An Extensive Review on Power Quality Conditioning in LV Distribution Networks

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Abstract- Power Quality and Custom Power are two different terms in electric power system. PQ is the definition of a unique standard which the system operators should respect precisely. However the custom needs can be not satisfied respecting this standard. Custom Power requirements in some senses could be in contrary with standard PQ definition and in some cases these two areas could find common needs and challenges. This investigation presents PQ standard definition and limits for LV system and later it talks about commonly used custom power definition and requirements in order to find out where these two areas can be along each other. Nowadays in power systems the PQ is an important are of interest from several points of views. Improving the PQ in an electrical grid will decrease the system losses and increase transmission and distribution systems capability. So, the standard defines appropriate working condition where the grid and electrical equipments of user can work properly. An extensive survey of literature has been reported on power quality conditioning in LV distribution networks in this investigation.

Keywords- Power Quality, unified power quality conditioner, smart grid, Open UPQC.

I. INTRODUCTION

Today, both power suppliers and consumers are obliged to comply with various Power Quality (PQ) standards proposed by international bodies such as IEEE and IEC worldwide. The numbers of vulnerable loads which are very sensitive to PQ problems have increased in the modern power system and at the same time the number of PQ polluting factors has also escalated. The increased penetration of distributed generation sources in to the power system has further contributed to existing PQ complexities. These distributed generation sites are often fuelled by renewable energy sources such as wind and solar. The random nature of these energy sources poses a reliability threat to the power system.

Generators driven by renewable sources such as wind that are connected to the power system at distribution level rely on a healthy power grid for proper operation. Some PQ events like voltage sag which can occur due to any fault occurring upstream of the Point of Common Coupling (PCC) can lead to mal-function and hence disconnection of these distributed generators. The disconnection of such small scale generators can lead to a deficiency in generation capacity and possibly system instability. This potential problem becomes more significant as more such generators are connected at a distribution level. Therefore, the existing grid codes for renewable sources such as wind have been revised and disconnection of generation during certain PQ events is to be avoided. Grid integration of this type of generation requires some special measures to be taken to achieve grid code compliance and for better operational reliability.

The application of power electronics devices in the field of wind generation to provide reactive power compensation, additional fault ride through capability and to maintain PQ at the PCC is gaining popularity. A Unified Power Quality Conditioner (UPQC) is an up-to-date PQ conditioning device of the custom power device family [7]. The concept being relatively new is still being researched. It is speculated that this will be a universal solution to all power quality issues because of its voltage and current compensating capability.

Electrical power system has been struggling with power quality and reliability problems since decades. Nowadays, the most important difficulties are meaningly growing amount of consumed power, rapid development of renewable and distributed energy sources [4] and increasing the share of non-linear loads [11]. These, and many other phenomena, cause deterioration of supply voltage parameters, such as:

- voltage fluctuations/flicker,
- voltage unbalance,
- higher harmonic content
- voltage dips and swells,
- Interruptions in power supply.

These phenomena have a serious negative impact on the units generating, transmitting and distributing electricity, and on connected loads.

They increase reliability of power supply for customers; however, they do not consider power quality issues, which are becoming serious problem for Distribution System Operators (DSO) and consumers.

Recently, the power quality has been mostly noticed by DSOs. Heavy industrial loads, drawing reactive or non-linear current caused deterioration of supply voltage quality and additional losses in distribution network. Compensation of these phenomena was performed by passive reactive power sources and harmonic filters.

Voltage fluctuation is series of voltage changes or a cyclical variation of the voltage envelope. It can be a systematic variation or a series of random voltage changes. Voltage fluctuations in most cases are introduced to the network by load variations, especially its reactive power. Arc furnaces are the most common cause of voltage fluctuations. Continuous, rapid variations in the load current amplitude can cause voltage variations often referred as “flicker”. The term flicker is derived from the impact of the voltage fluctuation on lighting intensity.

Three-phase voltage unbalance is the maximum deviation among the three phases from the average three-phase voltage divided by the average three-phase voltage. The ratio of the negative or zero sequence is given in percentage.

Higher harmonics are sinusoidal components of voltage or current, with a frequency equal to an integer multiple of the fundamental frequency of the supply voltage [10]. Harmonic currents result from the normal operation of non-linear devices on the power system.

Electrical power is extremely important raw material that should be available in terms of quality. It is used almost every field in human life, besides in all commercial activities. Essential missions of the organizations which generate, transmit and distribute electrical energy are to provide uninterrupted, cheap and high quality service to the consumers

II. SYSTEM MODEL

A Unified Power Quality Conditioner (UPQC) is a relatively new member of the custom power device family. It is a combination of shunt and series compensators. The concept of UPQC was first introduced in 1996 by authors of [7,8]. It is speculated that almost any Power Quality (PQ) issues can be tackled with this device. Generally PQ problems arise either because of supply voltage distortion or because of load current distortion. Since a UPQC has both series and shunt compensators, it can handle supply voltage and load current problems simultaneously when installed at the point of common coupling. It can protect sensitive loads from power quality events arising from the utility side and at the same time can stop the disturbance being injected in to the utility from load side. This work explores the structure, different control techniques and potential new applications of the UPQC.

a. The structure of UPQC

The UPQC is a power electronics based compensator which works on the principle of active filtering. It is a combination of Shunt (SHUC) and Series (SERC) Compensators, cascaded via a DC link capacitor. Based on the position of the SHUC and the SERC two configurations of a UPQC are possible. Schematic diagrams of the two configurations are presented in Figure 2.1 and Figure 2.2.

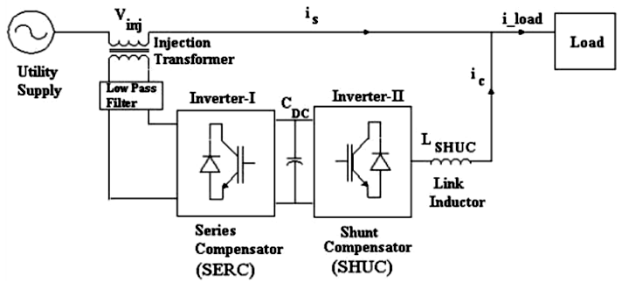

Figure 2.1 Right Shunt UPQC configuration.

Each compensator of the UPQC consists of an IGBT based full bridge inverter, which may be operated in a voltage or a current controlled mode depending on the control scheme. Inverter I (Series Compensator, SERC) is connected in series with the supply voltage through a low pass LC filter and a transformer. Inverter II (Shunt Compensator, SHUC) is connected in parallel to the load through a smoothing link inductor. The SERC operates as a controlled voltage source and compensates for any voltage disturbance in the network. The SHUC operates as a controlled current source and compensates for reactive or harmonic elements in the load. It also acts as a real power path and maintains the DC link voltage at a constant value by charging the DC link capacitor continuously.

b. Control of UPCQC

The UPQC system is inherently complex and requires sophisticated control systems to achieve the satisfactory performance. A fast DSP or a microprocessor is often utilized to carry out the complex control. It is typically controlled in a modular fashion. Separate control loops are designed for the SHUC and the SERC, which work independently. The only interaction between the compensators is through the DC link, which can be controlled by regulating the DC link voltage.

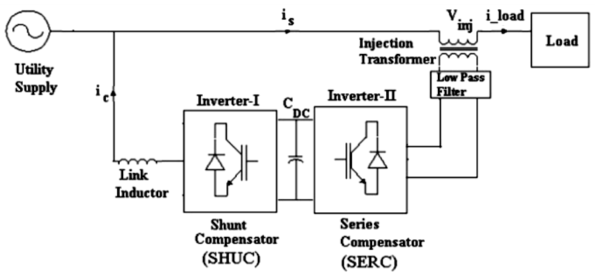

Figure 2.2 Left shunt UPQC configuration.

Different compensating techniques in the literature are discussed in the following section. They utilize one or the other form of three basic theories, namely Instantaneous Reactive Power theory (IRP or p-q theory), Synchronous Reference Frame (SRF) theory and Symmetrical Component theory. A brief explanation for each technique is provided here.

c. Applications of UPQC

Due to the power conditioning capability of the UPQC, it can find numerous applications in the modern power systems. It is worth exploring the new areas of application of this versatile device. Different users can choose different quality of electricity in this system. The key part of the customer quality control center is a UPQC, which assures high quality power to important users. Correa J.M. e reports the application of a UPQC in a high frequency AC micro-grid. The micro-grid consists of small generators with local loads. The UPQC, when connected at the high frequency common bus, compensates for reactive power, load current harmonics and voltage distortions.

III. LITERATURE REVIEW

SR. NO.	TITLE	AUTHORS	YEAR	APPROACH
1	Power Quality Conditioning in LV Distribution Networks: Results by Field Demonstration.	H. Hafezi, G. D’Antona, A. Dedè, D. Della Giustina, R. Faranda and G. Massa,	2017	Reported an interesting solution is represented by the open unified power quality conditioner (Open UPQC).
2	Effects of power quality limits on LV-network design,	M. Nijhuis and J. F. G. Cobben,	2016	Reported comparison and investigation of various requirements with respect to adequate earthing, voltage variations, flicker and overloading are
3	Smart distribution system Volt/VAR control using the intelligence of smart transformer	H. A. Gabbar and K. Sayed,	2016	Reported the dynamic performance of a smart distribution system
4	Protection analysis for plant rating and power quality issues in LVDC distribution power systems	A. Emhemed and G. Burt,	2015	Work discusses the international installation progress of LVDC systems and their relevant standards in different sectors
5	Power quality conditioning system based on Lithium-Ion Ultracapacitors for Electric Vehicles Quick Charging Stations,	A. Quadrelli et al.	2015	Work describes an innovative power conditioning system with energetic storage based on Lithium-Ion Ultracapacitors which have high performance
6	Harmonic emissions in grid connected PV systems: A case study on a large scale rooftop PV site	A. Chidurala, T. K. Saha, N. Mithulananthan and R. C. Bansal,	2014	Reported harmonic distortion issues accompanied with solar PV inverter due to variations in solar irradiance has been thoroughly analyzed.
7	Hybrid passive and communications-based methods for islanding detection in medium and low voltage smart grids,	A. Cataliotti, V. Cosentino, N. Nguyen, P. Russotto, D. Di Cara and G. Tinè,	2013	Reported an hybrid solution, for both low voltage (LV) and medium voltage (MV) applications,

H. Hafezi, G. D’Antona, A. Dedè, D. Della Giustina, R. Faranda and G. Massa, [1] Power quality in LV distribution networks is already a concern in many European countries especially where there is a strong presence of renewable energy generation. Therefore there is a growing interest in new solutions able to improve the power quality level of such a system. Among them, an interesting solution is represented by the open unified power quality conditioner (Open UPQC) proposed within the present work. The system consists of a single or three-phase ac/dc power converter installed at customer's premises and a main single or three-phase ac/dc power converter in the MV/LV substation. The work discusses the design, simulation and implementation phases related to an Open UPQC installed in a real LV distribution grid in the city of Brescia (Italy) within the smart domo grid project, co-funded by the Italian Ministry of Economic Development. Results from the field installation show the effectiveness of the proposed solution to face power quality issues in distribution networks.

M. Nijhuis and J. F. G. Cobben, [2] For the design of the LV-network, not only the requirements with respect to the loading of the cable play an important role, but also power quality aspects such as flicker and voltage variations should be taken into account. In this investigation, various requirements with respect to adequate earthing, voltage variations, flicker and overloading are investigated and compared. As the current approach with respect to the assessment of these quantities is limited, more risk based asset management approaches have been evaluated in this study. By evaluating these requirements for both rural, sub-urban and urban conditions, the differences in the driving factors for the LV-network design become apparent for geographical customer distributions. This study showed among others that the optimisation of the fuse breaking capacity based on the number of connected customers can for instance greatly increase the possible length of a LV-feeder. Moreover, for a network structure consisting of a single line the impedance based requirements, i.e. flicker and safety, are driving. If a branched network structure is used, the requirements with respect to voltage variations and overloading become more important.

H. A. Gabbar and K. Sayed,[3] This exploration presents the dynamic performance of a smart distribution system. A detailed power distribution system model has been developed with a smart electronic transformer using the MATLAB/ Simulink power systems simulation package. The results are presented using this simulation to illustrate the capability of Smart transformer units to assist with voltage regulation of LV feeders. Low voltage distribution networks are recovered from minor and severe perturbations in the AC system is verified. Simulations conducted on case study network representing a typical 4-wire LV distribution system under different load/generation conditions. The LV network fed on 22 kV distribution system through a smart transformer. The results demonstrate the improving the network power quality levels and eliminate the voltage unbalance.

A. Emhemed and G. Burt., [4] Low Voltage DC (LVDC) distribution systems have the potential to be considered as an efficient platform for facilitating the connection of more distributed energy resources. The applications of LVDC are still at an early stage due to the lack of mature experience and standards. Over and above, the protection challenges that are presented by integrating DC installations in existing AC systems are one of the key issues that are delaying the wide uptake of LVDC technologies. In response to these issues, this exploration discusses the international installation progress of LVDC systems and their relevant standards in different sectors. This includes data centres, buildings, and utility last mile distribution systems. The work also investigates the impact of using traditional LV protection methods on the performance of a faulted LVDC network, and on the associated post-fault power quality performance. A typical UK LV network is energised using DC and modelled in PSCAD, and used for the protection studies under different DC fault conditions.

A. Quadrelli et al., [5] Power Conditioning Systems (PCSs), also known as Active Filters or Custom Power, are innovative devices based on Power Electronics widely used on Medium Voltage (MV) and Low Voltage (LV) power transmission networks to improve the quality of power distribution and compensate local disturbances. Some of common features are improving the quality of the power supply of particularly sensitive loads to network disturbances, such voltage sag compensation or short interruptions, peak shaving, active power factor correction. Such type of devices, especially with the primary function of peak-shaving, are very suitable coupled with Electric Vehicle Quick Charging Stations (EVQCS) due the considerable power absorbed by them from the three-phase network (in our case 400 V-50 Hz) especially at the beginning of the charging (several kW for some minutes). In this way, the network will be relieved of high power peaks need that would cause an impact on utilities and necessary investments by the distributor. This work describes an innovative power conditioning system with energetic storage based on Lithium-Ion Ultracapacitors which have high performance in terms of specific energy and long service life. The device is designed and built to be a support for an EVQCS. The prototype is actually installed in the experimental area of Enel Ingegneria e Ricerca, located in Livorno, where a series of tests has proven its functionality and benifts for the grid. Future tests will be dedicated on interaction with a Li-ion storage system to improve energy services.

A. Chidurala, T. K. Saha, N. Mithulananthan and R. C. Bansal, [6] With rapid increase in installation of rooftop Solar Photovoltaic (PV) systems in low voltage (LV) distribution networks, power quality becomes a key area of interest. Among various poor power quality problems in LV networks, harmonic distortions, which could come from several sources, have become a major concern. The solar PV systems can generate harmonics itself. Besides this, the increasing use of power electronics based nonlinear loads and PV system penetrations in the network inducing harmonics lead to poor power quality resulting in overheating of equipment and malfunction of controls. In this exploration, harmonic distortion issues accompanied with solar PV inverter due to variations in solar irradiance has been thoroughly analyzed. Simulations have been performed in IEEE-13 bus distribution system with nonlinear loads to examine the harmonic emissions from conventional PV system for varying solar condition. To verify the simulation results and capture the trends harmonic measurements were made at the University of Queensland 1.2 MW PV site. The research has also proposed a control algorithm for the harmonic compensation. Simulation results confirm that the proposed controller has effectively eliminated the harmonic issues for varying solar conditions.

A. Cataliotti, V. Cosentino, N. Nguyen, P. Russotto, D. Di Cara and G. Tinè, [7] Islanding condition takes place when a distributed generator (DG) continues to power a part of the grid even if power from electric utility is no longer present. Adverse effects of islanding are power quality deterioration, grid-protection interference, equipment damage, and personnel safety hazards. For these reasons, DG systems must detect an islanding condition and immediately disconnect from the grid (anti-islanding protection). This work proposes a hybrid solution, for both low voltage (LV) and medium voltage (MV) applications, which makes use of passive and communication-based methods for islanding detection. Among the existing communication technologies, the study is focused on power line communications (PLCs). An interface device for DGs is presented, which implements the proposed method. An analysis of the proposed solution is carried out and its feasibility is showed, by means of simulation and experimental results.

IV. PROBLEM STATEMENT

The challenges posed by modern power systems and the search for better PQ has attracted more and more researchers into this field. Technologies such as Flexible AC Transmission Systems devices (FACTS) and custom power devices emerged as a result of continuous improvement of PQ. FACTS devices are applied in transmission level for reactive power compensation and power flow control. Therefore they improve the reliability and quality of power transmission systems. The application of power electronics to power distribution system for the benefit of a customer or group of customers is categorized under generic name-custom power devices. These problems may include unwanted harmonic current propagation from the load side into distribution networks, excessive VAR demand, voltage unbalance, or voltage fluctuation (sag/swell) in the utility. The UPQC installed as an interface between consumer and utility, aims to mitigate the VAR demand appropriately and provide additional fault ride through capability to its consumer. Considering the PQ and custom power issues and modern systems in the main power network, for improvement of the PQ in LV electrical network towards the customer, variety of configuration with electronic interface between network and loads have been introduced to electrical power system.

V. CONCLUSION

The work revived possible solutions for PQ and Custom Power improvement within a LV distribution network. If a power problem causes a failure or mis-operation in the electrical or electronic equipment that causes an economical and environmental loss. To detect the problems in the power line and determine solutions to these problems it is necessary to use power quality (PQ) monitor devices in the supply and demand sides. As technology improves PQ becomes very important since new and different electrical and electronics devices are available in the market. Managing harmonics in a power system is considered a joint responsibility involving both end users and system owners or operators so, harmonic limits are recommended for both voltages and currents. Harmonic voltage distortion limits are provided to reduce the potential negative effects on user and system equipment.

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