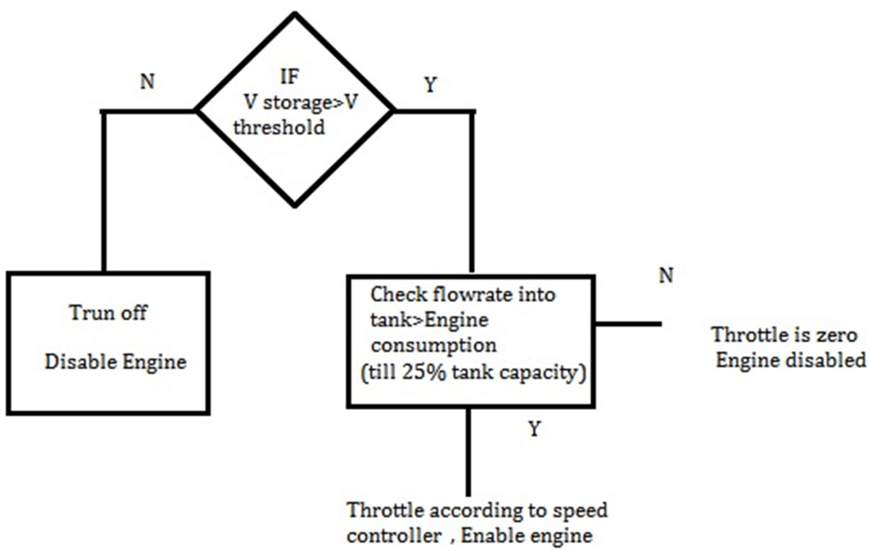


Figure 3: Tank control logic

C. Internal Combustion Engine

The biogas electricity generation can be made possible by the application of a micro turbine or an internal combustion engine or a sterling engine. The internal combustion engine is preferred for below 100kw electrical generation. Usually engines operating in Otto cycle are considered but for better electrical performance Otto – diesel cycles are considered. The IC engine is controlled by an electronic control unit (ECU) which control the engine based on various parameters like throttle control to ignition control. To simplify we are only focusing on throttle control. The Figure 4 shows the process intended for running an engine on biogas. The velocity regulator is actually the throttle(fuel injector) which control the fuel flow into the engine cylinder.

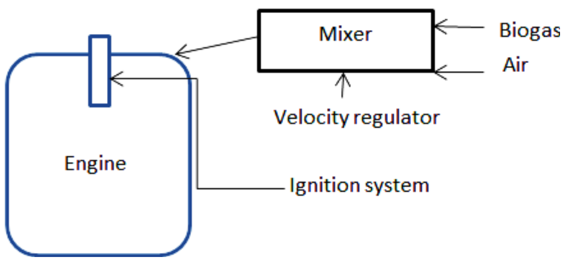


Figure 4: Biogas implementation on a spark ignition engine

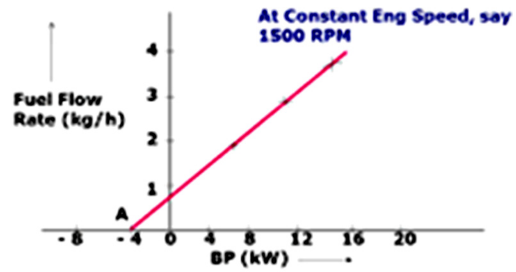


Figure 5: Willian's line for finding friction power

The following are some calculations for the analysis

A. *Fuel consumption:*

$$\mathrm{FC} = \frac{\mathrm{V}_f}{t} \tag{3}$$

where, V_f is the volume in liter of fuel consumed and t is time duration taken.

B. *Specific fuel consumption:*

$$\mathrm{SFC} = \frac{\mathrm{V}_f \times \rho}{\mathrm{E}} \tag{4}$$

where, ρ is the density of fuel (kg/litre) and E is electrical energy (kWh).

C. *Thermal efficiency:* The chemical energy in fuel is first converted into heat energy the heat energy is then converted into mechanical energy. In order to find the energy in fuel we only need to find out how much heat energy is in the fuel. This is obtained by

$$\mathrm{Q}_f = m_f \times \mathrm{LHV} \tag{5}$$

The LHV represents the low heating value of fuel (kcal/kg).

The thermal efficiency:

$$\eta_{\mathrm{th}} = \frac{859.845}{Q_f} \times 100\% \tag{6}$$

D. *Break power:*

Break power is obtained by

$$\mathrm{BP} = \frac{2\pi\, \mathrm{N}_{\mathrm{rpm}} \mathrm{T}}{60} \tag{7}$$

Here N_{rpm} is rotor speed in rpm and T is the shaft torque.

E. *Friction power:* Friction power (FP) is found out from the plot between specific fuel consumption vs brake power. The line extended from plot touching the negative *x* axis gives the friction power.

F. *Mechanical efficiency:* The mechanical efficiency of an engine gives how much of the produced mechanical energy is available in the shaft after the losses are considered. The range of mechanical efficiency is usually around 90%.

Mechanical efficiency

$$\eta_{\mathrm{mech}} = \frac{\mathrm{BP}}{\mathrm{BP} + \mathrm{FP}} \tag{8}$$

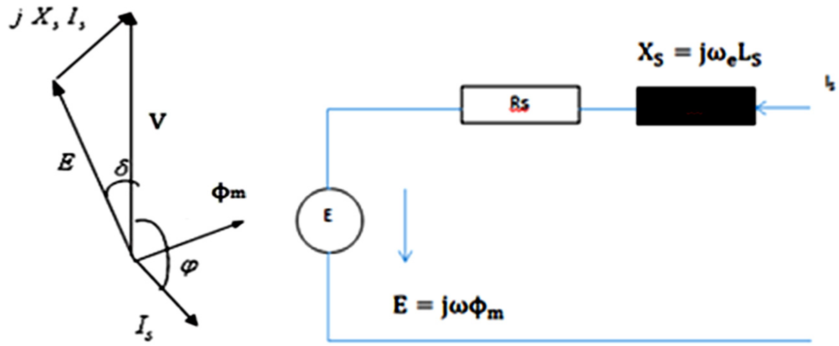


Figure 6: (a) Phasor diagram of a PMSG, (b) Equivalent circuit of a PMSG

3. PERMANENT MAGNET SYNCHRONOUS GENERATOR

The PMSG is utilized for its characteristic of not needing a separate supply for field excitation, lower maintenance and having high torque density compared to induction generators, and switched reluctance machines.

The dq axis representation of a permanent magnet synchronous machine (for a balanced system the 0-axis quantities are equal to zero). The electromagnetic torque is given by:

$$T_e = 1.5p\phi_{pm}i_{sq} \tag{9}$$

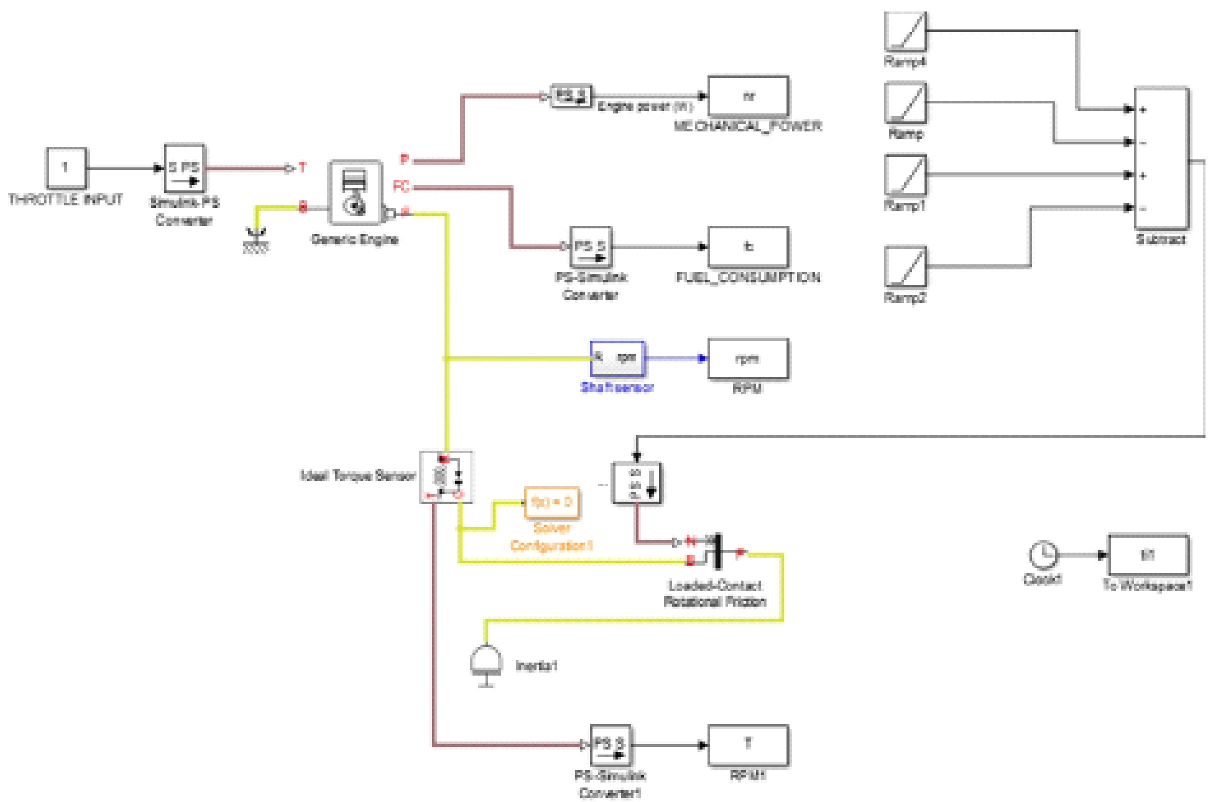


Figure 7: The open loop simulation of an IC engine

The rotor frequency (f_e) and generated voltage (E) are related with pole flux (ϕ_{PM}) as given in (10). The equivalent circuit of a round rotor PMSG is shown in Figure 6(b) The Figure 6(a) shows the phasor diagram.

$$E = 2\pi f_e \phi_{PM} \tag{10}$$

Table 1
Simulation Parameters

Parameters	
Engine parameter	*Value*
Throttle	Varying from 0-1
Engine Power (HP)	2
Engine speed at maximum power (RPM)	1750
Fuel consumption per revolution(mg/rev)	96.57
Initial throttle	0.5
Initial RPM	960
Inertia	0.08

4. SYSTEM VALIDATION USING SIMULINK

A. Open Loop IC Engine Simulation

For the purpose of studying, the IC engine is simulated in MATLAB Simulink. The engine chosen is a 4 stroke spark ignition engine. The table I give the parameters used for simulation. The simulation is carried out in open loop as shown in the Figure 7. The load given is a friction load the normal component is inputted as a series of ramp signals added and converted to a physical signal. The throttle is varied from 0.5 to 0.8. First the model validation is carried out by plotting torque speed characteristics (Figure 9a). Then mechanical efficiency vs RPM is done (Figure 9b).

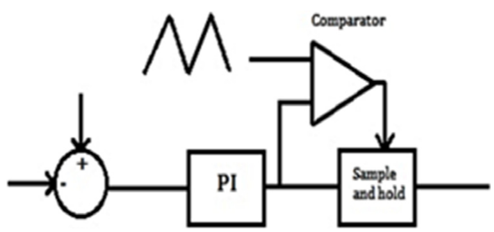


Figure 8: Speed controller for an IC engine

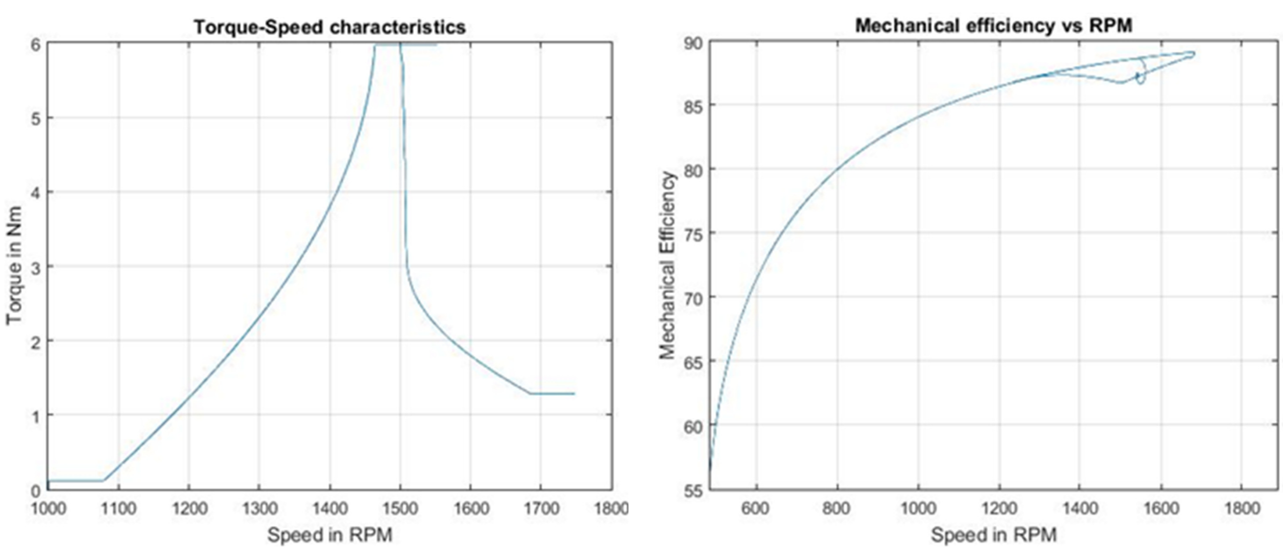


Figure 9: (a) The validated torque speed characteristic and (b) mechanical efficiency vs RPM

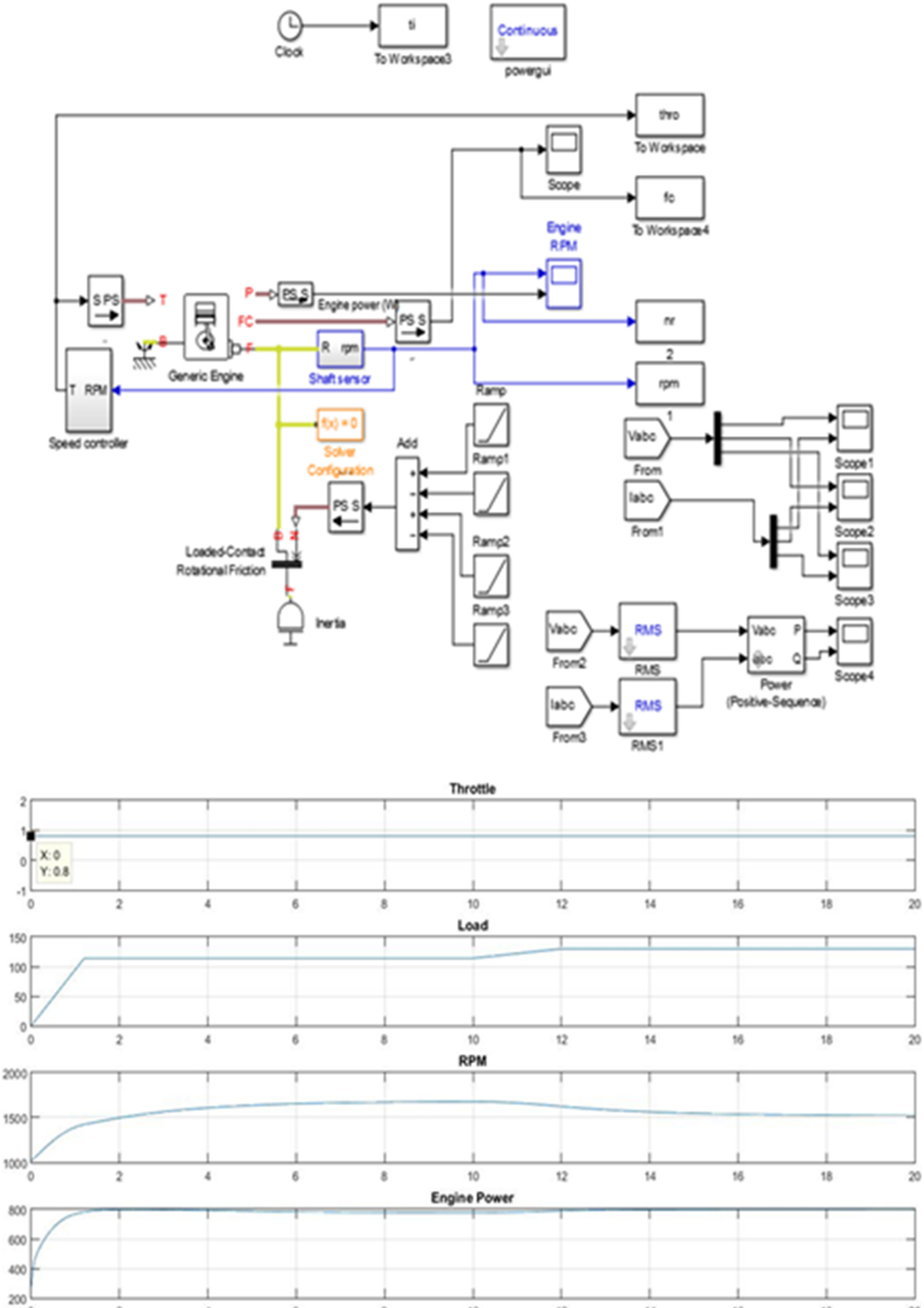


Figure 10: (a) Speed controller for an IC engine, (b) The open loop engine output waveform for a throttle input of 0.8

After validation the output wave forms for different throttle are plotted the output wave forms for a throttle input of 0.8 is shown in Figure 10(b). By analyzing the wave forms it is clear for each throttle the engine attains a stable speed. By increasing throttle this speed increases. If throttle is made high the engine speed will increase rapidly. In order to avoid this speed controller can be proposed. For controlling the speed a PI controller based speed control can be implemented. The speed is to be maintained at 1500rpm at all the time.

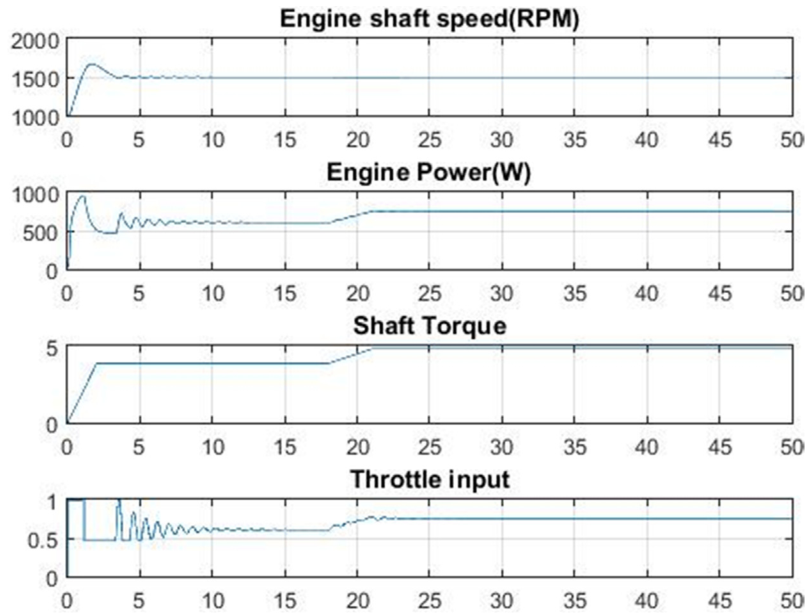
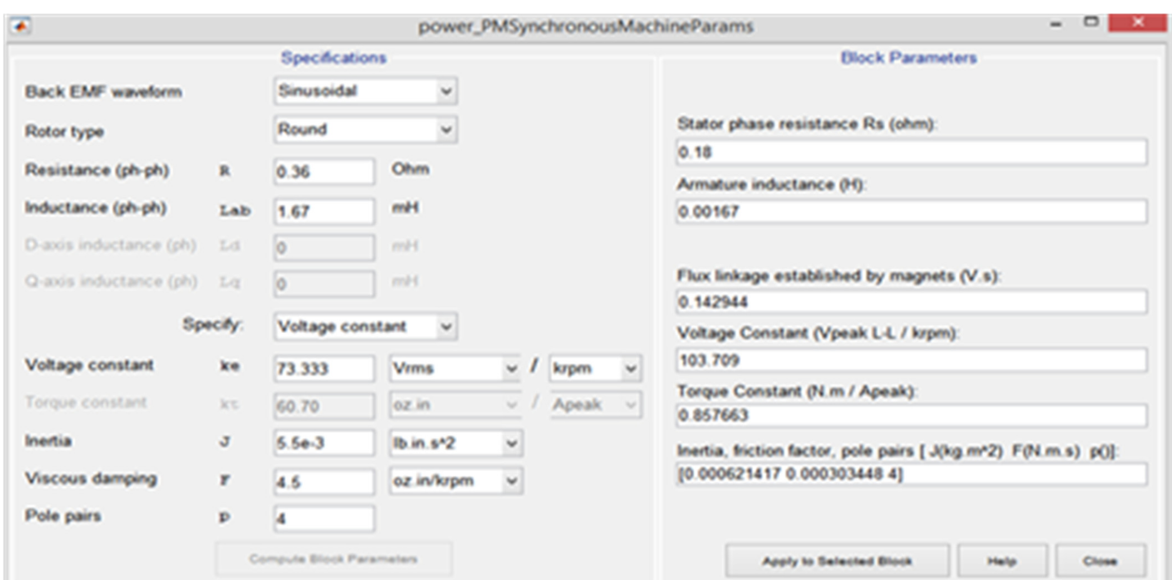


Figure 11: Output of an IC engine with speed controller

B. IC Engine Simulation with Closed Loop Speed Controller

The speed control logic is given in Figure 8. The speed controller controls the throttle value depending on the shaft speed error. A Sample and hold is used so that sudden error change doesn't affect the system. The Figure 10(a) gives the Simulink implementation and Figure 11 gives the output wave forms.



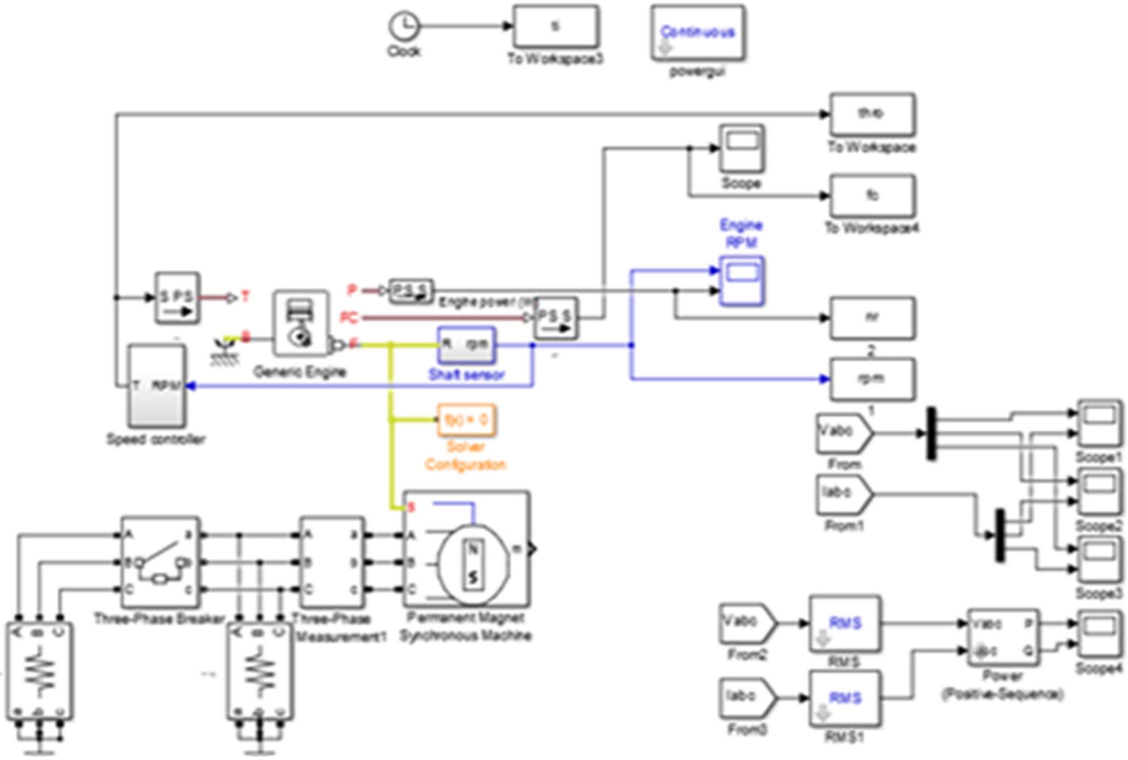


Figure 12: (a) PMSG parameters, (b) Schematic with PMSG and speed controller for an IC engine

C. IC Engine Coupling to a PMSG

The tested system is now coupled to a PMSG for power generation. Since the generated voltage from the PMSG depends on the rpm only, at stabilized speeds the output of PMSG is stable [13]. The PMSG was designed for a 110V line to line voltage. The rated speed was selected as 1500rpm. The Figure 12(a) shows the parameter selection of a PMSG and Figure 12(b) and Figure 13 gives the SIMULINK schematic and output waveforms respectively.

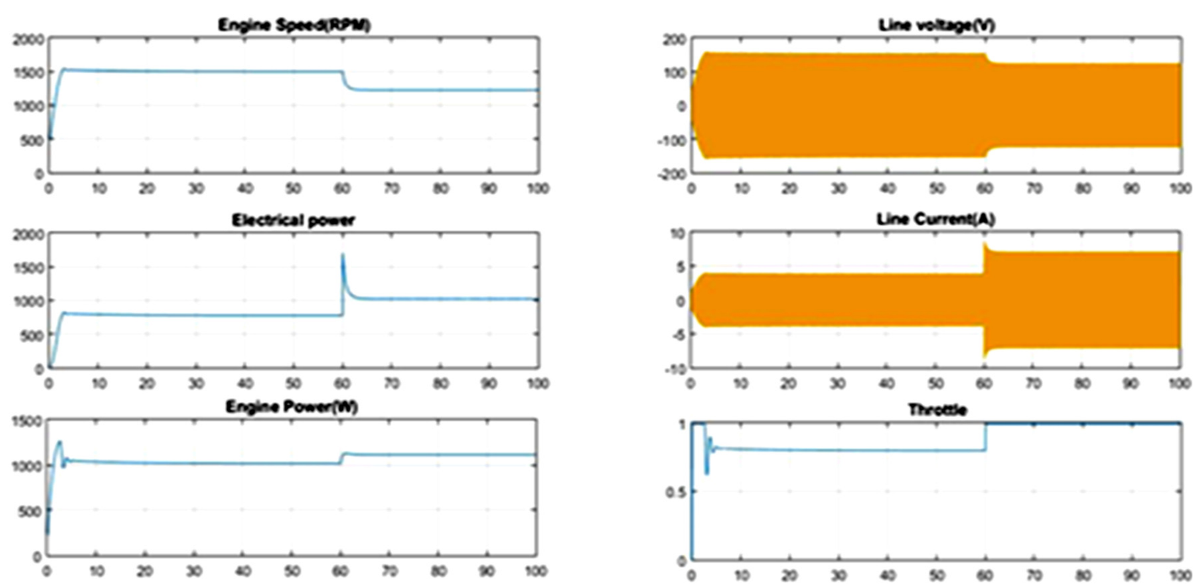


Figure 13: Output wave forms for the IC engine coupled to PMSG and with a speed controller

5. DC BUS INTEGRATION

The DC bus integration of the system can be done by using a rectifier and converter. If the rectifier is uncontrolled two stages of converter are required, one for power flow control and the other for maintaining the output voltage. For a controlled rectifier only one converter stage is required. The controlled rectifier can have power flow control into the dc side. The converter will regulate the output to the dc bus voltage. Here we have a six pulse converter and a buck boost [14] converter in cascade for dc bus integration of the whole system.

The Figure 14 shows the Simulink schematics of the whole system. The Table 2 gives the parameters of the dc bus integration system Figure 15(b) shows the converter output wave forms and the Figure 15(a) shows 6 pulse rectifier output. The Figure 15(b) shows negative because the converter is a basic buck boost converter.

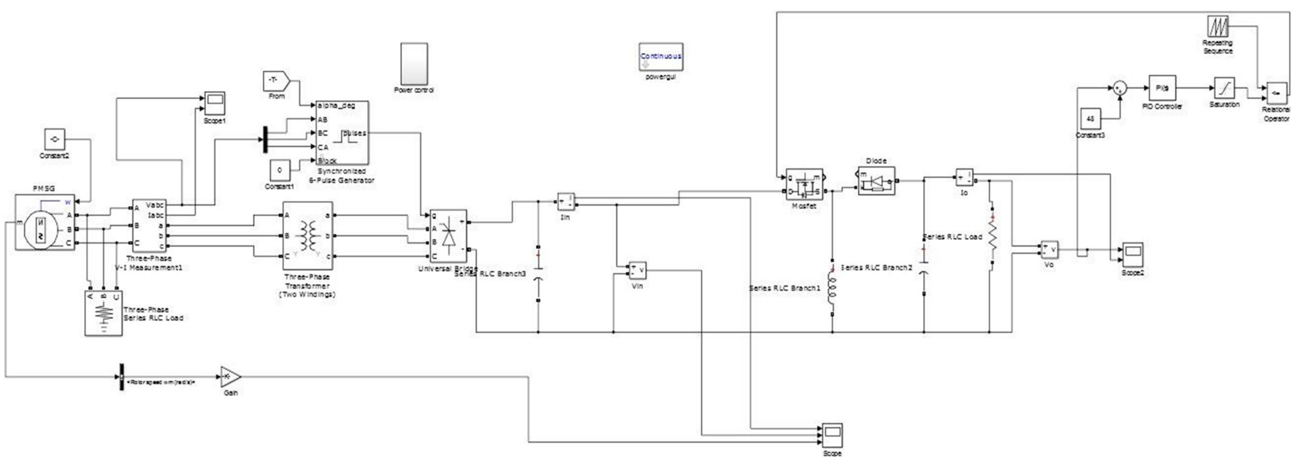


Figure 14: DC bus integration Simulink schematic

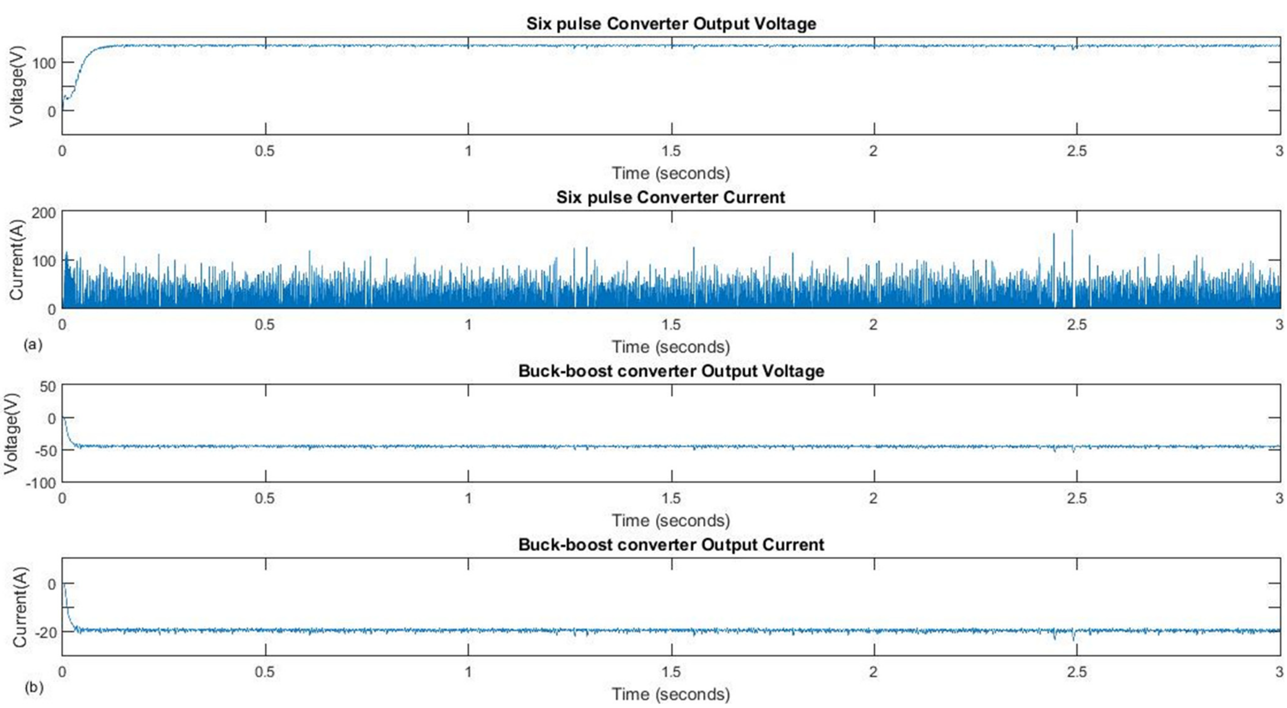


Figure 15: (a) Six pulse converter output wave forms (b) Buck boost converter output

Table 2
Simulation Parameter for DC Bus Integration

Converter and Rectifier Parameters	
Parameter	*Value*
Three phase two winding transformer	110/48V
Converter filter Inductance	649.3 μH
Capacitance at six pulse converter out	946.9 μF
Converter filter capacitance	946.9 μF
Converter switching frequency	20kHz
DC bus voltage	48V

6. CONCLUSION

The Simulink validation of an IC engine coupled to a PMSG is achieved. The speed controller for engine using throttle control is possible and integrating the source to the DC bus is also shown. The study indicated that PSMG IC engine system has potential for powering a home. The system can be used for water heating purpose and can be proved with the help of hardware.

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