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STEADY STATE ANALYSIS OF FUZZY LOGIC BASED ELECTRONIC LOAD CONTROLLER FOR SELF EXCITED INDUCTION GENERATOR

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ABSTRACT

The objective of this paper is to implement fuzzy logic control in electronic load controller for voltage and frequency regulation of a 3-phase self excited induction generator feeding balanced resistive load. In micro hydro power generation applications, an ELC is required to maintain constant voltage and frequency of SEIG for a fixed excitation. Here fuzzy logic based ELC for SEIG for constant input power applications is modeled in MATLAB-SIMULINK and analyzed for steady state operation along with self excitation process. Simulation results show the performance of fuzzy logic based ELC for no load to full consumer load.

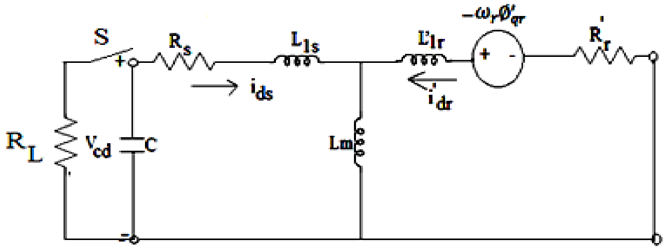
Keywords : Fuzzy logic , ELC , SEIG

1 INTRODUCTION

IN today's world, the fossil fuels have major share in the generation of electricity. The major concerns related to the use of fossil fuels are their limited stock, growing fuel prices, inability to meet growing energy requirements in future and not being environment friendly etc. These concerns have led the researchers towards developing technology for harnessing electricity from renewable energy resources. Among these resources, micro hydro power generation system is an attractive alternative for remote and hill locations, where water resources are easily available. For operation of power plants in such locations requirements are low price, robust construction of generating system, minimal maintenance requirement and ability to be operated by unskilled operator. To fulfill these requirements, SEIG appears to be right candidate due to its advantages like brushless rotor (squirrel cage), self excitation feature, less maintenance, inherent short circuit and overloading protection [1], [10]. The SEIG has one drawback. It has poor voltage and frequency regulation as the input power is uncontrolled and excitation is also kept fixed in micro hydro applications. Therefore, some mechanism is needed in such applications to keep voltage and frequency of SEIG constant despite variation in consumer load. One method is to maintain overall output power of SEIG constant at any instant. In this scheme, an electronic load controller is connected in parallel with the consumer load across the terminals of SEIG. ELC consists of 3-phase uncontrolled bridge rectifier, LC filter, IGBT switch, bleeder resistor, and dump resistor [2]. Here fuzzy logic control is implemented for PWM generation for switching of IGBT switch. The proposed ELC will be tested for 3-phase balanced resistive load.

2 SEIG MODEL AND OPERATION OF ELC

The model of SEIG is similar to that of the induction motor. d-q model of SEIG is used to represent the SEIG as it provides complete solution during self excitation process [4]. Also steady state and transient state of SEIG is easily analyzed by d-q model. a-b-c to dq0 transformation transfers a rotating a-b-c system to stationary dq0 system. All the time varying inductances can be eliminated by referring the stator and rotor variables to a stationary reference frame dq0. The fig. 1 shows the d axis model of SEIG and fig. 2 shows the q axis model of SEIG referred to stator in stationary reference frame. The modeling equations of SEIG are given in [1], [2], [3]. The initial conditions are assumed for residual magnetic flux in rotor [3].



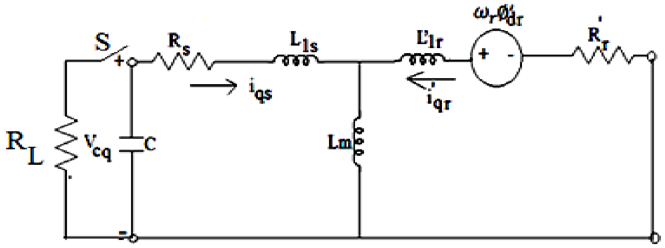
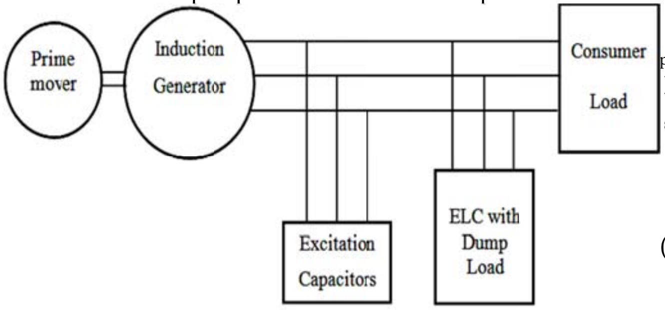


Fig. 1- d axis model of SEIG in stationary reference frame referred to stator

Fig. 2- q axis model of SEIG in stationary reference frame referred to stator

The ELC works on the fixed point operation in which excitation and output power is held constant for keeping voltage and frequency of SEIG constant [4],[5]. The ELC maintains constant load across SEIG by consuming the difference of output power and consumer power.



$$P_{Output} = P_{Consumer} + P_{Dump} \quad (1)$$

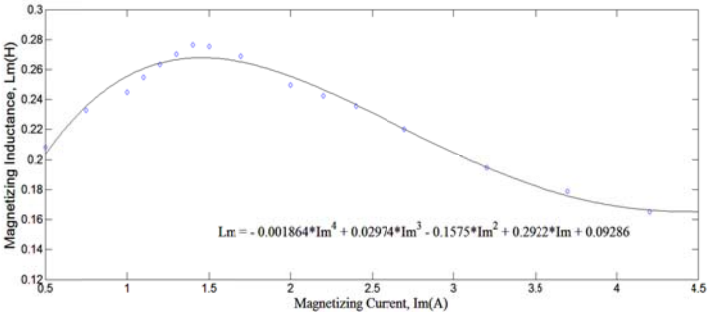
Where, P_{Output} is the Overall output power, $P_{Consumer}$ is the consumer load power, and P_{Dump} is the dump load power.

Fig. 3- Block diagram of SEIG with ELC and consumer load

3 PARAMETER ESTIMATION OF SEIG WITH ELC

The dc resistance test, no load test and blocked rotor test are performed to calculate SEIG parameters. For the induction motor the magnetization reactance L_m is calculated at rated voltage but for SEIG L_m is calculated from the unsaturated region of L_m versus I_m curve [3]. The synchronous speed test is performed to obtain L_m versus I_m curve and magnetization curve of SEIG which is drawn between phase voltage E versus I_m. The value of L_m is to be chosen from the unsaturated region of L_m versus I_m because in this region SEIG voltage becomes stable after transients during self excitation process are over. The effect of magnetic saturation is taken into account by simulating saturation. Also the calculation of minimum excitation capacitance at no load may be calculated from the point of intersection of no load magnetization curve with the capacitive load line [6] or from the analytical method [2], [8]. At rated load, the value of excitation capacitance rises from its no load value. It can be calculated from simulation at constant voltage at rated load or from analytical method. Bank of 3-phase capacitors are connected in delta configuration as: $C_{Delta} = 1/3\ C_{Star}$.

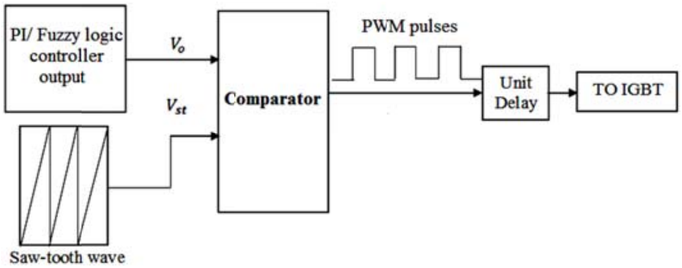
In fig. 4, the magnetization curve is fitted with fourth degree polynomial which is given by equation (2). Here the saturated region of curve is chosen for the stable voltage build up during self excitation process.



$$E = 3.263\ I_m^4 - 28.17\ I_m^3 + 64.77\ I_m^2 + 36.51\ I_m + 8.371 \quad (2)$$

Fig.4- Magnetization curve of SEIG

Also the L_m versus I_m curve (shown in fig. 5) is also best fitted with fourth order polynomial which is given by equation (3). Here L_m first increases gradually for lower values of I_m, and then it begins to decrease exponentially for higher magnetizing current.



$$L_m = -0.001864\ I_m^4 + 0.02974\ I_m^3 - 0.1575\ I_m^2 + 0.2922 I_m + 0.09286 \quad (3)$$

Fig. 5- Lm versus Im plot

4 CONTROL LOGIC OF AN ELC

The heart of the ELC is PWM generation scheme for switching of dump load according to the consumer load variation. In this paper fuzzy logic is implemented for PWM generation. Fig. 6 shows PWM generation block diagram using fuzzy logic.

Fig. 6- Block diagram of PWM generation

In PWM generation the magnitude of saw tooth carrier wave is compared with PI or fuzzy logic controller output for each sample time. The switching logic is defined as;

$$S = \begin{cases} 1 & , \quad V_o < V_{st} \\ 0 & , \quad V_o \geq V_{st} \end{cases} \quad (4)$$

The ELC consumes current as given [1]

$$i_L = \left({}^{V_d}\!/_{R_{D1}} \right) + S \left({}^{V_d}\!/_{R_{D2}} \right) \quad (5)$$

Where, R_{D1} is bleeder resistor and R_{D2} is dump load resistor.

V_d is the output voltage of 3 phase uncontrolled rectifier. The rating of dump load is determined as [2];

$$R_{d2} = \frac{V_d^2}{P_{rated}} \quad (6)$$

The output voltage, V_d of 3 phase uncontrolled bridge rectifier is calculated as;

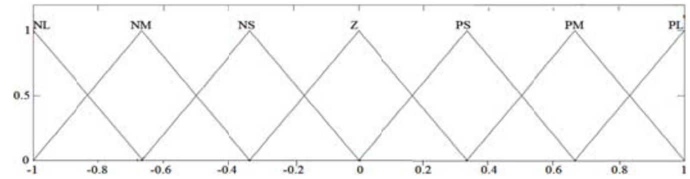
$$V_d = \frac{3\sqrt{2}}{\pi} V_{LL} \quad (7)$$

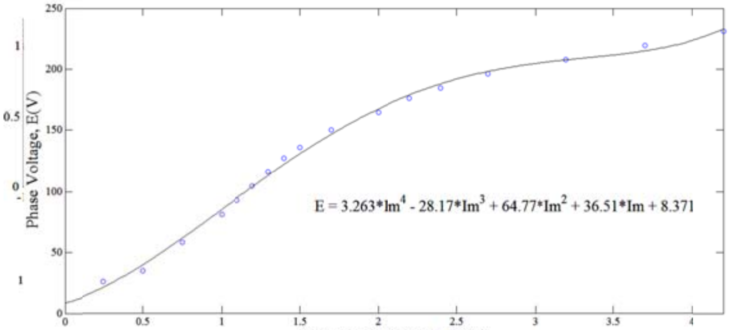
Here V_{LL} is the line to line voltage of SEIG.

According to the switching logic, digital pulses are generated. S=0, means 'LOW' pulse i.e. switch is open while S=1, means 'HIGH' pulse i.e. switch is closed. The width of these pulses varies according to the duration of positive and negative magnitude of error signal. That's why these pulses are called pulse width modulated pulses. In this manner PWM controls the switching of IGBT switch which in turn controls the dump power consumption.

5 FUZZY LOGIC CONTROL

Fuzzy logic is based on theory of fuzzy sets which relates to the classes of objects having boundaries without crisp. In fuzzy logic, membership is a matter of degree. The advantages of fuzzy logic are: easy and flexible approach, ability to blend with conventional control systems, based on linguistic terms and logic based on past experience etc. Fuzzy Inference System has five components: fuzzification, rule base, implication, aggregation and defuzzification. In first step fuzzification, input and output crisp variables are converted into fuzzy variables. In second step rule base "if and then" rules are defined. These rules establish a relation between input space to output space. In case of two input variables fuzzy operators like 'AND' and 'OR' in antecedents are applied. The third step implication is the process of shaping the fuzzy set in the consequent based on the results of the antecedent i.e. output fuzzy set is truncated according to the result of antecedent. In forth step, aggregation, the output fuzzy sets for each rule are aggregated into a single output fuzzy set for each output variable. After aggregation the aggregate of a fuzzy set consists of range of output values and so it must be defuzzified, hence the last step defuzzification, converts the result of aggregated output into a single number i.e. crisp value. The methods of defuzzification are: centroid, middle of maximum, largest of maximum and smallest of maximum etc. The centroid method is widely used. Here the two input variables 'Error' and 'Derror' and one output variable 'control signal' are chosen. The rule base and Ranges of these variables are defined according to the previous experience gained by the performance of the PI controller based system. The mamdani FIS is modeled with fuzzy logic tool box in MATLAB / SIMULINK. Fig. 7, fig 8 and fig. 9 show the input and output fuzzy variable membership diagrams. Each input variable has 7 membership functions. The output fuzzy variable has 7 membership functions.





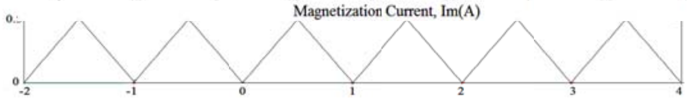


Fig.7- membership function diagram of fuzzy variable "Error"

Fig.8-membership function diagram of "Derror"

Fig. 9- membership function diagram of output fuzzy variable

Table 1- Rule base for fuzzy logic controller

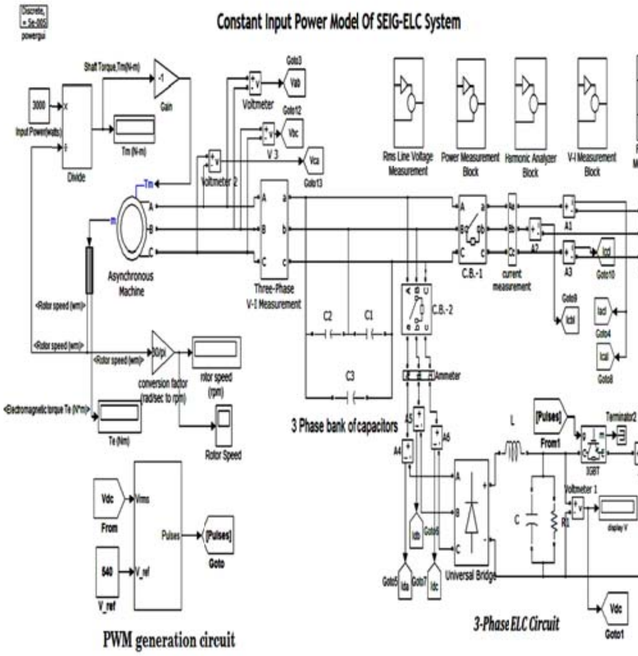
Error / Derror	NL	NM	NS	Z	PS	PM	PB
NL	NL	NL	NM	PS	PS	PM	PM
NM	NL	NM	NM	PS	PS	PM	PM
NS	NM	NM	NS	PM	PS	PM	PM
Z	NM	NM	NS	PM	PS	PM	PL
PS	NM	NS	Z	PM	PM	PM	PL
PM	NS	NS	Z	PM	PM	PS	PL
PM	NS	NS	Z	PM	PM	PS	PL

Here membership function NL means 'negative large', NM means 'negative medium', NS means 'negative small', Z means 'zero', PS means 'positive small', PM stands for 'positive medium' and PL stands for 'positive large'. Derror is the change in error signal in a sample time.

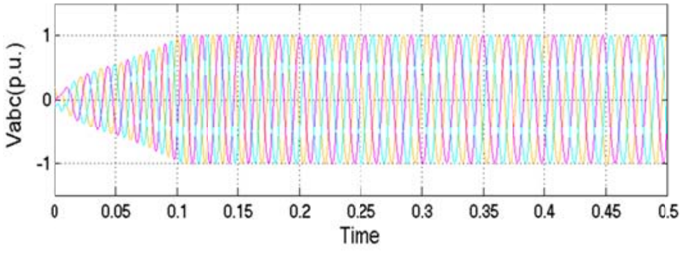
Range of Error signal = [-1 1]
Range of Derror signal = [-1 1]
Range of output signal = [-2 4]

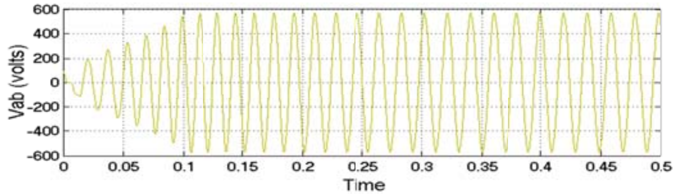
6 MODEL DESCRIPTION AND SIMULATION PARAMETERS

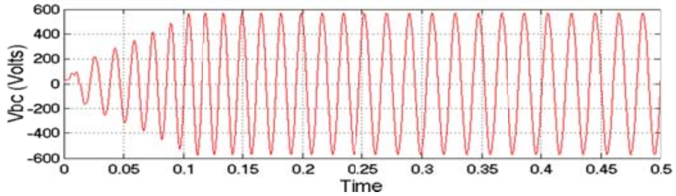
The simulation model of self excited induction generator with ELC is modeled in MATLAB-SIMULINK. Input power of induction generator is held constant at 3000 watts. The rated output power is 2000 watts. Here the ELC is modeled to provide load control from no load to 2000 watts of consumer load. Balanced 3 phase excitation is provided by bank of 3 phase capacitors connected in delta configuration. Circuit breakers C.B.-1 and C.B.-2 are programmed to connect and

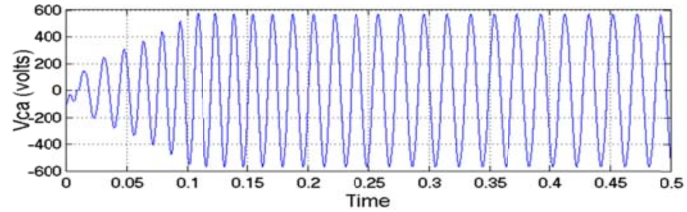


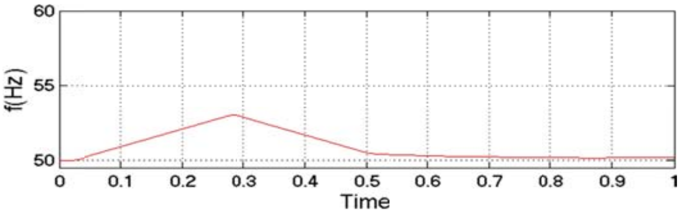
disconnect the consumer load and ELC respectively. In ELC circuit LC filter is used to filter out the ac ripples present in output voltage and current. PWM generation circuit generates PWM using fuzzy logic method. The range for fuzzy variables is determined by experience gained by the performance of the SEIG-ELC system with PI controller. The PWM pulses are fed to the IGBT switch for controlling dump power consumption. The machine parameters for simulation are: 3.7 kW, 4 poles, 415 V, 50 Hz, squirrel cage J=0.0131 N-m². Stator resistance R_S=3.2 ohm, rotor resistance (referred to stator) R'_r = 0.657ohm, L_m = 168.75mH, leakage reactance, L_S=L'_r=17.63 mH Excitation Capacitance at no load= 25.5 μF and at full load=35μF. Rated consumer load = 2 Kw. Initial conditions for simulation are: stator current, i_a = i_b = i_c =2A, initial slip= -0.0000000001p.u. ELC ratings are: Rated power =3 kW, L_f=40mH, C=530μF, R_{D1}=1000 ohm, dump load R_{D2}=100 ohm, snubber circuit parameters are: snubber resistance = 0.1 Mega ohm, bridge rectifier snubber parameters are: r_s=2000 ohm and c_s=0.058μF, reference voltage= 540 V, PI controller parameters: Kp= 4, Ki = 0.5. For steady state analysis the load is gradually increased in small steps.











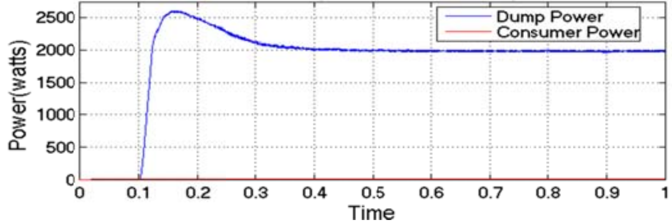


Fig. 10- Simulation model of SEIG with ELC for constant input power in SIMULINK

7 RESULTS

(i)- Self excitation process waveforms:

Fig.11 – 3 phase p.u. voltage waveforms

Fig.12- Line voltage Vab waveform

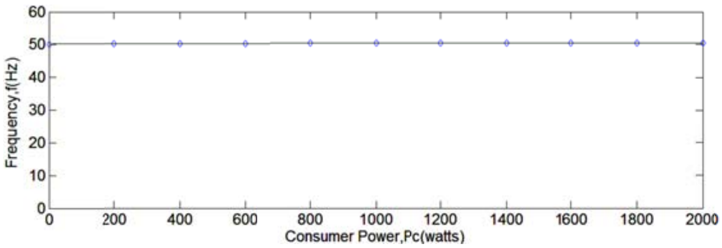
Fig. 13- Line voltage Vbc waveform

Fig. 14- Line voltage Vca waveform

Fig. 15- Frequency versus time plot

Fig. 16- Power plot at no consumer load

Fig. 11 shows the 3 phase p.u voltage waveform during self excitation process in which no consumer load is connected. The base line voltage is 400 V. Fig. 12 shows the waveform of line voltage Vab. Fig. 13 and fig. 14 shows the waveforms of line voltage Vbc and line voltage Vca. At 0.1 s the no load line voltages becomes 400.2 V. The plot between frequency and time during self excitation is shown in fig. 15. ELC starts its



operation at t = 0.1s as the line voltage reaches just above the base voltage 400 V. After transients die out, the ELC consumes rated power of 2000 watts as shown in the fig. 16.

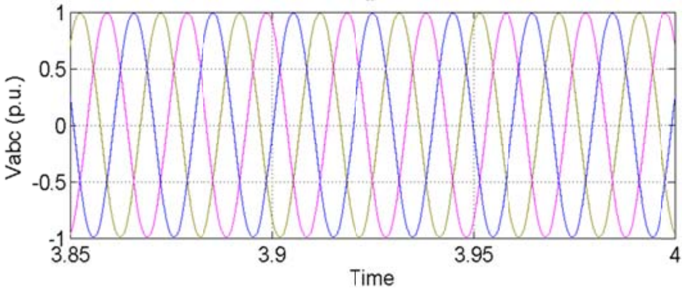
(ii)- Steady state analysis results:

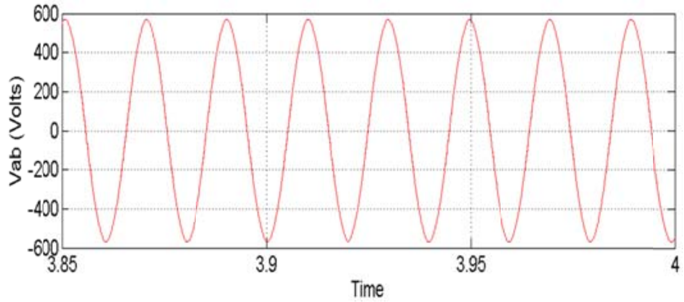
Fig. 17- Dump power versus consumer power plot

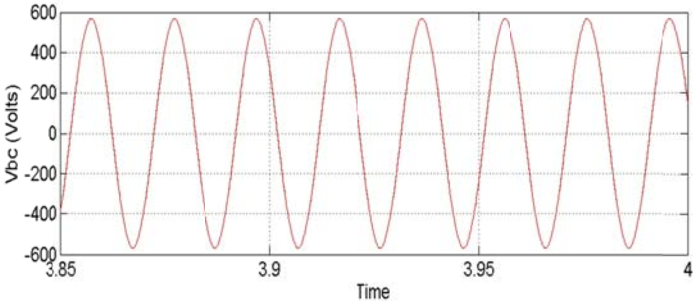
Fig. 18- Line voltage versus consumer power plot

Fig.19- Frequency versus consumer power plot

Fig. 17 shows the variation of dump power with the increase in consumer load power. ELC maintains the total load across SEIG constant, hence the plot is linear. The dump power decreases linearly with the increase in consumer load. Fig. 18 shows the variation of line voltage versus the consumer load. Line voltage at no load is 400.2 V. The plot shows that the line voltage remain constant as the line voltage at full load is 399.2 V which is near to no load voltage. Fig. 19 depicts variation of frequency with the increase in consumer load. The no load frequency is 50.12 Hz while at full load it rises to 50.52 Hz; hence the plot is straight line.







(iii)- Steady state waveforms on application of full load

Fig. 20- steady state 3 phase p.u. voltage waveform

Fig. 21- steady state waveform of Line voltage, Vab

Fig. 22- Steady state waveform of line voltage, Vbc

Fig. 23- Steady state waveform of line voltage, Vca

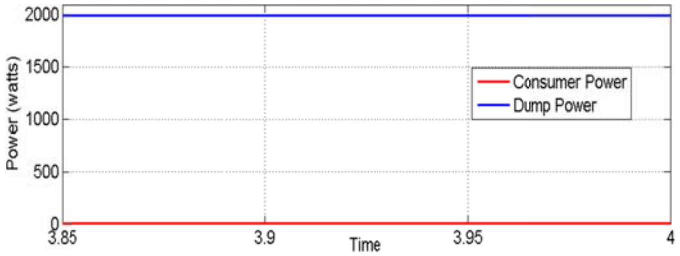
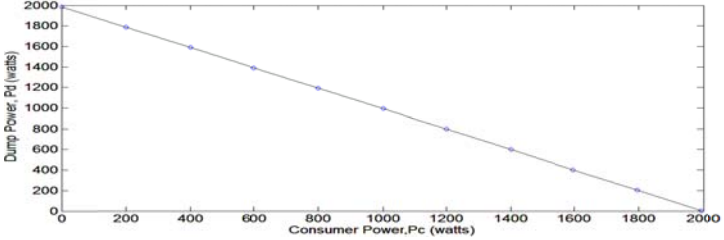


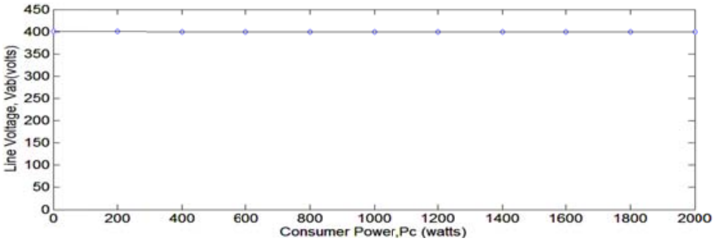
Fig. 24- Steady state power plot

Fig. 20 shows the steady state waveform of 3 phase p.u. voltages on application of full load. The nature of waveform is sinusoidal. Fig.21 an shows the maximum value of line voltage 567 V on full load. Fig. 22 and fig. 23 show the steady state waveforms of line voltages, Vbc and Vca with maximum value of line voltage 567 V. fig. 24 shows the power plot during full consumer load application. On full load application, the dump power becomes zero as shown in fig.24.

8 Conclusion

The fuzzy logic based electronic load controller was analyzed for steady state operation of SEIG feeding 3 phase balanced resistive load. The self excitation process is also shown where voltage and frequency reached their final steady state very quickly. The steady state results show the ELC maintain total output load constant at rated load, thus it maintains voltage and frequency constant during steady state analysis. The no load to full load (2kW) variation in voltage is 1 volt only. The variation in frequency from no load to full load is found 0.4 Hz only. The steady state waveforms at no load and full load show the fast and excellent control of fuzzy logic based ELC in voltage and frequency regulation.





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