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Design and Modeling of Fuzzy Logic Based Voltage Controller for an Alternator

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Abstract - Wide range of electrical apparatus used in industrial application require automatic voltage regulator for stability purpose. As the loud on an alternator is varied, its terminal voltage is also found to vary. This variation terminal voltage is due to voltage drop in armature and armature reaction, therefore this paper aims to design voltage regulator to maintain the terminal voltage of alternator at constant value at load condition. The armature voltage of a synchronous generator is controlled by varying the field voltage using fuzzy logic based control method. Voltage difference between the immediate output voltage and the rated voltage of the generator is used to process the rate of change of voltage error. The amount of armature voltage that has to be applied to the alternator is varied by the controller to keep the output of alternator at its rated value. The system is designed and simulated using MATLAB simulink.

Index terms- alternator, fuzzy logic controller (FLC), voltage control.

I INTRODUCTION

The system dynamics of the alternator (Synchronous generators) can be easily studied by modelling in SIMULINK. Synchronous generators are the primary energy conversion devices of the world's electric power systems. The voltage regulation is of a critical importance in such type of generators. Fuzzy logic controllers are rapidly becoming a viable alternative for classical controllers. Fuzzy logic control devices are becoming a more attractive solution for real time control situations [2].

The voltage regulation system is designed using Fuzzy logic controller. It adjusts the output voltage of the generator in order to maintain it at a relatively constant value. This is achieved by comparing the output voltage with a reference voltage and from the difference (error); it makes the necessary adjustments in the field voltage to bring the output voltage closer to the required value.

II SYSTEM CONFIGURATION

The figure below gives the system description.

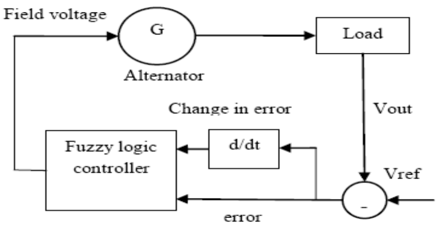

Fig 1: Closed loop control system

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An alternator running at rated speed and rated armature voltage experiences a varying load. As the armature voltage fluctuates with the changing load, the excitation current into the field of the generator must be altered to bring the armature voltage back to its rated value. This is accomplished with an intelligent control strategy. The line to line voltage of the alternator will be fed into the controller where the immediate armature voltage is compared to its rated voltage to find the voltage error that exists. It will then find the rate of change of voltage by comparing the previous voltage value to the immediate armature voltage. These two inputs will be evaluated using a fuzzy logic-based control algorithm and an output signal will be produced. This output is introduced to the alternator to maintain the output voltage at the rated value.

III MATHEMATICAL MODELING

Any kind of modeling of electrical machine such as synchronous generator starts with measurements on real model because it is necessary to determine all essential parameters. The other possibility is to obtain generator parameters from manufacturer or determinate our own parameters if generator prototype is being build. After that generator model can be made by using all mathematical equations which describes the generator. This model is used for analysis of dynamic behavior due to varying load.
Alternator: The d-q equivalent circuit of the synchronous generator is shown in Fig 2. The model is represented in the rotor reference frame (q-d frame). All rotor parameters and electrical quantities are viewed from stator. They are identified by primed variables. The subscripts used are defined

- *d, q:* d and q axis quantity
- *R, s:* Rotor and stator quantity
- *l, m:* Leakage and magnetizing inductance
- *f, k:* Field and damper winding quantity

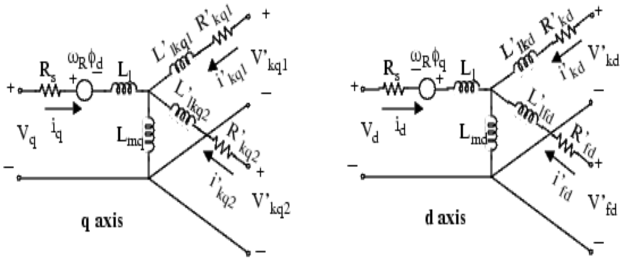


Fig 2: Electrical model of the synchronous generator

With the following equations

$$V_d = R_s i_d + \frac{d}{dt}\phi_d - \omega_R \phi_q$$

$$V_q = R_s i_q + \frac{d}{dt}\phi_q - \omega_R \phi_d$$

$$V'_{fd} = R'_{fd} i'_{fd} + \frac{d}{dt}\phi'_{fd}$$

$$V'_{kd} = R'_{kd} i'_{kd} + \frac{d}{dt}\phi'_{kd}$$

$$V'_{kq1} = R'_{kq1} i'_{kq1} + \frac{d}{dt}\phi'_{kq1}$$

$$V'_{kq2} = R'_{kq2} i'_{kq2} + \frac{d}{dt}\phi'_{kq2}$$

$$\phi_d = L_d i_d + L_{md}\left(i'_{fd} + i'_{kd}\right)$$

$$\phi_q = L_q i_q + L_{mq} i'_{kq}$$

$$\phi'_{fd} = L'_{fd} i'_{fd} + L_{md}\left(i_{fd} + i'_{kd}\right)$$

$$\phi'_{kd} = L'_{kd} i'_{kd} + L_{md}\left(i_d + i'_{fd}\right)$$

$$\phi'_{kq1} = L'_{kq1} i'_{kq1} + L_{mq} i_q$$

$$\phi'_{kq2} = L'_{kq2} i'_{kq2} + L_{mq} i_q$$

Simple hydraulic turbine: It is used as the prime mover for the alternator. It has a penstock, unrestricted head and tail race, and with either a very large or no surge tank.

The penstock is modeled by assuming an incompressible fluid and an incompressible fluid and a rigid conduit of length L and cross section Penstock head losses are proportional to flow squared and f_p is the head loss coefficient usually ignored.

From the laws of momentum, the rate of flow of conduit is

$$\frac{d\bar{q}}{dt} = \left(\bar{h}_o - \bar{h} - \bar{h}_1\right) g \qquad \text{A/m} \qquad (4.13)$$

$\bar{q}$	turbine flow rate m^3/sec
A	penstock area m^2
L	penstock length m
g	acceleration due to gravity m/sec^2
$\bar{h}_o$	static head of water column m
$\bar{h}$	head at turbine admission m
$\bar{h}_1$	head loss due to friction in the conduit m

Expressed in per unit, this relation is

$$\frac{dq}{dt} = \frac{1 - h - h_1}{T_w}$$

where h and h_1 are the head at the turbine and head loss respectively in per unit with h_{base} defined as the static head of the water column above the turbine.

$$T_W = \frac{L}{A}\frac{q_{base}}{h_{base} g} \quad \text{sec}$$

q_{base} is defined as the turbine flow rate with the gates fully open

The per unit flow rate through the turbine is

$$q = G\sqrt{h}$$

In an ideal turbine, mechanical power is equal to flow times the head with appropriate conversion factors

The fact that the turbine is not 100% efficient is taken into account by subtracting the no load flow from the actual flow giving the difference as the effective flow, which, multiplied by head produces mechanical power. There is also speed deviation damping effect which is a function of gate opening.

Per unit turbine power on generator MVA base is expressed as

$$P_n = A_t h\left(q - q_{nl}\right) - DG\Delta W$$

Where

q_{nl} per unit no load flow accounting for turbine fixed power losses

A_t proportionality factor and is assumed constant

$$A_t = \frac{Turbine..MW.rating}{(Gen..MVArating)h_r\left(q_r - q_{nl}\right)}$$

Simulink provides the model of alternator and hydraulic turbine. The values are changed as per the requirements.

IV FUZZY LOGIC CONTROLLER

Fuzzy logic control is a non-mathematical decision algorithm that is based on an operator's experience. This type of control strategy is suited well for non- linear systems such as the synchronous generator, which exhibits non-linearity between the field current In and the armature voltage out [3].

FLC contains three basic parts: Fuzzification, Base rule, and Defuzzification. FLC has two inputs which are: error and the change in error, and one output. The Fuzzy Controller structure is represented in fig.4. The role of each block is the following:

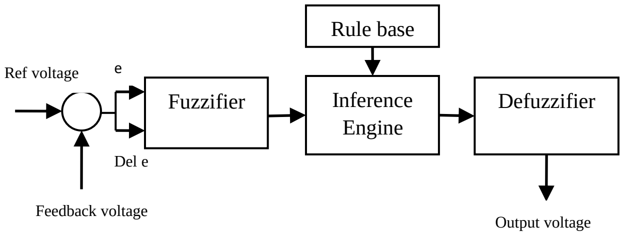


Fig 3: The general structure of Fuzzy Logic Controller

Fuzzifier converts a numerical variable into a linguistic label.. In a closed loop control system, the error (e) between the reference voltage and the output voltage and the rate of change of error (del e) can be labeled as zero (ZE), positive small (PS), negative small (NS), etc. In the real world, measured quantities are real numbers (crisp).

The FLC takes two inputs, i.e., the error and the rate of change of error. Based on these inputs, The FLC takes an intelligent decision on the amount of field voltage to be applied which is taken as the output and applied directly to the field winding of generator. Triangular membership functions were used for the controller.

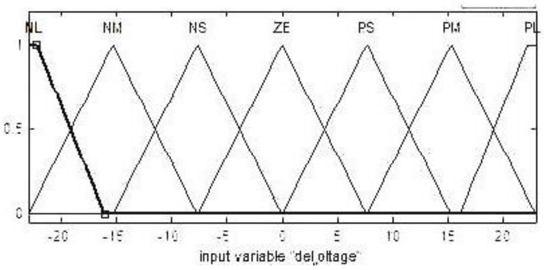


Fig 4. Membership function of voltage

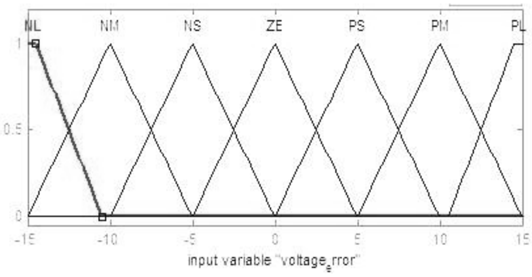


Fig 5. Membership function of voltage error

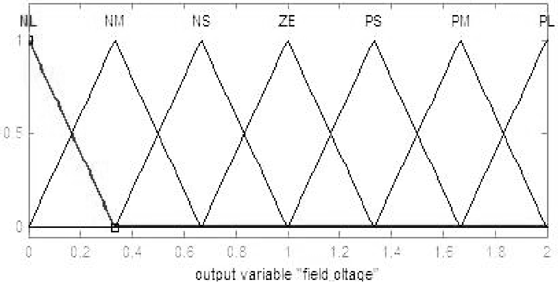
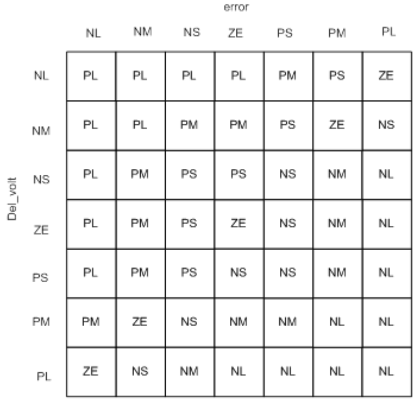


Fig 6. Membership function of output field voltage

Rule base stores the data that defines the input and the output fuzzy sets, as well as the fuzzy rules that describe the control strategy. Mamdani method is used in this paper. Seven membership functions were used leading to 49 rules in the rule base.

Table 1: Rule base for fuzzy controller



Del_volt \ error	NL	NM	NS	ZE	PS	PM	PL
NL	PL	PL	PL	PL	PM	PS	ZE
NM	PL	PL	PM	PM	PS	ZE	NS
NS	PL	PM	PS	PS	NS	NM	NL
ZE	PL	PM	PS	ZE	NS	NM	NL
PS	PL	PM	PS	NS	NS	NM	NL
PM	PM	ZE	NS	NM	NM	NL	NL
PL	ZE	NS	NM	NL	NL	NL	NL

Inference engine applies the fuzzy rules to the input fuzzy variables to obtain the output values.

Defuzzifier achieves output signals based on the output fuzzy sets obtained as the result of fuzzy reasoning. Centroid defuzzifier is used here.

V SIMULATION AND RESULT ANALYSIS

Simulation is carried out MATLAB Simulink. Open loop and closed loop using fuzzy logic controller is simulated. The hydraulic turbine runs the alternator, the line voltage is rectified which is the output.

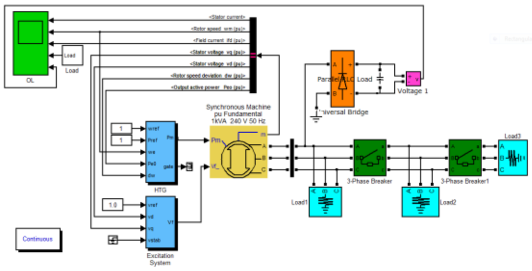
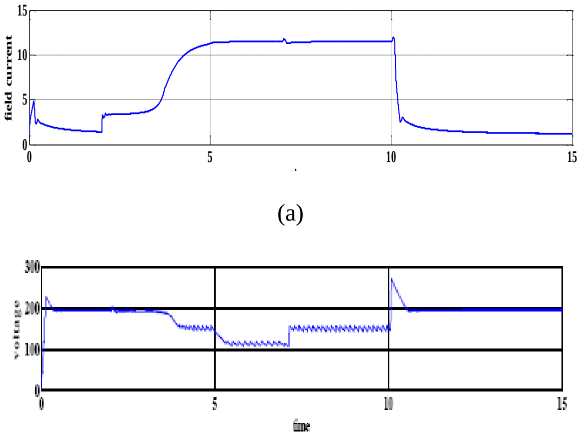


Fig 7: Simulink model of Open loop system

In the open loop system, the load is increased at t=2sec and then again at t=5sec which results in the increase in the field current and decrease in the voltage. Similarly, load is decreased at t=7sec and t=10sec which decreases the field current and increases the voltage as shown in fig 5.



(a)

(b)

Fig 8: Open loop performance of the system (a) field current of the alternator (b) voltage of the alternator.

In the above system, the voltage varies when the system is loaded. This is overcome by the closed loop controller, where the variation is limited to some extent. The simulink model of which is shown in fig 7.

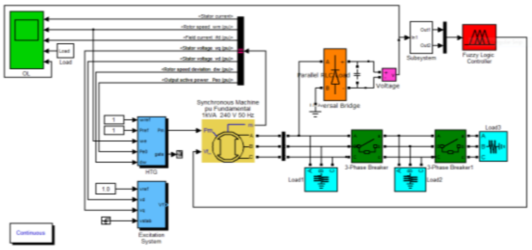
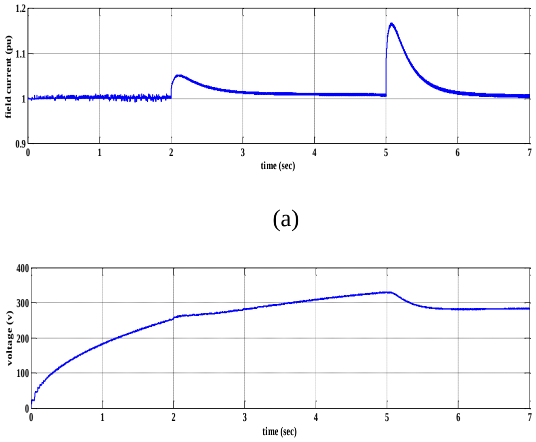


Fig 7: Simulink model of Closed loop system

In the above system, the alternator is loaded at t=2sec and then the load is increased at t=5sec which results in the momentary shooting of the field current and voltage is fairly constant as shown in fig 5.



(a)

(b)

Fig 9: Closed loop performance of the system (a) field current of the alternator (b) voltage of the alternator

The output voltage seems to be constant, but the variation still exists. This phenomenon is avoided in the closed loop fuzzy logic system which justifies the proposed controller. Fig 9 shows the system incorporated with fuzzy logic controller.

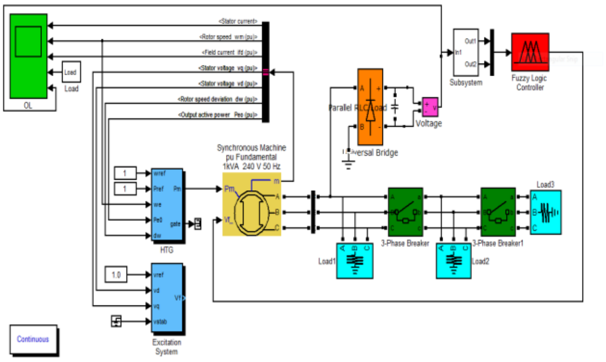
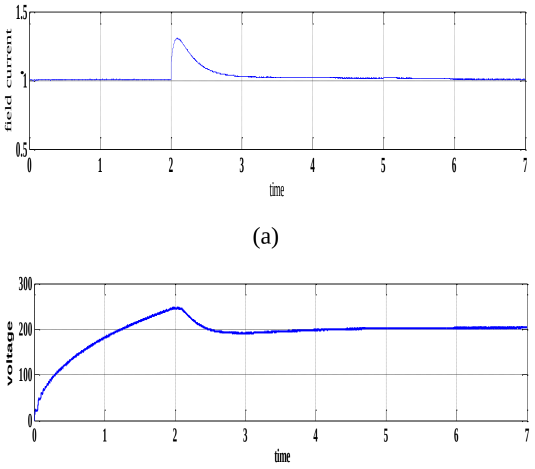


Fig 10: Simulink model of closed loop with FLC

In the FLC system, the immediate output voltage of the alternator and the difference between the present and previous output voltage is fed to the fuzzy controller; the output of which in turn feeds the field voltage of the alternator. Here the alternator is loaded at t=2sec and further at t=5sec for which the output voltage is comparatively constant. This gives a better performance than that of closed loop without fuzzy logic controller.



(a)

(b)

Fig 11: Performance of the system with FLC (a) field current of the alternator (b) voltage of the alternator.

VI CONCLUSION

In this paper the design and modeling of a fuzzy logic controller for an alternator to control its voltage is discussed. The controller is to regulate the output voltage of a synchronous generator by varying the voltage that was applied to the field of the generator in real time. This is accomplished by a fuzzy logic control system.

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