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Analysis the Effect of Using Synchronous Motor as a Synchronous Condenser for Power Factor Improvement of 3-Phase Cage Rotor Induction Motor

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ABSTRACT

Synchronous motors working at a capacitive power factor of 0.8 are obtained by providing a Over excitation, meaning operation at a capacitive power factor to improve the power factor of the system when connected to an inductive load, as is the case with an induction motor. A synchronous motor that is over-excitation will act like a capacitor and suck up the current that lead the voltage. A synchronous motor that works without a load that is given over excitation will function as a synchronous compensator whose capacitive value can be adjusted. The condition of this synchronous compensator is installed on a cage rotor induction motor as a power factor improvement. The results of this study showed that the power factor value of the induction motor before installing the synchronous compensator was $\cos \varphi = 0.88$ and the reactive power was 132,84 VAR, after installing the synchronous compensator, $\cos \varphi = 0.91$ to 0.99 and the reactive power was 68 VAR to 28,2 VARs

INTRODUCTION

The term for a synchronous motor that is without load and given more gain (over excited) in its field amplifier is called a synchronous condenser. The anchor coil on the sator connected to a three-phase source will cause a rotating field and the field coil on the rotor connected to a DC direct current source gets a pull from the sator rotating field pole until it rotates at the same speed (synchronous). To generate the required ggm flux of the motor, the field current must be sufficient, so that the sator does not need to provide magnetic current or reactive power. If the field current in the rotor decreases or the gain decreases, then the sator will draw the magnetic current from the mesh which results in the motor will work with the power factor late. If the rotor oenguatan current is excessive or the gain is over, then the motor will work on the power factor ahead of time, this is due to excessive ggm flux so it must be balanced, so the sator must draw a capacitive current from the mesh. From this it proves that the working factor of the synchronous motor can be regulated by changing the gain current or rotor field current. (If). The direct current source will rattle after the rotor rotates at synchronous speed, because the synchronous motor will work when $N_s = N_r$, if this has not been achieved then the motor will not work [1, 2, 3].

A. Loaded Conditions

The synchronous motor will occur opposite emf, due to the rise of the current flowing at the anchor as compensation for the increase in torque and power by the load, as shown in Figure 1. If there is an increase in the load on the motor shaft, the rotor speed will decrease momentarily [4, 5].

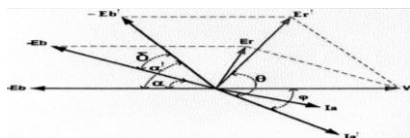


Figure 1. Effect of Load Increase on Term Current because it takes time for the motor to absorb additional power from the mesh. Although it is still rotating at synchronous speed, the rotor will still lag behind by the δ torque angle of the

sator field. The emf that will be induced at the new rotor position and get to know the sator field is "EB". At the moment of no load or light weight Eb and V are almost directly opposite, but at the time of load increase the poles of the rotor are left behind by the angle of torque δ . Eb when loaded shifts as much torque from the no-load position. The motor will absorb power from the mesh to compensate for the increase in shaft load, without resulting in a change in average speed. But when the load continues to increase, bias causes the motor to exit the synchronous state and stop rotating [4, 5].

B. No-Load Condition

A no-load synchronous motor in a certain state of gain can give rise to reactive power, At normal gain so that E is equal to V the motor is in the floating state because it does not give or draw current, so the power angle δ equal to zero. At more reinforcement so that E is greater with V, so that capacitive current is drawn from the mesh. So the motor serves as a reactive power generator of a capacitive nature. At the time of strengthening it is less so that E is smaller than V and the magnetizing current is drawn from the mesh, so the motor serves as a reactive power generator of an inductive nature [5, 7, 8].

C. Effect of Field Current Change

Figure 2. shows the vector diagram of a synchronous motor with different power factors and a fixed load state. The anchor current (IA) supplied from the meshes will be large when the power factor is "lagging" (less amplifier), then decreases when the power factor is "Unity" and returns when the power factor is "leading" (more linking). From this change can be depicted in the form of a V curve, as seen in Figure 2, [5].

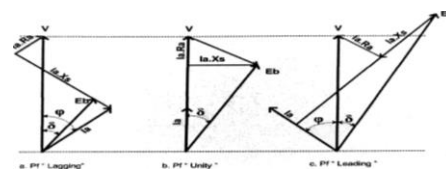


Figure 2. Load State Vector Image, With Different Power Factors

When the synchronous motor is in a non-load condition, over-strengthening will function as a capacitor, so it has the ability to fix the power factor of the electrical network to which the motor is connected. This happens because the reactive power generated by the motor will compensate for the excess flux in the electrical network, this is the motor called a synchronous condenser or synchronous capacitor [5].

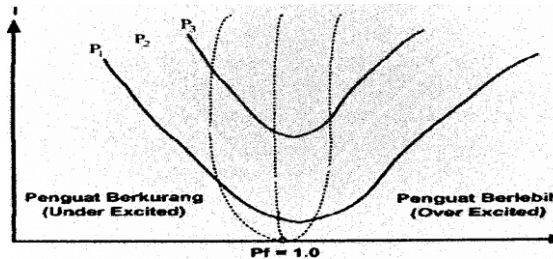


Figure 3. Synchronous Motor V Curve

When the field current is raised further, the anchor current becomes ahead (leading) and the motor becomes a capacitive load. It acts like a combination of resistors-capacitors absorbing negative $-Q$ reactive power (supplying Q reactive power to the system). The relationship between the anchor current I_a and with the field current I_f , for a fixed load current will be in the form of a V Curve, several curves for different power magnitudes. Anchor current occurs in the power factor of one where there is only a real supplied to the motor. At other points reactive power is supplied to or from the motor. For a new current that is lower than the value that causes the minimum I_a , then the anchor current will lag (lagging) and absorb Q , and this condition of the motor is considered to be less gain (under-excitation). For a field current greater than the value that causes the minimum I_a , then the anchor current will precede (lead) and supply Q , this condition is called Over-Excitation [4].

D. Power Factor

Power factor or working factor is the comparison between real power (watts) with pseudo-power/total power (VA), or the focal angle between real power and pseudo-power/total power. The higher the power factor, the effectiveness of power tools will be better and vice versa the lower the power factor has an

impact on the low effectiveness of power tools, to calculate the power factor formulated with.

Where:

$$\cos \phi = p/s \quad \dots \dots \dots (1)$$

Where:

- $\cos \phi$ = power factor
- p = real power
- s = apparent power

The power factor has a huge influence on the quality of the power source and the performance of the power tools. As a result of high KVARH consumption leads to the formation of a large power factor angle. The result of the widening of the power angle has an impact on the low value of the power factor, losses to electrical power and a decrease in the effective working power of the power source. Lower power factor than 0.99 or 0.86 decreases the working efficiency of the power tool. Working power (KW) cannot work optimally or in proportion to the available power. This is shown in figure 4, [11].

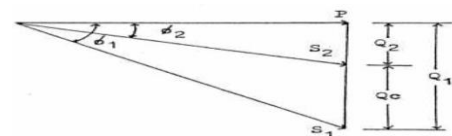


Figure 4. Power Factor Angle

Determine the capacity size of the Q_c capacitor based on the reactive power requirement for power factor improvement. The reactive power of the capacitor (Q_c) is: [8].

$$Q_c = P \{ \tan (\cos^{-1} P_{f1}) - \tan (\cos^{-1} P_{f2}) \} \quad \dots \dots \dots (2)$$

Where:

- P = Active Power (W)
- P_{f1} = initial power factor before repair
- P_{f2} = power factor after repair

- Determine capacitor reactance (X_c)

$$X_c = V^2 / Q_c \quad \dots \dots \dots (3)$$

- X_c = capacitive reactance (Ω)
- V = RMS voltage (volts)

Q_c = reactive power of the capacitor (VAR)
 Determine the capacity of the capacitor (C)

$$C = 1 / (2\pi f \omega X_c) \dots\dots\dots (4)$$

Where:

C = capacitor capacitance (farad)

f = fundamental frequency (Hz)

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- Data analysis or discussion is carried out by calculating the necessary parameters such as calculating the capacitance value of each change in the gain current in the synchronous motor (Excitation current) at the more gain position.

METHODS

- Literature study, namely looking for material related to this research such as reference books, articles, journals and others
- Observation is to collect data by direct observation as has been done by directly measuring the desired results
- Testing Synchronous motor as a synchronous condenser mounted directly in parallel on the cage rotor induction motor to improve the working factor of the reduction motor, as shown in Figure 5. This test was carried out at the

RESULTS AND DISCUSSION

No-load Synchronous Motor Testing

This test is carried out to determine the type of reactive power (inductive or capacitive) that the synchronous motor produces from the change in its excitation current of 0.2 A to 1.0 A.

A. Material Characteristics Test

The results of testing the characteristics of the sandblasting waste material can be seen in Table 2 below:

Table 1. No-Load Test Data and Excitation Current 0.2 A to 1.0 A

M (Nm)	0									
I_{exc} (A)	0,2	0,3	0,4	0,5	0,6	0,7	0,8	0,9	1,0	
I (A)	0,47	0,36	0,26	0,16	0,11	0,15	0,21	0,31	0,4	
Cos φ	0,27	0,33	0,54	0,59	0,82	0,62	0,38	0,29	0,26	
P_m (Watt)	29	27	28	23	22	29	30	31	33	
Q (VAR)	102 _I	73 _I	48 _I	29 _I	12 _I	31 _C	43 _C	66 _C	93 _C	

B. Induction Motor Testing Compensation

Table 2. Uncompensated Induction Motor Testing Data

V (Volts)	380				
M (Nm)	0.00	0,55	1,50	2,05	2,55
N (Rpm)	2968	2940	2858	2800	2728
I_m (A)	0,31	0,40	0,88	1,16	1,48
P_m (W)	44,0	92,0	182,0	240,0	301,0

Q (VAR)	55,0	60,0	86,0	112,0	145,0
Cos ϕ	0,61	0,76	0,83	0,86	0,90

C. Testing of Induction Motor with Synchronous motor Compensator as Synchronous Condenser

Table 3. Induction Motor Testing Data with Compensation

M (Nm)	1,5						
I_{EX} (A)	0,60	0,65	0,70	0,75	0,80	0,85	0,90
I_m (A)	0,72	0,70	0,68	0,65	0,64	0,63	0,64
P_m (W)	151,0	151,1	151,1	151,0	151,1	151,0	151,1
V (Volts)	231	231	231	231	231	231	231
Cos ϕ	0,88	0,91	0,93	0,95	0,96	0,98	0,99

D. Testing of No-load Synchronous Motor: From the measurement of the no-load

Synchronous motor Table 1, the composition of inductive reactive and capacitive reactive power is obtained by regulating the amplifying current. This data is depicted with a V curve, as in Figure 7. From this figure, it can be seen that the minimum anchor current occurs at a power factor of one (unity) where only real data is absorbed in the motor. At an amplifier current that is lower than the value that causes the minimum motor current, the motor current will lag behind (Lagging) and will absorb reactive power (Q). This condition is said to be an Under Excitation motor. When the motor gain current is greater (Over Excitation) than the value that causes the maximum motor noise, then the anchor current will precede (Leading) and the motor will absorb the reactive power (-Q) or supply the reactive power to the mesh.

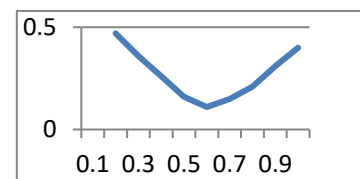


Figure 7. V Curve (IA) Excitation Current Function (IIX)

This over-strengthening results in excess flux, so it will draw capacitive current from the mesh. Therefore, a synchronous motor that is operated without load will function as a capacitor if it is given more reinforcement so that it can diffuse to improve the inductive load power factor. From the curve, the synchronous motor functions as an inductor, namely at a gain current or excitation current of 0.2 mA to 0.6 mA and can function as a capacitor at a gain current of 0.62 to 1 mA.

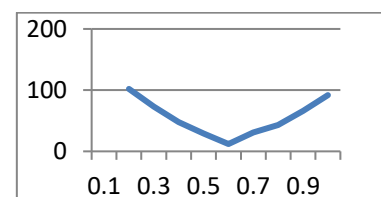


Figure 8. V Curve (Q) Excitation Current Function (IIX)

Figure 8. Is a change in reactive power to changes in excitation currents, it is seen that inductive reactive power is present in the excitation current range of 0.20 mA to 0.58 mA, where GGL (E) is smaller than the voltage (V) so that the magnetizing current is drawn from the mesh. At the time of excitation current of 0.60 mA the motor in the floating state does not give or draw current, so the emf is equal to the voltage (V). Capacitive reactive power is found in the excitation current range of 0.62 mA to 1.0 mA. where the electromotive force (ggL) is greater than the voltage (V) so that the capacitive current is drawn from the mesh.

E. Testing of induction motor with synchronous condenser compensation:

From the results of Table 3, the results of improving the power factor of the induction motor with a synchronous motor as a synchronous condenser can increase the power factor and decrease the reactive power absorbed by the motor. Power Q 1 and Cos φ 1 are parameters of reactive power and power factor generated before compensation and power Q 2 and Cos φ 2 are parameters after being cleared. The measurement results before compensating for the power factor (Cos φ) 0,88 occur in synchronous motors that are still in a less amplified condition or still absorb reactive reactive power (Q1) of 132.84 VAR with an amplifying current (Iex) of 0.6 A. After increasing the synchronous motor amplifier current from 0.65 to 0.90, The power factor (Cos φ) increases from 0.91 to 0.99 and the reactive power absorbed by the motor decreases from 68.78 VAR to 21.49 VAR. Reactive power (Q3) is obtained from reducing reactive power before being compensated (Q1) with reactive power after being compensated (Q2). Ractive power (Q3) and capacitance value (C) for the increase in

synchronous motor gain current are shown in Table 4. Caculation of capacitance values and after compensation and capacitance values are as follows. Reactive power Q 3 is the difference parameter between Q 1 and Q 2 to determine the capacitance of the synchronous condenser (C). As for the calculation of the reactive power value, the power factor and the capacitance of the synchronous condenser are:

Known:

$$I_{ex} = 0,6 \text{ A}$$

$$P_1 = 151 \text{ Watt}$$

$$\text{Cos } \varphi_1$$

$$= 0,88$$

$$V_m$$

$$= 231 \text{ Volt}$$

$$Q_1 = P \times \tan(\cos^{-1} 0,88) = 151 \times \tan(41,34) = 151 \times 0,88 = 132,84 \text{ VAR}$$

$$Q_2 = 151 \times \tan(\cos^{-1} 0,91) = 151 \times \tan(24,49)$$

$$= 151 \times 0,455$$

$$= 68,78 \text{ VAR}$$

$$Q_3 = Q_1 - Q_2$$

$$= 132,84 \text{ VAR} - 68,78 \text{ VAR}$$

$$= 64,06 \text{ VAR}$$

$$X_e = V^2 / Q_3 = 231^2 / 64,06 = 53361 / 64,06 = 1158,5 \Omega$$

$$C = 1 / (X_e \times 2\pi \times 3,14 \times 50)$$

$$= 1 / (1158,5 \times 314)$$

$$= 1 / 363772,3$$

$$= 6,35 \times 10^{-4} = 2,74 \times 10^{-6} \text{ F}$$

The calculation of the capacitance value on the synchronous condenser for Cos φ others is listed in Table 4.

Table 4. Calculation of Capacitance Value on Synchronous Condenser

I_{EX} (mA)	0,65	0,70	0,75	0,80	0,85	0,90
$\text{Cos } \varphi_1$	0,88					
$\text{Cos } \varphi_2$	0,91	0,93	0,95	0,96	0,98	0,99
Q_1 (VAR)	132,8					
Q_2 (VAR)	68,78	59,66	49,6	44,04	30,66	21,49
Q_3 (VAR)	64,06	73,18	83,24	88,8	102,18	111,35
$C_{CONDENSER}$ (μF)	2,74	4,36	4,95	5,29	6,06	6,65

From the calculation of Q_1 reactive power before compensation is 132.8 VAR and Q_2 reactive power after compensation drops from 68.78 to 21.49 VAR and the capacitance value of the synchronous condenser also increases from 2.74 to 6.65 micro Farad, as well as the power factor increases from 0.91 to 0.99. This parameter increase causes the vector angle value between real power and apparent power (φ) to shrink so that the reactive power (VAR) becomes low. This reduction in reactive power is due to the addition of reactive resources that are capacitive. This reduction process can occur because the load is inductive and capacitive in the opposite direction as a result of which the reactive power becomes small.

CONCLUSION

From the results of this study, it can be concluded that it is as follows: (1) The synchronous motor can absorb inductive reactive power at reduced gain i.e. from 0.2A 0.6 A and can absorb capacitive reactive power at a gain of more than 0.62 A to 1.0 A, this condition synchronous motor is called

a synchronous condenser. (2) The effect of using a synchronous motor as a synchronous condenser to improve the power factor in the induction motor can be done by connecting the parallel synchronous motor both in the star and triangular relationships and increasing the excitation current until capacitive reactive power is generated. The value of the power factor before compensation is 0.88 at an amplifier current of 0.6 mA and after compensation the power factor increases from 0.91 to 0.99 at a reinforcing current of 0.65 A to 0.90 A. (3) Improvement of induction motor power factor after compensation obtained reactive power reduced from 132.8 VAR to 28.2 VAR and the capacitance value of the synchronous condenser increased from 2.74 μF to 6.65 μF .

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