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# Review of Power Quality Improvement Techniques in HVDC Systems Using FACTS Devices

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## ABSTRACT

In a recent trend for controlling of most of the industrial loads is mainly based on semiconductor devices which cause such loads to be more sensitive against power system disturbances. Thus, the power quality problems have gained more interest recently. This paper presents a review of some of the disturbances, on the source side that may cause problems on the load side. The focus is given on problems associated with voltage dips as voltage dips have been reported to be the most severe problems to industrial loads. The power quality has an important role in the power supply industry. As the power providers are turning to smart grid and smart meters, the standards for power quality needs to be revisited. The power quality can be categorized into two groups, one addressing the standard for the power quality supplied at the grid level and the other group which deals with the factors that affect the power quality at user level. These factors include harmonics, voltage changes, sags, transients, voltage unbalance, etc. These factors will provide us in-depth details about the power system network. In this paper, an overview of various factors will be presented in order which can affect the power quality of the system.

**Keywords:** Power quality, Flexible AC transmission system (FACTS) devices, UPFC, SVC, STATCOM.

## I. Introduction

Power quality (PQ) is an important factor that influences the power system and all levels of electricity consumers [1]. A power quality issue is defined as "a voltage, current, or frequency fluctuation in the power grid resulting in system or equipment failure." The development of devices which integrate power electronics has a major impact on the quality of power which are consumed by the devices. Switched Mode Power Supplies (SMPS), Voltage and Current Regulators, Lamps which consumes low power, Arc Welders, etc., are just a few wide ranges of applications for power electronic devices. The load or equipment creates harmonics that disturbs the modern power distribution system. Due to the interest growing in using renewable energy sources for power generation, distribution networks are prone to power quality issues. In this context, both the power industry and the electrical end users are increasingly concerned about the quality of their electricity. Customers demand higher levels of power quality than the current that power grids provide. Therefore, the quality of power should be maintained at a higher level using various techniques which are available. Active power filters (APFs) have been proposed as useful tools for enhancing the quality of power. Active power filters are classified as series or shunt based on the following criteria: Series

APFs are frequently used to eliminate voltage-based distortion, whereas shunt Active Power filter which are implemented to reduce current-based distortion. UPQC is a fusion of a shunt and a series active power filter. UPQC reduces current and voltage-related distortion simultaneously and independently[2-3]. In UPQC, the configuration is linked by a DC link, whereas in DPFC, it is linked by transmission lines.

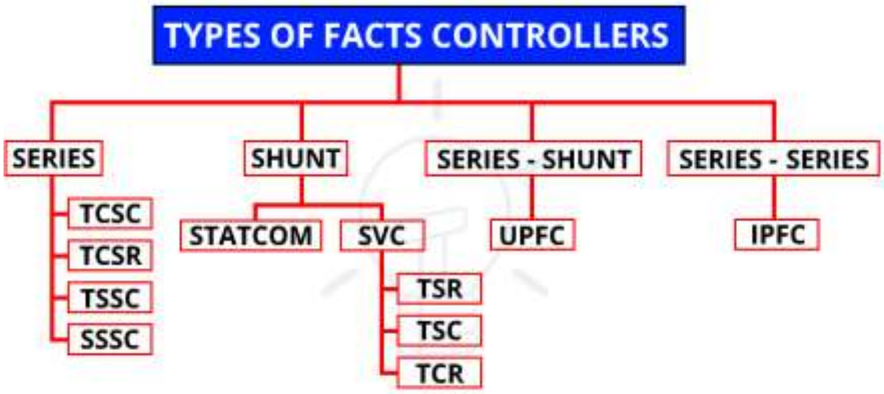


**Fig.1. Fact Controllers.**

**II. Power Quality Parameters**

Power quality is a measure of various parameters like voltage current and frequency within its predefined range. If there has any deviation generated various problems like voltage sag, voltage swell, transient, flicker, harmonics etc. which can be responsible for poor power quality [4].

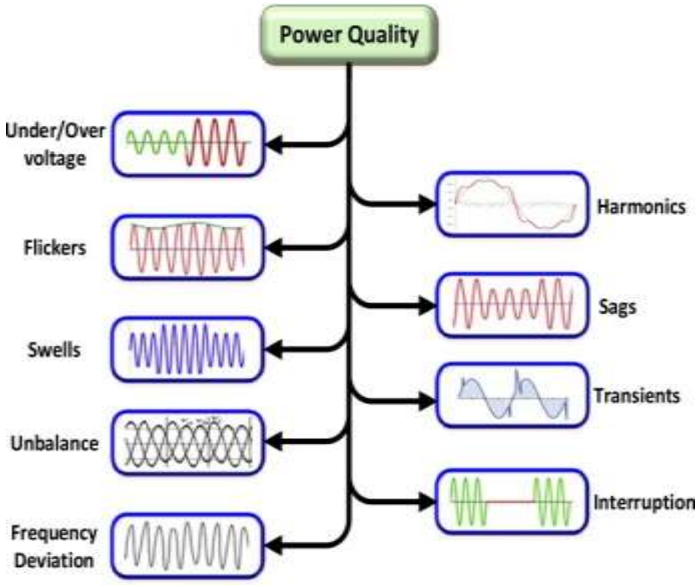


**Fig.2.Power Quality Parameters.**

Transients

It is an event that is undesirable and momentary in nature. It is the sudden change in one stead state operating condition to another. Transients can be classified into two categories:

1. Impulsive and
2. Oscillatory Impulsive Transient

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An impulsive transients a sudden non–power frequency change in the steady-state condition of voltage, current, or both that is unidirectional in polarity (either positive or negative). Impulsive transients are normally characterized by their rise and decay times. Due to high frequency nature, the shape of impulsive transients may be changed quickly by circuit components and may have significant different characteristics when viewed from different parts of the power system. They are generally not conducted far from the source [5]

Oscillatory Transient

An oscillatory transient is a sudden, non–power frequency change in the steady-state condition of voltage, current, or both, that includes both positive and negative polarity values. Instantaneous value of oscillatory transient changes polarity rapidly.

Long-Duration Voltage Variations

When the rms value of voltage deviates for duration more than 1 minute, it is termed as long duration voltage variation.

Short-Duration Voltage Variations

When the rms value of voltage deviates for duration less than 1 minute, it is termed as long duration voltage variation. Each type of variation can be designated as instantaneous, momentary, or temporary, depending on its duration.

Voltage Imbalance

Voltage imbalance is defined as the maximum deviation from the average of the three-phase voltages or currents, divided by the average of the three-phase voltages or currents, expressed in percent. The ratio of either the negative- or zero-sequence component to the positive sequence component can be used to specify the percent unbalance. The source of voltage unbalances is single phase loads on a three-phase circuit. Voltage unbalance can also be the result of blown fuses in one phase of a three phase capacitor bank. Severe voltage unbalance can result from single-phasing conditions.

Power Quality Problems poor load power factor

the ratio of the real power flowing to the load to the apparent power in the electric circuit is called the power factor of the power system .it is an very important term of power system .the capacity of the circuit for doing work in a particular time is called real power and product of current and voltage is called apparent power. In power system because of various use of semiconductor devices or nonlinear load the wave shape of voltage and current are distorted which create the apparent power will be greater than the real power and get low power factor in the circuit. In case the power factor is low in an electric power system the amount of current flowing in the circuit draws more than a load with a high power factor for the same amount of useful power transferred. When the circuit has high current the energy lost in the circuit is higher and required larger wires and other electric equipment. [6]

Harmonics: - harmonics are sinusoidal voltage or current components having frequency are integer multiples of the supply frequency. Distortion means the alteration of the original shape of an object image sound waveform or other form of information and representation. Harmonics are also a type of distortion which changes the voltage and current waveform of fundamental power frequency. Various nonlinear loads , power semiconductor devices, flurescent lamps adjustable speed drives personal computers etc. are generated harmonics in power system .this create various harmful effect in system it can reducing the efficiency of system, plant mal-functioning of equipments , aging of installation ,overheating and failure of machines ,overloading of power factor correction capacitors and power transformers.[7] Notching in low voltage:-when the current is commuted from one phase to another phase some disturbance in voltage waveform is called voltage notching .this is a type of power quality disturbance .voltage notch disturbs the voltage waveform and excites the natural frequency of the system usually these frequency range are in radio frequency range .which introduce the harmonic and nonharmonic frequency that are much higher than those found in higher voltage system .excision frequency create high frequency oscillations in the voltage of converter circuit .voltage notch damage capacitor banks ,create parallel resonance signal interference in logic and communication circuit, over loading in electromagnetic filters.[8]

## III. Benefits of Utilizing Facts Devices

The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows [9]:

• Better utilization of existing transmission system assets
• Increased transmission system reliability and availability
• Increased dynamic and transient grid stability and reduction of loop flows
• Increased quality of supply for sensitive industries
• Environmental benefits Better utilization of existing transmission system assets In many countries, increasing the energy transfer capacity and controlling the load flow of transmission lines are of vital importance, especially in de-regulated markets, where the locations of generation and the bulk load centers can change rapidly. Frequently, adding new transmission lines to meet increasing electricity demand is limited by economical and environmental constraints. FACTS devices help to meet these requirements with the existing transmission systems [10].

## IV. Literature Review

**Mitra Nabian Dehaghani et al. [1]** The rapid integration of distributed generation (DG) units in distribution networks, driven by the integration of renewable energy sources (RESs) such as solar and wind, has introduced significant power quality (PQ) challenges. These challenges, including voltage sags, harmonic distortions, and reactive power imbalances, pose risks to the stability, reliability, and efficiency of distribution systems. This paper provides a comprehensive review of PQ improvement techniques tailored for distribution systems, including filters, controllers, conditioners, flexible AC transmission systems (FACTS) devices, machine learning (ML) tools, and optimization methods. Special emphasis is placed on distributed artificial intelligence (DAI) frameworks, which offer decentralized, adaptive, and scalable solutions for managing the complexities of high RES penetration. A comparative analysis highlights the advantages of DAI over conventional and AI-based strategies in addressing the dynamic and real-time requirements of modern distribution systems. The paper concludes by emphasizing the need for integrating DAI-based control mechanisms to ensure sustainable, reliable, and high-quality power delivery in RES-dominated distribution networks.

**Chintalapudi V Suresh et al. [2]** The increasing demand for reliable and efficient power transfer in connected systems drives the use of Flexible AC Transmission System (FACTS) controllers. This paper provides a detailed comparison of three key FACTS devices: Phase Shifting Transformer (PST), Unified Power Flow Controller (UPFC), and Optimized Unified Power Flow Controller (OUPFC). It evaluates their performance under normal and outage conditions. The analysis involves IEEE-14 and IEEE-30 multi-area test systems using Newton-Raphson load flow, integrating device models into the power flow equations. Four scenarios are examined: base system, PST, UPFC, and OUPFC. Two performance measures are defined: maximum branch gain and sum-branches gain. Population statistics, including mean, standard deviation, and coefficient of variation, are calculated to assess effectiveness across corridors and devices. The results indicate that OUPFC consistently offers the highest improvements in transfer capacity, achieving gains over 600 % in weak corridors and recovery ratios above 120 % under N-1 outage conditions. UPFC serves as a strong middle-ground device, restoring 70–90 % of lost transfer during outages, while PST provides targeted but cost-effective improvements. The statistical data reveal that performance variability increases with network size, highlighting the necessity for optimization in placement. The study's innovation lies in combining deterministic, statistical, and contingency viewpoints, backed by visual results and planning recommendations. The findings offer practical guidelines for FACTS deployment, balancing technical effectiveness with cost considerations.

**Muhammed F. Alwaeli et al. [3]** This research proposes an intelligent technique designed to optimize the power quality of grid-connected hybrid power systems that use both solar photovoltaic and wind energy. Regrettably, these hybrid systems are liable to the damaging environmental results of weather gusts, which could lessen average system efficiency. Moreover, several faults, such as three-phase faults and voltage fluctuations on the point of common coupling (PCC), can adversely affect system balance. To address those challenges, Static Synchronous Compensators (STATCOMs) are employed to enhance the integration of renewable energy sources (RESs) by providing vital reactive energy support. This examination additionally highlights the importance of advanced optimization techniques for tuning controllers, given the complexity of hybrid systems. The proposed observation indicates the application of a grey wolf optimization (GWO) primarily based on the multi-objective function. This algorithm acts to improve control parameters, thus increasing the system's reliability. The developed strategy is presented in several processes.

**Ban H. Alajrash et al. [4]** Incorporating Flexible AC Transmission Systems (FACTS) devices into modern power systems is a crucial field of study, mainly due to the growing adoption of renewable energy sources. This paper thoroughly examines the role and efficacy of FACTS devices in improving power quality and maintaining stability in both conventional power systems and those that heavily rely on renewable energy sources. At first, the central aspect of the review centers on different FACTS devices, including Static VAR Compensators

(SVC), Thyristor Controlled Series Capacitors (TCSC), Unified Power Flow Controllers (UPFC), and distributed power flow controllers (DPFC). A comprehensive analysis of each device's operational principles, benefits, and constraints is provided. The paper assesses the efficacy of these devices in addressing the challenges associated with integrating renewable energy. These functions encompass their involvement in maintaining voltage levels, stabilizing frequency, controlling power flow, and enhancing the power system's ability to respond to sudden changes. This paper compares various FACTS devices in different scenarios to emphasize their efficacy in specific contexts. Furthermore, the paper outlines the emerging difficulties in power systems caused by the incorporation of fluctuating renewable energy sources, such as wind and solar power.

**Adel A.Abou El-Ela et al. [5]** Distribution systems face significant challenges in maintaining power quality issues and maximizing renewable energy hosting capacity due to the increased level of photovoltaic (PV) systems integration associated with varying loading and climate conditions. This paper provides a comprehensive overview on the exit strategies to enhance distribution system operation, with a focus on harmonic mitigation, voltage regulation, power factor correction, and optimization techniques. The impact of passive and active filters, custom power devices such as dynamic voltage restorers (DVRs) and static synchronous compensators (STATCOMs), and grid modernization technologies on power quality is examined. Additionally, this paper specifically explores machine learning and AI-driven solutions for power quality enhancement, discussing their potential to optimize system performance and facilitate renewable energy integration.

**Ahmed Tchvagha Zeine et al. [6]** This study introduces an enhanced variant of the Genghis Khan Shark Optimizer (GKSO) algorithm, designed to improve its search performance when solving the Optimal Power Flow (OPF) problem, particularly in power systems incorporating Flexible AC Transmission Systems (FACTS) devices and wind energy sources. The proposed approach, referred to as the Enhanced Genghis Khan Shark Optimizer (EGKSO), addresses the limitations of the original GKSO, which, despite its simplicity and effectiveness, may suffer from premature convergence and entrapment in local optima. To overcome these shortcomings, EGKSO incorporates significant improvements in both the exploration and exploitation phases of the optimization process. Exploration is enhanced through a stochastic mutation mechanism that promotes the discovery of new regions in the search space, while exploitation is refined using an adaptive strategy that intensifies the search around promising solutions.

**Tarikua Taye et al. [7]** Voltage magnitude limit violations (under/over-voltage), phase unbalance and occasional conductor overloads are among the most frequent and operationally critical problems in European low-voltage (LV) distribution networks, and their incidence is rising with electrification, power-electronic loads and distributed generation. This paper proposes a DSO-oriented, operationally grounded mitigation framework that coordinates four field-ready devices: autotransformers, on-load tap changers, zigzag filters and a local power-balancing device to restore voltage compliance and reduce unbalance without relying on customer participation, advanced communications or complex power-electronic converters.

**Subhashree Choudhury et al. [8]** Recently, the exponential decay of traditional petroleum and coal-based reserves with the ever-rising energy demand has led to the need for alternate energy sources. Distributed Generation (DG) based on renewable energy sources serves as a viable alternative solution for researchers to counter the issue of rising load. Hence the use of renewable energy sources is of utmost priority. Renewable non-traditional energy resources also have the advantage of being an unlimited energy source and climate-friendly in nature. In this context, distributed micro-generating units come into the picture, popularly known as MicroGrid (MG). The MGs are small-scale resources generating electrical energy and connected to the main utility through power electronic converters. The main drawbacks associated with MGs are their association with converters and switching devices, which leads to the injection of disturbances in the power system.

**Harshal Vitthalrao Takpire et al. [9]** Power quality (PQ) is mandatory to ensure the safety, energy efficiency, performance of the equipment, environmental standards and production targets. However, overheating and breakdown of machines reduce the PQ, which increases the maintenance costs and reduces the lifespan of the machine. Conventional control strategies had poor dynamic performance and limited adaptability, while considering complex and non-linear conditions. Therefore, the research work implements the Bubble-net Communication optimization based Adaptive Fuzzy Neural Network-Bidirectional Long Short-Term Memory (BC-AFBTM) Model on the Unified Power Quality Conditioner (UPQC) device, to mitigate the harmonic issues such as sag, swell, interruptions and harmonic fluctuations, which contribute to enhance the PQ and stability performance of the power system.

**Musawenkosi Lethumcebo Thanduxolo Zulu et al. [10]** Microgrids are the most efficient method for generating, distributing, and regulating power for consumers using localized distributed energy resources. Nevertheless, achieving optimal economic dispatch and power quality enhancement in microgrids is a significant and challenging topic since solar and wind power generation are inconsistent. In this paper, optimization, and improvement of power quality in a maximum power point tracker (MPPT) based system utilizing artificial intelligence (AI) techniques are studied. The efficiency of a photovoltaic and wind energy system is maximized in this work by using an AI optimization strategy to determine the best scaling parameters for a fuzzy logic-based MPPT controller. This paper presents an improved fuzzy logic and artificial bee colony (FLABC) technique for optimization and power quality enhancement in an MPPT-based system. optimal economic dispatch solution for a microgrid, with the goal of meeting load and balance demand, while reducing the cost of power generation and gas emissions. The FLABC technique is proposed for optimization and power quality enhancement in an MPPT-based hybrid renewable system.

**Akhil Nigam et al. [11]** From the last few years power demanding is increasing as per load requirement. The condition of power demand is not accompanied by only generation and transmission of electricity. Many industrial power plants are running on higher capacity to fulfill load requirement. There are many issues such as voltage instability and power quality which led to many power plants. In distributed generation generators are distributed asynchronous type and mostly affected by the reactive power. They basically cannot generate reactive power but draws away from the power system. It causes the voltage drop to the consumer side which may be not acceptable.

**Rayed AlGhamdi et al. [12]** In hybrid renewable energy systems (HRES), particularly with solar, fuel cell, and battery components, common PQ disturbances that occur are voltage sags, swells, and fluctuations. An intelligent FLRNN-FOPID-DSTATCOM control framework is proposed that integrates a Fractional-Order PID (FOPID) controller, whose parameters are optimized using a novel Draft-Mongoose Tailored Earthworm Optimizer (DTEO), and a Fractional-Order Lipschitz Recurrent Neural Network (FLRNN), for PQ improvement under varying load and source conditions. The simulated experimental setup used the MATLAB/Simulink environment, after which this approach underwent a rigorous comparative study with traditional PID, Meta-heuristic PI/PID, and Sliding Mode Controllers (SMC). The quantitative nature of the results proves a substantial reduction of THD down to 0.0043 from undefined baseline THD values, signifying very good harmonic suppression. The system is able to stabilize the PV voltage and current from varying ranges of −200 V to 350 V and −800 A to 300 A, respectively, to steady outputs of 350 V and 300 A.

**Engidaw Abel Hailu et al. [13]** The secure operation of a power system depends on the available security evaluation tools and improvement techniques to tackle the disturbances or contingencies. The main objective of the survey presented in this paper is to provide a comprehensive review to the researchers, academicians, and utility engineers on the available techniques of static security assessment and improvement in modern power systems. Various performance indices are used to express the severity of limit violations from security margins typically in transmission line loading and buses voltage magnitude under a given disturbance or contingency.

**Karuppasamy et al. [14]** Anthony Recently, there has been a significant focus on voltage stability in power systems due to the difference between power generation and demand. Maintaining voltage stability poses challenges in power system planning and security assessment. Elements such as the growing demand for electricity, depletion of fossil fuels, environmental concerns, and infrastructure reliability have prompted power utility corporations to incorporate renewable sources into traditional power systems. However, there are issues with system voltage stability when non-dispatchable renewable energies like solar and wind energy are integrated into the current transmission and distribution networks.

**K. Sakthivel et al. [15]** Multilevel inverters (MLI) perform a significant role in microgrids to overcome the power demand for various load conditions due to violations of load day by day in recent centuries and enhance the reliability of Renewable energy sources (RES) for higher power and higher voltage applications. In the review paper to enhance the reliability of Multilevel inverters, a detailed investigation of the study of Power quality improvement using Machine learning techniques is presented. Fault tolerance, fault detection, reduced number of switches, reduced harmonics from the output voltage for calculating (THD) Total harmonic distortion from the output waveform, and ensuring the Modulation index (MI) from the input waveform, are implemented in the review for various applications.

## V. Conclusion

Flexible Alternating-Current Transmission Systems (FACTS) is a recent technological development in electrical power systems. It builds on the great many advances achieved in high-current, high-power semiconductor device technology, digital control and signals gained with the commissioning and operation of high-voltage direct-current (HVDC) links and static VAR compensator (SVC) systems, over many decades, may have provided the driving force for searching deeper into the use of emerging power electronic equipment and techniques [5]. Due to the, every time higher requirements of the liability and quality of the electricity the implantation of devices capable of guaranteeing these requirements will keep increasing. FACTS devices are improving the operation of an electric power system. The influences of such devices on steady state variables (voltage levels, transmission losses, and generating costs) are very remarkable. The benefit for each type of FACTS can be associated with its particularities and properties. They control the interrelated parameters that rule the operation of the transmission systems, including the serial impedance, the derivation impedance, the current, the voltage, the phase angle and the muffling of oscillations to different frequencies under the nominal frequency.

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