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ANALYSIS OF AC VOLTAGE CONTROLLER BASED ELECTRONIC LOAD CONTROLLER FOR SELF-EXCITED INDUCTION GENERATOR

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ABSTRACT

This work, presented the analysis of electronic load controller (ELC) for isolated asynchronous generator (IAG) with improved power quality. Conventional electronic load controller based on ac-dc converter with single dump load which distorted the generator terminal voltage, generator terminal current, capacitor bank current, rectifier current. To improve the performance of system, ac voltage controller system with fuzzy logic is used. The proposed ELC based system is configured with ac voltage controller with resistive load. The IAG-ELC system performance is done with ac voltage controller, with ac voltage controller there is low distortions introduces in the generator terminal voltages and current. Then ac voltage controllers are used with higher efficiencies and with fewer distortions. Proposed system is developed in MATLAB/SIMULINK environment and power system toolboxes.

Keywords: Isolated asynchronous generator (IAG), Electronic load controller (ELC), Fuzzy logic controller (FLC), Ac voltage controller.

1. INTRODUCTION

There is critical ascent in the energy demand during last few years and the rate of utilization of non-renewable energy system is expanded spirally. Because of condition concerns and the global condition arrangement the issues of the sustainable power source is getting much consideration now. In present time renewable energy based plant is essential where grid connection is not existing. The small isolated plants can efficiently fulfil the necessity of the power in these sites. For isolated operated system isolated induction generator is one of the best option because it has several advantages [1], [2] such as ruggedness, brushless, maintenance free, self protection against short circuit and reduced unit cost. These generator are used with wind and small hydro sources. The hydro sources i.e. mini-hydro (100kW to 1MW), micro-hydro (10kw to 100kW) and pico-hydro (less than 10kW) these are suitable for the off grid operation [2]-[4].

If there is change in the load at generator then terminal voltage increases sharply this effects the normal operation of the equipment's which is associated to the terminals. Then we need to design the controller which keeps up the terminal voltage with limits during changes in the load. The generated power is more than the consumed power then the generator speed increases which causes to increase in generator terminal voltage and frequency. For keeping up the terminal voltage and frequency of the generator constant, the electronic load controller [5]-[7] is proposed. ELC operation depends on total generated and consumed power should be matched. When the generator load change or when the generator is operated at light load then ELC consume the remaining power that make the total generated power equal to the total power consumed by consumer load and ELC[11]-[12]. Electronic load controller having dump load, rectifier bridge, chopper and PI controller. When consumer load is varying then ELC feeding the dump resistive load accordingly and dump load power is controlled by varying duty ratio of chopper. Two types of electronic load controllers are reported in literature, first one is ac voltage controller with back to back thyristor feeding a fixed dump load, firing angle of thyristor is controlled which varies dump load power[5], and second one is the rectifier-chopper feeding a fixed resistance on DC side [6]. ELC is used with thyristor controlled bridge which provides a compelling answer for reduce the distortion in voltage and current [8], [9].

This paper work proposes the analysis of ac voltage controller which limits distortion in voltage and current of the generator. The resistive load are used with ac voltage controller. The results are compared with PI and FLC controller. The following system, shown in fig.4, is designed and simulated in the MATLAB/SIMULINK.

2. CONFIGURATION OF SYSTEM

In the presented diagram of SEIG-ELC for minimization of the variation in terminal voltage of stand-alone asynchronous generator. SEIG-ELC system contains the induction machine driven by prime mover, a three-phase capacitor bank and an electronic load controller. The introduced ELC is a chopper circuit per phase Sa, Sb and Sc switches in series with the three phase dump load shown in fig1. When the generator at the light load rotor speed get increases, which result increase in the voltage frequency.

At the state of light load remaining power of generator should be consumed by ELC. Electronic load controller having the three-phase dump load, anti-parallel connected IGBT switches.

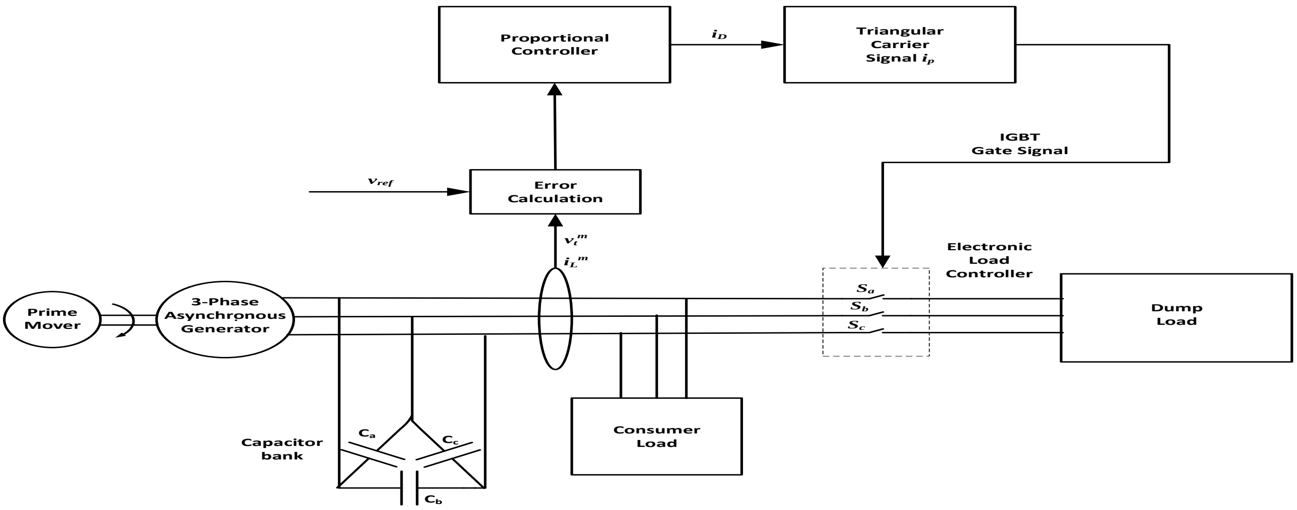


Fig. 1: Block diagram of SEIG-ELC

3. SYSTEM DESCRIPTION

The introduce diagram of conventional isolated asynchronous generator (IAG)-ELC system. It consists of three phase self-excited asynchronous generator driven by constant prime mover. The fixed value of excitation capacitor bank is connected at the terminal of the IAG, which provide the constant voltage at terminal of greater at rated load. When the generator at the light load rotor speed get increases, which result increase in the voltage and frequency. At the state of light load remaining power of generator should be consumed by ELC.

The ELC, having uncontrolled rectifier series with the IGBT based chopper, PI controller, filtering capacitor and dump load. Duty ratio of the chopper so adjusted that generated power is equal to the consumed power ($P_{gen} = P_{con} + P_{ELC}$), the change in the input voltage of the generator is sensed by the voltage sensor and is compared with reference voltage signal and resulting error signal encouraged to the PI controller, output of PI controller is compared with saw-tooth carrier waveform with fixed amplitude and frequency generates PWM signal which acts as a gating signal for the chopper.

4. MODELLING OF THE SYSTEM

The proposed system consists of isolated asynchronous generator, capacitor bank, consumer load and ELC system [6]. Mathematical modelling of above subsystems are explained below.

A. Modelling of IAG

The SEIG system is developed in stationary d-q reference and the significant volt-ampere equations are-

$$[v] = [R][i] + [L]p[i] + \omega_g [G][i] \qquad (1)$$

Current derivative can be communicated as

$$p[i]=[L]^{-1}\{[v]-[R][i]-\omega_g[G][i]\} \quad (2)$$

Where $[v]$, $[i]$, $[R]$, $[L]$ and $[G]$ are defined in appendix 1.

The electromagnetic torque of SEIG is

$$T_e=\left(\frac{3P}{4}\right)L_m\left(i_{qs}i_{dr}-i_{ds}i_{qr}\right) \quad (3)$$

Electromagnetic torque equation is

$$T_{shaft}=T_e+J\left(\frac{2}{P}\right)p\omega_g \quad (4)$$

The subsidiary of rotor speed from (4) is

$$p\omega_g=\left(\frac{P}{2}\right)\frac{\left(T_{shaft}-T_e\right)}{J} \quad (5)$$

Where P is the number of poles and T_{shaft} is input torque to shaft of SEIG constant prime mover, J is the moment of inertia.

The SEIG works in the saturation area and its magnetizing characteristics in nonlinear in nature. Hence, the magnetizing current ought to be figured in each progression of coordination regarding stator and rotor d-q current.

$$I_m=\frac{\left\{\left(i_{ds}+i_{dr}\right)^2+\left(i_{qs}+i_{qr}\right)^2\right\}^{1/2}}{\sqrt{2}} \quad (6)$$

The magnetizing inductance (Lm) is figured from magnetizing characteristics which is gotten by synchronous speed test for machine under test (15kW) operating as the SEIG and in given as

$$L_m=a+bI_m+cI_m{}^2+dI_m{}^3 \quad (7)$$

Where the coefficients a, b, c and d are in appendix 2.

The three phase generator currents are gotten from d-q axes components utilizing the connection

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix}\begin{bmatrix} i_{ds} \\ i_{qs} \end{bmatrix} \quad (8)$$

The line current of the generator can be communicated as far as the phase currents as

$$\begin{aligned} i_{ga}&=i_c-i_a \\ i_{gb}&=i_a-i_b \quad (9) \\ i_{gc}&=i_b-i_c \end{aligned}$$

And phase voltages are

$$v_a + v_b + v_c = 0 \quad (10)$$

Applying KCL to the circuit comprising excitation capacitor and consumer load, node current equations are obtained as

$$C_a pv_a - C_c pv_c = i_{pca} - i_{pcc} = i_{ca} = i_{ga} - (i_{aL} + i_{Da})$$

$$C_b pv_b - C_a pv_c = i_{pcb} - i_{pca} = i_{cb} = i_{gb} - (i_{bL} + i_{Db})$$

$$C_c pv_c - C_b pv_b = i_{pcc} - i_{pcb} = i_{cc} = i_{gc} - (i_{cL} + i_{Dc})$$

Where, i_{aL} , i_{bL} and i_{cL} are the line currents of the load and i_{Da} , i_{Db} and i_{Dc} are the ELC currents.

Substitution of eq.(10) into (11) then derivatives of ac voltages areas.

$$(C_a + C_c) pv_a + C_c pv_b = i_{ca} \quad (14)$$

$$-C_a pv_a + C_b pv_b = i_{cb} \quad (15)$$

Where,

$$Keq = C_a C_b + C_b C_c + C_c C_a \quad (18)$$

For balance excitation, with equal excitation capacitors $C_a = C_b = C_c = C_x$ then $K_{eq} = 3C_x^{\ 2}$ and eq. (16) and (17) simplify to

$$pv_a = \frac{(i_{ca} - i_{cb})}{3C_x}$$

$$= \frac{\left[\{i_{ga} - (i_{aL} + i_{Da})\} - \{i_{gb} - (i_{bL} + i_{Db})\}\right]}{3C_x} \quad (19)$$

$$pv_b = \frac{(i_{ca} + 2i_{cb})}{3C_x}$$

$$= \frac{\left[\{i_{ga} - (i_{aL} + i_{Da})\} - 2\{i_{gb} - (i_{bL} + i_{Db})\}\right]}{3C_x} \quad (20)$$

From three-phase voltages v_a , v_b and v_c of EIG by solving the eq. (19) , (20) and (10), the d-q axes voltages in stationary reference frame are as follows;

$$v_{ds} = \left(\frac{2}{3}\right)\left\{v_a - \left(\frac{v_b}{2}\right) - \left(\frac{v_c}{2}\right)\right\}$$

$$v_{qs} = \left(\frac{2}{3}\right)\left\{\left(\frac{\sqrt{3}v_b}{2}\right) - \left(\frac{\sqrt{3}v_c}{2}\right)\right\}$$

B. Modelling of static load

Three phase resistive load, equations of line current

$$i_{aL} = i_{pa} - i_{pc} = \left(\frac{v_a}{R_{La}}\right) - \left(\frac{v_c}{R_{Lc}}\right) \quad (21)$$

$$i_{bL} = i_{pb} - i_{pa} = \left(\frac{v_b}{R_{Lb}}\right) - \left(\frac{v_a}{R_{La}}\right) \quad (22)$$

$$i_{cL} = i_{pc} - i_{pb} = \left(\frac{v_c}{R_{Lc}}\right) - \left(\frac{v_b}{R_{Lb}}\right)$$

(23)

C. Modelling of ELC

The ELC model is comprises of the uncontrolled rectifier bridge, PI control circuit, IGBT switch which goes about as chopper and dump load. The stator voltage is sustained to the uncontrolled rectifier bridge of the ELC through a small value of source inductance L_f and resistance R_f . Filtering capacitor C associated over the diode rectifier bridge to filter out the ripples in output dc voltage of bridge. The volt-current for the controller is given below

$$v_{\max} = 2R_f i_d + 2L_f pi_d + v_d \quad (24)$$

In the above equation derivative of ELC current i_d is-

$$pi_d = \frac{\left(v_{\max} - v_d - 2R_f i_d\right)}{\left(2L_f\right)} \quad (25)$$

Here, $v_{\max}$ is the maximum ac line voltage (v_a, v_b, v_c, -v_a, -v_b and -v_c) depending upon which diode is conducting and v_d is dc-link voltage. The load in three phase is obtained (i_{Da}, i_{Db} and i_{Dc}) by using the magnitude i_d and direction corresponding to conducting pairs of diodes.Charging and discharging of the filtering capacitor of the ELC, C is given as

$$pv_d = \frac{\left(i_d - i_L\right)}{C} \quad (26)$$

Where, $i_L = \left\{\left(v_d / R_{dL1}\right) + S\left(v_d / R_{dL2}\right)\right\}$

Here S is the switching function which indicates the switching status of chopper.

Output of PI controller v_o is compared with saw-tooth PWM carrier waveform. Saw-tooth waveform is-

$$v_{st} = A_m t / T_p$$

Where, A_m is amplitude of saw-tooth carrier waveform (2.65V), t is the time in μs and T_p is time period of 200 μs of the saw-tooth PWM carrier wave. Output of the controller is compared with Saw-tooth carrier waveform and output is given to the chopper switch. The switching logic is as follows.

If $v_{st} > v_0$ then $S = 1$ and

If $v_{st} < v_0$ then $S = 0$

Here, S is the switching function of the IGBT based chopper switch.

The complete numerical model of IAG-ELC system is represented through using eq.(1) to eq.(26).

5. CONTROL OF PROPOSED SYSTEM

Fuzzy logic controller

"Fuzzy Logic is a branch of Artificial Intelligence. It owes its origin to Lofti Zadeh, a professor at the University of California, Berkley, who developed fuzzy set theory in 1965". Taking into account inaccuracies and uncertainties FL is an expansion of Boolean logic which gives out important contribution to the reasoning. The essential idea of FL is that the yes and no answers are converted into variables which are express as words and not dependent on mathematical model.

(a) Fuzzification

The way toward changing over a yes or no answer otherwise called fresh information esteem intolanguage in words or etymological is called "fuzzification". The membership function qualities are designated to the linguistic factors characterized by one fuzzy subset factors.

(b) Membership function

Membership functions given to the controller are chosen keeping the base as sources of info given to the controller. The inputs are Error (e_ω) and change in error (Δe_ω). Incremental change in controller (U) being the output. The above parameters are characterized inside the scope of [0 1]. There, FLC can supplant the regular PI controller to take care of the advancement issue. In fig 2 presented error input and fig 3 presented output of modulation index.

$$\Delta e_\omega(k) = e_\omega(k) - e_\omega(k-1)$$

The ordinarily utilized technique is MAX-MIN. The output membership function of the standards are portrayed by two essential administrators, MIN (Minimum) administrator and MAX (Maximum) administrator. The set of rules represent the conduct of control variables that gives relationship amongst input and output variables. By understanding the conduct of system the rule base is determined that is really connection between fuzzy output to fuzzy input.

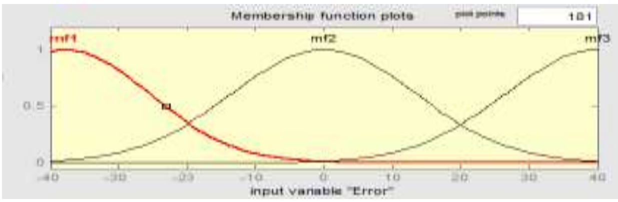


Fig: 2 Membership function of error input

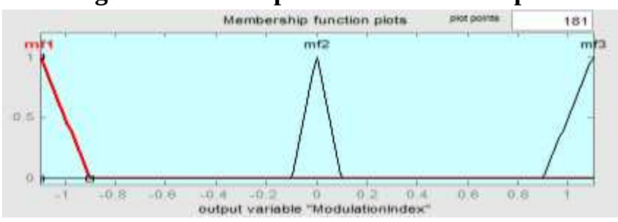


Fig: 3 Membership function of modulation index output

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)

6. SIMULATION RESULTS

(a) Matlab Simulation

A 15 kW, 440 V, 50 Hz induction machine is used as anIAG
and the ELC is modelled using available power electronics block-set like as ac voltage controller are used to create the desired pulse operation. Simulation is done in MATLAB presented in fig4.

(a) Results and Discussion

Case 1. Performance analysis of IAG-ELC with ac voltage controller for resistive load using PI controlle-

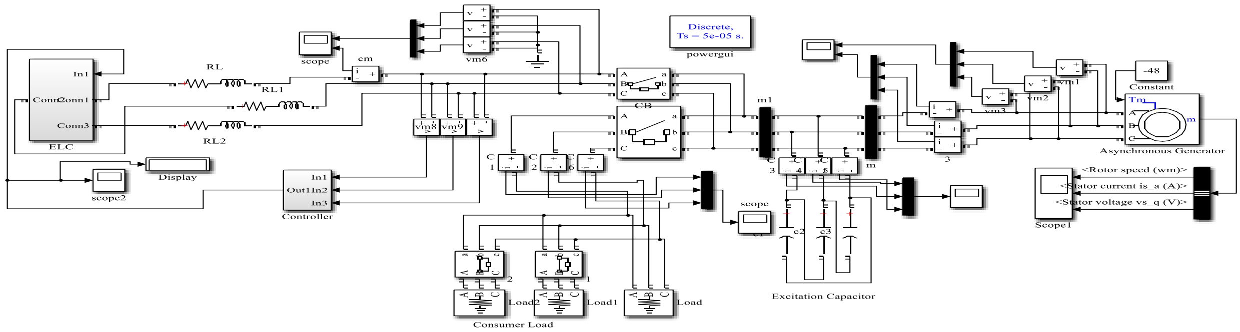


Fig.4 Simulink model of ELC-IAG system

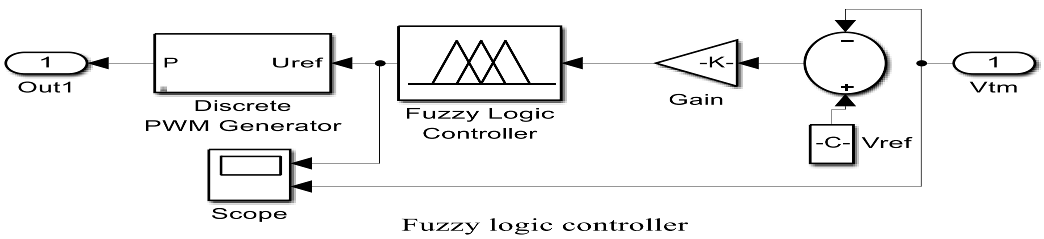
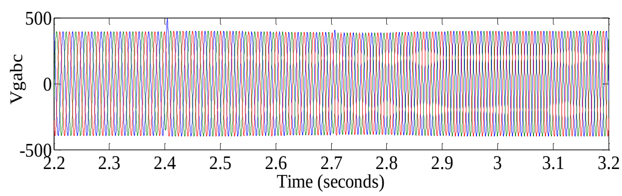


Fig:5 subsystem of FLC controller

Performance of IAG-ELC system with resistive load is considered, and the step change in resistive load presented in fig 6,which observe the effects on Generator voltage (V_{gabc}), current (I_{gabc}), ELC current (I_{ea}), consumer load current (I_{Labc}), Excitation current (I_{cabc}) and change in frequency and speed. Here generator is loaded with 12kW load, at 2.4 sec load is reduces to 5kW, at 2.7 sec load is increase to 7kW correspondingly. At that point there is low unexpected change in the generator voltage.



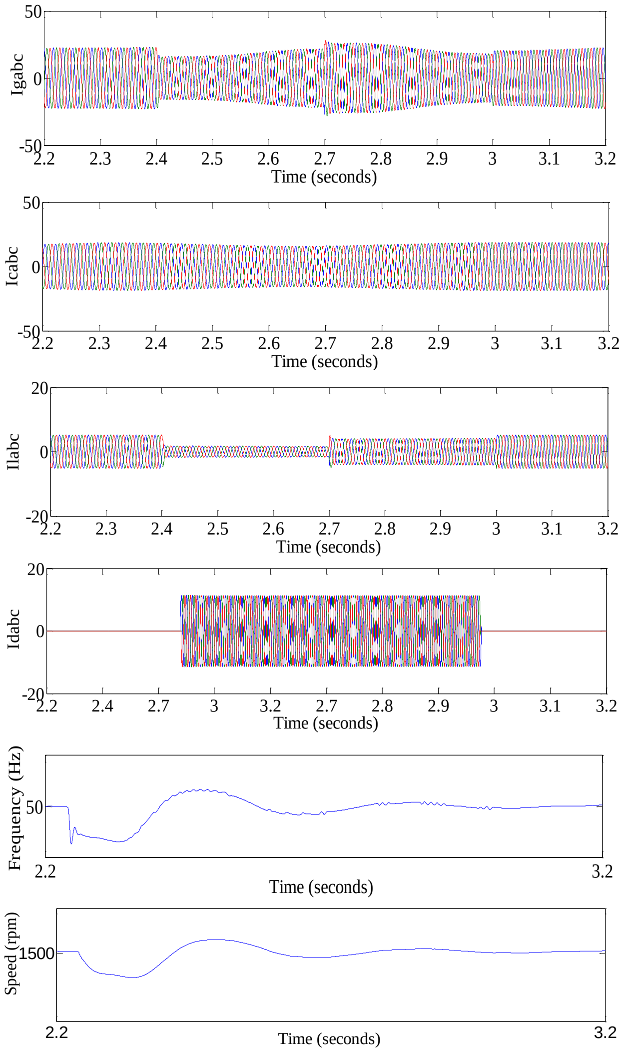
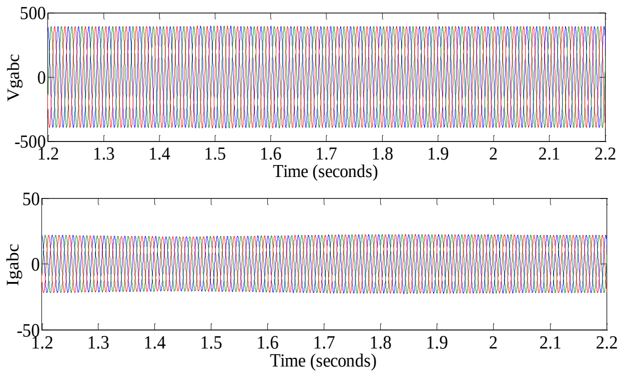


Fig: 6 AC voltage controller with resistive load, Generator voltage (V_{gabc}),current (I_{gabc}), Excitation current (I_{cabc}), Consumer load current (I_{Labc}), Dump load current(I_{cabc}), Frequency, Speed of IAG

Case 2. Performance analysis of IAG-ELC with ac voltage controller for resistive load using FLC controller-

Performance of IAG-ELC system with resistive load is considered, and the step change in resistive load, when FLC is used presented in fig7,which observe the effects on Generator voltage (V_{gabc}), current (I_{gabc}), ELC current (I_{ea}), consumer load current (I_{Labc}), Excitation current (I_{cabc}) and frequency and speed. Here generator is loaded with 12kW load, at 1.4 sec load is reduces to 5kW, at 1.7 sec load is increase to 5kW correspondingly. When the fuzzy logic controller is used then the output come in less time and also FLC give the better output than PI controller. Then there is no unexpected change in the generator voltage.



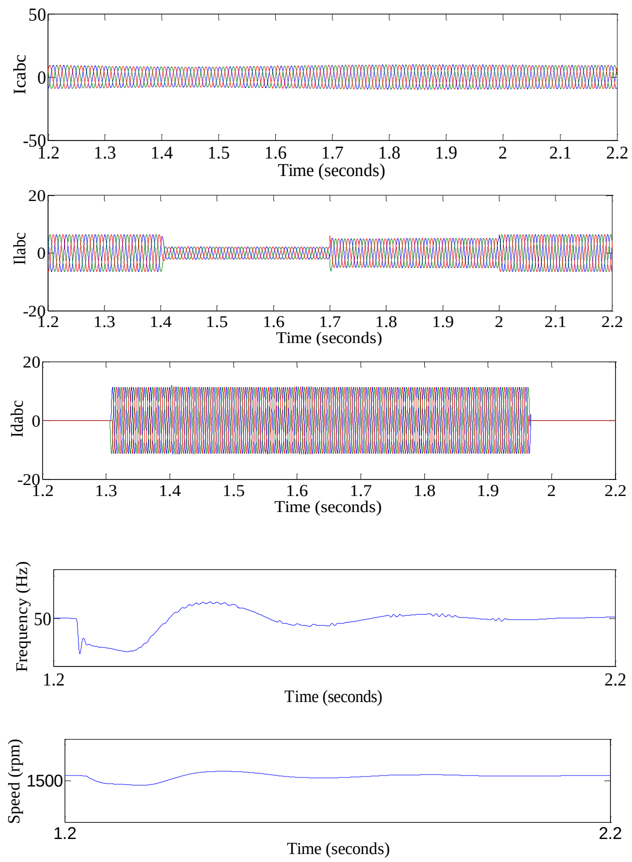
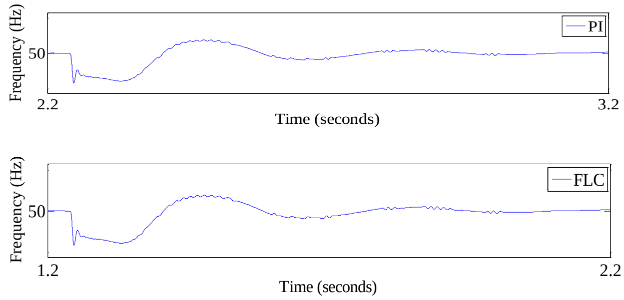


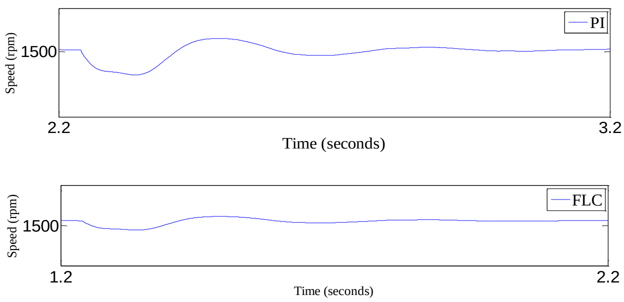
Fig: 7 Ac voltage controller with resistive load using FLC Generator voltage (V_{gabc}), current (I_{gabc}), Excitation current (I_{cabc}), Consumer load current (I_{Labc}), Dump load current(I_{cabc}), Frequency, Speed of IAG.

Case 3. Compared results of IAG-ELC with ac voltage controller for resistive load using PI and FLC

Ac voltage controller using the PI and FLC controller the speed and frequency is varying, then the compared representation of speed and frequency given in fig 8,(a)and (b). In the given model, speed of IAG is 1500 rpm and frequency is 50 HZ. Therefore, the output of FLC is more reliable then PI controller within less time.



(a)



(b)

Fig: 8 PI and FLC comparison of (a) Frequency, (b) Speed of IAG

7.CONCLUSION

An ELC based SEIG has been designed. The design was tested using simulation. The mathematical model of complete system is presented and Simulink model is developed. The results of the PI controller and FLC controller have been compared and developed the Simulink model for the ac voltage controller which consists of the anti-parallel connected IGBT switches, which is simple and the ac loads are connected at the dump load which minimizes the change in the terminal voltages of the generator without any distortions introduces in them. The study has provided more detailed information on the performance of the SEIG, such as steady state and transient waveforms, variation of basic parameters such voltage, current, speed and torque with loads.

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APPENDIX I

Matrices if eq. (1) is defined as

$$[v] = [v_{ds} \quad v_{qr} \quad v_{dr} \quad v_{qr}]^T$$

$$[i] = [i_{ds} \quad i_{qr} \quad i_{dr} \quad i_{qr}]^T$$

$[R]$, $[L]$ and $[G]$ in (1) represents 4×4 matrices of resistance, inductance, and speed inductance, respectively are defined as-

$$[R] = diag[R_s \quad R_s \quad R_r \quad R_r]$$

$$[L] = \begin{bmatrix} L_{ss} & 0 & L_m & 0 \\ 0 & L_{ss} & 0 & L_m \\ L_m & 0 & L_{rr} & 0 \\ 0 & L_m & 0 & L_{rr} \end{bmatrix}$$

$$[G] = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & -L_m & 0 & L_{rr} \\ L_m & 0 & L_{rr} & 0 \end{bmatrix}$$

Where $[L_{ss}] = L_s + L_m$ and $[L_{rr}] = L_r + L_m$, here subscript *d,q* refers to *d* and *q* axes in stationary reference frame, s and r refer to stator and rotor, and m refers to magnetizing components.

APPENDIX II

Parameters of the IAG 15kW, 440V, 30A, 50H_Z, four pole three-phase squirrel-cage induction machine is used as the IAG. The parameters of the generator are as follows:

$$R_s = 1\Omega$$

$$R_r = 0.77\Omega$$

$$X_{ls} = \omega L_s = 1\Omega$$

$$X_{lr} = \omega L_r = 1\Omega$$

$$J = 0.1384 \, {kg}/{m^2}$$

The coefficients of the magnetizing curve in the equation $L_m = a + bI_m + cI_m{}^2 + dI_m{}^3$, For 7.5kW are as follows: $a = 0.1407, b = 0.0014, c = -0.0012, d = 0.00005$