# Frequency Control Of Micro Hydro Power Plant Using Electronic Load Controller

Pankaj kapoor*, Lobzang Phunchok**, Sunandan Kumar***, Asst. Prof. Om Prakash Rahi****

*(Department of Electrical Engineering, NIT Hamirpur,
** (Department of Electrical Engineering, NIT Hamirpur,
***(Department of Electrical Engineering, NIT Hamirpur,
**** (Department of Electrical Engineering, NIT Hamirpur,

## ABSTRACT

**Water turbines, like petrol or diesel engines, will vary in speed as load is applied or relieved . Although not such a great problem with machinery which uses direct shaft power, this speed variation will seriously affect both frequency and voltage output from a generator. Traditionally, complex hydraulic or mechanical speed governors altered flow as the load varied, but more recently an electronic load controller (ELC) has been developed which has increased the simplicity and reliability of modern micro-hydro sets. An ELC is a solid-state electronic device designed to regulate output power of a micro-hydropower system and maintaining a near-constant load on the turbine generates stable voltage and frequency. In this paper an ELC constantly senses and regulates the generated frequency. The frequency is directly proportional to the speed of the turbine.**

***Keywords*** **–** Micro hydro power plant, Synchronous generator, Electronic load controller, IGBT, Sim power.

## 1 INTRODUCTION

Flowing and falling water have potential energy. Hydropower comes from converting energy in flowing water by means of a water wheel or through a turbine into useful mechanical power. This power is converted into electricity using an electric generator or is used directly to run milling machines. The concept of generating electricity from water has been around for a long time and there are many large hydro-electric facilities around the world. What is new to most people is the idea that this same concept will work on a smaller – and even individual – scale. With the rising costs of utility power and refinements to micro-hydro systems, it is now not only possible, but also very practical, to look at water as the source for your electricity [1].

- MHPP generally classified as having generating capacity between 5kw to 100kw.
- Depending on individual circumstances, people find that they need to develop their own source of electric power.
- MHPP system offer a stable, inflation proof, economical and renewable source of electricity.
- MHPP fulfill your basic needs like lighting etc.
- A 100 kW system will produce 100 standard units of electricity in 1hour.
- Most of MHPP is 'run of river means not need of large dam .
- 'Fuel-free' source of power.
- Different to large hydro since environmental impacts of installation are negligible[1].

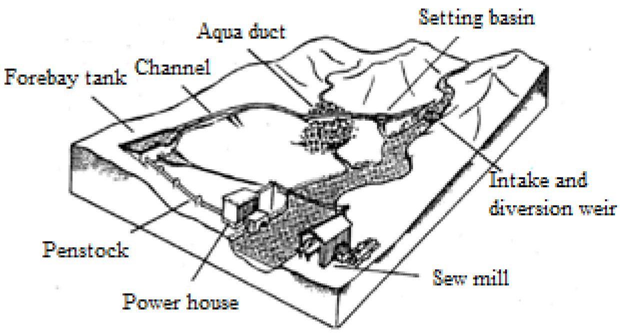



**Fig 1: Civil components of MHPP**

- Renewable energy source therefore helping to reduce greenhouse gas emissions and having a net positive impact on the environment.
- Constant generation over long periods unlike wind and solar power
- Good correlation with demand (more hydro energy is available in winter when heating loads are high)
- Long lifetime of systems, typically 30 years or more
- Low maintenance requirements and running costs
- Reasonable payback for grid -connected systems, often 5-8 years or less

## 2 MODELING OF CONTROLLER

The considered Controller consists of an uncontrolled diode rectifier bridge, a control circuit, a solid-state switch (IGBT) operating as a chopper and the dump load (resistors). The stator voltage is fed to the controller circuit through a small value of source inductance ($L_f$) and resistance ($R_f$) . A filtering capacitor

(C) is connected across the rectifier output to filter out the ac ripples of the dc voltage. In above $T_m$ and $T_e$ are positive for generator and negative for motor. The combined inertia of rotor and generator is accelerated by unbalance in the mechanical and electrical torque. Thus equation can be written as[2,11]

$$J\frac{d\omega m}{dt}=T_a=T_m\text{-}T_e \quad (1)$$

Where J = Combined inertia of generator and turbine kg-$m^2$ $\omega_m$ =Angular velocity of rotor mech rad/sec; t = time in seconds.

If the synchronous generator which is connected to turbine rotating at angular velocity $\omega_r$ rad/sec and $\delta$ is the angular position of rotor in radians calculated with respect to reference position. The per unit form of the equation can be written as

$$\frac{d\Delta\overline{\omega}r}{dt}=\frac{1}{2H}(\overline{T}_m\text{-}\overline{T}_e\text{-}K_D\Delta\overline{\omega}_r) \quad (2)$$

Where $K_D$ is damping coefficient, H is the normalized inertia constant represents K.E stored in the rotor. The mechanical starting time $T_M$ = 2H sec, is defined as time required for rated torque to accelerate the rotor from stand still to rated speed. The change in angular position of rotor is given by

$$\frac{d\delta}{dt}=\omega_o\Delta\overline{\omega}_r \quad (3)$$

Where $\Delta\overline{\omega}_r$ is the per unit angular velocity of rotor in electrical rad/sec. The volt–current relation of the complete load controller system is

$$V_{max}=2R_fi_d + 2L_fpi_d+v_d \quad (4)$$

from which the derivative of controller current (id) is defined as

$$Pi_d=\frac{Vmax-vd-2Rfid}{2Lf} \quad (5)$$

Where, $v_{max}$ is the maximum value of ac line voltages ($v_a$ ,$v_b$, $v_c$, -$v_a$, -$v_b$ and –$v_c$ )depending on which diode pair is conducting and vd is the dc-link voltage. The ac dump load currents in the three phases ($I_{Da}$ , $I_{Db.}$ and $I_{Dc}$) are obtained by using the magnitude of $I_d$ and direction (sign) corresponding to conducting pairs of diodes

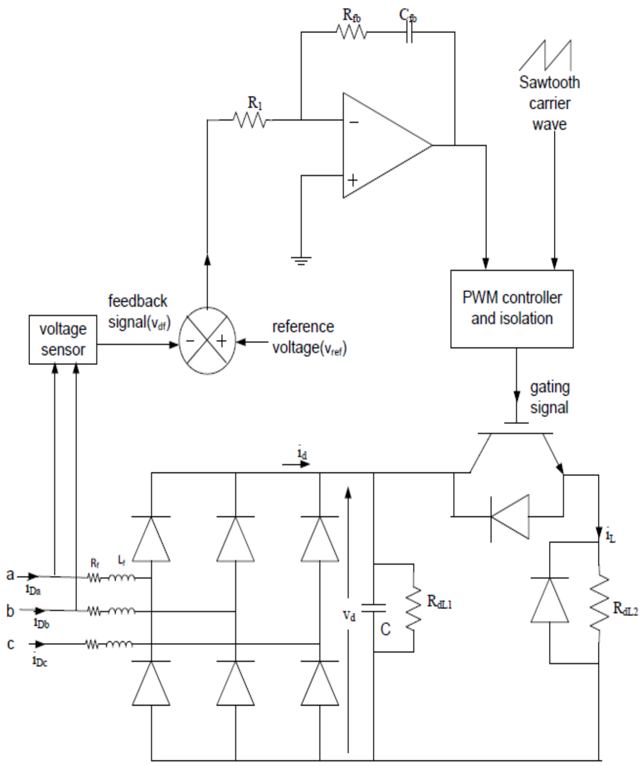



**Fig 2: Schematic diagram of controller with Control circuit**

Charging and discharging of the filter capacitor is expressed as $Pv_d$=$Pv_d\frac{(id-iL)}{C}$ (6)

$$\text{with } I_L=\frac{vd}{Rdl1}+S\frac{vd}{Rdl2} \quad (7)$$

where, S is the switching function indicating the switching status of the IGBT switch. When the switch is closed, then S = 1 and when the switch is opened, then S = 0. The switching states of the IGBT chopper (S = 1 or 0) depend on the output of Pulse Width Modulation (PWM) wave with the varying duty cycle which compares the output of Proportional Integral (PI) voltage controller.

## 2.1 MODELING OF CONTROL SCHEME OF CONTROLLER

The closed-loop control is the heart of controller and it plays a vital role in keeping the terminal voltage of the SG constant. The SG output voltage is sensed using a step-down transformer and converted to dc through a single-phase rectifier circuit for the feedback signal, as shown in Fig. 5.4. A small capacitor ($C_s$ ) is used to filter the ripples out from the rectified voltage to be used as the feedback signal ($v_{df}$) and it is compared with the reference voltage($v_{ref}$ ) [3]

The error voltage is fed to a PI voltage controller. The output of controller is compared with the saw tooth carrier waveform to result in the PWM signal to alter the duty cycle of the chopper. The single-phase rectifier circuit used in this feedback loop is modeled as [4]

$$V_f = R_{ff}i_{df}+L_{ff}+Kv_{df} \quad (8)$$

Here, $v_f$ is the absolute value of the instantaneous value of the ac output voltage of the step-down transformer corresponding to the SG voltage ($v_a$ or $-v_a$) depending on which diode pair is conducting and $v_{df}$ is the dc voltage. $R_{ff}$ and $L_{ff}$ are the resistance and leakage inductance of the step-down transformer, respectively. K is a constant depending upon the tapping of the potentiometer. The derivative of current ($I_{df}$) is given as [5]

$$pi_{df} = \frac{(vf - Kvdf - Rffidf)}{Lff} \qquad (9)$$

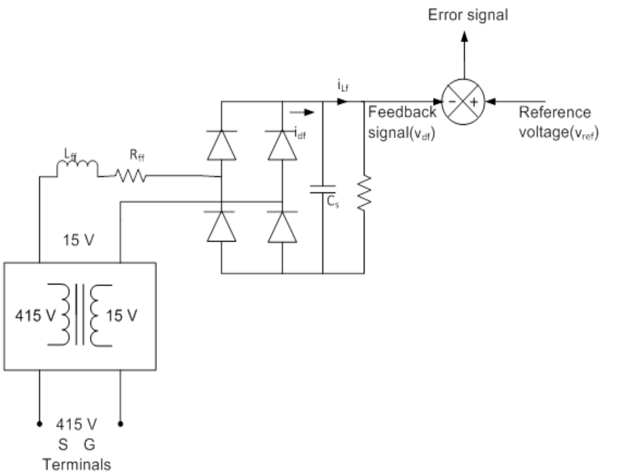



**Fig: Voltage Sensing Circuit**

Charging and discharging of the filtering capacitor ($C_s$) at the output of the single-phase uncontrolled rectifier is as follows [6]:

$$pv_d = \frac{idf - Rffidf}{CsK} \qquad (10)$$

Voltage $v_{df}$ is used as the feedback voltage signal and compared with the reference signal. The resulting error is fed to the PI voltage controller. The analog PI voltage controller modeled as [7]

$$P\, v_{01} = K_1 \frac{Vref - vdf}{Tcc} \qquad (11)$$

$$v_{02} = K\,(v_{ref} - v_{df}) \qquad (12)$$

The output signal of the PI controller ($v_0$) is

$$v_0 = v_{01} + v_{02} \qquad (13)$$

where $v_{ref}$ is the reference voltage, K1 = $R_{fb}$ /R1 = 34.55 and $T_{cc}$ = $R_{fb}$ $f_b$ = 0.1935 as $R_{fb}$ = 194 k Ω, $R_1$ = 5.6 k Ω, $C_{fb}$ = 1 µF. R1, $R_{fb}$ and R1are the input resistance, feedback resistance, and feedback capacitance used in the analog PI controller. The output of the PI controller (v0) is compared with the saw-tooth PWM carrier waveform. The saw tooth waveform is defined a [8]

$$v_{st} = \frac{Amt}{Tp} \qquad (14)$$

where $A_m$ is an amplitude of the saw tooth carrier waveform (2.38 V), t is time in micro sec's, and $T_p$ is a time period (200µs) of the saw tooth PWM carrier wave. The PI controller output voltage ($v_0$) is compared with the saw tooth carrier waveform and output is fed to the gate of the chopper switch (IGBT), which is operated as: S = 1, when $v_{st}$ > $v_o$, and S = 0, when $v_{st}$ < 0, where S is the switching function used for generating the gating signal of the IGBT of the chopper of the controller [9]. The PWM signal is fed to an opto-isolator, which isolates the power circuit and the control circuit. The opto-isolator inverts the signal at its output and hence a single stage transistor amplifier is used at its output, which again inverts the signal to regain the original signal. This signal is then fed to a push-pull amplifier, which drives the IGBT chopper with the appropriate duty cycle [10].

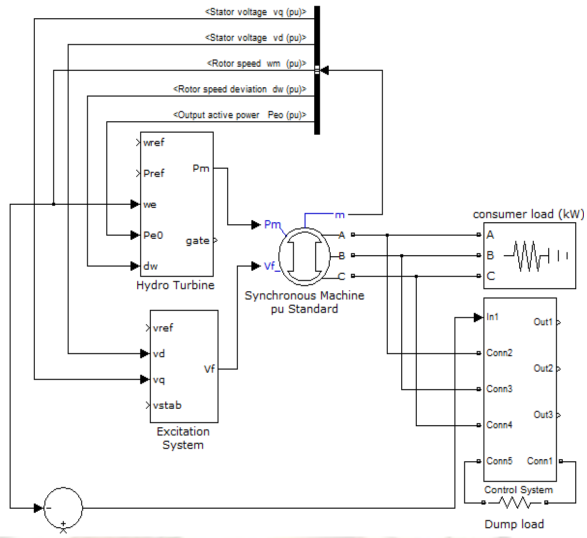
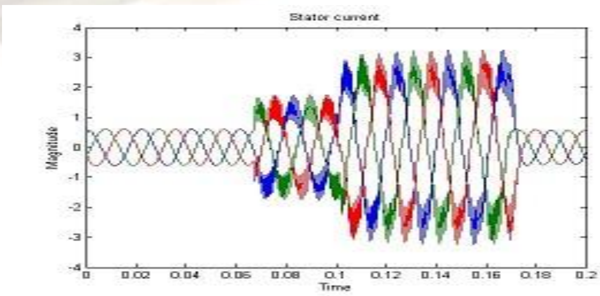



**Fig: Control Diagram of Proposed System**

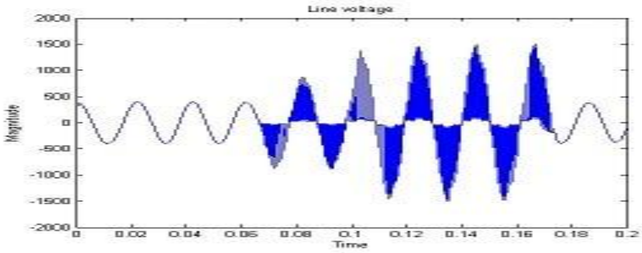
## 3 Simulation results and discussion

The objective of this work is to simulate a Synchronous generator with load controller under various operating conditions. The complete MATLAB Simulink model is developed with the help of sim power system block sets. In each case , Synchronous generator is starting at different operating characteristics of voltage build up for all three lines at Synchronous generator terminals, Rotor speed and stator 3- phase current, voltages, speed, excitation voltage, error frequency and frequency of generated voltage, and controller $I_d$ &$V_d$ is simulated with respect to simulation time respectivel

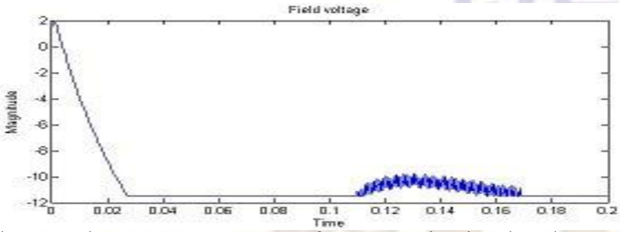
1 Three line currents build up at Synchronous generator terminals start at time 0.179 sec with the magnitude of 0.6pu. as shown in fig 1



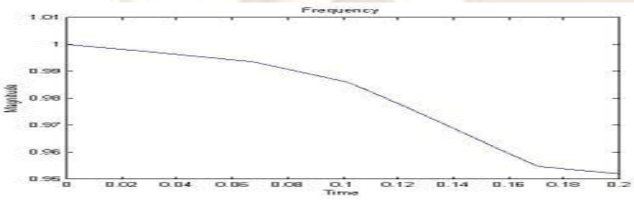
2 Three line voltage build up at Synchronous generator terminals start at time 0 sec and start excited from the rate value. as shown in fig 2



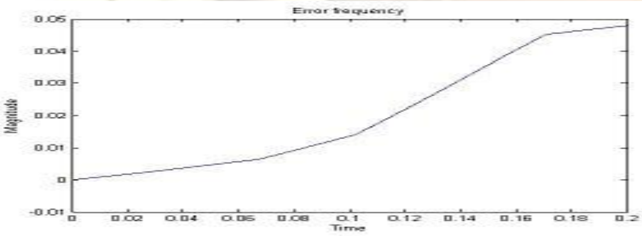

3 The Excitation voltage is simulated as shown in fig.3. It having value of 0.16(pu) and become constant



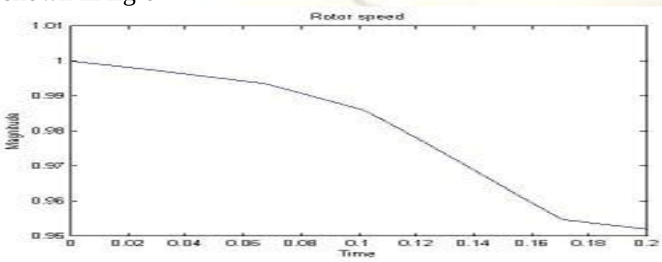

4 The Synchronous generator's frequency is simulated. It slowly as shown in fig 4



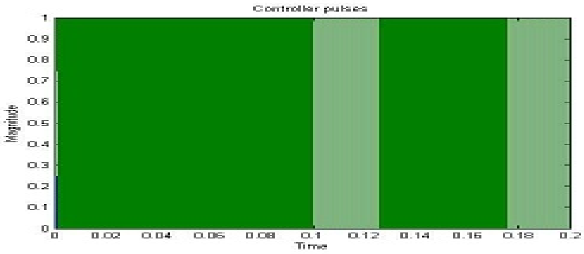

5 The SG error frequency is simulated as shown in fig 5.



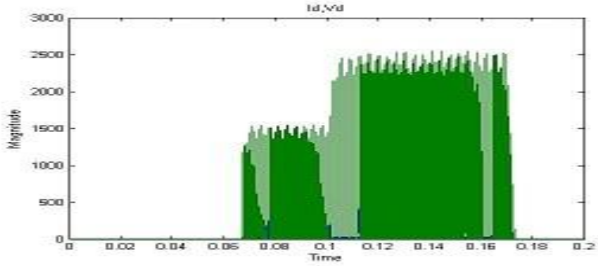

6 The rotor speed (pu) of Synchronous generator is simulated. It slowly start from 0 sec. and goes up to its rated value in negative direction (as the case of generator) as shown in fig 6




7 The Synchronous controller pulses signal behaviour is simulated as shown in fig 7




8 The Synchronous generator's controller characteristic of $I_d$ & $V_d$ is simulated as shown in fig 8




## Conclusion

The objective of this work is to simulate a Synchronous generator with load controller under various operating conditions. The complete MATLAB Simulink model is developed with the help of sim power system block sets. The idea behind this simulation of Micro hydro power plant was that with the change in load, the speed of the rotor changes. Excess load should be dumped to maintain the speed. The characteristics of rotor speed and frequency are having negative slope, that is, they are decreasing with increase in load. The error in frequency is rising. Pulses are given to the controller to switch on the controller accordingly. Controller brings a dump load into the picture. Rests are the voltage and current characteristics which are normal waves. The disturbance in the voltage waveform is because of the switching of the CB at that instant. The voltage and current pulses are of zero and one magnitude because of the low resistance value.

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