The Effectiveness of a Unified Power Quality Conditioner with Fuzzy Logic Controllers & PI

Mohammad Makassar, Raghvendra Singh, Samir Kumar Mishra[2]
Faculty of Engineering & Technology, Rama University, Mandhana, Kanpur, U.P., India
Email Id: mohdmudassir904@gmail.com,

Abstract-

Power electronics can process electricity in the most economical and efficient manner, it plays a significant part in the transmission and utilisation of electrical power. Nevertheless, power electronic devices' nonlinear features result in two significant drawbacks: they produce harmonics and use utility lagging current. Unified power quality conditioners, or UPQCs, are being employed as a universal active power conditioning device to adjust reactive power and harmonics in recent years. An improved form of the unified power flow controller is called UPQC (UPFC). The speed and accuracy with which compensating signals are generated determines how well UPQC performs. To increase the power factor, the UPQC reduces harmonics and supplies reactive power to the power systems network.

1. 0 Introduction

Power electronics can process electricity in the most economical and efficient manner, it plays a significant part in the transmission and utilization of electrical power. Nevertheless, power electronic devices' nonlinear features result in two significant drawbacks: they produce harmonics and use utility lagging current. Unified power quality conditioners, or UPQCs, are being employed as a universal active power conditioning device to adjust reactive power and harmonics in recent years. An improved form of the unified power flow controller is called UPQC (UPFC). The speed and accuracy with which compensating signals are generated determines how well UPQC performs. To increase the power factor, the UPQC reduces harmonics and supplies reactive power to the power systems network.

As the non linear load consists of the major portion of the total load for the last two three decades, reactive power compensation and harmonic filtering have received a great deal of attention. To restrict the consumers against excessive loading VARs and harmonics, stricter standards has been laid down by the utilities. Most popular among them is standard 519-1992 [1].

Static VAR compensators using thyristor switched capacitors (TSC) and thyristor control inductors (TCI) [2], [3] have been traditionally used for reactive power compensation. As the VAR generated in these schemes are directly proportional to the energy storage capability of capacitors and inductors, there is considerable increase in the size of these elements when the VARs to be compensated are large. Moreover TSC and TCI produce additional current harmonics. Therefore shunt passive filters require filtering them out.

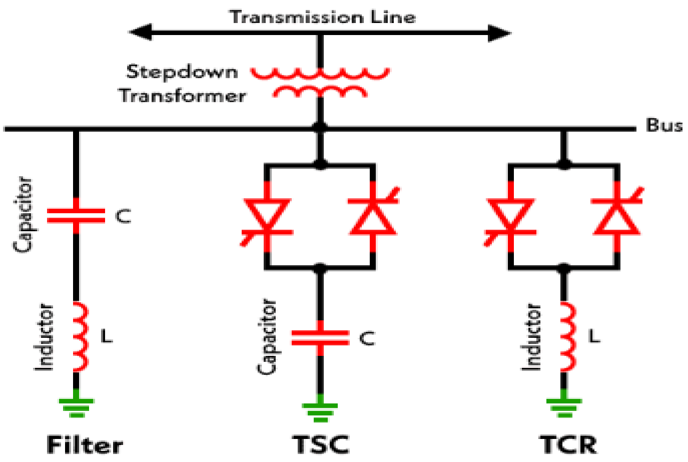

Figure: 2.7 VARs to be compensated

Active power filter (APF) using voltage or current source inverter can be used for reactive power compensation and harmonic filtering together. The major advantage of using voltage source or current source inverter is that the size of the energy storing element is drastically reduced as compare to TSC or TCI.

The shunt APF is the most commonly used APF. The power circuit of shunt APF is shown in Fig. 1.1. In shunt APF, a reactive volt ampere calculation estimates the real component of the load current, $I_{pl}$and then determines the resistive component of the load current by subtracting I_{pl} from I_L(I_{ql}= I_L - I_{pl}). If nonlinearity present in the load current, it is present in I_{ql} as well. Since compensation current *Icomp* is made to follow I_{ql}, load harmonics also get eliminated. Apart from shunt APF various other APF topologies such as series active filter, hybrid series active filter and power line conditioner have been proposed in the literature [4]-[7].

The series active filter as shown in Fig. 1.2 is connected in series with supply mains using a matching transformer. Its limitation is that the presence of active impedance in series with source produces voltage harmonics.

$$I_L = I_{pl} + I_{ql}$$

Using combine series APF and shunt APF unified power flow controller (UPFC) realized, which performs active power compensation, reactive power compensation and phase angle regulation. UPFC believed to be the most complete power conditioning device. But as the time changes, problem also changes. Now days electrical engineers facing problem regarding harmonic compensation, voltage sag and voltage flickering and UPFC is not able to overcome these problems. So a new concept based on UPFC derived called unified power quality conditioner (UPQC) as shown in Fig. 1.3, which performs all the basic functions of UPFC in addition it also compensate for current voltage harmonics with constant voltage maintenance at load terminals.

1.1 Unified Power Quality Conditioner

The UPQC is the most versatile and complex of the FACTS devices, combining the features of the STATCOM and the SSSC. The UPQC can provide simultaneous control of all basic power system parameters, transmission voltage harmonic compensation, impedance and phase angle. It is recognized as the most sophisticated power flow controller currently, and probably the most expensive one. The basic components of the UPQC 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.

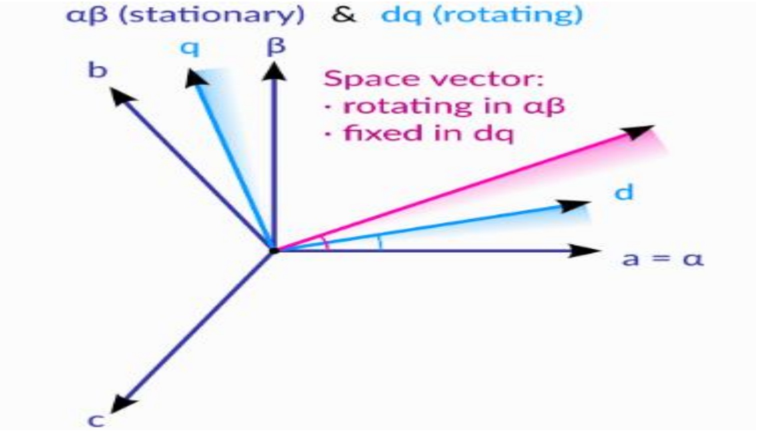

Figure: 2.1Frame transformation (abc to αβ)

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 UPQC is equal only to the losses of the inverters and their transformers.

Control strategy plays vital role in overall performance of power conditioner. Control strategy includes features like rapid detection of harmonic signals by maintaining higher accuracy, fast processing, and faster dynamic response of the controller.The control strategy can be realized using discrete analog and digital devices or advanced programmable devices, such as single chip micro computers, DSPs etc [10].

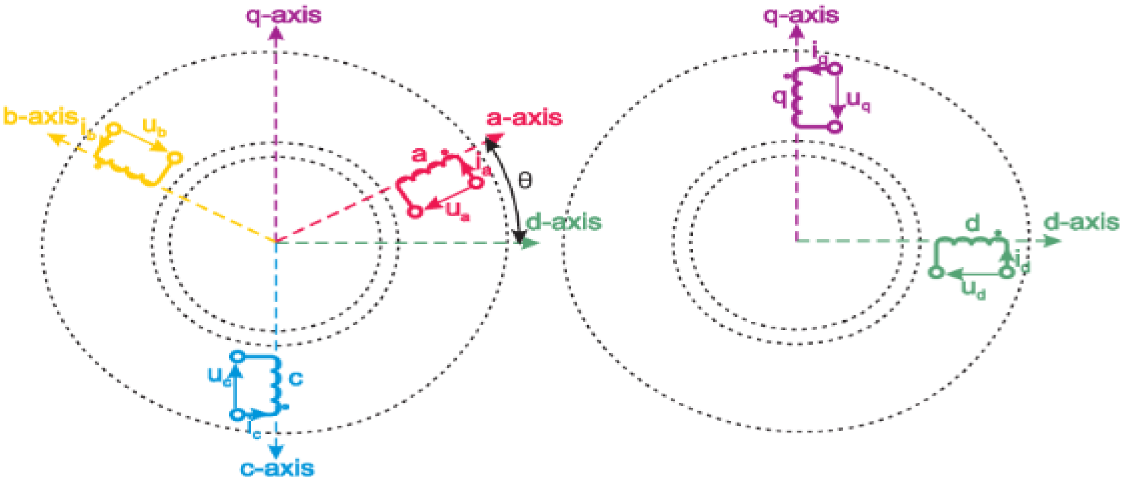

Figure: 2.2 ab to dq transformation

The control strategy determined by the appropriate switching pattern or signal obtained by compensating gate signal compared obtained by comparing with its reference value. Since derivation of reference signal plays an important role in control strategy, many theories and techniques were proposed in recent years. There are number of control strategies were proposed among them dq method is used in the present work and discussed below:

It is established that the active filter flows from leading voltage to lagging voltage and reactive power flows from higher voltage to lower voltage. Therefore both active and reactive power can be controlled by controlling the phase and the magnitude of the fundamental component of the converter voltage with respect to line voltage. dq theory provides an independent control of active reactive power by controlling phase and the magnitude of the fundamental component with respect to converter voltage [16].

According to the dq control theory three-phase line voltages and line currents are converted in to its equivalent two-phase system called stationary reference frame. These quantities further transformed into reference frame called synchronous reference frame. In synchronous reference frame, the components of current corresponding to active and reactive power are controlled in an independent manner. This three-phase dq transformation and dq to three-phase transformation are discussed in detail in this chapter. The outer loop controls the dc bus voltage and the inner loop controls the line currents. The instantaneous real power at any point on line can be defined by:

$$P=V_rI_r+V_bI_b+V_cI_c$$

And we can define instantaneous reactive voltage conceptually as a part of three phasevoltage set that could be eliminated at any instant without altering p.

Reference frame theory based d-q model of shunt active filter is presented in this section. While dealing with instantaneous voltages and currents in three phase circuits mathematically, it is adequate to express their quantities as the instantaneous space vectors [10]. Vector representation of instantaneous three phase quantities R, Y and B which are displaced by an angle 2π/3 from each other is shown in Fig.2.1 [17].

2.3 Compensation Strategy

As shown in Fig. 2.3, $v_s$is the supply voltage. v_c, I_c are the series compensation voltage, shunt compensation current and Vl, Ilhe load voltage and current respectively. The source voltage may contain negative, zero as well as harmonic components. The per phase voltage of the system can be expressed .Where v_{1pa} is the fundamental frequency positive sequence components, $v_{1na}$and v_{10a} are negative and zero sequence components respectively. The last term of equation represents the harmonic content in the voltage. In order for the load voltage to be perfectly sinusoidal and balanced, the series filter should produce a voltage ofIn the latter section, it will be shown how the series-APF can be designed to operate as a controlled voltage source whose output voltage would be automatically controlled according to the above equation.

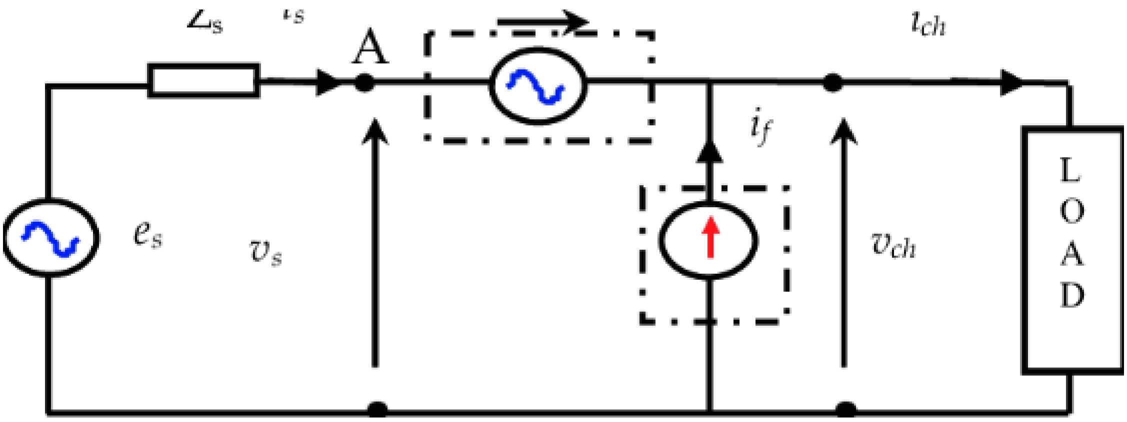

Figure: 2.3 Equivalent circuit diagram of UPQC

The functions of the shunt active filter is to provide compensation of the load harmonic current, load reactive power demand and also to maintain dc link current constant. To provide load reactive power demand and compensation of the load harmonic and negative sequence currents, the shunt-APF acts as a controlled current source and its output components should include harmonic, reactive and negative-sequence components in order to compensate these quantities in the load current [6].

2.4 Basic Control Function

It is evident from above discussion that UPQC should separate out the fundamental frequency positive sequence components first from the other components. Then it is required to control both series and shunt active filter to give output as shown respectively. The control strategy uses a PLL based unit vector template for extraction of reference signal from the distorted input supply.

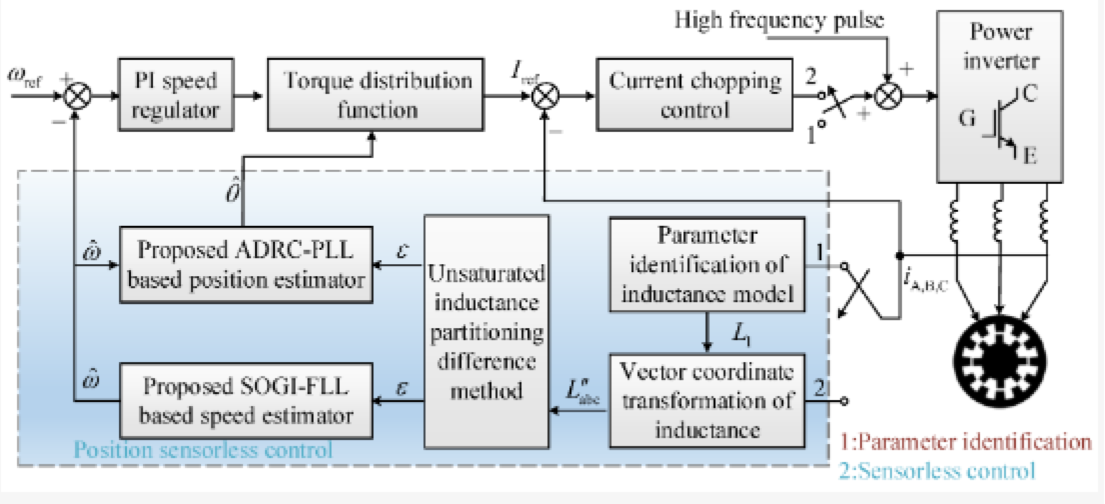

Figure: 2.6. Schematic diagram of the proposed PLL control scheme

The block diagram of extraction of unit vector template is as given in Fig. 2.4.

2.5 Result & Discussion

Voltage stability, harmonic reduction, load balancing, and other power quality parameters can all be improved by using a unified power quality conditioner with fuzzy logic control. As a result, linked loads would probably receive a more steady and dependable power supply from a more robust and efficient power conditioning system that can dynamically adapt to changing load conditions and disturbances

The transient performance of the five-phase induction motor drive is enhanced compared to three-phase drives, leading to improved load handling capacity and speed response. The increased number of phases also improves fault tolerance capability and reduces per-phase current for machines with the same rating. Furthermore, stator ohmic losses are reduced.

The proposed inverter drive system demonstrates its potential in industrial applications by utilizing fewer components compared to conventional five-phase inverters. It offers advantages such as improved efficiency, enhanced transient performance, and increased fault tolerance, highlighting its suitability for industrial drive systems.

REFERENCE

[1] R.José*etal.*,“Multilevelconverters:Anenablingtechnologyforhigh-poer applications,” *Proc. IEEE*, vol. 97, no. 11, pp. 1786–1817, 2009, doi: 10.1109/JPROC.2009.2030235.

[2]J.Rodríguez,J.S.Lai, and F. Z. Peng, “Multilevel inverters: Asurveyoftopologies,controls,andapplications,”*IEEETrans.Ind.Electron.*, vol. 49, no. 4, pp. 724–738, Aug. 2002, doi:10.1109/TIE.2002.801052.

[3] J. Rodríguez, S. Bernet, B. Wu, J. O. Pontt, and S. Kouro,“Multilevel voltage-source-converter topologies for industrialmedium-voltage drives,” *IEEE Transactions on IndustrialElectronics*, vol. 54, no. 6. pp. 2930–2945, Dec. 2007. doi:10.1109/TIE.2007.907044.

[4] M. Malinowski, K. Gopakumar, J. Rodriguez, and M. A. Perez,“A survey on cascaded multilevel inverters,” *IEEE TransactionsonIndustrialElectronics*,vol.57,no.7.pp.2197–2206,Jul.2010.doi:10.1109/TIE.2009.2030767.

[5] J.Rodriguez,S.Bernet,P.K.Steimer,andI.E.Lizama,“Asurveyon neutral-point-clamped inverters,” IEEE Transactions onIndustrial Electronics, vol. 57, no. 7. pp. 2219–2230, Jul. 2010.doi:10.1109/TIE.2009.2032430.

[6] S.KumarandP.Agarwal,“Anoveleighteen-levelinverterforanopen-end winding induction motor,” India Int. Conf. PowerElectron. IICPE, vol. 2015-May, pp. 2–7, 2015, doi:10.1109/IICPE.2014.7145017.

[7] S. Kumar and P. Agarwal, “A nine-level inverter for open-endinduction motor,” 2014 Recent Adv. Eng. Comput. Sci. RAECS2014, pp. 6–8, 2014, doi: 10.1109/RAECS.2014.6799640.

[8] R. Sachan, N. Kumar, A. Arvind, A. K. Arya, and S. Kumar,“Reduced Switch Count 36 level Inverter for Open End WindingInduction Motor Drive,” 2019 2nd Int. Conf. Power EnergyEnviron. Intell. Control. PEEIC 2019, pp. 180–185, 2019, doi:10.1109/PEEIC47157.2019.8976554.

[9] M. Sharifzadeh and K. Al-Haddad, “Packed E-Cell (PEC)convertertopologyoperation andexperimentalvalidation,” IEEEAccess, vol. 7, pp. 93049–93061, 2019, doi:10.1109/ACCESS.2019.2924009.

[10] S. M. Suhel and R. Maurya, “A New Switching Sequences ofSVPWMforSix-PhaseInductionMotorwithFeaturesofReducedSwitching Losses,” CES Trans. Electr. Mach. Syst., vol. 5, no. 2, pp.100–107,2021,doi:10.30941/CESTEMS.2021.00013.

[11] S.Kumar and P. Agarwal,“Performanceevaluationofmulti-levelinverter fed open-end winding IM drive under two differentmodulation schemes,” 2017 6th Int. Conf. Comput.

Appl. Electr.Eng. - Recent Adv. CERA 2017, vol. 2018-Janua, pp. 1–6, 2018,doi:10.1109/CERA.2017.8343343.

[12] N. Bodo, E. Levi, and M. Jones, “Investigation of carrier-basedPWM techniques for a five-phase open-end winding drivetopology,” IEEE Trans. Ind. Electron., vol. 60, no. 5, pp. 2054–2065, 2013, doi: 10.1109/TIE.2012.2196013.

[13] V. Jayakumar, B. Chokkalingam, and J. L. Munda, “Acomprehensivereviewonspacevectormodulationtechniques for