Active Power Quality Management (APQM) in Smart Micro Grids

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Abstract

In this manuscript, a new concept of active power quality Management (APQM) is presented. In which, instead of solely controlling the nodal power quality in a power system, the power quality is seen as a network level issue and a high level management method to deal with this issue in distribution networks is presented. Analogous to how Active Network Management (ANM) enables increased levels of hosting capacity for interconnection of DERs by managing thermal and voltage constraints, APQM maps consumer requirements and technical and regulatory standards to specific areas and actively manages operational power quality limits, rather than relying on interconnection planning screens. APQM includes re-structuring of distribution network and integration of renewable energy sources (RES) to increase the supply reliability for critical loads, smart management and optimized installation of power quality improvement devices (PQID) to enhance the distributed power quality improvement, adding ancillary functionalities to installed distributed energy resource (DER) power electronic converters to increase the cost-effectiveness of distributed energy resources. Last but not the least, in this paper, also coordinated control of the PQIDs and high-penetration non-linear loads will be discussed.

1 Introduction

Due to the increasing penetration of converter connected energy resources, consumer electronics, and on the other hand increase in, awareness of the public on power quality issues, penetration of power quality sensitive loads, smart metering devices, and etc., power quality is becoming an issue of high importance for utilities and consumers. The levels of power quality required on different nodes (or Zones) of the network are not the same, e.g. critical loads such as data centres, hospitals, communication systems require a high level of power quality that includes high availability, and low-distortion voltage and current [1, 2]. However, the power network can be susceptible to natural disasters such as hurricanes, earthquakes, and storms and the power network should be prepared for these events in advance to avoid any serious problems. Today, power quality delivered to customer points of connection is managed by static regulatory and planning rules that relate to voltage delivery limits, harmonic content limits, and supply availability. This means power quality delivered is within a tolerance threshold, often above or below the required service levels of different customers [3-5]. This standardisation has been historically important for planning methodologies that assume passive network operation and for the most sensitive customer loads. As the penetration of power electronic devices and non-linear loads is increasing in the power grid, these issues have an increasing impact on the power systems. Customers with power quality requirements more stringent than network wide standards, have been required to self-manage through the use of local site-specific PQ improvement devices. It highlights the importance of having different levels of power quality for different zones to survive extreme conditions or to flexibly satisfy the power quality requirements of different customers. Contrary to some power network issues that emerge from higher levels of the power system, power quality issues usually start from the distribution network level, which again makes the importance of distribution level power quality management clear. Power electronic based devices can support the power quality of the grid by locally compensating for the harmonics using active and passive power filters, voltage sag and swells using uninterruptible power supply (UPS), automatic voltage regulator (AVRs), dynamic voltage restorers (DVRs), reactive power compensation (STATCOMs), and similar issues [1, 6, 7]. Although this method of power quality improvement has been working until now, due to changes in the consumer load from both sensitivity and power quality pollution aspects, it will not be as effective as it was before. Furthermore, other than financial aspect of PQID installation, since most of the PQIDs are power electronic based, which may create other issue in power system stability and protection, adding single devices to improve the zonal power quality does not seem to be the best solution [8]. Instead, using the recent technologies to have an active management on power quality improving and deteriorating devices would be an alternative to adding more power electronic based devices to the power system. The concept of smart grids makes it easier to introduce the flexibility, resilience, improved power quality and the integration of RESs to the traditional power systems altogether. These objectives could be achieved by the means of modern metering and monitoring devices, fast and accurate communication systems, novel control methods for power electronic based RESs and distributed or central management systems [9]. Several solutions for this issue are presented in this paper including novel ideas on power quality management. These solutions include distributed, optimized installation of active or passive PQIDs based on the fundamental and harmonic power flow analysis [10], using different control methods to improve the quality of the output/input power in power electronic converters [11-15], getting ancillary services from power electronic based distributed generation units to operate as PQIDs and to actively control and manage high-penetration non-linear loads such as electrical vehicle supply equipment (EVSE) and heat pumps (HP) which is described in details in section 3.

2. Concept Definition

Fig. 1**Error! Reference source not found.**, represents the power grid today, where a mixture of different types of loads and consumers have different power quality requirements are supplied with power of same power supply and therefore experience the same power quality level. As the penetration of power electronic devices and non-linear loads is increasing in the such grids, these issues will have an larger impact on consumers, either through higher costs or lower power quality levels. On the other hand, power electronic based devices, can support the power quality of the grid by locally compensating for harmonics, voltage sag and swells, reactive power compensation and similar issues but as it is explained, this may not be the best solution.

Starting from the distribution level, a coordinated control method could be applied to high-penetration non-linear loads such as EVSEs or HPs. This coordinated control, unlike the previously proposed smart charge management methods for EVSEs that have concentrated on voltage and demand management [16], takes into account the power quality limitations when controlling the mentioned units. A high-level explanation of the coordinated control of EVSEs could be seen in Fig. 2. The active power quality management concept, shown in Fig. 3, combines a number of planning and management tools to supply different levels of power quality to different customers, with minimum cost and maximum reliability. At the device level, there are couple of solutions to maintain the required power quality, for example to minimize the output/input distortion of the power electronic based devices, new control methods are applied to novel converter topologies. Passive filters are one of the cheapest power quality improvement devices, but may not be as effective as they could be if used in isolation. A combination of passive, active and hybrid filters will help supressing the harmonics and locally compensate the distortions. Recently, the idea of utilizing the distributed energy resources converters for ancillary services has been introduced and deployed to support the power system by locally compensating for the harmonics [17].

With the falling cost of Information and Communication Technologies (ICT) and the proliferation of measurement and control capabilities, power quality planning and operation paradigms should be revisited to ensure they are optimal for the demands of today's grid. Not only are new power quality improvement solutions available i.e. smart impedances, electrical springs or multifunctional distributed generation units [18, 19] but through measurement and control, a variable and actively controlled level of power quality could be dispatched to meet the specific needs of customers in a network zone. In a world of increasing converter connected loads and DERs, there is doubt that if it is cost effective to actively monitor and manage power quality compared to passive operation managed through device regulations and planning level thresholds. So, active power quality management using planning and management tools to coordinate highly distorted loads, such as EV charge points and heat pumps, could ensure that the power quality levels of distinct zones are maintained within the defined limits.

Fig. 1. Today's power system with new power quality challenges

3 Methodology of APQM

Active Power Quality Management (APQM) as it could be seen in Fig. 3 makes use of existing and new power quality improvement solutions to improve the power quality of the power systems in a cost efficient way. As it can be seen in Fig. 4, the solutions in APQM include different stages summarized as,

- Customer and zonal assignment of required levels of power quality to be assigned by planning and engineering teams;
- Coordinated management of impactful loads (e.g. non-linear or unbalanced loads such as EVSEs), PQIDs and RESs with ancillary services;
- Active control and optimization of local/zonal PQIDs
- Prioritizing supply delivery to critical and sensitive loads during contingencies through network reconfiguration;
- Proactive islanding of operational zones during grid instability and low power quality events.

Power Quality Zones definition

Different zones of the power system need different levels of power quality, e.g. the power quality level required for a hospital is not the same as for an industrial district. Power quality can be managed with more flexibility in a zonal -

Fig. 2. Sample power system with coordinated EVSE management

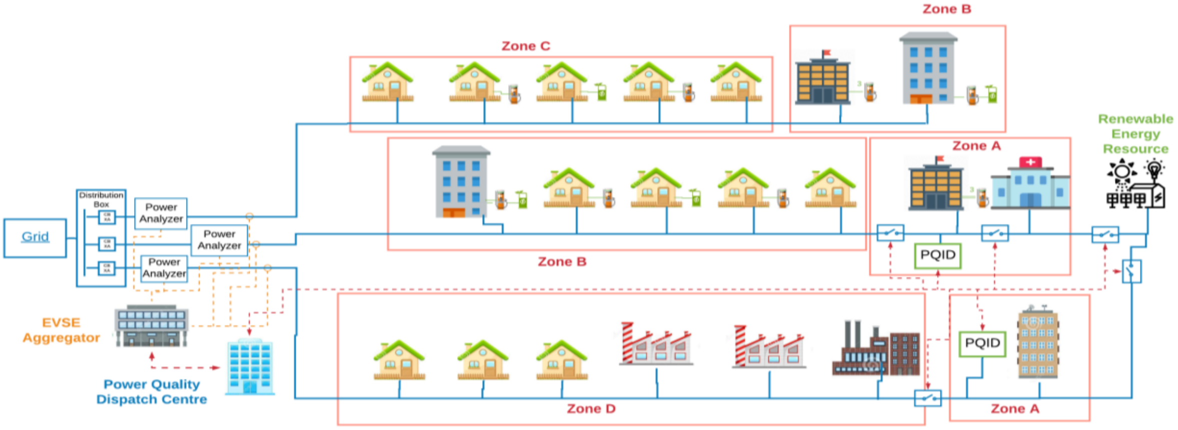

Fig. 3. Sample power system with active power quality management concept applied

network to satisfy the individual customers. By defining different power quality zones, within the power systems, the concentration on power quality improvement in zones with critical loads increases significantly, while having an acceptable power quality level for the other zones and keeping the costs at a reasonable margin. Power quality levels would be defined based on the, availability of the power, voltage and frequency stability, voltage and current distortions and resiliency to any types of natural disasters.

Coordinated control of EVSEs, PQIDs and RESs

The coordinated management of non-linear loads such as EVSEs or HPs is an active planning and management tool to support the increasing penetration of the EVSEs before reaching the nominal grid harmonic pollution level. This method, in a similar way to smart EV charging scenario, manages the charging events in a zone, having a two-way communication system with EVSEs to read their data and send required signals for the coordinated operation. The main advantage of this coordinated EVSE management is to bring in the power quality concerns into the optimized management. The concept of coordinated EVSE management, has been summarized in Fig. 2 which could be applied to any sample network even with different EVSE aggregators.

Optimized local PQID installation

Mapping locations of impactful loads, makes the power quality planning decisions easier to implement if required. If there is enough information about the load nature distribution, it provides a good support for local management of power quality issues. Active control and optimization of local zonal power quality improvement devices improves the device performance and maximises the efficiency by aggregated management of the power quality improvement devices.

Grid Reconfiguration and RES ancillary services

In this concept, the power electronic based distributed energy resources would have an important impact, to increase the power supply reliability as well as providing power quality improvement services as ancillary service. Any unused capacity of the converters could be used as active power filters, to locally compensate for current/voltage distortions.

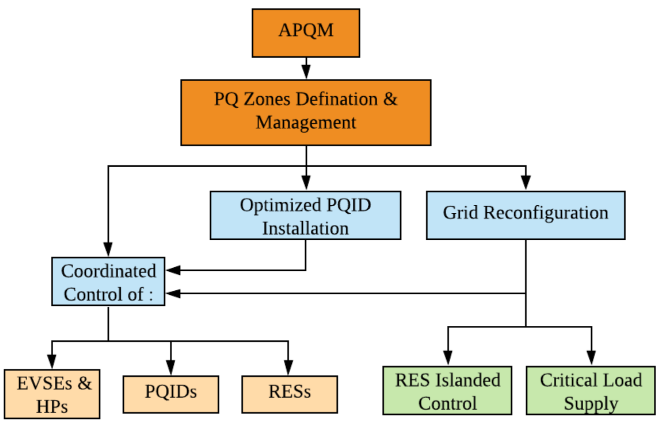

Fig. 4. The APQD simple principle

During contingencies and outages, distributed energy resources converters could behave as a grid forming converter, supplying the critical, high priority loads and supporting the black/grey start of the power grid.

All the mentioned layers are controlled with a central controller which does not replace the local controller but supports defining of different power quality zones in the distribution network. This concept grants the power system planning team more flexibility in dealing with power quality issues that are available today. As presented in Fig. 3, different solutions could be applied to each zone to individually improve the power quality without affecting the supply quality of the other zones. The existing power quality improvement devices, continue to operate. To satisfy the power quality requirement of the specified zone the only difference would be the additional aggregated control from the power quality dispatch unit.

4. Conclusion

In this paper, the concept of active power quality management in distribution networks is introduce. In order to have a power grid with multiple-levels of power quality, it is essential to have a management (dispatch) unit, which has a coordinated control over high-penetration non-linear loads, PQIDs, RESs, and also on the supply of power to critical loads through reconfiguring the power grid. In this way, a hierarchical control approach is applied to manage the power quality over the distribution network. This hierarchy starts from lower levels with coordinated control of loads and PQIDs and ends up with the high level control on central management of the power quality which guarantees different power quality levels to satisfy different customers based on their requirements.

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