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The Power Factor Correction Features

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Abstract—**This paper discusses the power factor features in detail. It presents information on power quality, the definition of the power factor, making sense of the power factor, calculating power factor, power factor correction, troubleshooting power factor correction capacitors, and the benefits of power factor correlation.**

Keywords—power factor; power factor correction; voltage; optimization; power quality

I. THE POWER FACTOR CORRECTION FEATURES

1.1 Power Factor

Power factor is a vital component of power quality and is required for the most effective operation of a site. It explains the relationship between reactive power, which is consumed but not directly used, and real power, which is actively employed by electrical equipment to produce the useful output [1]. Collectively, they constitute a site's apparent power, with the power factor representing the difference between real and apparent power.

An efficient and quality power factor is essential for the proper functioning of electrical appliances. The power factor of an electrical system measures how efficiently it uses the electricity it receives [1]. The ratio of apparent to active power occurs when:

- Active power (P), measured in Watts, is the energy needed to do work such as illuminating a room.
- Quantified in volt-ampere-seconds (var), reactive power (Q) quantifies the energy that is held but reflected back to its source.
- The vector total of active and reactive power, measured in Volt Amperes, is known as apparent power (S).

A low power factor indicates that equipment and site are consuming excessive quantities of electricity without creating useful outputs, hence inflating energy costs. Typically, a site's power factor is around 80% and 90%, but it can drop as low as 50%, significantly raising energy expenses. High reactive power can potentially result in reactive power charges from the electricity provider. An inadequate power factor also increases equipment wear and associated maintenance expenses [2].

The power factor represents the efficiency of energy. Typically, it is stated as a percentage where a lower percentage, represents the use of less efficient energy.

The power factor (PF) is the proportion of the apparent power (kilovolt amperes) to the working power (kilowatts [kW]) (kVA) [1]. Apparent power is the quantity of energy used to operate machines and gear over a given time. It is determined through multiplication. The outcome is reported in units (kVA).

PF represents the proportion between the actual power utilized within the circuit and the apparent power supplied to it. A power factor of 96% is more efficient than a factor of 75%. In many places, PF values below 95% are deemed inefficient [2].

1.2 Making Sense of Power Factor

It is possible to understand the power factor by using a variety of analogies. The Beer Analogy is one of these analogies. As depicted in Fig. 1 below [3], each component of the Beer

Figure 1: Making Sense of Power Factor; The Beer Analogy

Analogy has a unique representation, including beer, foam, and mug.

These representations include;

- Beer represents the useful power (kW) (kW).
- Foam is reactive power (kVAR) and represents lost or wasted energy. When energy is produced, such as through heat generation, nothing is accomplished.
- The mug represents the apparent power (kVA).

A hundred percent efficient circuit means the demand is equivalent to available power. Whenever demand exceeds available power, the utility system is placed under stress. The majority of utilities calculate demand using the mean load placed within a quarter to half an hour. In a situation where the demand needs are not consistent, the utility needs to maintain a significant amount of reserve content compared to when the needs remain constant [4].

Peak demand is the highest level of demand. The difficulty for utilities is meeting the peak demand of each customer. Unless there are sufficient reserves, utilizing electricity at the peak of demand can disrupt the total supply [4]. Consequently, utilities charge for peak demand for certain customers utilities

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may further apply the highest peak over the whole billing period.

Utilities impose levies on businesses having a low power factor. Similar to driving a gas guzzler, inefficiency can incur substantial expenses. Low power factor, leads to an inefficient circuit and thus the greater the total running expenses. The possibility that utilities may punish a customer for overuse increases with the operational cost [5]. In the vast majority of AC circuits, the power factor is never equal to one due to the presence of interference along the lines of power.

1. How to Calculate Power Factor

Computing power factor requires a power analyzer working power and apparent power and calculating their proportion.

Watts are used to determining useful power, whereas VA is used to measure supplied power. The two ratios are essentially apparent power to supplied power which is illustrated in Fig. 2 below.

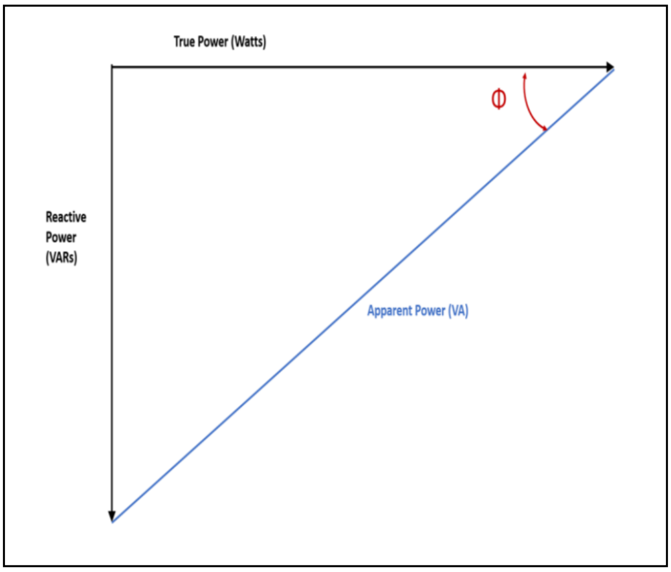

Fig. 2: An Illustration of Power Factor Formula

As seen in the diagram, the power factor contrasts the actual utilized with the apparent power of the load. The ability to execute tasks is referred to as real power. By adjusting for the power factor, one can avoid power factor penalties [5].

A low or poor power factor indicates that power is being used inefficiently. This is crucial for enterprises since it can lead to the following:

- A decrease in the amount of usable power available
- Heat-related harm to the insulated including other components of the circuit.
- A necessary increase in conductor and apparatus sizes

Finally, because a lower power factor necessitates supplying the load with a larger current, the power factor raises the general charge for the power supply system [5].

2. Power Factor Correlation

Power factor correction uses capacitors to reduce the reactive power component of an alternating current (AC) circuit, hence improving the circuit's efficiency and decreasing the circuit's current consumption [6].

Direct current (DC) circuits make it easy to calculate the power dissipated by the connected load as the product of the DC voltage and the DC in watts (W). The electrical power used by a resistive load is linear in the applied voltage since the current is proportionate to the voltage for a given load. In an AC circuit, however, things are quite different since reactance affects the circuit's behavior [5].

Power lost in an alternating current (AC) circuit is equal to the product of the volts and amperes at any given instant, or watts, since AC voltage (and current) are sinusoidal and vary continuously in magnitude and direction with time at a rate determined by the source frequency [5].

In a direct current (DC) circuit, the average power is simply V*I, but in an alternating current (AC) circuit, the average power is different because many AC loads have inductive components such as coils, windings, and transformers, where the current is slightly out of phase with the voltage, causing the actual power dissipated in watts to be less than the product of the voltage and current. This is because we also need to account for the phase angle () between circuit resistance and reactance [6].

3. Troubleshooting Power Factor Correction Capacitors

Using correction capacitors in power factor prevents utilities from charging higher rates when the power factor drops below certain levels, hence lowering energy expenses [1]. These capacitors are frequently installed by facilities when power factor issues emerge due to inductive loads. Capacitor banks often run for a long time but must be regularly tested to ensure they are functioning correctly. The amount of power correction available may be reduced by issues like loose connections, blown fuses, or failing capacitors [6]. These issues might even result in a complete system failure or a fire in very severe circumstances. The inspection of power factor correction capacitors and how to prevent these issues are covered below.

When troubleshooting power factor correction capacitors, safety comes first. Long after the electricity to them has been cut off, energy storage devices called capacitors still have the ability to shock a person to death [7]. The discharge circuit is usually present in capacitors; however, when the circuit malfunctions, there is a prolonged shock danger. When testing with the voltage attached, one must use the utmost caution. Training that is particular to the tools, how they are used, and the job you are expected to do is required for capacitor bank maintenance [8]. Additionally, NFPA 70E-compliant personal protective equipment (PPE) is necessary.

Working with current transformer (CT) circuits involves additional risks, such as wiring and short blocks. CT is often found in the switchboard, not the container housing the capacitor bank [6]. The CT wire still poses a risk of electrical shock despite the de-energizing capacitor bank. The CT may acquire a fatal voltage between its terminals in instances where the circuit is opened when there is a load.

How does the power factor work? The overall demand a facility makes on the utility to provide current and voltage, regardless of whether it really works, is known as the

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apparent power [1]. When the power factor goes below a certain threshold, often 90%, utilities typically charge a higher rate.

Power Factor = True power (KW) / apparent power (KVA)

50 KW/52KVA = .96 (good)

50 KW/63 KVA = .79 (poor)

The most frequent reason for low power factor is motor inductance; when motors are not fully loaded, the issue only worsens. The power factor is also decreased by harmonic currents reflected back into the systems.

A meter must monitor current, power, voltage, and demand all at once for at least one second to determine the power factor. These measurements cannot be made with a digital multimeter, but they may be made over time using a power quality analyzer clamp to provide an accurate picture of power use [1]. To get a more profound knowledge of power factors and other characteristics over time, a power logger, another kind of power quality equipment, may carry out a 30-day load study.

Power factor correction capacitors may be added to the distribution system of the facility to improve the low power factor. The most effective way to do this is with an automated controller that turns reactors and capacitors on and off [6]. A fixed capacitor bank is used in the simplest applications.

1) Capacitors Longevity

Capacitors should last for many years without experiencing any problems when used normally. Power correction capacitors and accompanying electronics, however, might experience early failures due to factors including high ambient temperatures, insufficient ventilation, and harmonic currents. Failures may result in significant increases in energy costs and, in the worst instances, the possibility of fires or explosions. Therefore, it's crucial to regularly check power factor correction capacitors to ensure they are functioning correctly [6]. The websites of the majority of manufacturers host the service bulletins. The suggested preventive maintenance frequency for them is typically every two years.

Using an infrared imager during the inspection is important for assessing the health of capacitors [9]. A thermal imager is the most useful instrument for assessing capacitor banks. Prior to testing, the system has to be powered on for at least an hour. To begin, one needs to confirm that all of the stages are linked by looking at the controller's display. Next, make sure the cooling fans are functioning correctly. Before one opens the doors, scanning the enclosure with an infrared camera is necessary [9]. And, in accordance with arc-flash evaluation, a person needs to be in the necessary personal safety gear.

Use the thermal imager to inspect the power and control wires for any loose connections. By demonstrating a temperature rise caused by the increased resistance at the connected site, a thermal assessment may detect a poor connection. The desired connection should register not exceeding 20^0 than the surrounding air. At points of connection, there should be minimal to no temperature variation from phase to phase or bank to bank [9].

By emphasizing temperature variations between blown and undamaged fuses, an infrared examination may find blown fuses [10]. The quantity of available correction is decreased by a damaged fuse in the banks stage of a capacitor. Some appliances have blown fuse indications, whereas others don't. Shut down the whole bank if you discover a blown fuse and investigate the source. Faulty capacitors, reactor issues, and faulty are a few prevalent culprits [6].

It is recommended to check for variations in each capacitor's temperature. It should be cooler if a capacitor is not required or attached at the time of inspection [6]. Also, convection may cause component temperatures to be greater in the upper parts. However, if the controller claims that all phases are linked, then temperature variations often suggest an issue [11]. High pressure, for instance, can cause the internal pressure interrupter of the capacitor to activate prior to the fuse in the external location, abruptly disconnecting the capacitor.

2) Current Measurement

Measurements of current are also necessary for troubleshooting [12]. Using a multimeter and a current clamp, a current measurement of each stage's three phases should be made as part of preventive maintenance and documented. The current clamp is used to measure current input [2]. Computation is needed to translate the value of the measured current to the flowing current in the switchboard. If one measures 2 A and the current transformer has a rating of 3000 A to 5 A, the actual current is. In addition, while all stages are connected, check for phase imbalance in the current flowing along the breaker into the capacitor bank [11]. Please keep track of all readings in a log so that future readings may be compared to them.

Troubleshooting during capacitance measurements is also essential [12]. De-energizing the capacitor bank and waiting within the recommended timeframe before measuring capacitance. Also, there is a need to verify there is no AC present while tiring the appropriate personal protective equipment and a correctly rated meter [9]. Observing the lockout/tagout protocol is also key. What follows is testing each step using a DC meter set to 1000 V dc and qualified for the voltage to be tested. Voltage should not exist. Voltage is a sign of an undischarged capacitor. If no voltage is found, one needs to use the capacitance meter to measure it [13]. Then, compare the measurement to each stage's manufacturer's requirements.

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3) Cleaning

Cleaning and visual examination are also required throughout the inspection process. Making a thorough visual check is quired. Significant checks include discolored parts of a capacitor, bulging capacitors, and indications of moisture or warmth. For cooling fans, clean the filters or replace them. Use a vacuum to clean the equipment; never use pressurized air. Before capacitors' re-energizing, one needs to perform an integrity test for insulation in bus conductors [6]. To avoid inaccurate readings from phase to phase, the line side breaker or fuses on the control power transformer must be removed. When maintained correctly and in line with the manufacturer's recommendations, capacitors for power factor correction are designed to last for many years of use. Regular inspections of capacitor banks ensure that they are functioning safely and conserving the predicted amounts of energy.

4. Benefits of Power Factor Correction

The cost of energy is reduced. Reactive energy penalty is avoided, kVA demand is decreased, and power losses in the installation's transformers and conductors are minimized using power factor modification [7]. Power factor adjustment is one method for lowering the use of reactive power. The ratio of real to reactive power is referred to as the power factor. The power factor is worse if your demand for reactive power is more significant than your need for actual power.

Poor power factor makes it necessary to use more kVA to provide a given amount of kWh, which raises demand costs. Increased energy losses in cables, switchboards, and transformers and the risk of overloading and overheating electrical infrastructure and apparatus are further detrimental implications of weak power factors [7]. Reactive power delivered by the grid is reduced using power factor correction (PFC) technology, which lowers customers' demand costs.

Additionally, power capacity is increased via power factor correction. PFC technology put on the LV side of an MV/LV transformer increases the power available at the secondary. A high-power factor allows for more efficient usage of an electrical system's components [7]. Minimal setup time is another perk. Since the compensated arrangement draws less current for the same amount of active power, the conduit cross-section may be lowered by using PFC technology.

The voltage fluctuations are also reduced as a result of power factor correction. By putting capacitors upstream of the point where the PFC device is coupled, network overloading may be prevented, and harmonics can be reduced [7].

II. CONCLUSIONS

In conclusion, power factor correction is a significant area of study in electrical engineering and physics. Different aspects including power quality, the definition of the power factor, making sense of the power factor, calculating power factor, power factor correction, troubleshooting power factor correction capacitors, and the benefits of power factor correlation provide a better comprehension of power factor correction features and its application.

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