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An Efficient Shunt Active Filter for Harmonic Reduction in Hospital Building Electrical Installation

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Abstract: This paper proposes an efficient shunt active filter for harmonic reduction in hospital building electrical installation. Harmonic installation in distribution system is caused by non-linear electrical loads, especially those containing coils, such as air conditioners, pump machines, fans, and others. Harmonic can cause excessive heat in a distribution transformer that supplies an electrical installation in a multi-storey building. This heat is a power loss and has the potential to shorten the life of a distribution transformer, so that efforts are needed to reduce harmonics. One effective method to reduce harmonics is to use active filters. In this study, a shunt active filter application in the electrical installation of a hospital building was carried out. The results showed that the filter was able to reduce harmonic currents significantly, so that the harmonic threshold was still in accordance with the IEEE standard.

***Index Terms**: Active filter, harmonic, hospital building.*

I. INTRODUCTION

The power factor or work factor is the ratio between active power expressed in watts and apparent power expressed in VA [1]. Another definition of power factor is the cosine value from the angle formed between real power and apparent power. In electric power distribution systems, high-value reactive power causes the angle between real power and apparent power to become significant. This large angle results in a low power factor value [2]. Inductive electrical loads are the cause of the low value of a system's power factor [3] - [4].

An ideal condition will be achieved when the electrical load that is served by electric power feeders is resistive. This resistive load has a power factor of one. In this condition, the maximum power transferred is equal to the capacity of the distribution system [5]. Thus, with the load induced and if the power factor ranges from 0.2 to 0.5, the capacity of the power distribution network becomes depressed. Thus, the reactive power (VAR) should be as low as possible for the same kW output in order to minimize the total power requirement (VA) [6]-[7]. Power Factor describes the phase angle between active power and apparent power. Low power factor is detrimental because it results in high load current. These power factor improvements use capacitors [8]-[10].

Power factor plays an important role in determining the power quality of a power system, including electrical systems in office buildings. A good power factor is also able to save significant electrical energy consumption [11]-[13]. However, it is important to carefully calculate the capacitor capacities required for the improvement of power factor. A lot of research has been done to improve power factor of electric power system, among others improvement of load motor power factor, power factor improvement on industry, and others [14]-[15].

In this research, the power factor improvement on the electrical installation of the multi-storey building uses the bank capacitor. The object of research is the hospital building electrical installation in Yogyakarta. First of all do the audit of electrical energy on the installation of the building. This energy audit aims to get actual data about power factor condition. Based on the actual conditions then calculations are made to determine the capacity of capacitors needed to increase the power factor of the system. In this research, reactive power injection was carried out by installing capacitor banks. The power factor and some other variables have been measured after the bank capacitor was installed. The results of the measurements were analyzed to obtain conclusions about the successful installation of bank capacitors for the improvement of electric power factor.

II. LITERATURE REVIEW

Power Factor in Power System

Quality electricity is electricity that has voltage and a constant frequency according to its nominal value. Within the specified range, the frequency is stable and very close to the nominal value. Problems that often occur in the quality of electrical power are electrical power problems that experience deviations in voltage, current, and frequency, causing failure or operation error on the equipment. Electric power supply from the generator to the load is operated within the tolerance limits of the electrical parameters such as voltage, current, frequency, and waveform.

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Changes and deviations outside the tolerance limit of these parameters are very influential on the quality of the power, which causes inefficient operation and can damage the device. Power quality is much influenced by the type of load that is not linear, unbalanced loading, harmonic wave distortion that exceeds the standard, and others.

The decrease in power quality can cause an increase in losses on the load side, even cause a decrease in power capacity at the source of the plant.

The advantages of power factor improvement through the installation of capacitors are [16]-[17]:

1. For Consumer, especially company or industry:
- Only one investment is required for the purchase and installation of capacitors and no ongoing costs.
- Reduce the cost of electricity for the company, because:
  (a) reactive power (kVAR) is no longer supplied by utility companies so total demand (kVA) is reduced and
  (b) the value of a fine paid if operating at a low power factor can be avoided.
- Reduced distribution loss (kWh) in network / factory installation.
- The voltage level at the end load increases so as to improve motor performance.

2. For electric utility suppliers,
- The reactive component on the network and the total current in the end-end system is reduced.
- The loss of power I squared R in the system decreases due to the decrease of the current.
- The capacity of power distribution networks increases, reducing the need to install additional capacity.

Installation of capacitors can be divided into 3 parts, namely:

1. Global compensation

   Along with this method the capacitor is installed in the parent panel. The descending current from the installation of this model is only in the interface between the MDP panel and the transformer. While the current passing after the MDP does not decrease thereby the loss due to heat dissipation in the conductor after MDP is not affected. Moreover the installation of power with a fairly long delivery Delta Voltage is still quite large.

2. Sectoral Compensation

   With this method a capacitor composed of several capacitor panels mounted in the SDP panel. This method is suitable for industries with large installed load capacity up to thousands of kva and the distance between the MDP and SDP panels is quite far apart.

3. Individual Compensation

   With this method the capacitor is directly mounted on each load, especially having a large power. This method is actually more effective and better from the technical point of view. But there are drawbacks that must provide a space or a special place to put the capacitor so as to reduce the aesthetic value.

Electricity load is defined as the amount of electric power used by consumers. Electrical loads can be divided into balanced loads and unbalanced loads. At a balanced load, the amount of power generated by a three-phase generator or the power absorbed by a three-phase load is obtained by adding up the power of each phase. In a balanced system, the total power is equal to three times the phase power, because the power in each phase is the same. In large DC currents, inductive loads and capacitive loads do not affect the circuit, so that the load is only pure resistive load. In the AC circuit, capacitive and inductive loads will affect the circuit, so that the working load is resistive, inductive load, and capacitive load. Here is the understanding of resistive, capacitive, and inductive loads.

A resistive load is generated from a circuit consisting of a resistor in the form of a pure resistor. This load only absorbs active power and does not absorb reactive load at all. At resistive loads, the current and voltage will be in phase. The inductive load is a load that absorbs active and reactive power by lagging power factor, ie when the voltage precedes the current by an angle ɵ. Inductive loads are generated from electrical components that contain a coil of wire wrapped around an iron core. Examples of electrical equipment that are inductive loads are motors and transformers. Inductive loads are generated from circuits that contain passive components, in the form of inductors. The capacitive load is a load that contains passive components, namely capacitors. Capacitive loads absorb active power and emit reactive power. The waveform of a capacitive load is the current that precedes the voltage. Here are the waves generated at capacitive loads, as shown in Figure 1.

The quality of a voltage in distribution networks always experiences dynamics. One of the dynamics that occurs is a decrease in electrical voltage. This decrease in voltage can be caused by electrical loads that suck up substantial currents. This phenomenon can be caused by enormous reactive power consumption. High reactive power consumption is generally caused by electric motor loads that have a tremendous power capacity. When this large power capacity electric motor starts to run, the absorbed current is substantial. Therefore a power capacitor is needed to overcome the problem of voltage drop when the motor starts.

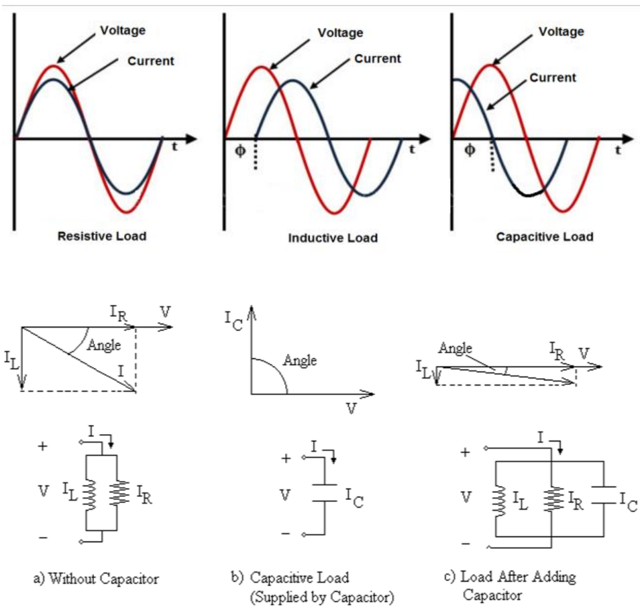

Figure 1. Effect of capacitor for the power factor improvement

The power capacitor functions to compensate for the sizeable reactive power. With the power capacitors, reactive power can now be supplied to large-capacity motors. In the end, the installation of capacitors can reduce reactive power demand from distribution system centres or substations. Power capacitors will usually be activated after the reactive power needs of the electrical loads consist of large-capacity motors. The effect of installing power capacitors on a distribution network can be shown in Figure 1.

Power Factor Improvement

In general, in the industrial sector that operates large capacity, electric motors have a moderate motor power factor. Based on several surveys conducted by the researchers, there are about 62% of the loads of the electric motor that have a power factor which results in an accumulation of the overall system power factor to below. Electric motors have low power factors because they consist of inductive load coils. The power factor of this electric motor varies, from 0.30 to 0.95. This power factor generally depends on motor capacity and operating conditions when run. This low power factor is very detrimental to operational costs because of the use of electricity that is not optimal and efficient. Therefore, in any industry, the amount of power factor is always a concern for a method to solve it.

Series capacitors are capacitors that are installed in series with lines. Use of series capacitors to compensate for inductive reactance. In Figure 2, it can be seen that the capacitor is a negative reactance and will reduce the inductive reactance, which is positive. The use of series capacitors can minimize voltage drops caused by channel inductive reactance and increase the voltage.

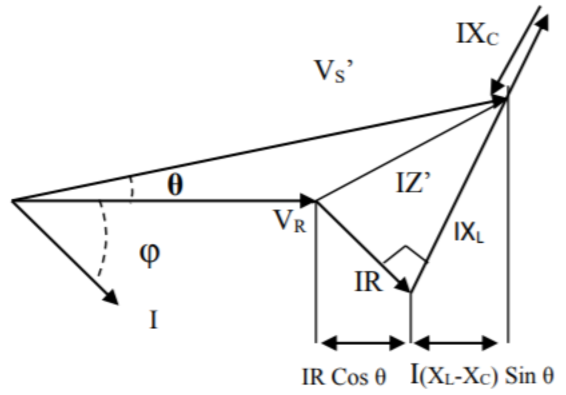

Figure 2. Series compensation curve

In general, the voltage drop equation after a series capacitor compensation can be shown in the following equation:

$$V_D = IR\cos\varphi + I\,(X_L - X_C)\sin\varphi \qquad (1)$$

If the capacity selection of the series capacitors is too large compared to the desired inductive reactance compensation value, it will cause easy over compensation so that the system will experience a leading power factor. Besides, the installation of series capacitors will cause a ferrous resonance in transformers, subsynchronous resonance while starting at the motor load, and the difficulty of installing protection systems for series capacitors, the application of series capacitors is rarely used in distribution systems.

The shunt capacitor is a capacitor that is installed in parallel with the line, and is often applied to distribution systems because it can overcome voltage drop, reduce power losses, and improve the value of the power factor, and easy to apply protection systems. The use of parallel capacitors can provide reactive power compensation to the load. The current injected by a parallel capacitor can change the current vector in the leading direction so that the voltage drop due to the inductive load of the channel can be overcome, and the voltage at the load is maintained at the desired condition.

The capacitor bank is a capacitor consisting of more than one unit of capacitors connected in parallel and in series to inject reactive power into the electric power system to minimize the voltage drop and power losses. In a distribution system, if a network does not have reactive power sources in the area around the load, all of its reactive load needs are borne by substations that are supplied from generators at the power plant. The reactive current will flow in the network resulting in a power factor decrease, voltage drop, and increased power losses so that the installation of capacitor banks can improve the quality and stability of the system in good condition.

Bank capacitor models used in distribution systems include fixed capacitor banks and automatic capacitor banks. The difference between the two capacitor bank models is that the automatic capacitor bank can switch each unit of the capacitor and each capacitor segment in it so that the determination of the reactive power capacity injected can be adjusted to the needs of the system. In contrast, the fixed capacitor bank only has the capability of large-scale injection fixed reactive power. While based on the configuration, the bank capacitors consist of one phase and three phases. Single-phase bank capacitors have capacitors units that are connected in parallel in one segment, each segment of capacitors can be connected in series or parallel as needed, it is also owned by a three-phase capacitor bank. However, the three-phase capacitor bank has a delta and star winding configuration according to the needs of the capacitor.

In general capacitor bank with delta winding configuration is used to compensate for reactive power in three-phase motor loads. Its use is found in the industrial world, while bank capacitors with star/wye configuration are used to compensate for reactive power in electric power systems at the distribution level and transmission.

III. METHODOLOGY

The main target in this research is the improvement of power factor using the installation of capacitor bank. Based on the theory, the installation of capacitors is also able to increase the system voltage profile. With the improvement of power factor system, then the energy saving of electricity will also be obtained, because electric power can be utilized optimally.

The research steps are:

1. Conducting audit of electrical installation at the hospital building electrical installation in Yogyakarta. This audit is done to get actual data about electrical installation that is voltage system, nominal current, power factor, harmonics, and power frequency.
2. Conducting the design of proper electrical installation to improve the system power factor, including the installation plan of the capacitor installation.

3. Perform the capacity of capacitor calculations to be used for power factor improvement in order to improve the system voltage profile, using the power factor improvement table as shown in Figure 2.
4. Conducting the installation of bank capacitors on the installation of the hospital building electrical installation in Yogyakarta.
5. Conducting measurements of voltage, power frequency, and power factor after the installation of the capacitor.
6. Conducting an analysis of the results of the installation of a bank capacitor for the improvement of power factor and the system voltage profile.
7. Make conclusions and recommendations.

Factor K (kvar/kW)													
	final cosφ												
initial cosφ	0.80	0.85	0.90	0.91	0.92	0.93	0.94	0.95	0.96	0.97	0.98	0.99	1
0.60	0.583	0.714	0.849	0.878	0.907	0.938	0.970	1.005	1.042	1.083	1.130	1.191	1.333
0.61	0.549	0.679	0.815	0.843	0.873	0.904	0.936	0.970	1.007	1.048	1.096	1.157	1.299
0.62	0.515	0.646	0.781	0.810	0.839	0.870	0.903	0.937	0.974	1.01 5	1.062	1.123	1.265
0.63	0.483	0.613	0.748	0.777	0.807	0.837	0.870	0.904	0.941	0.982	1.030	1.090	1.233
0.64	0.451	0.581	0.716	0.745	0.775	0.805	0.838	0.872	0.909	0.950	0.998	1.058	1.201
0.65	0.419	0.549	0.685	0.714	0.743	0.774	0.806	0.840	0.877	0.919	0.966	1.027	1.169
0.66	0.388	0.519	0.654	0.683	0.712	0.743	0.775	0.810	0.847	0.888	0.935	0.996	1.138
0.67	0.358	0.488	0.624	0.652	0.682	0.713	0.745	0.779	0.816	0.857	0.905	0.966	1.108
0.68	0.328	0.459	0.594	0.623	0.652	0.683	0.715	0.750	0.787	0.828	0.875	0.936	1.078
0.69	0.299	0.429	0.565	0.593	0.623	0.654	0.686	0.720	0.757	0.798	0.846	0.907	1.049
0.70	0.270	0.400	0.536	0.565	0.594	0.625	0.657	0.692	0.729	0.770	0.817	0.878	1.020
0.71	0.242	0.372	0.508	0.536	0.566	0.597	0.629	0.663	0.700	0.741	0.789	0.849	0.992
0.72	0.214	0.344	0.480	0.508	0.538	0.569	0.601	0.635	0.672	0.713	0.761	0.821	0.964
0.73	0.186	0.316	0.452	0.481	0.510	0.541	0.573	0.608	0.645	0.686	0.733	0.794	0.936
0.74	0.159	0.289	0.425	0.453	0.483	0.514	0.546	0.580	0.617	0.658	0.706	0.766	0.909
0.75	0.132	0.262	0.398	0.426	0.456	0.487	0.519	0.553	0.590	0.631	0.679	0.739	0.882
0.76	0.105	0.235	0.371	0.400	0.429	0.460	0.492	0.526	0.563	0.605	0.652	0.713	0.855
0.77	0.079	0.209	0.344	0.373	0.403	0.433	0.466	0.500	0.537	0.578	0.626	0.686	0.829
0.78	0.052	0.183	0.318	0.347	0.376	0.407	0.439	0.474	0.511	0.552	0.599	0.660	0.802
0.79	0.026	0.156	0.292	0.320	0.350	0.381	0.413	0.447	0.484	0.525	0.573	0.634	0.776
0.80		0.130	0.266	0.294	0.324	0.355	0.387	0.421	0.458	0.499	0.547	0.608	0.750
0.81		0.104	0.240	0.268	0.298	0.329	0.361	0.395	0.432	0.473	0.521	0.581	0.724
0.82		0.078	0.214	0.242	0.272	0.303	0.335	0.369	0.406	0.447	0.495	0.556	0.698
0.83		0.052	0.188	0.216	0.246	0.277	0.309	0.343	0.380	0.421	0.469	0.530	0.672
0.84		0.026	0.162	0.190	0.220	0.251	0.283	0.317	0.354	0.395	0.443	0.503	0.646
0.85			0.135	0.164	0.194	0.225	0.257	0.291	0.328	0.369	0.417	0.477	0.620
0.86			0.109	0.138	0.167	0.198	0.230	0.265	0.302	0.343	0.390	0.451	0.593
0.87			0.082	0.111	0.141	0.172	0.204	0.238	0.275	0.316	0.364	0.424	0.567
0.88			0.055	0.084	0.114	0.145	0.177	0.211	0.248	0.289	0.337	0.397	0.540
0.89			0.028	0.057	0.086	0.117	0.149	0.184	0.221	0.262	0.309	0.370	0.512
0.90				0.029	0.058	0.089	0.121	0.156	0.193	0.234	0.281	0.342	0.484

Figure 2. The power factor improvement table for determining the capacitor capacity

IV. RESULTS AND DISCUSSION

In this research there are several variables observed are frequency system, system voltage profile, harmonic system, and system power factor. This observation is done by doing direct measurement on electric installation of the hospital building in Yogyakarta using power analyzer measuring instrument. The measurement results are shown in Figure 3, Figure 4, Figure 5, and Figure 6.

Figure 3 shows the frequency of the hospital electrical installation system in Yogyakarta. In general, the frequency of the installation system is relatively stable. In this study, frequency measurements were carried out for 24 hours. However, there are frequency fluctuations in the first 4 hours, although not large. This can be seen if seen in detail. The maximum power frequency is 50.3 Hz. This increase in frequency occurs in changing office buildings, which occur at 11:30 a.m. to 1:00 p.m. At this time duration the activity in the office building was relatively quiet because the employees were resting. Changes in power frequency in this duration are not large, so that not the whole affects the system.

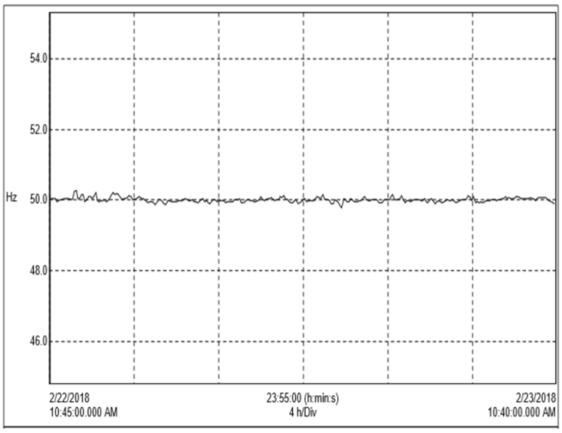

Figure 3. Power frequency of the hospital building electrical installation system in Yogyakarta

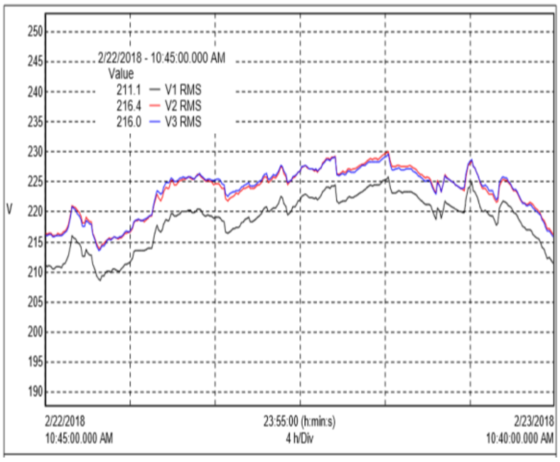

Figure 4. Voltage profile for single phase of the electrical installation system of the hospital building in Yogyakarta

Figure 4 shows the voltage profile for a single phase of the electrical installation system of a hospital building in Yogyakarta. This voltage is the result of the system voltage profile after installation of a capacitor bank with a capacity of 36 kvar. Based on Figure 4 it is observed that phase 1 voltage is 211 volts, phase 2 voltage is 216 volts, and phase 3 voltage is 216 volts. Phase 1 RMS voltage value is the result of the lowest voltage measurement. This happens because in phase 1 there is a load that is relatively greater than the other two phases, so that the phase voltage decreases significantly compared to the other phases. Based on Figure 4, it can also be seen that with the installation of bank capacitors, the voltage of each phase is still within tolerable limits.

Furthermore, the voltage profile for the phase to phase of the electrical installation system of hospital buildings in Yogyakarta is shown in Figure 5. It should be noted that the system voltage is the system voltage profile after the installation of a capacitor bank with a capacity of 36 kvar. In Figure 5 it can be seen that phase 1 voltage is 368 volts, phase 2 voltage is 378 volts, and phase 3 voltage is 369 volts. Phase 1 RMS voltage is the result of the lowest voltage measurement, because in phase 1 there is a load that is relatively greater than the other two phases.

As a result, the phase voltage decreases significantly compared to the other phases. Installing this bank capacitor of 36 kvar also produces a voltage for each phase still within tolerable limits. The highest phase to phase voltage in this case occurs in phase 2 because the load under this phase is relatively lower than the other phases.

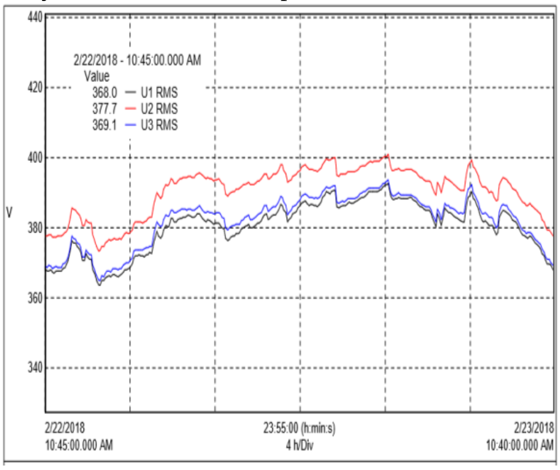

Figure 5. Voltage profile of the hospital building electrical installation system in Yogyakarta

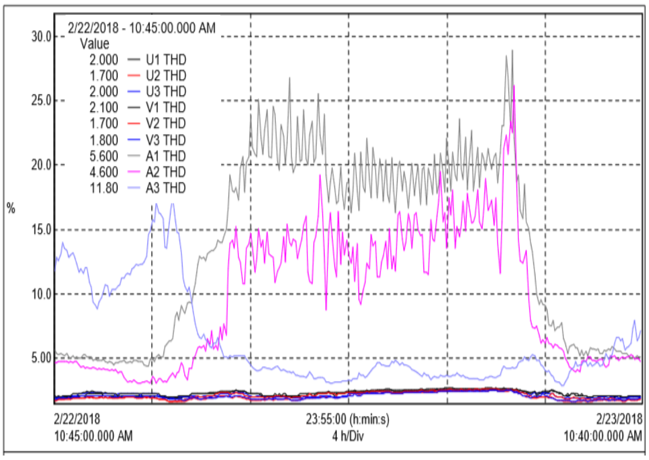

Figure 6. THD of the hospital building electrical installation system in Yogyakarta

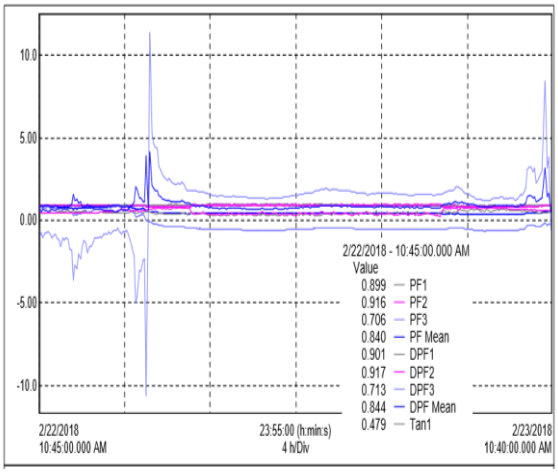

Figure 7. Power factor of the hospital building electrical installation system in Yogyakarta

The next investigation is the total harmonic authority (THD) of the electrical installation system of the hospital building in Yogyakarta. The THD of the electrical installation system is shown in Figure 6. The THD shown in the Figure is the result of observations after the installation of 36 kvar capacitors. In general, the results showed that THD has decreased significantly. The highest THD occurred in phase 3 which was 11.8%. This THD value exceeds the expected threshold, which is a maximum of 5% according to IEC standards. However, in other phases the THD is relatively small, which is below 5%.

The power factor of the system of electrical installation of hospital buildings in Yogyakarta is shown in Figure 7. This investigation of the power factor is the last observed variable. The power factor of the measurement results in Figure 7 is the system power factor after the installation of a capacitor bank with a capacity of 36 kvar. It can be seen in Figure 7 that the average power factor of the system is 0.85, which is relatively better than before the installation of power capacitors which is 0.68. Based on the measurement results shown in Figure 7 it can be observed that phase 1 power factor is 0.899, phase 2 power factor is 0.916, and phase 3 power factor is 0.706. Phase 3 power factor is the lowest because in this phase there are many inductive electrical equipment, namely electric motors in AC.

V. CONCLUSION

Some of the variables observed in this work are frequency systems, system voltage profiles, harmonics, and power factors. In this study direct measurements were made on the electrical installation system of hospital buildings in Yogyakarta using a power analyzer. An important result of this study is that the installation of 36 kvar capacitors is able to improve system power quality well. Installing 36 kvar bank capacitors can increase system power factor from 0.68 to 0.85. Installation of capacitors proved to be able to improve the performance of the electrical installation system in the hospital building.

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