ARM based electronic load controller for micro-hydropower stations

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Abstract. This paper presents a method for maintaining constant voltage and frequency of synchronous generator using Advanced RISC Machine (ARM) controller based Electronic Load Controller. Constant frequency and voltage can be generated by a Synchronous Generator only when a constant electrical load is maintained. It is achieved by using Electronic Load Controller (ELC). When synchronous generator is connected to a turbine or any sudden changing loads its voltage and frequency also varies. This Electronic Load Controller consist of ARM LPC 1768, ACS712 current sensor, Insulated-Gate Bipolar Transistor (IGBT), an auxiliary load and consumer load and is implemented using Pulse Width Modulation (PWM) technique. This Electronic Load Controller provides effective and easy way of controlling voltage and frequency for linear loads which obeys the ohm’s law. PWM technique is the fast response method compared to other methods having smooth speed control. So the load will be switched on/off properly and output voltage and frequency will be maintained.

1. Introduction

Due to low power ratings of micro hydro power stations, synchronous and asynchronous generators are mostly used to maintain the input hydro power constant due to fixed speed turbine. This will maintain the output of the synchronous generator to be kept constant. The major disadvantage of standalone micro hydro power stations is the variation of consumer load with the speed of the water turbine. Thus variation in speed of water turbine will give rise to changes in voltage and frequency of the generator output. The invention of ELC decreases the risk and complexity in maintaining the output of the synchronous generator used in micro hydropower stations. An ELC continuously measures and controls the generated power.

The basic concept of ELC is that it allows the generator to run at their full load power and electronic load is used just to observe the excess power generated by the synchronous generator. ELC measures the generator output speed and compares with the reference speed to control the power absorbed by the dump load to make the speed constant. An ELC is designed to maintain the output of the generators which are used in micro hydropower system. When the load connected increases above the rating of the generator, the excitation capacitors will supply the demand and when the consumer load decreases, then the excess power will be consumed by the dump load. Voltage and frequency can be kept constant by maintaining constant load. The controller adjusts for changes in the fundamental load via consequently varying the measure of amount of power delivered to the resistive load. This resistive load is also known as ballast load.

Neural-Network (NN) based ELC is implemented to control the isolated asynchronous generator which is connected to the uncontrolled turbine [1]. Sometimes the excess power to dump load is
greater than the consumer load, hence it is reduced by using Distributed Electronic Load Controller [2]. The sensor circuits are used along with DSP processor based distribution static compensator used as an electronic load controller (ELC) to maintain constant load for self-excited induction generator (SEIG) [3]. ELC offers the elemental reactive power and conjointly compensates harmonics of currents that could be a connection of voltage source converter and dc-link capacitance with a chopper which gives the control signal to chopper for turn on the auxiliary load and therefore improves the power quality of the overall system [4]. Controller maintains the constant load by varying loads of dump load and also frequency is made constant by giving frequency as feedback variable [5]. An analysis and design of ELC for 3-phase synchronous generator suitable for micro-hydropower stations with constant-input power is delivered. It also provides mathematical modelling of synchronous generator [6]. ELC was designed using uncontrolled rectifier, chopper switch and ballast load [7]. Decoupled electronic load controller along with voltage regulator is designed to control the isolated asynchronous generator [8]. Current controlled voltage source inverter based ELC is proposed. Fuzzy logic is implemented instead of PI controller [9]. Fuzzy logic based electronic load controller also developed. Fuzzy logic gives the output control pulse in simple ways [10].

This paper proposed an Electronic Load Controller which is simpler to design; operation is easier, cost efficient and easy to control that uses Pulse Width Modulation technique to generate pulses to smooth turn on of IGBT. LPC1768 is used to generate Pulse Width Modulation (PWM) pulse.

2. Block diagram of proposed Electronic load controller

Electronic Load Controller (ELC) used in power plants to maintain constant frequency and voltage of generator by diverting excessive energy to dummy loads. Power diversion is done by Insulated Gate Bipolar Transistors (IGBT). By using ELC, power input of generator will be equal to power output of generator. The block diagram of the proposed Electronic Load Controller is shown in figure 1.

![Block diagram of proposed Electronic load controller](image)

**Figure 1.** Block diagram of proposed Electronic load controller.

Synchronous generator is connected to the consumer load and dump load/ballast load. Current sensor is connected to any one of the phases of consumer load to measure the phase current and sensed value is given to the microcontroller LPC1768. PWM pulses are given to the IGBT via IGBT driver circuit. IGBT is then connected to the dump load. Optocoupler is connected between microcontroller and the IGBT driver.

Synchronous generator has rated voltage of 440V and rated current of 3A. The output voltage of Synchronous generator is kept constant. For this a constant current was fixed (2A) and the current to the consumer load is sensed continuously. The sensed current was read by the ARM LPC1768. If the sensed current is lower than the fixed current, then the microcontroller produces the PWM pulses according to the difference in the current. The PWM pulses is given to the optocoupler which is used to separate the low power and the high power circuit. The same pulses is also applied to the IGBT gate which connects the dump load to the generator output and the same current is maintained in the
generator and the output voltage is maintained at constant. The microcontroller is programming using these equations (1), (2), (3) and (4).

Let,

\[
P_G = \text{Power generated} \\
P_C = \text{Power consumed by consumer load} \\
P_D = \text{Power consumed by Dump load} \\
I_D = \text{Dump load current} \\
I_G = \text{Generator output current} \\
I_C = \text{Consumer load current}
\]

We know that,

\[
P_D = P_C + P_D \quad \text{Eqn. (1)}
\]

\[
I_G = I_C + I_D \quad \text{Eqn. (2)}
\]

Generator current is kept constant at 2A (IG).

Current sensor output = consumer load current.

\[
I_D = I_G - I_C \quad \text{Eqn. (3)}
\]

\[
I_D = 2 - I_C \quad \text{Eqn. (4)}
\]

2.1. Dump load/ballast load

Dump load/Ballast load is fundamentally resistive load (obstruction) used to dump the extra power generated by the generator in the form of heat. Usually air heaters, water heaters will guarantee long life, maintenance free and economically useful. When the dump load is turned on, it consumes the full excess power generated irrespective of the rating of the dump load hence dump loads must be turned on/off by PWM pulses to avoid excess power to the loads otherwise loads will damage.

2.2. Insulated Gate Bipolar Transistor (IGBT)

IGBT is a 3-terminal power semiconductor switch which is used to control the high current circuit. They are similar to working of the MOSFET. In spite of the fact that they display quick turn-on, their turn-off is slower than a MOSFET in terms of current fall time. Trench IGBT FGA25N120AN TD is used which is 1200-V non-punch through (NPT). To withstand the voltage of 400V, FGA25N120ANTD IGBT is used. The IGBTs are connected in series inverted mode as it conducts for the positive cycle only. So there are two IGBTs used for each phase. The IGBT FGA25N120ANTD is shown in the Figure. For each IGBT, heat sink is attached to cool the IGBT as it conducts high current.

2.2.1. IGBT configuration per phase

The IGBT configuration per phase is shown in the figure 2.

![IGBT Configuration](image-url)
IGBT conducts for only positive cycle and series inverted IGBT topology is implemented to control the turn on and turn off of the ballast load because one IGBT conducts in positive cycle whereas other conducts in negative cycle. The series inverted IGBT is connected to each phase. The PWM pulses from the LPC 1768 (PIN 21, 22, 23) for each phase R, Y, B are connected to the IGBT’s in every phase. The same PWM pulse is applied to two IGBT’s connected in the same phase.

2.3. ACS current sensor

It is used to measure either AC or DC current up to 20A and it is an accurate sensor. This sensor can be used to measure high AC current. The pin VCC and ground of current sensor is connected to the LPC1768. VOUT is used to give power supply to sensor and the output voltage is proportional to the connected/consumer load. The current is taken at pin OUT. The sensor is connected in between the generator and the consumer load. The features of ACS current sensor are,

- Output sensitivity - 100 mV/A.
- Extremely stable output offset voltage.
- Factory trimmed for accuracy.
- Magnetic hysteresis is nearly zero.

2.3.1. Interfacing current sensor with microcontroller

The purpose of using microcontroller is to generate PWM pulses for switching of dump loads via IGBT. The PWM pulse must be generated as per the current to the consumer load. This process is done by microcontroller LPC 1768.

Out of 40 pins, pin 15 is used to sense current from the current sensor, pin 21, 22, 23 are used to take out generated PWM pulses to turn on the dump loads. Reasons for using this LPC 1768 are,

- Low power consumption.
- Easy to program.
- Online compiler is readily available to check the code.
- Easy to generate the PWM pulses.

The current to the consumer load is sensed by current sensor ACS 712 and given to microcontroller through pin 15. From that current to the dump load is calculated and the current through three phases are obtained. The sinusoidal current is converted into PWM pulse by comparison with constant DC supply. Then the generated PWM pulse from pin 21, 22, 23 is given to IGBT in each phase respectively through optocoupler and gate driver for turning dump load ON and OFF.

2.4. Optocoupler

Optocoupler is placed between the microcontroller and driver circuit to prevent microcontroller LPC1768 from high voltages. In this, MOC3021 optocoupler is used. It has 6 pins. Out of 6 pins, four pins are used. PIN1: Anode is connected to the LPC1768 and receives the PWM pulse from the microcontroller. PIN2: Cathode is connected to the ground. PIN4 and PIN6: Main terminal is connected to the IGBT driver to give PWM pulse.

2.5. IGBT driver

The magnitude of PWM pulses from the microcontroller is not enough to drive the IGBT, hence IGBT driver is used in between the microcontroller and the IGBT. IRS 2110 driver is used to drive the IGBT. The IRS2110 is given with PWM pulses from the optocoupler which is then amplified by the driver and then given to the IGBT gate where it is connected in series inverted mode.
3. Pulse Width Modulation

In Pulse Width Modulation, the analog signal is encoded into series of signal pulses. The PWM pulse is produced by comparing the reference signal with the carrier signal. The frequency of carrier signal should be higher than the reference signal so that waveform perceived by the load must be smooth as possible. The figure 3 represents the sinusoidal PWM technique.

PWM Sampling Theorem states that, “a continuous time signal can be represented in its samples and can be reconstructed back when sampling frequency $f_s$ is higher than or equal to the two times the highest frequency of signal”.

$$f_s = 2f_h$$

The PWM technique is based on the two signals: carrier signal and modulation signal. The modulation signal should be generated from the magnitude of current flow to the consumer load. The consumer load current can be varied from 0A to 2A. The carrier signal is generated as triangular wave which is of very higher frequency (switching frequency of IGBT). The two signals are generated correctly by programming the ARM microcontroller. Whenever the magnitude of modulation signal is greater than the magnitude of carrier signal, the output switching pulse is presented. Then the switching pulse is applied to the IGBT to control the load connected to the synchronous generator.

![Figure 3. PWM pulses generation.](image)

### 3.1. Advantages of proposed system

The advantages of the proposed method are,

- No hammer effect from load changes.
- High reliability and simple circuit.
- Low maintenance.
- ELC have low wear and tear on mechanical parts.
- It can be easily fitted in electrical system and easy to operate.
- Less expensive.

4. Simulation and results

4.1. Simulation circuit

The simulation for the proposed ELC is carried out in the MATLAB software. The Simulink model of the proposed system is shown in the figure 4. It consists of synchronous machine, consumer load, ballast load, PWM pulse generation circuit and excitation system for the synchronous machine. The ballast and consumer load is connected in parallel to the synchronous generator. Whenever there is sudden change in the load occurs, the voltage across the generator varies. The variation in the voltage causes drastic effect to the other loads connected to the machine. The current in any of the phase is
measured and is compared with the reference current. The error is measured and is given to the PID controller. The control signal is generated by PID controller and is compared with carrier signal. In MATLAB carrier signal is generated by the Repeating sequence block. The output of the comparator gives PWM pulses. The PWM pulses controls the IGBT switching and the constant load is maintained. Hence, the output voltage and frequency of the synchronous generator is kept constant.

Figure 4. Simulink model.

4.1.1. Results of the simulation

The voltage level of the synchronous generator without ELC and with ELC is shown in the figure 5 and figure 6. Without ELC whenever load changes, the output voltage level changes and cannot be kept constant. With ELC is connected in parallel with consumer load to the synchronous generator, then the voltage is maintained at constant. There are three different regions A, B, C shown in the simulation output. Whenever voltage level is reduced by 10V, then ELC will enter makes the voltage constant.

Figure 5. Voltage control without ELC.
The proposed system is implemented using the Arduino UNO board. The relay and solenoid valve are controlled automatically and can be controlled manually using the Blynk Application on an android mobile phone. The android phone is connected to the board using the ESP8266 Wi-Fi module. The four parameters namely moisture, temperature, humidity and intensity is monitored and controlled using the ON/OFF switch button displayed on the Blynk Application. The sensor results viz., humidity, temperature, moisture, sunlight intensity and the status of the motor is linked with the Blynk app shown in figure 3 is the reading taken from the field model created in an area of about 30cm×30cm. When the moisture is above 250% the motor is turned OFF automatically or manually through the Blynk Application. Also the device is programmed such that if the light intensity is above 25% the motor will be still ON until the moisture reaches 300% to compensate the effect of sunlight.

5. Results and discussion
The below figures show the PWM pulses corresponding to the dump load. When consumer load current is IC=2A, then the current absorbed by the dump load is 0A. The PWM pulse generated from LPC1768 has no pulses and IGBT will not turn on hence the ballast load is not connected to the generator. The corresponding pulse waveform is shown in figure 7.

![Figure 7. PWM pulse when IC = 2A.](image)

When consumer load current is IC=1A, then the current absorbed by the dump load is ID=1A. The PWM pulse generated from LPC1768 has pulses according to the current magnitude and so IGBT will turn on and the dump load is connected to the generator. The corresponding pulse waveform is shown in figure 8.
When consumer load current IC =0A, then the current absorbed by the dump load is ID=2A. The PWM pulse generated from LPC1768 has pulses according to the current magnitude and so IGBT will turn on and the ballast load is connected to the generator. The corresponding pulse waveform when IC = 0A is shown in figure 9.

The hardware output and model of electronic load controller is shown in figure 10 and figure 11.
Figure 11. Hardware model.

The hardware setup of the arm based electronic load controller is shown in figure 12.

Figure 12. Hardware setup.

6. Conclusion
The arm based electronic load controller maintains voltage and frequency for linear loads by switching the loads at constant time intervals. The software simulation for various load values were stimulated and the model is also implemented in hardware. The socio-economic impacts of the proposed system are,

- This can help in getting electricity to rural parts and hill areas of the world which is not directly connected to the grid.
- Charging or water heating as dump loads for surplus power.

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