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Power Quality Improvement and Mitigation Case Study with Distributed Power Flow Controller

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ABSTRACT

According to growth of electricity demand and the increased number of non-linear loads in power grids, providing a high quality electrical power should be considered. In this paper, voltage sag and swell of the power quality issues are studied and distributed power flow controller (DPFC) is used to mitigate the voltage deviation and improve power quality. The DPFC is a new FACTS device, which its structure is similar to unified power flow controller (UPFC). In spite of UPFC, in DPFC the common dc-link between the shunt and series converters is eliminated and three-phase series converter is divided to several single-phase series distributed converters through the line. The case study contains a DPFC sited in a single-machine infinite bus power system including two parallel transmission lines, which simulated in MATLAB/Simulink environment. The presented simulation results validate the DPFC ability to improve the power quality.

INTRODUCTION

Electrical energy is the most efficient and popular form of energy because it can be use easily at high efficiency and reasonable cost. The first electric network in the USA was established in 1882 and after that every corner of earth connected through these lines. The modern society has come to depend heavily upon continuous and reliable availability of electricity. Computer and telecommunication networks, railway network banking, post office , life support system are few application that just cannot function without electricity whose life is thrown out of year, in case the electric supply is disrupted. Apart from that the industrial development totally depends upon the supply and quality of electricity.

The power quality has serious economic implications for customers, utilities and electrical equipment manufacturers. There is an exponential increase in the number of non-linear loads in power distribution networks due to advance in power electronics technology The non-linear loads (mostly consisting of solid state converters) cause harmonic distortion of voltage and current. Complications related to the use of non-linear loads for these systems have been a major issue for a long time for both power providers and users alike. The issue in electricity power sector delivery is not confined to only energy efficiency and environment but more importantly on quality and continuity of supply or power quality and supply quality. Electrical Power quality is the degree of any deviation from the nominal values of the voltage magnitude and frequency. Power quality may also be defined as the degree to which both the utilization and delivery of electric power affects the performance of electrical equipment. But now-a-days the quality of electricity is decreasing due to the nonlinear loads. Non-linear load generally denotes the power electronics and semi-conductor device application. This draws nonlinear current from the source. This is because they convert one form of electric energy to another form of electric energy and in these conversion lots of switching devices are used which makes the current discontinuous. Discontinuity of this current injects non-linearity in the supply current. This non-

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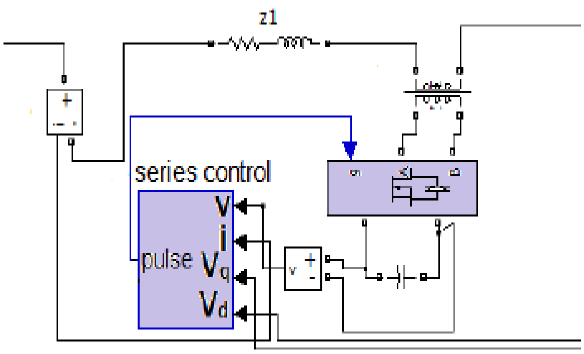
linear quantity contains harmonics and to eliminate this harmonics we required power filters.

In the last decade, the electrical power quality issue has been the main concern of the power companies. Power quality is defined as the index which both the delivery and consumption of electric power affect on the performance of electrical apparatus. From a customer point of view, a power quality problem can be defined as any problem is manifested on voltage, current, or frequency deviation that results in power failure. The power electronics progressive, especially in flexible alternating-current transmission system (FACTS) and custom power devices, affects power quality improvement. Generally, custom power devices, e.g., dynamic voltage restorer (DVR), are used in medium-to-low voltage levels to improve customer power quality. Most serious threats for sensitive equipment in electrical grids are voltage sags (voltage dip) and swells (over voltage). These disturbances occur due to some events, e.g., short circuit in the grid, inrush currents involved with the starting of large machines, or switching operations in the grid. The FACTS devices, such as unified power flow controller (UPFC) and synchronous static compensator (STAT-COM), are used to alleviate the disturbance and improve the power system quality and reliability. In this paper, a distributed power flow controller, introduced in as a new FACTS device, is used to mitigate voltage and current waveform deviation and improve power quality in a matter of seconds. The DPFC structure is derived from the UPFC structure that is included one shunt converter and several small independent series converters, as shown. The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude.

For power-quality improvement, the development of power electronic devices such as flexible AC transmission system (FACTS) and custom power devices have been introduced as an emerging branch of technology providing the power system with versatile new control capabilities. Advanced control and improved semiconductor switching of FACTS devices have achieved a new era for power-quality mitigation. Conventionally passive L-C filters were used to reduce harmonics and capacitors were employed to improve the power factor of the ac loads. But these passive filters have the demerits of fixed compensation, large size, and resonance. Currently unified power flow controller (UPFC) is the most powerful device which can simultaneously control all the parameters of the system such as line impedance, transmission angle, bus voltage, etc. UPFC is the combination of static compensator (STATCOM) and static synchronous series compensator (SSSC) coupled via a common DC link. The Distributed Power Flow Controller (DPFC) recently presented in is a power flow device within the FACTS family, which provides much lower cost and higher reliability than the conventional FACTS devices. It is derived from the UPFC and has the same capability of simultaneously adjusting all the parameters of power system like line impedances transmission angle and bus voltage magnitude.

CIRCUIT DIAGRAM



POWER QUALITY

Power quality determines the fitness of electrical power to consumer devices. Synchronization of the voltage frequency and phase allows electrical systems to function in their intended manner without significant loss of performance or life. The term is used to describe electric power that drives an electrical load and the load's ability to function properly. Without the proper power, an electrical device (or load) may malfunction, fail prematurely or not operate at all. There are many ways in which electric power can be of poor quality and many more causes of such poor quality power.

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Power Quality is an important issue for electricity consumers at all levels of usage, particularly industries and the services sector. We extensively use sensitive power electronic equipment and non-linear loads these days in industry, commercial and domestic applications. In such an environment, problems like power surges/sags, poor voltage and frequency regulation, harmonics, switching transients, electrical noise and the Electro-Magnetic Interference effect are frequently encountered. This leads to damage of capital-intensive appliances, safety concerns, loss of reliability and above all a huge economic loss.

Power Quality (PQ) related issues are of most concern nowadays. The widespread use of electronic equipment, such as information technology equipment, power electronics such as adjustable speed drives (ASD), programmable logic controllers (PLC), energy-efficient lighting, led to a complete change of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality problems . Due to their non-linearity, all these loads cause disturbances in the voltage waveform. Along with technology advance, the organization of the worldwide economy has evolved towards globalization and the profit margins of many activities tend to decrease. The increased sensitivity of the vast majority of processes (industrial, services and even residential) to PQ problems turns the availability of electric power with quality a crucial factor for competitiveness in every activity sector. The most critical areas are the continuous process industry and the information technology services. When a disturbance occurs, huge financial losses may happen, with the consequent loss of productivity and competitiveness. Although many efforts have been taken by utilities, some consumers require a level of PQ higher than the level provided by modern electric networks. This implies that some measures must be taken in order to achieve higher levels of Power Quality.

Reliable and clean electric power is the demand of this modern society. Reliability means without interruption electricity must be provided and if there will be any then it must be repaired soon. Clean electric power means the voltage and currents are in phase and the wave shape of both the electrical quantity must be sinusoidal. Now these are the electric power condition at ideal case; but in reality it is different. Power quality has different meanings to different people. Institute of Electrical and Electronic Engineers (IEEE) Standard IEEE1100 defines power quality as “the concept of powering and grounding sensitive electronic equipment in a manner suitable for the equipment”. There is a broad range of power quality problems associated with power systems based on time such as long duration variations, short duration variations and other disturbances. All electrical devices are prone to failure or malfunction when exposed to one or more power quality problems.

Power systems are designed to operate at frequency of 50 Hz. However, certain types of loads produce currents and voltages with frequencies that are integer multiples of the 50 Hz fundamental frequency. These frequency components are a form of electrical pollution known as harmonic distortion. Harmonic distortion has sparked research that has led to the present-day understanding of PQ problems. In this section, the concept of harmonic distortion is introduced and its impacts on electric PQ are discussed.

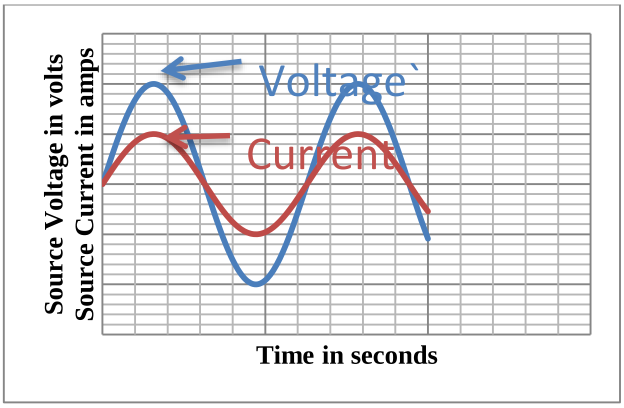

Fig. 1 Linear loads

It is the objective of the electric utility to supply its customers with a sinusoidal voltage of fairly constant magnitude. The generators that produce the electric power, generate a very close approximation to a sinusoidal signal as shown in fig.2.1 are called linear elements.

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However, there are loads and devices on the system which have non-linear characteristics and result in harmonic distortion of both the voltage and current signals. As more non-linear loads are introduced within a facility, these waveforms get more distorted as shown in fig..

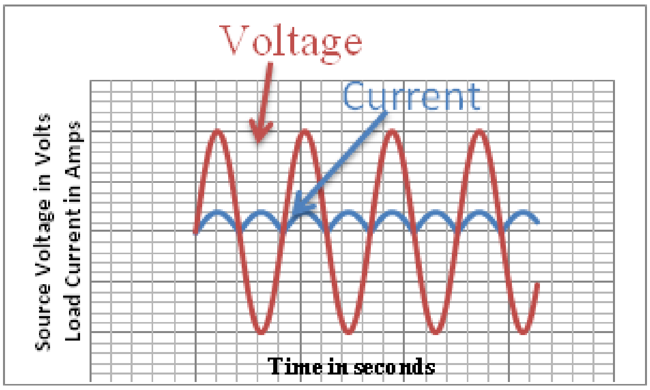

Fig. 2. Non-Linear Loads

Voltage Sag: voltage sag (also called a “dip”) is a brief decrease in the rms line voltage of 10 to 90 percent of the nominal line-voltage. The duration of a sag is 0.5 cycle to 1 minute. Common sources that contribute to voltage sags are the starting of large induction motors and utility faultsVoltage sags (dips) are short-duration reductions in rms voltage caused by short-duration increases of the current. The most common causes of the over currents leading to voltage sags are motor starting, transformer energizing and faults. A sag is decrease in voltage at the power frequency for duration from 0.5 cycle to 1min. Voltage sags are usually associated with system faults but can also caused by energisation of heavy loads at starting of large motors.

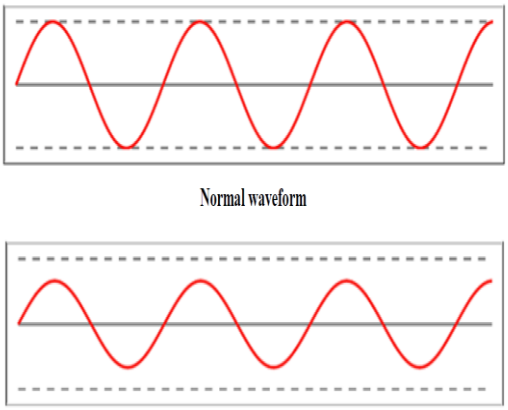

Fig.3 Voltage Sag

Voltage Swell:

A swell is a brief increase in the rms line-voltage of 110 to 180 percent of the nominal line-voltage for duration of 0.5 cycle to 1 minute. The main sources of voltage swells are line faults and incorrect tap settings in tap changers in substations. Voltage swell is an rms increase in the a cm voltage, at the power frequency, for duration from a half cycle to a few seconds. As shown in Fig 4. Voltage can rise above normal level for several cycles to seconds. Voltage swells will normally cause damage to lighting, motor and electronic loads and will also cause shutdown to equipment. The severity of voltage swell during a fault condition is a function of fault location, system impedance and grounding.

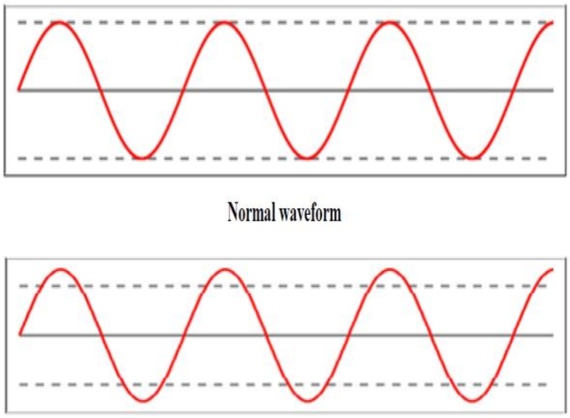

Fig. 4 Voltage Swell

Interruption:

An interruption is defined as a reduction in line-voltage or current to less than 10 percent of the nominal, not exceeding 60 seconds in length. Interruptions can occur due to power system faults, equipment failures and control malfunctions. An interruption is defined as complete loss of supply voltage or load current.

Interruptions can be the result of power system faults, equipment failures, and control malfunction. There are three types of interruptions which are characterized by their duration:

1. The momentary interruption is defined as the complete loss of supply voltage or load current having a duration between 0.5 cycles & 3 sec.

2. The temporary interruption is the complete loss lasting between 3 seconds and 1 minute.

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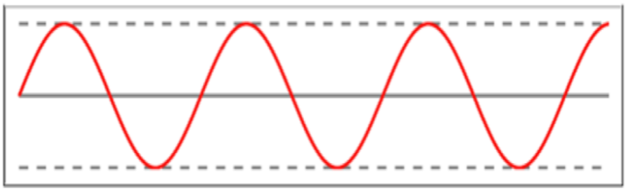
3. The long term interruption is an interruption which has a duration of more than 1 minute



Normal waveform

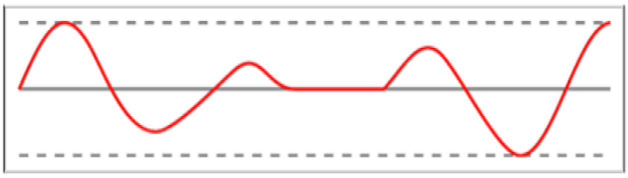
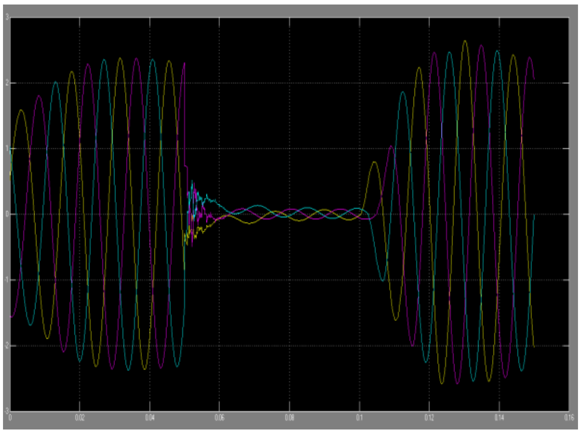
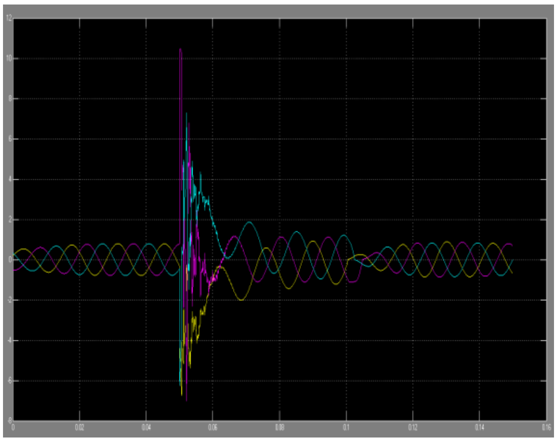


Fig.5 Interruption

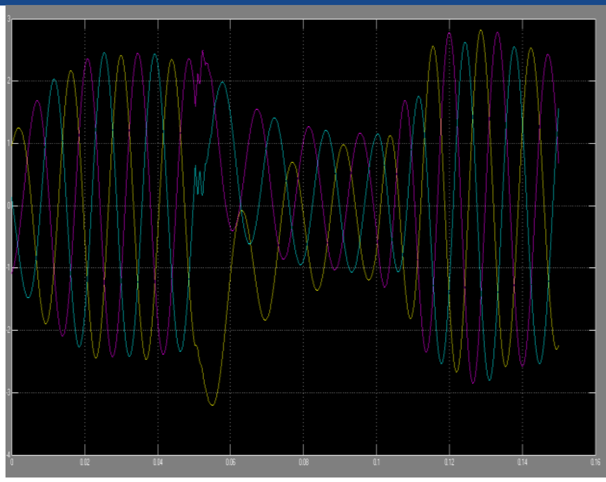
SIMULATION RESULT



Three-phase load voltage waveform without DPFC



Three-phase load current waveform without DPFC



Three-phase source current waveform without DPFC

CONCLUSION

To improve power quality in the power transmission system, there are some effective methods. In this paper, the voltage sag and swell mitigation, using a new FACTS device called distributed power flow controller (DPFC) is presented. The DPFC structure is similar to unified power flow controller (UPFC) and has a same control capability to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude. However, the DPFC offers some advantages, in comparison with UPFC, such as high control capability, high reliability, and low cost. The DPFC is modeled and three control loops, i.e., central controller, series control, and shunt control are design. The system under study is a single machine infinite-bus system, with and without DPFC. To simulate the dynamic performance, a three-phase fault is considered near the load. It is shown that the DPFC gives an acceptable performance in power quality mitigation and power flow control.

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