Snubber Network Design for Triac Driving Single – Phase Industrial Heater by Applying Fuzzy Logic Method

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ABSTRACT

Power switches require snubbing networks for driving single – phase industrial heaters. Designing these networks, for controlling the maximum allowable rate of rise of anode current (di/dt) and excessive anode – cathode voltage rise (dv/dt) of power switching devices as thyristors and Triacs, is usually achieved using conventional methods like Time Constant Method (TCM), resonance Method (RM), and Runge-Kutta Method (RKM).

In this paper an alternative design methodology using Fuzzy Logic Method (FLM) is proposed for designing the snubber network to control the voltage and current changes.

Results of FLM, with fewer rules requirements, show the close similarity with those of conventional design methods in such a network of a Triac driving 1.2 kW heater of an industrial plastic extruder machine.

The similarity, between Fuzzy Logic results and conventional techniques results, is confirming the applicability of the fuzzy logic in designing these snubbing networks.

Keywords: Fuzzy Logic Method, Triac, Snubber Parameters.

تصميم شبكة الزجر لترایاك یسیطر على سخان صناعي أُحادي الطور باستعمال طریقة المنطق العشوائي

الخلاصة

ان مفاتیح القدرة تحتاج الى دوائر الزجر للسیطرة على السخانات صناعیة احادیة الطور. تصمیم هذه الدوائر, للسیطرة على اعلى حد مسموح في ارتفاع تیار القطب الموجب (di/dt) وارتفاع الفولتیة المفرطة بین القطبین (dv/dt) لمفاتیح القدرة كالثایرستور والترایاك, عادةً یتم باستعمال الطرق التقلیدیة مثل (TCM, RM, RKM).

إن هذا البحث یعرض طریقة تصمیم بدیل باستعمال الطریقة المنطقیة العشوائیة لتصمیم دائرة زجر تسیطرعلى تغیر الفولتیة والتیار.

ان نتـائج (FLM), التـي تتطلـب أقل عدد مـن القوانين, توضـح تشـابه وثيـق مـع نتـائج تصـميم الطرق التقليدية لشبكة الزجر الخاصة بترايك يسيطر علـى 1.2 KW جهازسـخان صـناعي طـارد للبلاستيك.
ان هذا التشابه بين نتائج المنطق العشوائي ونتـائج الطـرق التقليديـة يؤكـد قابليـة التطبيـق للمنطـق العشوائي في تصميم دوائر الزجر.

INTRODUCTION

Power semiconductor devices are the most important functional elements in all power conversion applications. The power devices are mainly used as switches to convert power from one form to another. They are used in motor control systems, uninterrupted power supplies, high-voltage dc transmission, power supplies, induction heating, and in many other power conversion applications [1].

Reliable operation of a thyristor demand that its specified ratings are not exceeded. In practice, a thyristor may be subjected to sudden over rated voltages and currents. During a thyristor turn-on, di/dt may be prohibitively large. Also, a false triggering due to high value of dv/dt may cause a thyristor to be turned on i.e. a spurious signal across gate-cathode terminals may lead to unwanted turn-on. A thyristor must be protected against all such abnormal conditions for satisfactory and reliable operation of Silicon-Controlled Rectifier (SCR) circuit and the equipment [2], which can otherwise cause unintended break over leading to malfunction of the circuit and possible failure of the device [3]. Adopted techniques to protect SCRs are:

a) Di/dt protection. If the rate of rise of anode current is large as compared to the spread velocity of carriers, local hot spots will be formed and may destroy the thyristor. Therefore, anode current rise at turn-on time must be kept below the specified limiting value. This is done by using a small inductor, called di/dt inductor, in series with the anode circuit as shown in fig.1. Local spot heating can also be avoided by insuring that conduction spreads to the whole area as rapidly as possible. This can be achieved by applying a gate current nearer to the maximum specified gate current [2].

b) Dv/dt protection. If the rate of rise of suddenly applied voltage across thyristor (dv/dt) is high, the device may get turned on. Controllable Triacs and thyristors can latch ON from an excessive rate in anode voltage rise during device turn – ON, or from transients. This will cause erratic equipment behavior and may result in total failure in many industrial applications [2], thus excessive dv/dt must be avoided.

Dv/dt suppression is achieved by means of snubber circuit, which is basically consists of a series-connected resistor and capacitor placed in shunt with an SCR, as shown in Figure (1).

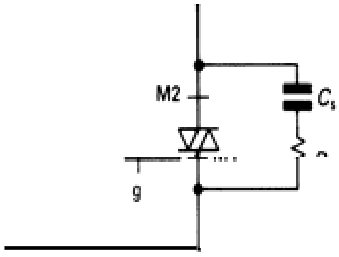


Figure (1) Triac with snubbr circuit.

Normally, the LCR circuit is slightly under damped, and when a step forward voltage is applied to it, the peak voltage appearing across the device and its rate of change are both limited to acceptable values [3].

Snubber circuits and soft switching techniques are applied to power electronic switches to reduce the power dissipation in the devices; in the case of bipolar power semiconductors; it includes prevention of second breakdown. They are also used to reduce total losses of the converter [4].

This work is based on fuzzy logic that has been successfully employed for the design of LCR snubber circuit and found to give good and realistic results since these results are within the acceptable range that the conventional methods bound.

LITERATURE REVIEW

It is useful to present a survey of the previous studies dealing with fuzzy analysis of different systems, especially that dealt with SCR.

K. Zawiriski, K. Urbanski, and J. Ferenc [5], presented an application of fuzzy logic controller (FLC) for controlling of thyristor DC drive. Comparison between the fuzzy control system and an ordinary digital control system, carried out by simulation method, proving that FLC is a robust controller which gives better performance in the range where non-linearity and parameter variation is observed.

N. Kaur and Y. Singh [6], developed Fuzzy Logic based optimal control system for input voltage regulation of SCR, this is further optimized by Genetic Algorithm. The input voltage regulation of SCR is needed to meet the varying load current demand in various industrial applications of the device.

J. Du, G. Mo, G. Wu, and K. Huang [7], proposed a Constant-current soft starting based on fuzzy control strategy. In this method, the fuzzy control rules are adjusted based on the changes of the starting current in time, which effectively eliminates current and torque oscillation compared with the traditional PID control soft starting. Checking full-voltage method is proposed based on simulation results of the relationship between voltage-drop of thyristor and rotate speed of motor. With the method, starting time is shortened, and harmonic of current and heat of thyristor are reduced.

M. Hoseynpoor, and M. Davoodi [8], investigated the functionality of thyristor controlled series capacitor and tried to improve its abilities by changing the conventional applied controlling approaches and utilize it as a fault current limiter using fuzzy control method.

FUZZY SET THEORY

Fuzzy control provides a formal methodology for representing, manipulating, and implementing a human's heuristic knowledge about how to control a system. The fuzzy controller has four main components:

The “rule-base” holds the knowledge, in the form of a set of rules, of how best to control the system.

The “inference mechanism” evaluates which control rules are relevant at the current time and then decides what the input to the plant should be.

The “fuzzification interface” simply modifies the inputs so that they can be interpreted and compared to the rules in the rule-base.

The “defuzzification interface” converts the conclusions reached by the inference mechanism into the inputs to the plant [9].

Fuzzy logic involves complex mathematical computations associated with fuzzification, rule-base evaluation, and defuzzification [10].

The mathematical model is seen as an approximation of the real system. A controller designed based on this model is assumed to work effectively with the real system if the error (difference) between the actual system and its mathematical representation is relatively insignificant.

The majority of fuzzy logic control systems are knowledge-based systems in that either their fuzzy models or their fuzzy logic controllers are described by fuzzy IF-THEN rules, which have to be established based on experts’ knowledge about the systems, controllers, performance, etc. Moreover, the introduction of input-output intervals and membership functions is more or less subjective, depending on the designer’s experience and the available information [11].

CASE STUDY

A Triac driving a heater that heat plastic materials to a certain temperature; relying on the material type: must be protected against high rate of changes of current and voltage during the switching transients of the device.

The snubbing circuit; which is a protection technique that reduces the effect of changes; can be designed by evaluating its parameters: resistance (***R***), capacitance (***C***) and (or) inductance (***L***).

1- Snubber Parameters Calculation

The evaluation of snubber parameters can be accomplished using fuzzy logic method utilizing the equations below [12]:

$$\frac{di}{dt} = \frac{V_A(max)}{R^2.C} \quad \dots (1)$$

$$\left(\frac{di}{dt}\right)_{(max)} = \frac{V_A(max)}{L_{min}} \quad \dots (2)$$

$$V_{A(max)}=I_{L(max)}.R_L \quad \dots (3)$$

Where:

$V_{A(max)}$: capacitor peak applied voltage (charg ing voltage).

$I_{L(max)}$: maximum load current injected into the heater.

R_L: load resistance.

To design a fuzzy controller, inputs and outputs of fuzzy controller is determined at the first step. In this paper; load resistance and di/dt are considered as inputs; Triac type MAC2237 is used, where the design is according to the critical manufacturer specification of it (Maximum rate of change of currents di/dt = 13.5 A/ μs) which represents the boundary of its member ship. The controller outputs are the snubber parameters (C, R, & L).

Inference engine follows the rules of Mamdani Inference engine [13] whose structure has been defined in Table (1):

Table (1). Rules governing the Values of C, R, and L.

Fuzzy Antecedent Premises		**Fuzzy Consequent Premises**		
		Then C is	**Then R is**	**Then L is**
IF R_L or di/dt is	VS	VL	M	VL
	S	L	SM	L
	M	M	S	M
	L	S	VS	S
	VL	VS	VVS	VS

<u>Note:</u> The explanations of the abbreviations used in constructing the rules in Table (1) are:

VVS: very very small
VS: very small
S: small
SM: small medium
M: medium
L: large
VL: very large

Figure (2). shows the fuzzy inference system for evaluating snubber circuit parameters.

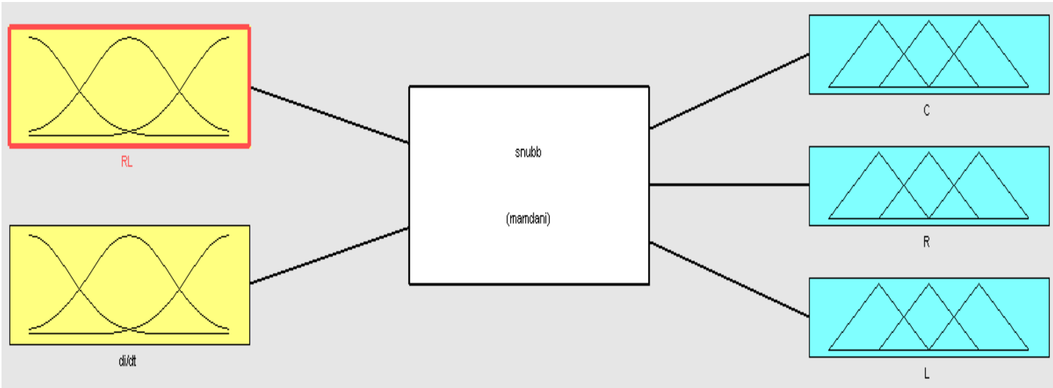
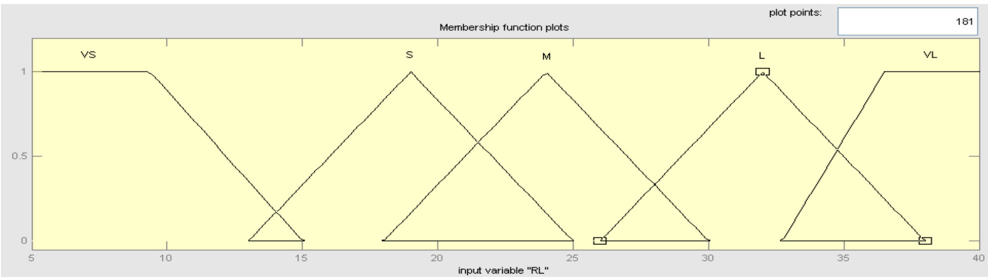
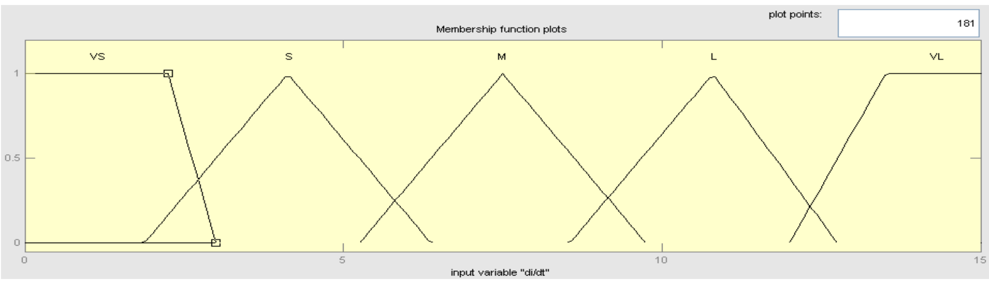


Figure (2) Fuzzy inference system.

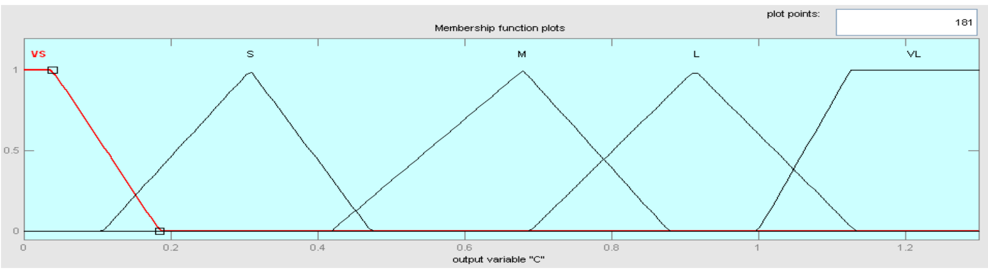
Memberships of the R_L (load resistance), and di/dt that is forming the rules governing C, R, and L values are shown in Figure (3).



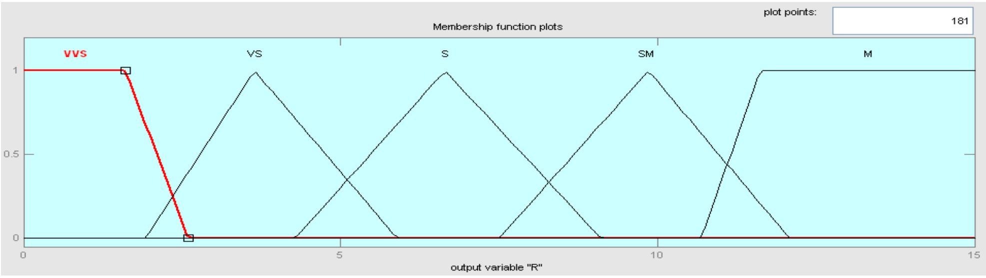
(a) Input-1- for input variable "RL"



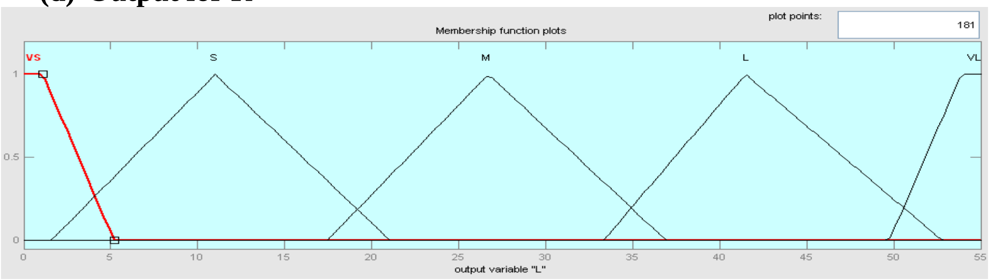
(b) Input-2- for input variable "di/dt"



(c) Output for C



(d) Output for R



(e) Output for L

Figure (3) Membership functions of inputs and outputs to calculate snubber parameters.

RESULTS OF SNUBBER CIRCUIT

When applying rules that relates the outputs according to the values of inputs that are illustrated in Table (1); using GUI that is provided by MATLAB software; the resultant parameters as shown in Figures (4, 5, and 6) are:

C=0.64 (μF), R=7.11 (Ω), and L=27.6 (μH)

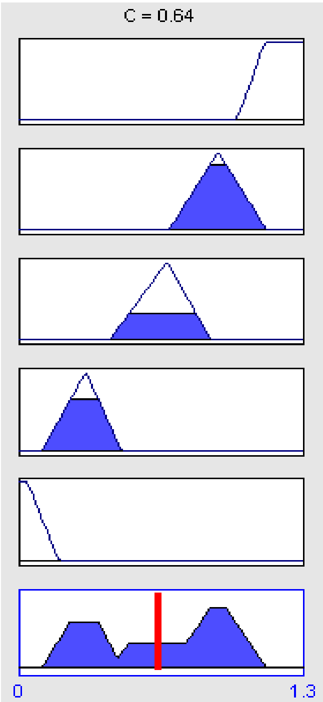


Figure (4) Result of C.

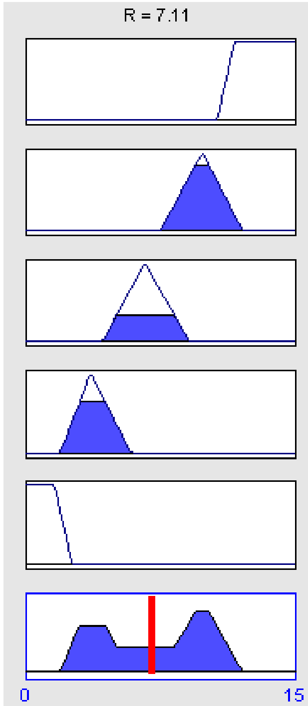


Figure (5) Result of R.

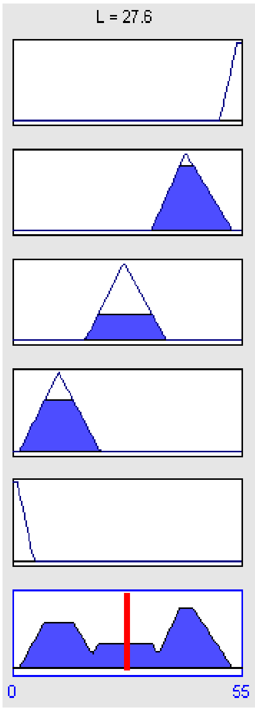


Figure (6) Result of L.

DISCUSSION

Figure (7) shows the step response of the three conventional methods as given by reference [12] besides the step response of the new fuzzy logic method. The comparison is obtained with a Matlab/ Simulink model that has been built for this purpose.

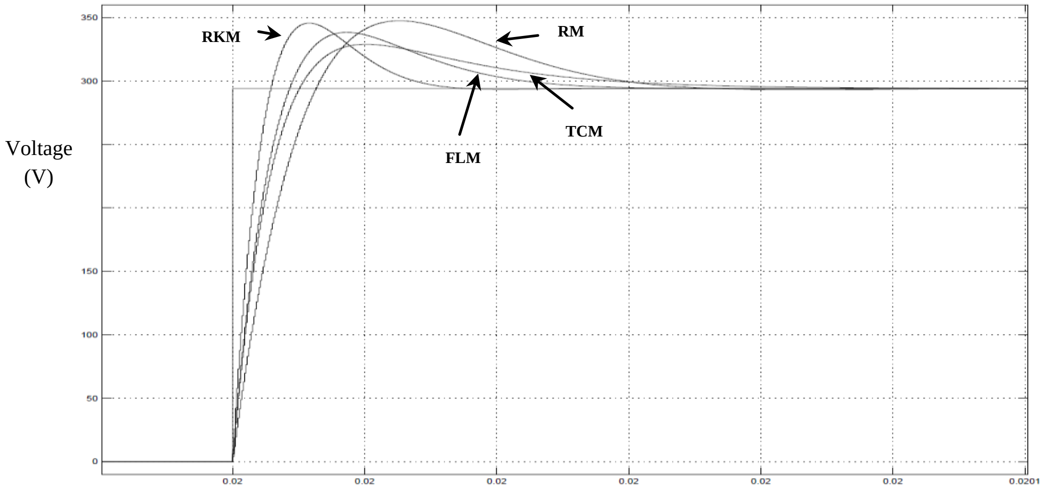


Figure (7) Snubber network step response for the four design methods.

Table (2) shows the results of snubber parameters using numerical solutions (TCM, RM, & RKM) [12], and (FLM). Also, the wattage of the snubber network resistance is included.

Table (2) Snubber circuit parameters results.

Method	R (Ω)	Wattage of R (W)	L (µH)	C (µF)
TCM	4.15	6.535	21.7	1.26
RM	8.5	3.58	50	0.69
RKM	8.056	1.763	21.7	0.34
FLM	7.11	3.257	27.6	0.64

The comparison of capacitor, resistor, and inductor values of FLM with the conventional methods shows that:

1) Fuzzy calculations give comparable results.
2) The parameter values difference between all methods are within an acceptable range.
3) It is obvious that snubber resistance wattage is within an acceptable value when compared with those for both TCM and RM.
4) Parameter tuning can be used to minimize variations from conventional values.

CONCLUSIONS

From the obtained results it can be depicted that the snubber network parameters of FLM have values that lies between the RKM and the RM regarding the settling time of the system and with a less maximum over shoot voltage.

This study is useful to determine snubber circuit design for any thyristor with its own critical manufacturer specifications.

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