Design Consideration for Efficiency Enhancement of Induction Generator using Fuzzy Logic

SHELLY VADHERA
Electrical Engineering Department
National Institute of Technology, Kurukshetra
Kurukshetra, Haryana
INDIA
shelly_vadhera@rediffmail.com

Abstract: - In this paper the data is collected for eighteen induction machines of different ratings in order to facilitate the study of magnetization characteristics in particular and for design considerations of induction generators in general. The analysis of data as per proposal explained helps to decide the specific limits/bounds of machine parameters. Further this paper highlights the ease with which fuzzy logic can facilitate the designer for judicial selection of machine parameters for efficiency improvements.

Key-Words: - efficiency, fuzzy logic, machine parameters, magnetization characteristics, induction generator

1 Introduction

Global demand for energy is increasing at a breathtaking pace, which requires significant investment in new power generation capacity. As the demand for energy continues to soar the supply of fossil fuels is dwindling. The general consciousness of finite and limited sources of fossil fuels on earth and international disputes over the environment, global safety, and the quality of life have created the need to trigger the renewable sources of energy like wind, hydro, photovoltaic and fuel cells which are clean, safe and sustainable. Moreover the use of renewable energy for the supply of electricity will broaden the energy base and relieve the strained power grids with rolling blackouts. In order to avoid the worst ravages of climate change, global emissions need to start declining before 2020. The power sector is not the only culprit when it comes to climate change, but it is the largest source of emissions, accounting for about 40% of CO_2 and 25% of overall emissions. Wind energy is the only power generation technology that will be able to make a substantial difference in CO_2 emissions in the crucial timeframe up to 2020. It is quick to install, and on track to saving 10 billion tons of CO_2 by 2020. Wind energy, however, is a massive indigenous power source that is available virtually everywhere in the world. There are no fuel costs, no geo-political risk and no supply import dependency. The wind energy demand is bound to boom further when the cost efficiency attains parity with other competing energy sources.

In this new millennium, induction generators with cage rotors are by far the most common type of energy conversion devices used in wind energy conversion. For its simplicity, robustness, and variable speed operations, the induction generators are favoured for a small hydro and wind power plants. More recently, with the wide spread use of power electronics, computers, and electronic microcontrollers; it has become easier to administer the use of these generators and to guarantee their use for the vast majority of applications. To achieve the desired performance of any electrical generator, design modifications are to be incorporated accordingly. The design of the machine may vary depending upon its specific application. For example, air craft generators require minimum weight and maximum reliability and ease of servicing, large hydro power generators require better starting torque per ampere, induction generators for renewable energy applications require good steady and dynamic active and reactive capabilities and better efficiency. In case of self excited, a trade off with consistent saturation curve might be important.

An induction generator is long term investment and therefore during design considerations a paramount importance is laid to maximize the machine efficiency. Machine losses may be reduced by using better quality materials, as well as by proper selection of design parameters. Howsoever, the design of electrical machines particularly induction generators, is also closely constrained by the performance limits, technical and economic properties of materials. The technical developments permit better utilization of the materials, whereby reducing the size and cost of induction generators.

Maximum ambient temperature, cooling systems, and magnetic material, when considered in the design and optimization of especially high rated machines, strongly affect the size of machine and consequently the cost of the machine itself and its associated systems. Efficiency is one of the important issues in case of induction generator. Such machines in grid connected mode, with minimum losses may be capable to transfer the power from wind to electrical systems even at low operating slips, corresponding to small speed variations above the synchronous speed. Therefore, in this paper an attempt has been made to study the data related to magnetization characteristics and other parameters of various induction machines from design point of view.

The work pertaining to the steady state analysis and design of induction generator in self-excited and grid connected modes was undertaken to study the key parameters that influence the working of induction generator under any operative condition. According to the literature available the authors feel that till date no research publication describes the use of fuzzy logic for a designer to select the machine parameters for efficiency improvement. Therefore, this issue as discussed in the paper is a new concept for the design of induction generators. Until now, [1] had used fuzzy logic for steady state analysis of self excited single phase two winding induction generator, [2] had used fuzzy logic for determining optimal capacitors required for maximum output power of a single phase self excited induction generator (SEIG), [3] had evaluated the performance of SEIG using fuzzy logic whereas [4] had applied fuzzy logic for design of induction motor. However the fuzzy logic based controllers find its application in wind turbines connected to induction generator [5], SEIG [6] and doubly fed induction generators [7-8]. The use of neuro fuzzy logic controller for power system stabilizer in a wind turbine based power system network is shown in [9]. Ref. [10-11] throws light on various applications of fuzzy logic in engineering fields but no work seems to be reported till now particularly regarding the use of fuzzy logic for design considerations of induction generator.

2 Study of magnetization characteristic

In an induction generator the saturation state of the magnetic circuit has significant influence over its performance. In order to explore this fact, the study of magnetization characteristics of eighteen machines had been undertaken. The magnetization characteristics of these machines are obtained from [12-26] and are converted to per unit values. Depending upon the nature of magnetization curve, first six machines [M-1 to M-6] may be clubbed together in one group whereas the remaining machines [M-8 to M-18] are clubbed in to other group. Fig.1 represents the variation of air gap e.m.f. with magnetizing reactance of machines M-1 to M-6 whereas the variations of efficiency with slip for these machines are shown in Fig. 2. Similarly Fig. 3 represents the variation of air gap e.m.f. with magnetizing reactance of machines M-8 to M-18 whereas the variations of efficiency with slip for these machines are shown in Fig. 4.

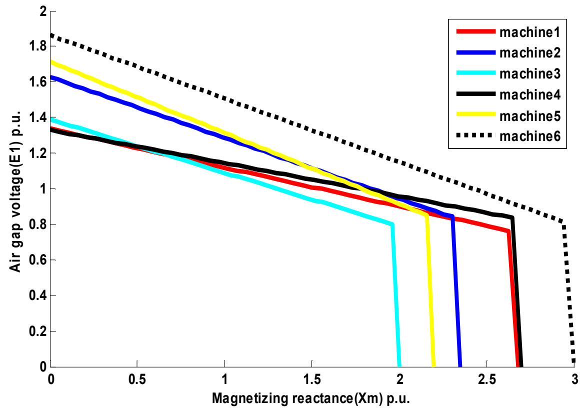

Fig. 1 Linear magnetization characteristics of machines M-1 to M-6

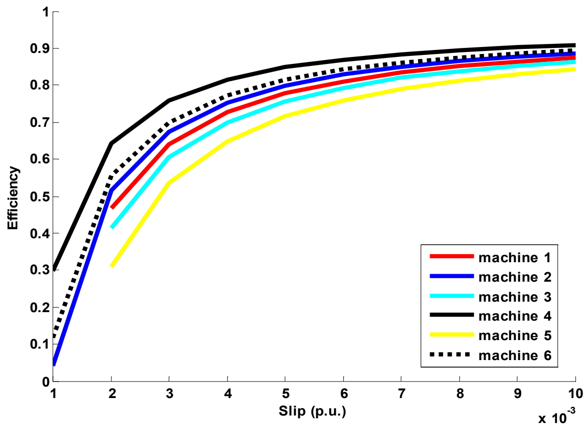

Fig. 2 Variation of efficiency with slip for machines M-1 to M-6

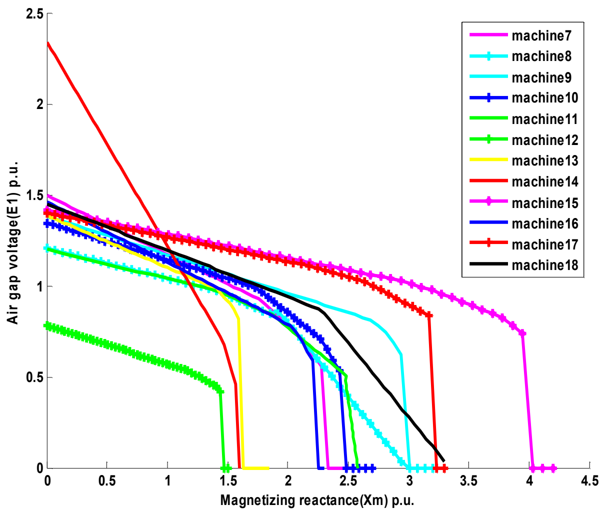

Fig. 3 Non-Linear magnetization characteristics of machines M-7 to M-18

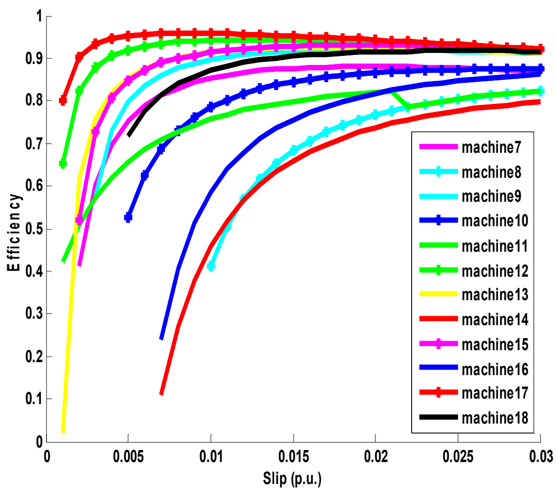

Fig. 4 Variation of efficiency with slip for machines M-7 to M-18

An observation of Fig. 1 to Fig. 4 shows that:

- Maximum value of magnetizing reactance for any machine plays an important role to decide the operating efficiency.
- Air gap voltage level corresponding to maximum value of magnetizing reactance also effects the efficiency.
- In general a machine with higher value of 'Xm' and corresponding high air gap voltage level results in to better efficiency.
- Efficiency of any machine is affected due to its nature of magnetization curve which is dependent upon the construction of magnetic part and its material.

3 Fuzzy logic for the design considerations of induction generator

Apart from the nature of magnetization curve as desired in section II, there is a need to explore the role played by other parameters such as stator resistance, rotor resistance and leakage reactance to decide the efficiency. Here Matlab based fuzzy logic is proposed to facilitate the aim.

Appendix I gives per unit values of stator resistance (R1), rotor resistance (R2) and leakage reactance (Xl) along with unsaturated values of magnetizing reactance (Xm), maximum value of air gap voltage (E1) under saturated condition and maximum value of efficiency attained by respective machine. In Appendix II, all values have been arranged in descending order and further replaced by respective machine (as shown in Appendix III). Now the data as shown in Appendix III may be used to define the membership function for five input variables i.e. R1, R2, Xl, Xm, and E1 whereas, efficiency may be taken as output variable and these are shown in Table 1. However such selections may vary from person to person, depending upon the design skill. For all eighteen machines the rules defined in fuzzy set theory are tabulated in Table 2.

Table 1 Selection of range for membership functions

Inputs ↓ /MF→	VL	L	M	H	VH
R_1 (p.u.)	0.03-0.045	0.04-0.05	0.045-0.06	0.05-0.08	0.07-0.1
R_2 (p.u.)	0.02-0.04	0.038-0.045	0.04-0.06	0.055-0.07	0.065-0.1
X_l (p.u.)	0.03-0.05	0.045-0.08	0.075-0.1	0.09-0.13	0.12-0.2
X_m (p.u.)	1-1.65	1.5-2.0	1.9-2.59	2.3-3	2.8-4.0
E_1 (p.u.)	0.7-1.0	0.95-1.35	1.3-1.47	1.45-1.9	1.8-2.5
Efficie-ncy	0.79-0.8	0.8-0.85	0.85-0.9	0.9-0.95	0.95-1

Table 2 Assigning membership functions

Machine No.	R_1	R_2	X_l	X_m	E_1	Efficiency
M-17	L	VL	VH	VH	M	VH
M-12	VL	VL	VL	VL	VL	H
M-15	H	VH	M	VH	M	H
M-13	M	L	L	L	M	H
M-9	M	L	M	H	M	H
M-18	M	H	M	M	M	H
M-4	L	M	H	H	L	H
M-7	H	VL	H	M	H	M
M-6	H	VH	VH	H	H	M
M-10	VH	H	H	H	L	M
M-2	M	H	M	M	H	M
M-16	M	VH	H	M	M	L
M-1	M	M	M	H	L	L
M-3	VL	M	L	L	M	L
M-11	VH	H	H	M	L	L
M-8	VH	H	H	H	L	L
M-5	H	H	M	M	H	VL
M-14	VH	H	L	VL	VH	VL

From Table 2 it can be seen that very high (VH) efficiency is attained for machine M-17 when;

- stator resistance (R_1) is low (L); (which is as per desire*)
- rotor resistance (R_2) is very low (VL); (which is as per desire*)
- leakage reactance (X_l) is high (VH); (which is undesired*)
- magnetizing reactance (X_m) is very high (VH) ; (which is as per desire*)
- air gap voltage (E1) is medium (M) ; (which is undesired*) [* As per available literature, the values of stator resistance, rotor resistance and leakage reactance on low side whereas magnetizing reactance and air gap voltage on high side are desirable to attain high efficiency for induction generator.]

The above statement reflects that a high efficiency can be attained even if any one of the parameters deviates from its desired value but is counter balanced by other parameters. This gives the required flexibility to the designer to attain the goal.

Fig. 5 shows the fuzzy system block diagram prepared in the fuzzy logic / Matlab showing five input variables i.e. (R_1, R_2, X_l, X_m, E_1) and efficiency as an output variable whereas Fig. 6 shows the rules written according to Table 2 in a fuzzy rule editor. Fig. 7 to Fig.12 gives membership function plots for stator resistance (R_1), rotor resistance (R_2), leakage reactance (X_l), magnetizing reactance (X_m), air gap voltage (E_1) and efficiency respectively. The use of triangular membership function has been selected in this paper. Finally Fig. 13 and Fig. 14 gives the fuzzy rule viewer as attained in fuzzy logic / Matlab.

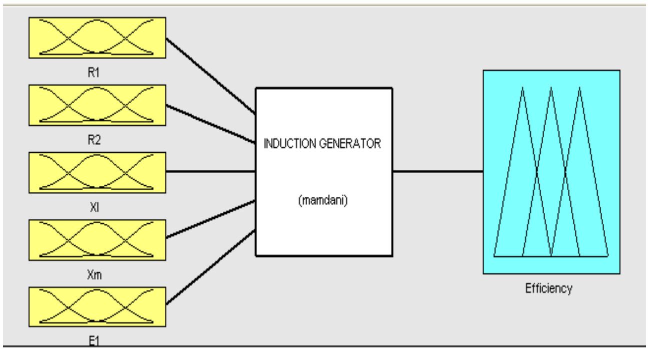

Fig. 5 Fuzzy system block diagram

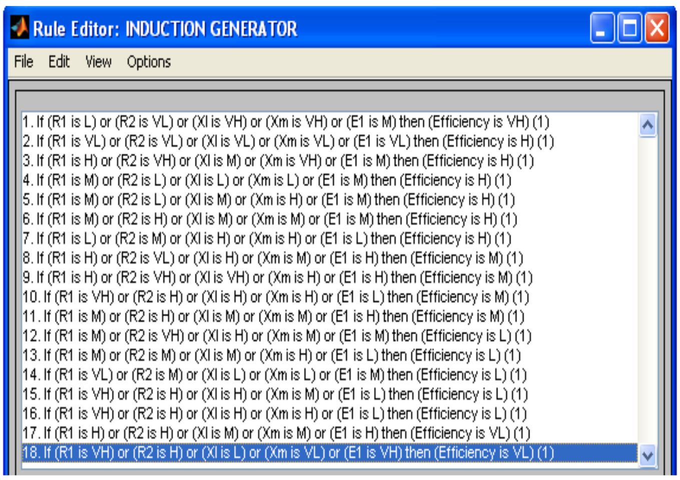

Fig. 6 Fuzzy rule editor

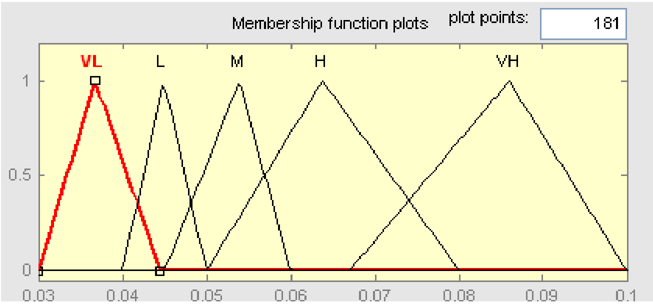

Fig. 7 Membership function plots for stator resistance

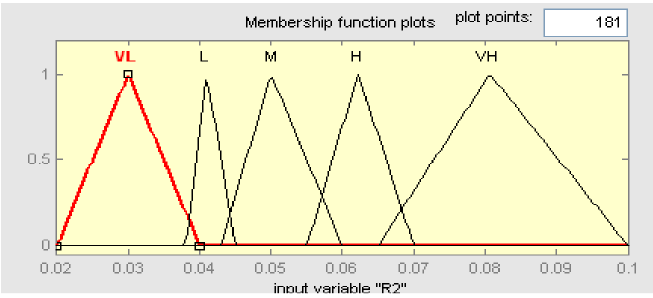

Fig. 8 Membership function plots for rotor resistance

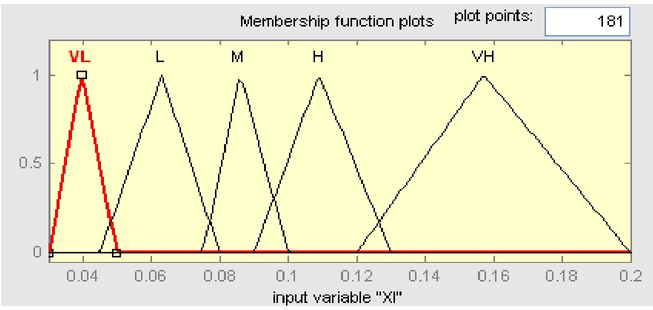

Fig. 9 Membership function plots for leakage reactance

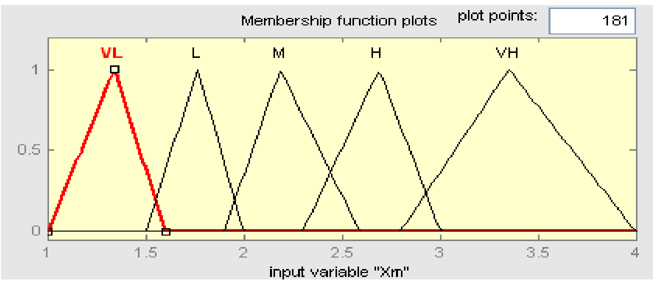

Fig. 10 Membership function plots for magnetizing reactance

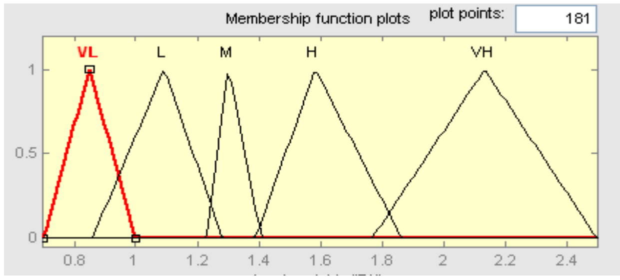

Fig. 11 Membership function plots for air gap voltage

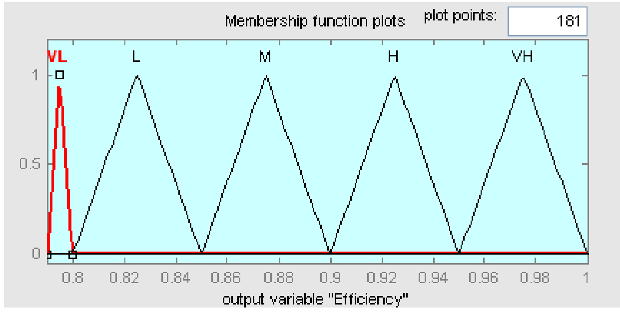

Fig. 12 Membership function plots for efficiency

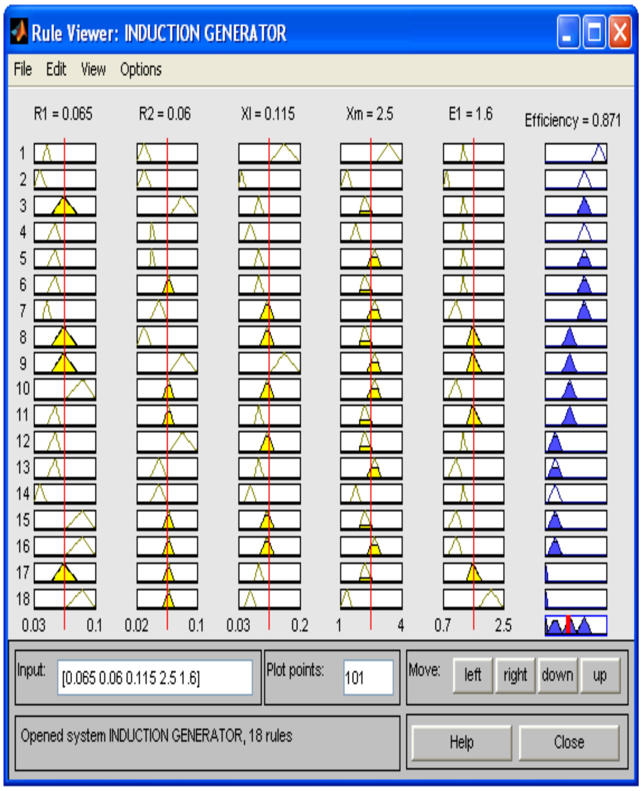

Fig. 13 Fuzzy rule viewer

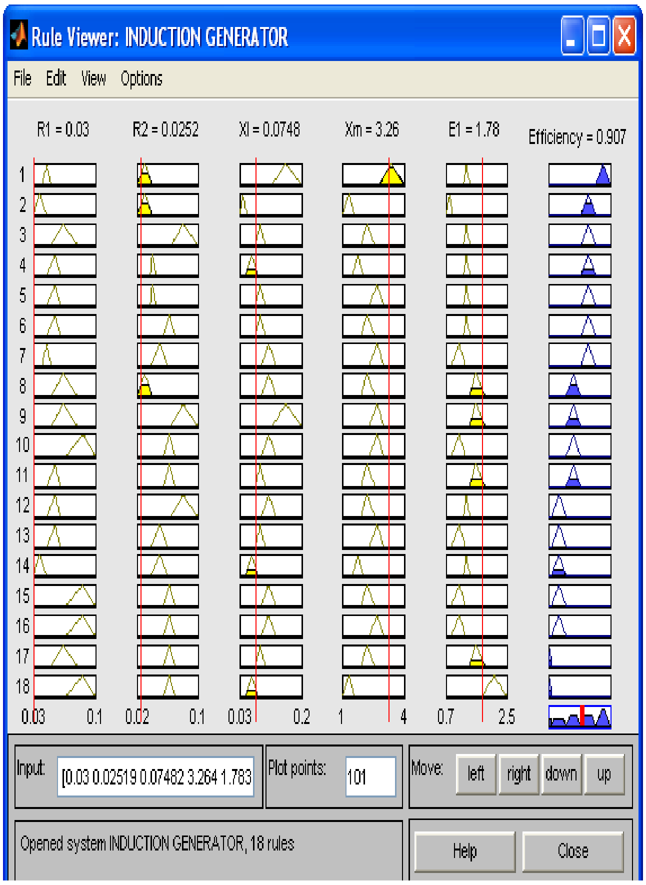

Fig. 14 Fuzzy rule viewer with improved efficiency

Conclusion

As observed from Fig. 13 and Fig. 14, rule viewer window in fuzzy logic / Matlab gives the flexibility to designer to look into the effects of change of input parameters on the output i.e. efficiency. Therefore designer has the opportunity to change any one of the parameters at the cost of others, without loosing desired output. Such exercise does not need any calculations; here in fuzzy logic it only needs the movement of cursor from one position to other. Henceforth Matlab based fuzzy logic as proposed proves its worth in facilitating the designer for judicial selection of machine parameters for efficiency improvements in general.

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