Topological Survey of Unified Power Quality Conditioner

Anuradha Pateriya[1], Dr Preeti Jain[2]

[1]*Student, Department of Electrical Engineering, Jabalpur Engineering College, Jabalpur Madhya Pradesh, India*
[2]*Assistant Professor, Department of Electrical Engineering, Jabalpur Engineering College, Jabalpur Madhya Pradesh, India*

---***---

Abstract – *The Deregulated structure of Modern Power System (MPS) enforces the service provider to maintain power quality at aspects. The MPS is highly burdened with non-linearity in current and voltage. This is because there has been a high penetration of power electronic based load which injects harmonics into the system. This non-linearity may interfere the whole system and can results in voltage and frequency instability. Hence it is important rectify various Power Quality Issues (PQI) due to system non-linearity. In the beginning Active Power Filter (APF) were used to mitigate PQI. APF may be connected in shunt or series combination with the system and has selective features. Unified Power Quality Conditioner (UPQC) is a compensator which can be connected both in series and shunt simultaneously to mitigate various PQI and has wide range of features. UPQC has numerous topologies as per the system requirement. This paper presents the topological survey of all the available topologies of UPQC.*

Key Words: *Modern Power System (MPS), Power Quality Issues (PQI), Active Power Filter (APF), Unified Power Quality Conditioner (UPQC), Voltage Source Inverter (VSI).*

1. INTRODUCTION

Power sector reforms begun in late 90' century. Earlier power sector was regulated structure in which authority was owned by single entity. But in late 90' century and in the early 20' century power sector was converted into deregulate structure in which multiple entities can be involved to participate in power sector operation and management [1]. In deregulated market structure it is the responsibility of service provider to maintain the good quality and continuity of supply [2].

The Modern Power System (MPS) has undergone numerous reforms. Also, the technological development in semiconductor devices has leads to high efficiency and precise equipments. The Power Semiconductor Devices (PSD) induces harmonics in the current as well as voltage waveforms. Also, to meet increasing power demand and reduce carbon emission Renewable Resources (RR) are used. To integrate RR into existing network topology, PSD are employed. This in-turn injects harmonics. High harmonic content distorts the voltage and current waveforms and generate numerous Power Quality Issues (PQI) [3].

To safeguard the precise equipment of the system and to improve the quality of supply at consumer end, it is required to mitigate PQI. As the importance of quality of supply started with the deregulated structure, earlier filter elements were used. Filters are designed with lumped parameters of inductance, resistance and capacitance (LRC). When a fixed parameter of LRC is used in filter design it is a passive filter [4] and it suffers from high losses and low efficiency. Hence an active filter design is developed [5,6]. As the technology evolve further, a new class of PSD is developed named Custom Power Devices [7,8] which are the specifically designed to meet the particular requirement of PQI of Distribution System (DS). The CPD are classified as network regenerative and compensating type as shown in fig. 1. The *network configuring types* are based on GTO/thyristors devices generally meant for fast current limiting, current breaking, voltage stabilization and load switching. The CPDs of network reconfiguring type are [9,10]:

- Solid State Current Limiter (SSCL)
- Solid-State Transfer Switches (SSTS)
- Static Electronic Tap Changers (SETC)
- Solid State Circuit Breaker (SSCB)

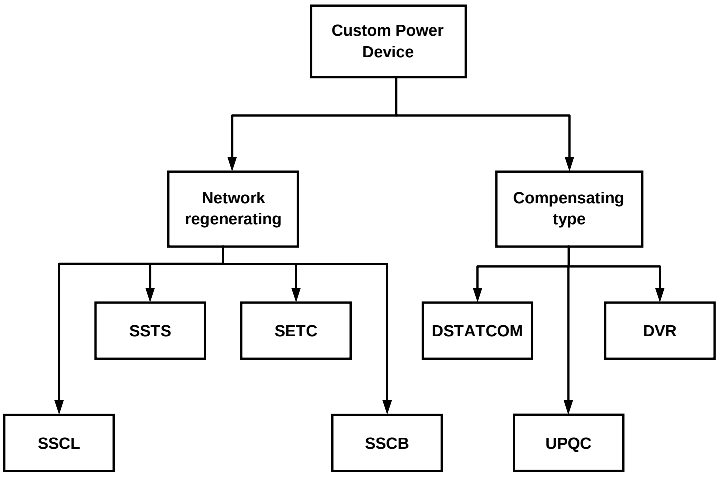

Fig-1: Classification of Custom Power Device

The compensating types are used to resolve various power quality issues like load balancing, voltage regulating and improving power factor. The compensating types of CPDs are most popularly used in present scenario. It is specially customized power electronic converters to meet the consumer specifications. The compensating type CPD [11,12] are:

- Distribution-STATCOM (D-STATCOM)
- Dynamic Voltage Restorer (DVR)
- Unified Power-Quality Conditioner (UPQC)

This paper presents the comprehensive review on numerous topologies available in literature for mitigating various PQI.

2. UNIFIED POWER QUALITY CONDITIONER (UPQC)

UPQC is one of the powerful tools used for PQ compensation, where shunt and series converters functionalities are integrated together to accomplish superior control over several PQ problems at the same time [13-14]. The basic circuit topology of UPQC is presented in figure 2, which comprise of two converters. One converter is connected at source side which is generally a series converter coupled using inter-link transformer. Another is shunt converter which is shunted directly at load side. And the two converters are coupled using DC-link capacitance. Series-converter behaves as sinusoidal-voltage source which has the capability to eliminating load current harmonics. In conventional UPQC topology the two coupled converters are designed using two level Voltage Source Inverters (VSI) [15]. VSI is a PSD designed using IGBT, GTO etc. It is used to inoculate compensating current in a way to remove load current harmonics hence the current taken from source is completely sinusoidal.

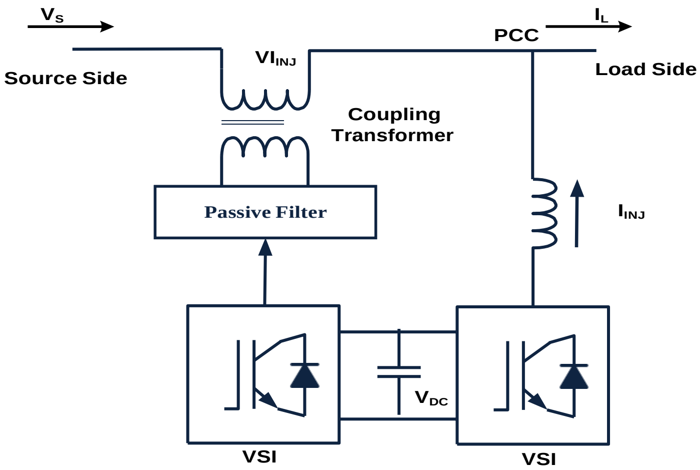

Fig. 1.4 Single-phase UPQC

UPQC performs the operations of a Distribution Static Compensator (DSTATCOM) and Dynamic Voltage Regulator (DVR) simultaneously. It is installed where simultaneous operation shunt and series compensation is required. A DS may encompass unbalance, distortion and even dc components. Hence UPQC operate with all these aspects in order to provide shunt or series compensation.

3. CLASSIFICATION OF UPQC

The UPQC has broad 2 classification based on 1) physical structure [16]– [18] and 2) Compensation it provides [19]. Available research witnesses' numerous configurations to form a UPQC system as shown in Fig. 2. [20]. UPQC is sub-classified based on 1) converter topology; 2) supply system and 3) System configurations for single and/or three-phase system. Furthermore, as per the application-oriented topologies are, UPQC-P, UPQC-Q, UPQC-L, UPQC-R, UPQC-D, UPQC-DG, UPQC-I, UPQC-L, UPQC-MC, UPQC-MD, UPQC-ML, UPQC-P, UPQC-Q, UPQC-R, and UPQC-S.

The converter of UPQC cab be designed using voltage source or Current Source Inverter (CSI)configuration [21]. The CSI shares a common energy storage inductor Ldc to form the dc link. A voltage blocking diode connected in series with switch is required to realize this topology as shown in fig-3. The VSI is another topology which is widely adopted and very popular in designing UPQC as already discussed in fig-1. The advantages offered by VSI topology over CSI include lighter in weight, no need of blocking diodes, cheaper, capability of multilevel operation, and flexible overall control.

The electrical supply system is single and three phase based. Hence UPQC can be designed for both the configuration. Fig-4 presents the most popularly adopted 1-phase topology [22]. For 3-phase system the topologies can be based on 3-phase 3-wire and 3-phase 4-wire. The widely adopted 3P3W topology is presented in fig-5 [23]. Apart from the three-phase loads, many industrial plants often consist of combined loads, such as, a variety of single-phase loads and three-phase loads, supplied by 3P4W source [24]. The fourth wire is neutral conductor which causes an excessive neutral current flow and, thus, demands additional compensation requirement as shown in fig-6.

Based on the system UPQC configuration, it can be either right shunted as previously discussed in fig.1. or it can be left shunted as shown in fig-7 [25]. There could be also interline type of topology that is UPQC-I as shown in fig-8. UPQC-I can be connected between two feeders through which simultaneous compensation of two DS can be achieved [26]. Another unique topology is multi-converter based, in which an additional converter is connected to support the DC-bus as shown in fig-9 [27]. With advent in development of multi-level inverter (MLI) topology, the UPQC converters are replaced by MLI in place of VSI/CSI as shown in fig-10. This improves the performance of UPQC [28].

Now, based on the application different topologies are also available. Particularly to provide active power control UPQC-p can be designed. For reactive power control UPQC-R is available in literature. For apparent power control UPQC-S is available. Hence UPQC presents versatility in topology to meet the complete system requirement [29-30].

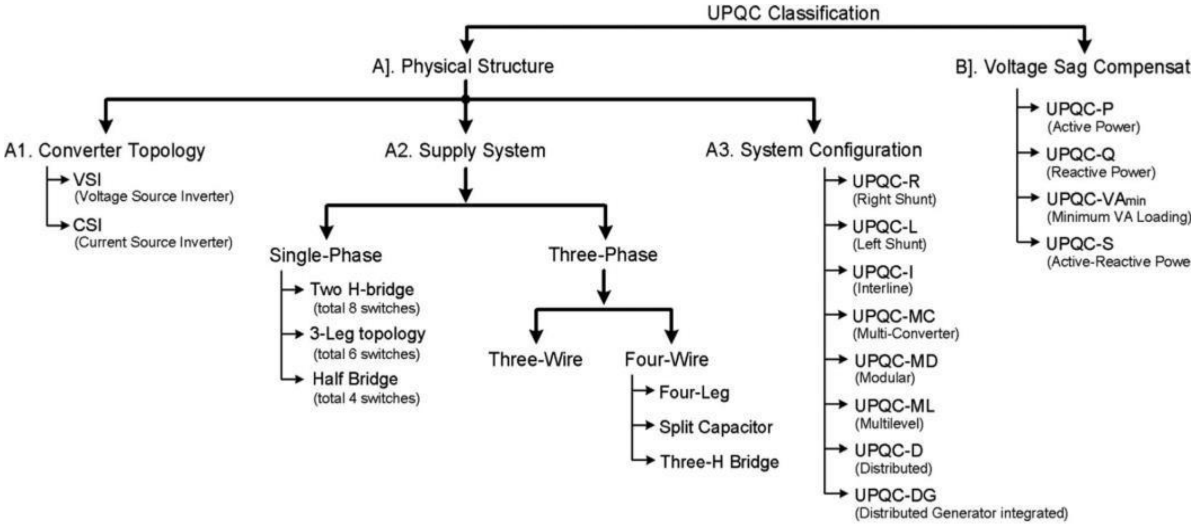

Fig-2: Classification of UPQC

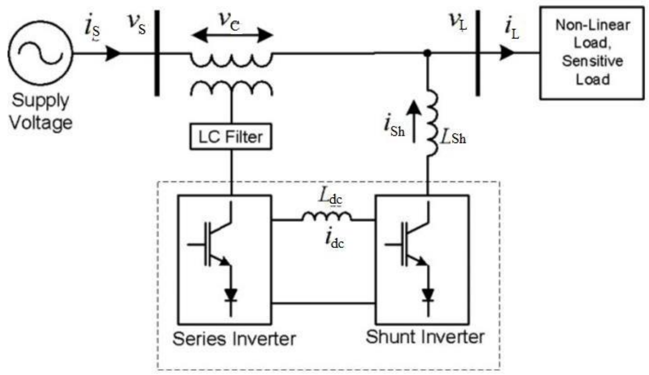

Fig-3: CSI based UPQC

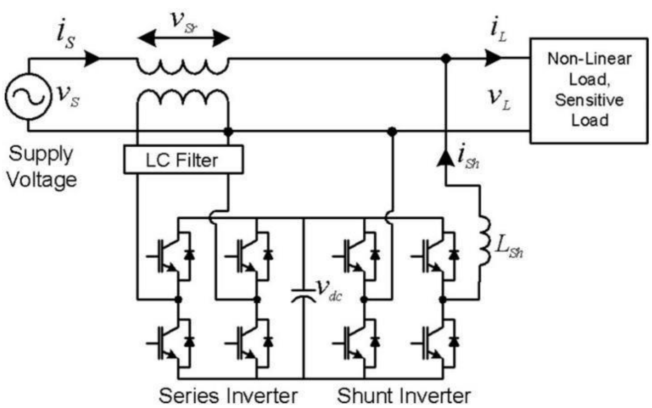

Fig-4: 1-Phase UPQC

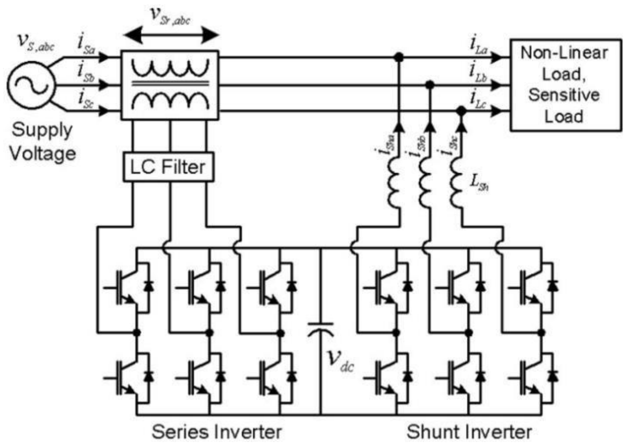

Fig-5: 3P3W UPQC topology

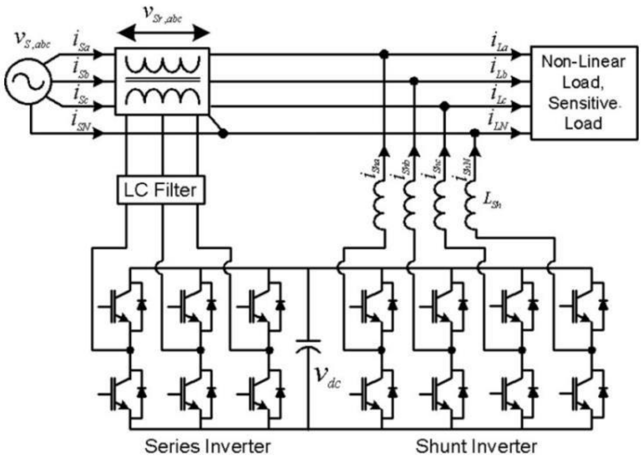

Fig-6: 3P4W UPQC topology

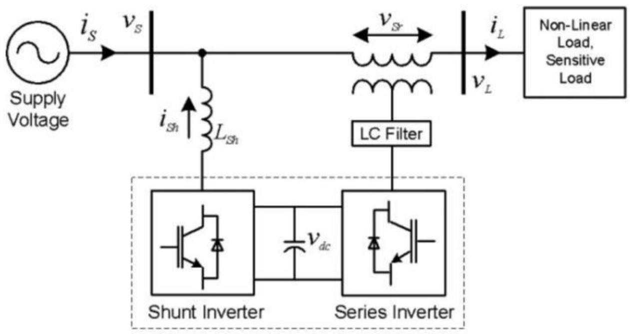

Fig-7: UPQC-L topology

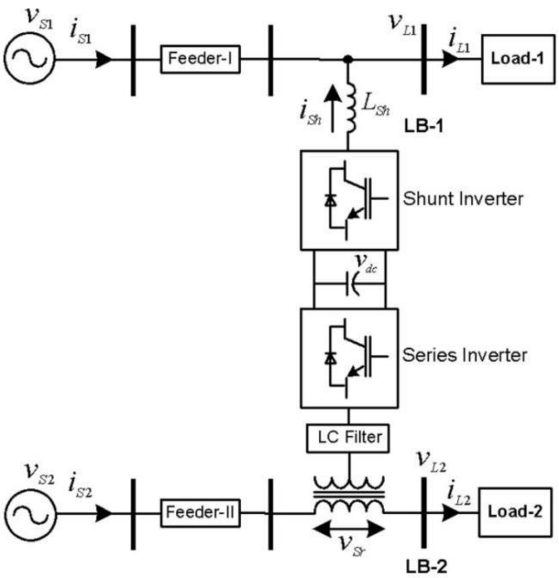

Fig-8: Interline UPQC topology

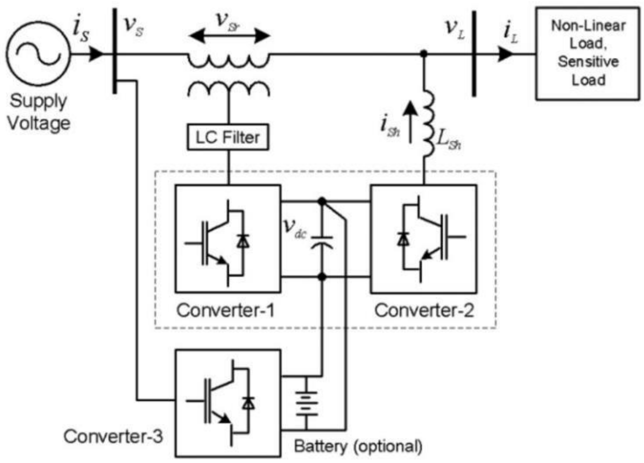

Fig-9: Multi-converter UPQC topology

3. APPLICATION OF UPQC

UPQC has wide range of application in DS. It has capability of mitigating more or less all the PQI such as; harmonics in source as well as load current, sag in voltage, swell in voltage, momentary interruption, transients in voltage and current, power factor, etc. DS suffers random and frequent issues of voltage sag which may be the result of faults in power system. Faults may be symmetrical (three phase) and unsymmetrical (involving 1/2 phases). In case of symmetrical-faults, only magnitude compensation is required. While for unsymmetrical both magnitude and phase correction is required. UPQC has the capability of simultaneous magnitude and phase angle compensation for voltage and current and its application is reported in literature [31-37]. Another increasing area of research in UPQC is its application in integrating RR such as solar and wind with the utility system. This research work is not much reported [38,39], since this area is not much explored. In case of PV fed UPQC (PV-UPQC), UPQC perform dual function of integrating UPQC with grid as well as mitigating numerous PQI. PV-UPQC can supply active as well as reactive power to DS simultaneously, hence increases the stability and reliability aspects of the system. Which is the most desirable feature of MPS, hence the application of UPQC in MPS is increasing day-by-day. It is attracting researchers to explore its numerous applications.

4. CONCLUSIONS

For customer satisfaction it is the responsibility of service provider in a deregulated power sector to provide good quality of supply. Modern distribution system is highly burdened with non-linear loads and high rating PSD. Numerous topologies are available in literature to improve PQ of the supply system. Particularly in DS, UPQC is widely adopted for precise power flow control and harmonic less supply. This paper presents a comprehensive review on UPQC topologies with its application. Also working principle overviewed with its system configuration. As per the application there are numerous variants of UPQC is available in literature. All the variants with their design aspects are shortly discussed in this paper.

REFERENCES

[1] Bardhan, R., Debnath, R., & Jana, A. (2019). Evolution of sustainable energy policies in India since 1947: A review. Wiley Interdisciplinary Reviews: Energy and Environment, 8(5), e340.

[2] Raikar, S. B., & Jagtap, K. M. (2018, March). Role of deregulation in power sector and its status in India. In 2018 National Power Engineering Conference (NPEC) (pp. 1-6). IEEE.

[3] H. Awad, M. H.J Bollen, "Power Electronics for Power Quality Improvements," IEEE Symposium on Industrial Electronics, 2003, vol.2, pp. 1129-1136.

[4] H. Akagi, "Trends in active power line conditioners," IEEE Trans. Power Electron., vol. 9, no. 3, pp. 263–268, May 1994.

[5] B. Singh, K. Al-Haddad, and A. Chandra, "A review of active filters for power quality improvement," IEEE Trans. Ind.

Electron., vol. 46, no. 5, pp. 960–971, Oct. 1999.

[6] M. El-Habrouk, M. K. Darwish, and P. Mehta, "Active power filters: A review," IEE Electr. Power Appl., vol. 147, no. 5, pp. 403–413, Sep. 2000.

[7] N. G. Hingorani, "Introducing custom power", IEEE spectrum, 32(6), 41-48, 1995.

[8] Olimpo Anaya-Lara and E. Acha, "Modeling and Analysis of Custom Power Systems by PSCAD/EMTDC", IEEE Transactions On Power Delivery, VOL. 17, NO. 1, January 2002.

[9] S. K. Jain, P. Agrawal, and H. O. Gupta. "Fuzzy logic controlled shunt active power filter for power quality improvement." IEE Proceedings-Electric Power Applications, vol. 149, no. 5, pp. 317-328, 2002.

[10] Y. Pal, A. Swarup, and Singh, B., "A review of compensating type custom power devices for power quality improvement", In Power System Technology and IEEE Power India Conference, POWERCON 2008. pp. 1-8, October 2008.

[11] Chirag Patel and Ranjit Mahanty, "Unified power quality conditioner using a fuzzy controller." International Journal of Emerging Electric Power Systems, vol. 11, no. 4, 2010.

[12] N. G. Hingorani and L. Gyugyi, Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems. New York: Institute of Electrical and Electronics Engineers, 2000.

[13] B. N. Singh, A. Chandra, K. Al-Haddad, and B. Singh, "Fuzzy control algorithm for universal active filter," in Proc. Power Quality Conf., Oct. 14–18, 1998, pp. 73–80.

[14] M. Aredes, K. Heumann, and E. H. Watanabe, "An universal active power line conditioner," IEEE Trans. Power Del., vol. 13, no. 2, pp. 545–551, Apr. 1998.

[15] M. C. Wong, C. J. Zhan, Y. D. Han, and L. B. Zhao, "A unified approach for distribution system conditioning: Distribution system unified conditioner (DS-UniCon)," in Proc. Power Eng. Soc. Winter Meet., Jan. 23–27, 2000, pp. 2757–2762.

[16] M. Hu and H. Chen, "Modeling and controlling of unified power quality conditioner," in Proc. Adv. Power Syst. Control, Operation Manage., Oct. 30–Nov. 1, 2000, pp. 431–435.

[17] D. Graovac, V. Katic, and A. Rufer, "Power quality compensation using universal power quality conditioning system," IEEE Power Eng. Rev., vol. 20, no. 12, pp. 58–60, Dec. 2000.

[18] Y. Chen, X. Zha, J. Wang, H. Liu, J. Sun, and H. Tang, "Unified power quality conditioner (UPQC): The theory, modeling and application," in Proc. Int. Conf. Power Syst. Technol., 2000, pp. 1329–1333.

[19] V. Khadikikar, "Enhancing Electric Power Quality Using UPQC: A Comprehensive Overview," IEEE Transactions on Power Electronics, Vol. 27, No. 5, May 2012. Pp. 2284-2297.

[20] Kesler and E. Ozdemir, "A novel control method for unified power quality conditioner (UPQC) under non-ideal mains voltage and unbalanced load conditions," in Proc. Appl. Power Electron. Conf., Feb. 21–25, pp.374–379.

[21] E. Meli´ın, J. R. Espinoza, J. A. Munoz, C. R. Baier, and E. E. Espinosa, ˜ "Decoupled control of a unified power quality conditioner based on a current source topology for fast AC mains disturbance compensation," in Proc. IEEE Int. Conf. Ind. Technol., Mar. 14–17, 2010, pp. 730– 736.

[22] M. Basu, S. P. Das, and G. K. Dubey, "Experimental investigation of performance of a single phase UPQC for voltage sensitive and nonlinear loads," in Proc. 4th IEEE Int. Conf. Power Electron. Drive Syst., Oct. 22–25, 2001, pp. 218–222.

[23] Y. Cheng and L. Philippe, "Advanced control methods for the 3-phase unified power quality conditioner," in Proc. Power Electron. Spec. Conf., Jun. 20–25, 2004, pp. 4263–4267.

[24] Y. Pal, A. Swarup, and B. Singh, "A comparative analysis of three-phase four-wire UPQC topologies," in Proc. Int. Conf. Power Electron. Drives Energy Syst, Dec. 20–23, 2010, pp. 1–6.

[25] Jayanti, M. Basu, M. Conlon, and K. Gaughan, "Performance comparison of a left shunt UPQC and a right shunt UPQC applied to enhance fault-ride-through capability of a fixed speed wind generator," in Proc. Eur. Power Electron. Appl., Sep. 2–5, 2007, pp. 1–9.

[26] A. K. Jindal, A. Ghosh, and A. Joshi, "Interline unified power quality conditioner," IEEE Trans. Power Del., vol. 22, no. 1, pp. 364–372, Jan. 2007.

[27] R. Mohammadi, R. Y. Varjani, and H. Mokhtari, "Multiconverter unified power-quality conditioning system: MC-UPQC," IEEE Trans. Power Del., vol. 24, no. 3, pp. 1679–1686, Jul. 2009.

[28] I. Rubilar, J. Espinoza, J. Munoz, and L. Moran, "DC link voltage unbalance control in three-phase UPQCs based on NPC topologies," in Proc. 42nd Ind. Appl. Soc. Annu. Meet. Ind. Appl. Conf., Nov. 5–8, 2007, pp. 597–602.

[29] X. Li, G. Zhu, S. Duan, and J. Chen, "Control scheme for three-phase four-wire UPQC in a three-phase stationary frame," in Proc. 33rd Annu. Conf. IEEE Ind. Electron. Soc., Nov. 5–8, 2007, pp. 1732–1736.

[30] Mufioz, J. Reyes, J. Espinoza, I. Rubilar, and L. Moran, "A novel multi-level three-phase UPQC topology based on full-bridge singlephase cells," in Proc. 33rd Annu. Conf. IEEE Ind. Electron. Soc., Nov. 5–8, 2007, pp. 1787–1792.

[31] Hosseini, S. Mehdi. "The operation and model of UPQC in voltage sag mitigation using EMTP by direct method." *Emerging Science Journal* 2.3 (2018): 148-156.

[32] Khadkikar, Vinod, et al. "Analysis of power flow in UPQC during voltage sag and swell conditions for selection of device ratings." *2006 Canadian Conference on Electrical and Computer Engineering*. IEEE, 2006.

[33] Gayatri, M. T. L., Alivelu M. Parimi, and AV Pavan Kumar. "Utilization of Unified Power Quality Conditioner for voltage sag/swell mitigation in microgrid." *2016 Biennial International Conference on Power and Energy Systems: Towards Sustainable Energy (PESTSE)*. IEEE, 2016.

[34] Khadkikar, Vinod, and Ambrish Chandra. "UPQC-S: A novel concept of simultaneous voltage sag/swell and load reactive power compensations utilizing series

inverter of UPQC." *IEEE transactions on power electronics* 26.9 (2011): 2414-2425.

[35] Rajarajan, R., and R. Prakash. "MITIGATION OF VOLTAGE SAGS AND STABILITY ANALYSIS OF DISTRIBUTION SYSTEM BASED ON UPQC USING SUBSTANTIAL TRANSFORMATION INTRINSIC ALGORITHM (STIA)." *Journal of Critical Reviews* 7.4 (2020): 847-854.

[36] Xu, Yunfei, et al. "Voltage sag compensation strategy for unified power quality conditioner with simultaneous reactive power injection." *Journal of Modern Power Systems and Clean Energy* 4.1 (2016): 113-122.

[37] Basu M, Das S.P. and Dubey G.K., "Performance study of UPQC-Q for load compensation and voltage sag mitigation." IECON 02, IEEE, Volume: 1, 5-8 Nov 2002, pp. 698 -703.

[38] Campanhol, Leonardo Bruno Garcia, et al. "Single-stage three-phase grid-tied PV system with universal filtering capability applied to DG systems and AC microgrids." *IEEE transactions on power electronics* 32.12 (2017): 9131-9142.

[39] Devassy, S., & Singh, B. (2017). Design and performance analysis of three-phase solar PV integrated UPQC. *IEEE Transactions on Industry Applications*, *54*(1), 73-81.