Power Qualiy Problems and it's improvement using FACTS devices

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Abstract—
Modern power systems are continuously being expanded and upgraded to cater the need of ever growing power demand. This paper explains the problems that are due to poor Power Quality in electrical systems and shows their possible financial consequences and improvement of power quality. Power Quality is characterized by parameters that express harmonic pollution, reactive power and load unbalance.. It is shown that by using the right technology a variety of Power Quality problems can be solved rendering installations trouble free and more efficient, and can render them compliant with even the strictest requirements. Flexible AC transmission systems or FACTS are devices which allow the flexible and dynamic control of power systems. . Finally, an introduction to the basic circuits of several FACTS controllers is provided with a focus on their system performance characteristics.

Keywords— Controllers, FACTS devices, Installation factors, Power quality, Power quality problems.

Introduction

Power quality is an issue that is becoming increasingly important to electricity consumers at all levels of usage. Sensitive equipment and non-linear loads are commonplace in both the industrial and the domestic environment; because of this a heightened awareness of power quality is developing. The sources of problems that can disturb the power quality are: power electronic devices, arcing devices, load switching, large motor starting, embedded generation, sensitive equipment, storm and environment related damage, network equipment and design.

If the Power Quality of the network is good, then any loads connected to it will run satisfactory and efficiently. Installation running costs and carbon footprint will be minimal.

If the Power Quality of the network is bad, then loads connected to it will fail or will have a reduced lifetime, and the efficiency of the electrical installation will reduce. Installation running costs and carbon footprint will be high and/or operation may not be possible at all.

1. COST OF POOR POWER QUALITY:

Poor Power Quality can be described as any event related to the electrical network that ultimately results in a financial loss. Possible consequences of poor Power Quality includes as follows

Unexpected power supply failures (breakers tripping, fuses blowing).

1. Equipment failure or malfunctioning.
2. Equipment overheating (transformers, motors) leading to their lifetime reduction.
3. Damage to sensitive equipment (PC's, production line control systems).
4. Electronic communication interferences.
5. Increase of system losses.
6. Need to oversize installations to cope with additional electrical stress with consequential increase of installation and running costs and associated higher carbon footprint.
7. Penalties imposed by utilities because the site pollutes the supply network too much.
8. Connection refusal of new sites because the site would pollute the supply network too much.
9. Impression of unsteadiness of visual sensation induced by a light stimulus whose luminance or spectral distribution fluctuates with time (flicker).

The following are the main contributors to Low Voltage poor Power Quality can be defined:

1. Reactive power, as it loads up the supply system unnecessary, Harmonic pollution, as it causes extra stress on the networks and makes installations run less efficiently,
2. Load imbalance, especially in office building applications, as the unbalanced loads may result in excessive voltage imbalance causing stress on other loads connected to the same network, and leading to an increase of neutral current and neutral to earth voltage build-up,
3. Fast voltage variations leading to flicker.

All this phenomena potentially lead to inefficient running of installations, system down time and reduced equipment life and consequently high installation running costs.

The solution to improve the power quality at the load side is of great important when the production processes get more complicated and require a bigger liability level, which includes aims like to provide energy without interruption, without harmonic distortion and with tension regulation between very narrow margins. The devices that can fulfill these requirements are the Custom Power; a concept that we could include among the FACTS, but that is different to them because of their final use. In fact the topologies that they employ are identical to the ones in the FACTS devices with little modifications and adaptations to tension levels; therefore they are most oriented to be used in distribution networks of low and medium tension, sometimes replacing the active filters.

Recent developments in electrical power systems such as deregulation, open access, and cogeneration are creating

Scenarios of transmission congestion and forced outages. Addition of new transmission lines is an almost impossible solution due to environmental and other considerations, and developing new approaches to Power System Operation and Control is the need of the hour for overload relief and efficient .and reliable operation

2. Overview of the classification of FACTS Devices: The FACTS technology has a collection of controllers, that can be used individually or co-ordinated with other controls installed in the network, thus permitting to profit better of the network's characteristics of control. The FACTS controllers offer a great opportunity to regulate the transmission of alternating current (AC), increasing or diminishing the power flow in specific lines and responding almost instantaneously to the stability problems. The potential of this technology is based on the possibility of controlling the route of the power flow and the ability of connecting networks that are not adequately interconnected, giving the possibility of trading energy between distant agents.

2.1. Advantages of using FACTS devices in the power system network

1. Mitigate environmental and The benefits of utilizing FACTS devices in electrical transmission systems can be summarized as follows:

• 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 asset.
• Provide dynamic reactive power support and voltage control.
• Reduce the need for construction of new transmission lines, capacitors, reactors regulatory concerns.

2. Improve aesthetics by reducing the need for construction of new facilities such as transmission lines.

• Improve system stability.
• Control real and reactive power flow.
• Mitigate potential Sub-Synchronous Resonance problems.

2.2. Classification of FACTS devices:

There are different classifications for the FACTS devices:

• Depending on the type of connection to the network FACTS devices can differentiate four categories

- Series controllers
- Derivation controllers
- Serial to serial controllers
- Serial-derivation controllers

• Depending on technological features, the FACTS devices can divided into two generations

First generation: used thyristors with ignition controlled by gate (SCR).

- Second generation: semiconductors with ignition and extinction controlled by gate (GTO's, IGBT's IGCT's etc).

The main difference between first and second generation devices is the capacity to generate reactive power and to interchange active power.

FACTS DEVICES	ATTRRIBUTES TO CONTROL
Static Var Compensator SVC(TCR,TCS,TRS)	Voltage control and stability, compensation of VAR´s. muffling of oscillation
Thyristor Controlled Series Compensations (TCSC,TSSC)	Current control, muffling of oscillations transitory, dynamics andof voltage stability, limitation of fault current.
Thyristor Controlled Reactor Series (TCSR,TSSC)	Current control, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current
Thyristor Controlled Phase Shifting Transformer(TCPST,TCPR)	Control of active power, muffling of oscillations, transitory, dynamics and of voltage stability.
Thyristor Controlled Voltage Regulator(TCVR)	Control of reactive power, voltage control, muffling of oscillations, transitory, dynamics and voltage stability.
Thyristor Controlled Voltage Limited(TCVL)	Limits of transitory and dynamic Voltage.

TABLE 1: FIRST GENERATION FACTS DEVICES.

FACTS DEVICES	ATTRIBUTES TO CONTROL
Synchronous Static Compensator(STATCOM)	Voltage control, compensation of VAR´s, muffling of oscillations, Stability of voltage.
Synchronous Static Compensator(STATCOM with storage)	Voltage control and stability, compensation of VAR´s, muffling of oscillations, transitory, dynamics and of tension stability
Static Synchronous Series Compensator(STATCOM without storage)	Current control, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current
Unified Power Flow Controller(UPFC)	Control of active and reactive power, voltage control, compensation of VAR´s, muffling of oscillations, transitory, dynamics and of voltage stability, limitation of fault current

Interline Power	Control of reactive power, voltage.
Back to Back(BtB)	control, muffling of oscillations, transitory, dynamics and of voltage stability

TABLE 2. SECOND GENERATION FACTS DEVICES

1. ***Serial controllers:*** *It* consists of variable impedances a condenser, coil, etc or a variable electronics based source at a fundamental frequency. The principle of operation of all serial controllers is to inject a serial tension to the line. Variable impedance multiplied by the current that flows through it represents this serial tension. While the tension is in quadrature with the line current the serial controller only consumes reactive power; any other phase angle represents management of active power. A typical controller is Serial Synchronous Static Compensator (SSSC).

2. ***Controllers in derivation.*** As it happens with the serial controller, the controller in derivation can consist of variable impedance, variable source or a combination of both. The operation principle of all controllers in derivation is to inject current to the system in the point of connection. Variable impedance connected to the line tension causes variable current flow, representing an injection of current to the line. While the injected current is in quadrature with the line tension, the controller in derivation only consumes reactive power; any other phase angle represents management of active power. A typical controller is Synchronous Static Compensator (STATCOM).

3. ***Serial-serial Controllers.*** This type of controllers can be a combination of coordinated serial controllers in a multiline transmission system. Or can also be an unified controller in which the serial controllers provide serial reactive compensation for each line also transferring active power between lines through the link of power. The active power transmission capacity that present a unified serial controller or line feed power controller makes possible the active and reactive power flow balance and makes the use of transmission bigger. In this case the term "unified" means that the DC terminals of the converters of all the controllers are connected to achieve a transfer of active power between each other. A typical controller is the Interline Power Flow Compensator (IPFC)

4. ***Serial-derivation Controllers.*** This device can be a combination of serial and derivations controllers separated, co-ordinately controlled or a unified power flow controller with serial and derivation elements. The principle of operation of the serial-derivation controllers is to inject current to the system through the component in derivation of the controller, and serial tension with the line utilizing the serial component. When the serial and derivation controllers are unified, they can have an exchange of active power between them through their link. A typical controller is Unified Power Flow Controller (UPFC), which incorporating function of a filtering and conditioning becomes a Universal Power Line Conditioner (UPLC).

3. Factors for FACTS devices Installation:

There are three factors to be considered before installing FACTS devices:

1. The type of device
2. The capacity required
3. The location that optimize the functioning of the device

Of these three factors, the last one is of great importance, because the desired effect and the proper features of the system depend of the location of FACTS.

Steps for the identification of FACTS Projects:

1. The first step should always be to conduct a detailed network study to investigate the critical conditions of a grid or grids' connections. These conditions could include: risks of voltage problems or even voltage collapse, undesired power flows, as well as the potential for power swings or sub synchronous resonances;
2. For a stable grid, the optimized utilization of the transmission lines– e.g. increasing the energy transfer capability – could be investigated;
3. If there is a potential for improving the transmission system, either through enhanced stability or energy transfer capability, the appropriate FACTS device and its required rating can be determined;
4. Based on this technical information, an economical study can be performed to compare costs of FACTS devices or conventional solutions with the achievable benefits.

IV. FACTS devices used in power systems:

3.1. Static VAR Compensator (SVC)

The conventional static VAR compensator consists of a capacitor in parallel with a thyristor controlled reactor (Fig.1). It is conventionally used to stabilise a bus bar voltage and improve damping of the dynamic oscillation of power systems. Many SVCs have been deployed since 1970.The SVC has a single port with a parallel connection to the power system, so the first symbol in its classification string is $S1$ = **1P**. The thyristors are naturally commutated, so $S2$ = **NC**. They switch at the mains frequency, so $S3$ = **LF**. As shown above, there is insignificant energy storage and $S4$ = **ZES**. Finally, the SVC has no dc port: $S5$ = **NDC**. Therefore its classification under this scheme is:

Static VAR Compensator: **1P-NC-LF-ZES-NDC**

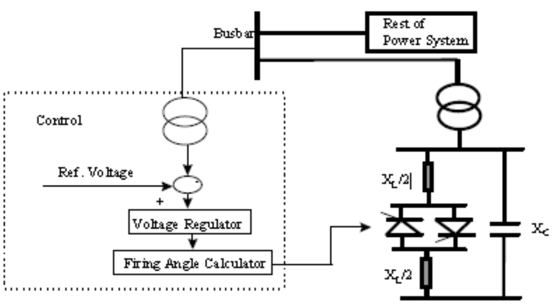

Fig1: Static Var Compensator

3.2. Static Synchronous Compensator (SSC)

The SSC comprises a voltage source inverter which is connected to power system through a transformer (Fig.2). Corresponding to Fig. 2, the SSC can draw either capacitive or inductive current. The voltage source is created from a Capacitor and therefore a SSC has very little active power capability. However, its active power capability can be increased if a suitable energy storage device is connected across the DC capacitor.Excluding the dc port, the SSC is a one-port circuit shunted across a bus bar (*S*1 = **1P**); it uses forced commutation (*S*2 = **FC**); its switching frequency is high (*S*3 = **HF**); its energy storage element is a dc capacitor (*S*4 = **CES**); and this implies a dc port (*S*5 = **DC**).

Static Synchronous Compensator:

1P-FC-HF-CES-DC

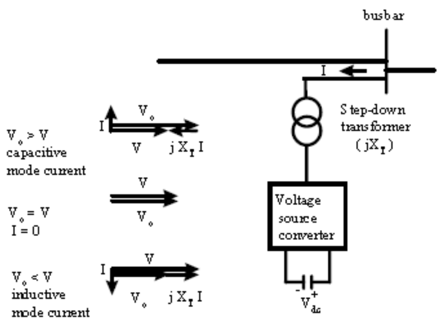

Fig.2: Static synchronous compensator

3.3. Thyristor Controlled Series Capacitor (TCSC)

The TCSC consists of a series capacitor bank, shunted by a Thyristor Controlled Reactor to provide a smoothly variable series capacitive reactance. Fig. 3 shows a TCSC in series with a transmission line. It injects a series voltage proportional to the line current but in quadrature with it. Inserting a TCSC modifies the equivalent reactance of the line, and the active power flow can be varied. The TCSC is a one-port circuit in series with a transmission line; it uses natural commutation; its switching frequency is low; it contains insignificant energy storage elements; and it has no dc port.

Thyristor Controlled Series Capacitor:

1S-NC-LF-ZES-NDC

-NC-LF-ZES-NDC

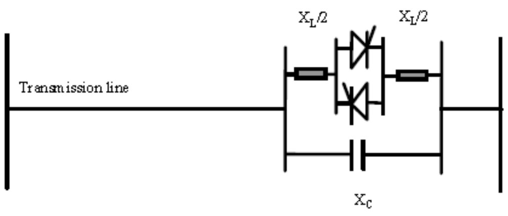

Fig.3 Thyristor controlled series capacitor

3.4Static Synchronous Series Compensator (SSSC)

The SSSC is a static, synchronous generator operated as a series compensator. Its output voltage is in quadrature with the line current, and is controllable independently of it. Its purpose is to increase or decrease the overall reactive voltage drop across the line and thereby control the transmitted power. Fig.4 shows the SSSC model. It employs a step-down transformer, whose leakage inductance forms the reactance in series with an ac/dc converter. The SSSC is a one-port circuit in series with a transmission line; it uses forced commutation; its switching frequency is high; its energy storage element is a capacitor and it has a dc port.

Static Synchronous Series Compensator:

1S-FC-HF-CES-DC

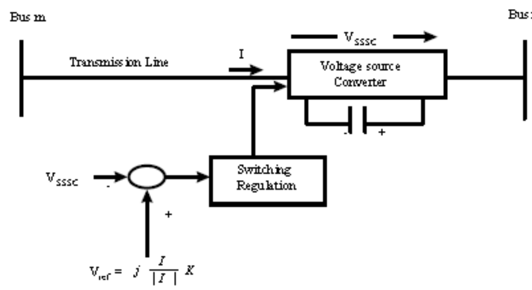

Fig 4: Static Synchronous Series Compensator

3.5 Interphase Power Controller (IPC)

The IPC is a series controller of active and reactive power. It consists of inductive and capacitive branches subjected to separately phase-shifted voltages. The active and reactive power can be set independently by adjusting the phase shifters and/or branch impedances, using mechanical or electronic switches. The IPC can regulate both the direction and the amount of active power transmitted through a transmission line.

The IPC is a two-port circuit (in series with a transmission line and in parallel with a bus bar); it usesnatural commutation; its switching frequency is low; it has insignificant energy storage; and it has no dc port.

Interphase Power Controller: **2-NC-LF-ZES-NDC**

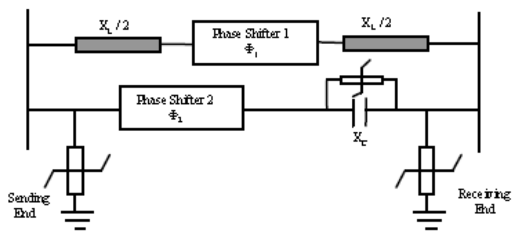

Fig 5: Interphase Power Controller

3.6 Unified Power Flow Controller (UPFC)

The UPFC (Fig.6) is a combination of an SSC and an SSSC, sharing a common dc link. The UPFC can control both the active and reactive power flow in the line. It can also provide independently controllable shunt reactive compensation. In other words, the UPFC can provide simultaneous control of all the basic transmission line parameters.

The UPFC is a two-port circuit (in series with a transmission line and parallel with a bus bar), it uses forced commutation;

its switching frequency is high; it has capacitive energy storage; and it employs a dc port.
The UPFC allows a secondary but important function such as stability control to suppress power system oscillations improving the transient stability of power system. It combines together the features of the Static Synchronous Compensator (STATCOM) and the Static Synchronous Series Compensator (SSSC). In practice, these two devices are two Voltage Source Inverters (VSI's) connected respectively in shunt with the transmission line through a shunt transformer and in series with the transmission line through a series transformer, connected to each other by a common dc link including a storage capacitor.
Unified Power Flow Controller:
2-FC-HF-CES-DC

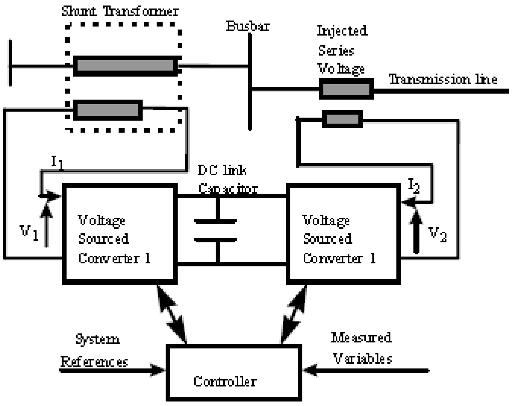

Fig 6: Unified power flow controller

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 equipmen and techniques. 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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