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Implementation of an Automatic Capacitor Bank Control System Using PLC For Power Factor Optimization

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ABSTRACT

The efficiency and stability of electrical power systems are greatly influenced by the power factor. A lowpower factor can lead to increased losses and higher electricity bills, especially in industrial environments. This study presents the implementation of an automatic capacitor bank control system using a Programmable Logic Controller (PLC) to optimize the power factor in an electrical installation. The system is designed to monitor reactive and active power in realtime, and automatically switch capacitor banks on or off based on the load condition. By utilizing PLC technology, the system ensures precision, reliability, and ease of modification according to operational requirements. Testing results demonstrate a significant improvement in power factor after the system is applied, as well as reduced reactive power consumption. This research contributes to the development of smart, automated solutions for energy efficiency in industrial power management systems.

Keywords: Power Factor, Capacitor Bank and PLC (Programmable Logic Controller).

INTRODUCTION

In the modern industrial landscape, energy efficiency is no longer a mere option it is a necessity that directly affects operational costs and the sustainability of power systems. One of the key indicators of electrical efficiency is the power factor. A low power factor indicates a high proportion of reactive power ini the system of reactive power in the system, which does not perform useful work but still flows through the electrical network, burdening equipment and reducing overall system efficiency.

In Indonesia, power utilities such as PLN impose penalties on industrial consumers whose power factor falls below the standard threshold (typically below 0.85). This drives the need for technical solutions that can continuously and automatically improve power factor. One of the conventional and widely adopted methods is the installation of capacitor banks to compensate for reactive power. However, without an automatic control system, these capacitor banks often fail to adapt to dynamic load variations, which limits their effectiveness. The Programmable Logic Controller(PLC) offers a highly reliable and flexible solution for realtime industrial automation. With its programmable logic capabilities, a PLC enables the design of control systems that can directly read electrical parameters from sensors or digital meters and then automatically switch capacitor units on or off based on real-time reactive power requirements.

This research focuses on the design and implementation of an automatic capacitor bank control system using PLC to optimize power factor in industrial electrical installations. The system integrates current and voltage sensors to compute active power, reactive power, and power factor, and processes the data in the PLC to determine appropriate control actions. The main contribution of this research is to present a practical and automated approach to managing

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fluctuating reactive power without the need for manual intervention. The system is expected to enhance reliability and energy efficiency by maintaining an optimal power factor, thereby supporting industrial productivity and reducing energy costs significantly.

LITERATURE REVIEW

Energy.

Energy is the ability to perform actions or work (effort). The word "Energy" comes from the Greek word "ergon" which means work. In doing something, we always utilize energy either consciously or unconsciously or Energy can be defined as power or force to do something or even the act of moving and shifting, which in general can be defined as the ability to do a job (Parta Setiawan, 2021). The following are the properties of energy. Energy Transformation means that Energy can be changed into another form. For example, Electrical Energy into Light Energy. Energy Transfer with the intention of Heat Energy from a material or place can be transferred to another place or material. For example, heating water in a pan, with heat energy originating from the fire transferred through the pan material so that it heats the water and after passing the boiling point of water, the water will evaporate.

Energy can be transferred from another object by a force that causes a shift/displacement. In this case it is often referred to as Mechanical Energy. Kinetic energy into electrical energy. Example: Windmills, generators. Electrical energy becomes sound energy.Examples: electric bell, car horn. Electrical energy is often expressed using certain electrical quantities (Beritajambi, 2017). such as some of them are as follows:

- Electrical voltage.
  Electrical Voltage can be defined as the difference in electrical potential that occurs at two points in an electrical circuit or the amount of energy needed to move a unit of electrical charge from one place to another. Electrical voltage is usually expressed in Volts and is calculated or measured using a Voltmeter.
- Electrical Resistance.
  Electrical resistance can be defined as the ratio of the voltage of an electronic electrical device to the electric current passing through it or the ability of a material to inhibit or prevent the flow of electric current. Electrical resistance is usually expressed in ohms symbolized by the Omega symbol "Ω" and measured using an Ohmmeter.
- Electric current.
  Current Electricity is a flow of electrons that move/transfer from atom to atom that occurs in a conductor at a certain speed in a certain time. The emergence of electric current is due to the potential difference at both ends of the conductor which occurs because it receives energy. To push the electrons to move from place to place. The movement of the electron flow will go to a place with weaker pressure. The size of the electric current depends on the power plant that produces the power. Electric driving force is needed so that we can utilize electrical energy, but this power must be sufficient and in the right amount. Based on this, the electric current must be able to flow and be disconnected at a stable speed. The speed of electric current movement is called the current rate which can be written as I with units of Ampere and measured using an Ammeter
- Electromotive Force (EMF).

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Electromotive Force can be defined as the amount of electrical energy that is converted into non-electricity or other amounts that can be converted into electrical energy as a potential difference between the ends of the poles of an electric current source when the electric current source is not flowing electric current. The amount of electromotive force is usually expressed in the form of Volt units and is measured using a Voltmeter.

- Capacitance.
  Capacitance can be defined as a measure of the amount of electrical charge that can be stored as a predetermined amount of electrical potential. The amount of Capacitance is expressed or measured in Farad units.

Electric Power System.

An electric power system consists of three main parts, namely the power plant center, transmission lines and distribution system. In general, the good or bad of the electric power transmission and distribution system is mainly reviewed from the quality of power received by consumers. Good power quality includes adequate power capacity and constant voltage at nominal voltage. Voltage must always be kept constant, especially at voltage losses that occur at the end of the line. Unstable voltage can cause damage to equipment that is sensitive to voltage changes (especially electronic devices). Voltage that is too low will cause electrical equipment to not operate properly. Likewise, voltage that is too high can potentially damage electrical equipment, including changes in frequency values that will be greatly felt by electricity users whose use is related to/depends on frequency stability. Consumers in this group are usually industrial/factory consumers who use automatic machines using time/frequency settings such as motor equipment. Therefore, frequency and voltage stability must always be controlled to avoid possible risks so that damage to system failure can be avoided (Jefri Arianto, 2015). For an illustration of the electrical power system in Indonesia in general, it can be seen in Figure 1 below:

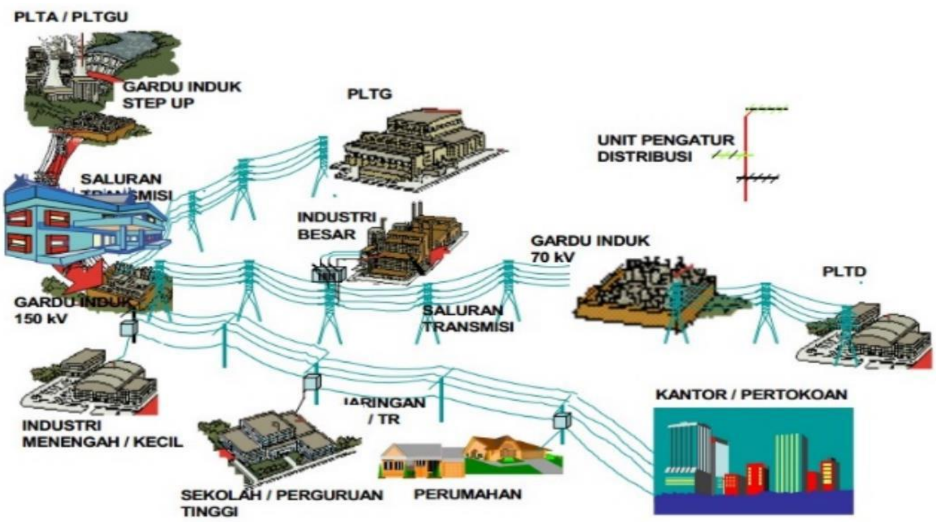

Figure 1. Electric Power Distribution System

Distribution Network serves to channel and distribute electric power from distribution substations to customers/electricity consumers with adequate service quality. One element of service quality is service continuity which depends on the topology and construction of the network and medium voltage equipment.

Distribution System Network.

This system can use overhead lines, overhead cables, or underground cables according to the desired level of reliability and environmental conditions and situations. This distribution channel is stretched along the area that will be supplied with electricity to the load center. The Distribution System Network is divided into 2 (two), namely the Primary Distribution System Network and the Secondary Distribution System Network. Where the Primary Distribution Network System is a medium voltage electric power distribution network (20 kV). The primary distribution network is a feeder network. The primary distribution network starts from the secondary side of the power transformer installed at the substation to the primary side of the distribution transformer installed on the line poles (Suhadi et al., 2008).

The radial system in the distribution network is an open system, where the electric power distributed radially through the substation to consumers is done separately from each other. This system is the simplest system among the other systems and the cheapest, because according to its construction this system requires very little use of electrical materials, especially if the distribution distance between the substation and the consumer is not too far. This open radial system is the least reliable, because the distribution of electrical power is only done using one channel. This model network when it gets a disturbance will stop the distribution of electric power enough long before the disturbance is repaired again. Therefore, the continuity of service in this open radial system is less reliable. In addition, the longer the distance of the line from the substation to the consumer, the voltage conditions are increasingly unreliable, in fact getting worse because the voltage losses will be greater. This means that the service capacity for this open radial system is very limited (Suhadi et al., 2008).

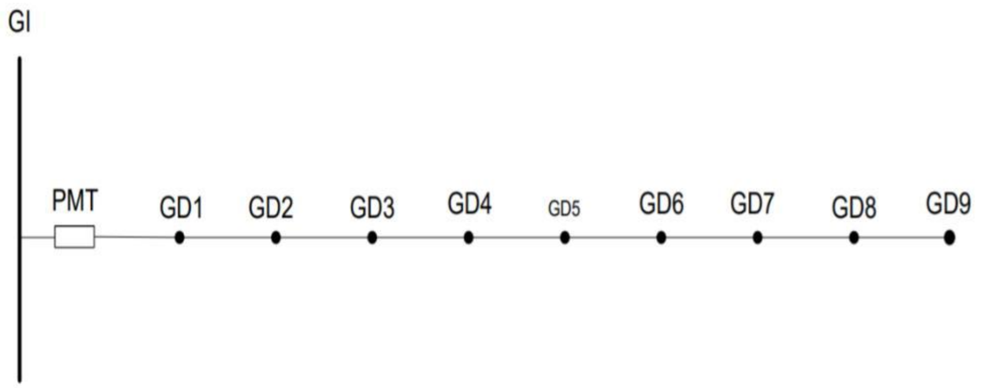

Figure 2. Radial Distribution System Network

Information :
GI = *Main Substation*
PMT = *Circuit Breaker*
GD = *Distribution Substation*

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In addition to the basic forms of existing distribution networks, modified forms have also been developed, which aim to improve the reliability and quality of the electrical system. One popular modified form is the spindle form, which usually consists of maximum of 6 feeders in loaded condition, and one feeder in working condition without load. The 6 feeder channels operating in loaded condition are called "working feeders" or working channels, and one channel operated without load is called "express feeder" (Suhadi et al., 2008).

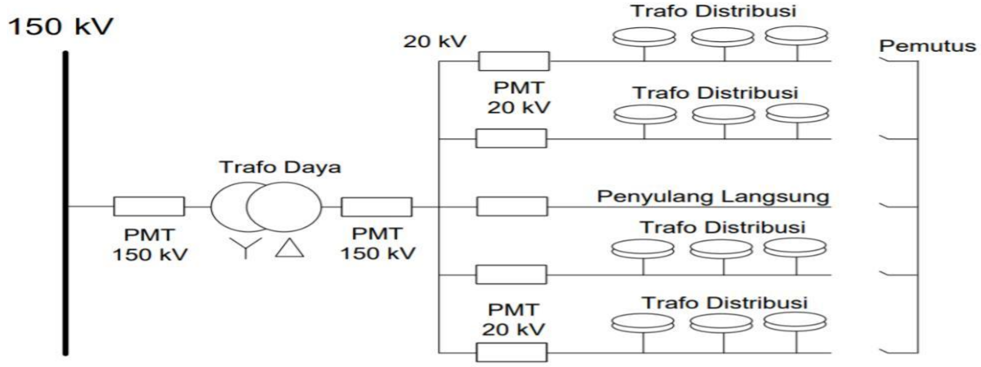

Figure 3. Spindle Distribution System Network

Information :
PMT = *Circuit Breaker*
kV = *kilo Volt*

A closed circuit system in a distribution network is a distribution system through two or more feeder channels that are interconnected to form a ring-shaped circuit. This system iseconomically profitable, because disturbances in the network are limited only to the channels.only thedisturbed ones. While for other channels can still distribute electric power from other sources in an undisturbed circuit. So that the continuity of electric power source service can be guaranteed properly. What needs to be considered in this system is that if the load served increases, the capacity condition of this closed circuit system will get worse. However, if more than one source point (Power Plant) is used in this network system, this system will be widely used, and will produce better voltage quality, and its voltage regulation tends to be small (Suhadi et al., 2008).

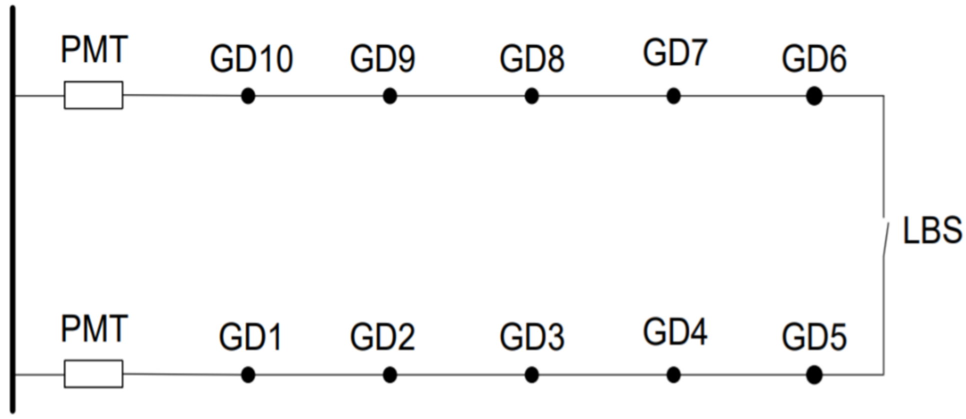

Figure 4. Ring Distribution System Network

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Information :
GI = *Main Substation*
PMT = *Circuit Breaker*
GD = *Distribution Substation*
LBS = *Load Breaker*

METHODS

This research employs an experimental approach by designing, assembling, and testing an automatic capacitor bank control system integrated with a Programmable Logic Controller(PLC). The study is carried out in stages including system analysis, component selection, circuit design, programming, and performance testing.The system is designed to continuously monitor electrical parameters such as voltage, current, power factor, and reactive power. When the power factor drops below a predefined threshold(e.g.,0.85), the system automatically activates one or more capacitor units to compensate for reactive power and improve the power factor.

Components Used

- Programmable Logic Controller
  (PLC): Functions as the main controller that processes input data and determines control actions.
- Current and Voltage Sensors (CT and VT)
  Measure real-time electrical parameters in the load.
- Capacitor Bank
  A set of capacitors divided into stages that can be switched on/off automatically.
- Power Meter / Multifunction Meter
  Sends data to the PLC for processing.
- Contactor Relays
  Used to switch each capacitor stage on or off based on PLC output.
- HMI(optional)
  Allows operators to monitor and manually override the system if needed.

The logic is implemented using ladder diagram programming in the PLC. The key funct ions include:

- Reading real-time voltage, current, and power factor data.
- Comparing measured power factor with the setpoint.
- Determining the number of capacitor stages to activate.
- Sending control signals to the contactors to engage the appropriate capacitor stages.

Operation Workflow

1. System starts and reads real-time data from sensors/meters.
2. If the power factor is below 0.85, the PLC activates the first capacitor stage.
3. The system continues monitoring. If the power factor is still low, additional capacitor st ages are activated until the desired range is reached.
4. If the power factor becomes too high(overcompensation), the PLC deactivates stages ac cordingly.

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Testing and Evaluation

The system is tested under various simulated load conditions to assess:

- Response time of the system in adjusting power factor.
- Accuracy of measurements.
- Effectiveness in reducing reactive power consumption.
- Stability and safety of the switching mechanism.

Performance before and after the implementation is compared to determine improvement in power factor and overall system efficiency. This survey was conducted to determine the FCO manufacturing process where previously the FCO tube used was no longer reliable after a disturbance occurred that caused the FCO tube to be damaged/burned/broken, therefore one of the handling of the burning FCO tube was using a modification of the Urgent Cut Out Tube which could be used after going through a feasibility test Operation.

Urgent Cut Out Cylinder is one of the solutions, especially at PT PLN (Persero) UIW North Sumatra UP3 Medan at ULP Medan Baru in handling FCO disruptions as an effort to accelerate handling of FCO disruptions amidst the difficulty of reaching certain areas for the provision of materials or taking materials in the midst of the Covid-19 Pandemic so that these conditions affect the availability of the materials needed. Where this Urgent Cut Out Cylinder can be easily made by utilizing several FCO ex-dismantled materials and additional new materials. The naming of the cylinder referred to as the "Urgent" cylinder originated from its use which was used at certain times or emergencies due to limited materials during the Covid-19 pandemic.

RESULTS AND DISCUSSION

Result Automatic Capacitor Bank.

The implementation of the automatic capacitor bank control system using a Programmable Logic Controller(PLC) was tested under various load conditions to evaluate its performance in improving power factor and reducing reactive power consumption. The system operated as intended, where the PLC successfully read realtime data from the multifunction power meter, including voltage, current, active power, reactive power, and power factor. Based on the programmed logic, the PLC was able to make decisions to activate or deactivate capacitor stages accordingly. Initial testing showed that, without compensation, the average power factor ranged from 0.65 to0.75, depending on the load. After implementing the automatic capacitor bank control system, the power factor improved significantly to a range of 0.90 to0.96, consistently meeting the recommended minimum threshold of 0.85.

The activation of the capacitor bank also led to a noticeable decrease in reactive power (kVAR). The average reduction in reactive power ranged from 20% to40%, depending on the load profile and compensation stage activated. Throughout the testing phase, the system maintained stability, and no abnormal behavior was observed. The capacitor switching process operated smoothly without voltage spikes or in rush current issues, confirming the safety of the control logic and hardware configuration.

Table 1. Power Factor Improvement Chart

Load Condition	Before Compensation	After Compensation
Low Load	0.70	0.92
Medium Load	0.68	0.94

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High Load	0.65	0.96

Table 2. Reactive Power Reduction Chart

Load Condition	% Decrease in Reactive Power
Low Load	25 %
Medium Load	30%
High Load	40%

Risk Analysis Data.

Based on the implementation of the installation of Research Objects that have been carried out during the planned period in table 1 (Research Schedule), there are several things that must be considered, including the following:

1. In handling disturbances on damaged/burned/broken FCOs, this is done by replacing the material, especially the FCO tube. In addition to the acceleration of handling disturbances being influenced by the distance traveled, this acceleration is also influenced by the availability of materials, the condition of the terrain traversed and the number of technical officers available for the number of disturbances being served at that time.
2. This tool has not been tested for long-term installation, therefore, in accordance with its name which is urgent, the installation should be temporary and in this research object, the installation lasted 1 (one) month and then the material was replaced with a new FCO, which caused another blackout.
3. Given the many types of FCOs currently installed, it is possible that the length and width of the FCO hanger (Hang) may not match the object of this research, but this can be anticipated by re-measuring the length of the existing FCO tube and cutting the pipe according to needs.
4. When connecting the pipe and socket, it should be installed as tightly as possible so that there are no gaps for water to enter the FCO tube, causing a short circuit. Therefore, it would be better to provide adhesive glue so that it can cover the gaps between the pipe socket and the PVC pipe tube.
5. In addition to providing adhesive glue between the pipe and socket, the connection will still have the potential for a short circuit if the Urgnet Cut Out tube is used for a long period due to the connection.

Discussion.

The results from the testing phase demonstrate that the implementation of a PLCbased automatic capacitor bank control system is effective in improving the power factor in an industrial electrical system. The system responds in realtime to fluctuating load conditions by analyzing electrical parameters and making logical decisions for capacitor stage activation.The improvement in power factor from the initial range of 0.65–0.75 to a post-implementation range of 0.90 0.96 shows that the system performs well in maintaining the desired power quality.

This ensures that the industrial load operates closer to unity power factor, which:

- Minimizes power losses,
- Reduces electricity costs associated with low power factor penalties,

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- Increases the life expectancy of electrical equipment due to reduced stress from reactive c urrents.

In addition, the reactive power reduction of40% indicates that the system is not only improving power factor numerically but also contributing to real energy efficiency in the network by minimizing the unnecessary circulation of non-working power. From the control system perspectiveonfirms that the PLC can adapt quickly to changes in power factor, which is critical for real-time compensation in dynamic industrial loads. This responsiveness, combined with stability and safety in capacitor switching, reflects a successful integration of control logic, sensor feedback, and hardware configuration.Overall, this study validates the potential of PLCbased automation to optimize power factor in industrial environments through intelligent, flexible, and responsive control.

CONCLUSION.

The implementation of an automatic capacitor bank control system using a Programmable Logic Controller(PLC) has proven to be an effective solution for optimizing power factor in industrial electrical systems. The study demonstrates that by leveraging realtime electrical measurements and programmable control logic, the system can dynamically adjust the number of capacitors engaged based on load conditions. This ensures improved power factor, reduced reactive power losses, and enhanced energy efficiency. Key benefits observed include:

- An increase in power factor to values consistently above 0.90,
- A reduction in reactive power consumption by up to 40%,
- Quick system response time ranging between 1–3 seconds,
- Minimized risk of overcompensation or undercompensation.

Furthermore, the PLC-based approach offers flexibility, scalability, and reliability, making it suitable for various industrial applications. The results underscore the importance of integrating automation and control systems to meet modern energy efficiency standards and reduce electricity costs. This research contributes to the advancement of smart electrical infrastructure by providing a practical and adaptive solution for managing reactive power and maintaining optimal power quality.

REFERENCES

Aryza, S., Irwanto, M., Lubis, Z., Siahaan, APU, Rahim, R., & Furqan, M. (2018). A Novelty Design Of Minimization Of Electrical Losses In A Vector Controlled Induction Machine Drive. In IOP Conference Series: Materials Science and Engineering (Vol. 300, No. 1, p. 012067). IOP Publishing.

Alexandru C. and Tatu NI, "Optimal design of solar trackers used for photovoltaic strings," J. Renew. Sustain. ENERGY, vol. 5, 2013.

Badaruddin. 2012, Research Journal. The Effect of Load Imbalance on Neutral Current and Losses in Distribution Transformers of the Gading Icon Rusunami Project, Jakarta.

Daman Suswanto. 2009. ELECTRICAL POWER DISTRIBUTION SYSTEM, Electrical Engineering, Faculty of Engineering, Padang State University, Padang.

H. Satria et all (2022). Design and Demonstration of the Use of Automatic Hand Washing Sink

International Journal of Economic, Technology and Social Sciences
e-ISSN 2775-2976
International Journal of Economic, Technology and Social Sciences
url: https://jurnal.ceredindonesia.or.id/index.php/injects
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Technology in Covid-19 Pandemic Conditions. *International Journal of Education, Information Technology, and Others*, *5*(2), 127-132.

Kadir, Abdul.2000. "Distribution and Utilization of Electric Power." Publisher of the University of Indonesia (UI-Press), Jakarta.

Mungkin, M., & Satria, H. (2023). Desain Sistem Panel Surya Fleksibel dengan Penambahan Reflektor Cermin untuk Peningkatan Output Konversi Energi Listrik.

SPLN 42-10. 1993. Aerial Stranded Cable Rated Voltage 0.6/I KV (NFAZX-T / NFA2X / NF2X). Jakarta.

SPLN 56-1.1993. Low Voltage Electric Power Connection (SLTR) Department of Mining and Energy State Electricity Company. Jakarta.

PT.PLN. 2010, Low Voltage Electric Power Network Construction Standards, Book 3.Jakarta.

Hamdani, H., Tharo, Z., & Anisah, S. (2019, May). Performance Comparison

Ya'u JM, A Review of Solar Tracking Systems and Their Classification," J. Energy, Environ. Chem. Ind., vol. 2, no. 3, 2017, pp. 46–50.