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Simulation Study on Power Factor Correction Controlling Excitation Current of Synchronous Motor with Fuzzy Logic Controller

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Abstract: The correction of power factor in electric power systems is called reactive power compensation. A synchronous motor is used as a capacitive reactive power generator in compensation systems. It is less costly for an enterprise to use a synchronous motor as both mechanical power generator and power factor corrector, which increases their efficiency. There are various studies on increasing the efficiency, capacity and stability of a power system using power factor correction under different operating conditions. This study focuses on the power factor correction of the system by controlling the excitation current of the synchronous motor via fuzzy logic thanks to the asynchronous motor connected to the system.

Keywords: *Power factor, Fuzzy Logic, Synchronous Motor.*

1. Introduction

As a result of technological improvements, energy consumption has increased in recent years due to the increasing use of inductive loads in industrial applications. Besides active power, inductive loads also absorb reactive power from the grid [1].Although reactive power absorbed from the transmission line loads it, it cannot be converted to the energy [2]. Therefore, reactive power absorbed from the grid causes losses in electric power systems, and these losses must be minimized. The minimization of energy losses will reduce cable and other measurement and protection costs, thus creating a more cost-effective electric power system. This can only be achieved when reactive power needed by the inductive loads, which the transmission line feeds, is supplied to the load as closely as possible. Reactive power needed by the loads is supplied statically by a capacitor or reactor and dynamically by a synchronous motor [3-5]. Reactive power compensation via a synchronous motor can be achieved by changing the excitation current of the motor if the motor operates in a capacitive or inductive character [6]. In addition, the amount of reactive power that a synchronous motor absorbs from the grid can be adjusted thanks to the excitation current. An efficiently compensated system will improve the power factor, minimize losses and become efficient [7-9]. This study focuses on the power factor correction of an electric power system using a fuzzy logic based and excitation current controlled synchronous motor. Because it is difficult to determine control parameters via methods requiring mathematical models when a synchronous motor is used for power factor correction, a fuzzy logic based compensation control system was used in this study.

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2. Power Factor

Reactive power compensation plays an important role in the improvement of efficiency and capacity of electric power systems. The current of inductive power consumers is supplied by two components of the current. The former is active current converted to work while the latter is reactive current which creates the necessary magnetic field for electric machinery and devices.
Types of power corresponding to these currents are:
S = Apparent Power (VA),
P = Active Power (W),
Q = Reactive Power (On), then

$$S = \sqrt{P^2 + Q^2} \quad (1)$$

the equation above can be obtained, which can be geometrically defined as a power triangle as shown in Fig.1.

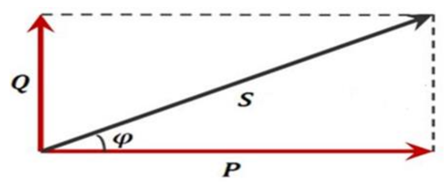

Figure. 1 Power triangle [11].

Here, φ is defined as the phase angle. Cos φ is the power factor, which is defined as follows [12].

$$\cos\varphi = \frac{P}{S} \quad (2)$$

3. Synchronous Motor

Synchronous motor is an alternative current motor in which rotor rotational speed is equal to the rotational speed of the stator rotating field and the rotation speed does not vary in loading. When excitation current of the synchronous motor changes, it absorbs ohmic, inductive and capacitive current [13]. In a synchronous motor operating at a constant load and voltage, the characteristic which yields the relationship between excitation current and stator current is called V-current. The point at which excitation current forming the lowest load current at a constant load exists is called ohmic operating point of the motor. The synchronous motor operates inductively under an excitation current lower than that of the ohmic operating point while it operates capacitively under an excitation current higher than that of the ohmic operating point. V-curves which account for the relationship between load current and excitation current for different loads of the synchronous motor are shown in Fig 2.

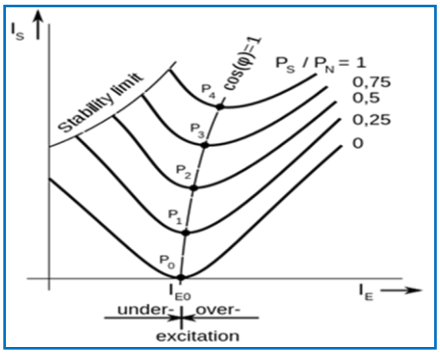

Figure 2. V-curves of the synchronous motor under different loads [21].

As shown in Fig. 2, V-curve of the synchronous motor varies based on different loads. V-curves are at the outermost part when the motor operates at an unloaded state, and they come closer to the ohmic operation curve as the motor is loaded. In case of ohmic operation, the necessary excitation current in the unloaded state increases in a directly proportional way to the load, which is because armature reaction varies depending on the various loads and the saturation increases.

4. Fuzzy Logic Control

Fuzzy logic is defined as a mathematical order created in order to explain fuzzy situations and work under fuzzy conditions. Fuzzy logic can control systems when knowledge and predictions about the system are placed within it. In other words, a mathematical model of the system to be controlled is not needed. Fuzzy logic control system consists of four basic units: general fuzzification, inference, defuzzification and rule base [15].A block diagram of a general fuzzy logic controller is shown in Fig. 3.

Fuzzification is the process of converting inputs obtained from the system to linguistic qualifiers as symbolic values. The fuzzy clusters and membership degrees to which inputs belong are identified thanks to the membership function, and linguistic values such as big or small are assigned to the numerical values.

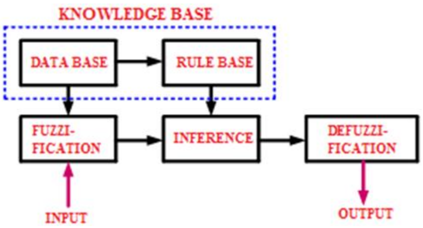

Figure. 3 The block diagram of a fuzzy logic controller

Fuzzy inference unit creates fuzzy results by applying fuzzy values obtained from the fuzzification unit to the rules in the rule base. The connection between inputs and outputs is created using rules in the rule base. The value obtained in this unit is converted to a linguistic expression based on the rule table and transferred to the defuzzification unit. This study benefits from Mamdani method, which is the most widely used method among fuzzy inference methods.

Defuzzification unit helps distinguish between the non-fuzzy real value to be applied and fuzzy knowledge transferred from the decision unit. Defuzzification is the process of converting fuzzy knowledge to precise results.Various methods are used in defuzzification process. Among these methods, center of gravity method is the most widely used defuzzification method. The equation for this method is given in equation 3.

$$y = \frac{\sum_{i=1}^{n} y_i . \mu_A(y_i)}{\sum_{i=1}^{n} \mu_A(y_i)} \qquad (3)$$

Knowledge base is a data table consisting of knowledge related to the system to be controlled. The connections between inputs and outputs are created using rules in the rule base. If a rule base is to be developed for a system, input values that may influence system output must be identified [16-17].

5. Fuzzy Logic Controller Design

V-curves of the synchronous motor and reactive power that it absorbs from the grid were used to design fuzzy logic controller in this study. Fig.4 and 5 were drawn based on the data obtained from the performance of synchronous motor under nominal conditions. Based on these graphs, the reactive power that the synchronous motor absorbs from the grid and changes in the excitation current of the synchronous motor eliminated the need for a mathematical model, and thus a power factor correction was performed via the synchronous motor based on fuzzy logic.

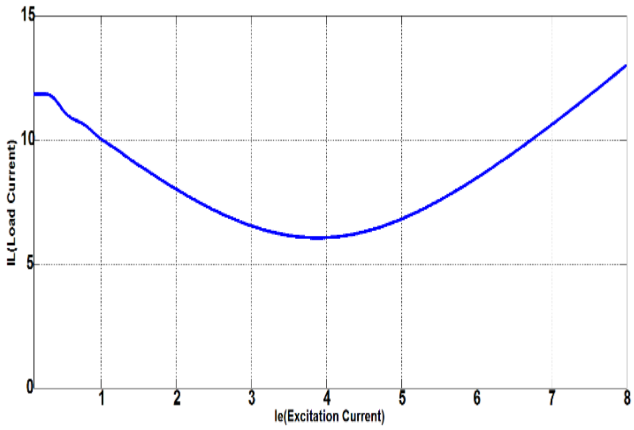

Figure 4. Changes in the excitation current (V-curve)

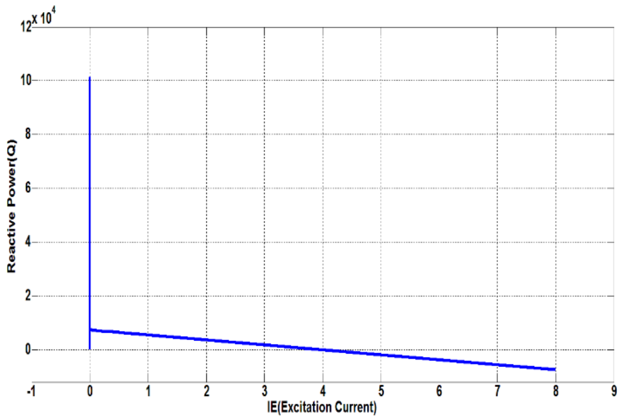

Figure. 5 Changes in the excitation current and reactive power that the synchronous motor absorbs from the grid

The block diagram shown in Fig. 6 was used to create the curves shown in Fig. 4 and 5.

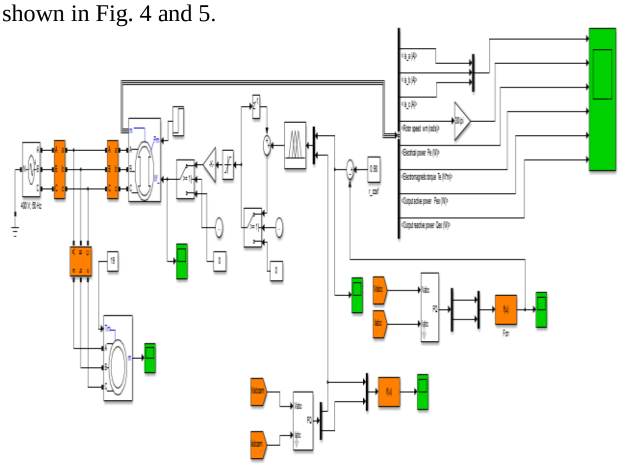

Figure. 6 The block diagram of the control system [18].

Input variables of the fuzzy logic control unit designed for this study were determined as error (e), Q (reactive power) and output variable (I_E). Error (e) is found when power factor value is subtracted from input reference power factor value as given in equation 4.

$$e = \cos\varphi ref - \cos\varphi sist. \quad (4)$$

Q (reactive power) as an input variable is applied to the controller input, and its unit is 'Var'. Output variable (IE) denotes the current flowing through excitation windings of the synchronous motor, and its unit is ampere. Five different linguistic variables, NB (Negative Big), NS (Negative Small), Z (Zero), PS (Positive Small) and PB (Positive Big), are defined for error (e), Q (reactive power) and excitation current (IE), which are the variables of the fuzzy logic controller unit. Membership functions in the form of triangles and trapezoids were designed for error, reactive power and excitation current. These membership functions are shown in Fig.7, 8 and 9.

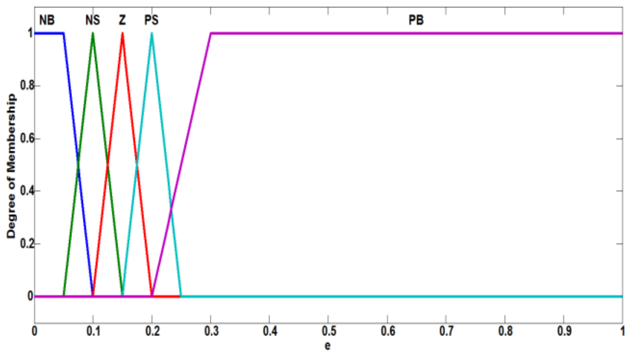

Figure.7 Membership functions designed for error

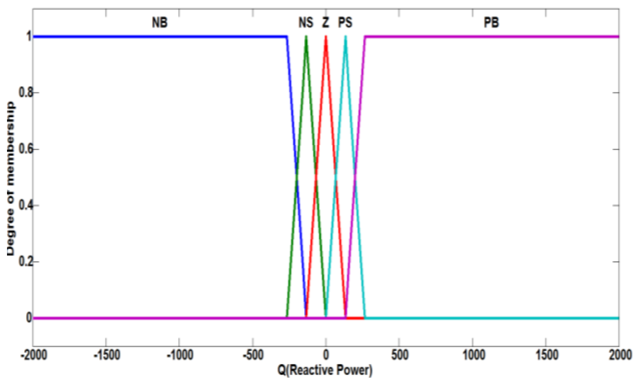

Figure. 8 Membership functions designed for reactive power

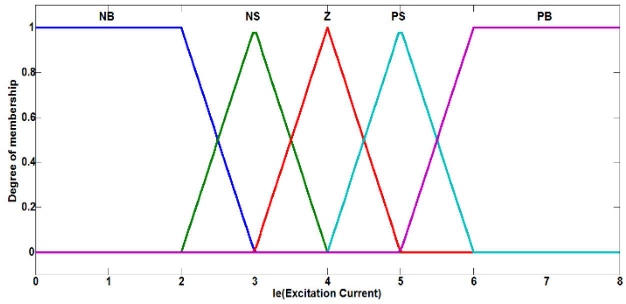

Figure. 9 Membership functions designed for excitation current

Five membership functions that are widely used in the designed fuzzy logic controller unit were assigned, and they proved to be suitable for this study. The sum of control rules are twenty-five. Fuzzy rules are given in table 1.

Table 1. Table of rules

Ie		Q				
		NB	NS	Z	PS	PB
e	NB	NB	NB	NB	NS	Z
	NS	NB	NB	NS	Z	PS
	Z	NB	NS	Z	PS	PB
	PS	NS	Z	PS	PB	PB
	PB	Z	PS	PB	PB	PB

As far as the performance of fuzzy controller is concerned, rule base uses existing knowledge about the behavior of a system to be controlled instead of a mathematical model of the system. Such knowledge is used during design process, which helps placing longstanding experiences in the system following a process of interpretation [19].

6. Simulation Studies

Power factor is a parameter that measures the efficiency of electricity energy. The efficiency of electric power system is directly proportional to its power factor. Asynchronous motors possess feedback power factor. The power factor of synchronous motor can feed back or forward when the excitation current is adjusted. The values of the asynchronous motor and synchronous motor used in the simulation study are given in table 2 and 3.

Table 2. Asynchronous motor parameters

Parameter	**Value**
Nominal Power(P)	3 kW
Nominal Revolution[n]	1430 rpm
Nominal Voltage(V)	400 V
Nominal Current(I)	6.7 A
Nominal Load Torque(M)	19 Nm
Pole pairs(p)	2
Frequency(f)	50 Hz
Rotor Type	Squirrel-cage
Stator Resistance[R_s]	1.45 ohm
Stator Inductance[L]	12.2 mH
Rotor Resistance[R_r']	1.93 ohm
Rotor Inductance[L_r']	2.66 mH
Mutual Inductance[L_m]	187.8mH
Friction Factor[F]	0.03 N.m.s
Mechanical Inertia[J]	0.03 kg.m^2

Table 3. Synchronous motor parameters

Parameter	Value
Nominal Power(S)	8.1 kVA
Nominal Revolution[n]	1500 rpm
Nominal Voltage(V)	400 V
Nominal Field Current(I)	4 A
Nominal Load Torque(M)	7 Nm
Pole pairs(p)	2
Frequency(f)	50 Hz
Rotor Type	Salient pole
Stator Resistance[R_s]	1.62 ohm
Stator Inductance[L]	4.527 mH
Field Resistance[$R_f^{'}$]	1.208 ohm
Field Inductance[$L_f^{'}$]	0.01132 H
Mechanical Inertia[J]	0.0923 kgm^2
Friction Factor[F]	0.009 N.m.s

Three-phase stator currents supplied by the power system to the asynchronous motor at a nominal load are shown in Figure 10. Three-phase stator currents supplied by the power system to the synchronous motor at a nominal load are shown in Figure 11. The velocity of synchronous motor at a nominal load is given in Figure 12. The velocity of asynchronous motor at a nominal load is given in Figure 13.

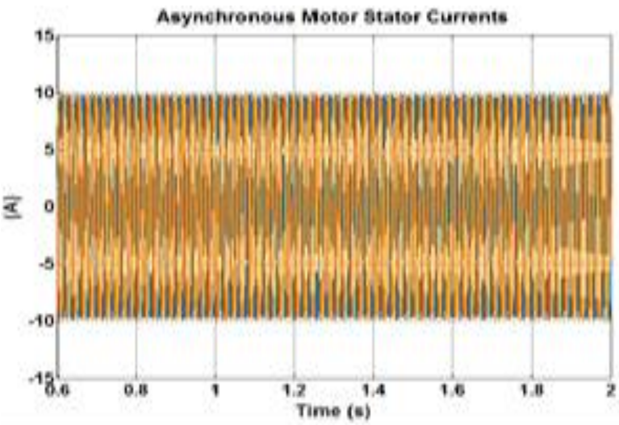

Figure 10. Three phase stator currents of the asynchronous motors at a nominal load.

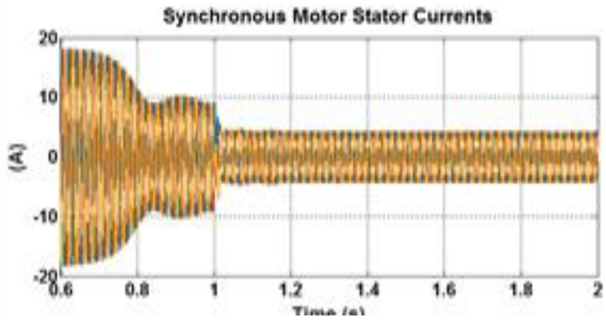

Figure 11. Three phase stator currents of the synchronous motors at a nominal load.

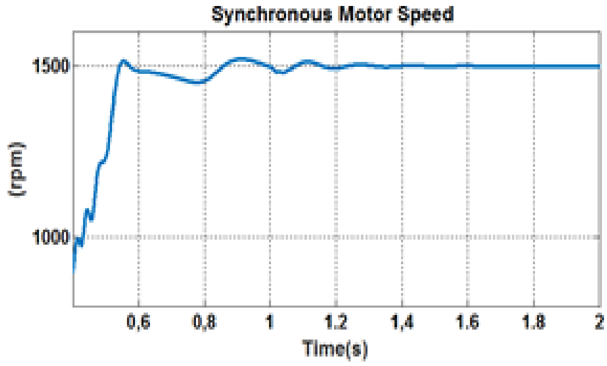

Figure 12. The velocity of synchronous motor at a nominal load.

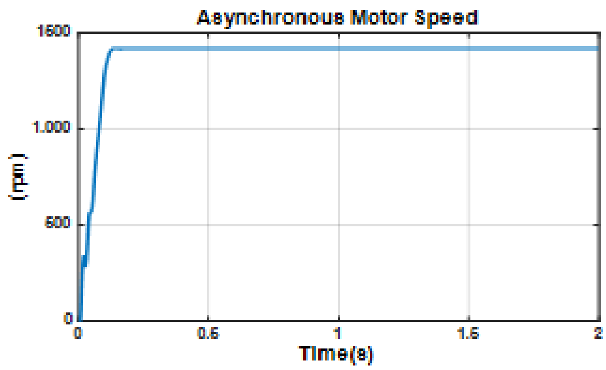

Figure 13. The velocity of asynchronous motor at a nominal load

When voltage is applied to the stator windings of the synchronous motors, they cannot move forward due to their inertia. Therefore, several methods exist to start the synchronous motor. In the present study, the synchronous motor was started as if it were an asynchronous motor.

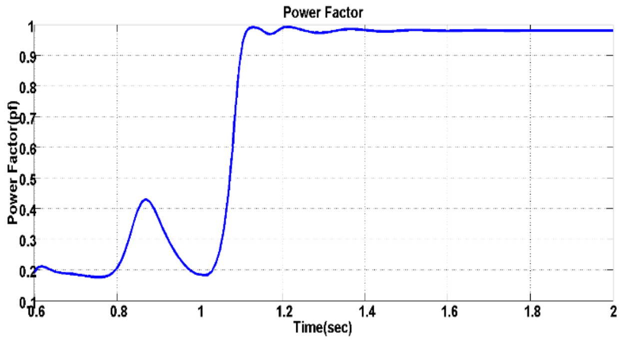

Figure.14 Corrected power factor of the system

As shown in Fig.14, the synchronous motor reached a synchronous speed after it moved for 1.1 seconds. Afterwards, an excitation current of 5 percent is applied to the synchronous motor via fuzzy controller, which supplied reactive power in a capacitive character to the power system of the synchronous motor. Thus, the synchronous motor compensated itself and fixed the power factor of the system at 0.98, which was 0.8 at the beginning.

7. Conclusion

In the present study, a fuzzy logic control method was used in order to create a more sensitive power system performance and increase system efficiency instead of a conventional control system requiring mathematical models for the calculation of controller parameters. During the operation of control system, the excitation current of the synchronous motor, the reactive power that it absorbs from the grid and its power factor were constantly observed. These values were evaluated in the rule table, and it was aimed to more effectively apply the change in the excitation current of synchronous motor to the system. Contrary to previous studies, this new fuzzy logic control method increases the power factor to a more favourable level by effectively adjusting the excitation current based on the reactive power that the synchronous motor absorbs from the grid**.**

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