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Research Article

Power factor correction for energy efficient at public hospital of Manokwari

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Abstract
The power factor grades are an indicator to determine the effectiveness of the electric power either distributed or used by consumers. A high power factor indicates that the electrical loads are using energy efficiently. Due to the increase in inductive load, there will be a decrease in the power factor, which in turn affects the distribution of electrical energy. In this research, an investigation has been carried out to observe the background that influences the low power factor at public hospital (RSUD) of Manokwari and recommend the need for a basis for improving the power factor at the hospital. Primary data on lighting and electrical equipment, along with their respective electric power capacities and power factors, are collected and measured onsite. Then the data is analysed based on the theoretical basis of power factor improvement. Based on the investigation, there are two focus points in the hospital to be observed, i.e., motor pumps and total load at the main panel. The calculation results show that pump motors 2 and 3 need to be compensated by increasing the power factor to 0.9 so that reactive power is reduced to 1.42 kVAR and 1.24 kVAR, respectively. In the same way, apparent power can also be upgraded to 0.85 kVA and 1.46 kVA by installing bank capacitors of 30.35 μF and 26.63 μF, respectively. On the other hand, the largest load connected to the main panel needs to be corrected to reduce the reactive power and apparent power to 17.86 kVAR and 9.5 kVA through the installation of a capacitor bank of 387.75 μF. This correction will increase energy efficiency while gaining economic benefits on both electricity bills and waiving penalties.
Keywords: energy efficient; Manokwari; PLN; Power factor; RSUD.

1. Introduction

The availability of electrical energy is always related to financing issues, both in terms of investment costs to build the electricity generation and distribution system as well as operation and maintenance by the provider, as well as the issue of the cost of daily electricity usage in kilowatt hours (kWh) by consumers. In this regard, the electricity company as a provider and manager of the electric power system and consumers as users both expect the availability of a quality, efficient, and profitable power system for each party (A. J. Hanson & D. J. Perreault, 2018; Wahab et al., 2021).

The state electricity company (PLN) is responsible for overseeing all of Indonesia's electricity. In the process of managing electricity, PLN has various regulations that are generally based on standards that have been determined internationally, such as general electrical installation requirements, including regulations regarding power factor (cos θ).

The power factor is the use of reactive power (kVAR) by consumers, which is stipulated through the regulation of the Ministry of Energy and Mineral Resources (ESDM) (Ministry of ESDM, 2014) concerning electricity tariffs and kVAR rates provided by PLN to each consumer class. At a lagging current, PLN determines the power factor to be over 0.85; if it is less than this value, it is considered a low power factor.

There are two types of loads seen in distribution networks: capacitive loads and inductive loads. As a result of the voltage rate being delayed and the current wave position shifting in front of the voltage wave (leading), capacitive loads absorb active power and emit reactive power. Active and reactive energy are absorbed by inductive loads, which causes a delay in the current rate and a shift in the position of the current wave relative to the voltage wave (lagging). The power factor will drop as the inductive load increases. This will result in increased power losses and decreased capacity for power delivery (Karmiathi & Adiana Putra, 2022).

High harmonic content, distorted/discontinuous current waveforms, or a considerable phase mismatch between the voltage and current at the load terminals can all contribute to a poor power factor. An inductive load, such as an induction motor, power transformer, lighting ballasts, welder, or induction furnace, is typically the cause of poor load current phase angle. Power factor correction can help a bad power factor caused by an inductive load, but a poor power factor caused by a distorted current waveform necessitates expensive harmonic filters or a redesign of the apparatus in order to see a noticeable improvement (Pradhan et al.,2013).

The cause of the low power factor is due to the use of inductive electrical equipment found in the coil, such as electric motors, TL lamps, stavolts, welding equipment, and others. On the generation side, this condition will lead to a reduction in the capacity of the distributed electric power, so that the generator must increase its capacity to meet the shortage. Meanwhile, on the consumer side, the low factor can result in a reduction in the consumer's installed electric power capacity. This condition is, of course, detrimental to both providers and consumers, so efforts should be made to improve it (Karmiathi & Adiana Putra, 2022).

An important electrical power parameter that causes a lower power factor is reactive power. Reactive elements and three-phase system imbalances are the two main causes of it (Coman et al., 2020). For instance, when reactive power and unbalanced load current are absorbed by a single-phase load, AC rotary machines will experience additional losses. Low power factor caused by unbalanced current is highly disruptive to sensitive electronic equipment. Numerous authors have investigated various methods (Zaidi & Ali, 2018a).

The public hospital (RSUD) of Manokwari is a relatively large consumer of electric power and has currently increased its power capacity to 147 KVA, categorized in the social consumer class (S2). As a large consumer who also uses a lot of inductive electrical equipment such as electric motors, transformers in electronic circuits, stabilizers, and UPS, it is necessary to have complete data about electrical power and power factor values in the network that is useful for monitoring or evaluating the effectiveness and efficient use of electricity, both in the present and for future development purposes. RSUD Manokwari is currently in the process of being built to improve various facilities according to the current needs of health services, which are strongly influenced by the status of Manokwari city as the capital city of Papua Barat Province, which also has an impact on the capacity and needs of medical and non-medical equipment. The total electric power capacity requirement according to the data in the Manokwari Hospital development master plan is 2x400 KVA, so automatically consumers from the S3 social class (over 200 KVA) will be fined for excess kVAR usage due to a decrease in the power factor of the institution. For this reason, this study investigates the background that influences the low power factor and recommends the need for a basis for improving the power factor at Manokwari Hospital.

Based on the preliminary study, it was found that a detailed study to find an effective power factor solution at the Manokwari public hospital has never been carried out. Therefore, the novelty of this study is more emphasised in solving the problem of low power factor in the hospital.

2. Literature Review

Power factor improvement is crucial for efficient and reliable operation of electrical systems. It helps optimize energy usage, reduce losses, and ensure the optimal utilization of electrical infrastructure. This improvement refers to the process of increasing the power factor of an electrical system. The power factor is a measure of how efficiently electrical power is being used in a system. It is the ratio of real power (measured in kilowatts or kW) to apparent power (measured in kilovolt-amperes or kVA). A low power factor indicates that a significant portion of the electrical power is being wasted, leading to inefficiencies in the system.

In AC (alternating current) electrical systems, the power factor is affected by the phase difference between the voltage and current waveforms. Ideally, the voltage and current should be in phase, resulting in a power factor of 1 (or unity power factor). However, due to the presence of inductive loads such as motors, transformers, and fluorescent lighting, the current waveform can lag behind the voltage waveform, leading to a reduced power factor.

Due to the phase shift between the current and voltage, a portion of the AC power consumed by inductive loads is utilised to maintain magnetic reversals. This energy is considered squandered because it is not used for productive purposes. The purpose of power factor correction circuits is to reduce reactive power and improve the efficiency with which inductive devices consume AC power. Therefore, power factor improvement is essential for several reasons as follows.

a. **Efficient power usage**. A high power factor means that a larger portion of the apparent power is being converted into useful work (real power). This results in reduced energy losses, increased energy efficiency, and lower electricity bills (Abdelmenim et al., 2019; I. Ahmad et al., 2019; Karmiathi & Adiana Putra, 2022; Patra & Ramchandra, 2020; Pradhan et al., 2013.; Rahman et al., 2022; Sr et al., 2022).

b. **Reduced electrical system stress**. Low power factors can cause increased current flow in electrical distribution systems, leading to overheating of transformers, cables, and other equipment. Improving the power factor reduces the current flow, resulting in reduced stress on the system (Kalhari et al., 2022; Tarnapowicz & German-Galkin, 2019; Terui, 2019; Zaidi & Ali, 2018a).

c. **Compliance with utility requirements**. Some utility companies impose penalties or additional charges for low power factor, as it can cause additional strain on their distribution infrastructure. By improving the power factor, businesses can avoid these penalties and charges (Bakalos, 2020; Dimitrova & Zlatev, 2020; Maurya et al., 2020; Petrauskas & Svinkunas, 2021, Petrauskas & Svinkunas,2022).

There are several ways to enhance the power factor of a load or installation but incorporating power factor correction capacitors into the network is a prevalent method.

a. **Capacitor banks**. Capacitors can be connected in parallel with the inductive loads to supply reactive power, compensating for the lagging current and improving the power factor. Capacitor banks are commonly used for power factor correction in industrial and commercial applications (Dimitrova & Zlatev, 2020; Kalhari et al., 2022; Karmiathi & Adiana Putra, 2022; Rahman et al., 2022).

b. **Synchronous condensers**. Synchronous condensers are rotating machines that operate without a mechanical load but provide reactive power to the system. They are particularly useful in large power systems where significant reactive power support is required (Abdelmenim et al., 2019; Ahmed & Husain, 2018; Terui, 2019).

c. **Active power factor correction (APFC)**. APFC systems use power electronic devices such as thyristors or transistors to monitor the power factor in real-time and inject the required amount of reactive power to maintain a high power factor. APFC is commonly used in applications where the load varies dynamically(Aung, n.d.; Haneda, 2020; Panchade & Pathare, 2019; Sr et al., 2022; Zaidi & Ali, 2018b).

d. **Harmonic filters**. In systems with non-linear loads that introduce harmonic currents, such as variable speed drives, harmonic filters can be employed to mitigate the harmonics and improve the power factor (Masuda & Sugawara, 2021; Maurya et al., 2020; Rajalakshmi & Kavitha, 2018; Sr et al., 2022).

3. Methods

3.1. Research Procedures

The research was carried out at the public hospital (RSUD) of Manokwari with the following research procedures:

a) Conduct a preliminary study to set the stages of the research.
b) Collect data for each electrical component from the main panel to the branch panels.
c) Record the number of lighting and electrical equipment along with their respective electric power capacities.
d) Perform power factor measurements on 3-phase water pump motors and the main distribution panel (MDP).
e) Analyse the measurement results according to the theoretical basic as given in (Dimitrova & Zlatev, 2020; Kalhari et al., 2022; Karmiathi & Adiana Putra, 2022)
f) Provide recommendations for improvements to the electrical power factor at RSUD Manokwari.

3..2 Materials and Tools

The materials of this research will be the object to be observed at the RSUD of Manokwari as follows:

a) The materials used as research instruments are the electrical components used in the RSUD, which consist of: The main panel unit, which consists of main distribution panel (MDP), single distribution panel (SDP) of 1 and 2, transformers, a 3-phase generator set (genset), and all components of medical and non-medical electrical equipment, as well as all types of lighting used in buildings and the other areas of around the hospital.
b) The tool used for power factor measurement is a digital cosine metre with the type of Hioki 3286-20.

3.3. Observation Variables

The observation variables of this research including power factor, real power, and current and voltage at each section at:

a) The main panel as a source and supplier of electricity in all parts of the hospital,
b) The water pump room, which uses several 3-phase electric motors.
c) The air conditioning machine (AC) and TL lamp.

3.4. Power Factor

In its distribution, the AC electric power system is influenced by three types of loads, which must be controlled by the electricity provider and user for the effectiveness of the electrical power being distributed. The three are resistive loads, inductive loads, and capacitive loads, because not all of the power supplied from the a power grid or generator can be used entirely, but there are elements in it that affect the effectiveness of sending and using the electric power. Power factor (*pf*) is defined as the ratio of the active power (*P*) and apparent power (*S*). The high reactive power will increase the angle θ resulted in a lower power factor as ilustrated in Figure 1(Diniş et al., 2018).

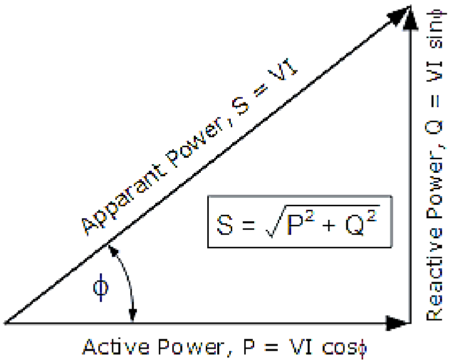

Figure 1 Triangle of power factors

The value of the power factor is a parameter used to determine the effectiveness of the electric power distributed and used by consumers. The burden on electrical installation's transformers and conductors is reduced via improved power factor adjustment. A low power factor raises the cost of electrical energy used, which has financial repercussions as well (Coman et al., 2020).

In Indonesia, PLN sets the power factor value at the limit of 0.85 to 1.0 for lagging power factor loads (inductive loads) and also for power factor loads that are leading (reactive loads), even though this load rarely occurs. The power factor beyond this value is considered detrimental to the provider because the capacity of the electricity distribution network is under pressure, so the generation source must increase or adjust the capacity of the electricity that is distributed to balance the reactive power requirements (Q) in the electricity network.

The electric power in the AC system as the name implies is generated from alternating electric waves (AC = Alternating Current / sinusoidal). In Joule's law, the electric power symbol P (watts) is defined as the rate of delivery of electrical energy per unit time (joules/second). that is (D. Ahmad & Muhammad, 2018; Kayisli et al., 2017; Wahab et al., 2021; Yendi & Sigit, 2021; Zaidi & Ali, 2018a):

$$P = VI\cos\theta \quad (1)$$

$$Q = VI\sin\theta \quad (2)$$

$$S = VI = \sqrt{P^2 + jQ^2} \quad (3)$$

$$pf = \frac{P}{S} \quad (4)$$

In equations 1 to 4, the parameters *P, Q, S, q, V, I*, and *pf* are the active power, reactive power, apparent power, power angle, terminal voltage, load current, and power factor, respectively.

Power factor is influenced by the electrics load connected to a power grid. The electrics load can be clasified in to thee types as folows (Sari et al., 2022).

a) **Resistive loads**. These loads come from electrical devices that are purely resistors, such as heating elements and incandescent lamps. Because it is passive, the resistive load will not shift the position of the current wave or AC voltage and so a sinusoidal wave on a purely resistive load. It can be seen in the Figure 2 that the value of the average power is always be positive because the voltage wave and electric current are in the same phase. This is why a purely resistive load will always be supported by 100% real power.

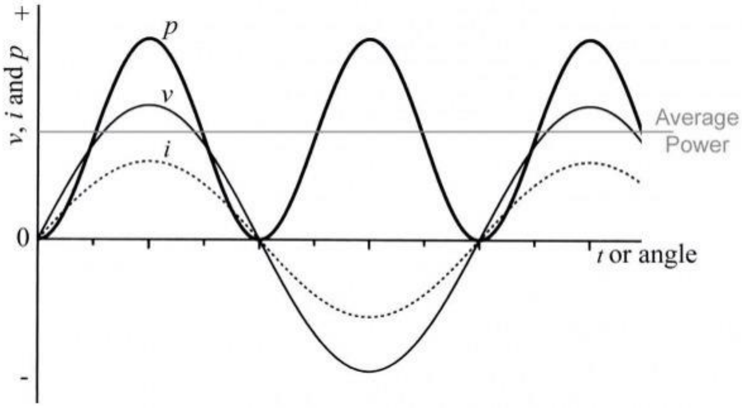

Figure 2 Sinusoidal Wave AC Resistive Load

b) **Inductive loads**. These loads come from equipment that uses wire coils (coils), such as motors, transformers, and relays. In operation, the coil requires magnetic field induction to work. The generation of this magnetic field becomes an inductive load so that it absorbs reactive power in the system and results in the loss of some of the electric power that is distributed along the electric power lines. This causes the provider to increase the capacity of the electric power source (generation) to overcome the excess reactive power so that the power factor can be close to 1. The AC system has a current value that goes up and down to form a sinusoidal wave, and the magnetic field in the coil is blocking changes in electric current, causing the electric current in the motor to lag 90 degrees against the electric voltage as in the sinusoidal graph. The electric current wave will be lagged 90° by the voltage wave when inductive load is applied as figured in Figure 3. It is on this basis that inductive loads are known as lagging loads (current lags voltage). It also appears that due to the shift in the electric current wave above, the average power value becomes zero. In the first quarter wave, the power is absorbed by the inductive load, but in the second quarter wave, the power is returned to the AC power source. This shows that a pure inductive load does not consume any real power; a pure inductive load only uses reactive power.

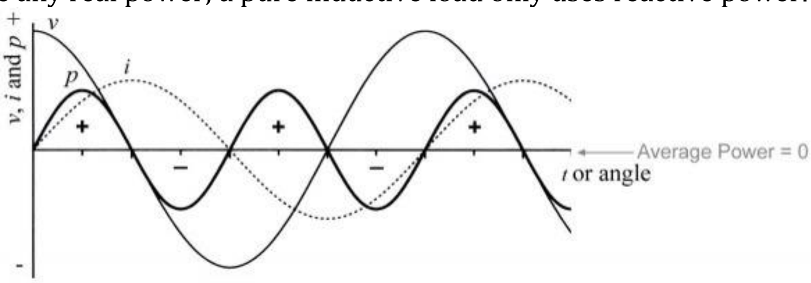

Figure 3 AC Electric Wave with Pure Inductive Load

c) **Capacitive loads**. These loads are the opposite of inductive loads. If the inductive load prevents changes in the value of the AC electric current, then the capacitive load prevents changes in the value of the electric voltage. This property indicates that the capacitor acts as if it stores a momentary voltage. The capacitive component is contained in a capacitor, which is an electrical device that is useful for balancing inductive loads, but its use requires precise calculations because it can cause a leading power factor to the voltage so that capacitors become reactive power-generating components. When a capacitive load is applied to AC voltage supply, the capacitor will store and release electric voltage according to changes in the input voltage so that the AC current waves lead the voltage by 90°.

3.5 Power Factor Correction

Electricity providers encourage industrial customers to increase their power factor for a variety of reasons. To begin with, increasing power factor can significantly reduce the monthly electricity bill. Secondly, a high power factor assists in minimising transformer efficiency losses. Adding a power factor correction system increases a consumer's electricity network's effective capacity so that it extends the life of electrical apparatus. A power factor compensation network reduces the power required by a load, thereby increasing the power factor overall. The compensation network enables electrical loads to attain a power factor between 0.95 and 0.98. In general, utility companies consider a power factor of 0.85 or less to be inadequate (D. Ahmad & Muhammad, 2018).

Widespread use of semiconductor devices for power factor correction is also common. Using semiconductors to enhance the power factor of a circuit is commonly referred to as active compensation. Commonly, overexcited synchronous machines are utilised to enhance the power factor of a network. In an AC circuit, magnetic reversal occurs 50 or 60 times per second owing to the phase difference between the current and voltage. A capacitor contributes to the enhancement of the power factor by alleviating the supply line of reactive power. This is accomplished by the capacitor storing the magnetic reversal energy.

Because the power factor is caused by an excess in the absorption of reactive power, certain groups of electric power providers are subject to fines if the total recorded kVARH usage in a month is higher than 0.62 times the number of energy usage and usage energy in peak load time of the concerned month both in kWh so that the average power factor (*pf*) is less than 0.85.

To improve the power factor, one must compensate for inductive power with reactive power sources through the use of capacitive capacitor components. The compensation process can be completed with the following steps:

- knows in advance the value of the initial power factor when machine tools or electrical networks are used by inductive loads.
- Calculates the corner value of the power factor according to the measured data.
- determines the value of the capacitor is done using the following equation (1) to (3).

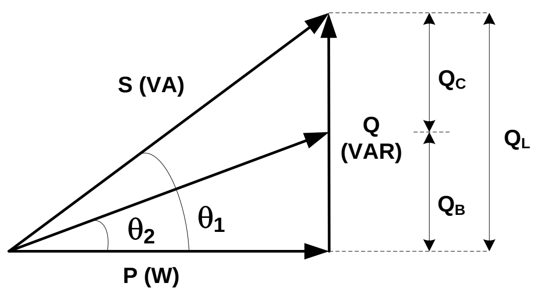

Figure 4 Power factor improvement diagram

Power factor correction can be based on Figure 4 (Wahab et al., 2021), where the reactive power of the current power factor (Q_L) and the desired power factor value (Q_B) are given as follows (D. Ahmad & Muhammad, 2018; Kayisli et al., 2017; Mohammad & Aji Muharam, 2017; Wahab et al., 2021; Yendi & Sigit, 2021; Zaidi & Ali, 2018a).

$$Q_C = Q_L - Q_B = S\sin(\theta_1 - \theta_2) \tag{5}$$

Based on the power triangle in Figure 1, it is shown that the angle θ is affected by the increasing of reactive power (Q), which is directly proportional to the apparent power (S). Therefore the capacitance needed to improve the power factor can be calculted as follows (D. Ahmad & Muhammad, 2018; Kayisli et al., 2017; Wahab et al., 2021; Yendi & Sigit, 2021; Zaidi & Ali, 2018a).

$$C = \frac{Q_C}{2\pi f V^2} \tag{6}$$

In equation (5) and (6), θ_1, θ_2, Q_C, f, and V are current power angle, desired power angle, desired reactive power, grid frequency, and grid voltage.

Capacitors are very useful in improving power factor, and typically, capacitors can be installed in three different ways, as follows:

a) **Global compensation**. In this way, the capacitor is installed in the main distribution panels (MDP). In this method, the corrected current is the total current in the conductor between the MDP panel and the transformer. While the current passing after MDP is not affected, losses due to heat dissipation in the conductor after MDP are relatively unaffected.
b) **Sectoral Compensation.** Installation of capacitors are directly on the single distribution panels (SDP).
c) **Individual Compensation**. In this way, the capacitor is directly attached to each load.

Power factor quantifies the effectiveness with which electrical loads convert electrical power into useful labour. It is the ratio of the functional power (working power) supplied to the total power (apparent power). A high power factor indicates that the electrical loads are using energy efficiently, whereas a low power factor indicates that the electrical loads are using energy inefficiently. A low power factor causes significant energy loss and reduces the electrical system's capacity. A phase difference between current and voltage at the terminals of an electrical load or a distorted current waveform can induce it (Karmiathi & Adiana Putra, 2022).

Connecting proper capacitors can remedy a low power factor caused by induction motors, transformers, and other inductive loads. Harmonic filters are used to remedy a low power factor produced by a distorted current waveform. The process of producing the magnetic field required by an inductive load results in a phase difference between voltage and current. A capacitor compensates for the lagging current by supplying a leading current. Power factor correction capacitors are intended to keep the power factor as near to one as feasible. Although power factor correction capacitors can significantly lower the demand on the supply caused by an inductive load, they have no effect on the load's operation. Capacitors serve to reduce electrical distribution system losses and costs by neutralizing magnetic current (I. Ahmad et al., 2019).

4. Results and Discussion

The public hospital (RSUD) of Manokwari, as a health service center for the people of Manokwari city and surrounding districts, requires the same thing to offset the need for increased facilities and infrastructure, namely the need for medical and non-medical equipment and improvements to building and room infrastructure at the RSUD to meet the needs of health services for the community.

The source of electricity at RSUD comes from the government electrical company (PLN) and is the main source used to supply electricity throughout the building and area of the hospital. Electric power is supplied from PLN, which is connected via a distribution transformer with a capacity of 160 kVA. Besides that, the RSUD uses a generator as a backup power source to support the continued availability of electric power when the PLN network is out or due to other disturbances. The generator unit installed has a capacity of 300 kVA of the silent type and has been operating since June 2014.

4.1. Electrical Loads

A low power factor caused by induction motors, transformers, and other inductive loads can be addressed by connecting appropriate capacitors. The addition of harmonic filters corrects a low power factor induced by a distorted current waveform (Kalhari et al., 2022). The process of creating the magnetic field required by an inductive load results in a phase difference between the voltage and current. A capacitor corrects the power factor by delivering a leading current to compensate for the trailing current. Power factor correction capacitors are intended to keep the power factor as close to unity as feasible. Although power factor correction capacitors can significantly lower the demand on the supply caused by an inductive load, they have no effect on the load's operation. Capacitors serve to eliminate losses in the electrical distribution system and lower electricity bills by neutralizing magnetic current (Dimitrova & Zlatev, 2020). In addition to increasing the power factor, the installation of this capacitor bank is also expected to reduce power losses and voltage drops and avoid excess kVARh charges imposed by PLN (Karmiathi & Adiana Putra, 2022).

The power factor on the public hospital of Manokwari, is influenced by induction motor used in pumps and equipments in the hospital including medical and non-medical tools, lamps, and air conditioner. According to the load classification on the power factor, the types of electrical loads at RSUD are divided into several groups, as shown in Table 1 as follows.

Table 1. Electrical group loads

No	Equipments	Power (W)	Percentage (%)
1	Induction motor (3 phase)	73,549	26.23
2	TL lamps	13,374	4.77
3	XL lamps	5,342	1.91
4	Medical/non-medical/incandescent lamps	73,454	26.20
5	Medical and non-medical electronic equipment	14,046	5.01
6	Air Conditioner (1 phase motor)	100,643	35.89
∑		280,408	100.00

Table 1 shows that the inductive loads of single-phase motors used in air conditioners and refrigerators, electric motors of 3-phase and 1-phase of water pumps, and TL lamps have dominated the loads and reached 67% of total loads. On the other hand, the resistive load only takes up about 33% of the loads. This configuration has the potential to reduce the power factor.

4.2. Power Factor Correction of Pumps

Based on the existing configuration, power factor improvements will be focused on individual power factor improvements in pump housings and globally on main distribution panel (MDP). Thus, the power factor measurement will be carried out in both parts, as given in the Tables 2 and 3.

Table 2. Power factor measurements of water pump unit

No	Motor Number	Voltage (V)	Current (A)	Power factor	Real power (kW)
1	Pump 1	383	5.65	0.870	1.83
2	Pump 2	386	7.44	0.758	3.77
3	Pump 3	385	4.32	0.411	1.18

The measurement data in Table 2 shows that when operating pumps, pump 1 has a good power factor over the standard of 0.87, indicated that this electric motor works at full load. In contrast to the motor pump 2, which has a low power factor value of 0.758. This machine functions to push water into the upper reservoir at a height of 12 metres. Power factor over the standard reached 0.87 that indicates that this electric motor works at full load. In contrast to the motor pump 2 which has a low power factor value of 0.758. On pump motor 3, the measured power factor is very low, about 0.41, because it operates in no-load conditions since there is no water in the reservoir at the time of taken measurement. This condition frequently occurs because there is no automatic switch to turn it off.

Based on these conditions, the poor power factor in pumps 2 and 3 will be corrected by compensating the reactive power, which is calculated in equations (5) to (6). Power factor at pump 2 is planed to be corrected from 0.758 to 0.900, so that θ_1=40.71° and θ_2=25.85°. Therefore, the reactive power should be compensated to be the desired reactive power (Q_B) as follows.

$$S_L = \frac{P}{\cos\theta_1} = \frac{3.77}{0.758} = 4.97kVA$$

$$Q_L = S_L \sin\theta_1 = 4.97\sin(40.71) = 3.24kVAR$$

$$S_B = \frac{P}{\cos\theta_2} = \frac{3.77}{0.9} = 4.12kVA$$

$$Q_B = S_B \sin(\theta_2) = 4.12\sin(25.85) = 1.82kVAR$$

The different reactive powers are calculated based on both current and desired reactive powers to meet the minimum capacity of the placement capacitor as follows.

$$Q_C = Q_L - Q_B = 3.24 - 1.82 = 1.42kVAR$$

$$C = \frac{Q_C}{2\pi f V^2} = \frac{1.42}{2\pi(50)386^2} = 30.35\mu F$$

It is found that pump 2 should be equipped with a capacitor with a minimum capacity of 30.35 μF so that apparant power decreases about 17.10% from 4.97kVA to 4.12 kVA by upgrading the power factor to 0.9. On the other hand the reactive power is also reduced from 3.24 kVAR to 1.82 kVAR. The same steps were also applied to pump 3, so that reactive power is reduced from 1.81 kVAR to 0.57 kVAR using a capacitor capacity of 26.62 μF. This reduction will cause the litghten of apparent power by about 52.71% from 2.77 kVA to 1.31 kVA.

From the above calculation, it is proved that by using the capacitors to compensate the reactive power of Pumps 2 and 3, the reactive power of both pumps is reduced about 1.42

kVAR and 1.23 kVAR. This changes will have advantages for the RSUD to minimize the electricity bills of both pinalty and energy consumption.

4.3. Power Factor Correction of MDP Panel

The second focus for observing the power factor is global compensation based on the power factor measurement shown in Table 3.

Table 3. Power factor measurements of MDP panel

No	Measurement time	Voltage (V)	Current (A)	Power factor	Real power (kW)
1	Daylight	383	115.1	0.788	60.17
2	Night time	387	137	0.876	80.44

The measurement data in Table 3 shows that during the day the power factor in general can be low, about 0.788, due to the use of peak loads during the daylight (during peak hours), which is caused by the use of medical and non-medical equipment, such as air conditioning machines.

The following is the calculation for improving the power factor at the main source at the main MDP panel, which can be calculated as same as previous subsection. The result shows that by improving the power factor to 0.9, the appearant power can decrease about 12.44% from 76.36 kVA to 66.86 kVA. The reactive power will be compensated about 29.15 kVAR using 387.75 μF.

4.4. Discussion

The electric load installed in the hospital is 280 kW (330 kVA) at a power factor of 0.85. With a PLN supply transformer of 160 kVA, this condition will be another problem because the transformer cannot work to supply loads to the hospital at the same time. For this reason, it is necessary to use the power effectively and efficiently, one of which is by improving the power factor so that the installed capacity can be maximized and other losses due to excess kVAR penalties can be reduced or even avoided.

According to the identification results, inductive loads at Manokwari Hospital account for 67% of the total load when using pump motors, air conditioners, and other medical and non-medical equipment. The remaining 33% is a resistive load from the use of heaters and incandescent lamps. This large inductive load has the potential to weaken the power factor, so it is necessary to take preventive steps to improve the power factor.

Improvement of power factor in Manokwari hospital can be done individually on the electric pump and centrally on the MDP panel. This different treatment is carried out because this water pump can work at any time as needed and does not depend on working hours. As for the overall load handled by the MDP, global compensation will be carried out so that all loads can be compensated in one panel.

In improving the power factor in the water pump section to 0.9, it causes a decrease in apparent power of 17.10% at pump 2 and 52.71% at pump 3 through the installation of capacitors of 30.35 μF and 26.62 μF, respectively. Additionally, pumps 2 and 3 can each reduce the reactive power by 1.42 kVAR and 1.23 kVAR, respectively.

In the MDP panel, power factor improvements need to be carried out during the day, when almost all medical and non-medical equipment must be on and the AC must work optimally when activity increases in the building. For this reason, the power factor on the MDP panel needs to be increased from 0.788 to 0.9 by installing a 387.75 μF capacitor. The installation of these capacitors is expected to reduce reactive power consumption by 29.15 kVAR and apparent power by 9.5 kVA. These results are confirmed by previous research that used capacitor banks to improve power factor grades. (Dimitrova & Zlatev, 2020; Kalhari et al., 2022; Karmiathi & Adiana Putra, 2022; Rahman et al., 2022).

The results of the calculations for improving power factor in hospitals by compensating for reactive power using capacitors as compensators show a decrease in electricity consumption. This decrease can be seen from the decrease in the amount of power absorbed by the electric loads, either through the pumping machine or the electrical loads supplied by the MDP panel. This reduced the absorbtion of electric power indicates that the use of electric power is more optimal and efficient, and there have been savings in the use of electric power. These savings will have an impact on reducing costs that must be incurred by the hospital, either through paying routine electricity bills or paying compensation for excessive use of reactive power. The calculation results also show that the use of a capacitor with the correct value is able to improve the power factor, and the use of electric power becomes more optimal in accordance with the installed electric load capacities.

5. Conclusions

In this research, an investigation has been carried out on the low power factor at Manokwari Hospital. The research begins with the identification and classification of the hospital's loads, and then calculations are carried out for power factor correction in an effort to increase the efficiency of using electric power.

Based on the investigations, it is planned to carry out power factor correction on the pump motor individually and on the main distribution panel (MDP) that accommodates other loads. The results of the calculations show that the power factor at pump 1 and the load on the MDP panel at night have met the electrical company (PLN) standard of 0.85. However, the power factor of pumps 2 and 3 as well as other loads on the MDP panels that work during the day do not meet the standards, so it is necessary to do a compensatory reactive power. Installing bank capacitors at these loads will carry out this compensation.

The calculation results show that pump motors 2 and 3 need to be compensated to improve the power factor to 0.9 so that the reactive power is lightening about 1.42 kVAR and 1.24 kVAR, respectively. In the same way, apparent power is also upgraded to 0.85 kVA and 1.46 kVA by installing capacitors bank of 30.35 μF and 26.63 μF, respectively. On the other hand, the power factor of largest load connected to the MDP panel needs to be corrected to reduce the reactive and apparent powers about 17.86 kVAR and 9.5 kVA through the installation of a capacitor bank of 387.75 μF. Through the power factor correction, the problem of inefficiency in the use of electric power at public hospital of Manokwari can be addressed. Furthermore, with this power factor correction will have an economic impact on hospital managers ability to pay electricity bills due to reduced power consumption and avoidable penalties.

A power factor correction controller is in charge of controlling capacitors during reactive power compensation. This type of controller is deployed in the majority of industries. Further research can be done on designing a power factor correction system for the public hospital in Manokwari.

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Author Contribution

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