Power factor correction of the industrial electrical system during large induction motor starting using ETAP power station

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Abstract. This paper presents the power factor correction of the electrical system during the induction motor starting using ETAP power station. There are some problems faced by the electrical system when the motor is started, including voltage drop, high insulation current, and low power factor. The starting motor method used in this paper is starting with VFD. The aim of this research is to improve the power factor during the starting time. The system with a capacitor resulted in a low power factor that lowers the quality of electrical power. By adding capacitor 30 kVAR with each step 0.1 kVAR in the system, the power factor increased to 95.5%.

1. Introduction
Induction motors are the most widely used electric motors in the industry; therefore induction motors are the most widely produced throughout the world and their numbers continue to increase significantly. One of the benefits of an induction motor is that the starting motor does not need an external circuit for starting. However, this starting effect on the utility and on the motor itself where it cannot be ignored. When a voltage is applied to the motor, most of the voltage is taken from the utility which causes a decrease in the system voltage. Due to the highly inductive nature of the motor, the power factor at the start is quite low, usually decreasing by 10-20%. Therefore the most effective component when starting a motor is reactive power to improve the system power factor.

During the last few years, the starting motor method has become the focus of research. Various methods of induction motor starting are known, including the Direct On-Line (DOL) method, Starting Y-delta, Auto-transformer, soft starter, and VFD. Several studies have discussed how to overcome the decrease in power factor when starting a motor by using supporting devices such as capacitor and SVC. These devices are widely explained to overcome the problem of voltage drop during the starting of a large power induction motor and without affecting the dynamics of the induction motor. In the research of J. Williams [1] capacitor can improve electrical system performance during the process of starting large capacity motors and the research conducted by Ho-Chiao Chuang et al. [2] recalls the efficiency of induction motors and improvement of power factors by improving frequency and voltage using SCR.
2. Starting Analysis of Induction Motor
During the motor starting period, Induction motors is at rest, & it appears just like a short-circuited transformer and if connected to the full supply voltage, draw a very high current known as the “Locked Rotor Current.” The Locked Rotor Current (LRC) is a function of the terminal voltage of the motor and the motor design. The current is about six times the motor rated current, which therefore results in voltage dip in the system and poses disturbances to the normal operation of other system loads. The magnitude of this dip is proportional to the magnitude of the surge and the impedance of the system. Because of the highly inductive nature of the motor circuit at rest, the power factor of the surge is quite low, usually on the order of 10 to 20 percent. As the motor accelerates to rated speed, the surge decays and the system voltage recovers. One of the starting methods is known as VFD.

VFD is a solid state, electronic device that varies input voltage and frequency to the motor to reduce the peak starting current and starting torque. As the output of the drive increases, the input to the motor decreases. The VFD is an electronic electric motor starting aid device (commonly applied to pumps, air handlers, etc.). It functions by electronic power principles in varying the frequency of the input power to the motor, thereby controlling the motor speed. This gives reduced motor starting current, reduction in thermal and mechanical stresses on motor and belts during starting, etc [3].

3. Power Factor Correction
The cosine of the angle between voltage and current in an AC circuit is known as the power factor. In an AC circuit, there is generally a phase difference $\phi$ between voltage and current. The term $\cos \phi$ is called the power factor of the circuit. If the circuit is inductive, the current lags behind the voltage and the power factor is referred to as lagging. However, in a capacitive circuit, the current leads the voltage and the power factor is said to be leading.

The analysis of the power factor can be made in terms of power drawn by the AC circuit. The power triangle OAB showed (figure 1). Where $OA = VI \cos \phi$ and represents the active power in watts of kW, $AB = VI \sin \phi$ and represents the reactive power in VAR of kVAR, $OB = VI \cos \phi$ and represents the apparent power in VA of kVA.

![Figure 1. The power triangle](image)

$$OB^2 = OA^2 + AB^2$$  \hspace{1cm} (1)

$(Apparent power)^2 = (active power)^2 + (reactive power)$

$$(kVA)^2 = (kW)^2 + (kVAR)^2$$  \hspace{1cm} (2)

$\cos \phi = OA/OB$, $\cos \phi = power\ factor$
The low power factor is mainly due to the fact that most of the power loads are inductive and, therefore, take lagging currents. In order to improve the power factor, some devices taking leading power should be connected in parallel with the load. One of such device can be a capacitor. The capacitor draws a leading current and partly or completely neutralizes the lagging reactive component of load current. This raises the power factor of the load.

The use of capacitors as starting aids to electrical motors are aimed at reducing the voltage dip experienced by neighboring loads during the in-rush moment of these electrical motors by connecting them to either the motor bus or the motor terminals [4], this is because these capacitors generate reactive power. They are known as capacitor banks or reactive power banks. One major merit of this starting aid method is its ability to improve the power factor of electrical machines when connected in parallel to the electrical machines [5,6]

4. Study Simulation
In this case, the single system line has two induction motors, 100 HP and 50 HP 0.4 kV, VFD (Variable Frequency Drive), Capacitor bank (0.1 Mvar), Static load 5 kVA, Dynamic load 10 kVA. Single line diagram is shown in (figure 2).

5. Result and Analysis
The case study for VFD starting adopts the system configuration shown in figure 3 with a low-voltage drive. The VFD is rated at VA and 0.4 kV at 50 Hz. The step-up transformer is rated at 100 kVA with multiple secondary taps, and its impedance is 5.2%. The required surface voltage under normal operating conditions is achieved by adjusting the secondary tap settings of the step-up transformer for various system configurations. Four starting frequencies, namely, 7, 8, 9, and 10 Hz, are applied to the VFD. Before installing the capacitor, the power factor of the motor is 84.5% as shown in (figure 3).

The figure shows the load flow of the circuit with a capacitor. The installed capacitor is a capacitor with a capacity of 30 kVAR. It shows that the power factor of the motor is improved to 95.5%. (Figure 5) shows the bus voltage of the motor and figure 6 shows the terminal voltage of the motor base.
6. Conclusion
In this paper, the power factor of the system that consists of high-power induction motors can be improved by adding the capacitor bank in the system. To improve power factor from 84.5% to 95% and to minimize the dip in system voltage, the system is installed with capacitor bank 30 kVAR with each step 0.1 kVAR. VFD is added to the system to reduce the suddenly high current in starting the induction motor.

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