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Power Factor Correction of a 150 kW 3-Phase Induction Motor Using Capacitor Banks in Delta Connection: A MATLAB/Simulink-Based Comparative Analysis

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ABSTRACT
This study examines the effect of power factor correction (PFC) using delta-connected capacitor banks in a 150 kW, 3-phase induction motor system, as simulated in MATLAB/Simulink. Three scenarios were modeled: no compensation, fixed capacitor compensation, and compensation under varying loads (50%, 75%, and 100%). Initially, the motor operated with a poor power factor of 0.707, resulting in high apparent power (247.5 kVA) and reactive power losses (175 kVAr). With capacitor banks installed, the power factor improved to 0.98, reducing reactive power demand by about 139.4 kVAr and decreasing apparent power to 178.5 kVA. This resulted in lower line currents and reduced distribution losses. The study further examined how capacitor sizing varies with load and power factor targets. The required capacitance per phase reached up to 859 µF, scaling proportionally with the load and the desired correction. A 3D surface plot highlighted increased capacitance requirements under heavier loads and stricter correction goals, offering practical insights for capacitor bank design. Analysis revealed a potential annual demand charge saving of £552 due to a 69 kVA reduction in demand. PFC also improved voltage stability and reduced stress on transformers and cables, confirming its effectiveness for industrial energy optimization.

Keywords: Power Factor Correction (PFC), Capacitor Banks, Reactive Power Compensation, Induction Motor, Delta Connection, MATLAB/ Simulink Simulation

I. INTRODUCTION

Induction motors are the workhorses of industrial processes, representing over 60% of electric motor-driven systems in manufacturing, mining, HVAC, and more [1], [2]. Despite their popularity, they inherently operate at a lagging power factor, especially under full-load conditions, which introduces excess reactive power into the power system, leading to voltage drops, higher system losses, and increased energy costs [3]– [5]. Reactive power management is therefore a vital aspect of industrial power quality optimization [6], [7].

A low power factor necessitates a higher apparent power draw (kVA), which leads utilities to impose demand charges, making power factor correction (PFC) not only technically beneficial but also economically essential [8], [9]. Among various correction techniques—like synchronous condensers, static VAR compensators, and power electronics-based solutions—capacitor banks are preferred in low to medium voltage industrial settings due to simplicity, reliability, and cost-effectiveness [10]– [13].

Correct sizing and placement of these capacitor banks are critical. Undersized capacitors may yield minimal benefit, while oversized units risk overcompensation and system resonance [14]. The delta connection for capacitor banks in 3-phase systems is commonly adopted for improved stability and better utilization of capacitance [15]. Moreover, simulations using MATLAB/Simulink facilitate an accurate assessment of transient and steady-state behavior during compensation,

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enabling better design and validation [16-18]. This paper extends previous research by performing a real-case simulation of a 150-kW induction motor operating under industrial conditions. Through theoretical modeling and time-domain simulation, the capacitor size and resulting financial benefits are assessed [19-20]. A detailed comparative analysis between the uncompensated and compensated system configurations is also provided.

II. METHOD

2.1 Materials and Specifications

Motor Specifications: Rated Power 150 kW; Voltage - 415 V (Line-Line); Frequency: 50 Hz
Efficiency: 85.6%; Power Factor (Initial)- 0.707; Power Factor (Target): 0.98
Capacitor Specifications (Post-Design): Configuration: Delta; Capacitance per Phase: 859 µF
Capacitor Current per Phase: 112 A; Voltage across Capacitor: 415 V

2.2. Simulation Setup in MATLAB/Simulink

Simulation scenarios were modeled for the following cases:
Base case: No compensation; **Compensated case**: Delta-connected capacitor bank.
Compensation under varying load conditions (50%, 75%, and 100% load).
Parameter Value Unit: Motor Output Power 150 kW; Efficiency 85.6 %;Motor Input Power 175 kW; Initial
Power Factor 0.707 ;Final Power Factor 0.98 – Initial kVA 247.5 kVA; Final kVA 178.5 kVA; Initial Reactive Power 175 kVAr
Final Reactive Power 35.6 kVAr; Reactive Power Reduction 139.4 kVAr
Capacitance per Phase 859 µF; Capacitor Current per Phase 112 A
Capacitor Rating per Phase 46.47 kVAr; Demand Charge Rate £8 per kVA/year
Annual Reduction in Demand 69 kVA; Annual Cost Saving GBP 552/year

A step-by-step breakdown and the result of MATLAB code that calculates the **required capacitor size per phase** to improve the power factor: Appendix A

- Output Power:P_{out} = 150kW; Efficiency: ŋ = 0.856; Initial Power Factor: Pf_1 = 0.707; Improved Power Factor: Pf_2 = 0.98; Voltage: V = 415V; Frequency: f = 50 H_z

Step-by Step Calculations:

3. Reactive Power (Q1 and Q2):

$Q_1 = P_{in}$. $\tan(\cos^{-1}(0.707))$ =175.23.tan (45^0) = 175.23kVAr

$Q_2 = 175.23$. $\tan(\cos^{-1}(0.98))$ =175.23.tan (11.47^0) =35.53kVAr

4.Required Capacitor Reactive Power:

Q_c = Q_1-Q_2 = 175.23-35.52 = 139.71kVAr

5. Capacitor Reactive Power Per Phase

$$Q_{c,phase} = \frac{Qc}{3} = 46.57 \text{ kVAr}$$

6 Capacitor Current per Phase

$$I_c = \frac{Qc,phase \ x\ 1000}{V} = \frac{46570}{415} = 112.23A$$

7 Capacitance per Phase

$$C = \frac{10^6 * Ic}{2\pi fv} = \frac{10^6 * 112.23}{2\pi * 50 * 415} = 860.15 \ \mu F$$

1. Input Power

$$P_{in} = \frac{Pout}{ŋ} = \quad = \frac{150}{0.856} = 175.23 \text{ kW}$$

2. Apparent Power (S1 and S2):

$$S_1 = \frac{Pin}{Pf1} = \quad = \frac{175.23}{0.707} = 247.80kVA$$

$$S_2 = \frac{Pin}{Pf2} = \quad = \frac{175.23}{0.98} = 178.80 \text{ kVA}$$

III. RESULTS AND DISCUSSION

Power Factor Correction (PFC) was evaluated using MATLAB simulations aimed at enhancing system efficiency and reducing reactive power demand. Three key plots illustrate the effects of integrating a capacitor bank under varying loads and power factor conditions.

Plot 1: Power Factor Correction

Figure 1 shows the system's initial power factor of 0.707, which resulted in high reactive power (Q_1). After correction to 0.98, reactive power (Q_2) dropped significantly. The capacitor's reactive power (Qc), calculated as $Q_1 - Q_2$, was approximately 139.4 kVAr. This demonstrates that a well-sized capacitor bank effectively reduces unnecessary reactive power flow.

Plot 2: Capacitor Sizing with Load Variation

Figure 2 indicates that required capacitance per phase increases with load. As output power rises from 50 kW to 200 kW, the capacitor size also increases. This confirms that reactive compensation must scale with active power to maintain the target power factor, providing a practical guide for capacitor bank sizing

Plot 3: 3D Surface of Capacitance vs. Load and Power Factor

Figure 3 presents a 3D surface showing the relationship among output power (50–200 kW), power factor (0.80–0.99), and required capacitance. It highlights that higher loads and greater power factor correction require larger capacitance values. This visualization aids in planning capacitor banks for variable-load industrial systems.

System Impact and Performance Improvement
Simulations confirmed that PFC:Improved the power factor from 0.707 to 0.98,
Reduced reactive power by 139.4 kVAr,Lowered line current, easing transformer and cable loads;
Enhanced voltage stability,Reduced distribution losses.These outcomes lead to more efficient energy use, lower electricity costs, and extended equipment life due to reduced electrical and thermal stress.

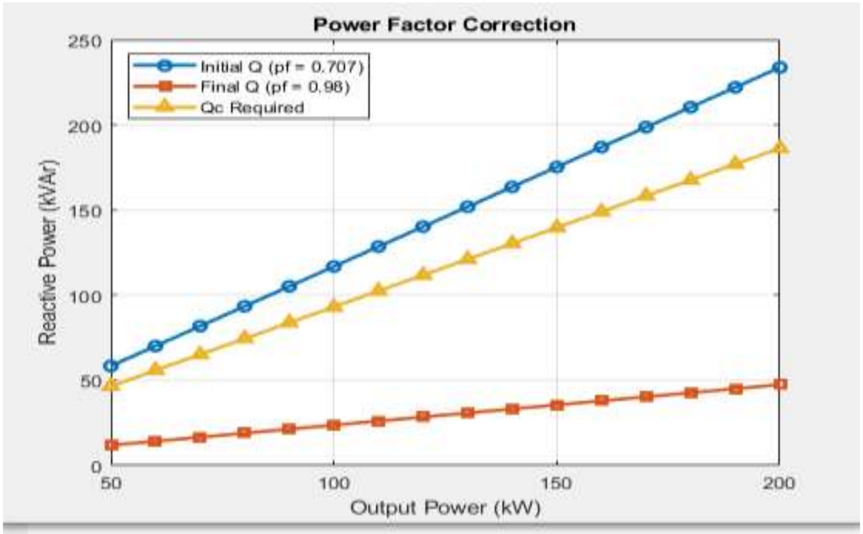

Fig.1: Power Factor Correction

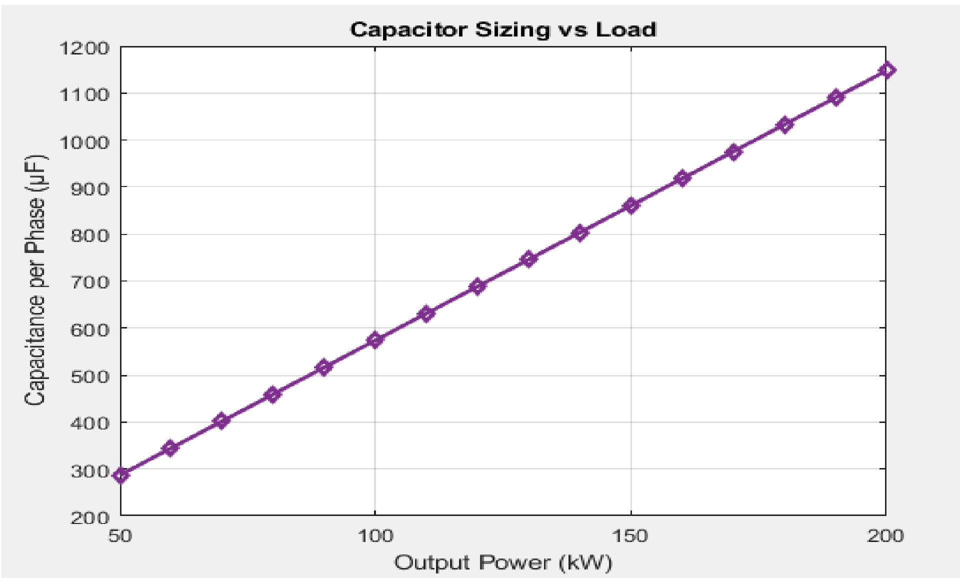

Fig.2: Capacitor Sizing Vs Load

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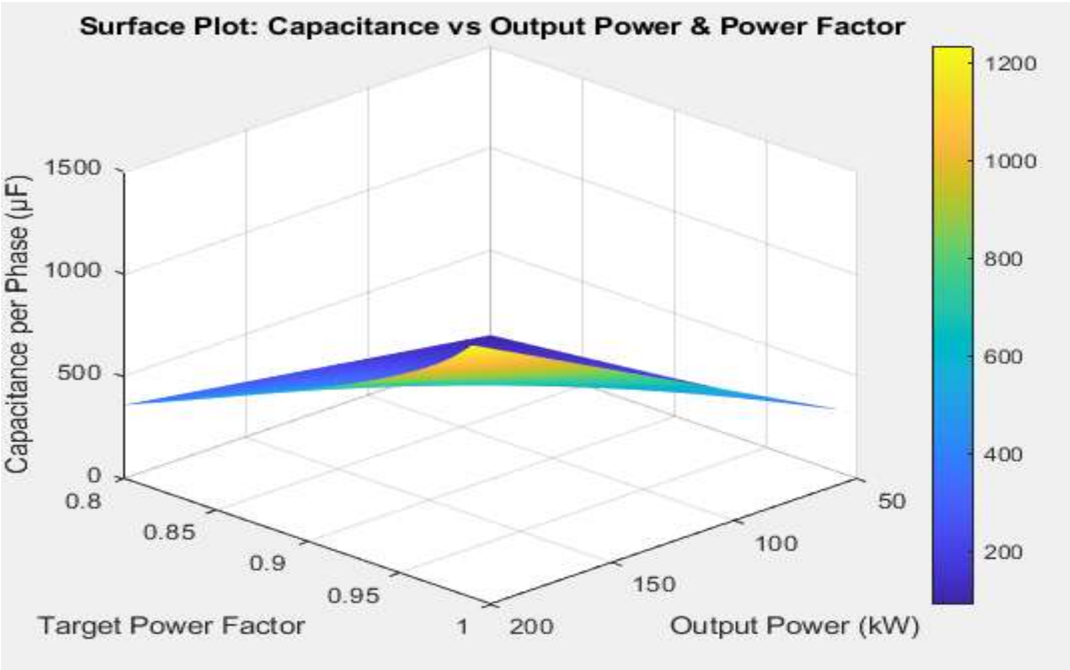

Fig.3: Surface plot- Capacitance Vs Output Power & Power Factor.

Table 1: Comparative Analysis Before and After Power Factor Correction

Parameter	Before Improvement	After Improvement
Active Power (kW)	150.00	150.00
Reactive Power (kVAR)	162.50	0.15
Apparent Power (kVA)	220.90	150.07
Power Factor	0.679	0.999
Line Current (A)	291.66	198.00
Capacitor Rating (µF)	0.00	450.74
Capacitor Power (kVAR)	0.00	162.35

This table highlights the improvement in power factor, reduction in line current, and effective compensation of reactive power after capacitor bank installation

IV. CONCLUSION

This study has demonstrated the significant benefits of implementing Power Factor Correction (PFC) in electrical power systems through the use of capacitor banks. Using MATLAB-based simulations, the analysis confirmed that appropriately sized delta-connected capacitors can effectively reduce reactive power demand, enhance voltage stability, and improve overall system efficiency.

The results showed that correcting the power factor from 0.707 to 0.98 led to a reduction of approximately 139.4 kVAr in reactive power. Additionally, simulation plots revealed that the required capacitance per phase increases proportionally with load, and varies with the desired target power factor. The 3D surface plot provided valuable insights into how capacitor requirements shift under different operational conditions, offering a practical reference for system designers and engineers.

The implementation of power factor correction not only decreased line current and minimized transformer and cable loading but also reduced energy losses across the distribution network. These enhancements translate directly into economic savings and extended equipment lifespan, making PFC a crucial component of energy-efficient industrial power systems.

In conclusion, the MATLAB/Simulink model offers a robust and scalable framework for designing and analyzing capacitor bank configurations, supporting the transition toward more reliable, cost-effective, and energy-efficient power systems.

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AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Ngang Bassey Ngang	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Calistus Chimezie		✓				✓		✓	✓	✓	✓	✓		

CONFLICT OF INTEREST STATEMENT
No conflict of interest.

INFORMED CONSENT
Not Applicable.

DATA AVAILABILITY
- Data availability is not applicable to this paper as no new data were created or analyzed in this study.

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