Mathematical Modeling of Unified Power Quality Conditioner for Distribution Power System

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Abstract
This paper deals with the structure of unified power quality conditioner (UPQC), which is used to eliminate power quality problems such as supply voltage and current harmonics, compensate reactive power, voltage sag/swell compensation on distribution system. The performance of the inverters depends on the control strategy used to generate reference signals for its operation. The mathematical analysis of UPQC is done to see its characteristic performance in the distribution system. This analysis is very useful for the selection of device rating and placement based on its particular application area in the power system.

1. Introduction

In electrical power system, with the development of power electronic devices there is an improvement in current and voltage handling capabilities of these devices leads to the possibility of an efficient control of the distribution power system. The power electronic devices used at the customer end known as custom power devices are broadly classified as network configuring type devices such as SSCL (Solid State Current Limiter), SSCB (Solid State Circuit Breaker), SSTS (Solid State Transfer Switch) and compensating type power devices such as DVR (Dynamic Voltage Restorer), D-STATCOM (Distribution Static Synchronous Compensator), UPQC (Unified Power Quality Conditioner).

It has been noted that these devices respond quickly to the changes in network parameters and conditions. These devices have been used to compensate the power quality problems in distribution systems such as voltage sag, voltage unbalance, harmonics and flicker which occur for short duration i.e. in millisecond range [1]. In this duration, a custom power device can inject both active and reactive power in the system for compensation of power quality issues in sensitive loads and then injects the power into the system provided by energy storage system. Unified power quality conditioner (UPQC) which is integrated of series and shunt compensators have been used to improve issues such as voltage sag/swell, unbalance, voltage flicker, current and voltage harmonics, dynamic active and reactive power regulation. It generates a compensating signal to equalize the effect of fault in the system and makes the system work on fundamental electrical parameters of system such as voltage, current and frequency, which enhances the reliability of the distribution power system [2].

UPQC can be used in case the load is linear, nonlinear, balanced or unbalanced and the system supply voltage is itself distorted or fluctuated at the same time thus to improve the current and voltage power quality issues simultaneously. In this paper a novel mathematical model of UPQC is derived and the extraction of controlling components and the basic control strategy based on synchronous d-q-0 reference frame is proposed.

2.Mathematical Model of UPQC

Mathematical modeling of unified power quality conditioner is done to analyze its characteristics when it is incorporated in the system to compensate the power quality problems. The unified power quality conditioner is installed in order to protect a sensitive load from all type of disturbances. It consists of a series and shunt voltage source inverters connected in cascade, sharing a common dc link. Mathematical modeling is mainly categorized as topology method which is based on differential equations representing a system and equivalent source method which is used in case of internal structure of the device has to be considered [3].

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A modeling is done considering the compensators as static to analyze its characteristics under unbalanced operating conditions. This modeling method is not only simple but can also be used to analyze the detailed internal characteristics that are very important to the analysis of the electronic switches based devices.

Consider the voltage at source, at the point of common coupling and voltage across load are denoted by V_S, V_{CC} and V_L respectively. The source and load currents are denoted by Is and I_l respectively. The voltage injected by series active power filter is denoted by Vsr., where as the current injected by shunt active power filter is denoted by Ish. Assuming the load voltage, V_l, as a reference and suppose the lagging power factor of the load is $\cos\Phi_l$.

$V_l = V_l$ at an angle 0^0 (1)

$I_l = I_l$ at an angle $-\Phi_l$ (2)

$Vcc = V_l(1+K)$ at angle of 0^0 (3)

Where factor 'K' represents the fluctuations in source voltage and is defined as

$$K = (Vcc - V_l) / V_l \quad (4)$$

The voltage injected by series active power filter is,

$$Vsr = V_l - Vcc = -K V_l \quad (5)$$

Assuming the UPQC to be lossless, the active power demanded by the load is equal to the active power input at point of common coupling. Thus it provides nearly a unity power factor source current, therefore, for a given load condition the input active power at point of common coupling can be expressed as

$$Pcc = P_l \quad (6)$$

$$Vcc = V_l * I_l * Cos\Phi_l \quad (7)$$

$$V_l = (1+K) * Is = V_l * I_l * Cos\Phi_l \quad (8)$$

$$Is = I_l / (1+K) * Cos\ \Phi_l \quad (9)$$

The above equation suggests that the source current I_S depends on the factor K, since Φ_l and I_l are load characteristics and are constant for a particular type of load. The complex power absorbed by the series active power filter can be expressed as,

$$S_{Sr} = V_{Sr} * Is \quad (10)$$

$$Psr = Vs*Is*Cos\Phi s = -K*Vl*Is*Cos\Phi s \quad (11)$$

$$Q_{Sr} = V_{Sr} * Is * Sin\Phi s \quad (12)$$

$\Phi_S = 0$ since unified power quality conditioner is maintaining unity power factor

$$Psr = Vsr*Is = -K*V_l*Is \quad (13)$$

$$Q_{Sr} \approx 0 \quad (14)$$

The complex power absorbed by the shunt active power filter can be expressed as,

$$S_{Sh} = V_l * I_{Sh} \quad (15)$$

The current provided by the shunt active power filter, is equal to the difference between the input source current and the load current, which includes the load harmonics current and the reactive current**.** Therefore

$$I_{Sh} = Is - I_l \quad (16)$$

Whereas

I_{Sh} = Is at an angle 0^0 - I_l at an angle – Φ_l (17)

$I_{Sh} = Is – (I_l * Cos\Phi_l – j * I_l * Sin\Phi_l)$ (18)

$I_{Sh} = (Is – I_l * Cos\Phi_l) + j * I_l * Sin\Phi_l$ (19)

$P_{Sh} = V_l * I_{Sh} * Cos\Phi_{Sh}$ (20)

$= V_l * ((Is – I_l) * Cos\Phi_l))$ (21)

The reactive power from the source flows to the load during the normal working condition when unified power quality conditioner is not connected in the circuit. While during the operating condition of UPQC, the shunt active power filter is put into the operation, the reactive power required by the load is now provided by the shunt active power filter. From equation (4), if K is less than zero (this condition is possible during the voltage sag at the source end), then the voltage at point of common coupling (V_{cc}) must have lesser value than the load voltage (V_l), then from equation (13), the series active power filter supplies the active power (P_{sr}) to the load and from equation (9), I_s will be more than the normal rated current. Thus it is concluded that the required active power is taken from the source itself by taking more current so as to maintain the power balance in the network and to keep the dc link voltage at acceptable range. [3]. Again from equation (4), if K is greater than zero(this condition is possible during the voltage swell at the source end), then the value of V_{cc} is greater than the V_l and the active power (P_{sr}) is absorbed from the source. If K = 0, then there is no exchange of power takes place through the UPQC, which is the normal working condition of the distribution system.

3.Control Strategy of UPQC

Any control strategy can be implemented in three steps; firstly by monitoring or detecting the power quality event second is identification of the event i.e. type of event and third step is by compensating it in minimal possible duration, so as to improve the system performance. To achieve a controlled system the potential transformer or voltage sensors voltage signals are sensed and using current transformer or current sensors current signals are sensed, the hall effect sensors and isolation amplifies are also used for gathering information about the system parameters [4]. Then the fundamental and harmonics quantities of sensed signals are separated so as to perform the compensation on the harmonic quantities.

3.1 Detection of current and voltage to be compensated

The current across load can be divided into two parts, one is the active component, and the other is the current to be compensated, which comprises of reactive current, harmonics current and negative-sequence current. The shunt

Inverter is controlled by current control algorithms, while the series inverter is controlled by the voltage control algorithm [5].

The main issue is to separate the active component from the whole current However the load current I_l can be expressed as

$I_l = I_{lp} + I_c$ (22)

Where I_l is the load current, I_{lp} is the active component and I_c is the current component to be compensated.

Therefore by using the synchronous dq-0 reference frame with the sine and cosine functions with park's transformation and applying the phase locked loop the fundamental positive sequence components are transformed into dc quantities in d and q axes, which can be further extracted using low-pass filter[6]. All harmonic components are transformed into ac quantities with a fundamental frequency sent from the applied loop. The abc-to-dq0 transformation depends on the d-q frame alignment at t = 0. The position of the rotating frame is given by ωt (where ω represents the dq frame rotation speed) [7] and the reference currents are obtained as

$$I_{ldq0} = \begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} \frac{2}{3} \begin{bmatrix} \cos\omega t & \cos(\omega t - 120^0) & \cos(\omega t + 120^0) \\ -\sin\omega t & -\sin(\omega t - 120^0) & -\sin(\omega t + 120^0) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix} \quad (23)$$

While by using the inverse transformation the active current components with the same frequency and phase-shift as that of system voltage are acquired as

$$\begin{bmatrix} I_{la} \\ I_{lb} \\ I_{lc} \end{bmatrix} = \begin{bmatrix} \cos\omega t & -\sin\omega t & 1 \\ \cos(\omega t - 120^0) & -\sin(\omega t - 120^0) & 1 \\ \cos(\omega t + 120^0) & -\sin(\omega t + 120^0) & 1 \end{bmatrix} \begin{bmatrix} I_d \\ I_q \\ I_0 \end{bmatrix} \quad (24)$$

The current to be compensated can be obtained by subtracting the I_{lpa}, I_{lpb}, I_{lpc}, from the detected load current I_{la}, I_{lb}, I_{lc} as

$I_{ac} = I_{la} - I_{lpa}$

$I_{bc} = I_{lb} - I_{lpb}$

$I_{cc} = I_{lc} - I_{lpc}$ (25)

Similarly, assuming the system voltage is balanced and symmetrical the series voltage source inverter is designed to compensate the voltage harmonics and flickers. The voltage component to be compensated can be determined as follows

$V_{ac} = V_{la} - V_{lpa}$

$V_{bc} = V_{lb} - V_{lpb}$

$V_{cc} = V_{lc} - V_{lpc}$ (26)

To keep the power factor in the acceptable range the reactive power needed to be compensated for which the capacitor banks form the DC-link between the series and shunt inverters of UPQC [8]. Furthermore the control schemes are applied to maintain the voltage across DC-link so as to control the reactive power flow in the system.

4.Conclusions

In this paper, a mathematical model of unified power quality conditioner keeping the compensators as static is analyzed. The control strategy is produced in accordance with the basic principles to make it operative to deal with the power quality problems in the distribution power system.

References

[1] NG Hingorani. Introducing Custom Power, IEEE Spectrum, 32, 1995, 41- 48.

[2] H Fuji, H Akagi. The unified power quality conditioner: the integration of series and shunt filters, IEEE Trans. on Power Electronics, 13, 1998, 315-322.

[3] A Elnady, MMA Salama. New functionalities of the unified power quality conditioner, Transmission and Distribution Conference and Exposition, IEEE/PES, 1, 2001, 415 -420.

[4] M Hu, H Chen. Modeling and controlling of Unified Power Quality Compensator, Proceedings of the 5th international Conference on Advances in Power System Control, Operation and Management, APSCOM 2000, Hong brig, od & r. 2000, 431-435.

[5] Y Chen, X Zha, J Wang, H Liu, J Sun, H Tang. Unified Power Quality Conditioner (UPQC): the Theory, Modeling and Application, Proceedings Power Con., 2000, 1329-1333.

[6] V Khadkikar, A Chandra, AO Barry, TD Nguyen. Analysis of power flow in UPQC during voltage sag and swell conditions for selection device ratings Industrial Electronics," IEEE International Symposium, 2, 2006, 9-13.

[7] M Hosseini, HA Shayanfar, M Fotuhi-Firuzabad. Modeling of unified power quality conditioner (UPQC) in distribution systems load flow, Energy Conversion and Management 50, 2009, 1578–1585.

[8] SA Taher, SA Afsari. Optimal location and sizing of UPQC in distribution networks using differential evolution algorithm, Math. Probl. Eng.., 2012, 1-20.