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POWER QUALITY DISTURBANCES AND CUSTOM POWER DEVICES

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Abstract: *Harmonics, flicker and imbalance have become serious concerns with the increasing use of nonlinear loads in industries. Lightning strikes on transmission/distribution lines and several network faults can also cause transients, voltage sag/swell and interruption. Decrease in the cost of power electronic devices and improvement in the efficiency of both power converters and energy storage components have increased the applicability of new technological solutions such as Custom Power devices to mitigate the power quality disturbances. Static Transfer Switch (STS) is generally used to mitigate voltage sag/swell and interruption, Active Power Filter (APF) is generally used to eliminate current harmonics, flicker and imbalance, Dynamic Voltage Restore (DVR) is generally used to compensate voltage sag/swell and Unified Power Quality Conditioner (UPQC) performs the tasks of DVR and APF. In this paper, the basics of power quality, configuration and operation principles of custom power devices are presented.*

Key words: *Power quality, Custom power devices, Sag/swell, Harmonic, Interruption*

GÜÇ KALİTESİ VE ÖZEL GÜÇ CİHAZLARI

Özet: *Lineer olmayan yüklerin endüstride artan kullanımıyla harmonik, kırpışma ve dengesizlikler önemli bir sorun olmuştur. Dağıtım/iletim hatlarında olan yıldırımlar ve çeşitli şebeke hataları geçişlere, gerilim düşümlerine/yükselimlerine ve kesintilere neden olabilir. Güç elektroniği cihazlarının fiyatlarının azalması, çevirici ve enerji depolama cihazlarının verimliliklerinin artmasıyla, yeni teknolojik çözüm olan Özel Güç Cihazlarının güç kalitesi problemlerini yok etmek için kullanılabilirliğini arttırmıştır. Statik Transfer Anahtarı (STA) genellikle kesintileri ve gerilim düşümü/yükselimini düzeltmek için kullanılır. Aktif Güç Filtresi (AGF) genellikle akım harmoniklerini, kırpışmaları ve dengesizlikleri elemek için kullanılır. Dinamik Gerilim İyileştirici (DGİ) genellikle gerilim düşümü/yükselimini kompanse etmek için kullanılır, Birleştirilmiş Güç Kalitesi Düzenleyici (BGKD)ise DGİ ve AGF'nin özelliklerini gerçekleştirir. Bu çalışmada güç kalitesinin temelleri, Özel Güç cihazlarının konfigürasyonları ve temel çalışma prensipleri sunulmuştur.*

Anahtar kelimeler: *Güç kalitesi, Özel güç cihazları, Gerilim düşümü/yükselimi, Harmonik, Kesinti*

1. POWER QUALITY DISTURBANCES

Power quality can be defined as having a bus voltage that closely resembles a sinusoidal waveform of required magnitude. Increasing number of sensitive devices to variations, the requirement for reducing losses and the behaviors of interconnected networks are some reasons which increase the importance of power quality concept. In the industry, power quality polluting loads are increasing day by day. The main reasons for concern with power quality (PQ) are as following (1):

- End user devices become more sensitive to PQ due to many microprocessor based controls.
- Complexity of industrial processes: the re-startup is very costly.
- Large computer systems in many businesses facilities
- Power electronics equipment used for enhancing system stability, operation and efficiency.

They are major source of bad PQ and are vulnerable to bad PQ as well.

- Deregulation of the power industry
- Complex interconnection of systems, which results in more severe consequences if any one component fails.
- Continuous development of high performance equipment: Such equipment is more susceptible to power disturbances.

The users demand higher power quality to use more sensitive loads to automate processes and improve quality. Some basic criterions for power quality are constant rms value, constant frequency, symmetrical three-phases, pure sinusoidal wave shape and limited Total Harmonic Distortion (THD). These values should be kept between limits determined by standards if the power quality level is considered to be high. Power quality covers several types of disturbances of electrical supply and power system disturbances. The cost of power interruptions and disturbances can be quite high as a result of the important processes controlled and maintained by the sensitive devices. Power quality disturbances can be summarized as follows (1):

- Transients
  - Impulsive transients: Sudden, non-power frequency change in the steady state condition of the voltage, current or both
  - Oscillatory transients: Voltage or current whose instantaneous value changes polarity rapidly.
- Short duration voltage variations
  - Sag: 0.1 ~ 0.9 pu; 0.5 cycles to one minute; caused by system faults, energisation of heavy loads and starting of large motors
  - Swell: 1.1 ~ 1.8 pu; 0.5 cycles to one minute; caused by system fault conditions
  - Interruption: Less than 0.1 pu; not exceeding one minute; caused by power system faults, equipment failures and control malfunctions
- Long duration voltage variations
  - RMS deviation longer than one minute; voltage, current, frequency
  - Types: overvoltage, under voltage
- Voltage imbalances

- Percentage maximum deviation from the average of three-phase voltages or currents

– Waveform distortions: DC offset, harmonics, notching, noise

– Power frequency variations
  - Deviations of the power system fundamental frequency from its specified nominal value
  - Depends on: load characteristics, response of generation control system to load

– Voltage fluctuations
  - Systematic variations of the voltage envelop or series of random voltage changes
  - Not normally exceed 0.9 to 1.13 pu

Power electronic based devices provide protection for industry and commercial customers from power quality disturbances basically sags, swells, harmonics, interruption and unbalance voltages that are shown in Figure 1.

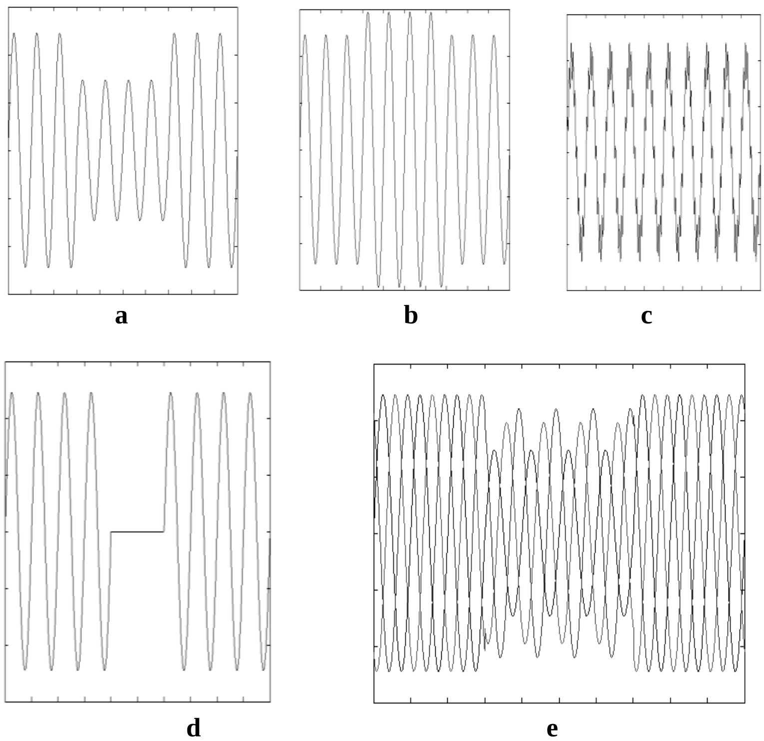

Figure 1. Waveforms of (a) Voltage sag, (b) Swell, (c) Harmonic, (d) Outage and (e) Unbalance

Table 1 lists the causes of the power quality disturbances (2).

Table 1. The causes of the power quality disturbances

Power quality disturbance, categories and causes		
Category	**Method of characterization**	**Cause**
Impulse transients	Magnitude duration	Lighting, load switching
Oscillatory transients	Waveforms	Lighting, line/cable switching, capacitor switching, transformer switching, load switching
Sags/swells	Waveforms, RMS vs time	Remote faults
Under voltages/ over voltages	RMS vs time	Overloading of feeder/motor starting, load changes, compensation changes
Interruptions	Duration	Breaker operation/fault clearing, maintenance
Harmonic distortion	Waveforms, harmonic spectrums	Nonlinear loads, system response characteristics
Voltage flicker	Magnitude, frequency of modulation	Intermittent loads, arcing loads, motor starting
Noise	Noise, coupling method, frequency	Power electronics switching, arcing, electromagnetic radiation

A number of national and local surveys helped to quantify the statistical aspects of this disturbance. The most common disturbances and the most commonly affected equipments are illustrated in Figure 2 (3). One report shows that power outages and interruptions cost the U.S. economy between $104 billion and $164 billion a year due to equipment damage, materials loss, idled labor and lost production or sales and another $15 billion to $24 billion a year is lost due to power quality phenomena (4).

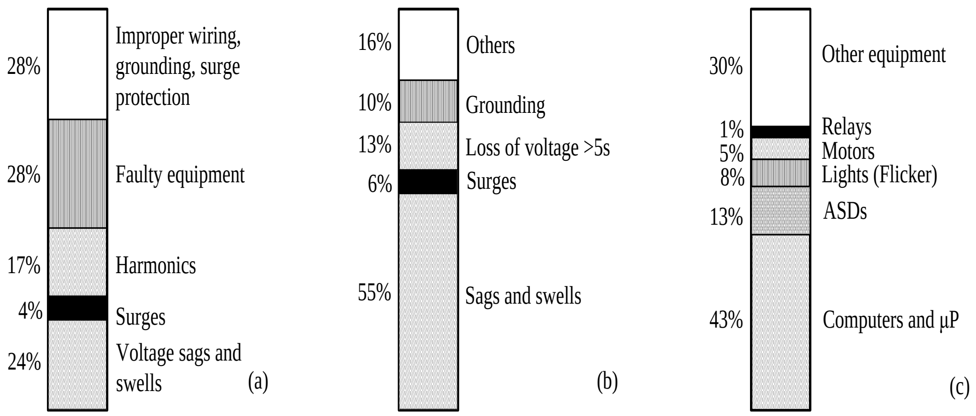

Figure 2. Basic disturbances: (a) Causes at customer side, (b) Causes at utility side and (c) Affected equipment

Another survey result is given in Figure 3. It is concluded that the voltage sag/swell and harmonics are most common power disturbances encountered in the industrial processes(5).

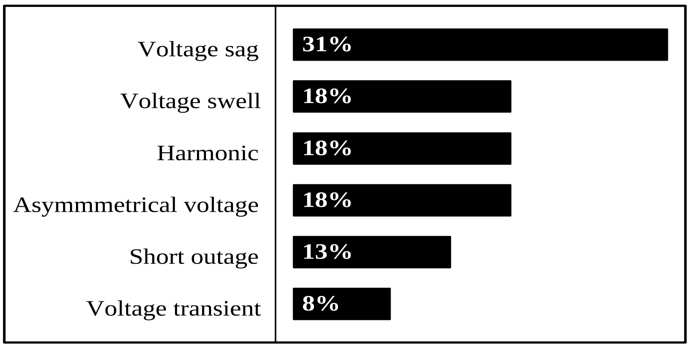

Figure 3. Percentage occurrences of PQ disturbances in equipment interruptions

If due to poor power quality the production is stopped, major costs are incurred. This is illustrated in Table 2 which gives an overview of typical financial loss due to a power quality incident (stop) in electrical installations for various industries (6).

Table 2. Examples of financial loss due to power quality incidents

Sector	Financial loss per incident
Semi-conductor production	3800000 £
Financial trade	6000000 £ per hour
Computer center	750000 £
Telecommunication	30000 £ per minute
Steel industry	350000 £
Glass industry	250000 £
Offshore platforms	250000-750000 £ per day
Dredging/land reclamation	50000-250000 £ per day

2. CUSTOM POWER DEVICES

Custom Power devices are also known power quality mitigating devices and they can increase the availability of sensitive loads in the system and supply reliable power. Custom power devices are typically building on the distribution system to provide higher power quality and most economic solution. High power solid-state switches such as insulated gate bipolar transistor (IGBT) and gate turn-off thyristor (GTO) with controlled turn- off capability are used to achieve high power quality. They perform rapid response and provide continuous and dynamic control in real time processes.

Custom power devices are mainly used in voltage sag mitigation, protection and control of sensitive loads, reactive power and voltage regulation and harmonic elimination applications. There are three principle elements to the custom power concept; these are (7):

– DVR as shown in Figure 4, it provides series compensation by voltage injection for power system sag and swell. It can supply or absorb both real and reactive power to compensate the disturbances. DVR is primarily for use at the distribution level.

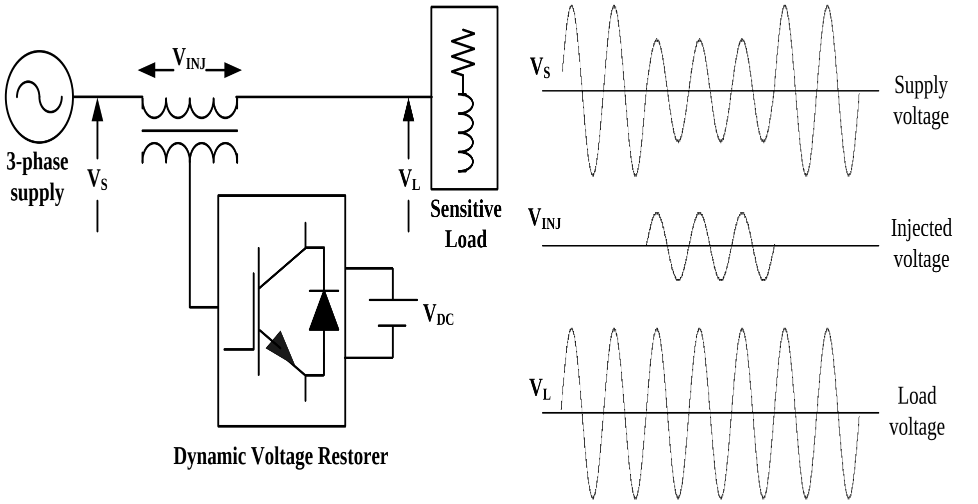

Figure 4. Single line circuit diagram of a DVR

– APF as shown in Figure 5, it provides continuously variable shunt compensation by current injection for eliminating voltage fluctuations and obtaining correct power factor in three-phase systems. An ideal application of it is to prevent disturbing loads from polluting the rest of the distribution system.

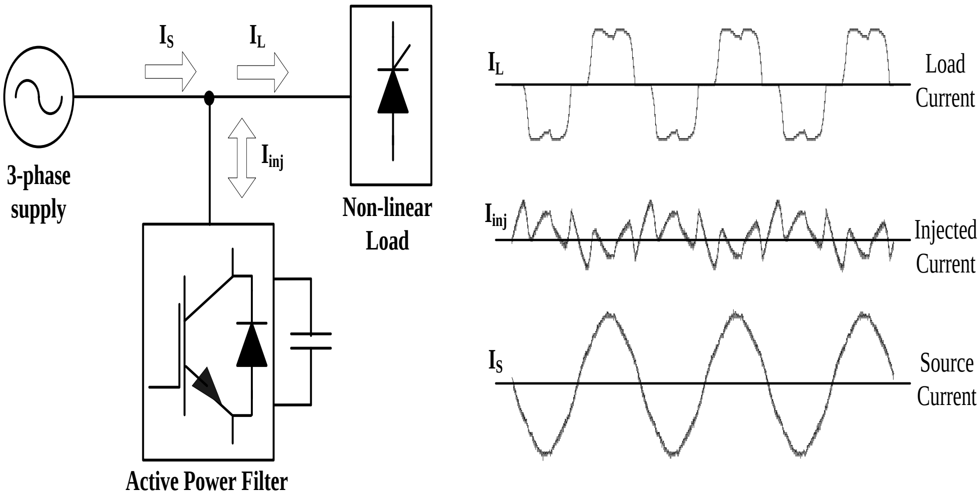

Figure 5. Single line circuit diagram of an APF

– UPQC consists of two voltage source inverters. It can simultaneously perform the tasks of APF and DVR. The basic circuit diagram of UPQC is shown in Figure 6. UPQC protect the loads against voltage sag, swell, voltage unbalance, harmonics and poor power factor. UPQC is a combination of a shunt (APF) and a series compensator (DVR) connected together via a common DC link capacitor. UPQC allows local distributors to supply different grades of power to the final customers (8).

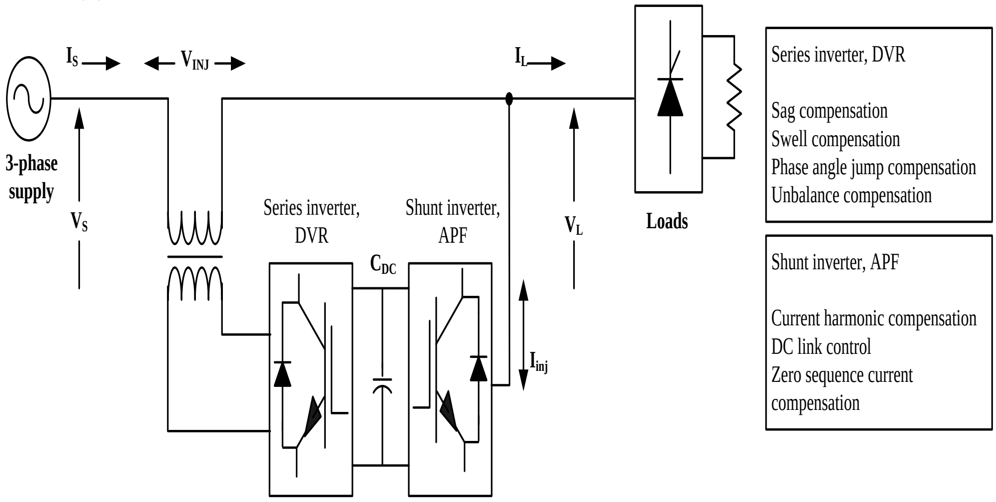

Figure 6. Single line circuit diagram of a UPQC

– STS as shown in Figure 7, it protects circuits from electrical disturbances by transferring load from a faulted line (main source) to a healthy line (back up source). SSTS does not operate in the same way as a conventional circuit breaker. It interrupts fault currents by monitoring both steady current and rate of change of current and only interrupts when the onset of a fault is detected.

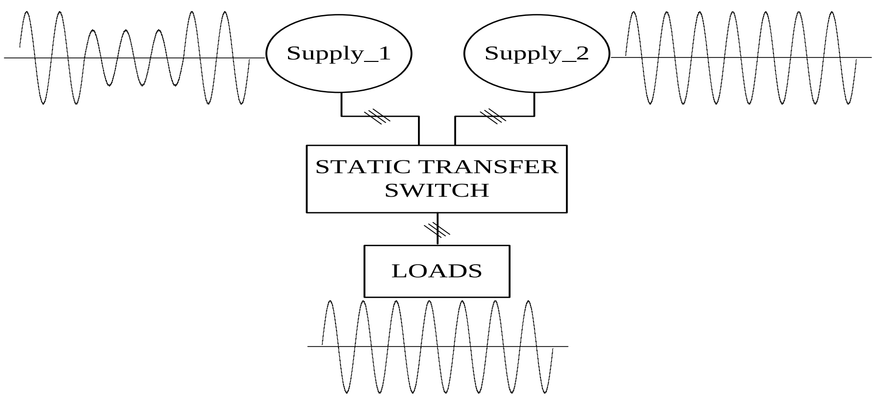

Figure 7. Single line circuit diagram of an STS

The study in (9) has presented electromagnetic transient models (PSCAD/EMTDC) of custom power devices, namely APF, DVR, and STS and applied them to the study of power quality. The proper selection of necessary custom power strategies in addition to accurate system modeling and appropriate protection devices will increase the power quality. The applications of custom power devices are summarized in Table 3.

Table 3. Custom power devices and their applications

Custom Power Devices	**Power System Disturbances**
Dynamic Voltage Restorer	Voltage sags, voltage swells, harmonic blocking, voltage balancing
Active Power Filter	Voltage regulation, harmonic elimination, correct power factor
Unified Power Quality Conditioner	Voltage sags, voltage swells, harmonic blocking, voltage balancing, Voltage regulation, harmonic elimination, correct power factor
Solid State Transfer Switch	Interruptions, current limiting

Any device that depends on a volatile memory chip for information storage is potentially at risk from power quality events. Many processes in industry depend on automated microprocessor control systems. Solutions to the power quality disturbances encountered with this type of devices that are known as sensitive equipment (10) These devices are usually installed in the low voltage system (< 1 kV) and three types are listed below:

– Programmable Logic Controllers (PLC)
– Electromechanical Relays and Motor Contactors
– Adjustable Speed Drives (ASD)

They often consist of protection for the control system alone, the actual process not being sensitive to the more common disturbances.

3. CONCLUSIONS

This paper describes several of the more common power quality disturbances such as current harmonics, flicker, imbalance, voltage sag, voltage swell and interruption. The causes, effects and mitigation techniques for each disturbance are clearly presented. The possible solutions to PQ disturbances are reviewed and the concept of custom power is explained. With the increasing number of power quality disturbances, the custom power devices such as APF, DVR, UPQC and UPQC will be mostly used in a near future. Both power suppliers and customers can satisfy the standard limits such as IEEE, IEC, ANSI, EN, CIGRE, BNS using custom power devices.

REFERENCES

1. Dong, Z.Y. and Saha, T. (2004). *Power Quality & Equipment Protection*. ELEC4301, pp. 1-34.
2. Shiva S. Rajat K.S. (1998). Review of Power Quality Applications of Energy Storage Systems, *Contractor Report*. Sentech Inc.. Sandia National Laboratories.
3. Emanuel A. E. Mcneill J. A. (1997). Electric power quality, *Annual review of energy and the environment*, 22:263-303.
4. Liu S. Singer C.H. Dougal R.A. (2006). Power anomaly effects and costs in low-voltage mobile power systems *aerospace and electronic systems, IEEE Transactions on Aerospace and Electronic Systems*, 42:612-624.
5. Seng L.Y. (2002). Probabilistic assessments of voltage-sag occurrence and the evaluation of the dynamic voltage restorer capability. *PhD thessis*. University of Manchester Institute of Science and Tech.
6. Kurt S. François D. (2010). The Importance Of Good Power Quality, *ABB Power Quality Products*, pp. 1-20.
7. Taylor G.A. (1995). Power Quality Hardware Solutions for Distribution Systems: Custom Power. IEE Reliability, *Security and Power Quality of Distribution Systems*, 11/1-11/9..
8. Brenna M. Tironi R.F. (2009). A new proposal for power quality and custom power improvement OPEN UPQC, *IEEE Transactions on Power Delivery*, 24: 2107-2116.
9. Lara O.A. and Acha E. (2002)ç. Modeling and Analysis of Custom Power Systems by PSCAD/EMTDC, *IEEE Transactions On Power Delivery*, 17(1): 266-272.
10. Stones J. and Collinson A. (2001). Special Feature: Introduction Power Quality. *IEE Power Engineering Journal*, 58-64.