International Journal of Current Engineering and Technology
ISSN 2277 - 4106

Available at http://inpressco.com/category/ijcet

General Article

Study of Different Methods for Enhancing Power Quality Problems

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Accepted 26 March 2013, Available online 1June 2013, **Vol.3, No.2 (June 2013)**

Abstract

Modern power utilities have to respond to a number of challenges such as growth of electricity demand especially in non-linear loads in power grids, consequently, some policies about the power with a higher quality should be considered. This paper deals with conceptual study of power quality improvements methods used to mitigate the voltage sag, swell, voltage dip suppression and removal of harmonics distortion like UPFC (Unified Power Flow Controller)which works to improve the power quality at demand side by power conditionings for harmonic elimination and simultaneous compensation of voltage and current, which improves the power quality offered for other harmonic sensitive loads, DPFC (Distributed power flow controller) is used to mitigate the voltage deviation and improve power quality. (UPQC) unified power quality conditioner for harmonic elimination and simultaneous compensation of voltage and current, which improves the power quality offered for other harmonic sensitive loads. DSTATCOM (Static Synchronous Reactive Compensator) is a shunt connected compensator to absorb or supply reactive current against voltage disturbances such as voltage sag, swell and flicker. DVR (Dynamic Voltage Restorer) is used for improving power quality & reduce the harmonics distortion of sensitive load. DVR Proposed not only to improve PQ but also to reduce HD due to the presence of non-linear load. Combined system constructed by Shunt Active Power Filter (SAPF) and Static Var Compensator (SVC) to improve the power Quality of the island microgrid, in which SAPF uses the positive sequence method for harmonic detection.

Keywords: *Power Quality, Distribution System, Sag, Swell .Unified Power Quality Conditioner (UPQC), DPFC (Distributed power flow controller harmonics, active power filter, power quality. Microgrid, power quality, PQ control method; SAPF; SVC; positive sequence method FACTS, custom power and power quality, mitigation, DVR (Dynamic Voltage Restorer)*

Introduction

Due to Power quality problems a wide range of disturbances like voltage swells/sags, flicker, harmonics, distortion, impulse transients and interruptions are occurred. Voltage swells are not as important as voltage sags because they are less common in distribution systems. Voltage sag and swell can cause sensitive equipment to fail or shut down, as well as create a large current unbalance that could blow fuses or trip breakers. These effects can be very expensive for the customers, ranging from minor quality variations to production downtime and equipment damage. Voltage sags can occur at any instant of time, with amplitude ranging from 10- 90 % and duration lasting for half a cycle to one minute .Voltage swell, on the other hand is defined as swell is defined as an increase in rms voltage or current at power frequency for durations from 0.5 cycles to one minute. The typical voltage injection capability of a DVR is in the range of 50%. Hence, to compensate for harmonics as low as 1% (or lower) the system must operate at modulation depths of around 2%; but high magnitude and phase accuracy must still be maintained for the compensation to be effective. Recent work (Metin Kesler et al,2009) has proposed a feed-forward approach for voltage harmonic compensation that also accounts for the sample delay and voltage drop across the filter inductance (Metin Kesler et al,2009). There are many different methods to mitigate voltage sags and swells but the use of a custom power device is considered to be the most efficient method. Many custom power controllers have already been discussed with sensitive loads under abnormal conditions. Many of these power controller devices we have discussed below to know about the voltage quality in terms of sag, swells and flickers and to improve quality of current at utility end with the help of their configurations and working principles. To solve this problem, custom power devices are used using MATLAB for static and dynamic load conditions (P.Ram Kishore et al).

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Dynamic voltage restorer (DVR)

Dynamic Voltage Restorer is a series connected compensator to generate a controllable voltage against the voltage disturbances. The technique of DVR is very cost effective and improves the voltage stability with competitive approach. For low voltage applications, single phase DVR topology is used and for medium voltage applications, three phase DVR topology is considered. (P.Ram Kishore et al)

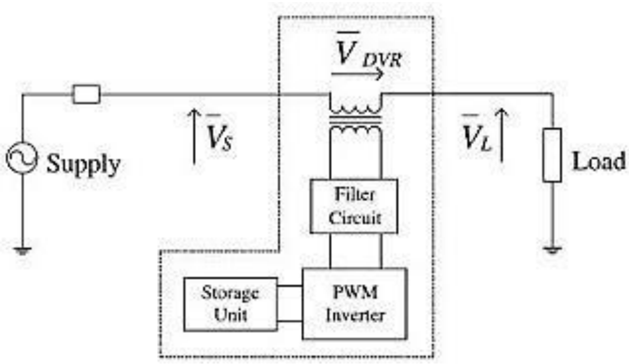

Figure 1: Schematic diagram of DVR

DVR is a series connected device designed to maintain a constant RMS voltage across a sensitive load. The DVR consists of:-

- An injection / series transformer.
- A harmonic filter.
- A Voltage Source Converter (VSC).
- An energy storage
- A control system

Schematic diagram of DVR is shown in fig. The main function of a DVR is the protection of sensitive loads from voltage sags/swells coming from the network. If a fault occurs on other lines, DVR inserts series voltage V_{DVR} and compensates load voltage to pre fault value (P.Ram Kishore et al).

Dynamic Voltage Restorers (DVR) are now becoming more established in industry to reduce the impact of voltage sags to sensitive loads . However, since voltage sags generally only occur a few times each year at any particular location, DVR system will generally spend most of its time in standby mode waiting for sag to occur**.** But unfortunately, it will still introduce extra impedance to the line, primarily due to the series transformer and this impedance will in turn cause a voltage drop to the load and increased load voltage harmonics when non-linear loads are present (Sandesh Jainet al,2012). In principle, it would be advantageous if the series connected inverter of the DVR could also be used to compensate for any steady state load voltage harmonics (Sandesh Jainet al,2012). This would increase the Power Quality 'value added' benefits to the system (which is the definition and driving force of Custom Power Applications) with minimal extra capital cost, but of course with some increase in inverter steady state losses. The limitations in achieving this objective are steady state power flow constraints and the low modulation depths that must be used with a DVR that has a typical voltage injection capacity. Fig. shows a typical DVR series-connected topology, with a short-term energy storage capability (such as a capacitor bank or batteries) to ride through a voltage sag. (Rosli Omar et al,2009)

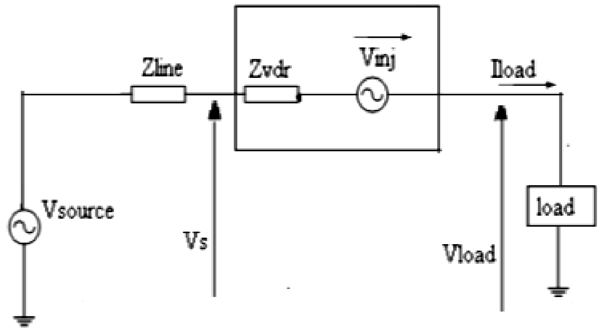

Figure 2: Typical DVR series connected topology (Sandesh Jainet al,2012)

Voltage support at a load can be achieved by reactive power injection at the load point of common coupling. The common method for this is to install mechanically switched shunt capacitors in the primary terminal of the distribution transformer. The mechanical switching may be on a schedule, via signals from a supervisory control and data acquisition (SCADA) system, with some timing schedule, or with no switching at all. The disadvantage is that, high speed transients cannot be compensated. Some sag is not corrected within the limited time frame of mechanical switching devices. Another power electronic solution to the voltage regulation is the use of a dynamic voltage restorer (DVR). DVRs are a class of custom power devices for providing reliable distribution power quality. They employ a series of voltage boost technology using solid state switches for compensating voltage sags/swells. The DVR applications are mainly for sensitive loads that may be drastically affected by fluctuations in system voltage.

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System Configuration and Operation Principle

This configuration shows a series compensated distribution system.DVR consists of voltage source inverter and the isolation transformer is connected in series between the load and point of common coupling (PCC).There is a bypass switch to conduct load current at the following conditions:

- Normal Utility Voltage
- Short circuit at utility side
- Inverter Failure

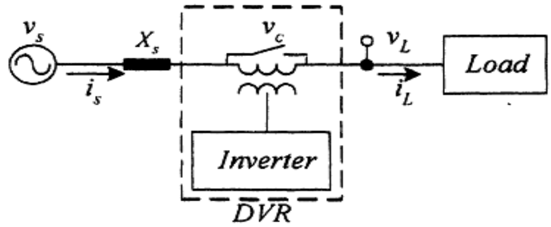

Figure3: Schematic diagram of a series compensator system

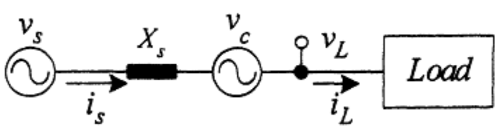

Figure4: Series compensator worked as a variable voltage source (Rosli Omar et al,2009)

Unified Power Quality Conditioner

Unified power quality control was widely studied by many researchers as an eventual method to improve power quality of electrical distribution system . The function of unified power quality conditioner is to eliminate the disturbances that affect the performance of the critical load in power system. In other words, the UPQC has the capability of improving power quality at the point of installation on power distribution systems.

The UPQC, therefore, is expected to be one of the most powerful solutions to large capacity loads sensitive to supply voltage flicker/imbalance (P.Ram Kishore et al). This paper represent, the proposed control algorithm for the UPQC is optimized and simplified without transformer voltage, load and filter current measurement, so that system performance is improved. The proposed control technique has been evaluated and dynamically tested under different load conditions using PSIM software. Below Figure shows a basic system configuration of a general UPQC consisting of the combination of a series active power filter and shunt active power filter. The main aim of the series active power filter is harmonic isolation between a sub-transmission system and a distribution system; it has the capability of voltage flicker/ imbalance compensation as well as voltage regulation and harmonic compensation at the utility-consumer point of common coupling (PCC). The shunt active power filter is used to absorb current harmonics, compensate for reactive power and negative-sequence current, and regulate the dc-link voltage between both active power filters.

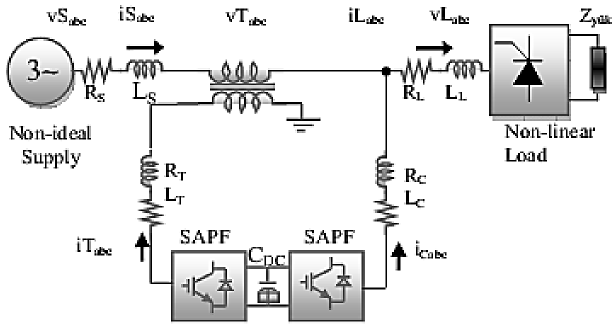

Figure5: Circuit Arrangement Unified Power Quality Conditioner (Metin Kesler et al,2009)

Fundamental knowledge

To show better about the principle and the theory about the high power UPQC, some fundamental knowledge about harmonic and harmonic elimination equipment is listed below.

Series active power filter

In power system, voltage out from turbine is promising to be sinusoidal. So if there is no nonlinear load connects to power grid between generator and the nonlinear load in question, a shunt APF is enough to keep both the voltage and the current of transmission line sinusoidal because the transmission line is composed of linear components such as resistances, inductions and capacitors. But in modern power system, power is transmitted for a long distance before delivery to the nonlinear load and power is distributed to many nonlinear loads in many difference places along the transmission line. The transmission of harmonic current causes harmonic voltage in transmission lines which increases possibility of damage to some critical loads such as storage devices and some micromachining devices. Shunt APF can do little with the damage caused by harmonic voltage in transmission line. A series APF is installed between power source and critical load so as to insulate voltage harmonic from the critical load (Kim et al. 2004). It is also promising to eliminate damages to load caused by some other supply quality issues such as voltage sage, instant voltage interrupts, flicks and over voltage.

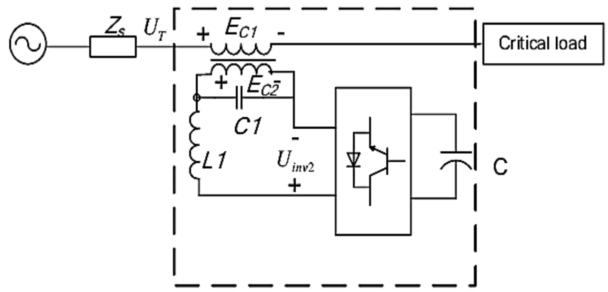

Figure6: Configuration of Series APF

Shunt active power filter

The distortion of current not only brings serious loss of power transmission, but also endangers power grid and power equipments. A harmonic current increase the current flowed through transmission lines and as a result power transmission loss is increased and power grid has to take a risk of higher temperature which threatens the safety of power grid. Harmonic current in transformers will make them magnetic saturated and seriously heated. Much noise is generated because of harmonics in equipments. Besides, harmonics make some instruments indicate or display wrong values, and sometimes make they work wrong.

To eliminate harmonic current produced by nonlinear loads, a shunt Active Power Filter (APF) is expected to connect parallel to power grid(Ahmed et al. 2010). Shunt APF draws energy from power grid and makes it to be harmonic current that is equal to the harmonic current produced by nonlinear load so that harmonic current doesn't go to transmission line but goes between nonlinear load and APF. Usually an inverter is employed to realize this function.

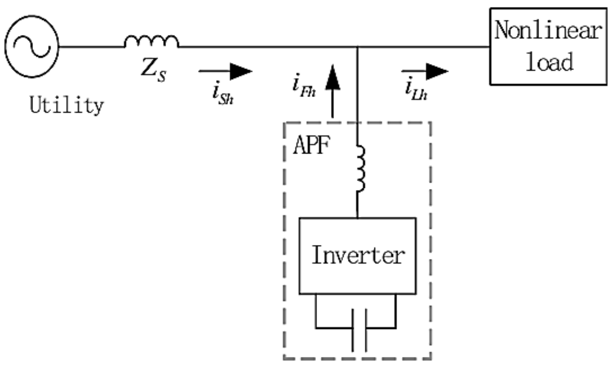

Figure7: Configuration of Shunt APF

Fig.2 shows Configuration of shunt APF, where Z_s is impedance of transmission line, i_{sh} is harmonic current trough transmission line, i_{Lh} is load harmonic current and i_{Fh} is harmonic current from APF. APF employs an inverter to generator a harmonic current that always keeps equal to load harmonic current, that is:

$$i_{Fh} = i_{Lh} \tag{1}$$

Then load harmonic current is intercepted by APF and will not pass through transmission line

$$i_{sh} = 0 \tag{2}$$

Usually a voltage source inverter which uses a high capacity capacitor to store energy in DC linker is used. Under some conditions, nonlinear load not only produces harmonic current but also produces much more reactive current. In order to avoid reactive current going to transmission line, the shunt equipment needs to compensate also the reactive current. Passive Power Filter (PPF) is usually added to APF to compensate most of reactive current and a part of harmonic current so as to decrease the cost.

Unified Power Flow Controllers

In the late 1980s, the Electric Power Research Institute (EPRI) introduces a new approach to solve the problem of designing, controlling and operating power systems: the proposed concept is known as Flexible AC Transmission Systems (FACTS) (Parvej khan et al,2012). It is reckoned conceptually a target for long term development to offer new opportunities for controlling power in addition to enhance the capacity of present as well as new lines (Arup Ratan et al) in the coming decades. Its main objectives are to increase power transmission capability, voltage control, voltage stability enhancement and power system stability improvement. Its first concept was introduced by N.G.Hingorani in April 19, 1988. Since then different kind of FACTS controllers have been recommended. FACTS controllers are based on voltage source converters and includes devices such as Static Var Compensators(SVCs)(Qing Fu et al,2012), static Synchronous Compensators (STATCOMs), Thyristor Controlled Series Compensators (TCSCs), Static Synchronous Series Compensators (SSSCs) and Unified Power Flow Controllers (UPFCs).Among them UPFC is the most versatile and efficient device which was introduced in 1991. In UPFC, the transmitted power can be controlled by changing three parameters namely transmission magnitude voltage, impedance and phase angle. Unified Power Flow Controller (UPFC) is the most promising version of FACTS devices as it serves to control simultaneously all three parameters (voltage, impedance and phase angle) at the same time. Therefore it is chosen as the focus of investigation. For the last few years, the focus of research in the FACTS area is mainly on UPFC. Many researchers have proposed different approaches of installing UPFC in power systems (Parvej khan et al,2012). The UPFC has been researched broadly and many research articles dealing with UPFC modeling, analysis, control and application have been published in the recent years. Mathematical models of UPFC has been developed to study steady state characteristics using state space calculations without considering the effects of converters and the dynamics of generator. The performance of UPFC has been reported by designing a series converter with conventional controllers. Many power converter topologies have been proposed for the implementation of FACTS devices such as multi pulse converter like 24 pulses and 48 pulses and multi level inverters. The advantages and limitations of high power converters have been discussed. The dynamic control of UPFC has been analyzed with six pulse converter using switching level model. Their proposed technique aims at to control the real and reactive power flow in the transmission lines, by effectively changing the firing angle of shunt converter and modulation index of the series converter. Dynamic control of UPFC has analyzed with two leg three phase converters by switching level model with linear and nonlinear loads. They suggests that the UPFC with their proposed controller successfully increase the real as well as reactive power flow and improves voltage profile for the duration of the transient conditions in the power transmission systems (Arup Ratan et al).

Working Principle of UPFC

The UPFC is the most versatile and complex of the FACTS devices, combining the features of the STATCOM and the SSSC. The main reasons behind the wide spreads of UPFC are: its ability to pass the real power flow bi-directionally, maintaining well regulated DC voltage, workability in the wide range of operating conditions etc .The basic components of the UPFC are two voltage source inverters (VSIs) sharing a common dc storage capacitor, and connected to the power system through coupling transformers. One VSI is connected to in shunt to the transmission system via a shunt transformer, while the other one is connected in series through a series transformer. The DC terminals of the two VSCs are coupled and this creates a path for active power exchange between the converters. Thus the active supplied to the line by the series converter can be supplied by the shunt converter as shown in figure. Therefore, a different range of control options is available compared to STATCOM or SSSC. The UPFC can be used to control the flow of active and reactive power through the transmission line and to control the amount of reactive power supplied to the transmission line at the point of installation. The series inverter is controlled to inject a symmetrical three phase voltage system of controllable magnitude and phase angle in series with the line to control active and reactive power flows on the transmission line. So, this inverter will exchange active and reactive power with the line. The reactive power is electronically provided by the series inverter, and the active power is transmitted to the dc terminals. The shunt inverter is operated in such a way as to demand this dc terminal power (positive or negative) from the line keeping the voltage across the storage capacitor V_{dc} constant. So, the net real power absorbed from the line by the UPFC is equal only to the losses of the inverters and their transformers. The remaining capacity of the shunt inverter can be used to exchange reactive power with the line so to provide a voltage regulation at the connection point The two VSI's can work independently of each other by separating the dc side. So in that case, the shunt inverter is operating as a STATCOM that generates or absorbs reactive power to regulate the voltage magnitude at the connection point. Instead, the series inverter is operating as SSSC that generates or absorbs reactive power to regulate the current flow, and hence the power flows on the transmission line. The UPFC can also provide simultaneous control of all basic power system parameters, viz., transmission voltage, impedance and phase angle. The UPFC has many possible operating modes: Var control mode, automatic voltage control mode, direct voltage injection mode, phase angle shifter emulation mode, line impedance emulation mode and automatic power flow control mode (Arup Ratan et al).

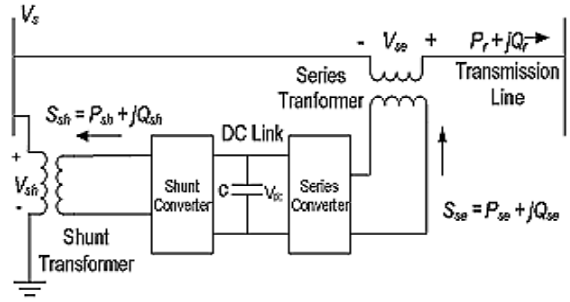

Figure 8:Circuit Arrangement of UPFC

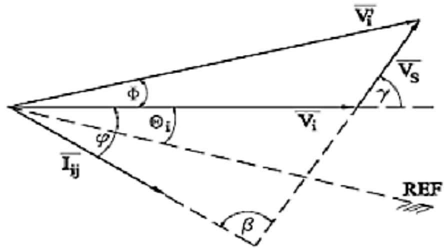

Figure9: Phasor Diagram of UPFC

Distributed Power Flow Controller

In the last decade, the electrical power quality issue has been the main concern of the power companies (Sudharshan Rao et al,2012). 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)(Rosli Omar et al,2009), are used in medium-to-low voltage levels to improve customer power quality (Arup Ratan et al). Most serious threats for sensitive equipment in electrical grids are voltage sags (voltage dip) and swells (over voltage) (Sudharshan Rao et al,2012). 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 (Parvej khan et al,2012), (Sandesh Jainet al,2012). In this paper, a distributed power flow controller,

Introduced in (Qing Fu et al,2012) 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 in Figure. The DPFC has same capability as UPFC to balance the line parameters, i.e., line impedance, transmission angle, and bus voltage magnitude (Sudharshan Rao et al,2012).

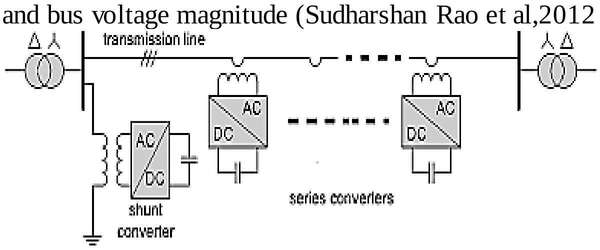

Figure10: DPFC Configuration

In comparison with UPFC, the main advantage offered by DPFC is eliminating the huge DC-link and instate using 3rd-harmonic current to active power exchange (Qing Fu et al,2012).In the following subsections, the DPFC basic concepts are explained.

A. Eliminate DC Link and Power Exchange

Within the DPFC, the transmission line is used as a connection between the DC terminal of shunt converter and the AC terminal of series converters, instead of direct connection using DC-link for power exchange between converters. The method of power exchange in DPFC is based on power theory of non-sinusoidal components (Qing Fu et al,2012). Based on Fourier series, a non-sinusoidal voltage or current can be presented as the sum of sinusoidal components at different frequencies. The product of voltage and current components provides the active power. Since the integral of some terms with different frequencies are zero, so the active power equation is as follow

$$p = \sum_{i=1}^{\infty} V_i I_i \cos \varphi_i$$

Where V_i and I_i are the voltage and current at the i^{th} harmonic, respectively, and φ_i is the angle between the voltage and current at the same frequency. Equation expresses the active power at different frequency components are independent. Based on this fact, a shunt converter in DPFC can absorb the active power in one frequency and generates output power in another frequency. Assume a DPFC is placed in a transmission line of a two-bus system, as shown in Fig.1. While the power supply generates the active power, the shunt converter has the capability to absorb power in fundamental frequency of current. Meanwhile, the third harmonic component is trapped in Y-Δtransformer. Output terminal of the shunt converter injects the third harmonic current into the neutral of Δ-Y transformer Consequently, the harmonic current flows through the transmission line. This harmonic current controls the DC voltage of series capacitors. Figure shown below illustrates how the active power is exchanged between the shunt and series converters in the DPFC. The third-harmonic is selected to exchange the active power in the DPFC and a high-pass filter is required to make a closed loop for the harmonic current. The third-harmonic current is trapped in Δ-winding of transformer. Hence, no need to use the high-pass filter at the receiving-end of the system. In other words, by using the third-harmonic, the high-pass filter can be replaced with a cable connected between Δ-winding of transformer and ground. This cable routes the harmonic current to ground.

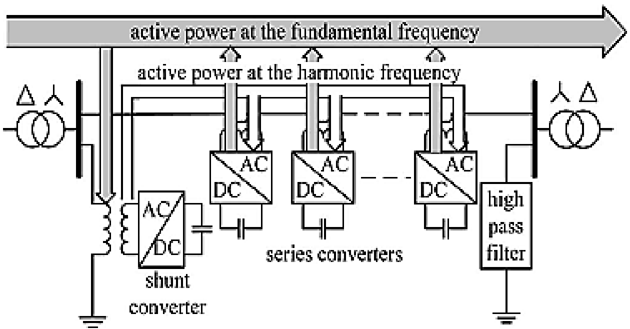

Figure 11: Active Power Exchange between DPFC Converter(Sudharshan Rao et al,2012)

Advantages of DPFC

The DPFC in comparison with UPFC has some advantages, as follows:

1) High control capability: The DPFC can control all parameters of transmission Network line impedance, transmission angle and bus voltage magnitude.

2) High reliability: The series converters redundancy increases the DPFC reliability during converters operation (Ma Zhengbo et al,2011). It means, if one of series converters fails, the others can continue to work.

3) Low cost: The single-phase converters rating, in comparison with three-phase converters is very low. Furthermore, the series converters, in this configuration, no need to any voltage isolation to connect in line. We can use the single turn transformers for series converters hanging. To explore the feasibility of the DPFC, a case study which is to use DPFC to replace UPFC of the Korea electric power corporation (KEPCO) is investigated. To achieve the same control capability as the UPFC, the DPFC construction requires less material (Qing Fu et al,2012).Microgrid supplied by renewable energy sources are increasingly studied, due to their insignificant environmental impacts, as opposed to the classical power plants. A microgrid can be defined as a low voltage network with its loads and several small modular generation systems typically interconnected at a single

point of common coupling (PCC). A microgrid may comprise a set of inverter-interfaced distributed energy resources such as photovoltaic arrays, wind turbines, fuel cells, micro turbines, energy storage devices (such as batteries and super capacitors),which are interconnected with the utility grid by power electronic devices. Due to the weather impact, micro sources like wind turbines and photovoltaic are intermittent and usually generate only constant active power or use Maximum Power Point Tracking (Sudharshan Rao et al,2012), (P.Ram Kishore et al); because of easy control, micro sources like micro turbines, fuel cells and barratries can use both PQ control and V/f control method, where V/f control method can ensure the stability of the voltage and frequency of microgrid (Metin Kesler et al,2009).

Due to the increasing application of power-electronic loads and the unstable output of renewable energy sources such as photovoltaic and wind farms, harmonics in microgrid is becoming a serious problem. Meanwhile, the variation in amplitude of the supply voltage can cause abnormal operation of sensitive equipments and it could be relieved by adopting reactive power compensation technology due to the ‘‘voltage-reactive power’’ droop characteristic. Currently, the compensation of all the undesired current Components can be ensured by using a SAPF that has the basic function to eliminate harmonics, unbalances and meet reactive power requirements of the load, so that the AC supply feeds only sinusoidal unity power factor currents (Ahmad Jamshidi et al,2012). Reference (Ahmad Jamshidi et al,2012) presents a three-phase four-wire grid-interfacing power quality compensator for microgrid applications to achieve an enhancement of both the quality of power within the microgrid and the quality of currents flowing between the microgrid and the utility system. Another solution for power quality improvement in the microgrid is presented in (Arup Ratan et al), which described the power quality control center (PQCC) for the microgrid systems to improve the power quality. PQCC is consisted of a series voltage compensator and a parallel battery energy storage system (BESS). Reactive power compensation, load power balancing and power factor correction can be achieved by using a SVC (Parvej khan et al,2012), (Sandesh Jainet al,2012). In (Qing Fu et al,2012), a SVC is used for load balancing and maintaining of power quality in an island microgrid. Under the premise of assuming that the micro source could supply adequate active power to the loads, this paper focuses on the power quality problems in an island microgrid and proposes a combined system of SAPF and SVC to improve the power quality. SAPF is used to restrain the harmonics of the inverter and SVC is used for reactive power compensation. Simulation results show the effectiveness of the combined system.

Microgrid configuration and control strategy

As research subject, the microgrid configuration used in this paper is shown in Fig. There are 2 micro sources which have already been inverted into three-phase AC power from DC power using Sinusoidal Pulse Width Modulation (SPWM). The two micro sources and loads comprise a microgrid connected with the utility grid by the switch KA. LOAD1 is a critical load and LOAD2 is a normal load. Here we adopt peer to peer control, in which each microsource is equivalent and has its particular control method, no communication between microsources is needed (Ma Zhengbo et al,2011). In the islanding mode, both of KA and K2 are open, the critical LOAD1 is supplied by both DG1 and DG2.We assumes that DG1 can supply adequate active power to LOAD1. The control strategy for islanding mode is designed as: the DG1 system adopts V/f control method to keep the voltage of Bus bar constant, the DG2 system adopts PQ control method so that its output power is constant. The configurations of V/f control method and PQ control method are shown in following figures.

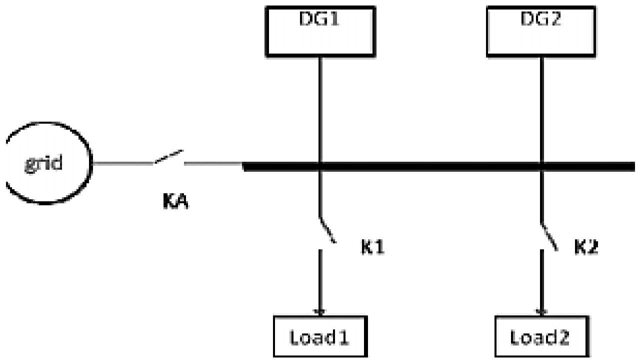

Figure 12: Microgrid Configuration(Ma Zhengbo et al,2011)

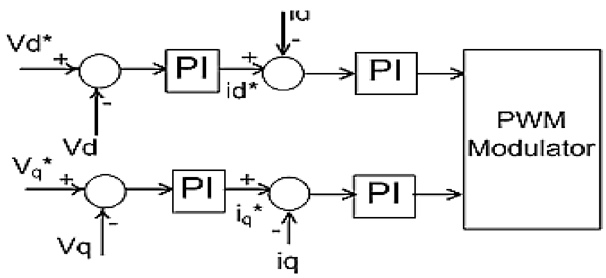

Figure 13: V/F control Scheme

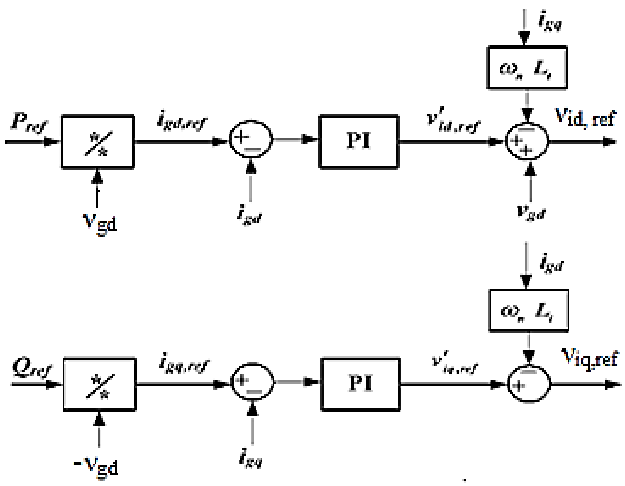

Figure14: Combined System for Power Quality Improvements

Although there are no specific international standards about isolated electrical systems, the power quality of microgrid should be similar to the interconnected systems. To solve the problems of power quality in the island microgrid, this paper proposes a combined system (Qing Fu et al,2012). The whole structure of the combined system is as: the SAPF is closed to the microsource and the SVC is set near the load, so the coupling between APF and SVC can be avoided when SAPF and SVC work simultaneously (Ma Zhengbo et al,2011).

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