UTILIZING AUTOMATIC POWER FACTOR COMPENSATION IN INDUSTRIAL APPLICATIONS TO REDUCE PENALTIES

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Abstract **- The increasing prevalence of sensitive loads has brought attention to power quality issues. Many of these loads utilize equipment that is vulnerable to voltage supply distortions or dips. Disturbances in distribution networks are the root cause of most power quality problems. Regulations, which are in place in many locations, impose limits on the distortion and unbalance that customers can introduce to a distribution system. Compliance with these regulations may necessitate the installation of compensators (filters) on customer premises. Utility providers are also expected to deliver low distortion balanced voltage to customers, particularly those with sensitive loads.**

In instances where a DVR (Dynamic Voltage Restorer) is linked to a specific load, it can inject compensating current to ensure that the total demand aligns with the utility connection specifications. Alternatively, this paper aims to explore a DVR that can effectively fulfil both of these functions.

KEYWORDS: Voltage supply distortions, Distribution network disturbances, Regulatory compliance, Compensators (filters), Utility connection specifications, Dynamic Voltage Restorer (DVR), Compensating current, Utility providers.

INTRODUCTION:

Reactive power in power distribution networks is a primary contributor to increasing system losses and various power quality issues. Traditionally, Static Var Compensators (SVCs) combined with passive filters have been utilized for active power compensation and mitigating power quality problems in distribution systems. However, SVCs, while effective at the transmission level, have limitations such as restricted bandwidth, a higher count of passive elements leading to increased size and losses, and slower response times, making them less suitable for modern distribution requirements.

An alternative compensating system has been proposed, integrating SVC and an active power filter to compensate three-phase loads within a minimum of two cycles. This approach involves a controller that continuously monitors load voltages and currents to determine the appropriate compensation needed with minimal response time. The Distribution Static Compensator (DVR) emerges as a solution to overcome the drawbacks of traditional methods, offering precise control and fast response during transient and steady states, with a reduced footprint and weight.

Essentially, a DVR functions as a converter-based distribution Flexible AC Transmission Controller, sharing similarities with a Static Compensator used at the transmission level. While the Compensator Technique at the transmission level handles fundamental reactive power and provides voltage support, the DVR operates at the distribution level or load end for dynamic compensation. Additionally, a DVR can act as a shunt active filter to eliminate unbalance or distortions in source current or supply voltage, conforming to IEEE-519 standard limits.

Given the multifunctional nature of a DVR, the primary goal of any control algorithm should be flexibility and ease of implementation, exploiting its capabilities to the fullest. Before choosing a control algorithm, the converter configuration is a crucial criterion, with two options: voltage source converter or current source converter, coupled with passive storage elements like capacitors or inductors, respectively. Voltage source converters are typically preferred due to their smaller size, lower heat dissipation, and lower capacitor cost compared to an inductor with the same rating.

PROPOSED SYSTEM:

We present a method for restoring the diminished power factor when a load is connected to a single-phase supply, experiencing reduced gain or a change in load conditions. This restoration is achieved through a compensation technique. A MOSFET-based inverter is powered by a 12-volt DC input, with PWM control supplied to the MOSFET gate and source through a dsPIC30F2010. The dsPIC30F2010 is powered by a multi-tapping transformer using an adapter, while the MOSFET receives a 5V input from the same transformer. The coding uploaded to the dsPIC30F2010 is designed to manage gain reduction and compensation.

An isolator and driver circuit employing TLP250, with a 12V input, is used to convert the 5V PWM from dsPIC30F2010 to a 12V PWM, isolating the ground to prevent potential circuit disturbances under abnormal conditions.

The experimental setup is connected to a CRO (Cathode Ray Oscilloscope) to observe input and output waveforms. The CRO displays an inverter waveform with an amplitude of 10 volts. To visualize disturbances in the load, the non-compensation button, or the so-called Gain reduction button, is switched ON, resulting in a non-compensated waveform representing a change in load or reduced power factor.

Subsequently, by activating the compensate button, the obtained waveform is compensated, restoring the actual inverter voltage. This process improves power quality, leading to an enhanced power factor.

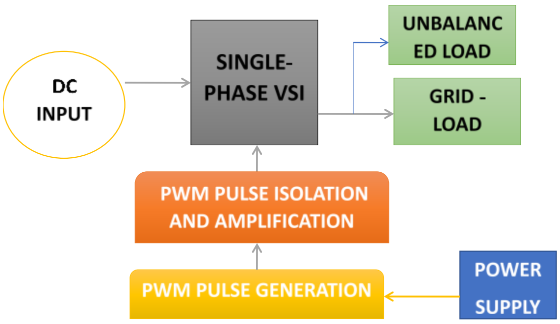

Fig: Block Diagram of the Proposed System

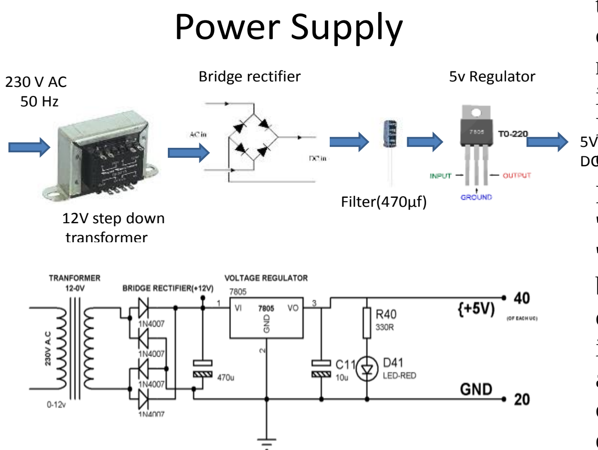

Fig: Power supply of the Proposed System

FACTS DEVICES:

In recent years, Flexible AC Transmission Systems (FACTS) have become widely recognized for enhancing controllability in power systems through the use of power electronic devices. Various FACTS devices have been deployed globally for different applications, and new types are currently in the process of practical implementation. The primary aim in most applications is to enable better controllability, preventing the need for costly or landscape-intensive expansions of power systems, such as upgrades or additional substations and power lines. FACTS devices offer improved adaptation to changing operational conditions and enhance the utilization of existing installations.

The fundamental applications of FACTS devices include:

1. Power flow control
2. Increased transmission capability
3. Voltage control
4. Reactive power compensation
5. Stability improvement
6. Power quality improvement
7. Power conditioning
8. Flicker mitigation
9. Interconnection of renewable and distributed generation and storage.

Efficient utilization of lines for active power transmission should ideally approach thermal limits. FACTS devices play a crucial role in shifting voltage and stability limits. Their importance grows significantly with increasing line length. The impact of these devices is realized through switched or controlled shunt compensation, series compensation, or phase shift control. Operating as fast current, voltage, or impedance controllers, FACTS devices leverage power electronics, allowing for very short reaction times, often below one second.

The evolution of FACTS devices is closely tied to advancements in power electronic components. The foundational concepts involve network elements influencing reactive power or the impedance of a segment within the power system. Figure 1.2 illustrates the number of basic devices categorized into conventional and FACTS devices.

Regarding the classification of FACTS devices as 'dynamic' and 'static,' it's essential to note that 'dynamic' denotes the rapid controllability facilitated by power electronics, distinguishing them from conventional devices. On the other hand, 'static' indicates that these devices lack moving parts, such as mechanical switches, to achieve dynamic controllability. Therefore, most FACTS devices can exhibit both static and dynamic characteristics.

COMPENSATION TECHNIQUES:

In 1999, the first Static Compensator with Voltage Source Converter, known as Compensator Technique, was inaugurated. The Compensator Technique exhibits characteristics akin to a synchronous condenser but, being an electronic device, lacks inertia. It surpasses the synchronous condenser in various aspects, including superior dynamics, lower investment costs, and reduced operating and maintenance expenses. Constructed with Thyristors featuring turn-off capability, such as GTO, or modern alternatives like IGCT or increasingly IGBTs, the static line determines the control characteristic for voltage with a specific steepness due to current limitations.

A noteworthy advantage of the Compensator Technique lies in its independence from the actual voltage at the connection point for reactive power provision. This is evident in the diagram, where maximum currents remain unaffected by voltage, distinguishing it from the SVC. Consequently, even during severe contingencies, the Compensator Technique maintains its full capability.

In the realm of distributed energy, Voltage Source Converters for grid interconnection are commonplace today. The ongoing development of the Compensator Technique involves its integration with energy storage on the DC-side. This combination of active and reactive power holds the potential for significantly enhancing performance in power quality and promoting balanced network operation.

COMPENSATOR TECHNIQUEs are structured on the Voltage Source Converter (VSC) topology and employ either Gate-Turn-off Thyristors (GTO) or Isolated Gate Bipolar Transistors (IGBT) devices. These systems act as rapid, electronic counterparts to synchronous condensers. When the COMPENSATOR TECHNIQUE voltage, Vs, (proportional to the dc bus voltage Vc) exceeds the bus voltage, Es, it generates leading or capacitive VARS. Conversely, if Vs is less than Es, it produces lagging or inductive VARS.

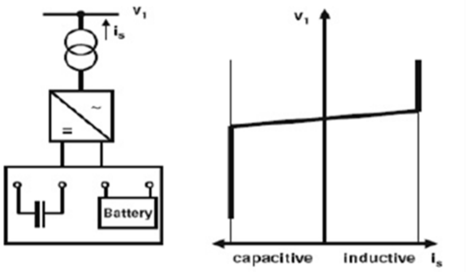

Fig. Compensator Technique Structure and Voltage / Current Characteristic

The three-phase COMPENSATOR TECHNIQUE capitalizes on the principle that in a three-phase, fundamental frequency, steady-state scenario, the instantaneous power entering a purely reactive device must be zero. To supply reactive power in each phase, the strategy involves circulating the instantaneous real power between the phases. This circulation is achieved by strategically firing the GTO/diode switches to maintain the phase difference between the ac bus voltage ES and the voltage generated by the Compensator Technique, VS. The ideal scenario involves constructing a device that circulates instantaneous power without the need for an energy storage device, essentially operating without a DC capacitor.

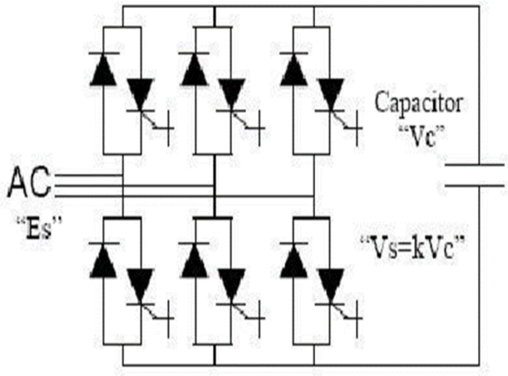

Fig. Pulses Compensator Technique

COMPENSATOR TECHNIQUE EQUIVALENT CIRCUIT:

Various control techniques can be employed for firing control in the Compensator Technique. One method involves fundamental switching of the GTO/diode, occurring once per cycle. Although this minimizes switching losses, it often necessitates more intricate transformer topologies. Alternatively, Pulse Width Modulated (PWM) techniques, involving more than one switch-on and switch-off operation of the GTO or IGBT switch per cycle, can be utilized. While this approach allows for simpler transformer topologies, it comes at the expense of higher switching losses.

The 6 Pulse COMPENSATOR TECHNIQUE, utilizing fundamental switching, inherently produces the 6 N1 harmonics. To mitigate these harmonics, various methods can be applied. These include the basic 12-pulse configuration with parallel star/delta transformer connections, the complete elimination of 5th and 7th harmonic current using series connections of star/star and star/delta transformers, and a quasi-12 pulse method employing a single star-star transformer with two secondary windings. Control of the firing angle produces a 30° phase shift between the two 6-pulse bridges, and this method can be extended to create a 24-pulse and a 48-pulse COMPENSATOR TECHNIQUE, further minimizing harmonics.

Another approach for harmonic cancellation involves a multi-level configuration, allowing for more than one switching element per level and, consequently, more than one switching operation in each bridge arm. The resulting AC voltage exhibits a staircase effect, dependent on the number of levels, and this staircase voltage can be controlled to eliminate harmonics.

THYRISTOR CONTROLLED SERIES CAPACITORS (TCSC):

Thyristor Controlled Series Capacitors (TCSC) are designed to address specific dynamic challenges within transmission systems. One key function is enhancing damping in large interconnected electrical systems. Additionally, TCSCs effectively mitigate the issue of Sub Synchronous Resonance (SSR), a phenomenon involving interactions between large thermal generating units and series-compensated transmission systems. The high-speed switching capability of TCSCs facilitates control over line power flow, enabling increased loading of existing transmission lines and swift readjustment of power flow in response to various contingencies. Moreover, TCSCs can regulate steady-state power flow within specified rating limits. From a technological standpoint, TCSCs share similarities with conventional series capacitors.

In the TCSC configuration, all power equipment, including the Thyristor valve controlling the main capacitor bank, is positioned on an isolated steel platform. Control and protection systems, along with auxiliary components, are situated at ground potential. The operational setup of a TCSC and its diagram are depicted in the figure. The firing angle and thermal limits of the Thyristors define the boundaries of the operational diagram.

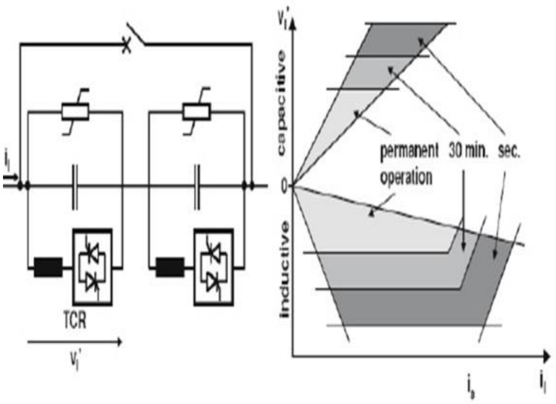

Fig. TCSC circuit and operation diagram

ADVANTAGES:

1. Ongoing regulation of the targeted compensation level
2. Seamless and direct management of power flow within the network
3. Enhanced protection for capacitor banks
4. Specific alleviation of sub-synchronous resonance (SSR) at a local level
5. Attenuation of electro-mechanical (0.5-2 Hz) power oscillations commonly occurring between regions in a large interconnected power network. These oscillations result from the dynamics of inter-area power transfer and often exhibit insufficient damping, particularly when the collective power transfer along a corridor is high relative to the transmission strength.

POWER QUALITY:

The modern container crane industry, much like other sectors, often finds itself captivated by the allure of advanced features such as vibrant diagnostic displays, high-speed performance, and automation capabilities. While these aspects and their associated computer-based enhancements are pivotal for efficient terminal operations, it is crucial not to overlook the foundational element. Power quality serves as the mortar that binds the building blocks.

The impact of power quality extends beyond terminal operational efficiency, influencing crane reliability, environmental considerations, and the initial investment in power distribution systems required for new crane installations. Reflecting on a utility company newsletter accompanying my recent home utility billing, it aptly states, 'Using electricity wisely is a prudent environmental and business practice that not only saves you money but also reduces emissions from generating plants and conserves our natural resources.

As container crane performance requirements continue to surge, with next-generation cranes already in the bidding process, the average power demands are expected to reach 1500 to 2000 kW – nearly double the total average demand from three years ago. This rapid escalation in power demand levels, coupled with an increasing population of container cranes, SCR converter crane drive retrofits, and the substantial AC and DC drives essential for powering and controlling these cranes, is anticipated to bring heightened awareness to the issue of power quality in the very near future.

POWER QUALITY PROBLEMS:

In the context of this article, power quality problems are defined as any power-related issue leading to the failure or malfunction of customer equipment, causing economic burdens to the user, or resulting in adverse environmental impacts. When applied to the container crane industry, power quality issues encompass:

1. Power Factor
2. Harmonic Distortion
3. Voltage Transients
4. Voltage Sags or Dips
5. Voltage Swells

AC and DC variable speed drives used on container cranes significantly contribute to total harmonic current and voltage distortion. While SCR phase control ensures a desirable average power factor, DC SCR drives operate at less than this. Additionally, line notching occurs during SCR commutation, creating transient peak recovery voltages that can be 3 to 4 times the nominal line voltage, depending on system impedance and drive size. The frequency and severity of these power system disturbances vary with drive speed, with harmonic current injection being highest at slow speeds. Power factor is lowest during slow speed or initial acceleration/deceleration, reaching its maximum value when SCR's are phased on to produce rated speed. Above base speed, power factor remains relatively constant. Container cranes often spend considerable time at low speeds during container handling, placing a greater kVA demand on the utility or engine-alternator power source.

Poor power factor not only burdens the utility but also affects voltage stability, potentially causing detrimental effects on the lifespan of sensitive electronic equipment. Voltage transients, generated by DC driveline notching, AC drive voltage chopping, and high-frequency harmonic voltages and currents, serve as significant sources of noise and disturbance for sensitive electronic equipment.

Despite these challenges, end users often remain unaware of power quality issues associated with container cranes, or they may neglect them due to the absence of immediate economic consequences. The emergence of power quality issues coincided with the multiplication of crane populations, increased power demands per crane, and the widespread adoption of static power conversion. Even today, power quality issues are often overlooked during competitive bidding for new cranes. Instead of focusing on raising awareness and understanding potential issues, crane builders and electrical drive system vendors may intentionally or unintentionally disregard power quality concerns. Solutions to power quality problems are available, representing a return on investment. However, if power quality is not specified, it is likely to be overlooked during implementation.

POWER QUALITY IMPROVEMENTS:

Improving power quality in container cranes is crucial, yet the individuals involved in specifying or purchasing these cranes may lack awareness of potential issues. This lack of awareness often stems from those not directly handling utility bills or considering power quality as someone else's responsibility. Consequently, many container crane specifications may not incorporate essential power quality measures like power factor correction and harmonic filtering. Even when specifications do include such requirements, they might lack clarity in defining criteria.

To address this, it is recommended to initiate discussions early in the crane specification process. This involves engaging with the utility company to understand any regulatory or contractual requirements. Additionally, collaborating with electrical drive suppliers helps in determining power quality profiles based on the proposed drive sizes and technologies for the project. Economic evaluations should extend beyond the current scenario, considering the potential impact of future utility deregulation and terminal development plans. By fostering awareness and proactively addressing power quality concerns, stakeholders can ensure optimal performance and longevity of container crane systems.

POWER QUALITY PENALITIES:

Many utility companies impose penalties for low power factor on monthly bills, but the lack of an industry standard means methods for metering and calculating these penalties vary widely. Some utilities meter kVAR usage and apply a fixed rate to the consumed kVAR-hours, while others monitor kVAR demands, penalizing if the power factor falls below a set limit over a demand period.

Certain utility companies serving container terminals may not currently enforce power factor penalties, but their service contracts with ports may mandate a minimum power factor over a defined demand period. Although these companies might not continuously monitor power factor or kVAR usage in monthly bills, they retain the right to assess penalties or demand corrective actions if the service contract criteria are not met.

For instance, a utility company serving multiple east coast container terminals in the USA doesn't include power factor penalties in monthly bills. However, their service contract stipulates that the average power factor should not be less than 85% under operating conditions. Failure to meet this criterion may require the customer to install corrective apparatus at their expense. The contract also emphasizes the importance of avoiding excessive harmonics or transients, possibly necessitating power conditioning equipment or filters, with IEEE Std. 519-1992 serving as a guide for design requirements.

Personnel responsible for maintaining container cranes or specifying new equipment in port or terminal operations need to be aware of these requirements. With the anticipated utility deregulation, utilities are likely to enforce such criteria more rigorously. Therefore, terminal operators should incorporate contingencies into their growth plans to address the potential economic impact of utility deregulation, even if they currently do not face penalty issues.

PRINCIPLE OF DVR:

A DVR (Dynamic Voltage Restorer) functions as a controlled reactive source, comprising a Voltage Source Converter (VSC) and a DC link capacitor connected in parallel. Its capability extends to both generating and absorbing reactive power. Conceptually, it draws parallels to an ideal synchronous machine, producing a balanced trio of sinusoidal voltages at the fundamental frequency. This machine's characteristics include controllable amplitude and phase angle, absence of inertia, instantaneous response, no alteration of system impedances, and the ability to internally generate both capacitive and inductive reactive power.

If the output voltage of the VSC is equal to the AC terminal voltage; no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DVR is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages.

It is to be noted that voltage regulation at Point of Common Coupling (PCC) and power factor correction cannot be achieved simultaneously. For a DVR used for voltage regulation at PCC the compensation should be such that the supply currents should lead the supply voltages and for power factor correction the supply current should be in phase with the supply voltages. The control algorithms studied in this paper are applied with a view to study the performance of a DVR for reactive power compensation and power factor correction.

When the VSC output voltage matches the AC terminal voltage, no reactive power is supplied to the system. In the capacitive mode, where the output voltage exceeds the AC terminal voltage, or in the inductive mode, where it is less, the DVR delivers reactive power. The quantity of reactive power flow is directly proportional to the voltage difference between the VSC output and the AC terminal.

It's important to highlight that achieving voltage regulation at the Point of Common Coupling (PCC) and simultaneous power factor correction is not feasible. When using a DVR for voltage regulation at the PCC, the compensation results in supply currents leading the supply voltages. Conversely, for power factor correction, the goal is to align the supply current with the supply voltages. This paper explores control algorithms with the aim of evaluating the DVR's performance in providing reactive power compensation and power factor correction.

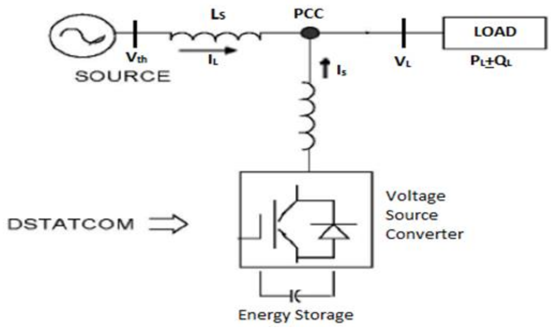

Fig. Basic structure of DVR

HARDWARE SETUP:

Fig: Experimental setup of APFC

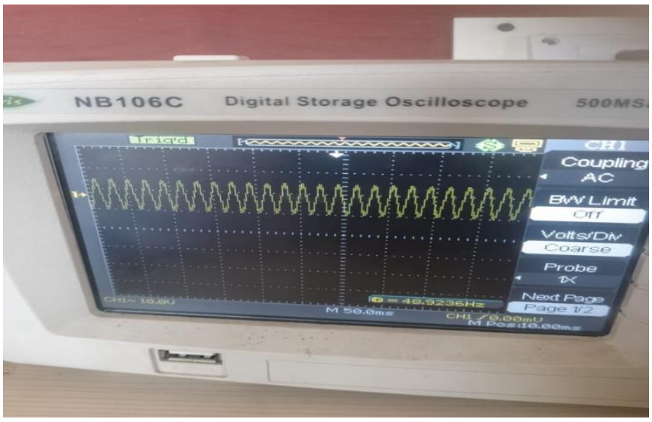

Fig: Output Wave form shown in DSO

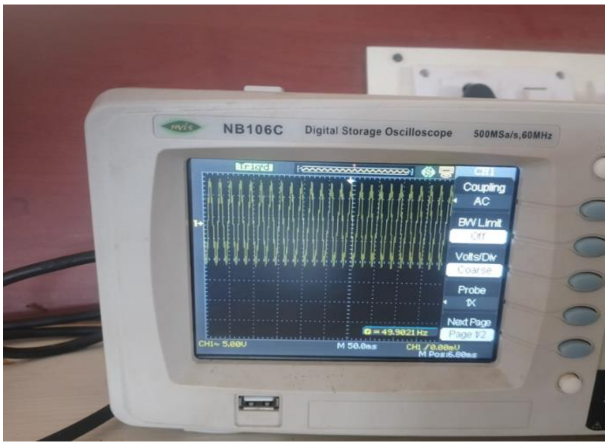

Fig: Input Wave form shown in DSO

CONCLUSION:

A control algorithm is presented for generating a reference load voltage in a voltage-controlled Dynamic Voltage Restorer (DVR). A comparative analysis is conducted between the proposed approach and the conventional voltage-controlled DVR. The introduced method offers several advantages, including injecting reactive and harmonic components of load currents at nominal load, leading to Unity Power Factor (UPF). Furthermore, the system maintains nearly UPF even with changes in load, achieves rapid voltage regulation during disturbances, and significantly reduces losses in both the Voltage Source Inverter (VSI) and feeder. Additionally, the proposed scheme exhibits enhanced sag supporting capability with the same VSI rating compared to the traditional approach. Both simulation and experimental results affirm that the proposed algorithm equips the DVR with the capability to address various Power Quality (PQ) issues effectively.

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