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Research Article

UNIFIED POWER QUALITY CONDITIONER FOR MULTI-FEEDER SYSTEMS TO COMPENSATE POWER FLOW

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ABSTRACT

PowerQuality (PQ) issues such as flicker and imbalance have become important concerns as nonlinear and electronically switched devices become more widely used in distribution networks and businesses. Lighting strikes on transmission lines, capacitor bank switching, and a variety of network faults can all create PQ issues such transients, voltage sag/swell, and interruption. For appropriate load performance, however, a growth in sensitive loads including digital electronics and complicated process controllers necessitates a pure sinusoidal supply voltage. It may be required to incorporate compensation in order to meet PQ standard limits. Active rectification and active filtering are examples of modern methods. A shunt active power filter(SAPF) is suitable for suppressing negative load influence on supply voltage irregularities; nevertheless, full correction may require a series active filter. It may be required to incorporate compensation in order to meet PQ standard limits. Active rectification and active filtering are examples of modern methods. A shunt active power filter is suitable for suppressing negative load influence on supply voltage irregularities; nevertheless, full correction may require a series active filter. In distribution systems, series active filters such as the Distributed Voltage Regulator (DVR) from the Custom Power (CP) family can be used to solve voltage difficulties, while parallel active filters such as the Distribution Static Compensator (DSTATCOM) can be used to improve current problems. Nowadays, an efficient combination of the above-mentioned CP devices is employed to instantly improve both voltage and current problems. Unified Power Quality Conditioner is the name of this gadget (UPQC).

Keywords – Power Quality, Shunt Active Power Filter, Distributed Voltage Regulator, Distribution Static Compensator, Unified Power Quality Conditioner

I. INTRODUCTION

The quality of the electrical power supplied equipment is referred to as power quality. Poor power quality can cause equipment to malfunction. The utility company may define power quality as reliability and claim that the system is 99.5 percent reliable. Electrical energy is a sort of energy that exists in nature. Because of its ability to convert between different types of energy and its transmission capabilities, electrical energy has become one of the most important sources of energy. From generation to consumption, electrical energy flows through three stages: generation, transmission, and distribution. Distribution systems are made up of a large-scale power system with numerous nodes. Electrical energy is transmitted from high voltage electricity to low voltage customer devices via distribution networks.On the consumer side, electrical businesses are responsible for preparing high-quality electrical energy. It is critical to pay attention to the energy quality in order for a device to function effectively. Electric gadgets may completely fail if the power quality is poor. As a result, electrical firms should monitor and control power quality issues. Additionally, users should avoid using gadgets that cause power quality issues. Voltage sag and swell, imbalance, zero sequence, and harmonics are the most common voltage issues. The most common issues right now are zero sequence, imbalance, reactive power, and harmonics. In distribution systems, series active filters such as Distributed Voltage Regulator (DVR) from the Custom Power (CP) family can be used to improve voltage problems and improve current problems.

II. LITERATURE REVIEW

In[1],the authors proposed the electric utilities are awakening to the fact that power quality counts with many a consumer- and counts for a lot. A new type of service contract between a utility and its large industrial or commercial clients. Power quality is a term often used today in describing an aspect of the electricity supply.The power electronic loads inject harmonic currents in to the utility system. Comparative evolutions of harmonic reduction techniques which satisfy the current harmonic limits specified by the IEEE standard 519 [2], and at the same time provide a regulated dc output voltage. The techniques considered include active and hybrid filters, and various current wave shaping approaches for a three-phase utility interface. Application of active power filters and harmonic related problems in utility and industrial power systems is increasing. Active power filter have attracted great attention and have been expected to be an effective remedy. Generally, an active power filter has been considered to be a current source connected in parallel with the load [3].

A UPQC the integration of series- and shunt active filters to compensate for supply voltage flicker/imbalance,[5] reactive power, negative-sequence current, and harmonics. To improving power quality at the point of installation on the power distribution systems or industrial power systems.

The UPQC provides no power factor correction in order to minimize the required rating of the shunt active power filter, it s capable of improving “power quality” as well as improving power factor [6].

In [7], the author proposed UPQC to improve the power quality of two feeders in a distribution system. The main aim of IUPQC to regulate the voltage terminals to protect the sensitive load from the disturbances. The sensitive load is fully protected against sag/swell and interruption.

III FACTS BASED SOLUTION

The development of power semiconductors with improved characteristics has provided the basis for a FACTS technology. This technology covers a variety

The Unified Power Flow Controller (UPFC) is able to control both the transmitted real power and independently, the reactive power flows at the sending- and the receiving –end of the transmission line [4].

control, short-circuit current limitation, etc. So it is the complete family that provides transmission flexibility, rather than the individual controllers. The non-linear loads in the electrical distribution network, power quality and reliability issues become essentials for the proper operation of industrial process where there are sensitive and critical loads. Digital electronic devices, particularly those with a memory, are extremely sensitive to very short-duration power disturbances.

The main objective behind the FACTS based controllers are

1. Power transfer capability of transmission system is to be increased.
2. The power flow is to be kept over the designated routes.

A. Multi Converter FACTS Devices

Power electronics controllers created to enhance the the individual members of the FACTS family are designed to solve a specific problem, e.g. active or reactive power flow

The following are the FACTS controllers employed in general,

1) Unified Power Flow Controller (UPFC)
2) Interline Power-Flow Controller (IPFC)
3) Generalized Unified Power-Flow Controller (GUPFC)
4) Interline Unified Power-Quality Conditioner (IUPQC). The aim of these devices is to control the power flow of multiline or a subnet work rather than control the power flow of a single line.

B. Proposed Modified Power Quality Conditioner

A new configuration of a UPQC is presented; it is called as MC-UPQC. The system is extended by adding a series-VSC in an adjacent feeder. The proposed topology can be used for simultaneous compensation of voltage and current imperfections in both feeders by sharing power compensation capabilities between two adjacent feeders which are not connected. The system is also capable of compensating for interruptions without the need for a battery storage system and consequently without storage capacity limitations. It is also possible to connect two VSCs to two different feeders in a distribution system is called IUPQC. This project presents a new UPQC called MC-UPQC. The internal structure of the MC-UPQC is shown in Figure 1 it consists of three VSCs (VSC_1, VSC_2, and VSC_3) which are connected back to back through a common dc-link capacitor. In the proposed configuration, VSC_1 is connected in series with BUS_1 and VSC_2 is connected in parallel with load L_1 at the end of $Feeder_1$. VSC_3 is connected in series with BUS_2 at the $Feeder_2$ end. Each of three VSCs in Figure 1 is realized by a three-phase converter with a commutation and high-pass output filter as shown in Figure 1.

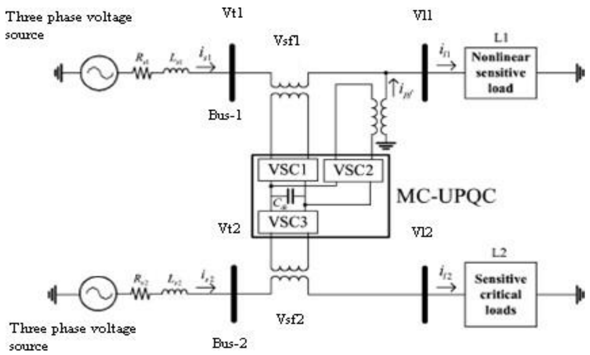


Figure 1 MC-UPQC used in a distribution system

In MC-UPQC, all the converters are supplied from a common dc-link capacitor and connected to the distribution system through a transformer. Secondary sides of the through a transformers are directly connected in series with BUS1 and BUS, and the secondary sides of the shunt-connected transformer is connected in parallel with loadL_1. The aims of the MC-UPQC shown in Figure 1 are

1) To regulate the load voltage (V_{l1}) against sag/swell and disturbances in the system to protect the nonlinear/sensitive load L_1;

2) To regulate the load voltage (V_{l2}) against sag/swell, interruption, and disturbances in the system to protect the sensitive/critical load L_2;

3) To compensate for the reactive and harmonic components of nonlinear load current (i_{l1}).

The load L_1 is a nonlinear/sensitive load which needs a pure sinusoidal voltage for proper operation while its current is non sinusoidal and contains harmonics. The load L_2 is a sensitive/critical load which needs a purely sinusoidal voltage and must be fully protected against distortion, sag/swell and interruption. These types of loads primarily include production industries and critical service providers, such as medical centers, airports, or broadcasting centers where voltage interruption can result in severe economical losses or human damages.

IV UPQC CONTROL STRATAGIES

In this paper, from the various system parameters, reference compensating current for reactive and harmonic compensation is generated based on synchronous reference frame method. The reference compensating voltage for the compensation of sag and swell is directly obtained by comparing the distorted supply voltage containing sag and swell with desired reference load voltage. After obtaining these reference compensating signals, they are given as reference signals to sinusoidal PWM based voltage source inverters for the generation of compensating waveforms. The MC-UPQC consists of two series VSCs and shunt VSC which are controlled independently. The switching control strategy for series VSCs and shunt VSC are selected to be Sinusoidal Pulse Width-Modulation (SPWM) voltage control and hysteresis current control respectively. With the wide application of nonlinear and electronically switched devices in distribution systems, the power quality problem becomes more serious.

This project proposes a new advanced custom power device UPQC deduces its mathematical model based on switching function and analyzes the control principle of such UPQC.

A. Shunt-VSC

Functions of the shunt-VSC are:

1) To compensate for reactive component of load L1 current;

2) To compensate for the harmonic components of load L1 current;

3) To regulate the voltage of the common dc-link capacitor.

Figure 2. shows the control block diagram for the shunt VSC.

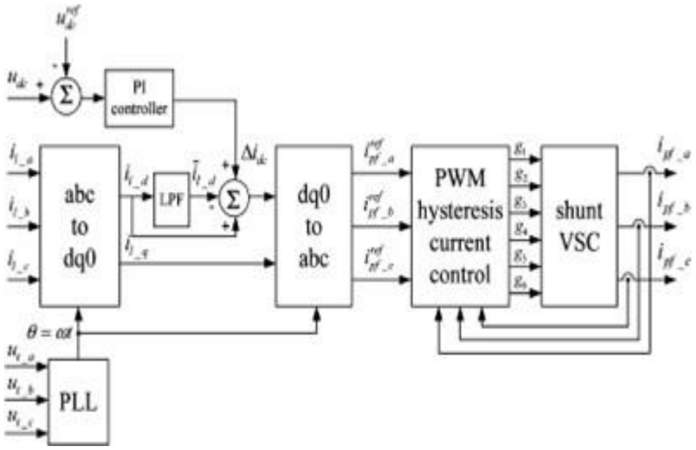


Figure 3 Control block diagram of shunt VSC

This means that there are no harmonic and reactive components in the feeder current. Switching losses cause the dc-link capacitor voltage to decrease. Other disturbances, such as the sudden variation of load, can also affect the dc link. In order to regulate the dc-link capacitor voltage, a proportional–integral (PI) controller is used as shown in Figure 3.

The measured load current $i1\_abc$ synchronous reference frame by using

$$i1_{dq0} = T\int_{abc}^{dqo} i1\_abc \text{ ----------- (1)}$$

All harmonic components are transformed into ac quantities with a fundamental frequency shift,

$$il_{\_d} = \bar{il}\_{}_{d} + \bar{il}\_d \text{ ---------- (2)}$$

$$il_{\_q} = \bar{il}_{\_q} + \bar{il}\_q \text{ ------------- (3)}$$

where $il_{\_d}il\_q$ are d-q components of load current, $\bar{il}_{\_d}, \bar{il}\_q$ are dc components, and $\tilde{il}_{\_d}, \tilde{il}_{\_q}$ are the ac components of $il\_{}_{d}$ and $il_{\_q}$. Consequently, the d-q components of the feeeder current are

$$is_{\_d} = \bar{il}_{\_d} \text{------- (4)}$$

$$is_{\_q} = 0 \text{------- (5)}$$

B. Series-VSC

Functions of the series-VSC are:

1) To mitigate voltage sag and swell
2) To compensate for voltage distortions, such as harmonics;

3) To compensate for interruptions (in feeder2 only).
4) The control block diagram of each series VSC is shown in Figure 4

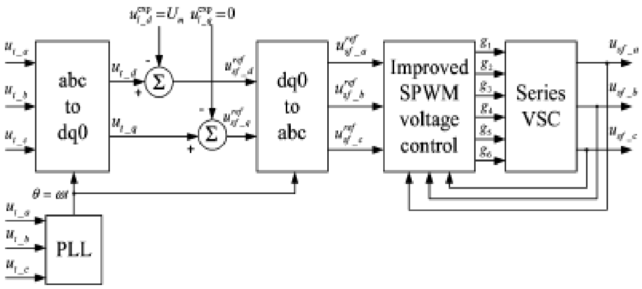


Figure 4 Control block diagram of Series VSC

The synchronous dq0 reference frame

using,

$$ut_{\_dq0} = T\int_{dq0}^{abc} ut\_abc = ut1p + ut1n + ut10 + uth - - - (6)$$

where,

ut1p, ut1n and ut10fundamental frequency positive-, negative-, and zero are-sequence components, respectively, and uth is the harmonic component of the bus voltage. Therefore, the expected load voltage in the synchronous dq0 reference frame ($ul_{\_dqo}^{exp}$) only has value,

$$ul_{\_dqo}^{exp} = \begin{matrix} Um \\ 0 \\ 0 \end{matrix} \text{-------- (7)}$$

The compensating reference voltage in the synchronous dq0 reference frame $usf_{\_dqo}^{exp}$ is defined as

$$usf^{exp}_{\_dqo} = ut_{\_dq0} - ul^{exp}_{\_dqo} \text{-----------} (8)$$

The compensating reference voltage is the transformed back into the abc reference frame. By using an improved SPWM voltage control technique (sine PWM control with minor loop feedback), the output compensation voltage of the series VSC can be obtained.

V MODULATION TECHNIQUES IN MC-UPQC

The performance of PWM, or Pulse-Duration Modulation **(**PDM), is a commonly used technique for controlling power to inertial electrical devices, made practical by modern electronic power switches. The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle. Generally pulse-width modulation techniques for frequency converters may be classified as follows: Carrier-Based Sinusoidal PWM, Hysteresis-Band PWM, Space Vector PWM, Selected Harmonic Elimination PWM (SHEPWM), Minimum current ripple PWM, Sinusoidal PWM with instantaneous current control and random PWM. PWM techniques applied to a three phase, two levels VSC shown in Figure 5a. In the absence of modulation, the waveform of phase voltage ea referred to (i) midpoint (N) of the DC capacitor and (ii) supply neutral are shown in Figure 5a. The line-to-line voltage (e_{ab}) waveform is shown in Figure 5b the VSC without modulation is termed as a square wave or six-step converter. The peak value of the fundamental frequency component of the phase voltage we wish to regulate the DC capacitor voltage (V_{dc}) and yet control the output AC voltage magnitude (in addition to its phase). Since the maximum value of the phase voltage injected is limited by V_{dc} we can Only control the width of the voltage pulses generated by switching between complementary devices (1 and 4 for phase a). Note that we can reverse the voltage polarity by switching device 1 and switching on 4. For simplicity, we ignore the dead time (blanking time) between the switching of devices 1 and 4 (and similarly in other two legs).

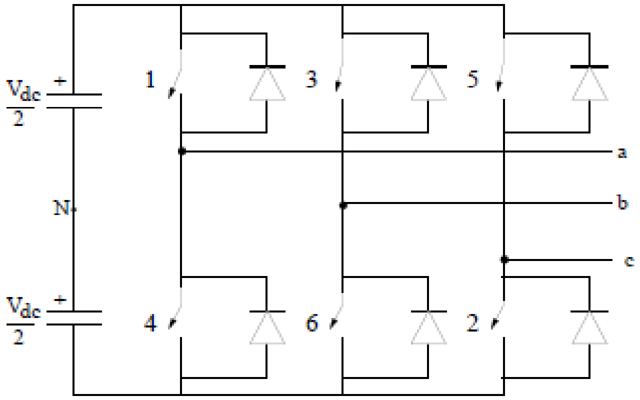


Figure 5a. A three phase two level VSC

Only control the width of the voltage pulses generated by switching between complementary devices (1 and 4 for phase a). Note that we can reverse the voltage polarity by switching device 1 and switching on 4. For simplicity, we ignore the dead time (blanking time) between the switching of devices 1 and 4 (and similarly in other two legs).

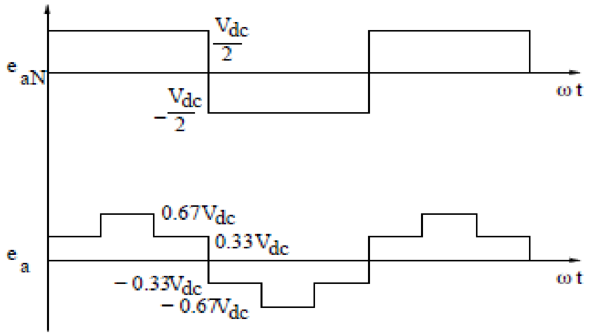


Figure 5b. Waveform of PWM

The objectives of PWM can be stated as follows.

1. To control the output AC voltage for a constant DC voltage.
2. To minimize the harmonics in the load subject to the constraints on the switching losses, generation of noise etc.The characteristics of the load may vary. However, typically the load behaves as a low pass filter.

Hence, if we reduce the lower order harmonics in the output AC voltage, it is advantageous in minimizing load current harmonics. Thus shifting the frequency spectrum of the injected voltage to the higher level is beneficial in improving the performance of the PWM-VSC.

A. Sinusoidal Pulse Width Modulation (SPWM)

Sinusoidal pulse width modulation is one of the primitive techniques, which are used to suppress harmonics presented in the quasi-square wave. In the modulation techniques, there are two important defined parameters:

(i) The ratio P = W_c/Wm known as frequency ratio, and

(ii). the ratio M = am/ac known as modulation index

The series injected voltage is in phase with the voltage drop developed across the line reactance; thus, the series compensation has the same effect as increasing the line reactance.

where Wc is the reference frequency, wm is the carrier frequency, Am is reference signal amplitude, and Ac is carrier signal amplitude.

Figure 5b illustrates a simple idea to generate a SPWM waveform. From Figure 6, the amplitude of the fundamental frequency components of the output is directly proportional to the modulation depth. The second term of the equation gives the amplitude of the component of the carrier frequency and the harmonics of the carrier frequency. The magnitude of this term decreases with increased modulation depth.

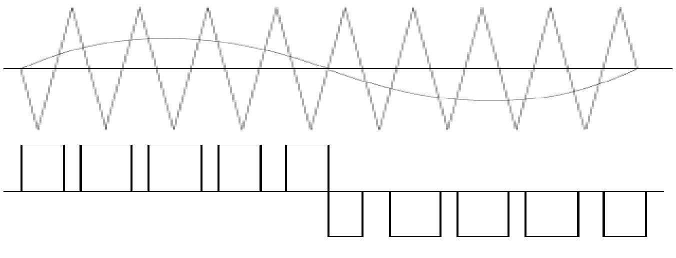


Figure 6 Sinusoidal PWM

$$V(t) = \frac{ME}{2}\mathrm{Cos}V(t) = M\,\frac{E}{2}\cos(\,\omega t + \varphi) + \frac{2E}{\pi}\sum_{m=1}^{\infty} J0\,\left(\frac{M\pi M}{2}\right)\sin\left(\frac{M\pi}{2}\right)\cos(m\omega t) \quad \text{---------------} \; (9)$$

$$+\frac{2E}{\pi}\sum_{m=1}^{\infty}\sum_{m=\pm 1}^{\infty} Jn\left(\frac{m\pi M}{\frac{2}{m}}\right)\sin\left((n + m)\pi/2\right)\cos\left(m\omega t + n\omega t + (m + n)\varphi\right)$$

where,

W_m - Angular frequency of modulating or sinusoidal signal.

W_c - Angular frequency of the carrier signal.

M - Modulation index.

E -DC supply voltage.

f - Displacement angle between modulating and carrier signals.

Because of the presence of sin (*mp*/2), even harmonics of the carrier are eliminated. Term 3 gives the amplitude of the harmonics in the sidebands around each multiple of the carrier frequency. The presence of sin ((*m*+*n*) *p*/2) indicated that, for odd harmonics of the carrier, only even-order sidebands exist, and for even harmonics of the carrier only odd order sidebands exist.

In addition, increasing carrier or switching frequency does not decrease the amplitude of the harmonics, but the high amplitude harmonic at the carrier frequency is shifted to higher frequency. Consequently, requirements of the output filter can be improved. However, it is not possible to improve the total harmonic distortion without using output filter circuits.

VI SIMULATION RESULTS

A. Test System

The system comprise of 22KV grid connected to the to the load through the transmission line by step down voltage to 440V. UPQC is fully protecting critical and sensitive loads against distortions, sags/swell, interruption in two-feeders system.

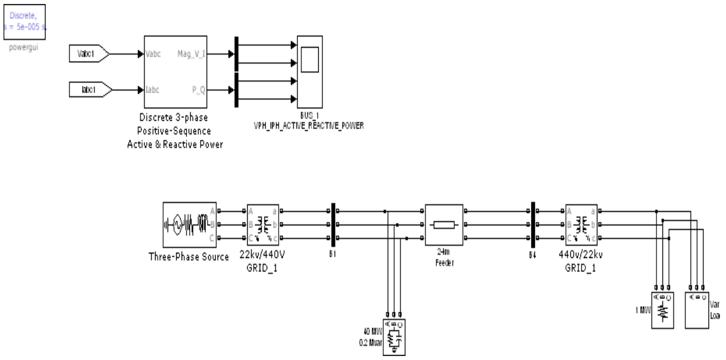


Figure 7a Test system for 2km feeder

B. VSC Based UPQC

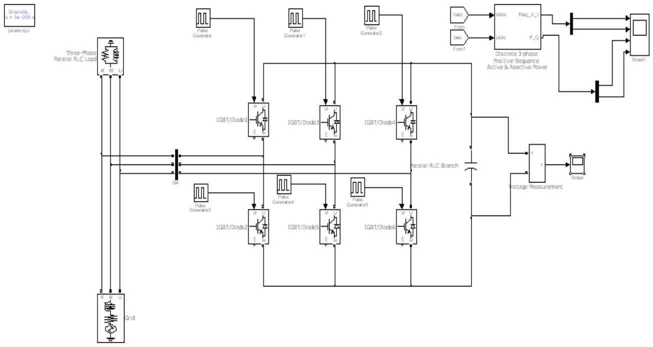
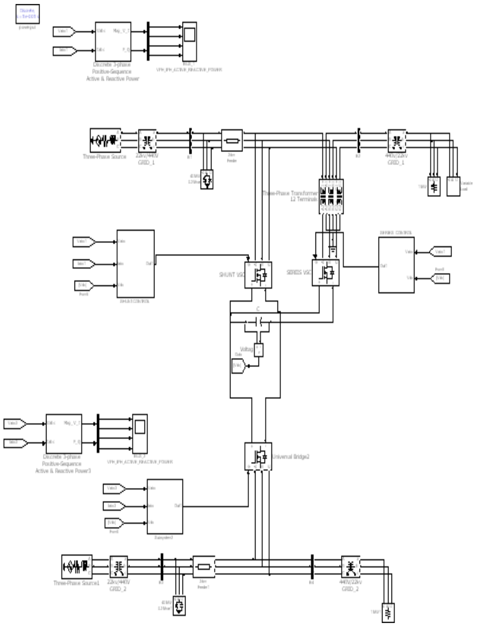


Figure 7b VSC based UPQC

C. Test System for 2 km feeder with UPQC

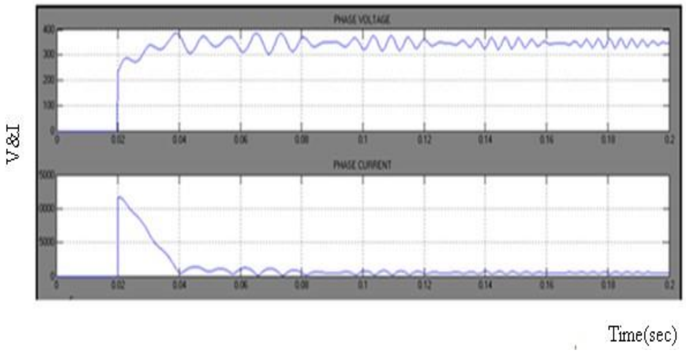


(c)

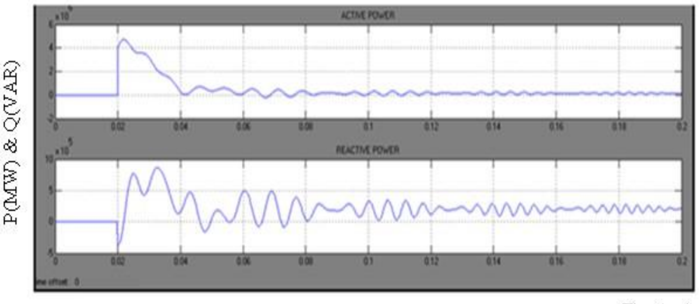
Figure 7c Test system for 2 km feeder with UPQC

A non-linear/sensitive load L_1 is supplied by feeder-1 while a sensitive/critical load L_2 is supplied through feeder-2. The performance of the MC-UPQC has been evaluated under various disturbance conditions such as voltage sag/swell in either feeder, fault and load change in one of the feeders.

D. Output Waveforms



(a)



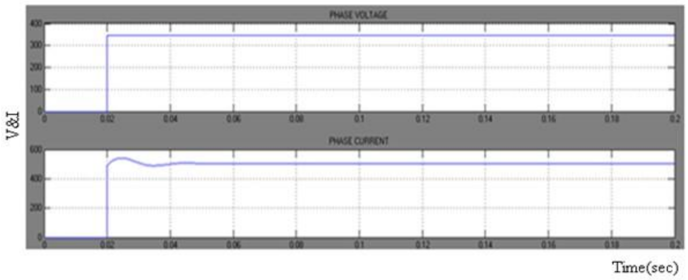
(b)

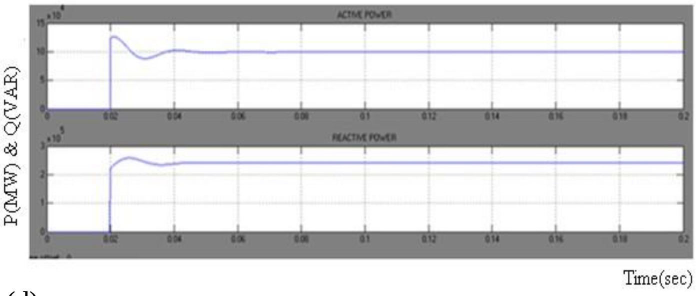
Figure 7d Output waveform for test system for 2km feeder

(a) Voltage and current across load

(b) Active and reactive power

Grid is connected with variable load across the 2km transmission line due to variable load the voltage sags and power oscillations produced in the transmission line. It is observed from the above waveform.



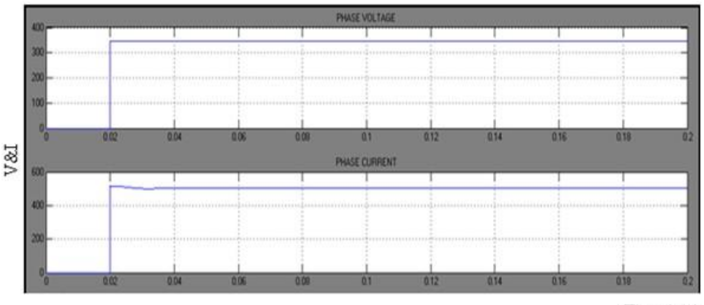


(d)

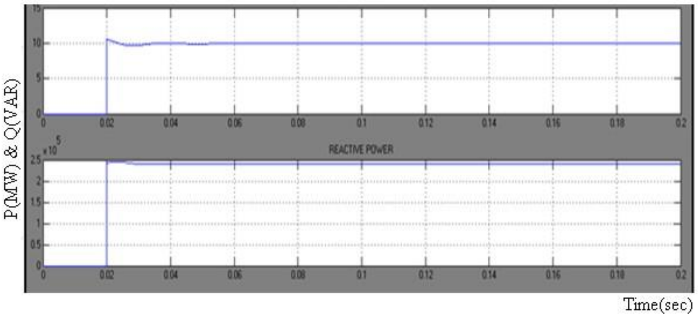
Figure 7e a) Output waveform for voltage and current magnitude (UPQC)

b) Active and reactive power on UPQC

UPQC is connected with variable load across the transmission line due to sensitive load the voltage sags/ swell will be produced the active and reactive power is distorted. It is observed from the above waveform.



(e)

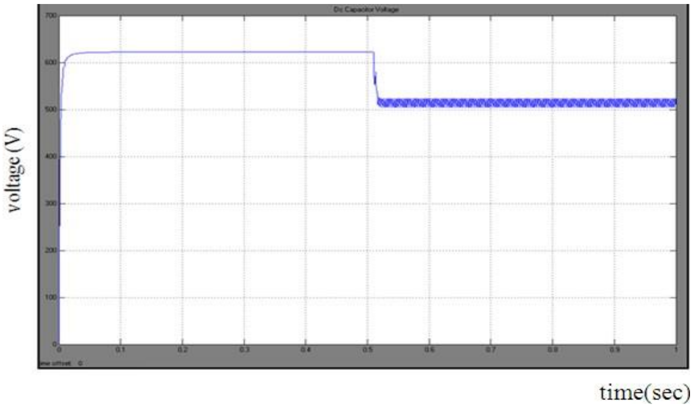


(f)

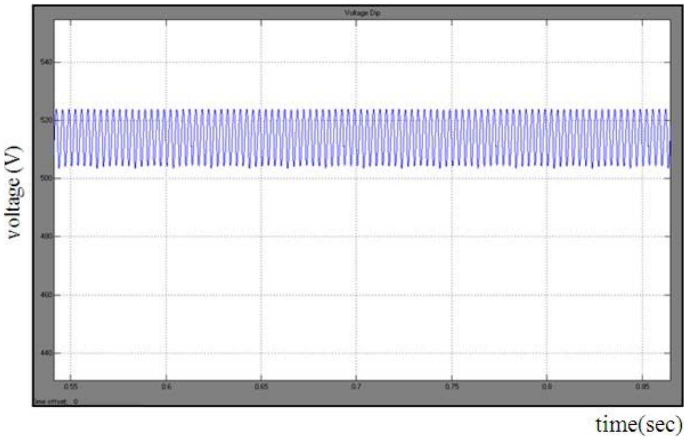
Figure.7f a) Output waveform for voltage and current compensation

b) Real and reactive power compensation

UPQC is fully protecting variable load and sensitive load aginst the distortions, sags, swell in the feeder system. And also compensation of reactive power is minimum and active power is constant.



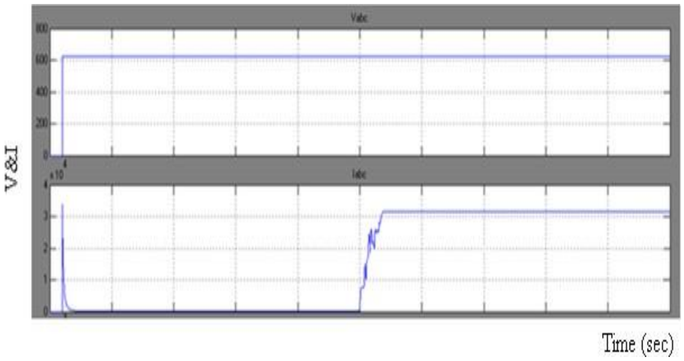
(g)



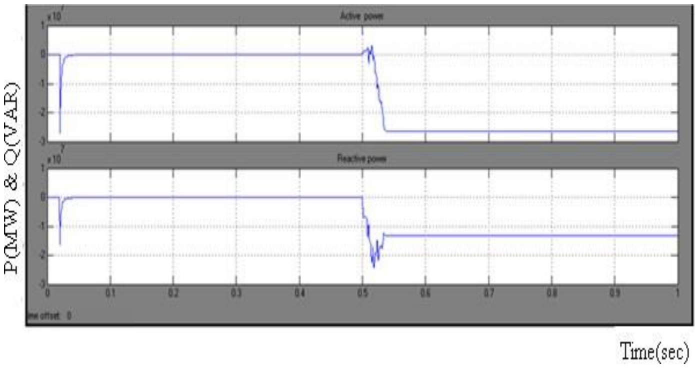
(h)

Figure.7 g) Output waveform for DC capacitor voltage

h) Output waveform for voltage dip



(i)



(j)

Figure.7 i) Output waveform for voltage and current magnitude

j) Real and reactive power with distortion

The MC-UPQC is fully protecting critical and sensitive loads against the distortions, sags, swells, and interruption in two feeders systems. And also compensation of reactive power should be minimum and active power kept in constant.

VII CONCLUSION

This project analysed the operation and control of MC-UPQC. The system is extended by adding a series VSC in an adjacent feeder. The device is connected between two or more feeders coming from different substations. A non-linear/sensitive load L_1 is supplied the Feeder1 while a sensitive/critical load L_2 is supplied through Feeder2. In case of voltage sag, the phase angle of the bus voltage in which the shunt VSC (VSC_2) is connected plays an important role as it gives the measure of the real power required by the load. The MC-UPQC can mitigate voltage sag Feeder1 and in Feeder2 for long duration. A new configuration for simultaneous compensation of voltage and current in adjacent feeders has been proposed. The new configuration is named MC-UPQC. Compared to a conventional UPQC, the proposed topology is capable of fully protecting critical and sensitive loads against distortions, sags/swell, and interruption in two-feeder systems.

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