DESIGN OF ELECTRONIC LOAD CONTROLLER BY USING COMBINATION METHOD FOR MICRO-HYDRO POWER PLANT AND ITS CONTROL AND MONITORING PROGRAM SIMULATION

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Abstract- In stand-alone micro-hydro power system, water turbine will vary in speed due to the variation of consumer load. This speed variation will cause in fluctuation in both voltage and frequency output from a generator. To solve this problem, electronic load controllers were invented and used by using single method in micro-hydro power system. Although using single method may satisfy for low power rating, it can not only generate the large amount of harmonics but also reduce the control resolution of system for large power rating. In this paper, combination method of binary load regulation and pulse width regulation is used to be minimal harmonic effect into the power system and to improve the control resolution. Microcontroller based proposed ELC design is simulated and studied on LCD display by Proteus 8 professional software.

Keywords- Binary Load Regulation, Combination Method, Electronic Load Controller (ELC), Pulse Width Regulation, Stand-Alone Micro-Hydro Power System.

I. INTRODUCTION

Micro-hydro power generations are emerging as a major renewable energy resource today. They have also been playing a great role to provide electricity to remote area especially in developing countries. Micro-hydro power stations are defined as hydro electric system up to 100 kW power range.

The problem in micro-hydro power system is fluctuation in frequency and voltage generated by the generator under consumer load variation which causes adverse affect in various electrical appliances. Electronic Load Controller (ELC) is used to solve that problem. Control is done by diverting the unused power to the ballast load. An ELC is a solid state electronic device designed to regulate output power of a micro-hydro power system and maintaining a near-constant load on the turbine. In this paper, the control system of hydro power generating plant with 60 kW synchronous generator is designed to regulate the power flow in the main load and ballast load. An ELC constantly senses and regulates the generated voltage and frequency. The voltage and frequency is directly proportional to the speed of the turbine.

II. ELECTRONIC LOAD CONTROLLER

Electronics Load Controller is an electronic governor that functions as a frequency and voltage regulator on a generator. Load control is suitable for a micro hydro power plant applied on rivers (without a dam). An ELC is also a solid state electronic device designed to regulate output power of a micro-hydro power system. Maintaining a constant load torque on the turbine may cause to be stable voltage and frequency generated by generator. The controller compensates for variation in the main load by automatically varying the amount of power dissipated in a resistive load, generally known as the ballast or dump load, in order to keep the total load on the generator and turbine constant. Water heaters are generally used as ballast loads.

There are several advantages of electronic load controller

1) ELC enables the use of simpler, cheaper turbine with less moving part.
2) No hammer effect from load changes.
3) ELC allows lighter, less robust penstock and imposes less wears and tears on machinery.
4) High reliability, low maintenance and simple to operate.
5) ELC can be fitted at any point in electrical system.
6) Ballast load can usefully deployed example water and/or space heaters implying 100% load factor of the power plant.
7) ELC is less expensive than equivalent flow control governor [1].

III. PRINCIPLE OPERATION OF ELC

The Synchronous generator–ELC system consists of a three-phase star-connected generator driven by a micro hydro turbine and an ELC. Since the input power is nearly constant, the output power of synchronous generator is held constant at varying consumer loads. The power in surplus of the consumer load is dumped in a dump load through the ELC. Thus, synchronous generator feeds two loads in parallel such that the total power is constant, that is,

$$P_G = P_C + P_D \tag{1}$$

Where,

P_G = Generated power of the generator (which should be kept constant),
P_C = Consumer load power, and
P_D = Dump load power

The power dissipated in the dump load can be used for battery charging, water heating, cooking, etc.

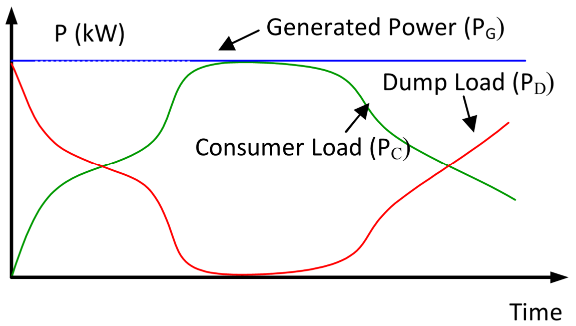

Fig.1 Principle operation of ELC

IV. LITERATURE REVIEW

The main type of ELC designs that are prevalent are:
1) Binary load regulation
2) Phase angle regulation
3) Pulse width regulation
4) Controlled bridge rectifier
5) Uncontrolled bridge rectifier with a chopper

Table I
Advantages and disadvantages of control methods

Method	Advantages	disadvantages
Binary load regulation	-Minimal harmonics	-Fixed damp load size -Requires large number of dump load -Effectiveness limited by number of dump loads.
Phase angle regulation	-Can use any number/size combination of dump load	-Harmonics -Effectiveness is limited by timing accuracy of trigger pulse. -Control system is complex.
Pulse width regulation	-Can use any number/size combination of dump load -Control system is simplest.	-Harmonics -Effectiveness is limited by timing accuracy of duty cycle.
Controlled bridge rectifier	-Can use any number/size combination of dump load	-Harmonics -Effectiveness is limited by timing accuracy of trigger pulse. -Control system is complex.
Uncontrolled bridge rectifier with a chopper	-Can use any number/size combination of dump load	-Harmonics -Effectiveness is limited by timing accuracy of duty cycle.

A. Binary Load Regulation

In binary load regulation the ballast load is made up from a switched combination of binary arrangement of separate resistive loads. In response to a change in the consumer load, a switching selection is made to connect the appropriate combination of load steps. This switching operation occurs during the transient period only, thereafter full system voltage is applied to the new fraction of the ballast load and hence harmonics are not produced by this method in the steady-state. In addition, it is usually the practice to adopt solid-state switching relays which include a zero-voltage switching circuit that reduces the harmonic distortion associated with the transient switching period [3]. Costs of Solid State relay are far higher than the TRIACS because each of them contains steering electronics. The number of dump loads and the associated wiring is high and to achieve smooth regulation, these dump loads should all have exactly the right capacity. With a low number of dump loads, steps between dump load combinations remain too large and the system cannot regulate smoothly.

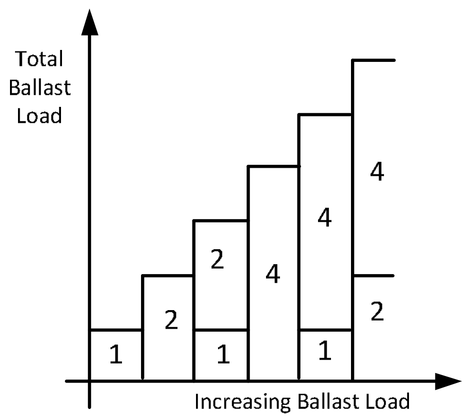

Fig.2 Binary weighted ballast load

B. Pulse Width Regulation

In pulse width regulation, AC voltage is first rectified and dump load is switched on and off with a variable duty cycle. Duty cycle is the ratio of switch on time of a cycle to the time for a cycle. Control is done by varying the on-time of a cycle when the time of a cycle is constant for fixed frequency. PWM control can have fast response and compared to other schemes they usually have very smooth speed control, but the transistor switching losses is really noticeable and significant in high frequency [2]. Power insulated gate bipolar transistors (IGBT) or metal oxide semiconductor field effect transistors (MOSFET) should be used in this control method.

V. PROPOSED ELC DESIGN AND SYSTEM CONFIGURATION

The selected method of proposed ELC is the combination of binary load regulation and pulse width regulation. Because binary load regulation is minimal harmonics and pulse width regulation is fast respond compared to others schemes.

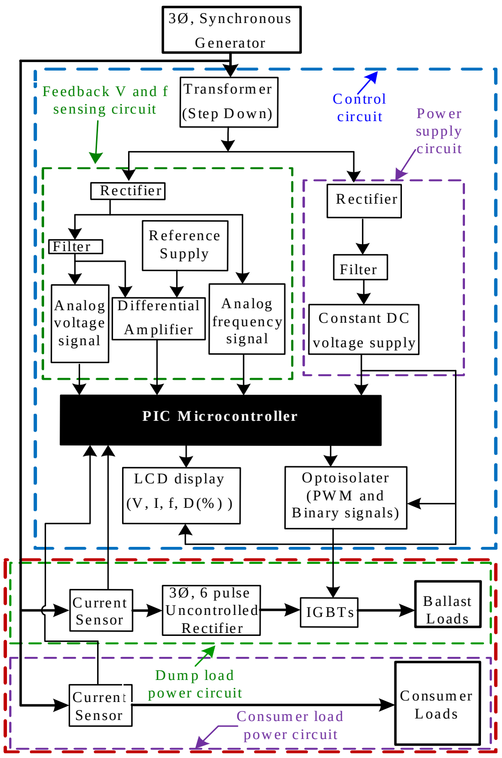

Fig.3 Block diagram of proposed ELC design

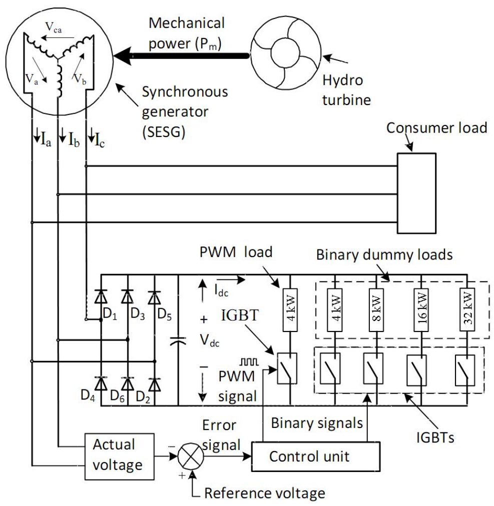

Fig.4 Power line circuit diagram of proposed ELC design

The main type of ELC designs that are prevalent are:
1) Feedback voltage and frequency sensing circuit
2) Power supply circuit and
3) Microcontroller, LCD display and optoisolator.

Control circuit consists of:
1) Dump or ballast load power circuit and
2) Consumer load circuit.

VI. DESIGN CALCULATION OF PROPOSED ELC

Electronic load controller circuits are developed based on various methods whilst holding their purposes. The main function of ELC is to dissipate the exceeded power in dump load and to obtain the balancing between the hydro turbine input and the generator output [5]. With the variation of consumer load, the load controller has to change the effective dump load resistance.

$$P_G = P_C + P_D$$

The power in dump load depends on both the duty cycle of PWM and binary load regulation and is given as:

$$P_D = P_B + P_{PWM} \quad (2)$$

$$P_{PWM} = (DV_{dc})^2 / R_D \quad (3)$$

where,
P_B = Binary load power
P_{PWM} = PWM load power
D = Duty cycle of PWM
V_{dc} = DC output voltage of uncontrolled bridge rectifier
R_D = Dump load resistance

The rating of dump load resistance is given by:

$$R_D = V_{dc}^2 / P_D \quad (4)$$

A. Generator Parameters

Three phase synchronous generator model of 60 kW, 440 V, 50 Hz, 4-pole is considered. The generator is salient pole type. The speed of synchronous generator is calculated as below:

$$N_s = 120\, f / p$$

(5)

where,
N_s = synchronous speed of generator
f = frequency of generated voltage
p = number of pole

B. Design of ELC

The rating of bridge rectifier and PWM switch depends on the rated voltage and power of the synchronous generator. The DC output voltage of uncontrolled bridge rectifier is given as below:

Rated load power P_L= 60 kW
System line voltage, V_L= 440V

$$V_{dc} = (3\sqrt{2}\, V_L)/\pi \quad (6)$$

$$V_{dc} = (3\sqrt{2} \times 440)/\pi = 594 \text{ V}$$

ELC current is given as,

$$I_{dc} = P_G / V_{dc} \quad (7)$$

I_{dc} = 60000/ 594 = 101 A

The total dump load resistance is calculated as :

$R_D = V_{dc}^2 / P_D = 594^2 / 60000 = 5.88\ \Omega$

For binary load arrangement, total dump load is divided into four dump loads. So,

$P_B = P_{B1} + P_{B2} + P_{B3} + P_{B4}$ (8)

P_B = 4 kW + 8 kW + 16 kW+ 32 kW = 60 kW

The individual dump load resistance is calculated as :

$R_{B1} = V_{dc}^2 / P_{B1} = 594^2 / 4000 = 88.2\ \Omega$

$R_{B2} = V_{dc}^2 / P_{B2} = 594^2 / 8000 = 44.1\ \Omega$

$R_{B3} = V_{dc}^2 / P_{B3} = 594^2 / 16000 = 22\ \Omega$

$R_{B4} = V_{dc}^2 / P_{B4} = 594^2 / 32000 = 11\ \Omega$

C. Design of DC Filter Capacitor

When the AC signal passed through rectifier it would become an uneven DC. A filtering section is used to smooth out this uneven DC signal. Filters filte unwanted AC in the output of a rectifier. The Ripple factor for C- filter is given by:

$r = 1/(4\sqrt{3}fCR_L)$ (9)

Where,

r = Ripple factor of C- filter

f = frequency (in Hz)

R_L = Resistance of dump load (in Ohm)

$C = 1/(4\sqrt{3}frR_L)$

Assume, the ripple factor is 15% for 3 phase, bridge rectifier,

$C = 1/(4\sqrt{3} \times 50 \times 0.15 \times 5.88) = 3273\ \mu F$

D. Design of Duty Cycle for PWM Load

Table II

Duty Cycle Calculation for 400 W range of PWM Load

P_L (W)	$V_o = \sqrt{P_L R_L}$ (V)	$I_o = V_o / R_L$ (A)	$D = V_o / V_i$
400	188	2.13	0.31
800	265	3.00	0.45
1200	325	3.68	0.55
1600	375	4.25	0.63
2000	420	4.76	0.71
2400	460	5.22	0.77
2800	497	5.63	0.84
3200	531	6.02	0.89
3600	563	6.38	0.95
4000	594	6.73	1

Table III

Sample Load Control Sharing of Combination System

P_C (kW)	$P_D=P_B+P_{PWM}$ (kW)	P_B (kW)	Binary Load Status (32, 16, 8, 4)	P_{PWM} (kW)	D (%)
60	0	0	0000	0	0
55	5	4	0001	1	0.50
45	15	12	0011	3	0.87
35.5	24.5	24	0110	0.5	0.35
30	30	28	0111	2	0.71
25.5	34.5	32	1000	2.5	0.79
16.5	43.5	40	1010	3.5	0.94
14.5	45.5	44	1011	1.5	0.61
0	60	60	1111	0	0

The calculation of duty cycle is heart of the PWM control for PWM load. PWM load control is required to smooth the load control system. Because 4 kW steps between binary dump load combinations cannot regulate the system smoothly. Proper duty cycle with switching frequency can be calculated according to PWM load range and resistance.

Duty cycle is calculated as:

$D = T_{ON} / T$ (10)

$T = 1 / f_{sw}$ (11)

Where,

D = duty cycle

T_{ON}= on-time of pulse width

T= the time of a cycle

f_{sw} = switching frequency of PWM

VII. SIMULATION STUDY OF PROPOSED ELC

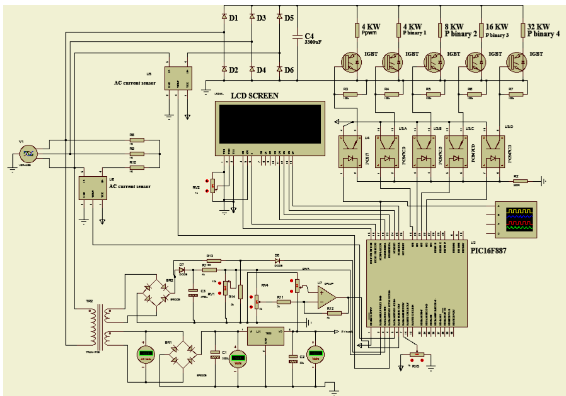

Fig.5 Complete circuit diagram of proposed ELC

Figure (6) show the complete circuit diagram of proposed ELC to simulate the monitoring system. In system monitoring, system line voltage, system frequency, consumer load current, dummy load current and duty cycle (%) of PWM are displayed on the LCD screen. PWM output waveform, binary load status and monitoring system are simulated for four mentioned cases by Proteus 8.0 professional software. The results of binary load status can be seen by the pin output status of microcontroller. In the simulation, both consumer and dump load are pure resistive loads. Therefore, power factor is assumed as unity.

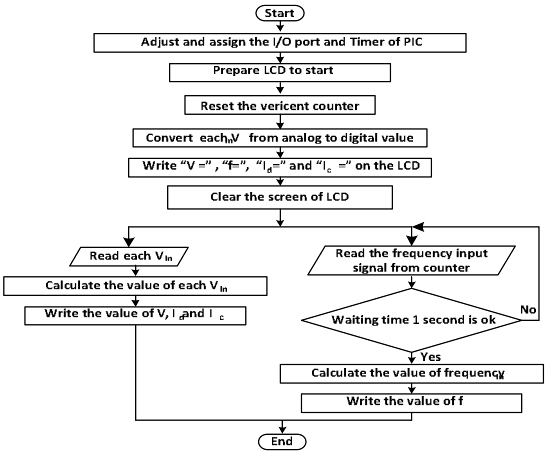

Fig.6 Flow chart program for voltage, current and frequency display of proposed ELC

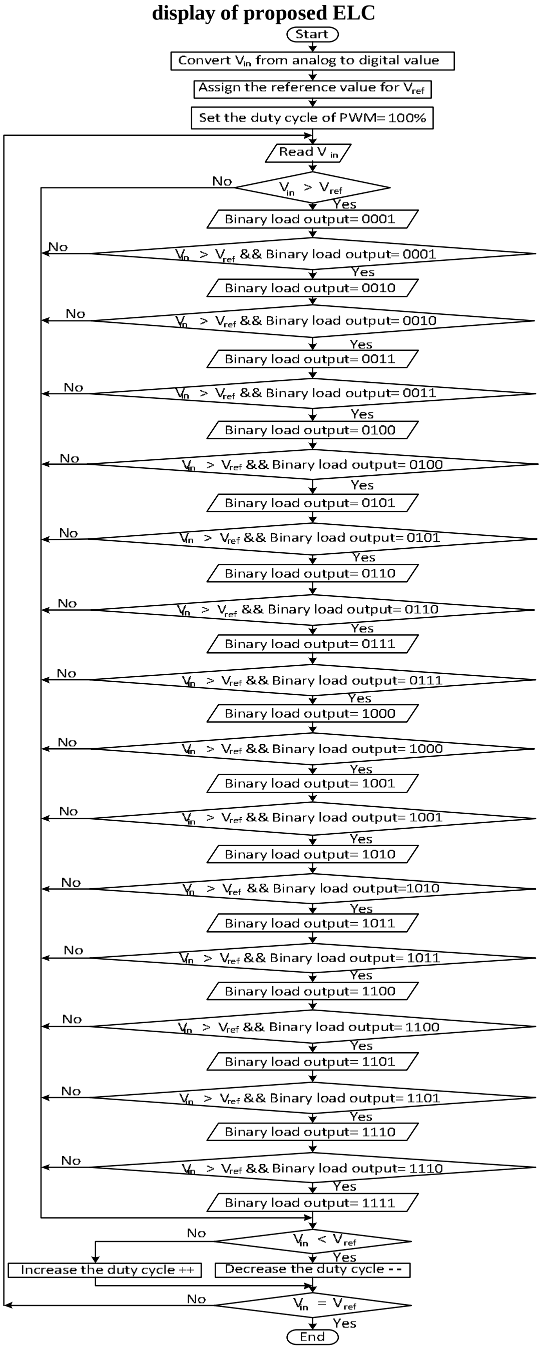

Fig.7 Flow chart program of proposed ELC control

A. Case I: Consumer load is 55kW and damp load is 5kW. According to table III for damp load sharing, duty cycle of PWM load is 50% for 1 kW and binary load status is 0001 for 4 kW.

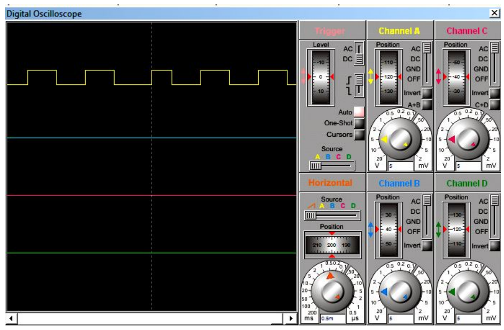

Fig.8 Simulation result of PWM

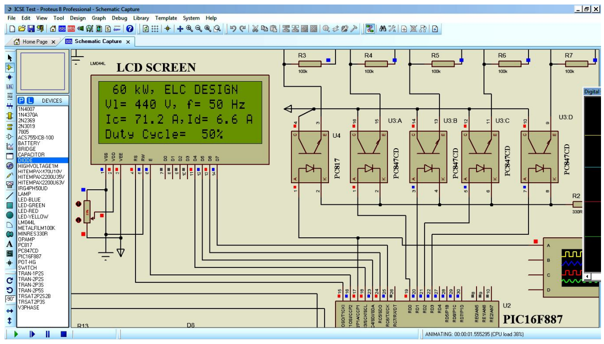

Fig.9 Simulation result of binary load status and monitoring system

B. Case II: Consumer load is 35.5 kW and damp load is 24.5 kW. According to table III for damp load sharing, duty cycle of PWM load is 35% for 0.5 kW and binary load status is 0110 for 24 kW.

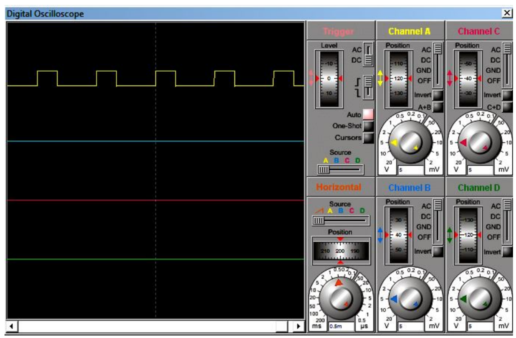

Fig.10 Simulation result of PWM

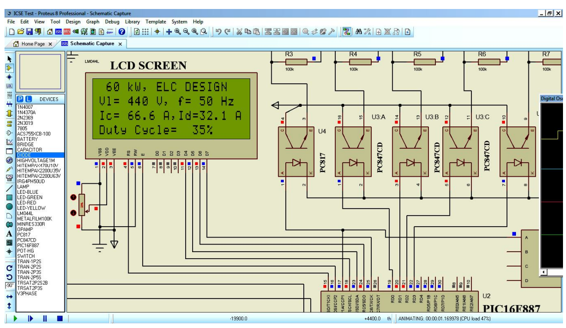

Fig.11 Simulation result of binary load status and monitoring system

C. Case III: Consumer load is 25.5 kW and damp load is 34.5 kW. According to table III for damp load sharing, duty cycle of PWM load is 79% for 2.5 kW and binary load status is 1000 for 32 kW.

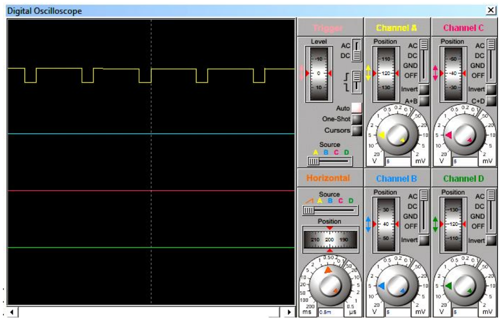

Fig.12 Simulation result of PWM

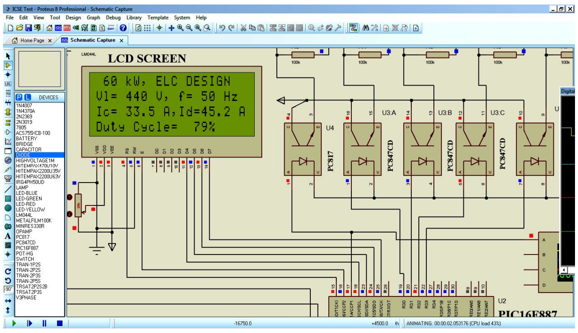

Fig.13 Simulation result of binary load status and monitoring system

D. Case IV: Consumer load is 14.5 kW and damp load is 45.5 kW. According to table III for damp load sharing, duty cycle of PWM load is 61% for 1.5 kW and binary load status is 1011 for 44 kW.

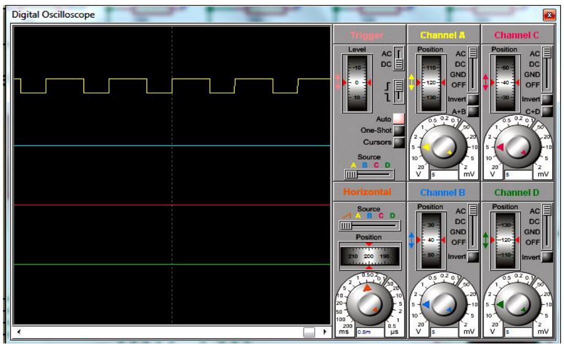

Fig.14 Simulation result of PWM

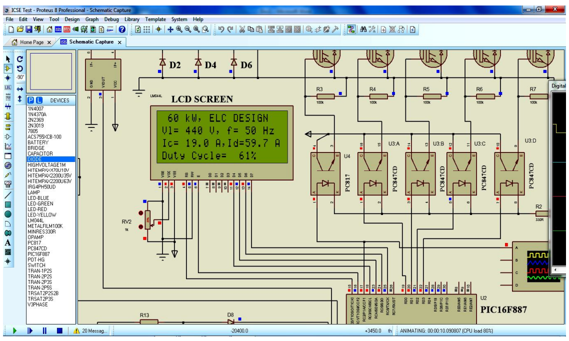

Fig.15 Simulation result of binary load status and monitoring system

CONCLUSION

The micro-hydro power generation is a viable option in remote and rural areas where grid electricity is not available. So, electronic load controllers (ELC) were being invented to be advance more and more with the wide using of micro hydropower generation. The developed microcontroller based ELC is found to be reliable, compact, cost effective and above all. Microcontroller based circuit can easily sense the system parameters such as voltage, current, frequency, power and power factor. It also provides the flexibility for change control parameters for providing a duty cycle over a wide range. The same ELC can also be used for different rating of machines, including single-phase machines by changing the control parameters in the program of the microcontroller. As the advantages of the minimal harmonics of binary load regulation and fast control respond of pulse width regulation, the proposed ELC is suitable for applications in stand-alone micro-hydro power plants.

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REFERENCES

[1] Vimal Singh Bisht, Y.R Sood, Nikhil Kushwaha, and ‘Suryakant, ‘Review On Electronic Load Controller’, 2012

[2] H.Ludens, Electronic Load Controller for micro-hydro system, 2010

[3] J.Portegijs, The Humming Bird' Electronic Load Controller / Induction Generator Controller, 2000

[4] Timothy L. Skvarenina, The Power Electronics Handbooks, 2002

[5] B. Singh, S.S.Murthy, M.Goel and A.K.Tandon, “A Steady State Analysis on Voltage and Frequency Control of Self-Excited Induction Generator in Micro-Hydro System”, 2006

[6] B.Singh, G.K.Kasal and S.Gairola, “Power Quality Improvement in Conventional Electronic Load Controller for

an Isolated Power Generation", IEEE Transactions on Energy Conversion, Vol. 23, No. 3, pp. 764-773, 2008.

[7] Bhim Singh and V. Rajagopal, "Battery energy storage based voltage and frequency controller for isolated pico hydro systems," Journal of Power Electronics, Vol. 9, No. 6, pp. 874-883, Nov. 2009.

[8] J.L. Ma´rquez, M.G. Molina, J.M. Pacas, "Dynamic Modeling, Simulation and Control Design of an advanced Micro-Hydro Power Plant or Distributed Generation Applications." Elsevier Trans. on Hydrogen Energy Policy,1-6,2010

[9] D. Henderson, "An Advanced Electronic Load Governor for Control of Micro Hydroelectric Generation"

[10] D. Henderson, "An advanced electronic load governor for control of micro hydro electric generation," IEEE Trans. Energy Conversion, Vol.13, No. 3, pp. 300-304, Sep. 1998.

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