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FUZZY LOGIC BASED VOLTAGE AND FREQUENCY OF A SELF EXCITED INDUCTION GENERATOR FOR MICRO HYDRO TURBINES FOR RURAL APPLICATIONS

[1]C.KATHIRVEL, [2]DR. K. PORKUMARAN,

[1]Assoc Prof., Department of Electrical Engineering, Sri Ramakrishna Engg College, Coimbatore, India.

[2]Principal, Dr. N.G.P. Institute of Technology, Coimbatore, India.

E-mail: [1]ckadhir@rediffmail.com , [2]porkumaran@gmail.com,

ABSTRACT

In this paper, a standalone electric generating system for remote locations is discussed. A typical micro hydro site layout and photograph which shows how the hydro power can be extracted is given. The three phase induction motor is used as a generator for producing three phase output by providing excitation through three capacitors connected in shunt. The design of the capacitor in a simple way is shown. To consume the excess power in the system an Electronic Load Controller (ELC) is used which will maintain the voltage and frequency within limits. The selection of components for ELC with the chosen device ratings is tabulated. Simulation was done on Matlab/Simulink using the Fuzzy Logic Controller. The membership functions and rules of the fuzzy controller are presented. The various models with the output waveforms are represented and discussed. It is shown that when the ELC is used, the output voltage and frequency remains within the limits when the load is changed from 300W to 600W. The experimental setup uses a separately excited DC motor coupled to a 1 H.P squirrel cage induction motor running at a speed above synchronous speed of the induction motor. Circuit diagrams, ratings and photographs of the experimental setup are provided. Drawbacks of the discussed system are enumerated and possible solutions and enhancements are briefed.

Keywords: *Fuzzy Logic, SEIG, Micro hydro, Stand alone, Excitation capacitor, ELC.*

1. INTRODUCTION

Electrical energy has conventionally being produced from the burning of fossil fuels. These have adverse problems like pollution, global warming, depletion of these fuels, etc. For places where the national grid has not yet reached the use of standalone generating systems working on renewable energy sources like hydro, wind, biomass, etc. are very attractive due to their less initial investment and environmental factors.

In this paper we are considering a micro hydro system working in standalone condition. Micro hydro systems are considered to be generating stations with power output less than 100KW. A conventional squirrel cage induction motor can be used as a generator if a capacitor bank of suitable rating is connected in shunt or series or a combination of both, for supplying the VAR required by the generator and the loads [1]–[4]. The rotor is rotated at speed above the synchronous speed of the motor.

The output voltage and frequency will be maintained within limits if full load is always connected. So when the consumer load is reduced the excess load is consumed by the electronic load controller.

The circuit schematic of the system under consideration is given in Fig. 1.

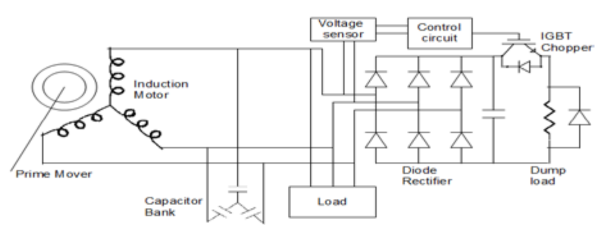

Figure 1. Circuit Schematic

2. MICRO HYDRO

It has been estimated that micro hydro energy sources are available in plenty. These kind of

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systems are usually seen in hilly areas where water flows as small rivers or streams. An arrangement such as the one shown in Fig. 2 can be used to divert a small portion of this water. A fore-bay is used to maintain the head constant, and so the fore-bay should be ideally full all the time. The excess water overflows into the same river.

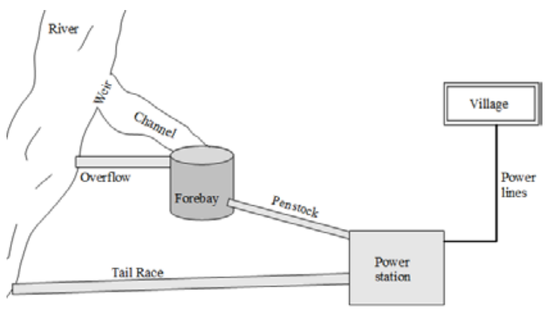

Figure 2. A Typical Micro Hydro Site

The schematic of micro hydro system is shown in Fig. 3.

The power relation is given by

$$P= \rho\, g\, Q\, H \qquad (1)$$

where
ρ= water density, (kg/m3)
g= gravitational acceleration, (m/s2)
Q= discharge, (l/ s)
H= head , (m)

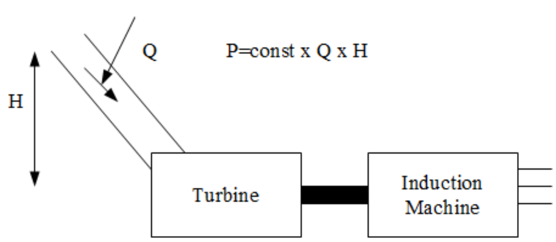

Figure 3. Power Output Of Hydro Turbine

A typical micro hydro site is depicted in the Fig. 4.

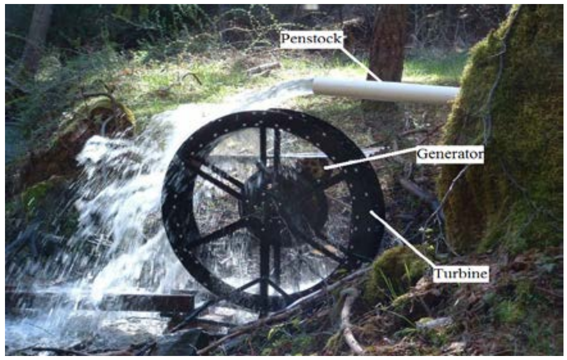

Figure 4. Photo Of Micro Hydro System

3. SELF EXCITED INDUCTION GENERATOR (SEIG)

3.1 *Generator*

For harnessing renewable energy sources like wind, hydro, biomass, etc. the self excited induction generator is a very good option [6]. Various operational aspects and applications of self excited induction generator have been investigated in the literature [1]–[15].A three phase motor with three excitation capacitors for three phase output can be used for this purpose as shown in Fig. 5.

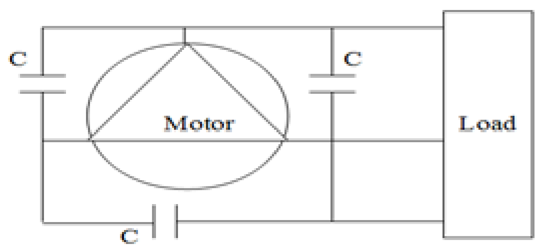

Figure 5. Three Capacitors For Three Phase Output

Normal single phase induction motors cannot be used as self excited single phase induction generators with some modifications or additions. Single phase induction machines of integral kW ratings are costly in comparison to three phase induction machine of equivalent size. It has been found that three phase SEIG can be used for supplying single phase loads. If capacitors of suitable rating are connected across any two windings in 1:2 ratios, then the motor can work as single phase generator with minimum unbalance in the winding currents. The third winding need not have any capacitors connected. In this manner the machine is found to be able to supply 80% of its rated output without excess current through the stator [16]. Such a configuration is shown in Fig. 6.

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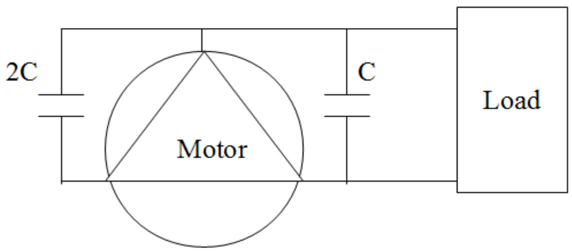

Figure 6. Two capacitors for single phase output

In this paper the first configuration was chosen. The motor is chosen taking into consideration the power output and the voltage rating. The rating of the machine is given in table I.

TABLE I - INDUCTION MACHINE RATINGS

Parameter	Value
Motor Type	Squirrel cage Induction motor
Phase	3 Phase
Line Voltage	230V
Rated speed	1485 RPM
Horse power	1 H.P

3.2 Capacitor

The capacitor is selected to produce rated voltage at full load. The selection can be as follows [17]

Apparent power, $S = \sqrt{3}\, V_L I_L$ (2)

Active power, $P = S\cos(\theta)$ (3)

Reactive power absorbed, $Q = \sqrt{S^2 - P^2}$ (4)

Per phase reactive power needed, $q = Q/3$ (5)

Voltage per phase, $V_P = V_L/\sqrt{3}$ (6)

Capacitive current, $I_c = q/V_P$ (7)

Capacitive reactance per phase, $X_C = V_P/I_c$ (8)

Capacitance per phase, $C = 1/2\,\Pi f\, X_C$ (9)

The capacitor so chosen was 27uF per phase.

4. Electronic Load Controller

The voltage rating of the uncontrolled rectifier and chopper switch will be the same and dependent on the rms ac input voltage and average value of the output dc voltage. The rating of various devices are given below[18].

The dc voltage is calculated as

$$V_{dc} = (3\sqrt{2}V_{LL})/\pi = (1.35)\, V_{LL} \quad (10)$$

where VLL is the root-mean-square (rms) value of the line-to line voltage of SEIG. For the 750 -W SEIG, the line voltage is 230 V and

$$V_{dc} = (1.35) \times 230 = 310.5\ V$$

An over-voltage of 10% of the rated voltage is considered for transient conditions and, hence, the rms ac input voltage will be (253 V) with a peak value

$$V_{peak} = (\sqrt{2}) \times 253\ V = 357.8\ V \quad (11)$$

This peak voltage will appear across the components of ELC. The current rating of the uncontrolled rectifier and chopper switch is decided by the active component of input ac current and calculated as

$$I_{AC} = P/(\sqrt{3}V_{LL}) \quad (12)$$

where VLL is the rms value of the SEIG terminal voltage and P is the power rating of SEIG. The active current of SEIG may be calculated as

$$I_{AC} = 750/(\sqrt{3} \times 230) = 1.882$$

The three-phase uncontrolled rectifier draws approximately quasi–square current with the distortion factor of (3/π=.955). The input ac current of ELC may be obtained as

$$I_{DAC} = I_{AC}/.955 = 1.882/.955 = 1.970 \quad (13)$$

The crest factor (CF) of the ac current drawn by an uncontrolled rectifier with a capacitive filter varies from 1.4 to 2.0; hence, the ac input peak current may be calculated as

$$I_{peak} = 2I_{DAC} = 2 \times 1.970 = 3.941 \quad (14)$$

So the maximum voltage may be 357.8 V and peak current may be 3.941 A in the uncontrolled rectifier. The rating of an uncontrolled rectifier and chopper switch was taken as 600 V and 5 A higher than 341.55V and 3.941 A, respectively.

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The rating of dump load resistance is calculated by

$$R_{\mathrm{D}} = (\mathrm{V}_{\mathrm{dc}})^2/P_{\mathrm{rated}}. \quad (15)$$

From this relation, the value of RD is computed as

$$R_D = (310.5)^2/750 = 128.5\,\Omega \quad (16)$$

The value of the dc-link capacitance of the ELC is selected on the basis of the ripple factor. The relation between the value of dc-link capacitance and ripple factor (RF) for a three-phase uncontrolled rectifier is

$$C = \{1/(12 f R_D)\}\{1 + 1/(\sqrt{2}\,RF)\} \quad (17)$$

If 5% ripple factor is permitted in the average value of dc-link voltage and RD is the dump load resistance. The capacitance is calculated using the

Previous formula and hence

$$C = \{1/(12\times 50\times 128.5)\}\{1 + 1/(\sqrt{2}\times .05)\} = 196.39\,\mu F$$

The selected ratings are given in table II.

TABLE II - RATINGS OF ELC COMPONENTS

Power rating of Motor (W)	Voltage rating of rectifier (V)	Current rating of rectifier (V)	Voltage rating of Chopper switch (V)	Current rating of Chopper switch (V)	Rating of dump load Ω	Rating of DC filtering capacitor µF
750	600	5	600	5A	125	200

If 5% ripple factor is permitted in the average value of dc-link voltage and RD is the dump load resistance. The capacitance is calculated using the previous formula and hence

4.1 *Control System*

Fuzzy logic algorithm

In this paper the control algorithm used is fuzzy logic. The system has been simulated in Matlab/simulink using fuzzy logic controller and the results are provided in the next section. The Fuzzy control is basically nonlinear and an adaptive in nature, giving the robust performance in the cases wherein the effects of parameter variation of the controller is present. It is claimed that the Fuzzy logic control yields the results which are superior to those obtained with the conventional controllers such as PI, SMC, and PID etc [19].

5. SIMULATION & RESULTS

Various blocks of the simulation is given in the following figures 7, 8,9,10. Figures 11 and 12 shows the membership functions of the fuzzy logic controller in the fuzzy logic toolbox.

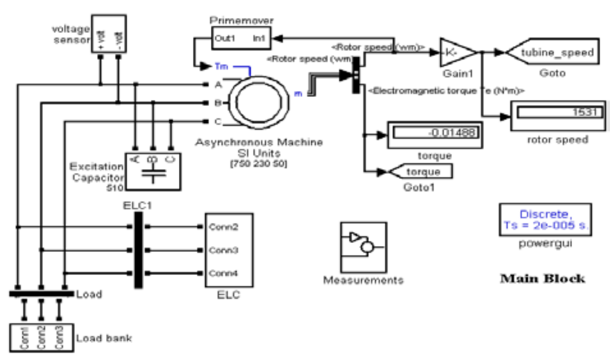

Figure 7. Main block

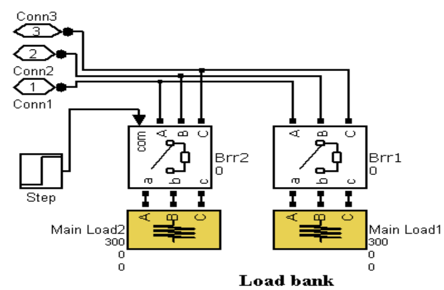

Figure 8. Load bank

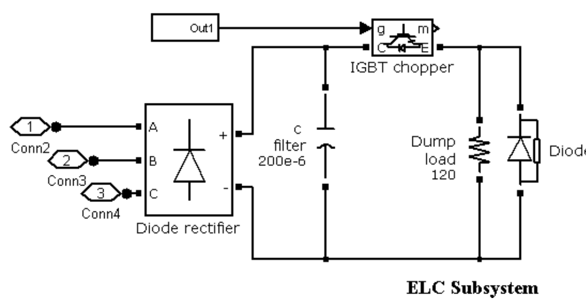

Figure 9. ELC subsystem

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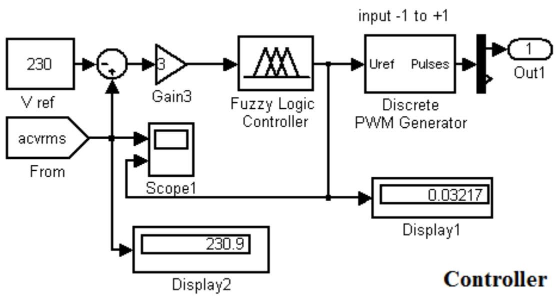

Figure 10. Fuzzy logic controller

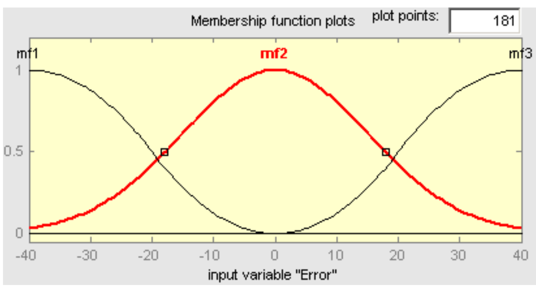

Figure 11. Membership function of error input

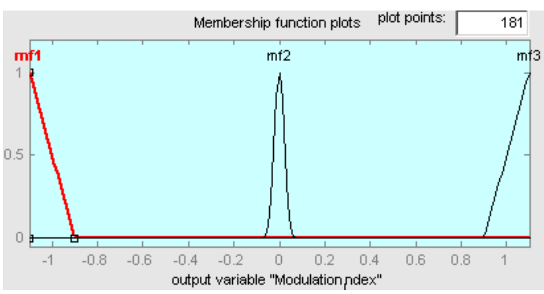

Figure 12. Membership function of modulation index output

Rules used for the fuzzy logic controller.

1. If (Error is mf1) then (Modulation_Index is mf1) (1)

2. If (Error is mf2) then (Modulation_Index is mf2) (1)

3. If (Error is mf3) then (Modulation_Index is mf3) (1)

The output waveforms are shown in Fig. 13 and 14. It can be observed that the initial load of 300W is changed to 600W at 2.5s and the voltage and frequency varies only slightly and is within the limits.

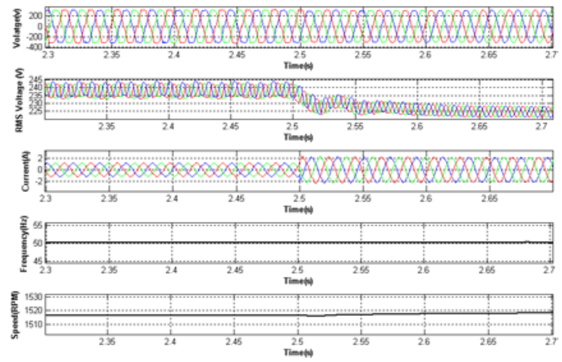

Figure 13. (a) Output voltage (b) Output RMS voltage (c) output current (d) Frequency (e) Speed.

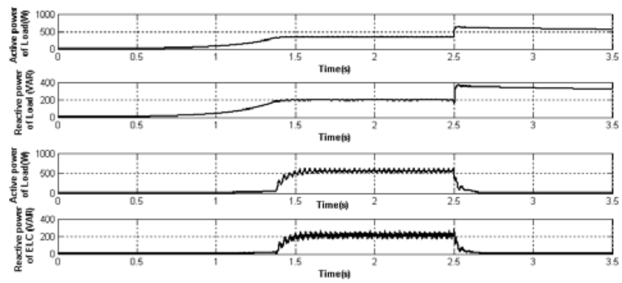

Figure 14. (a) Active power of load (b) Reactive power of load (c) Active power of ELC (d) Reactive power of ELC

6. EXPERIMENTAL SETUP

The experimental setup consists of a conventional three phase induction motor coupled to a separately excited dc motor.

The rating of the dc motor is given in table III.

Table III - DC Motor Ratings

Parameter	Value
Motor type	DC separately excited
Armature voltage	220V
Armature current	4A
Field Volatge	220V
Rated speed	1350 RPM

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Since in normally designed motor, the maximum speed can be allowed up to twice rated speed[20], the motor is made to run at 1520 RPM using field flux control as explained by Fig. 15 and 16.

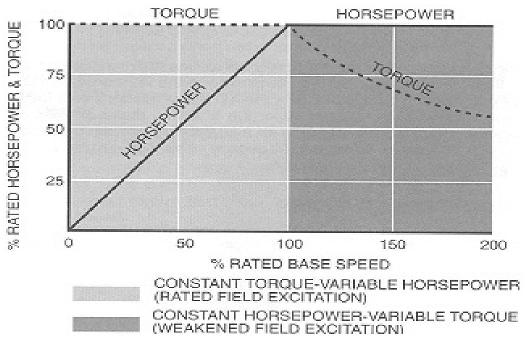

Figure 15. Field controlled DC motor

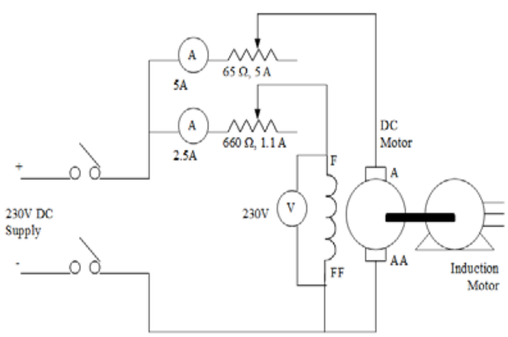

Figure 16. Circuit diagram of field controlled DC motor

The experimental setup is shown in figures 17 and 18.

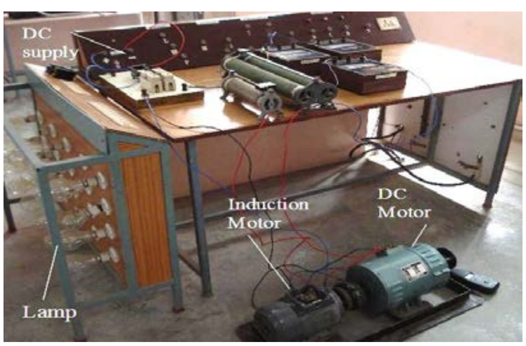

Figure 17. Experimental setup

Figure 18. Experimental setup with machine alone.

7. CONCLUSION

An ELC based SEIG has been designed. The design was tested using simulation. Work is going on to test the design on hardware. A drawback of the above system is that the voltage would drop considerably if inductive loads are used. One solution is to use switched capacitors as the voltage drops. To reduce harmonics and to improve the power factor the ELC can be integrated into a STATCOM and using its feedback diodes for rectification [21]. The IGBT chopper and dump load can be connected across the dc link capacitor of the STATCOM.

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