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Optimization Of A 20 Kv Capacitor Bank Energy Management System For Electrical Usage In Indihome Network Devices

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ABSTRACT

The increasing demand for stable and efficient electrical energy in telecommunication systems, particularly in IndiHome network infrastructure, requires a reliable energy management strategy. One of the key challenges faced is the presence of reactive power, which can reduce power factor efficiency and lead to higher energy losses. This study focuses on optimizing the energy management system using a 20 kV capacitor bank to improve power factor and reduce electrical losses in IndiHome network devices. The research involves the design, implementation, and analysis of a capacitor bank control system that responds dynamically to load variations. Through simulation and real-time testing, the system is evaluated based on its ability to maintain a high power factor, reduce energy consumption, and stabilize voltage levels. The results show that the optimized capacitor bank system can improve power factor to above 0.95 and reduce reactive power demand significantly, resulting in improved overall energy efficiency. This optimization not only reduces operational costs but also enhances the reliability and longevity of network equipment by minimizing voltage drops and harmonic disturbances. The study concludes that capacitor bank-based energy management systems are highly effective and essential for modern telecommunication infrastructure.

Keyword : Capacitor Bank; Power Factor; Energy Management; Telecommunication; IndiHome; 20 kV; Reactive Power.

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1. INTRODUCTION.

In the power distribution system, power factor is one of the important parameters that affect the efficiency of energy use. Low power factor not only increases power losses in the system, but also increases the load on the electricity distribution network, which ultimately has an impact on increasing operational costs. 20 kV capacitor banks have long been used as a solution to improve power factor through reactive compensation, especially in systems with varying loads such as telecommunications network devices. IndiHome network devices, consisting of various elements such as Optical Line Terminal (OLT), routers, and other distribution devices, are significant users of electrical energy on a national scale. The electrical load on these devices is often unstable due to variations in customer usage. This instability can cause a significant decrease in the power factor, thus impacting the efficiency of the electricity distribution system. Therefore, optimization of the energy management system is needed to increase the efficiency of electricity use, reduce power losses, and reduce operational costs.

Previous studies have shown that manual capacitor bank management is often ineffective in handling dynamic load variations. With the presence of programmable logic (PLC) and Internet of Things (IoT) based automatic control technology, capacitor bank management can be done more effectively and efficiently. This automation system allows real-time monitoring of power grid parameters, such as current, voltage, and power factor, so that capacitor banks can be operated adaptively as needed. This study aims to optimize energy management in a 20 kV capacitor bank using a PLC-based automation approach to improve the efficiency of electricity use in IndiHome network devices. By implementing this system, it is expected that the power factor can be improved, power losses can be minimized, and the stability of the electricity distribution system can be maintained. In addition, this optimization is also expected to provide economic benefits in the form of reducing operational electricity costs for telecommunications service providers.

2. LETERATURE REVIEW.

2.1. Power Quality

The increase in the need and consumption of electrical energy in terms of quality and quantity is one of the reasons why utility companies providing electricity need to pay attention to the issue of electrical power quality. Especially for industrial consumers who need a good electricity supply, namely in terms of continuity and also the quality of the supplied voltage (because industrial machines are sensitive to voltage spikes/instability), it is necessary to develop an industrial electrical power system that can provide services that meet the criteria desired by its consumers. The term electrical power quality is not new but has been an important issue in the industry since the late 1980s. Electrical power quality provides an overview of the good or bad of an electrical power system in overcoming disturbances in the system. Roger C. Dugan gives four main reasons for the need for more attention to power quality issues:

- Electrical devices used today are very sensitive to the quality of electrical power, where microprocessor-based devices and other power electronics require stable service voltage and the voltage level must also be maintained at the working voltage of the device.
- The increasing emphasis on overall power/electrical system efficiency has resulted in continued growth in the application of high-efficiency devices, such as electric motor speed control and the use of capacitor banks for power factor correction to reduce losses. This has resulted in increased harmonic levels in the power system and has caused many practitioners in the field of electric power systems to worry about the impact in the future (feared that it could reduce the capability of the system).
- Increasing consumer awareness of power quality issues. Where customers/consumers are becoming more aware of issues such as interruptions, sags, and transition switching and expect the electrical system to improve the quality of power delivered.
- Many electric power systems now have interconnections between networks, where this has the consequence that failure of any component will result in failure of other components.
- Problems that can arise from a power system with poor power quality can be in the form of surges or changes in voltage, current and frequency that will cause equipment failure or misoperation. Which failure damages electrical equipment both from the sender and the receiver side. For that, in order to anticipate losses that can occur both from PLN and the community, PLN must strive for a good electricity system.

2.2. Active Power (P)

Active power is a key component in an electrical system that describes the energy actually used to perform work or produce useful output. This concept is essential in understanding the efficiency and performance of various electrical devices, whether in homes, industries, or commercial facilities. Active power is measured in watts (W) or often on a larger scale such as kilowatts (kW) or megawatts (MW). Active power is the portion of the total electrical power consumed to perform real, usable energy, such as turning a motor, lighting a lamp, or heating an electrical element. In an electrical system, the total power supplied by sources often consist of three components: active power, reactive power, and apparent power.

- Active Power (P): Is the power that is actually used by the device to produce work energy. An example is the energy used by a fan to rotate.
- Reactive Power (Q): Is the power that is "borrowed" and "returned" by devices that have inductive or capacitive components, such as electric motors or transformers. This power does not produce real energy.
- Real Power (S): Is a vector combination of active power and reactive power, with units of volt-amperes (VA).

The relationship between these three components is described by a power triangle, with real power as the hypotenuse, active power as the horizontal side, and reactive power as the vertical side. Power factor (cosϕ\cos\phi) is very important in determining the efficiency of an electrical system. If the power factor is close to 1, it means that almost all of the power supplied is used as active power. Conversely, if the power factor is low, it means that much energy is wasted as reactive power. Active power is used in various electrical applications to drive equipment and produce the required energy. Some examples of the application of active power are as follows:

1. Household Appliances: Appliances such as lights, televisions, washing machines, and refrigerators use active power to operate. The amount of active power that used depending on the energy needs of the device. For example, a 20 watt LED lamp uses 20 watts of active power per hour to light a room.
2. Industry and Commerce: In industrial scale, large machines such as electric motors, pumps, and compressors use active power to generate mechanical power. Active power efficiency becomes very important in this sector because large energy usage affects operational costs.
3. Transportation: In modern transportation such as electric trains and electric vehicles, active power is used to drive the motor which is the main propulsion of the vehicle.

Active power is the main indicator of efficiency in an electrical system. The greater the active power generated compared to the total power supplied, the more efficient the system is. Therefore, efforts to improve the power factor are often made to maximize the use of active power and reduce energy losses.

One way to improve system efficiency is to install capacitors to compensate for reactive power. By balancing the reactive load, the power factor (cos ϕ\cos\phi) can be improved, so that the proportion of active power to total power becomes greater. Active power is directly related to the consumption of electrical energy recorded by the electricity meter in a house or building. Electrical energy is calculated as the product of active power over time, in watt-hours (Wh) or kilowatt-hours (kWh). This is usually the basis for electricity billing by electricity providers.

2.3. Leading Power Factor

Leading power factor is a state of power factor when it has the following conditions:

1. Electrical loads/equipment provide reactive power from the system or capacitive loads.
2. Current leads voltage, V lags behind I by an angle φ

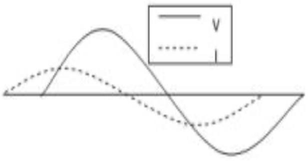

Figure 1. Current Leads Voltage by an Angle

Power factor has a value in the range between 0-1 and can also be expressed in percent. A good power factor is close to one.

$$Tan\ \varphi = \frac{Daya\ Reaktif\ (Q)}{Daya\ Aktif\ (P)}$$

$$= \frac{kVAR}{kW}$$

Since the active power component is generally constant (kVA and kVAR components change according to the power factor), it can also be written as follows:

- Reactive Power (Q) = Active Power (P) x Tan φ An example, the capacitor rating required to improve the power factor.
- Reactive power at initial pf = Active Power (P) x Tan φ1
- Reactive Power at fixed pf = Active Power (P) x Tan φ2

There is an increase in voltage due to increased power. If pf is less than 0.85 then the active power capacity (kW) used will decrease. The capacity will continue to decrease along with the decrease in the pf of the electrical system.

2.4. Properties of Electrical Load

In an electrical circuit there is always a source and load. If the power source is DC, then the nature of the load is only purely resistive, because the frequency of the DC source is zero. The capacitive reactance (XC) will be infinite which means that the capacitive will be open circuit. So the DC source will cause an inductive load and the capacitive load will not affect the circuit.

Resistive load which is a pure resistor, for example: Incandescent Lamp, Heater. This load only absorbs active power and does not absorb reactive power at all. Voltage and current are in phase. Mathematically stated:

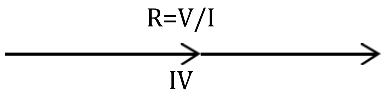

Figure 2. Current with voltage on a resistive load

Inductive load is a load that contains a coil of wire wound around it on a core usually like iron, Example: electric motors, inductors and transformers. This load absorbs active power (kW) and reactive power (kVAR). Voltage leads current by φ°. Mathematically stated:

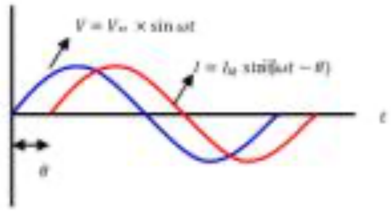

Figure 3. Current, voltage and self-induction CGL in inductive load.

Capacitive load is a load that contains a series of capacitors. This load has a power factor between 0-1 "leading". This load absorbs active power (kW) and outputs reactive power (kVAR). The current leads the voltage by φ°. Mathematically stated:

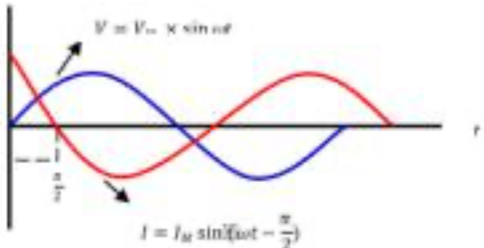

Figure 4. Current, Voltage and CGL self-induction in capacitive load

2.5. Intelligent Power Distribution Unit (IPDU).

One of the latest technologies currently that has a function in monitoring the use of electrical power is the IPDU Dominion PX 1000. IPDU Dominion PX is an Intelligent Power Distribution Unit (IPDU) that is used to inform power on technological equipment such as computers and communication devices using a computer network. With the IPDU Dominion PX 1000, a user can monitor the total power remotely according to the existing facilities of the IPDU Dominion PX 1000. In this final project, the design and creation of a computer network that will be used in monitoring power usage on Cisco equipment and analyzing the effects of inductive, resistive, and capacitive loads.

IPDU is a tool that functions to monitor electrical power on a device. So it is very easy for users to monitor power on the device. IPDU (Intelligent Power Distributor Unit) is a tool that can monitor the amount of electrical power usage on a device. The IPDU PX 1000 Block Diagram is shown in Figure 6.

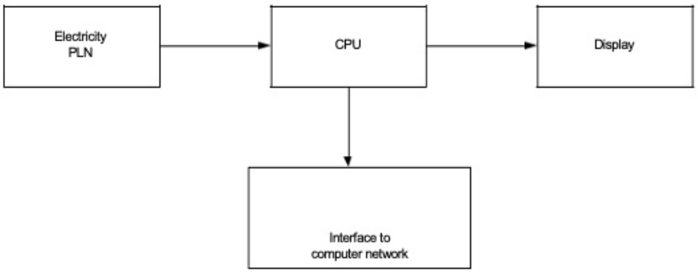

Figure 5. Dominion PX 1000 IPDU Block Diagram

Input in the form of PLN electricity originating from all equipment connected to the Dominion PX 1000 IPDU. All electric current enters the Current Trafo before entering the CPU. The CT output current will be processed by the CPU support device to perform various measurements. From this device the CPU can process measurement data into the required constants such as reactive power, active power, active energy. The CPU will process the measurement results to be connected to the network via an interface to the computer network.

3. METHOD

This research uses a quantitative-experimental method to evaluate and optimize the performance of a 20 kV capacitor bank for improving electrical efficiency in IndiHome network infrastructure. Data is collected from existing electrical systems used by IndiHome network devices. This includes:

- Measuring voltage, current, power factor, and reactive power.
- Identifying load types (inductive loads such as routers, switches, servers).

Tools: Clamp meter, Power Quality Analyzer (PQA), and digital multimeters. Based on the power factor data and reactive power requirements:

- The required kVAR rating of the capacitor bank is calculated.
- The capacitor bank is designed to operate at 20 kV with step control to adjust for load variations.

Calculation includes:

- Load flow analysis
- Power triangle method (kW, kVAR, kVA)
- Sizing formulas for power factor correction.

Simulation is conducted using software such as ETAP or MATLAB/Simulink to model:

- The existing system without capacitors
- The impact of capacitor installation on power factor and voltage profile
- Dynamic load response with and without compensation

The capacitor bank is physically installed at a main distribution point in the IndiHome system. Integration includes:

- Protection systems (relays, contactors, surge protection)
- Automatic control system (e.g., APFC panel) to switch capacitors based on load

After installation:

- Real-time monitoring is carried out using IoT-based sensors or smart meters.
- Power factor, current, voltage, and energy consumption are logged and compared with pre-installation values.

Data analysis focuses on:

- Power factor improvement
- Reactive power reduction (kVAR)
- Energy savings
- Reduction in electricity bills
- Voltage stability improvement

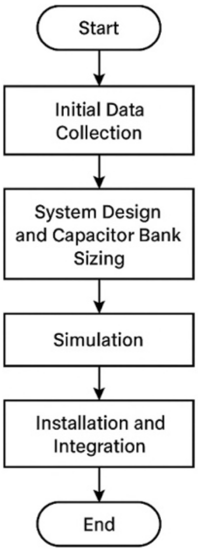

Figure 6. flowchart Design

The flowchart on the left illustrates the stages of the research methodology in a systematic manner:

- Start
  The process begins with the initiation of the research.
- Initial Data Collection
  Collection of initial data related to electrical parameters such as current, voltage, power factor, and reactive power from IndiHome network devices.
- System Design and Capacitor Bank Sizing
  System design and calculation of the capacitor bank size based on the required reactive power compensation.
- Simulation
  Simulation is carried out using engineering software to predict the impact of the capacitor bank on the system.
- Installation and Integration
  Implementation and integration of the capacitor bank into IndiHome's electrical distribution system.
- End
  The methodology process is completed.

RESULT.

4.1. Research Object

In this study there are several methods to overcome the voltage drop is to install a tap charger, transfer the load to other feeders, increase the surface area of the cross-section and install a capacitor bank, in this study using the capacitor bank installation method which is expected to improve the voltage drop. The use of capacitor banks is expected to improve the quality of electric power consisting of the desired power factor and voltage profile and can reduce energy losses in the medium voltage distribution system, considering that it is seen from a financial perspective and allows it to work more effectively. The research object used refers to figure 8 in simulink, real data table 1and table 2. The 20 KV distribution channel of indihome 07 feeder is made of aluminum alloy material which functions as a connector between poles.

From Figure 8 is the Simulink modeling of the 20 kV distribution system on the sending side of the Bumiayu 07 feeder where the condition of the capacitor bank has not been installed. From Figure 4.3 is the ETAP modeling of the 20 kV distribution system on the receiving side of the Bumiayu 07 feeder where the condition of the capacitor bank has not been installed.

a. Modeling of the Main Substation electrical power system at Indihome

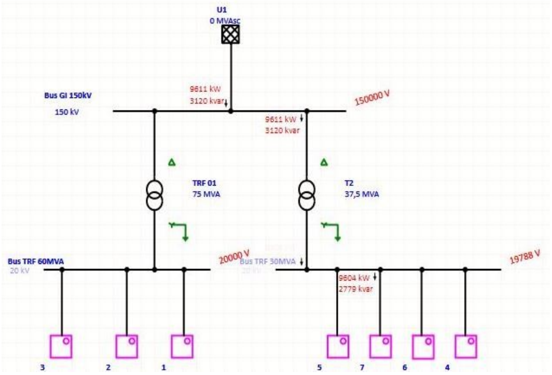

Figure 7. Simulation of Substation Electric Power System Indihome

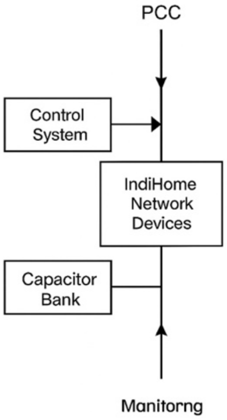

Figure 8. Block Diagram

The block diagram on the right illustrates the structure of the physical system and the flow of power/control, consisting of the following components:

- PCC (Point of Common Coupling): The connection point between the main distribution system and the IndiHome load.
- IndiHome Network Devices: Load devices such as OLTs, routers, and switches that consume electrical energy.
- Capacitor Bank: Connected to the system to compensate for reactive power and improve the power factor.
- Control System.

An automatic control system (such as an APFC panel) that regulates the activation or deactivation of capacitors based on load conditions.

Monitoring

- A real-time electrical parameter monitoring system used to evaluate performance and system efficiency.

4.2. Capacitor Bank Energy Management System.

To find out the quality of the voltage before the voltage drop repair is carried out, a simulation is carried out with Simulink software by referring to the data shown in table 1 and table 2. Then carry out a voltage drop simulation as shown in figure 10. The simulation begins by creating a single line diagram in the simulink software and then entering some data into the simulink software according to the simulation needs by referring to the single line diagram, then running the load flow to see the simulation results. In this simulation, observations are made on the base voltage and end voltage objects.

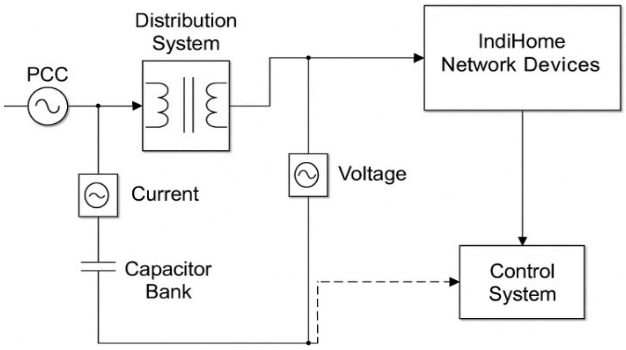

Figure 9. Simulation System

Finding the size of the capacitor bank needed to improve the voltage drop of the indihome 07 feeder using the menu or feature that already exists in the simulink software, namely optimal capacitor placement, where the size and location for placing the capacitor bank can be known using this feature, it makes it very easy for users to analysed a feeder or others in the distribution of electric power.

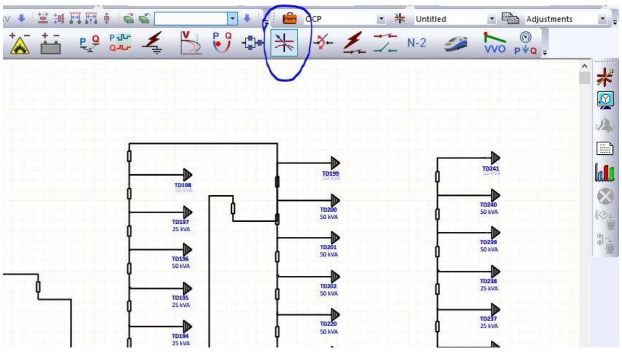

Figure 10. Optimal Capacitor Placement Features

In Figure 10 you can see the blue circle for the optimal capacitor placement menu or feature in Simulink software. In this case, the single line diagram must be completed first so that the placement and size of the capacitor bank required by the simulink software can be analyzed later.

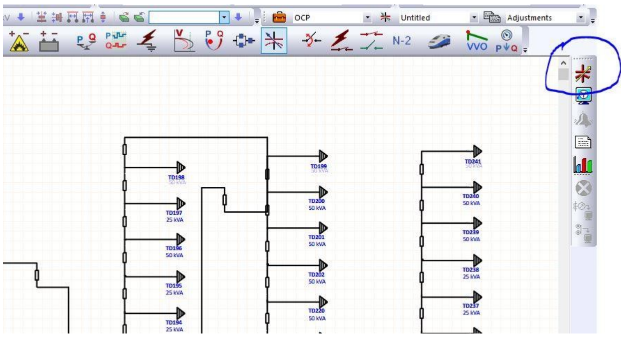

Figure 11. Run Optimal Capacitor Placement Feature

In Figure 11, you can see the blue circle for the run optimal capacitor placement menu or feature. This feature is run after the feature in Figure 13. The function of this feature is to run the optimal capacitor placement command to analyze the placement of the capacitor and the size of the capacitor.

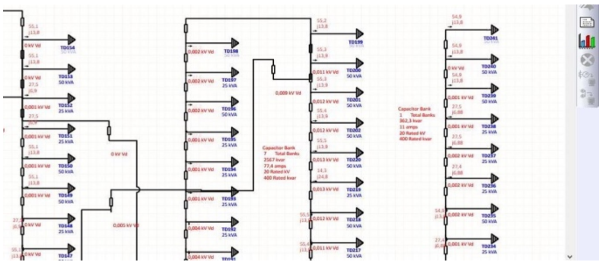

Figure 12. Optimal Capacitor Placement Feature Results On Simulink

Table 1. Capacitor Bank Capacity

No	Location	Total Banks	Qc (Kvar)	Rated kV	Amps	Rated kvar
1	Bus 219	7	2567	20	77.4	400
2	Bus 221	1	362.3	20	11	400

4.3. Testing the results of monitoring Cisco equipment

The monitoring results are Active Power, Apparent Power, Power Factor and Active Energy. Table 1 shows the results of active power monitoring. From these results it can be concluded that the size of Active Power depends on the device charged to each port.

Table 2. Results TableActive Power Monitoring

Switch					***Router***			**Mark**
Port I	***Port II***	***Port III***	***Port IV***	***Port V***	***Port VI***	***Port VII***	***Port VIII***	***Active Power***
√	-	-	-	-	-	-	-	19 W
√	√	-	-	-	-	-	-	34W
√	√	√	-	-	-	-	-	50W
√	√	√	√		-	-	-	66W
√	√	√	√	√	-	-	-	83W
√	√	√	√	√	√	-	-	83W
√	√	√	√	√	√	√		84W
√	√	√	√	√	√	√	√	85W

Table 2 shows the results of apparent power monitoring. From these results it can be concluded that the size of Apparent Power depends on the device loaded on each port.

Table 3. Results TableMonitoring Apparent Power.

Switch					***Router***			**Mark**
Port I	***Port II***	***Port III***	***Port IV***	***Port V***	***Port VI***	***Port VII***	***Port VIII***	***Apparent Power***
√	-	-	-	-	-	-	-	35 VA
√	√	-	-	-	-	-	-	61 VA
√	√	√	-	-	-	-	-	86 VA
√	√	√	√		-	-	-	112 VA
√	√	√	√	√	-	-	-	137 VA
√	√	√	√	√	√	-	-	136 VA
√	√	√	√	√	√	√		137 VA
√	√	√	√	√	√	√	√	139 VA

Table 4. Results TablePower factor monitoring.

Switch					***Router***			**Mark**
***Port* I**	***Port* II**	***Port* III**	***Port* IV**	***Port* V**	***Port* VI**	***Port* VII**	***Port* VIII**	***Power factor***
√	-	-	-	-	-	-	-	0.54
√	√	-	-	-	-	-	-	0.56
√	√	√	-	-	-	-	-	0.58
√	√	√	√		-	-	-	0.59
√	√	√	√	√	-	-	-	0.61
√	√	√	√	√	√	-	-	0.61
√	√	√	√	√	√	√		0.61
√	√	√	√	√	√	√	√	0.61

Table 4 shows the results of power factor monitoring. The Power factor value on the Switch from port I to port V experienced a stable change, namely with a difference of 0.1 to 0.2. While the Power factor value on the port starting from port VI to port VIII did not experience any change, namely remaining constant at a value of 0.61. From the results of the Power factor value starting from port I to port VIII, it can be concluded that the value of Active Power depends on on the device charged to each port.

Table 5. Results TableActive Energy Monitoring.

Switch					***Router***			**Mark**
***Port* I**	***Port* II**	***Port* III**	***Port* IV**	***Port* V**	***Port* VI**	***Port* VII**	***Port* VIII**	***Active Energy***
√	-	-	-	-	-	-	-	871 Wh
√	√	-	-	-	-	-	-	872 Wh
√	√	√	-	-	-	-	-	873 Wh
√	√	√	√	-	-	-	-	874 Wh
√	√	√	√	√	-	-	-	875 Wh
√	√	√	√	√	√		-	886 Wh
√	√	√	√	√	√	√	-	888Wh
√	√	√	√	√	√	√	√	889Wh

Table 5 shows the results of active energy monitoring. The Active Energy value on the Switch from port I to port V experienced a very stable change of 0.1 Wh. While the Active Energy value on the port from port VI to port VIII experienced a change of 1 Wh to 2 Wh. From the results of the Active Energy value from port I to port VIII, it can be concluded that the amount of Active Energy depends on the device charged to each port.

The placement of the capacitor at the optimal point is determined using the optimal capacitor placement method to obtain the specified voltage limit, the placement of the capacitor bank is placed at the most extreme point or the highest voltage drop value. The placement of the capacitor bank is placed at 3 points that have been selected at the optimal points that have previously been simulated to reduce the magnitude of the voltage drop value, Optimal Capacitor Placement simulink Power Station with the objective function of minimizing the cost of the distribution system is used in the optimization process of finding the point and the size of the capacitor in this study.

Table 6. Optimal Placement Point for Capacitors

No	Bank Capacitor Placement Location	Qc (Kvar)
1.	Bus 219	2567
2.	Bus 221	362.3
3.	Bus 230	362.5

If the connection between the client PC and the server PC is lost, information will appear in the IPDU event log stating that the SMPT delivery failed. If the connection between the client PC and the IPDU is lost, a warning will automatically appear that the user must log back in to be able to access the IPDU. In addition, another indicator appears, namely on the IPDU page taskbar there is a red X indicator. In this system, Windows Server Standard Edition 2003 is used to bridge between Client and IPDU to be able to send information messages automatically using SMTP. So that every time there is user activity indihome system.

The power factor value is influenced by the resistive, inductive and capacitive loads on the equipment used. Capacitive loads will increase the power factor and inductive loads will decrease the power factor. While resistive loads make the power factor ideal. In addition, the power factor is also influenced by the performance of the equipment, old equipment or equipment that has poor performance will reduce the power factor value, resulting in wasteful power consumption.

5. CONCLUSION

The implementation of a 20 kV capacitor bank energy management system for electrical usage in Indi-Home network devices has proven to significantly improve power quality and energy efficiency. Through careful system design, simulation, and integration, the capacitor bank effectively compensates for reactive power, thereby improving the overall power factor of the system. The use of automated control and real-time monitoring ensures that the capacitor bank operates optimally according to load conditions, reducing energy losses and preventing unnecessary penalties from utility providers. As a result, this system not only enhances the stability and reliability of the electrical supply to critical communication devices but also contributes to operational cost savings. This study demonstrates that optimizing capacitor bank systems in medium-voltage networks is a practical and effective approach to support energy efficiency goals, particularly in high-demand and sensitive environments like telecommunications infrastructure.

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