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Effect of Capacitor Capacitance on the Power Factor Performance of Single-Phase Induction Motors

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ABSTRACT

This study experimentally investigates the effect of capacitor capacitance variation on the power factor and operating characteristics of a single-phase induction motor under no-load conditions. Single-phase induction motors are widely used in residential and light industrial applications; however, their inductive nature often results in a low power factor and increased current consumption. To address this issue, capacitive compensation was applied by installing capacitors with different capacitance values *(4 μF, 6 μF, 12 μF, and 18 μF)* in the auxiliary winding circuit. The experimental setup was implemented in a controlled laboratory environment, and key parameters including power factor, stator current, electrical power consumption, starting voltage, and rotational speed were measured for each capacitance value. The results show that capacitor capacitance significantly influences motor performance. A capacitance of *4 μF* provides the most favorable operating condition, yielding the highest power factor while maintaining relatively low current and power consumption. Increasing the capacitance beyond this value leads to excessive leading compensation, which is associated with higher current draw, increased power consumption, and reduced rotational speed. These findings indicate that appropriate capacitor selection is critical for achieving effective power factor improvement without compromising energy efficiency. The outcomes of this study provide practical guidance for capacitor sizing in single-phase induction motor applications and contribute to a better understanding of reactive power compensation under no-load operating conditions.

Keywords: *capacitor capacitance; power factor; reactive power compensation; single-phase induction motor; stator current*

INTRODUCTION

Single-phase induction motors are extensively employed in residential, commercial, and light industrial applications, including ventilation units, water pumps, and small cooling devices. Their widespread use is primarily attributed to their structural simplicity, low cost, and modest maintenance requirements relative to other motor types, and to their dominant share in the global stock of low-power electric drives (Coutinho et al., 2023; Iegorov et al., 2021). In many household and rural installations where only single-phase supply is available, these machines remain indispensable, so even incremental performance improvements can yield meaningful energy savings at scale (Karpe et al., 2019; Parihar et al., 2018).

Despite these advantages, single-phase induction motors inherently exhibit important operational drawbacks, most notably low starting torque and a relatively poor power factor arising from the inductive nature of the stator windings and the pulsating air-gap field. A low power factor increases current demand and copper losses, reduces overall efficiency, and can impose additional stress on distribution networks, motivating continued efforts toward power factor improvement and loss reduction in such drives (Kaplun et al., 2022).

Capacitor-assisted configurations are widely adopted to mitigate these limitations. By introducing a phase displacement between the main and auxiliary winding currents, the series capacitor establishes a quasi-rotating magnetic field that enhances starting capability and can improve the steady-state power factor (Anagreh & Al-Ibbini, 2023; Dawood & Ali, 2022). However, the effectiveness of this approach is highly sensitive to the selected capacitance value. Undersized capacitance leads to insufficient phase shift and weak starting torque, whereas oversized capacitance can cause overcompensation, increased reactive current, higher losses, and reduced efficiency or overheating risk (Muteba, 2021).

Recent research has therefore focused on optimizing the interaction between winding design and capacitive compensation to enhance efficiency, torque, and power factor in single-phase and related induction motor topologies (Chasiotis & Karnavas, 2020). Several works have demonstrated performance improvements using analytical models, finite-element analysis, or power-electronic replacements for fixed capacitors, yet most investigations emphasize loaded operation, variable-speed control, or design optimization rather than systematic experimental characterization of unloaded machines (Almani et al., 2021; Kurt & Fenercioglu, 2025). Experimental studies specifically addressing the influence of capacitor value on key performance indicators such as power factor, stator current, starting voltage, and rotational speed under no-load conditions remain comparatively limited and report differing trends depending on motor design and operating regime (Alsharida et al., 2021; Al-Yoonus & Alyozbaky, 2021).

Accordingly, the present study experimentally examines the effect of capacitor capacitance variation on the power factor and principal operating parameters of an unloaded single-phase induction motor. The evaluated quantities include power factor, stator current, electrical power consumption, starting voltage, and rotational speed. The findings are expected to provide practical guidance for capacitor selection that improves power factor while avoiding unnecessary increases in current and energy consumption in single-phase induction motor applications.

RESEARCH METHODS

This study employs an experimental research design to investigate the effect of capacitor capacitance variation on the power factor of a single-phase induction motor. The experimental approach was selected to directly observe changes in motor operating characteristics resulting from different capacitor values under controlled laboratory conditions (Resketi et al., 2023).

Experimental Setup and Location

The experiment was conducted at the Electrical Engineering Laboratory over a seven-week period from April to May 2024. All measurements were performed under controlled environmental conditions to minimize external disturbances and ensure measurement consistency.

Test Object

The test object was a capacitor-start single-phase induction motor with the following specifications: nominal voltage of *230 V*, frequency of *50 Hz*, rated power of *1/3 HP*, rated current of *1.4 A*, and nominal power factor of 0.87.

All experiments were performed under no-load conditions, ensuring that the observed variations in electrical parameters were solely attributable to changes in capacitor capacitance (Sharma et al., 2016).

Research Variables

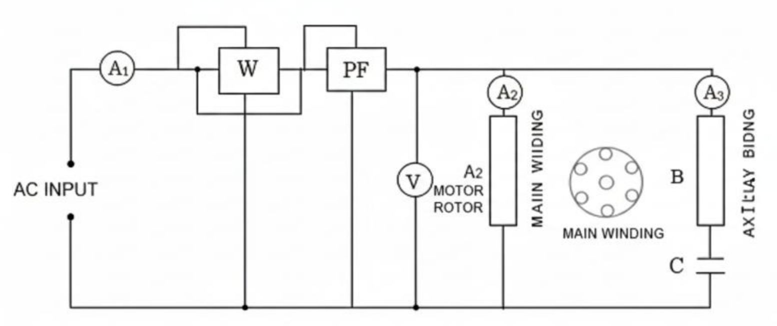
In order to ensure clarity and reproducibility of the experimental analysis, the variables considered in this study are defined and classified as follows.

1) Independent variable: capacitor capacitance (*4 μF, 6 μF, 12 μF, and 18 μF*).
2) Dependent variables: power factor ($\cos \varphi$), total stator current, electrical power consumption, starting voltage, and rotational speed (*RPM*).
3) Controlled variables: supply voltage (100 *V* during testing), supply frequency (*50 Hz*), motor configuration, and no-load operating condition.

Instruments and Materials

The experimental setup utilized standard electrical measurement instruments, including a wattmeter, voltmeter, ammeter, power factor meter, digital tachometer, variable power supply, and digital multimeter (Negahdari et al., 2019). Capacitors with different capacitance values were installed sequentially according to the experimental configuration shown in Figure 1.

Figure 1. Experimental setup of the single-phase induction motor test under no-load conditions.



All instruments were operated in accordance with the manufacturers' specifications to ensure measurement reliability.

Experimental Procedure

To systematically evaluate the effect of capacitor capacitance variation on motor performance, the experimental procedure was conducted through the following sequential steps.

1) Assembling the test circuit according to the configuration shown in Figure 1.
2) Conducting an initial test without a capacitor to establish baseline operating conditions.
3) Installing capacitors with capacitance values of *4 μF, 6 μF, 12 μF, and 18 μF* sequentially in the auxiliary winding circuit.
4) Energizing the motor and recording electrical parameters, including supply voltage, stator current, electrical power, power factor, and rotational speed.
5) Repeating measurements for each capacitance value under identical operating conditions.

All measurements were taken after the motor reached a steady-state condition to avoid transient effects during startup.

Data Analysis

The experimental data were organized in tabular and graphical forms to illustrate the relationship between capacitor capacitance and motor operating parameters. A descriptive–comparative analysis was employed to evaluate changes in power factor, current, power consumption, starting voltage, and rotational speed across different capacitance values (Kumar et al., 2014). The capacitor value that yielded the highest power factor with relatively low current and power consumption was identified as the most effective capacitance under no-load conditions.

RESULTS AND DISCUSSION

Research Result

Motor Performance without Capacitor

The initial experimental condition was conducted to evaluate the baseline behavior of the single-phase induction motor in the absence of capacitive assistance. This test was intended to confirm the necessity of a phase-shifting element for initiating motor rotation and to establish a reference condition for subsequent comparisons.

Table 1. Experimental Results of the Single-Phase Induction Motor without Capacitor

Test conditions:
Stator resistance $R_u = 16.6\ \Omega$
Auxiliary winding resistance $R_b = 55.1\ \Omega$

No.	Capacitor (μF)	Supply Voltage (V)	Total Current (A)	Main Winding Current (A)	Auxiliary Winding Current (A)	Power (W)	Power Factor	Speed (RPM)	Remarks
1	-	100	-	-	-	-	-	-	Motor did not rotate

Note: As reported in the *Results* section, the motor was unable to rotate in the absence of a capacitor, even when a supply voltage of *100 V* was applied. Consequently, current, power, power factor, and rotational speed could not be measured.

As shown in Table 1, the motor did not rotate when supplied with a voltage of *100 V* without capacitor installation. Under this condition, no measurable values of stator current, electrical power, power factor, or rotational speed were obtained. This result confirms that, without an auxiliary phase-shifting component, a single-phase induction motor is unable to generate the rotating magnetic field required for operation.

Motor Performance with Capacitor Installation

Following the baseline test, the motor was evaluated with capacitor installation to examine the effect of different capacitance values on its operating characteristics. Capacitors with capacitance values of *4 μF, 6 μF, 12 μF,* and *18 μF* were installed sequentially under identical test conditions.

Table 2. Experimental Results of the Single-Phase Induction Motor with Capacitor Installation

Test conditions:
Stator resistance $R_u = 16.6$
auxiliary winding resistance $R_b = 55.1$

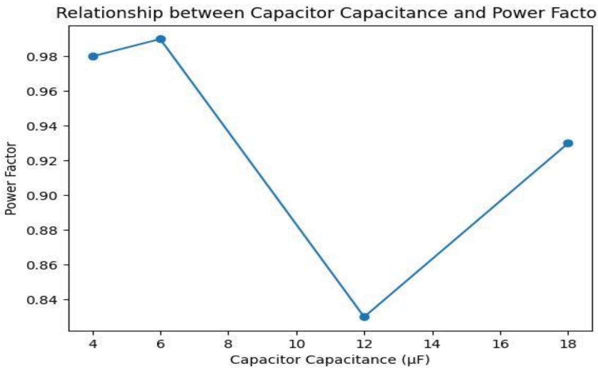
No.	Capacitor (μF)	Starting Voltage (V)	Supply Voltage (V)	Total Current (A)	Main Winding Current (A)	Auxiliary Winding Current (A)	Power (W)	Power Factor	Speed (RPM)	Operating Condition
1	4	90	100	0.32	0.20	0.10	30	0.98	2978	Lagging
2	6	75	100	0.35	0.05	0.30	34	0.99	2973	Leading
3	12	50	100	0.94	0.35	0.65	75	0.83	2950	Leading
4	18	42	100	1.55	0.82	0.78	145	0.93	2912	Leading

The data presented in Table 2 indicate that capacitor installation enabled the motor to operate and reach rotational speeds close to synchronous speed. However, variations in capacitance resulted in noticeable differences in power factor, stator current, electrical power consumption, starting voltage, and rotational speed. These results demonstrate that capacitor capacitance plays a critical role in determining the electrical and mechanical performance of the motor.

Effect of Capacitor Capacitance on Power Factor

To further illustrate the influence of capacitor capacitance on motor performance, the relationship between capacitance and power factor is examined graphically to emphasize changes in phase characteristics.

Figure 2. Relationship between Capacitor Capacitance and Power Factor



As illustrated in Figure 2, the power factor is strongly affected by capacitor capacitance. A lagging power factor is observed at a capacitance of *4 µF*, while higher capacitance values *(6 µF, 12 µF, and 18 µF)* shift the operating condition toward a leading power factor. The highest power factor values occur at *4 µF* and *6 µF*, followed by a reduction at higher capacitance levels.

Effect of Capacitor Capacitance on Starting Voltage

The effect of capacitor capacitance on the starting voltage of the motor is analyzed to assess how capacitance influences the voltage required to initiate motor operation.

Figure 3. Relationship between Capacitor Capacitance and Starting Voltage

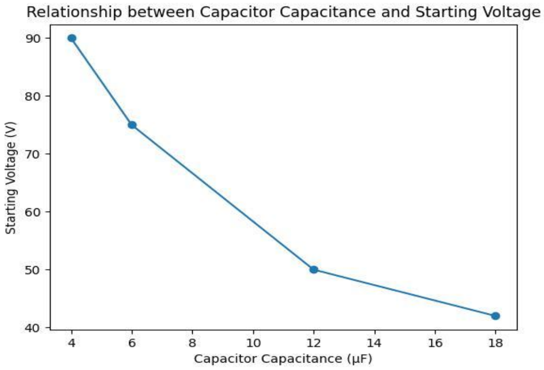
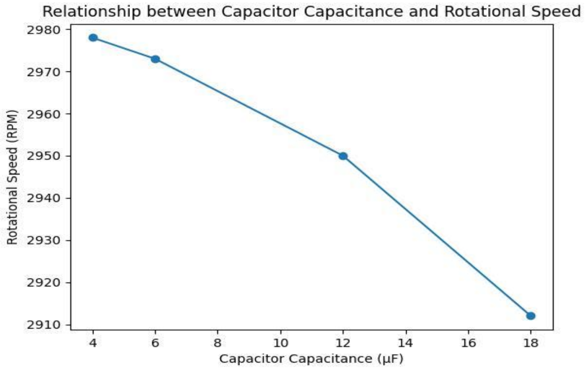


Figure 3 shows that the starting voltage decreases as capacitor capacitance increases. The highest starting voltage is observed at *4 µF*, whereas the lowest starting voltage occurs at *18 µF*. This trend indicates that larger capacitance values reduce the voltage required during motor startup.

Effect of Capacitor Capacitance on Rotational Speed

The variation in rotational speed resulting from changes in capacitor capacitance is presented to illustrate its effect on motor mechanical performance under no-load conditions.

Figure 4. Relationship between Capacitor Capacitance and Rotational Speed



As shown in Figure 4, motor rotational speed decreases gradually with increasing capacitance. The maximum speed is achieved at a capacitance of *4 μF*, while the minimum speed is recorded at *18 μF*, indicating that excessive capacitance adversely affects steady-state rotational speed.

Effect of Capacitor Capacitance on Total Stator Current

To evaluate the electrical demand imposed on the motor, the relationship between capacitor capacitance and total stator current is examined.

Figure 5. Relationship between Capacitor Capacitance and Total Stator Current

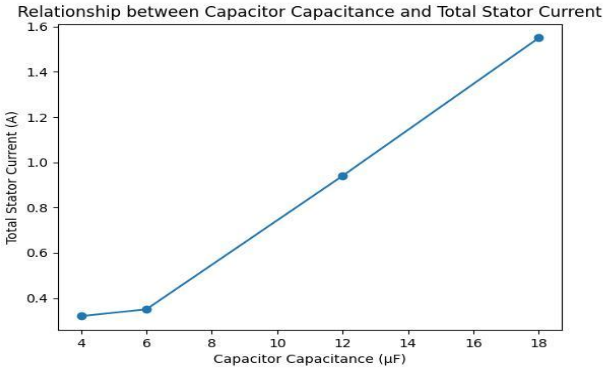
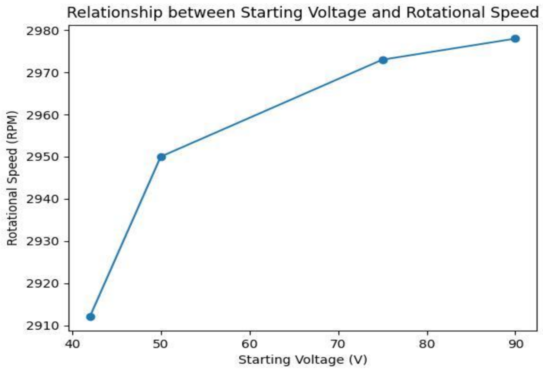


Figure 5 demonstrates that total stator current increases with increasing capacitance. The lowest current is observed at *4 μF*, while the highest current occurs at *18 μF*. This result reflects the increasing electrical load associated with higher capacitive compensation.

Relationship between Starting Voltage and Rotational Speed

The combined influence of starting voltage on motor rotational speed is examined to identify trends in motor response during startup.

Figure 6. Relationship between Starting Voltage and Rotational Speed



As illustrated in Figure 6, the relationship between starting voltage and rotational speed is non-linear. In general, higher starting voltage corresponds to higher rotational speed, although the rate of increase varies across different operating conditions.

Relationship between Stator Current and Electrical Power Consumption

Finally, the relationship between stator current and electrical power consumption is presented to clarify how current demand translates into power usage.

Figure 7. Relationship between Stator Current and Electrical Power Consumption

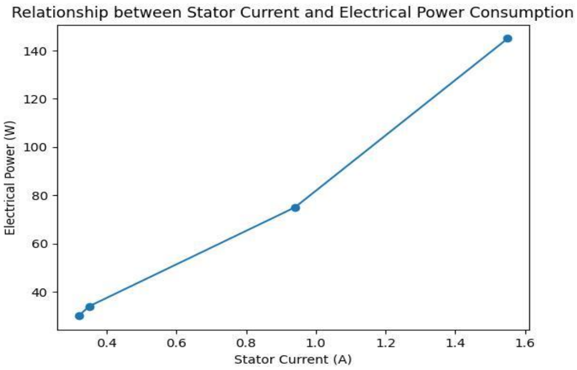


Figure 7 shows a direct relationship between stator current and electrical power consumption, where increases in current are accompanied by corresponding increases in power consumption.

DISCUSSIONS

The experimental results clearly demonstrate that capacitor capacitance significantly influences the electrical and mechanical characteristics of a single-phase induction motor operating under no-load conditions. The absence of a capacitor prevented motor rotation, highlighting the essential role of capacitive phase shifting in enabling motor operation.

Among the tested capacitance values, a capacitance of *4 μF* produced the most favorable operating condition. At this value, the motor achieved a high power factor while maintaining relatively low stator current and electrical power consumption. This indicates that the capacitive reactance at 4 *μF* effectively compensates for the inductive nature of the stator windings, resulting in a more balanced phase relationship between voltage and current.

As capacitance increased beyond *4 μF*, the operating condition shifted toward a leading power factor, indicating overcompensation. Although the magnitude of the power factor remained relatively high, the accompanying increase in stator current and electrical power consumption suggests reduced electrical efficiency. This behavior is attributed to excessive capacitive reactive current, which circulates within the motor windings without contributing to useful mechanical output.

The observed reduction in rotational speed with increasing capacitance further supports this explanation. Excessive capacitive compensation alters the electromagnetic field distribution in the motor, leading to changes in torque production and steady-state speed, even under no-load conditions. Similar trends have been reported in previous experimental studies, which emphasize that inappropriate capacitor sizing can negatively affect motor performance despite apparent improvements in power factor magnitude.

From a theoretical standpoint, capacitors in single-phase induction motors are intended to generate a phase-shifted auxiliary current that approximates a rotating magnetic field. When the capacitance value is appropriately selected, this mechanism improves power factor and reduces unnecessary current flow. However, excessive capacitance introduces surplus reactive power, increasing copper losses and degrading overall efficiency.

The results of this study are consistent with prior findings reported in the literature, which indicate that optimal capacitor selection is highly dependent on motor parameters and operating conditions. The identification of *4 μF* as the optimal capacitance under no-load conditions reinforces the importance of experimental validation when determining capacitor values for practical applications.

CONCLUSION

This study demonstrates that capacitor capacitance variation has a significant influence on the power factor and operating characteristics of a single-phase induction motor under no-load conditions. The installation of a capacitor enables motor operation by introducing the required phase displacement and directly affects power factor, stator current, electrical power consumption, starting voltage, and rotational speed.

Among the tested capacitance values, a capacitance of 4 μF provides the most favorable performance, yielding the highest power factor while maintaining relatively low current draw and electrical power consumption. Increasing the capacitance beyond this value tends to shift the operating condition toward excessive *leading* compensation, which is accompanied by higher current and power consumption as well as a reduction in rotational speed.

These findings highlight the practical importance of selecting an appropriate capacitor value to achieve effective power factor improvement without incurring unnecessary energy losses. From an application perspective, proper capacitor sizing is essential to ensure efficient and stable operation of single-phase induction motors.

The present study is limited to a single motor type operating under no-load conditions. Future research is recommended to investigate the effects of capacitor capacitance under varying load conditions and across different motor ratings to enhance the generalizability of the results.

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