Effect of the placement capacitor bank on electrical power quality in the ILST fan drive system

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ABSTRACT

Power quality is a critical aspect of the effective and dependable operation of electrical systems. In today's technologically advanced world, where industries rely significantly on electricity, understanding and maintaining power quality is critical. National Research and Innovation Agency (BRIN) has an important laboratory for aerodynamic testing technology service activities in Indonesia. This facility contains a closed wind tunnel, a DC drive system, and a DC electric motor. This innovative fan drive system employs a parallel DC drive system, with the master and slave motors connected to a master DC drive system and a slave DC drive system, respectively. The usage of a new system results in poor electrical power quality, with a power factor value of less than 0.85, resulting in higher electricity costs and increased current, which has an impact on other equipment, such as a rise in temperature. To improve the quality of electrical power according to standard operating procedures and lower electricity bills, the current work evaluated the new system using field tests and literature studies on the impact of installing capacitor banks in parallel DC motor systems to boost the power factor value. This evaluation aims to improve the quality of the ILST parallel electric power system by including a capacitor bank in each motor.

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1. INTRODUCTION

The Aerodynamics, Aeroacoustics, and Aeroelastic Laboratory (LA3) Unit has the capability to conduct evaluations of technological feasibility to assess its suitability for deployment in Indonesia. Comprising a closed wind tunnel, a DC electric motor, and a DC driving system, Indonesia low speed tunnel (ILST) facility incorporates advanced fan drive technology employing a parallel DC drive system [1]. The master and slave motors are linked in parallel to the master and slave drive systems, respectively. The DC motor parallel system has proven to be effective and efficient in the use of electric power, and the motor operates at a constant speed. Furthermore, this system maintains harmonic quality in accordance with IEEE standards [2]. The power supply for ILST is provided by two transformers with a capacity of 3 MVA, solely dedicated to testing operations. This study will assess the ILST drive system through field observation and literature review, with each DC motor being supported by an independent capacitor bank; therefore, the title of this research is the effect of the placement of 2 x 420 kVAR capacitor banks on the quality of the electric power ILST fan drive system. To conduct a thorough literature review and system identification, extensive data calculations and analysis were conducted. These efforts aimed to assess the current condition of the system and propose alternative solutions for enhancing system quality, especially concerning power factor values. By leveraging this information, enhancements can be made to the quality and efficiency of the ILST system [3]. Wind tunnel testing has advanced quite quickly since the turn of the century, with aerodynamic design remaining largely the same throughout the development cycle [4].

Wind tunnel testing is a popular tool for guiding specific design choices in thermal-fluid systems [5]. BRIN's Aerodynamics, Aeroacoustics, and Aeroelastic Laboratory (LA3) is tasked with preparing the application of technology related to aerodynamics, aeroelastics, and aeroacoustics, as shown in Figure 1, which has 4 test sections, namely an external balance, sting support, industrial, and empty boxes that can be interchanged, with a cross section of 3×4 m^2. The operating speed when testing models or samples is 70 m/s. This can be achieved with a 2.1 MW DC motor, which rotates an 8-blade fan with a diameter of 6 m. A DC drive is essentially a DC motor speed control system, as shown in Figure 2, that feeds power to the motor, allowing it to operate at the specified speed [6]. This setup involved driving the DC generator at a constant speed using an induction motor, and a variable voltage could be generated by adjusting the generator's field.

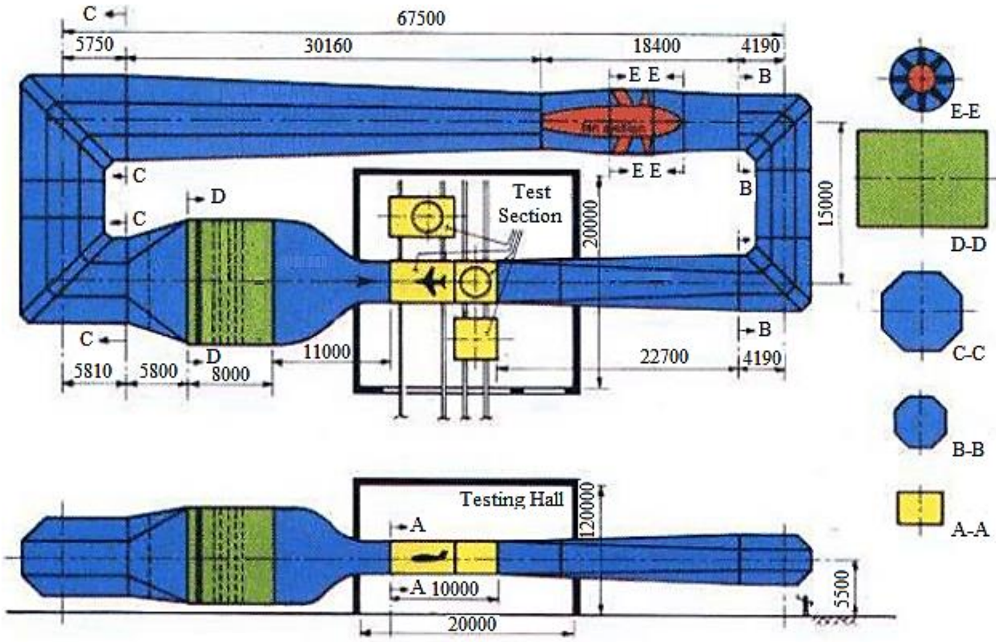


Figure 1. Indonesia low speed tunnel (ILST)

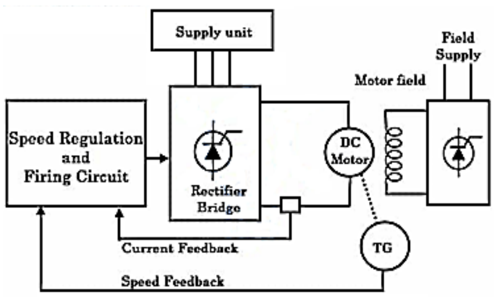


Figure 2. Schematics components of DC drives system

DC motor drives were used, and they have several advantages, such as only necessitating a single power conversion from AC to DC, being an adaptable speed machine, and being capable of achieving dynamic braking or regenerative braking in applications [7] and [8]. The investigation in this study concerning controlled rectifier drives will center on a three-phase controlled drive. The firing angle of the thyristors determines the level of DC output voltage generated by this rectifier. Consequently, harmonics will naturally arise [8]. Output voltage waveform, as in (1).

$$h = n \cdot f_{in} \quad (1)$$

Input current waveform, as in (2).

$$(mn \pm 1) \cdot f_{in} \quad (2)$$

Where: n = 1, 2, 3, …; f_{in} = input ac frequency; and m = pulse type of the bridge used in the drive.

In this study, the alternating current (AC) voltage input operates at a frequency of 50 Hz. Given that the DC drive utilizes a six-pulse configuration, this condition leads to the resulting formulations of (1) and (2) as (3) and (4). Output voltage waveform, as in (3).

$$h = 50n \quad (3)$$

Input current waveform, as in (4).

$$(5n \pm 1) \cdot 50 \quad (4)$$

Concerning the waveform of the output voltage, the subsequent equations delineate its average and root mean square (rms) values. [8], as (5) and (6).

$$\text{Vdc} = \frac{3\sqrt{3Vm}}{\pi}\, Cos\, \alpha \quad (5)$$

$$\text{Vrms} = \sqrt{3Vm}\sqrt{\frac{1}{2} + \frac{3\sqrt{3}}{4\pi}\, Cos\, 2\alpha} \quad (6)$$

Where: Vm is the peak value of the ac input voltage; and α is the firing angle.

Total harmonic distortion (THD) of an ac waveform is defined as how close the waveform is to a pure sinusoidal waveform. When a DC component is present, the THD is computed as (7) [8], [9].

$$\text{THDv} = \sqrt{\frac{V_{rms}^2 - V_{1,rms}^2}{V_{1,rms}}} \quad (7)$$

Where: V_{rms} represents the overall root mean square (rms) value of the waveform, encompassing the direct current (DC) component; and V_{1rms} denotes the rms value of the fundamental component of the waveform.

The displacement power factor and the distortion power factor amalgamate to constitute the input total power factor [10] [9] that is predominantly affected by the firing angle applied to the bridge thyristor, while the distortion power factor is predominantly influenced by the level of distortion, or THD [11], present in the system. Power quality encompasses the capacity of electrical equipment to efficiently utilize the supplied energy [12], including voltage instability, poor power factor, and harmonics [13], [14], and imbalances from electrical equipment such as electric motors. A proper torque vector control can also save energy for an electric motor [15]. Electric motors consume approximately 53% of global power consumption [16]. Due to concerns regarding climate change and crude oil costs, electric vehicles have garnered significant attention recently [17]. This has several effects, including increased energy consumption, prices, maintenance costs, instability and failure devices, and the need for energy management systems. Facts offer rapid control, including voltage, current, and phase angle. Additionally, they can regulate active and reactive power [18].

Harmonic filtering is the most effective approach to removing distortion from the power system while simultaneously providing reactive power for power factor correction coupled in series with a reactor. The values of L and C are configured to offset the necessary reactive power and to nullify the negative and zero sequence current components resulting from circuit imbalance [19], [20]. A standard harmonic filter comprises series resonant circuits for the 5th, 7th, and 11th harmonics. Simple calculations can be employed to identify the system's resonant frequencies [21]. The presence of resonances in close proximity to the characteristic harmonic frequencies of loads, identified as sources of harmonics, serves as an early warning sign of potential issues.

$$\text{h} = \frac{1}{2\pi\sqrt{Lsc * C}} = \sqrt{\frac{Xc}{Xsc}} = \sqrt{\frac{MVAsc}{MVAr}} \approx \sqrt{\frac{(100 * kVAtx)}{(kVAr * Ztx\%}} \quad (8)$$

Where: L_{sc} = short-circuit inductance (X_{sc} = reactance); C = capacitance of bank (Xc = reactance); MVA_{sc} = short-circuit capacity; MVA_r/kVA_r = capacitor bank rating; kVA_{tx} = stepdown transformer rating; and $Z_{tx\%}$ = stepdown transformer impedance.

The analysis of leading and lagging currents presumes that the system's loads exhibit linear voltage-current characteristics. Under specific assumptions, the power factor aligns with the displacement power factor (DPF). The displacement power factor has been fully computed. Using the conventional power factor triangle, the relationship can be summed up as (9).

$$\text{DPF} = \text{Cos}\,\varphi = \frac{kW}{kVA} \tag{9}$$

The method for calculating the power factor by nonlinear loads on the system. The ratio of real power to the circuit's total volt-amperes is known as the true power factor (TPF), as in (10).

$$\text{TPF} = \frac{Power\ real}{Volt\ Amperes\ total} = \frac{P}{Vrms{*}Irms} \tag{10}$$

The industry has developed a capacitor bank to enhance power factor and system efficiency for reducing harmonic voltage and correcting reactive power [22]. In distorted networks, shunt capacitor banks can be appropriately sized and positioned to achieve reducing harmonic voltage, correcting reactive power, improved voltage control, and reduced energy loss [23]-[25]. The capacitor current rating is calculated from its kilovolt-ampere-reactive (KVAR) rating by (11).

$$\text{KVAR} * \left(\frac{1000}{V}\right) = \text{amps} \tag{11}$$

2. METHOD

We utilized a research methodology to determine the optimal placement and sizing of capacitors. The capacitor bank was strategically located at two points employing the optimal capacitor placement method, leveraging ETAP software to analyze the electric power system's distribution to a feeder and its optimal capacitor placement feature, to determine the suitable size and placement of the capacitor bank. Meanwhile, determining the size of the capacitor bank capacity is based on the results of online measurements of the power factor capacity at a speed of 70 m/s, cos phi 0.75. When the power factor at that speed is known, the target power factor is determined, cos phi 0.85. From these two data, we can calculate the reactive power capacity of the capacitor that will be installed, so that the capacitance value per step is known. The research procedures are outlined into stages, as depicted in the flowchart shown in Figure 3 [2].

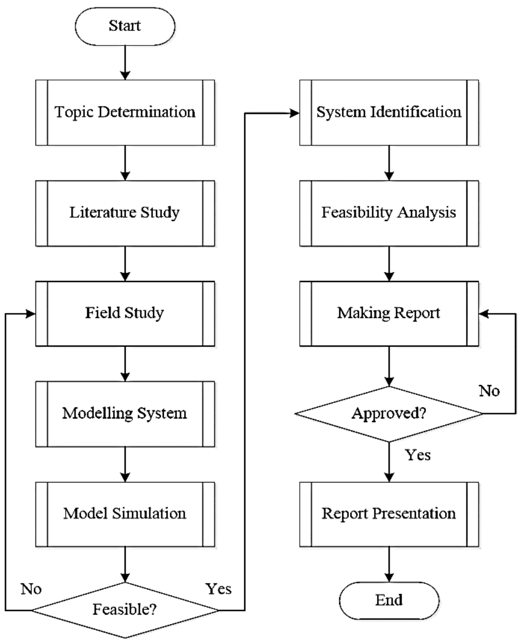


Figure 3. Research methodology flow chart

The selection of the paper's topic stems from the analysis of power factor measurements, comparing the ILST system's operation without a capacitor bank, as show in Figure 4 to its operation with a capacitor bank, as show in Figure 5, along with consideration of the monthly electricity bills reported by the local PLN. The author carried out direct measurements on the system using a power quality analyzer to obtain more accurate data and also carried out calculations based on existing data. Data is taken through direct measurements of the fan drive electrical parameters of the slave and master systems using a PQ meter. The recorded electrical parameter data is then processed using Vision Plus software. The processed data is used to calculate the kVAR quantity and compare it with the kVAR measurement results. After getting the measurement data and calculation results, the authors conducted a study of the results of the measurements that had been made. The method used in the measurement is shown in Figures 6(a) and 6(b) [2], [3].

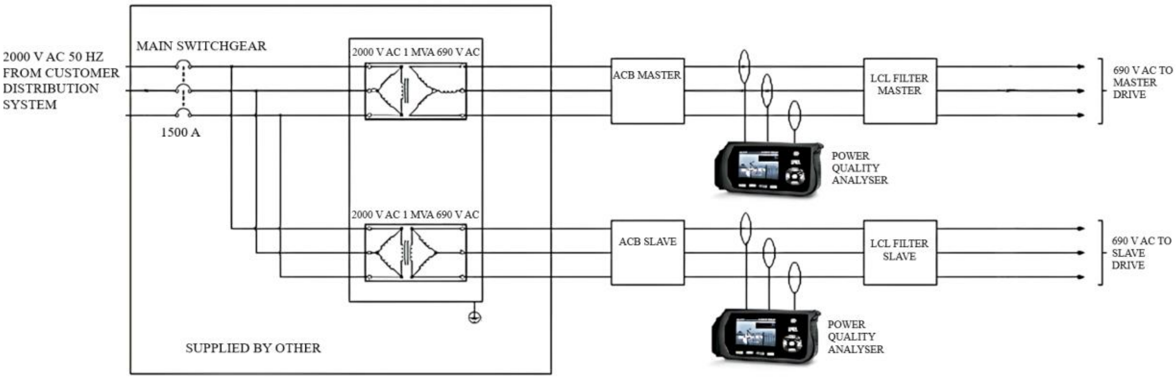


Figure 4. Single line diagram of ILST fan drive system without capacitor banks

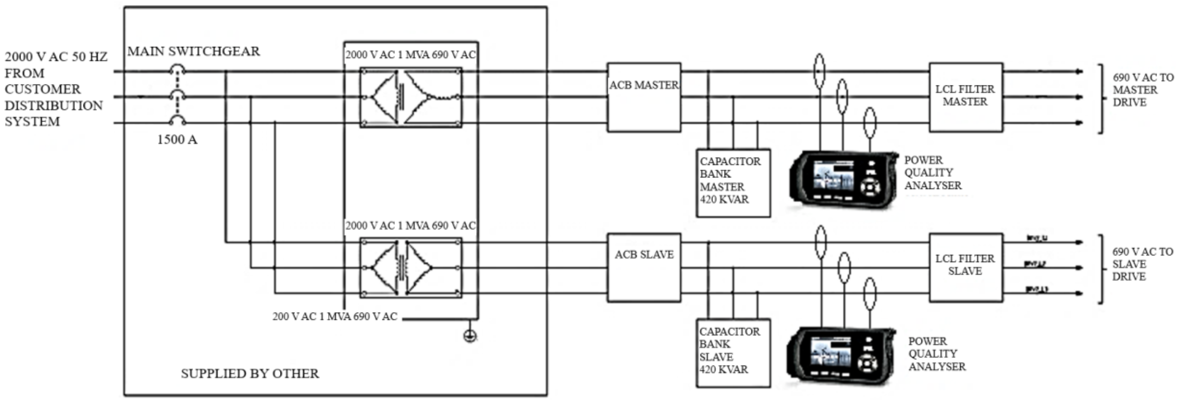


Figure 5. Single line diagram of ILST fan drive system with capacitor banks

3. RESULTS AND DISCUSSION

In this section, we will examine the current power factor of the fan drive system under two conditions: with and without a capacitor bank. By examining these scenarios, the author intends to offer suggestions for improving the power quality of the fan drive, with a specific emphasis on correcting the power factor. The capacitor banks, as a standard in the industry, play a role in compensating for reactive power within the electrical system and helping mitigate harmonic voltage [22]. Ideally, the voltage signal throughout the electric power system should be a stable sinusoidal waveform at 50 Hz. Although not without imperfections, the voltage signal produced by power system transformers closely resembles a near-perfect sinusoid with high precision. Nearly all electrical equipment is linked to this power system. Therefore, the electric power system is designed to operate on the basis of a sinusoidal voltage source [21].

3.1. Fan drive systems without capacitors bank

In this research, data was gathered while the ILST fan drive system underwent aerodynamic testing. The system operated at a velocity of 70 m/s, equivalent to a DC motor running within the range of 300 rpm.

Figure 6(a) shows the power factor characteristics of the existing fan drive power system. In the electric power system of the fan drive, from the initial stage until the rotation of the DC motor reaches 175 rpm, the power factor demonstrates a leading characteristic. Subsequently, it transitions to a lagging (inductive) characteristic from 180 rpm to 300 rpm, as depicted in Figure 7. The reactive power (AC input) measured by the instrument is observed to be capacitive from 0 to 175 rpm. This behavior can be attributed to the application of a capacitor bank in the LCL filter of the fan drive power system, which serves as an active system driver. As the rotational speed of the DC motor increases, the power factor value shifts towards the lagging region, accompanied by a decrease in capacitive reactive power. Figure 6(b). Explain when the rotation speed reaches 165 rpm, the power factor shifts to the lagging region, and the readings of reactive power (AC input) on the measuring instruments indicate inductive characteristics. With the ongoing increase in the DC motor's rotational speed, the power factor value decreases while the consumption of inductive reactive power rises. Ultimately, during the test run, the power factor value reaches 0.746 at 300 rpm, with a total reactive power consumption (AC input) of 849 kVAR.

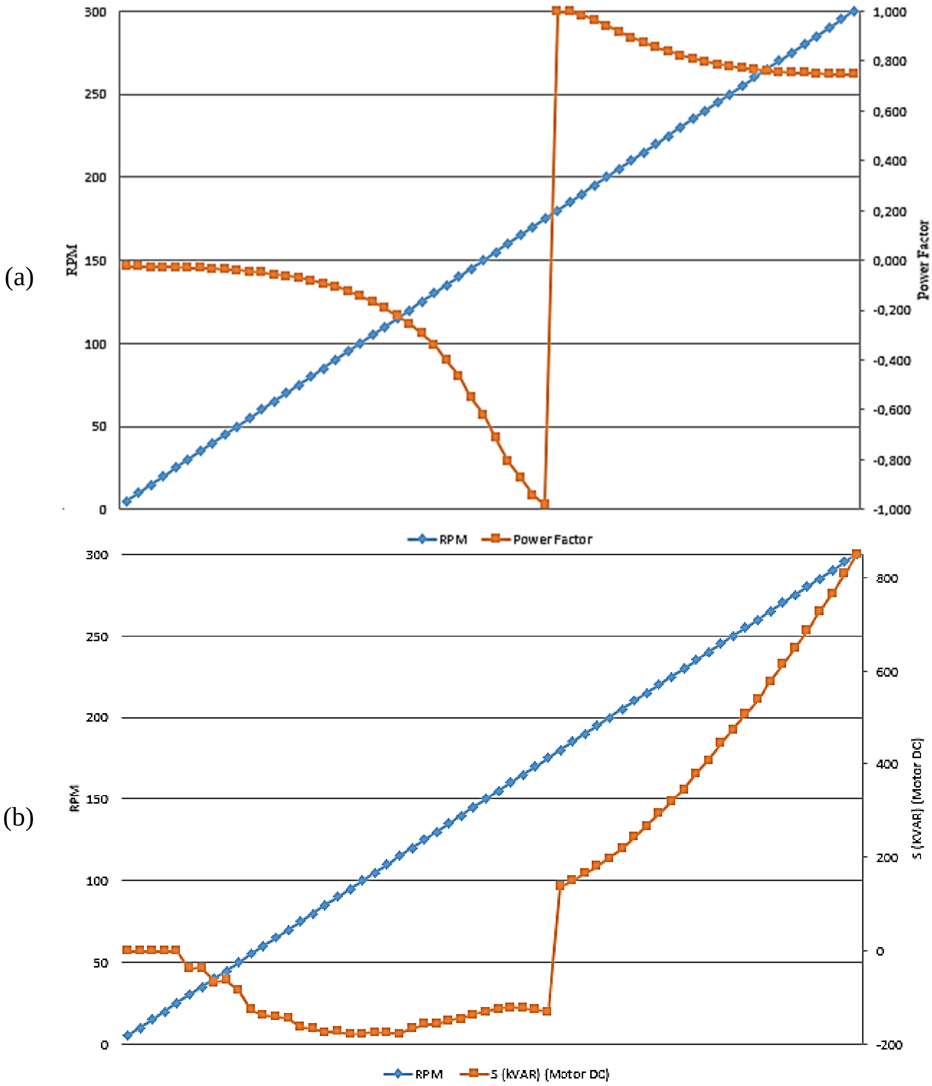


Figure 6. Characteristics without capacitors bank: (a) power factor characteristics before installed capacitor bank and (b) reactive power characteristics before installed capacitor bank

The AC supply is converted into DC by a DC drive power module. The DC power consumption of the motor is depicted in Figure 8. It is evident from the figure that as the rotational speed of the DC motor increases, so does the DC power consumption. At 300 rpm, the DC power consumption for each DC motor is 535 kW and 515 kW, respectively, resulting in a total of 1,050 kW.

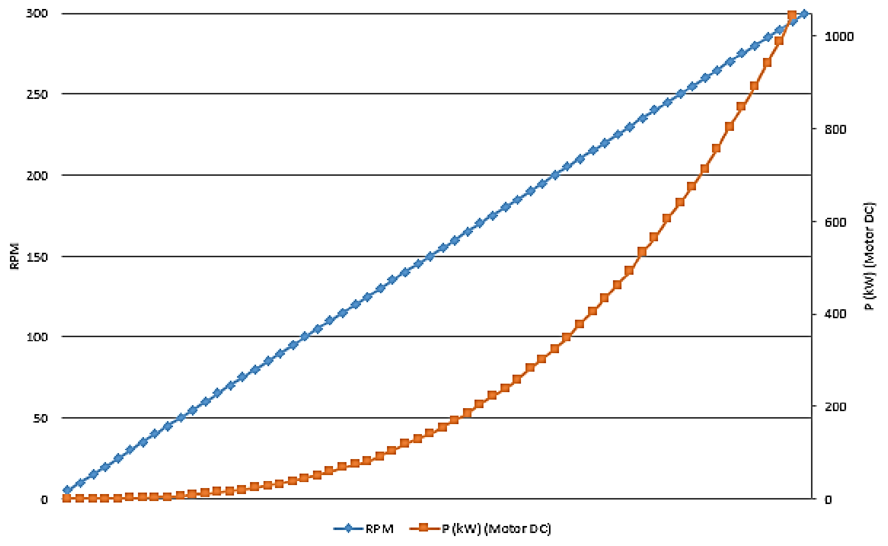
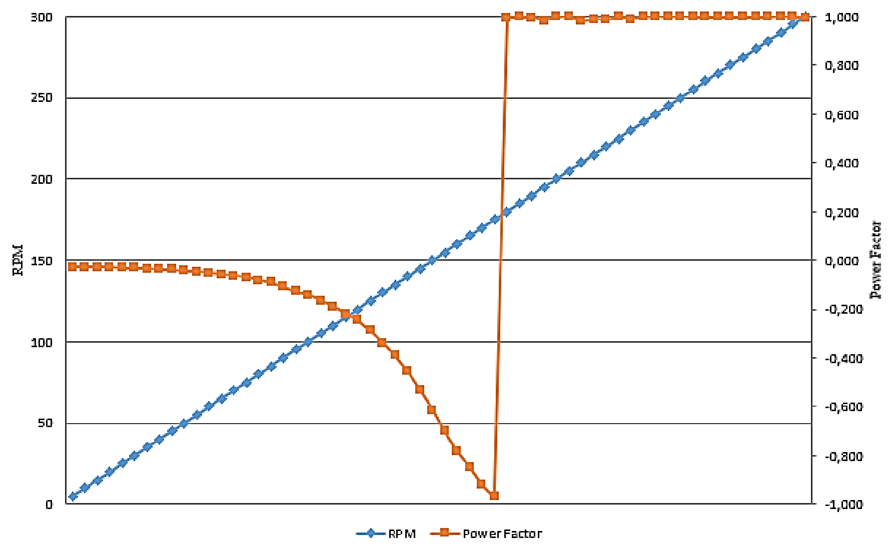


Figure 7. Active power characteristics without capacitors bank

(a)



(b)

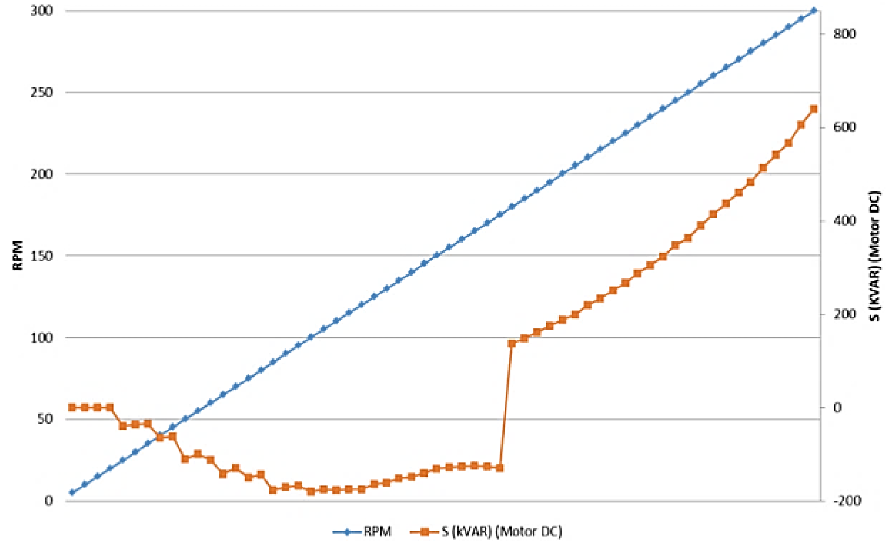


Figure 8. Characteristics with capacitors bank: (a) power factor characteristics after installed capacitor bank and (b) reactive power characteristics after installed capacitor bank

3.2. Fan drive systems with capacitors bank

In this research, several data points were recorded when the ILST fan drive system was run for aerodynamic testing using a power quality meter. The fan drive system is operated at a speed of 70 m/s with a target coefficient of friction of 0.85 at around 300 rpm. In the fan drive power system, the power factor from Figure 8(a). exhibits a leading (capacitive) characteristic from the initial stage until the DC motor rotation reaches 175 rpm, after which it transitions to a lagging characteristic from 180 to 300 rpm, as shown in Figure 9. Additionally, Figure 10 illustrates that the reactive power measured by the instrument is capacitive from 0 to 180 rpm. This occurrence is linked to the capacitor bank in the LCL filter, which is integrated into the fan drive power system as an active driver system. As the rotational speed of the DC motor increases, the power factor value moves towards the lagging region, accompanied by a decrease in capacitive reactive power. Figure 8(b). shows that at a rotation speed of 185 rpm, the power factor shifts towards the lagging zone, and the reading of reactive power (AC input) on the instrument indicates inductive characteristics. As the rotation speed of the DC motor continues to rise, the power factor value decreases while the consumption of inductive reactive power increases.

According to the conducted tests, the power factor reaches 0.994 at a rotation speed of 300 rpm, with a total reactive power consumption (AC input) of 576.2 kVAR. Specifically, the master bank capacitor accounts for 286.4 kVAR, while the slave bank capacitor contributes 289.8 kVAR. The AC supply is converted into DC by the DC drive power module, which serves as the power input for the DC motor. Figure 9 shows the power consumption of a DC motor. It's evident from the image that as the rotation speed of the DC motor increases, the DC power consumption also increases. At 300 rpm, the DC power consumption for each DC motor is 530 kW and 520 kW, respectively, resulting in a total of 1,050 kW.

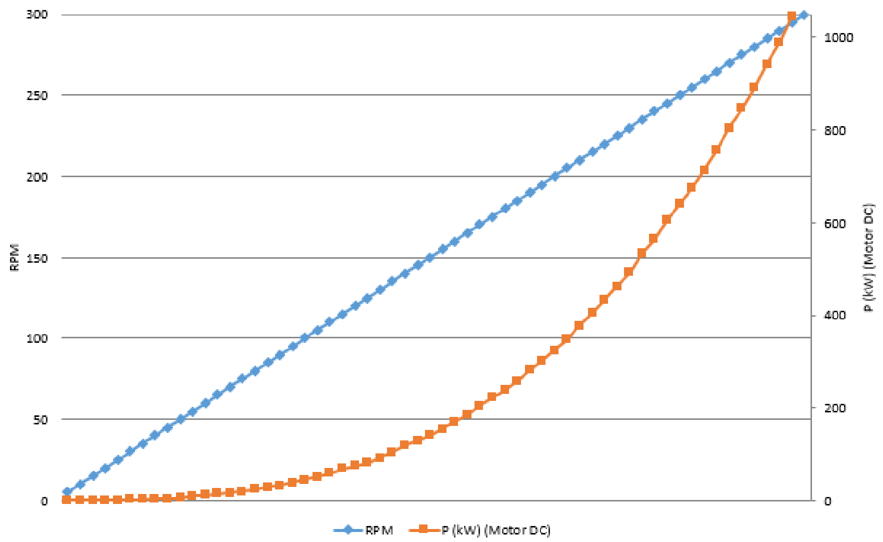


Figure 9. Active power characteristics with capacitors bank

4. CONCLUSION

From before and after installing the capacitor bank, it can be concluded that when the fan drive system does not use a capacitor bank, the power factor will decrease due to the increasing loading effect, which can endanger the system itself, but if a capacitor bank is added from 180 rpm to 300 rpm, the power factor tends to be more stable. in the range of 0.99, so it is effective in maintaining the voltage profile, reducing loading effects, reducing power losses, and being more efficient.

Judging from the use of reactive power, if not using a capacitor bank, the system absorbs reactive energy from PLN sources so that it can cause a penalty for the user because kVAR consumption has exceeded the minimum limit required by PLN of 0.85. However, when a capacitor bank is installed, the system's reactive power consumption is much more effective because it absorbs reactive energy from the installed capacitor bank compared to before because the capacitor bank is able to meet the reactive power requirements of a DC motor according to its load. Likewise with the real power consumption of the system when using a capacitor bank, power consumption is more efficient according to the increase in rpm on the DC motor. From this, the gradual increase in power does not necessarily increase sharply.

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