DESIGN OF AN ELECTRONIC GOVERNOR FOR A DIESEL GENERATOR WITH SYNCHRONOUS, ISOCHRONOUS AND ISLANDED MODES: TEACHING TOOL

M.P.L.Jayathilake[1], K.P.M.Karunanayake[2], A.M.M.Karunarathna[3], A.P.M.Kethumalika[4], J.R.Lucas[5], Narendra de Silva[6]

[1]luckshyam@yahoo.com, [2]moditha.rc@gmail.com, [3]amkmanjula@gmail.com, [4]kethu77777@gmail.com, [5]lucas@elect.mrt.ac.lk, [6]narendra.desilva@leco.lk

ABSTRACT

The design of the fuel valve of a diesel generator, and the algorithm to control the speed, is presented in this paper. Initially a control hardware circuit was designed and built, capable of controlling the fuel flow of the generator so that it can be operated at a desired speed in isochronous mode. Unlike in the traditional controllers, no speed sensor is required, and the instantaneous frequency is extracted from the generator output voltage waveform. This governor has been developed to have the ability to run in isochronous and islanded modes as well as the isochronous mode. The developed governor will be used as a teaching tool for electrical engineering undergraduates with the power system simulator that has been recently developed, to gain the real power system operation experience. ***Keywords*** **- Diesel generator, Electronic governor, Mechanical governor, Power system simulator, Fuel rack, Diesel engine**

1. INTRODUCTION

Governors are devices which are used to control the speed of a generator. When diesel generators are considered, the governor should be capable of handling the fuel flow to the engine when the speed is changed from the set speed [1]. Earlier, mechanical governors were used, but with the advancement of electronic components, the control features of governors have become much more flexible and electronic governors are more and more used for speed control [2]. When the load of the generator is changed, the speed of the engine will be changed resulting in a change in the frequency. So, to keep the engine running at a desired speed (or frequency), fuel flow to the engine needs to be controlled [3].

2. OBJECTIVE

In this project, an electronic governor for a diesel generator is developed to give the generator the ability to run in multi modes. The main objectives are as follows:

- To develop a linear actuator using an electric motor and to control the fuel rack position.
- To design a frequency detection system using the output voltage waveform of the generator.
- To control the fuel rack position by mounting the linear actuator to the fuel injection pump.
- To run the generator under isochronous mode using a tuned programmable controller.
- To develop the system to have the ability to run in asynchronous, synchronous and islanded modes.
- To combine the whole system of the generator with the power system simulator available at the power systems lab as a power source to be used as a teaching tool for the undergraduates.

3. MULTI MODES

Generators with mechanical governors normally run under isochronous mode, to balance the demand and supply [4].However, when more complicated features are needed, such as to run in synchronous mode with other generators, or to run in islanded mode, an electronic governor is needed. Thus the electronic governor of the diesel engine was modified to give it the ability to run in these three distinct modes. Initially, the generator was run in isochronous mode with the developed electronic governor. The control algorithm was then modified in order to run in the synchronous and islanded modes as well [2].

***A.* Isochronous Mode**

The three-phase diesel generator obtained for the project, being of small capacity had been designed with a mechanical governor to operate in standalone manner and thus operate in the isochronous mode [4]. When functioning in the isochronous mode, the governor would always try to keep the frequency of the output voltage of the generator at a fixed value regardless of the load demand. This control is achieved by varying the fuel flow to the diesel engine. If the load demand is increased, the output frequency will drop, and the governor will increase the fuel flow to the diesel engine until the output frequency is increased up to the fixed frequency value. If the load demand is decreased the output frequency will be increased and the governor will reduce the fuel flow to the diesel engine until the output frequency is reduced down to the fixed frequency value [4]. When the diesel generator with the developed governor is connected to the power system simulator to operate in the isochronous mode, no other power source should be connected.

***B.* Synchronous Mode**

In the synchronous mode, the frequency is not fixed with variation of the active power output [4]. Therefore in order to keep the frequency of an isolated system constant, there should be several droop settings in one generator (FIGURE1).Then, according to the variation of load, the droop setting can be changed in order to keep the frequency constant by getting a current feedback. The developed electronic governor has the ability to change the droop setting [4].Power system simulator has a synchronous generator coupled with an induction motor as a power source from one end and. The developed governor will operate in synchronous mode when the two power sources are connected.

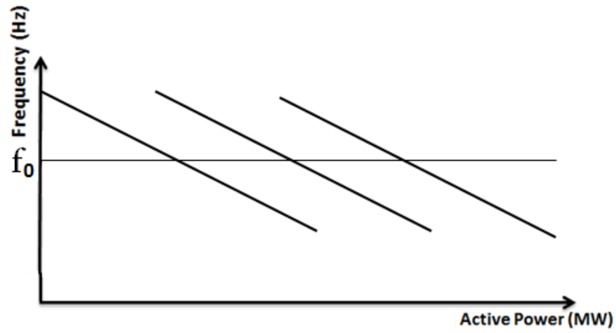


FIGURE1: Speed changer settings

***C.* Islanded Mode**

Islanding operation is a phenomenon that the power system is isolated and the generation control is done by the island itself. Here the generator should have an isochronous governor (flat droop curve). But in a networked power system, this type of operation can be naturally occurred due to failure of a tie line. In such a situation a generator or set of generators within the island may be operated in the islanded mode and the local loads can be fed by those generators although the rest of the network is not feeding in to the island. Such a situation is known as intentional islanding [5].

4. POWER SOURCE

***A.* Diesel Generator**

Diesel engines are widely used as prime movers for generators as they can be placed anywhere regardless of the location, resources, size etc. In today’s context, large diesel generators are connected to the grid while a large number of small scale diesel generators are used as backup power plans due to some unique advantages such as compactness, less initial cost, less fuel cost compared to gasoline, less pollution compared to gasoline, etc. However there are some disadvantages in diesel generators compared to some other sources like hydro, such as the presence of higher time constant which causes difficulties in controlling [3], [2].

***B.* In-built Mechanical Governor**

The Diesel generator had a fly-ball mechanical governor which could only be run under isochronous mode. The objective was to develop an electronic governor and mount it to the fuel injector pump while keeping the existing mechanical governor [1].

5. DESIGN AND DEVELOPMENT

A. Hardware Circuit

Diesel generator has a solenoid actuator in the fuel injector pump in order to control the fuel flow in starting state and stopping state of the generator. When the solenoid is de-energized, the fuel flow to the engine is fully closed and the generator is kept in the stopping state. And once the solenoid is energized, the fuel flow to the engine will be fully opened and the generator will be started with the support of starter motor, fuel pump and other auxiliary systems. Since the solenoid only changes the fuel flow between two states, the engine consists of a mechanical fly-ball governor to vary the fuel flow rate continuously within a small range such that the generator will be able to respond to the changes in the demand by varying fuel flow rate by smaller amounts [2], [3]. Initially it was decided to develop a controlled solenoid which could replace the existing solenoid which would work under the principle of PWM, consisting only two states. It was decided to increase the fuel flow by increasing the PWM duty cycle. But due to the limitations of the mechanical design of the existing diesel engine, linear actuator had to be designed analogously to change the fuel rack position [6].

In order to control the fuel rate continuously, the existing solenoid which has only two steps has been replaced with a linear actuator. This linear actuator is tailor-made for the available engine and has the dimensions of the existed solenoid. This actuator consists of a servo motor and a rack and pinion mechanism to convert the rotary motion of the servo motor to linear motion. A servo motor is used because it has an error feedback system which can rotate by a very precise angle without errors and also very convenient to use and program. Rack and pinion method is chosen since it has a less complex design and more compact in nature and can be easily coupled with a servo motor to gain a linear motion by converting the rotary motion of the motor. Even though this actuator acts as an electronic governor with an Arduino control circuit, the existed mechanical fly-ball governor is not removed when connected to the diesel engine. The control mechanism is achieved through coinciding operation of the mechanical fly-ball governor and newly added linear actuator. The frequency set point of the engine is set by varying the accelerator position. If only the mechanical fly-ball governor is in operation, the frequency set point is placed at 50 Hz and regardless of the power demand the fly-ball governor will try to achieve that by varying the fuel rack position. When the linear actuator is connected to the diesel engine the frequency set point is set to 60 Hz such that the mechanical fly-ball governor always tries to achieve the 60 Hz power output. This operates as it always opposes the action of the linear actuator and the rack of the linear actuator pushes the fuel rack position of the engine in order to control the fuel flow of the engine to achieve 50 Hz frequency.

B. Linear Actuator Mounting

The developed linear actuator consists of a servo motor and rack and pinion in order to convert the rotary motion to linear motion.

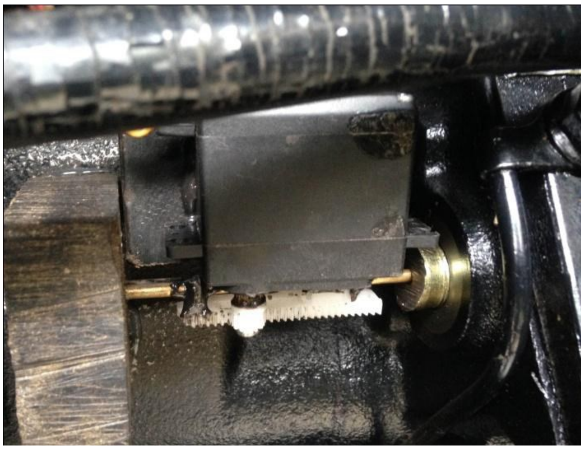


FIGURE2: Mounted linear actuator

B. Controller: Arduino Mega 2560

An Arduino board has been used as the control circuit and analog input is obtained from the frequency detection circuit. And the output signal to the servo motor in order to function the linear actuator is provided from the Arduino board. The program drives the servo motor by connecting the motor to PWM pin 8 of the Arduino, and a frequency detecting input to analog 0. The signal to the potentiometer from the feedback circuit will determine the position of the servo motor by sending a variable resistance current to the A0 analog port on the Arduino [7]. Then the Arduino code interprets to a pulsed signal to the servo motor to position the fuel rack based on the signal from the potentiometer. FIGURE3 shows the hardware arrangement with both servo motor and the feedback circuit with Arduino.

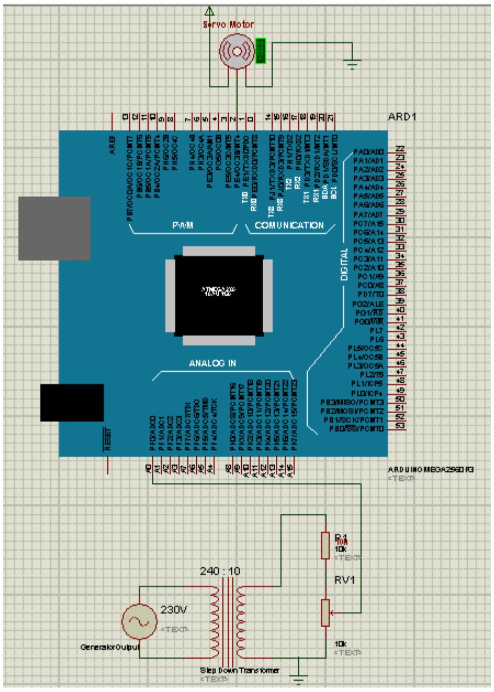


FIGURE3: Schematic circuit of Arduino Mega 2650 in Proteuss

C. Control Algorithm

The electronic governor is a combination of various subsystems as shown in the FIGURE4. Two separate Arduino Mega 2560 boards have been used for the convenience as it eliminates unwanted delays. There are several tasks that Arduino is expected to perform including frequency detection, active power measurement, measuring and monitoring of parameters to LCD/ serial monitor/serial chart, executing control method and servo motor driving. Therefore it is convenient to delegate work between two Arduino devices where one Arduino device is designated as slave device which will measure and monitor variables and send the required parameters to the master device when it asks and the master device will perform the controlling. I2C communication is maintained between the devices. A current transformer is used to obtain the current feedback and the output voltage is used after stepping down to obtain the voltage. Frequency calculation also is done using the output voltage. Open source software called serial chart is used to observe the results in the form of plots of frequency and current vs. time. These plots were used to verify the mode of operation of the electronic governor.

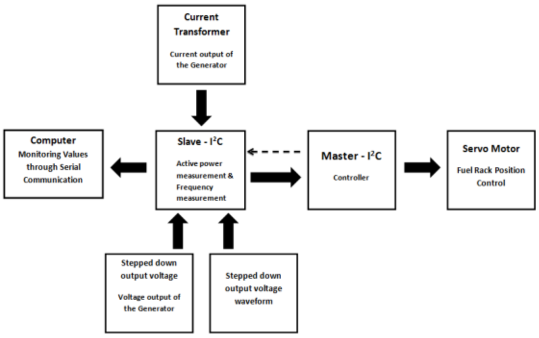


FIGURE4: Block diagram of system

FIGURE5: Controller

E. Frequency Detection Method

Controlling the governor is a challenging task due to the presence of time constants with a higher value. Magnetic pickup sensor, encoder and tachometer are some of the commonly used methods to measure the frequency. It adds additional hardware to the system. It is possible to measure the frequency using the output voltage waveform of the generator. Since the voltage rating of the Arduino 5 V, a step down transformer was used to convert 230 V to 5 V in order to analyse the sine wave. Potentiometer was used in order to adjust the voltage to 3 V rms value. Then the peak to peak value becomes approximately 4.25 V. And also signal had to be processed since the Arduino cannot read negative signals [8]. The stepped down voltage waveform is fed to an analog pin of the Arduino for sampling. Sampling time for the device is 0.112 ms. Using the available information, the time taken for reading of the analog pin to become zero is calculated since the negative half cycle of the waveform is read as zero value in the Arduino device. Using this derived value it is possible to calculate the frequency. The sampling rate has to be high in order to increase the accuracy of the reading [8].

Low resolution caused by sampling frequency is the main disadvantage of this method. And if the output voltage waveform is not generated due to malfunction in AVR, the system will fail to respond. However the controller can be programmed to eliminate such errors. This method is less expensive than using a separate sensor. As the circuit was interfaced with the computer through serial communication, it was possible to observe the performance of the existing mechanical governor [8].

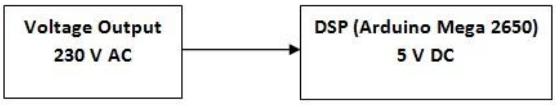


FIGURE6: Schematic diagram of the frequency detection system

The detection of frequency using the output voltage waveform instead of using a speed sensor reduces the complexity of the design and improves the controllability of the hardware. Inbuilt 10 bit ADC of Arduino is used to sample the instantaneous voltage output of the generator. Then the frequency of the signal is calculated using the sampled voltage values [8].

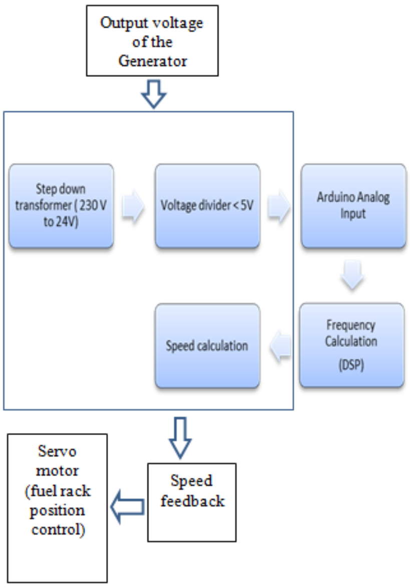


FIGURE7: Schematic diagram of the system

F. Control Algorithm

P control with speed and load feedback loops is used as the basic control method to achieve synchronous operation as shown in the block diagram in FIGURE8. Load reference and R are the variable parameters where load reference defines the power output at operating frequency of 50 Hz and R defines the slope of the characteristic curve. The isochronous mode can be achieved by changing the value of R in to zero which will eliminate the load feedback loop.

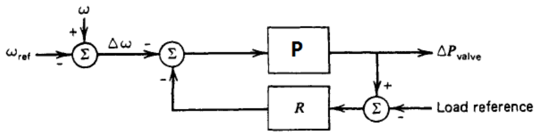


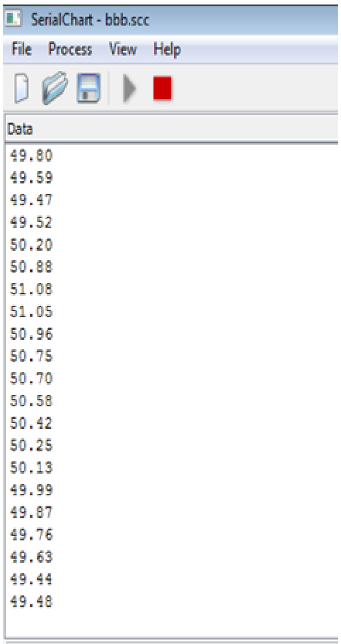
FIGURE8: Control block diagram

Islanded detection is obtained using a simple algorithm using the frequency and load plots. When the both generators are synchronized into the system and a sudden increase of fuel rack position of the diesel generator will give a significant increase in the generator load but not a significant change in the frequency. The reason behind this phenomenon is that, the increased fuel flow in the diesel generator will cause an increase in the mechanical torque in the generator which causes just an increase in the load but not the frequency where the system is considered to be a large one compared to a single generator. FIGURE13 shows a significant change in the load but not the frequency when the generator is synchronized to the system. FIGURE12 shows an isochronous governor where the change of fuel flow results a significant change in the frequency but not in the load where there is no other generators which can contribute to the reduced generation and keep the frequency under the recommended values which means it is islanded.

6. PROCEDURE OF EXPERIMENT

A. Sample Results

The results were obtained using the open source software called serial chart.



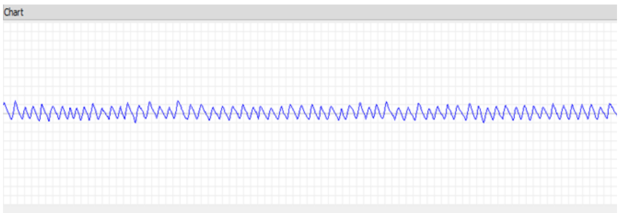
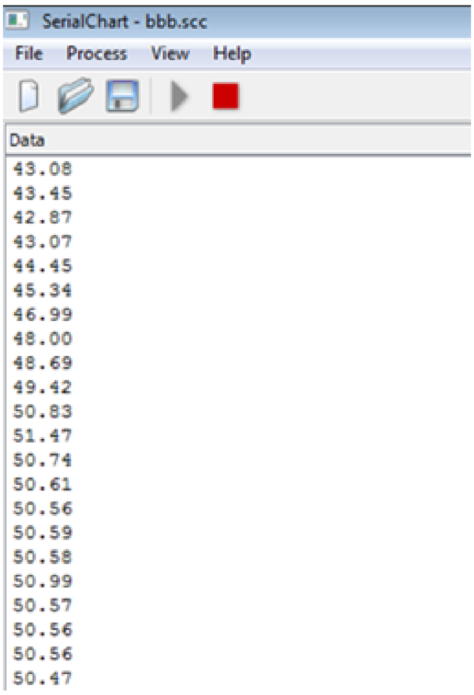


FIGURE9: Isochronous mode under no-load



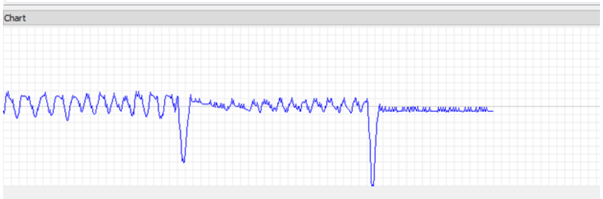


FIGURE10: Isochronous mode under step loads of 2.3 kW

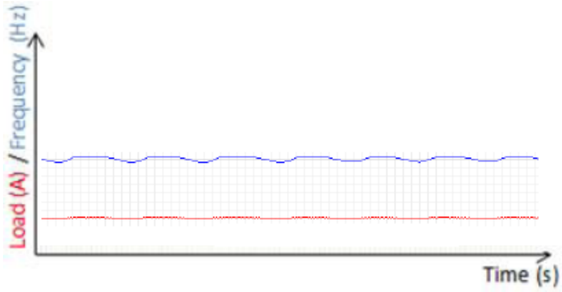


FIGURE11: Synchronous mode operation of developed governor

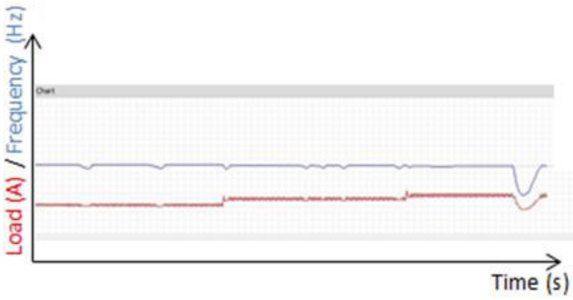


FIGURE12: Islanding effect when not connected to grid

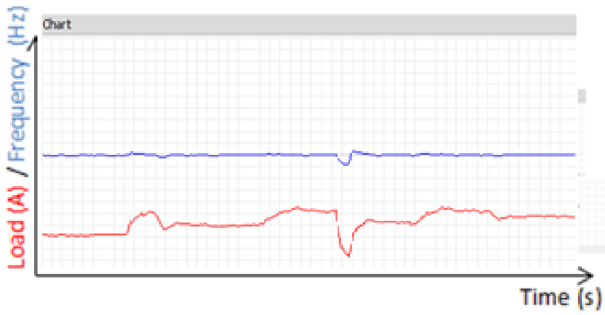


FIGURE13: Islanding effect when connected to grid

7. CONCLUSIONS

In this project, an electronic governor was developed which has the ability to operate under isochronous, synchronous and islanded modes. An actuator was developed using a rack and pinion mechanism with a servo motor to change the fuel rack position of the fuel injection pump of the engine. The actuator is directly controlled by the Arduino Mega 2560 without using any driver circuit. At the same time the Arduino device takes the output voltage waveform for the device into account and calculates the frequency of the waveform which is same as the speed of the shaft of the generator. This is achieved after reducing the voltages to a bearable value. The frequency is achieved using digital signal processing. The Arduino device is programmed so that it can control the actuator position using the feedback and the current position of the actuator. After implementing the isochronous mode, the system was then to work under synchronous mode and islanded mode. The biggest obstacle in this operation is the presence of the considerable time constant of the diesel engine where it takes a considerable time to respond to a change in fuel rack position. In this project, a pre-programmed governor is developed for the diesel generator. But modifications can be made in order to program according to the type of the application such that the user is able to use the governor for several applications. Here the islanding detection part is done manually and then the appropriate mode to be operated is given as a manual input. But with the modifications in the future islanding detection can be made automatically and appropriate mode can be chosen accordingly.

8. ACKNOWLEDGMENT

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