STATIC VAR COMPENSATION FOR SINGLE PHASE INDUCTION MOTOR OPERATION

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Abstract

This work presents the design of a static var compensation scheme that uses intelligent controllers to minimise the problems associated with excessive var consumption and the investigation of the impact of SVC on machine efficiency. The work describes the design of a var compensation scheme which uses a Pic Microcontroller to determine the phase difference between voltage and current of a single phase induction motor. The Microcontroller then uses its algorithm from the code to switch in capacitors to bring the power factor of the motor to a desired reference value.Tests were carried out on the motor to determine the appropriate capacitor sizes using different loads. These were used to construct the hardware for the SVC scheme

KEYWORDS: *Static VAR Compensation (SVC), magnetizing current, Zero Crossing Detector (ZCD), Power Factor Correction (PFC).*

I. INTRODUCTION

Majority of the loads in modern power distribution system are inductive. Static var compensators are used to provide continuous compensation for both inductive and capacitive loads; as such, they may be used for reactive power compensation for either voltage regulation or power factor correction [1]. The load due to an induction motor has inductors and resistors and that implies that the more current the motor draws, the more voltage drop. This is because voltage drop is proportional to current. All ac inductive devices and appliances (such as magnets, transformers, reactors and induction motors etc.) require two kinds of currents i.e. working power (kW) to perform actual work and reactive power (kVAR) to create and sustain the magnetic field in the circuit. By supplying the reactive power needed "locally", it means less current will be drawn from the line by the device or appliance which will result in less voltage drop. In making use of static var compensators to provide reactive power for inductive and capacitive loads, the power factor of the loads is improved which in turn reduces the stress on the supply line and saves cost [2].

In mathematical terms, the power factor of a load is the ratio of the active power to the apparent power. It is the cosine of the phase angle between voltage and current. In practical terms, the power factor is just a method of showing what portion of the apparent power is real or is being utilized to do active work such as lighting, heating, motion or some mechanical output. Reactive power is the result of current and voltage when they are out of phase. This reactive power only oscillates to and fro along the line in different quarters of cycle. This keeps flowing back and forth from the source to the load in the positive half cycle and from the load to the source in the negative half cycle. On the contrary, real power flows in one direction only from the source to the load. The flow of reactive power to and fro does not cause any transfer of power from the source to load. The reactive power though not utilised for work is inherent in the line due to capacitance and inductance in the line. The current which results from the reactive power flowing through the conductors is however capable of causing voltage drop and losses in the generating plant and transmission system [3]. The power factor cannot assume a value more than unity since real power cannot be more than apparent power. The power factor for a purely inductive load is zero because there is no consumption of real power while that for a purely resistive load is unity because the real power drawn by the load is same as the apparent power.

The basic concept of power factor correction is to locally provide or consume any reactive power to a load independently of the power supply. Since most of the industrial loads are inductive, it means if proper compensation is not provided for the loads, they would draw excessive current from the line which would cause greater losses for utility consumers who will have to bear the cost of increasing the cable ratings as well as the losses (I^2R loss) generated in such cables. The transmission of reactive power from the power generation plants to various loads is a heavy drain on utility providers as it could reduce the overall efficiency of power transmission and the voltage regulation would be much more complex. The strategy employed by utility providers is such that the high power factor customers are rewarded with lower charges while the low power factor consumer is punished with high billing. Consequently, it is only economically prudent to install power factor improvement devices for both domestic and industrial devices. Since the vast number of loads are inductive and draw reactive power from the power system, capacitors are utilized to provide the reactive power to the load and to minimise the lagging current [4].

The static var compensator is designed and used to regulate the amount of reactive power being generated or consumed in the power system. The static var compensator is also called a static reactive compensator. The output of static var compensator is adjusted to exchange inductive or capacitive current in order to control a power system variable such as the bus voltage [5]. The term static connotes that there are no moving (rotating) parts and is used to differentiate SVCs from other rotating schemes.

A static var compensator can generate or absorb reactive power and this helps in controlling system voltages. The output is completely variable from maximum absorption to maximum generation in contrast with fixed reactors or switched capacitors where only a fixed amount of leading or lagging reactive power can be switched into the system. Some of the benefits of using static var compensation as outlined by [6] are shown below:

- Flicker reduction
- Voltage stabilisation
- Reactive power compensation
- Elimination of harmonics and reduction of distortions in voltage
- Increased consumer's economic benefits.

Conversely, some of the impacts of operating equipment with low power factor include:

- Reduction of system capacity
- Increased penalty charges
- Transmission voltage drop
- Increased line losses
- Increased cable ratings

Overall, there is an increasing demand for energy while the natural resources for generating this energy are being depleted daily and as such, we cannot afford to waste energy on running motors and motor systems that are not efficient[7]. Given that motors and other systems that incorporate motor drives are the most commonly found in domestic, commercial and industrial applications, it has been observed by [8], that motors and their systems are a key area where significant energy savings can be made.

II. REQUIREMENTS AND POSSIBLE SOLUTIONS

An induction motor must run at a power factor that is lagging at all times because the input to its stator is the only way of getting the motor to be excited. In their normal operation, the power factor is very low when the induction motor is running at no-load and rises up to between 0.85 and 0.9 at the rated full load. This self-correction of the power factor is as a result of increased real current that the motor continues to draw when the load gets bigger. As the load changes to a bigger value, the reactive component of current consumed by the motor remains the same while the real (active) current increases, thus causing the power factor to increase. The large value of the magnetising current that is present in the motor regardless of the amount of load the motor is subjected to, limits the power factor from going behind 0.9 even when it is at full load [9].

The reluctance of the magnetic circuit in an induction motor is made much bigger because the presence of air-gap between the rotor and the stator. This is why the motor takes a large magnetising current to create the necessary flux in the air gap. The magnetising current is essential for the motor to operate though it does not add to the output of the motor; as it creates the flux in the iron.

For the purpose of minimising losses in distribution lines, power factor improvement is implemented to cancel out some portion of magnetising current required for the motor operation. Such a power factor improvement plan could be in the form a static var compensation scheme. The task to be undertaken in this project involves the design of a var compensation scheme for a single phase induction motor. The ratings of the motor are shown in table 1

Table 1 Ratings of the single phase induction motor.

Power	675 Watts
Voltage	0-135 V
Current	5 A
Pole	4
Frequency	50 Hz
Speed	1500 rpm

The switching of capacitors is key aspect of the reactive power compensation scheme. Consider the sinusoidal voltage signal shown in Figure1, if one tries to switch on capacitors at the time when voltage signal is at point A of waveform; there will be huge transients in the system. The best time to switch capacitors is at point B just when it is crossing zero because not much voltage is applied across it. Once the capacitor is on, then it gradually builds up.

As an illustration, there is a capacitor and it is empty. It has very low impedance so switching it at point A will result in large current hence the transients. Capacitors behave in a way similar to secondary cell batteries when there is an instantaneous change in the applied voltage. They respond to that change by causing a high current which declines over a period of time. This transient response of the capacitor could cause some damage to the circuit or trigger off some other problem that would cause the circuit to misbehave. To avoid this, it is better to switch it on at point B. That means there has to be a way of detecting when the signal is just about the zero value for switching

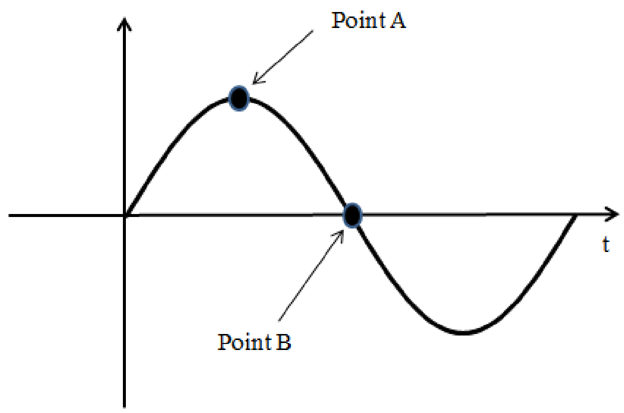

Figure 1 Voltage signal showing position for switching on capacitors

The physical switching of the capacitors can then be achieved using relays and relay driver IC combination or by TRIAC and DIAC combination depending on the level and isolation desired or intended in the design.

The automatic switching of capacitors can be done using intelligent controllers. One way of achieving this would be by using the programmable logic controller (PLC) to control the switching on and off of capacitors to correct the power factor. Another way would be to use the Pic Microcontroller which can be coded to make the desired decisions for switching of the capacitors.

The control unit forms the critical aspect of the system. The Pic Microcontroller can read the zero crossings of voltage and current waveform. By counting in parallel the time difference between zero crossings of voltage and current, the power factor can be accurately calculated. The microcontroller can make decision to switch on and off capacitors for compensation after comparing the calculated value of power factor with a reference power factor value. Again, the controller is able to switch capacitor safely because of zero crossing detection capability.

III. PROPOSED SYSTEM DESIGN

The scheme uses a PIC microcontroller chip as the brain of the system where all the computation and decisions are made. The Pic Microcontroller is a miniature computer in itself that is able to carry out the intelligent control of the system. A number of other power electronics devices are integrated in this design with capacitor banks. A schematic diagram of the system is shown in Figure 2. The switching of the capacitors would be done by making use of relays which are driven by a relay driver IC which is just a set of inverters inside the relay driver such that when a ZERO is sent to the input, it gives a ONE in the output.

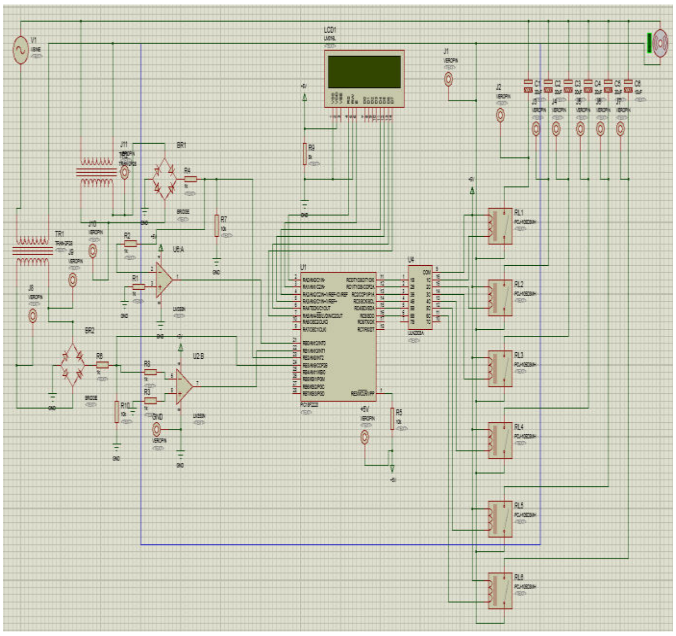

Figure 2.0: complete circuit diagram of the static var compensation scheme

The voltage and current signals from the potential transformer and the current transformer are fed to the zero crossing detectors which are operational amplifiers. These make it possible for the microcontroller to monitor constantly the zero crossing of current and voltage. The bridge rectifiers used for both current and voltage signals are for converting the analogue signals to digital signals as the microcontroller cannot handle ac values of voltage and current. The values of power factor as corrected by the Pic Microcontroller after selecting the needed value of capacitor for compensation after load monitoring are displayed on the LCD screen.

IV. DETERMINING THE MOTOR'S PARAMETERS

In many design strategies for correcting power factor to a desired value, the following formula is used to calculate the kVAR needed for compensation:

$$kVAR_{(required)} = \frac{hp \times 0.746}{\%Eff}\left(\frac{\sqrt{1-PFa^2}}{PFa} - \frac{\sqrt{1-PFt^2}}{PFt}\right) \qquad eqn\,1$$

Where,

hp is motor nameplate horsepower

%Eff is motor nameplate efficiency (value normally entered in decimal)

PFa is motor nameplate actual power factor

PFt is the target power factor.

Reference would normally be made to the motor manufacturer's data sheet to confirm the maximum kVAR of capacitors which could be added across the motor. The ratings of capacitors for compensation should not go beyond the maximum permissible rated kVAR that is stated on the motor data sheet in order to prevent self-excitation.

For this design, the necessary parameters such as the motor nameplate horsepower, motor nameplate efficiency and the motor nameplate actual power factor are not readily available because the equipment is an open frame dissectible machine which can be configured to allow approximately 60 electrical machines which can be assembled or dismantled down to component parts level (shaft, coils, pole-pieces, stator brush gear, etc.). More so, it is misleading to depend entirely on the machine datasheet for nameplate ratings when it could have been rewired. It is only possible to verify machine characteristics by carrying out certain tests. The following tests were carried out to facilitate the calculation of the required compensation for the equipment when it is configured as a four-pole, squirrel-cage, single phase induction motor:

1. No load test

This test is done by operating the motor without any load and by taking measurements of the input current, voltage and power with the use of an ammeter, a voltmeter and a wattmeter respectively. Recall that since

$$P = VIcos\phi \qquad eqn2$$

Therefore,

$cos\phi = \frac{P}{VI}$ (*is the no load power factor*)

In this four-pole assembly, P=2 and taking slip, S=0.5

$$n = \frac{60}{p}f(1-S) \qquad eqn3$$

$$n = \frac{60}{p}f(1-S) = \frac{60}{2} \times 50(1-0.05) = 1425\,rev/min$$

If the machine is operated using the same slip but a new frequency of 60Hz, the speed would change to 1710 rev/min. This equation above is only valid at specific values of load because the values of slip change with load changes. The readings obtained with the corresponding power factor are presented in Table 2.

Table 2 Values obtained for no-load test capacitor start/run operation

Voltage(V)	Cap (µF)	Current (Amp)	Current(on starting)	Power (watt)	Power factor
130	4	2.6	5.0	112	0.33
130	6	2.5	5.0	112	0.34
130	8	2.4	5.0	112	0.36
130	10	2.2	4.8	112	0.39
130	12	2	4.8	112	0.43
130	14	2	4.8	112	0.43

2. Load test

In this test, the supply voltage was kept constant at 130V and with a fixed capacitor value of 14µF in the start winding while the load was varied from no-load up to 1.0Nm in steps of 0.2Nm. The values obtained are shown in Table 3 below:

Table 3 Values obtained for load test operation

Voltage(V)	Load (Nm)	Current (Amp)	Power (watt)	Power factor
130	0	2	120	0.43
130	0.2	2	140	0.54
130	0.4	2.2	168	0.59
130	0.6	2.4	200	0.64
130	0.8	2.6	250	0.74
130	1.0	2.8	300	0.82

3. Short circuit test

To undertake a short circuit or block rotor test, the rotor is held fixed so that it will not rotate. Alternatively, a reduced voltage is supplied so as to limit the short circuit current. The results obtained from the short circuit test of a single phase induction motor can be used to determine the internal characteristics of the motor. Since the current through the stator could go beyond the rated current of the motor, it is safer to carry out this test quickly. The values obtained for this test are tabulated in Table 4 below:

Table 4 Values obtained for short circuit test operation

Voltage(V)	Current (Amp)	Power (watt)	Power factor
130	5	450	0.69

From the values above, it is possible to calculate the equivalent resistance and reactance of the motor, thus:

$$cos\phi_{SC} = \frac{P}{VI} = \frac{450}{130 \times 5} = \frac{450}{650} = 0.69$$

$cos\phi_{SC} = 0.69$is the short circuit (blocked rotor) power factor.

$$Z_{eq} = \frac{V_{sc}}{I_{sc}} = \frac{130}{5} = 26\ ohms$$

$$R_{eq} = \frac{W_{SC}}{I_{SC}^2} = \frac{450}{5^2} = \frac{450}{25} = 18\ ohms$$

$$X_{eq} = \sqrt{Z_{eq}^2 - R_{eq}^2} = \sqrt{26^2 - 18^2} = \sqrt{352}$$
$$= 18.76\ ohms$$

Since $X_1=X_2$,

$$X_2 = \frac{X_{eq}}{2} = \frac{18.76}{2} = 9.38\ ohms$$

Where X_2 is the rotor reactance referred to stator.

V. RESULTS

The task undertaken in this project involved the design of a static var compensation scheme for a single phase induction motor whose rated parameters are indicated in table3.1. Following the tests carried out on the motor, the necessary values of capacitors which can be used to provide adequate compensation for reactive power drawn by the motor have been determined. The following graph in Figure 3 depicts the relationship between the power factor and load of an induction motor even before reactive power compensation is provided.

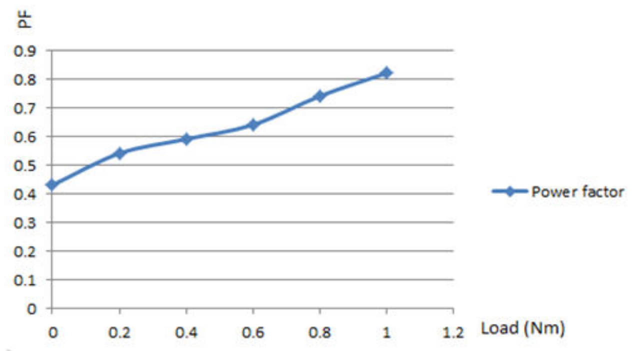

Figure 3 Relationship between power factor and load of 1-ϕ induction motor

The amount of reactive which can be provided for the motor to operate at a reference power factor of 0.95 and the corresponding load level is indicated in the Table 5.

Table 5 Capacitor ratings for possible correction

Load (Nm)	Power factor	Capacitor(μF) rating for compensation to 0.95pf
0	0.43	37.36
0.2	0.54	32.43
0.4	0.59	32.91
0.6	0.64	32.84
0.8	0.74	27.32
1.0	0.82	20.86

Standard values of capacitors which are close to the values as calculated from test results were selected for compensation.

VI. DISCUSSION OF RESULTS

The operation of a single phase induction motor indicates that the power factor of the motor improves as the motor runs from no-load to full-load. This means that operating these motors when the load is far below their capacities is wasteful and inefficient. However, once the motor has been loaded to its rated value, any additional load would cause the motor to stall. As the load of an induction motor approaches increases towards the rated load, the speed would decrease while the slip would increase in a corresponding manner. This increase in slip would reach a point where an additional torque would cause the motor to stall.

In theory, it is possible to use capacitors to provide 100% compensation for power improvement. In physical implementation, a power factor of about 95% is enough to guarantee maximum benefit. A target of 95% is even more reasonably when we consider the possibility of over-compensation of the system. Another consideration is that the availability of range of capacitor ratings is limited and so, it might not always be practical to raise the power factor of equipment to an exact value. This challenge becomes even deeper if the supply is not steady i.e. if the voltage supply is changing due to other loads on the distribution network or some other disturbances in the power network. This is because capacitor size for power factor improvement is partly affected by level of the supply voltage [10]. Therefore a change in voltage would slightly affect the operation of the static var compensation system.

Another factor to consider is that if the load for which power factor correction is designed is not a varying load, then it would be more economical to install fixed capacitors to provide compensation.

VII. CONCLUSION

It has been noted that a very little improvement in power factor could provide huge decrease in losses because losses have a directly proportional relationship with the current drawn by the single phase induction motor. On the contrary, running a motor on low power factor condition would lower the supply voltage due to large current drawn and the accompanying losses. This can cause sluggish motor operation and also generates extra heat in the equipment. This is just the impact on motor operation; the many other impacts of low power factor in equipment have already been highlighted in much the literature in this work

The installation of an appropriate reactive power compensation scheme would not only correct the power factor but will also maintain the normal voltage level. This can greatly enhance the motor efficiency and useful life.

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