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FUZZY LOGIC BASED OPTIMIZATION OF CAPACITOR VALUE FOR SINGLE PHASE OPEN WELL SUBMERSIBLE INDUCTION MOTOR

R. Subramanian [1], S.N. Sivanandam[2], V. Jethose [3] and A.M. Selvaraj [4]
Department of Electrical & Electronics Engineering, SNS College of Technology, Tamil Nadu, India
E-mail: [1]rama.smani@gmail.com, [3]vjithosh@gmail.com
[2]Former Professor, Department of Computer Science and Engineering, PSG College of Technology, Tamil Nadu, India
E-mail: drsns25@gmail.com
[4]Small Industries Testing and Research Centre (SITARC), Tamil Nadu, India
E-mail: sitarcinfo@sitarc.com

Abstract
Purpose – The aim of this paper is to optimize the capacitor value of a single phase open well submersible motor operating under extreme voltage conditions using fuzzy logic optimization technique and compared with no-load volt-ampere method. This is done by keeping the displacement angle (α) between main winding and auxiliary winding near 90°, phase angle (φ) between the supply voltage and line current near 0°. The optimization work is carried out by using Fuzzy Logic Toolbox software built on the MATLAB technical computing environment with Simulink software. Findings – The optimum capacitor value obtained is used with a motor and tested for different supply voltage conditions. The vector diagrams obtained from the experimental test results indicates that the performance is improved from the existing value. Originality/value – This method will be highly useful for the practicing design engineers in selecting the optimum capacitance value for single phase induction motors to achieve the best performance for operating at extreme supply voltage conditions.

Keywords:
Single- Phase, Induction Motors, Capacitance, Optimization, Fuzzy

1. INTRODUCTION

Alternating (AC) induction motors use a large share of a given industrialized country's generated electric power. It is estimated that roughly 70% of the India's total generated power is used to power the motors. To optimize the power consumption, it is often desirable for a motor selected for a given application to be able to drive the largest possible load at the lowest possible line voltage. The power factor is sometimes expressed as a cosine of the relative phase angle between the AC source voltage and AC motor current. Line losses and thereby line voltage drop is reduced if power factor is maintained unity or near unity as the current drawn by the motor be minimum.

In an AC induction motor, power directly fed from the electricity source, will run optimally (ie., power factor near to unity) only in a situation where the AC motor has the largest possible load and the source powering the motor is operating at the lowest possible line voltage. The electricity board insisting the end users (only industrial user) to maintain the power factor between 0.85 lead to 0.85 lag and this means that as much as 15% of source's generated power could be lost due to the line loss. Most of the electric power generated in India is derived from fossil fuels, such as coal, natural gas and oil. Hence there is a great need to optimize the operation of AC induction motors with given limited nature of the supply of such fuels.

The induction motors have its own unique characteristics which are valid only for designed frequency and voltage with a marginal tolerance [1]. Any change in the supply parameters beyond a certain limits, has direct effect on the motor performance. However, in actual field, especially agricultural sites, these fluctuations are quite heavy. As a result the motor pump set, though it is designed for high efficiency, under extreme voltage or frequency variations will operate as less efficient. This defeat the whole purpose of buying an efficient pump set [2].

It is noted that, only in India, an additional national standard IS: 7538 [3] is formulated for motors meant for wide voltage operations with a variation of +6% and -15% of rated voltage as its voltage band requirement. In motor has to get the input supply voltage from the feeder even with higher variation of +10% and - 40%. This is due to the prevailing situation of huge line losses and connected load beyond the capacity of the feeder. Hence the motors designed for rated voltage cannot deliver the same performance at extreme low voltage conditions [4].

Submersible motor-pumps set are most widely used in domestic and agricultural applications in low power ratings as the installation is very simple for termination of pipes and grounding [5]. Hence, this paper aims for obtaining an optimal solution of determining a capacitor value suitable for a 1hp / 0.75kW single phase permanent split capacitor open well submersible motor pump set suitable for operating under extreme voltage conditions. The main and auxiliary winding design parameters are kept constant for investigation purposes.

2. PROBLEM DEFINITION AND DESIGN APPROACHES

In general, the optimal design of electrical machines is a multi variable, non-linear, and constrained optimization procedure [6]-[8]. Particularly, finding an optimal solution to the single phase induction motors is relatively complex than the three phase induction motors. It is due to the reason that single phase capacitor motors have two windings (main and auxiliary) and a capacitor for which the optimal solution to be evolved considering their inter relationship and hence becomes a three dimensional problem.

In single phase induction motors, improvement of power factor, there by efficiency and torque, can be achieved by selecting suitable value of the capacitor connected either in series with main winding or auxiliary winding and both the windings as described in [9]. All the methods work fairly well when the supply voltage is constant and however, the problem objective is obtaining the optimal performance under extreme voltage fluctuations also.

Fig.1 shows a typical vector representation of currents of a single phase induction motor indicating its general pattern of sharing and displacement. It exhibits the phase angle ‘α’ displacement between the auxiliary winding and main winding and is deviating acute and obtuse of 90^o.

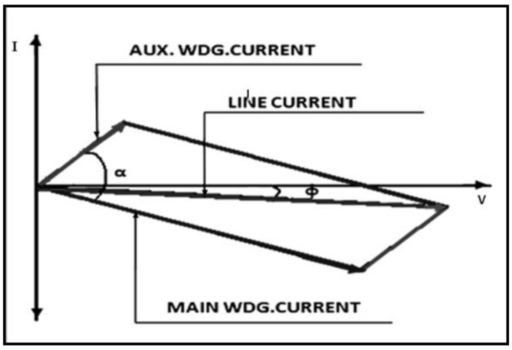

Fig.1.Typical vector representation of currents of a single phase induction motor

It is generally agreed that a capacitor motor should be designed to operate under nearly balance conditions at full load. For achieving good power factor and higher starting torque it is ideal to have the angular displacement of 90^o between the currents of main and auxiliary winding and phase angle ‘ϕ’ between line current and line voltage be 0^o as described in [10].

2.1 NO-LOAD VOLT-AMPERE (NLVA) APPROACH

Experiences have shown that the capacitor for extreme lower value of nominal voltage depends upon the displacement angle for practical motors. However, it does serve the designer a useful purpose to determine the value of microfarads for maximum starting torque and power factor. The no-load volt-ampere method is simple and close to the requirement, as it is nearly equal to the reactive volt-ampere at full load [11]. Using this method, the capacitive reactance in ohms and hence the capacitor value in Farads can be calculated from the following expressions.

$$X_c = v * (1+a^2) / I_o \quad (1)$$

and

$$C = 1/ 2 * \pi * f * X_c \quad (2)$$

where,

V – Supply voltage in volts

a - winding turns ratio between auxiliary and main winding

I_o – no-load current in amps

f – supply frequency in Hz

Table.1 Capacitor value using NLVA method

Supply Voltage (V)	No-Load Current (A)	Turns Ratio	Capacitive Reactance (Ohms)	Capacitor Value (micro Farads)
144	2.46	1.17	138.7	23
240	6.668	1.17	85.3	37
264	9.021	1.17	69.3	46

Table.1 gives the details of the capacitance value calculated for rated voltage and extreme operating voltage conditions using NLVA method and a mean value arrived as 35 micro farads.

It is to be noted that, from the above expressions 1 and 2, the value of capacitor can be found for only one rated supply voltage. Otherwise a mean value can be found for rated and extreme voltage operating conditions also. This mean value of capacitance may or may not provide an optimal solution. Hence, the manual selection of capacitance would not provide a satisfactory solution and a new approach is proposed.

2.2 FUZZY LOGIC OPTIMIZATION (FLO) APPROACH

Optimization in design of electrical machines means to find better solution from the design variables [12]-[13]. Different new optimization techniques are being used in the field of electromagnetics to provide the optimal solution for a given problem [14]. The classical methods of optimization problems [15] with a single-real variable are solved using bisection methods, where the main idea is to reduce an initial interval until a required minimum.

Differently from the classical optimization methods, the main idea in fuzzy optimization is to optimize objective function and constraints, simultaneously. In order to determine the optimal point (solution point), both objective function and constraints must be characterize by membership functions and they must be linked by a linguistic conjunction: “*and*” (for maximization) and “*or*” (for minimization) [16].

The fuzzy logic approach is applicable to search the optimum capacitance which tracks the change in capacitance for the change in the input voltage, power factor angle and Load angle. The fuzzy logic optimization approach (FLO) does not require any detailed mathematical model of the system and its operation is governed simply by set of rules. The principle of FLO is to select the optimum capacitance value such that the phase angle (ϕ) between the line current and voltage be minimum or zero degree and the displacement angle (α) between main and auxiliary windings be maximum or near 90 degree for extreme input voltage conditions.

Here the variable input voltage, power factor angle, and displacement angle are considered as input and change in the capacitance as output that tracks the optimum value. Triangular member functions for fuzzy computation are used, which gives more accuracy. Linguistic labels are assigned to each membership functions. The input signals are fuzzified and expressed in fuzzy sets. Using the set of rules, the output is obtained. This output is defuzzified by centroid method to obtain the final output.

2.2.1 Building systems with the fuzzy logic toolbox

Although it is possible to use the Fuzzy Logic Toolbox by working strictly from the command line, it is easier to build the system using graphical user interface. There are five primary GUI tools for building, editing, and observing fuzzy inference systems (FIS) in the Fuzzy Logic Toolbox: the Fuzzy Inference System or FIS Editor, the Membership Function Editor, the le Editor, the Rule Viewer, and the Surface Viewer. Type **fuzzy** in the command window to invoke the basic FIS Editor.

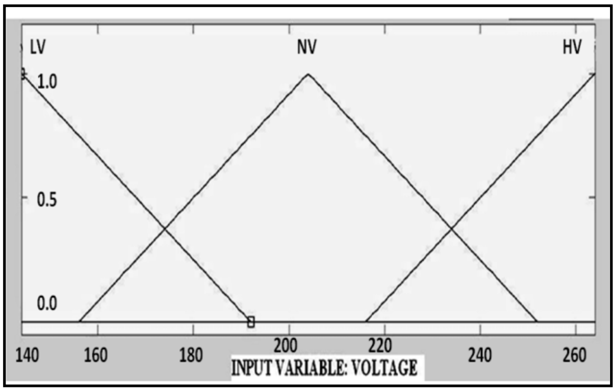

Fig.2.Membership function of input variable 'VOLTAGE'

In the FIS Editor, go to **File** and select either of the following.

New Mamdani FIS: to open a new Mamdani-style system with no variables and no rules called Untitled New Sugeno FIS: to open a new Sugeno-style system with no variables and no rules called Untitled.

New Mamdani FIS is selected for this present work. Five pop-up menus (default) are selected to change the functionality of the following five basic steps in the fuzzy

For **And method:** min is selected

For **Or method:** max is selected

For **Implication method:** min is selected

For **Aggregation method:** max is selected

For **Defuzzification method:** Centroid method is selected

The FIS Editor handles the high level issues for the system namely the number of Input and output variables used and their names. In this paper, three input and one output variables are selected. Input variable-1 is Input voltage (V), Input variable-2 is the displacement angle (α). Input variable-3 is the power factor angle (ϕ). Output variable is capacitance (C). Input voltage (V) range varies from 60% of Nominal value to 110%. The value works out from 144 volts to 264 volts. Displacement angle varies from 0 to 90^0 and Capacitance value range varies from 20 to 70μf.

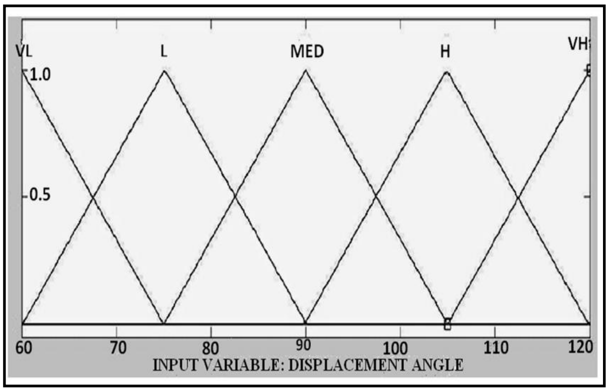

Fig.3.Membership function of input variable displacement angle 'α'

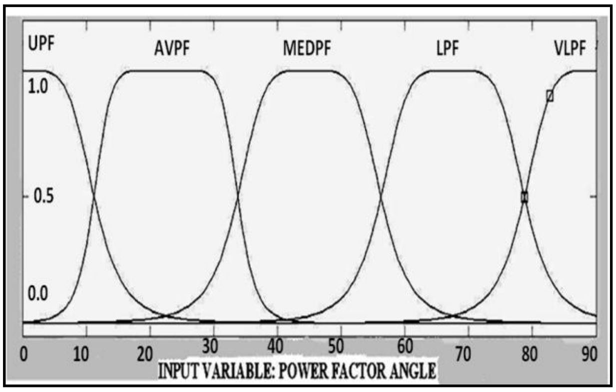

Fig.4. Membership function of input variable power factor angle 'φ'

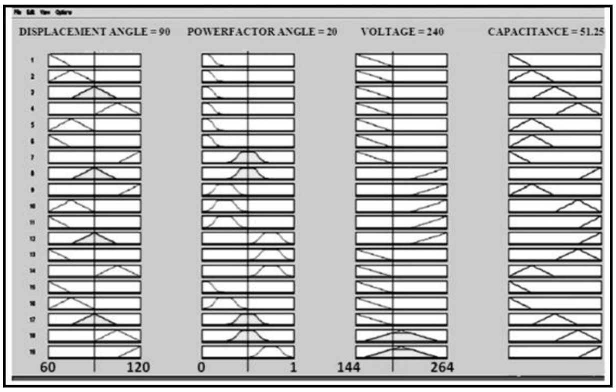

Fig.5. Output Ruler View

The Membership Function Editor is used to define the shapes of all the membership functions associated with each variable. In this present work, three membership functions are selected for input voltage. They are LV **(Low Voltage), NV (Nominal Voltage), HV (High Voltage)**. All the three membership functions are triangular shape as shown in Fig.2.

Five membership functions are selected for displacement angle. They are **VL, L, MED, H and VH**. These membership functions are as shown in Fig.3. Five membership functions are selected for power factor angle and they are **UPF, AVPF, MEDPF, LPF and VLPF**. These five membership functions are of gbellmf type as shown in Fig.4.

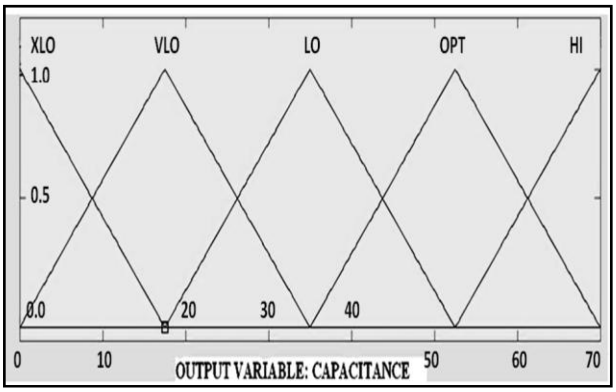

Fig.6. Membership functions of output variable 'Capacitance'.

The rule editor is for editing the list of rules that defines the behavior of the system. Constructing rules using the graphical rule editor interface is fairly self-evident. Based on the descriptions of the input and output variables defined with the FIS Editor, the rule editor allows us to construct the rule statements automatically, by clicking on and selecting one item in each input variable box, one item in each output box and one connection item.

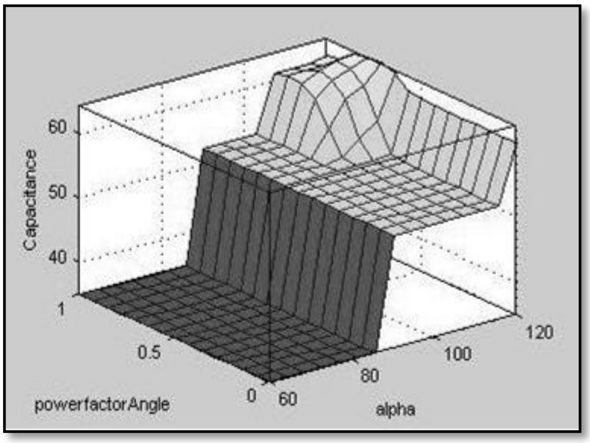

Fig.7. Output surface view

Choosing none as one of the variable qualities will exclude that variable from a given rule. Choosing not under any variable name will negate the associated quality. Rules may be changed, deleted, or added, by clicking on the appropriate button.

For the capacitor selection problem, rules are defined to determine the suitable values of capacitor for best performance. Such rules are expressed in the following form:

IF premise (antecedent), THEN conclusion (consequent). For determining the optimal capacitance, a set of multiple-antecedent fuzzy rules has been established. The inputs to the rules are the voltage, displacement angle and power factor angle and the output is the suitable capacitor variable for the variable three inputs.

In the present work 48 rules are constructed.

For Example:

If voltage is NV, displacement angle is MED and power factor angle is LPF then output capacitance is OPT.

If voltage is NV, displacement angle is MED and power factor angle is LPF then output capacitance is HIGH.

If voltage is HV, displacement angle is MED and power factor angle is LMED then output capacitance is LOW.

The rule viewer is a MATLAB-based display of the fuzzy inference diagram, used as a diagnostic tool; it can show which rules are active, or how individual membership function shapes are influencing the results. By interviewing the output obtained from the ruler view, the values of capacitance for different values of input voltage, varied range of displacement angle and different power factor angle can be obtained. The Fig.5 shows the ruler view output for a Nominal voltage and other two variable inputs and the capacitance obtained for that particular input. The Fig.6 shows the output variable to be optimized with five membership functions namely XLO, VLO, LO, OPT and HI assigned for the capacitance value.

Surface viewer shown in Fig.7 is used to display how one of the outputs depends on any one, two, or three of the inputs - that is, it generates and plots an output surface map of the system. It is observed from the ruler view and output member ship function that the optimal value of capacitance value converged at 51.25 micro farads for the optimization problem given.

A capacitor value of 50 microfarads is used for testing purposes as the value of 51.25 microfarads is not in the standard value of manufacture.

Hence, to compare and validate the results, an experimental set up to monitor the behavior of all the current values and performance parameters is made and the observations are presented in the next section.

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

A 1hp / 0.75kW single phase permanent split capacitor open well submersible motor pump set is tested, at Small Industries Testing and Research Centre, Coimbatore a quasi government organization, for comparing the optimum value obtained from NLVA and FLO approaches.

The test performed with different range of input voltages ranging from 60% to 110% of the rated value, with different capacitors values of 20, 36, 46, and 50 micro farads connected in series with auxiliary winding.

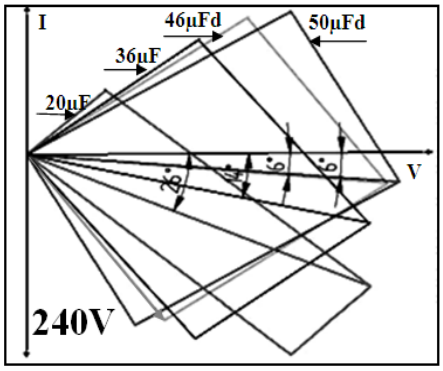

Fig.8. Vector representation of currents at 240 volts and with various capacitor values

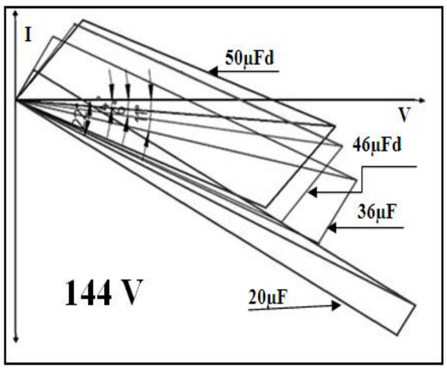

Fig.9. Vector representation of currents at 144 volts and with various capacitor values

Representation of current quantities in vector form gives an overall view on the behavioral change with respect to change in voltage, load and capacitor values [17]-[18]. Fig.8,9 and 10 shows the vector representations of line current, main and auxiliary winding currents for different value of capacitor values tested with rated voltage of 240 volts, extreme supply voltage conditions of 144 volts and 264 volts respectively, presented in a super imposed manner to visualize the change of vector pattern.

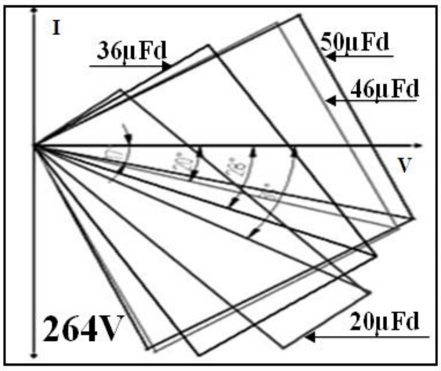

Fig.10. Vector representation of currents at 264 volts and with various capacitor values

It is observed from the vector diagrams that the capacitance value, keeping the main and auxiliary winding ratio constant, affects the power factor angle and displacement angle to a larger extent and the optimal value of power factor and displacement angle obtained with a capacitance value of 50 micro farads.

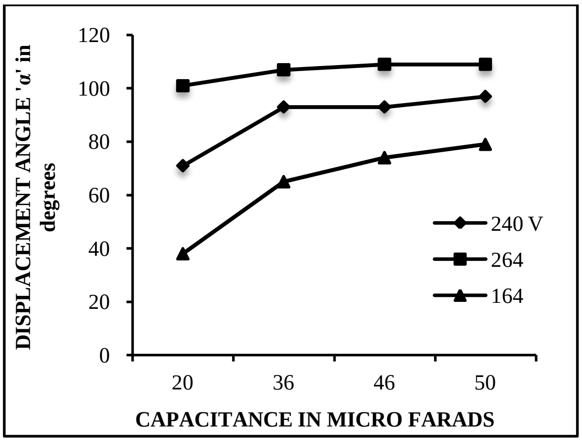

Fig.11. Convergence of displacement angle

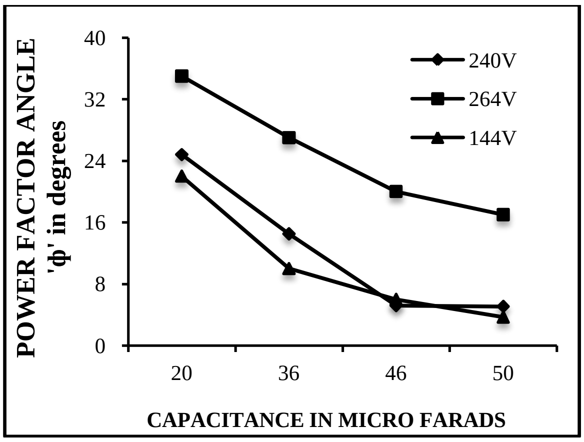

Fig.12. Convergence of power factor angle

The curves shown in Fig.11 and 12 also exhibits that the optimal value of displacement angle and power factor angle converged at 50 micro farads for rated and extreme supply voltage conditions.

4. CONCLUSION

In this paper, a fuzzy logic optimization (FLO) technique is presented for the optimization of capacitance value for the design of a single phase 1.0 hp/ 0.75kW open well submersible capacitor run induction motor. A comparison is made with the conventional technique of no-load volt-ampere (NLVA) technique and experimental results shows that the FLO approach provides an optimal value by which an improved performance behavior is observed when compared with the optimal value obtained using NLVA approach. Hence, FLO approach is found better in finding an optimal capacitor value suitable for operations in extreme supply voltage conditions.

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