POWER QUALITY ENHANCEMENT IN GRID INTEGRATED SYSTEM

Abstract

The proliferation of distorting loads has witnessed an exponential surge, consequently giving rise to power quality predicaments within electrical power systems. The seamless transmission of untainted electric power stands as a pivotal mission for power engineers. The repercussions of power quality anomalies can be keenly felt on end-user apparatus, encompassing electronic appliances and digital meters, thereby culminating in product impairment. In a bid to counteract these power quality apprehensions, bespoke power devices have assumed a decisive role in contemporary power systems. This discourse primarily centers on the investigation and configuration of SAF as a means to enhance the power quality for delicate PE loads, power transmission facilities, and power supplying systems.

Keywords: PQ Improvement, Active and Reactive power, Power Factor improvement, Shunt Active Filter, power grid integrated system, Current Harmonics.

Authors

Dr. P Lakshman Naik
Associate Professor
Department of Electrical and Electronics Engineering
VVIT, Guntur, AndraPradesh,India.

Dr. Ch. Rambabu
Professor
Department of Electrical and Electronics Engineering
VVIT, Guntur, AndraPradesh, India.

Dr. S V Padmavathi
Associate Professor
Department of Electrical and Electronics Engineering
SoT, GITAM, Hyderabad, TS, India.

Dr. P. Umapathi Reddy
Professor
Department of Electrical and Electronics Engineering
MBU,Tirupati, AndraPradesh, India.

Mr. K. Naresh
Associate Professor
Department of Electrical and Electronics Engineering
Usha Rama College of Eng & Tech.
AndraPradesh, India.

I. INTRODUCTION

The efficient transmission of clean power to end-users stands as a pivotal challenge for electrical power engineers. In the current landscape, electrical distribution systems contend with a multitude of distorting or nonlinear loads, as well as reactive loads. The prevalence of reactive loads contributes to an excessive demand for reactive power, leading to increased feeder losses and a reduction in the overall efficiency of active power flow within the distribution network. Concurrently, power electronic based loads such as electronic appliances, electric arc furnaces introduce significant asymmetric disturbances into the AC mains. These disturbances, often termed power quality issues, can cause voltage fluctuations, waveform distortions (harmonics), transients, flickering, variations in supply frequency, DC offsets, noise, and notches. Both balanced and unbalanced non-sinusoidal currents produce a slew of adverse effects including harmonics, elevated neutral currents, supporting power inefficiencies, undesired power factors, and unbalanced loading of the supplying mains. An undesired power quality not only leads to substantial losses and deteriorates consumer services, system efficiency.

In the early stages, LC passive filters were instrumental in mitigating power quality concerns in electrical power systems. However, the main disadvantages of passive filters – limited dynamic performance, their bulky size, fixed compensation requirements, and susceptibility to resonance – prompted power engineers to focus on innovative solutions. This led to significant advancements in the field of power electronics devices, paving the way for the emergence of active filters. Active filters rapidly replaced passive counterparts due to their agility and dynamism.

Among the various active filters, SAF have emerged as a cornerstone in PQ enhancement. SAFs have proven highly effective in rectifying disturbances related to electric power in distribution systems. Nearly all power quality issues associated with consumer loads can be resolved through the implementation of SAFs, including the utilization of STATCOMs.

The structure of the present article unfolds as follows: Section II delves into power quality concerns, their implications, and industry standards. Sections III, IV, V, and VI sequentially present the system configuration, controlling methodologies, merits, and major benefits of shunt active filters (SAFs), culminating in concluding section.

II. PQ STANDARDS AND POWER QUALITY ISUUES, EFFECTS

1. **Power Quality Standards:** At both national level and international levels, the R&D institutions such as IEEE and IEC collaborate with power engineers and research institutions to establish a cohesive platform for cooperation. Their aim is to ensure compatibility between end-user equipment and the system. International standards guidelines stipulate that electrical equipment's energy consumption must adhere to specified harmonic content limits. The injection of current or voltage is restricted based on the load and power system size. Working group members develop standards that define the parameters for power quality. According to IEEE Standard 519-1992 for systems below 69KV, the Total Harmonic Distortion (THD) value should not exceed 5%.

The PE based load currents cannot concur with system resonances. As per IEC Standard 61000-2-2*, particularly the third harmonic and its multiples, should be below 5%.

2. **Power Quality Issues:** "Power quality" has emerged as a prominent term in the realm of electric power systems. Presently the growing utilization of PE based or sensitive loads that draw undesired sinusoidal currents significantly impacts end-use equipment. This growing demand for highly reliable and quality power has led to increased awareness among both utilities and end-users. Key PQ concerns encompass:

   - **Voltage Variations:**Fluctuations in power system loads lead to voltage variations. Real and reactive powers are intricately linked to load variations. These variations are classified based on the RMS voltage and duration into short and long-duration voltage variations. The voltage fluctuations are commonly termed voltage flicker, depicting dynamic variations caused by load changes in system.

   - **Wave Distortion / Harmonics:**Harmonics, treated as integer multiples of the system's fundamental frequency, have been a subject of technical study since the 1930s and 1940s. They fall within the category of waveform distortion. Harmonics stem from sensitive or distorted loads such as power electronics devices, arc furnaces, within the system. Distorted loads exhibit non-proportional relationships between current and voltage. Waveform distortion is further classified into notching, noise, DC-offset, and interharmonics. The presence of DC content in AC current or voltage, termed DC-offset, is caused by factors such as geomagnetic disturbances and DC currents in AC networks, resulting in transformer saturation.

3. **Consequences of Power Quality Issues:** Power quality problems (PQ Concerns) yield consequences like overloading, overheating, increased losses, transformer saturation, data errors or losses, and malfunctions in equipment such as logic controllers, power meters. Specifically, harmonics induce overheating, proximity effects, and skin effects in electric conductors.

III.SYSTEM DISCRIPTION

Even with a variety of options available to enhance power quality, shunt active filters (SAFs) have gained widespread adoption due to their versatility and robust performance. Shunt active filters are primarily realized through pulse width modulated voltage source inverters (VSI) and current source inverters (CSI). These APF categorized based converter topology, power specifications and quick response.

1. **Converter-Based Classifications:**Shunt active filters can be classified into two main types: Current-fed type and voltage-fed type. The voltage-fed converters are favored due to their expandability, cost-effectiveness, and improved efficiency. They employ a bridge-structured configuration as depicted in Fig. 2. This type of inverter serves as undesired sinusoidal current source. The inclusion of a diode in series with the IGBT prevents opposite voltage flow, albeit at the cost of restricted switching frequency.

2. **Phase-Based Classifications:** The SAF filters are further categorized as phase levels, encompassing single-phase (two-wire) and three-phase (three-wire and four-wire)

systems. Three-phase supply system incorporates a neutral conductor to power numerous single-phase loads, issues like reactive power burden, excessive neutral current, harmonics, and unbalance may arise. Four-wire shunt active filters are designed to address these concerns. These filters can be implemented using both voltage-fed and current-fed converters. The midpoint configuration with capacitors is suitable for lower rating applications, whereas the switch-type filters stabilize the neutral of the active filter. Another configuration employs three single-phase bridge converters to ensure proper voltage matching and enhance reliability. The classification of shunt active filters based on converter type and phase configuration underscores their adaptability and effectiveness in mitigating power quality issues.

The desired model illustrated in Figure 1, encompasses the primary power circuits and a DC link voltage control unit. This configuration incorporates a VSC based active filter designed to address harmonic issues. The inherent dynamic capabilities of SAPF make them the prominent choice for mitigating harmonics within the envisaged electrical distribution system.

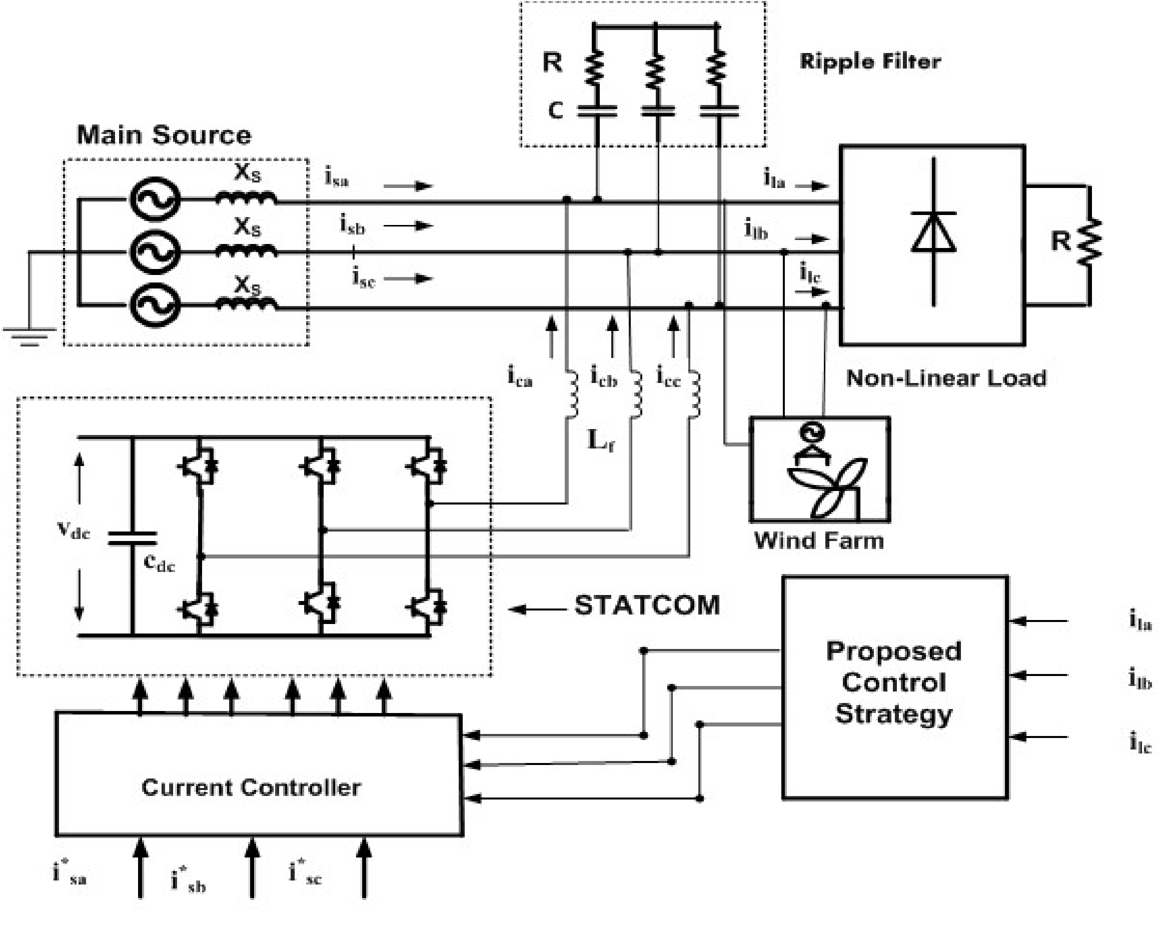

Figure 1: Desired Model for PQ Enhancement.

IV. CONTROL STRATEGY FOR GENERATION OF GATE PULSES

The efficacy of active filters heavily relies on their control strategies, which serve as the core of their operation. These strategies are pivotal in generating the necessary compensation current and are integral to the design of SAF, within the realm of 3-phase source systems supplying distorting loads, various control strategies exist, such as p-q theory, Id-Iq theory, PHC strategy, and UPF-Unity Power Factor method. This paper primarily focuses on p-q theory and Id-Iq theory.

1. **P-Q Theory:** This control methodology was initially introduced by Akagi and collaborators in 1984. This control strategy operates in the time domain. Its validity extends to steady-state as well as transient conditions. By employing α-β transformation, the set of voltages and currents are converted to α-β-0 coordinates. The phase voltages supplied by the source are represented as:

$$Va = VmSin(\omega t)$$

$$Vb = VmSin\left(\omega t - \frac{2\pi}{3}\right)$$

$$Vc = VmSin\left(\omega t - \frac{4\pi}{3}\right)$$

The currents for each phase can be computed as

$$i_{La} = \sum I_{Lan} Sin\{n(\omega t) - \theta_{an}\}$$

$$i_{Lb} = \sum I_{Lbn} Sin\left\{n\left(\omega t - \frac{2\pi}{3}\right) - \theta_{bn}\right\}$$

$$i_{Lc} = \sum I_{Lcn} Sin\left\{n\left(\omega t - \frac{4\pi}{3}\right) - \theta_{cn}\right\}$$

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix}$$

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

Where $\Delta = v_\alpha^2 + v_\beta^2$.

$$\begin{bmatrix} i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix} = \frac{1}{\Delta} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \bar{p} \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} i_{sa}^* \\ i_{sb}^* \\ i_{sc}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1/\sqrt{2} & 1 & 0 \\ 1/\sqrt{2} & -1/2 & \sqrt{3}/2 \\ 1/\sqrt{2} & -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i_0^* \\ i_{s\alpha}^* \\ i_{s\beta}^* \end{bmatrix}$$

2. **Id-Iq Theory:** This theory involves transforming the stationary system to a dq0 rotating system. The d-q reference frame is computed by the angle θ relative to the α-β frame, which is utilized in the p-q theory. The Park's transformation is defined as:

$$\begin{bmatrix}\mu_d\\ \mu_q\end{bmatrix}=\begin{bmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{bmatrix}\begin{bmatrix}\mu_\alpha\\ \mu_\beta\end{bmatrix}$$

$$\begin{bmatrix}I_d\\ \mathrm{I}_q\end{bmatrix}=\begin{bmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{bmatrix}\begin{bmatrix}I_\alpha\\ \mathrm{I}_\beta\end{bmatrix}$$

Where voltage and currents are

$$\begin{bmatrix}\mu_\alpha\\ \mu_\beta\end{bmatrix}=\begin{bmatrix}V_m\sin\omega t\\ V_m\cos\omega t\end{bmatrix}$$

V. PRACTICLE IMPLEMENTATION AND CONSIDERATIONS

This section presents the outcomes of a desired test model designed to enhance PQ using SAPF. In order to meet the whole load demand, the current is supplied from both the primary grid source and a green energy source as depicted in Figure 1. The SAF integrated into the grid system effectively dimishes the current harmonics generated by nonlinear loads. The system enumerates the parameter values utilized in the MATLAB simulation study aimed at nullifying current harmonics within this research endeavor. The single-phase source voltage is illustrated in Figure 2.

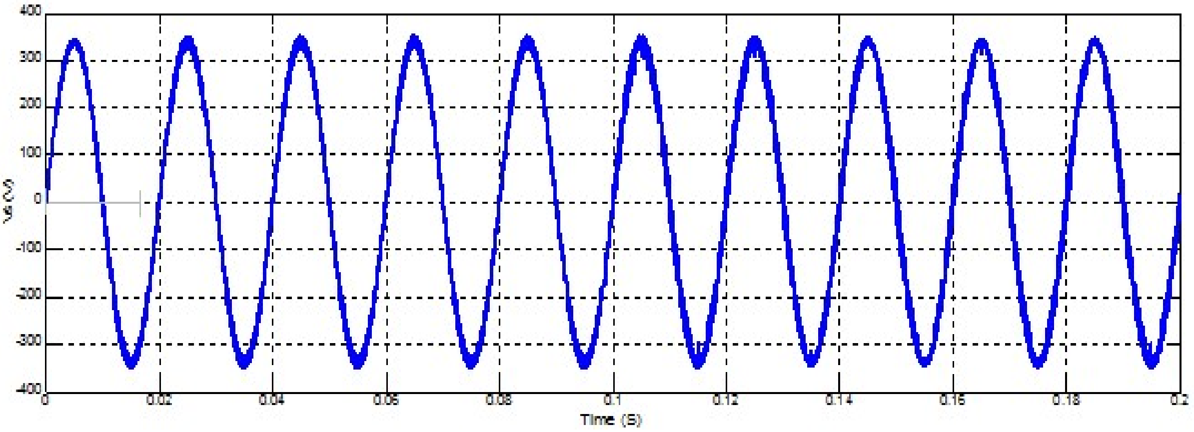

Figure 2: Supply Voltage to the Proposed Model

The source current analysis depicted for both with and without the STATCOM (Static Synchronous Compensator) as follows:

1. **With Shunt Active Filter (Statcom):** When the STATCOM is employed, it actively regulates the reactive power in the system, leading to a more controlled and balanced operation. The source current in Phase-a exhibits reduced harmonic content and improved power factor due to the compensating effects of the STATCOM.

2. **Without Shunt Active Filter (Without-Statcom):** In the absence of the STATCOM, the source current in first phase tends to exhibit higher harmonic distortion and a potentially lower power factor due to the impact of nonlinear loads or other power quality issues.

The implementation of the STATCOM helps to mitigate these adverse effects, resulting in a more stable and harmonically cleaner source current in first phase of the 3-phase system. As shown in Figure.3.

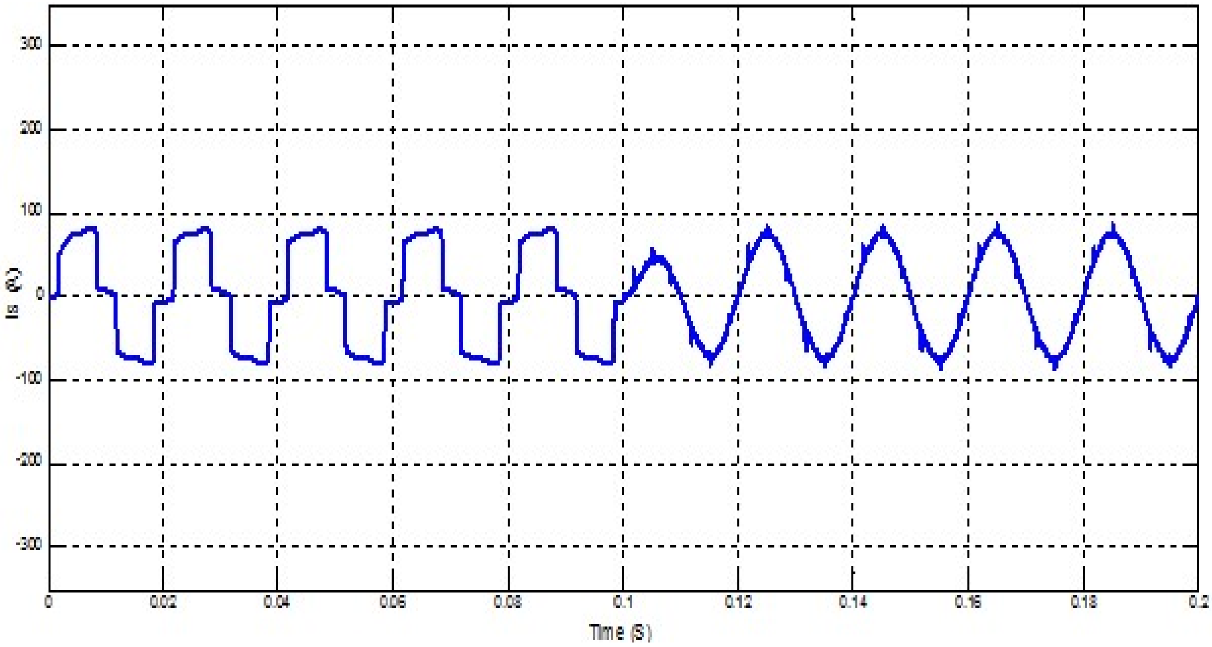

Figure 3: Phase-1 Current in three-phase System with & without Statcom.

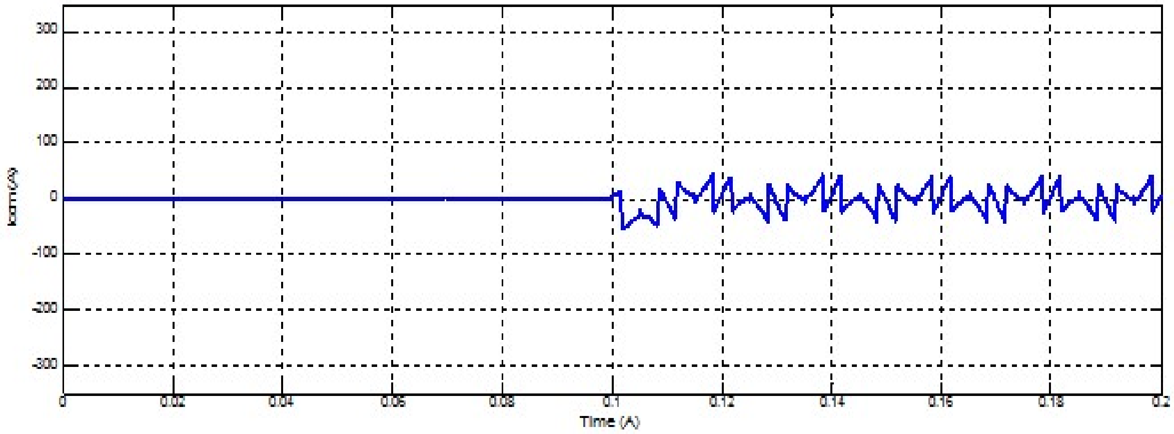

Figure 4: SAF injected current for *Phase-1* in three-phase system which mitigates Harmonics.

Figure.4 represents injection of current by shunt active power filter for reduction of harmonics into the proposed desired system.

VI. CONCLUSION

This chapter underscores the significance and advancement of SAF in the context of non-linear loads within power systems. Specifically, the utilization of STATCOM (Static Synchronous Compensator) is explored, where it is strategically connected at the load end to mitigate the harmonics introduced by loads. Beyond harmonics suppression, STATCOM demonstrates its capability in enhancing power factor and voltage regulation. The paper delves comprehensively into various aspects, providing clear insights into power quality concerns, the establishment of PQ standards, diverse control strategies, and the crucial advantages and applications associated with SAF, particularly STATCOM. Over the past two decades, the diligent research efforts in the domain of static reactive compensation technology, represented by shunt active filters, have yielded remarkable benefits. These advancements have rippled across end-users, utility companies, and wind farm developers. The integration of such technology has ushered in significant enhancements in power quality, operational efficiency, and the overall reliability of power systems.

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