A Review on Causes and Consequences of Power Quality Problems & their Mitigation Techniques

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Abstract- **Power quality has become a major concern in present era due to increase in modern sensitive and sophisticated loads connected to the distribution system. The electrical devices or equipment's are prone to failure when exposed to one or more power quality problems. This paper presents a comphrensive review on various power quality problems like Sag, Swell,Harmonics, Transients, Flickers, Noise etc. their causes ,effects, IEEE standards and employs various mitigation techniques like Active Power Filters (APF),Unified power quality conditioner (UPQC), which is the combination of both shunt and series active filter connected to dc common link.**

Index Terms- **Unified Power Flow Controller, Particle Swarm Optimization Voltage Source Invertor, voltage supply, voltage swells, voltage sags**

I. INTRODUCTION

Power Quality
The quality of power supply is a set of parameters which describes the process of electric power delivery to the user under normal condition. It determines the continuity of the power supply and characterizes the voltage supply [1, 4, 5, 10] [11, 16]]. When the voltage and current deviates from its normal values, it is called as event.

1. POWER QUALITY PROBLEMS

The most common types of Power Quality problems are presented below along with their description, causes and consequences:

- Voltage Sag or Dip
- Very short interruptions
- Long interruptions
- Voltage Spike
- Voltage Swell
- Harmonic distortion
- Voltage fluctuation
- Noise

1.1 Voltage sag (or dip): A decrease of the normal voltage level between **10% and 90%** of the nominal rms voltage at the power frequency, for durations of 0.5cycle to 1 minute.

Causes**:** Faults on the transmission or distribution network (most of the times on parallel feeders). Faults in consumer's installation. Connection of heavy loads and start-up of large motors.

Consequences**:** Malfunction of information technology equipment, namely microprocessor-based control systems (PCs, PLCs, ASDs, etc.) that may lead to a process stoppage. Tripping of contactors and electromechanical relays. Disconnection and loss of efficiency in electric rotating machines.

1.2. Very short interruptions: Total interruption of electrical supply for duration from few milliseconds to one or two seconds.

Causes: Mainly due to the opening and automatic re closure of protection devices to decommission a faulty section of the network. The main fault causes are insulation failure, lightning and insulator flashover.

Consequences: Tripping of protection devices, loss of information and malfunction of data processing equipment. Stoppage of sensitive equipment, such as ASDs, PCs, PLCs, if they're not prepared to deal with this situation.

1.3. Long interruptions: Total interruption of electrical supply for duration greater than 1 to 2 seconds[19]

Causes: Equipment failure in the power system network, storms and objects (trees, cars, etc) striking lines or poles, fire, human error, bad coordination or failure of protection devices.

Consequences: Stoppage of all equipments.

1.4. Voltage swell: Momentary increase of the voltage, at the power frequency, outside the normal tolerances, with duration of more than one cycle and typically less than a few seconds.

Causes: Start/stop of heavy loads, badly dimensioned power sources, badly regulated transformers (mainly during off-peak hours).

Consequences: Data loss, flickering of lighting and screens, stoppage or damage of sensitive equipment, if the voltage values are too high.

1.5. Harmonic distortion: Voltage or current waveforms assume non-sinusoidal shape. The waveform corresponds to the sum of different sine-waves with different magnitude and phase, having frequencies that are multiples of power-system frequency [22].

Causes: Classic sources: electric machines working above the knee of the magnetization curve (magnetic saturation), arc furnaces, welding machines, rectifiers, and DC brush motors.

Consequences: Increased probability in occurrence of resonance, neutral overload in 3-phase systems, overheating of all cables and equipment, loss of efficiency in electric machines, electromagnetic interference with communication systems, errors in measures when using average reading meters, nuisance tripping of thermal protections.

1.6. Voltage fluctuation: Oscillation of voltage value, amplitude modulated by a signal with frequency of 0 to 30 Hz.

Causes: Arc furnaces, frequent start/stop of electric motors (for instance elevators), oscillating loads.

Consequences: Most consequences are common to under voltages. The most perceptible consequence is the flickering of lighting and screens, giving the impression of unsteadiness of visual perception.

1.7 Noise: Superimposing of high frequency signals on the waveform of the power-system frequency.

Causes: Electromagnetic interferences provoked by Hertzman waves such as microwaves, television diffusion, and radiation due to welding machines, arc furnaces, and electronic equipment. Improper grounding may also be a cause.

Consequences: Disturbances on sensitive electronic equipment, usually not destructive. May cause data loss and data processing errors.

1.8 Voltage Unbalance: A voltage variation in a three-phase system in which the three voltage magnitudes or the phase-angle differences between them are equal [20].

Causes: Large single-phase loads (induction furnaces, traction loads), incorrect distribution of all single-phase loads by the three phases of the system (this may be also due to a fault).

Consequences: Unbalanced systems imply the existence of a negative sequence that is harmful to all three- phase loads. The most affected loads are three-phase induction machines.

II. IEEE POWER QUALITY STANDARDS

- IEEE SCC-22: Power Quality Standards Coordinating Committee
- IEEE 1159: Monitoring Electric Power Quality
- IEEE 1159.1: Guide For Recorder and Data Acquisition Requirements
- IEEE 1159.2: Power Quality Event Characterization
- IEEE 1159.2: Data File Format for Power Quality Data Interchange
- IEEE P1564: Voltage Sag Indices
- IEEE 1346: Power System Compatibility with Process Equipment
- IEEE P1100: Power and Grounding Electronic Equipment (Emerald Book)
- IEEE 1433: Power Quality Definitions
- IEEE P1453: Voltage flicker
- IEEE 5133 :Harmonic Control in Electrical Power Systems
- IEEE Harmonics Working group
- IEEE P519A: Guide for Applying Harmonic Limits on Power Systems
- Single protective devices
- IEEE P446: Emergency and standby power
- IEEE P1409: Distribution Custom Power
- IEEE P1547: Distributed Resources and Electric Power Systems Interconnection

III. MITIGATION TECHNIQUES FOR POWER QUALITY IMPROVEMENT

3.1 Line-voltage regulators: These are special transformers connected in series with the transmission line designed to regulate the voltage in accordance with the changes in the system. Examples of line voltage regulators are- tap changing transformers, CVT's, buck-boost regulators etc[18].

3.2 M-G Sets (Motor-generator Sets): These M-G sets are installed at the load side in order to supply power to critical loads during the interruptions from the power supply company. In this maintenance and safety are main

3.4 SVC (Static VAR Compensators)

3.5 UPS (Uninterruptible Power Supplies)

3.6 SMES (Superconducting magnetic energy storage)

All the above mentioned conventional devices are not suitable to mitigate voltage disturbances effectively[3,4]. Therefore, there is a need to use new type of devices known as Custom Power Devices like UPQC, AFC etc.

3.7 Active Power Filter

Backing to the active power filters, they can be understood as a controlled current sources or controlled voltage sources capable for compensating different power quality problems as, for instance, harmonic and unbalanced components, power factor, voltage sags or swells, damping low-frequency harmonic oscillations, and so on [14, 17]. Moreover, they are used as an interface for renewable energy sources in a new concept of distributed generation or even making the implementation of decentralized microgrids reliable [11, 17]. The main difference between active power filters and passive power filters is that APFs mitigate harmonics by injecting active power with the same frequency but with reverse phase to cancel that harmonic, where passive power filters use combinations of resistors (R), inductors (L) and capacitors (C) and does not require an external power source or active components such as transistors. This difference, make it possible for APFs to mitigate a wide range of harmonics.

<u>*Advantages of APF*</u>

- *Less Cost:* They are very much inexpensive than passive filters due to variety of cheaper op amp and the absence of costly inductors
- *Gain and Frequency Adjustment Flexibility: Since* the op-amp is capable of providing a gain, the input signal is not attenuated.
- *No loading problem:* They provide excellent isolation between the individual stages due to the high input impedance and low output impedance.

3.8 Unified power quality conditioner (UPQC*):* It is a custom power gadget, which mitigates voltage and current-related PQ issues in the power dispersion frameworks. The broad utilization of Power Electronics based hardware has delivered a noteworthy effect on quality of electric power supply. One present day and extremely encouraging arrangement that arrangements with both load current and supply voltage flaws are the UPQC. In this paper, Pi and Hysteresis controller based UPQC topology is proposed. The proposed topology empowers UPQC to have a lessened dc-interface voltage without bargaining its pay capacity. The normal exchanging recurrence of the switches in the VSI likewise diminishes; therefore, the exchanging misfortunes in the inverters decrease [1, 2, 3]. The shunt component is in charge of relieving the power quality issues caused by the consumer: poor power factor, load harmonic currents, load unbalance and DC balance [4, 5, 6]. The shunt some portion of the UPQC [7, 8, 9, 12] comprises of a VSI (voltage source inverter) associated with the normal DC stockpiling capacitor on the dc side and on the air conditioner side it is associated in parallel with the heap through the shunt interface inductor and shunt coupling transformer. The shunt interface inductor, together with the shunt sift capacitor is utilized to channel through the exchanging recurrence music delivered by the shunt VSI. The shunt coupling transformer is utilized for coordinating the system and VSI voltages [13, 15]. To accomplish its remuneration objectives, the shunt active filter infuses streams at the purpose of normal coupling with the end goal that the reactive and consonant segments of the heap ebbs and flows are wiped out and the heap current unbalance is disposed of. This present infusion is given by the dc storage capacitor and the shunt VSI [13]. In light of measured streams and voltages the control plot produces the fitting exchanging signals for the shunt VSI switches. The specific streams and voltages to be measured rely upon the connected control system. The shunt gadget is likewise utilized for giving a way to genuine power stream to help the operation of the arrangement associated VSI. Likewise, it keeps up consistent normal voltage over the DC storage capacitor. The shunt VSI is controlled in current control mode. The suitable VSI switches are turned on and off at certain time examples to such an extent that the streams infused by the shunt active filter track some reference ebbs and flows inside a settled hysteresis band (accepting a hysteresis controller is utilized) as indicated by the pay destinations. The VSI switches then again associate the dc capacitor to the framework, either in the positive or negative sense. At the point when the dc capacitor voltage is associated in the positive sense, it is added to the supply voltage and the VSI current is expanding. On account of the dc capacitor associated in the negative sense, its voltage is contrary to the supply voltage and the VSI current is diminishing. Thus, then again expanding and diminishing the current inside the hysteresis band, the reference current is followed. This control strategy is called "Hysteresis band control".

<u>*Advantages of UPQC*</u>

- Real and reactive power flow would be controlled with help of UPQC.
- Power quality issues such as sag, swell, harmonics and notches will be minimized.
- It is easy to control, because absence of multiple controllers.
- Overall cost of system will be reduced.
- Overall efficiency of the system will be improved.
- Switching frequency is fixed.
- Best option for dynamic conditions.

IV. RELATED WORK

Mani, P. K., and Dr K. Siddappa Naidu [1] UPQC is a custom power device, which mitigates voltage and current-related PQ issues in the power distribution systems. The widespread use of Power Electronics based equipment has produced a significant

impact on quality of electric power supply. One modern and very promising solution that deals with both load current and supply voltage imperfections are the UPQC. In this paper, Pi and Hysteresis controller based UPQC topology is proposed. The proposed topology enables UPQC to have a reduced dc-link voltage without compromising its compensation capability. The average switching frequency of the switches in the VSI also reduces; consequently, the switching losses in the inverters reduce. Sukumaran, Jithin, Amal Thomas, and Avik Bhattacharya. [2] In this paper, the author proposed a unified power quality conditioner for harmonic compensation with low voltage. In this work series capacitors are introduced in series with coupling inductors on on the shunt filters. This method helps in reducing voltage rating of the DC-link capacitor. It is a cost-effective solution in distribution side. The proposed methodology is tested in the simulation environment and found that it works effectively and provide robustness in the system. Vijayasamundiswary, S., and J. Baskaran [3] proposed a nine switch UPQC for the improvement in the quality of power. This method reduces the switching overhead, less commutation, fewer losses and low cost. This proposed system act as a back to back converter like a shunt filter and series filter. This method is based on the particle swarm optimization algorithm which is used for the optimized results. The result of the proposed system shows it is tested on the linear and non-linear loads. Bouzelata, Yahia, Erol Kurt, Rachid Chenni, and Necmi Altın. [4] Proposed a unified power conditioner which is fed by solar power. This system is also working well with the active power grid. The UPQC uses the photovoltaic system and its topology which is made up of the hybrid active power filter combination. This combination shares the common DC voltage with the active power filter. It eliminates the current distortion and voltage distortion after fifth and seventh harmonics to the AC main voltage. The simulation result of the proposed method shows that it performs better and provides effective results.
Gautam, A. K., Singh, S. P., Pandey, J. P., Payasi, R. P., & Gupta, N. [5] Because of quickly expanding utilization of power electronic gadgets in circulation framework, there are numerous mind-boggling issues are advanced in power dissemination framework ordered in current music and voltage music. Both Series and Shunt converters are important, for voltage and current quality control which is known as UPQC. This paper introduces the UPQC utilizing hysteresis control Band with PI controller for the Harmonic end and also remuneration of current and voltage, which enhances the power quality, offered to the next touchy burdens which are associated with the appropriation framework. Samal, Sarita, and Prakash Kumar Hota, [6] in this paper, the author discussed the problem related to the non-linear loads which decrease the source voltage. These problems are mainly sag, swell and voltage imbalance. All the problems are overcome by using the UPQC because it maintains the voltage and provides the better performance. In this work wind energy is used to feed in DC Capacitor to maintain the voltage level

Cheung, Victor SP, Shun Cheung Ryan YEUNG, Henry SH Chung, Alan WL Lo, and Weimin Wu, [7] the author proposed a transformer-less UPQC with fast dynamic control. The proposed system has four switching circuit which forms two half-bridge voltage source inverters in which one is connected in series and on is connected in parallel with the load. In this system same DC link is shared by two inverters. The parallel inverter is controlled by hysteresis current controller and provides the shape to the AC current. The results of the proposed system are compared with the existing method and it performs well. Vadivu, U. Senthil, and B. K. Keshavan, [8] in this paper, the author combines the UPQC and Wind energy conversion system to solve the problem related to the power quality in distribution systems. For the optimization, FireFly Algorithm is used and Recurrent Neural Network is used to train the optimization parameters. Shunt Active Power Filters are used for generating the optimal control pulses which are based on the source side and load side parameters. The performance of UPQC with FFA is enhanced and provides good power quality. Senthilkumar, A., and P. Ajay-D-Vimal Raj, [9] this paper displays a novel heuristic based adaptive control technique (ACT) for enhanced remuneration capacity of the UPQC. The pay capacity of UPQC is improved by the ideal control of DC connect voltage. Among all power quality (PQ) mutilations, voltage hang is the extreme PQ issue that fundamentally crumbles the control of DC interface voltage.

counterfeit consciousness strategies. Kumar, R., Singh, B., Shahani, D. T., & Jain, C. [10] in this paper the author proposed the dual tree-complex wavelet transform-based control algorithm for a distribution static compensator (DSTATCOM) for power quality improvement. This method is used to solve the problem of harmonics and voltage unbalancing. DSTATCOM is used to control the voltage source and load conditions. This method is implemented in the simulation environment for validation. The metric used for performance measurement is total harmonics distortion (THD). Tareen, W. U., Mekhilef, S., Seyedmahmoudian, M., & Horan, B. [11] proposed the Active power filter to improve the power quality in grid integration of wind energy conversion system. This method is used to reduce the issues related to power like size, cost, and grid-connected servers. This method helps in reducing voltage rating of DC-link capacitor. It is a cost-effective solution in distribution side. The proposed methodology is tested in the simulation environment and found that it works effectively and provide robustness in the system. Patjoshi, Rajesh Kumar, and Kamalakanta Mahapatra [12] This proposed calculation adaptively manages the DC-link capacitor voltage without using extra controller circuit and makes the control framework basic as it doesn't include any mind-boggling streamlining techniques. Besides, a nonlinear variable increase fluffy based hysteresis controller is proposed for controlling

the hysteresis band, which adequately lessens the band infringement and enhances the following conduct of UPQC amid stack transient, twisting and uneven supply states of power framework. The result of the simulation for the proposed method shows that it works effectively with PI and hysteresis controller. Hasan, Mashhood, Abdul Quaiyum Ansari, and Bhim Singh. [13] Proposed a design in which voltage source converter with three phase wire UPQC. provides appropriate switching frequency and ripple factor. This method is used to reduce the issues related to power like size, cost, and grid-connected servers. This method helps in reducing voltage rating of the Dc-link capacitor. It is a cost-effective solution in distribution side. The proposed methodology is tested on the simulation environment and found that it works effectively and provide robustness in the system. Kow, K. W., Wong, Y. W., Rajkumar, R. K., & Rajkumar, R. K. [14] reviewed artificial intelligence and conventional method in the power quality. In their paper, the author investigated the negative impact of the photovoltaic grid-tied system to the power network. In this research author surveyed on the power system monitoring, dynamic voltage regulator, and inverters[16] . This paper also contains the information related to a multi-mode operation in power environment.

V. CONCLUSION

This paper concludes that the presence of various power quality problems like sag , swell, flickers, notch, harmonics, transients in power delivered to end users greatly deteriorates its quality which has an adverse effect on equipment's connected to distribution system like transformers protective relays, malfunctioning of information technology equipment ,tripping of contractors, loss of efficiency in rotating machines, insulator flash over etc. which can be mitigated through various mitigation techniques like SVC,SMES APF,UPQC etc.UPQC is the most commonly used custom device which mitigates these power quality problems and thus improves power quality.

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