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POWER QUALITY MONITORING IN SMART DISTRIBUTION GRIDS

MONITORING KVALITETA ELEKTRIČNE ENERGIJE U PAMETNIM ELEKTRODISTRIBUTIVNIM MREŽAMA

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Abstract: A trend of developing electricity distribution networks towards a concept of smart distribution networks has been noted for quite some time. Tendency to integrate all different systems installed in electricity distribution network has also been observed as a part of the trend. This creates the opportunity for distribution system operators to efficiently utilise the data from all the different systems and all the electronic devices, installed in electricity distribution networks, for more comprehensive and accurate network power quality (PQ) monitoring. This paper presents the possibilities of implementation of Integrated Power Quality Monitoring System (IPQMS), which should integrate all the PQ data from all the available systems in smart distribution grids. The concept of advanced IPQMS is also presented. Apart from integration of PQ data, it would also estimate the state of PQ in an analysed area, perform localisation of disturbance sources and suggest mitigation measures. Furthermore, the paper presents the possibilities, advantages and needs for implementation of such a system based on real measurement results from the electricity distribution networks of the Public Electric Utility Elektroprivreda of Bosnia and Herzegovina d.d. - Sarajevo (JP Elektroprivreda BiH d.d. - Sarajevo). The conclusion is that the implementation of IPQMS system is necessary if the complete information about the state of PQ in electricity distribution networks of the future is required.

Keywords: power quality, monitoring, smart grids, electricity distribution network

Sažetak: Već duži niz godina primijetan je stalni trend razvoja elektrodistributivnih mreža ka konceptu pametnih elektrodistributivnih mreža. U sklopu ovog trenda može se primijetiti tendencija integracije svih sistema instalisanih u elektrodistributivnim mrežama. Ovo operatorima distributivnog sistema otvara priliku da na efikasan način iskoriste podatke iz svih sistema i/ili elektroničkih uređaja, instaliranih u elektrodistributivnim mrežama, za potpuniju i tačniju informaciju o kvalitetu električne energije (KEE) u ovim mrežama. Ovaj rad prezentira mogućnosti implementacije integrisanog sistema za monitoring KEE (IPQMS), koji bi integrisao podatke o KEE iz svih raspoloživih sistema u pametnim elektrodistributivnim mrežama. Iznesen je i koncept naprednog IPQMS sistema, koji bi pored prikupljanja podataka vršio i ocjenu KEE na posmatranom području, otkrivao uzroke smetnji te predlagao mjere za otklanjanje ovih smetnji. Također, ovaj rad prezentira mogućnosti, prednosti i potrebe za uspostavom jednog ovakvog sistema na osnovu realnih rezultata provedenih mjerenja u elektrodistributivnim mrežama JP Elektroprivreda BiH d.d. - Sarajevo Zaključak je da je uspostava IPQM sistema neophodna ako se želi imati potpuna informacija o stanju KEE u elektrodistributivnim mrežama budućnosti.

Ključne riječi: kvalitet električne energije, monitoring, pametne mreže, elektrodistributivna mreža

INTRODUCTION

Power quality (PQ) disturbances, such as harmonic distortion, interruptions, sags, flicker, etc., are always present in the electricity distribution network to an extent. Due to the above, the equipment used in the networks is constructed with a certain level of disturbance immunity. Furthermore, almost all of the equipment connected to the electricity distribution network has its impact to the magnitude and waveform of voltage (emission of current harmonics, flickers, etc.), and therefore it introduces disturbances into the network themselves. Therefore, PQ is defined through suitable standards and norms (EN 50160, IEEE 1159, etc.), regulating allowed amplitude, duration and frequency of disturbances in PQ.

Process of liberalisation of power sector and treatment of electricity as goods, results in electricity becoming a contractual matter between a customer and supplier. In addition to price, quantity and delivery terms present in any supply contract, those for supply of electricity also contain the required level of delivered power quality, often tied to the above mentioned suitable standards and norms of PQ. In the Federation of BiH, starting with 1 January 2017, Distribution System Operator (DSO) is required to deliver electricity pursuant to the requirements of EN 50160 [1] norm. On the other hand, pursuant to EU Directive [2],

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producer (supplier) of electricity (goods) is not responsible for the damages caused by use of electricity, if proven that the product is not "faulty" or if the "malfunctions" are within the legally defined norms.

In order to comply with the contractual terms or appropriate legislative, i.e. to verify compliance with those, it is necessary to have the information on magnitude of defined PQ parameters of electricity delivered to consumers. Therefore, the very information on the PQ of electricity being delivered to the end user is one of the key requirements for full and normal functioning of the open electricity market. In order to provide the information to verify the compliance with relevant regulatory and/or other requirements, and to detect the source and responsibility for disturbances in the network, it is necessary to have measurement of the defined PQ parameters, i.e. PQ monitoring in electricity distribution network. As this is strictly the responsibility of the DSO, many DSOs all over Europe and the world decide to install a PQ monitoring system within their IT systems [3]–[9].

Considering a high price of purpose-built PQ monitoring instruments and an increasing need to measure and assess PQ in every point of common coupling, the recent work saw focus on integration of all available PQ data into one system, providing fuller and more accurate information on PQ in the electricity distribution network.

On the other hand, current electric power networks are faced with a lot of challenges, including: continuous increase of electricity consumption, variability in generation of power from distributed generators, connection of a significant number of electric vehicles to the distribution network. These are just some of challenges faced or expected in the coming future, which will change the concept of operation of distribution networks. They were traditionally designed and built, and operated as passive, with the aim to provide unidirectional energy flow from transmission network to the end users, and not for bidirectional flow of electric energy in the network. Development and evolution of existing electric power networks towards the concept of smart grids is therefore essential. Smart grids will optimally use the existing network capacities with relatively lesser costs necessary for installation of modern measurement, communication and control equipment and technologies [10]. Therefore, a smart grid requires firstly a high level of observability and controllability, which means installation of different measuring and control elements and systems [10].

Introducing the concept of smart distribution grid enables DSO to carry out PQ monitoring through intelligent integration of all available PQ data from different systems installed in the electricity distribution network, at the level of one single PQ monitoring system.

This paper presents a continued research of IPQMS, published in [11] – [14]. The paper [11] presented the concept of integrated PQ monitoring through implementation of IPQMS in smart distribution grids. This concept was further developed in [12], presenting the concept of data collection based on gathering of only the interesting and required PQ data, and not all data from all the devices. Upgrading of smart meters, to become a key component of IPQMS, was proposed in [13].

Compared to earlier research, this paper proposes the concept of an advanced IPQMS. In addition to gathering of data, it would also assess the PQ in the observed area, detect causes of disturbances and propose measures to mitigate the disturbances. Additionally, this paper presents the opportunities, advantages and needs to establish such a system, based on real results of implemented measurements in the electricity distribution networks of the Public Electric Utility Elektroprivreda of Bosnia and Herzegovina d.d. – Sarajevo (EPBiH). This paper presents the results of research carried out in [15].

After the Introduction, the first chapter presents three levels of PQ monitoring: i) power quality monitoring system (PQMS), ii) integrated power quality monitoring system (IPQMS), and iii) advanced integrated power quality monitoring system (IPQMS). The second chapter presents the opportunities, advantages and needs to establish such a system, based on real results of implemented measurements in the electricity distribution networks of EPBiH. The paper ends with the conclusions.

1. LEVELS OF POWER QUALITY MONITORING SYSTEMS

1.1. Power Quality Monitoring System (PQMS)

Power quality monitoring systems are based on PQ monitoring instruments, measuring PQ parameters defined in relevant standards and regulations (usually EN 50160, IEEE 1159, etc.). The parameters are measured in accordance with the measuring methods defined in IEC 61000-4-30 [16]. The purpose-built PQ monitoring devices, known as power quality monitors (PQ monitors), used for PQ monitoring, are usually designed according to [16], and have the ability to evaluate the PQ parameters pursuant to the current PQ norms (EN 50160, IEEE 1159, etc.) and/or other, previously defined limits for the locations they are installed in. However, the price of PQ monitors limits their use only at the selected "significant" points of electricity distribution network (a small number compared to all points of customer/producer connections, electricity exchange sites, etc.). Furthermore, any analysis of source of voltage quality disturbance cannot be simply determined by measuring the voltage quality in only one point (point of common coupling), but must be analysed through negative recurrent impact of all electricity distribution network users. In other words, this means measuring voltage quality in a large number of electricity distribution network's points. Usual architecture of PQMS is shown in Figure 1.

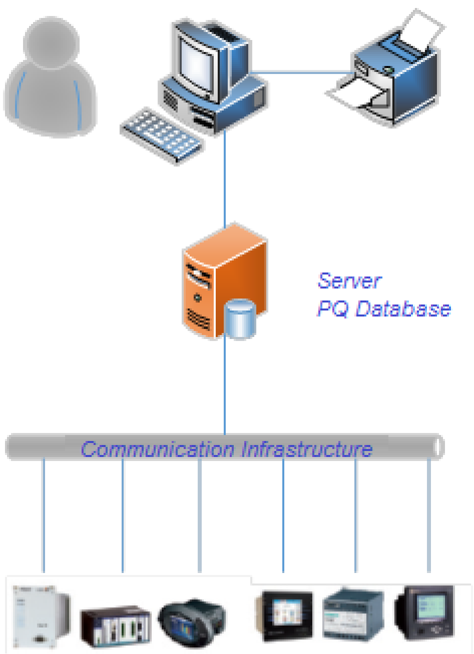

Figure 1: Power Quality Monitoring System (PQMS) [15]

On the other hand, development of electricity distribution network towards the concept of smart distribution grid, according to [10], is implemented through intelligent integration of all systems in order to efficiently provide for sustainable, economic and secure supply of electricity. Therefore, significant attention was paid lately to research as to how to utilise data from other systems and/or electronic devices installed in the distribution networks for other purposes. In order to assist DSO in PQ monitoring in "real time", i.e. the need of DSO to have PQ information from as many points/parts of electricity distribution network as possible, attention is lately being paid to integration of all available PQ data from the electricity distribution network at the level of a single PQ monitoring system.

1.2. Integrated Power Quality Monitoring System - IPQMS

Considering different levels of technological development and different concepts in development of certain systems, including:

- PQMS (Power Quality Monitoring System),
- SCADA (Supervisory Control and Data Acquisition),
- AMR/AMI (Automatic Meter Reading/Advanced Metering Infrastructure),
- EVMS (Electric Vehicle Management System),
- and other future systems,

there is no single architecture of integrated power quality monitoring system (IPQMS) in electricity distribution networks. It is being adjusted to the existing structure of the electricity distribution network and its concept of further development, as it is shown in Figure 2.

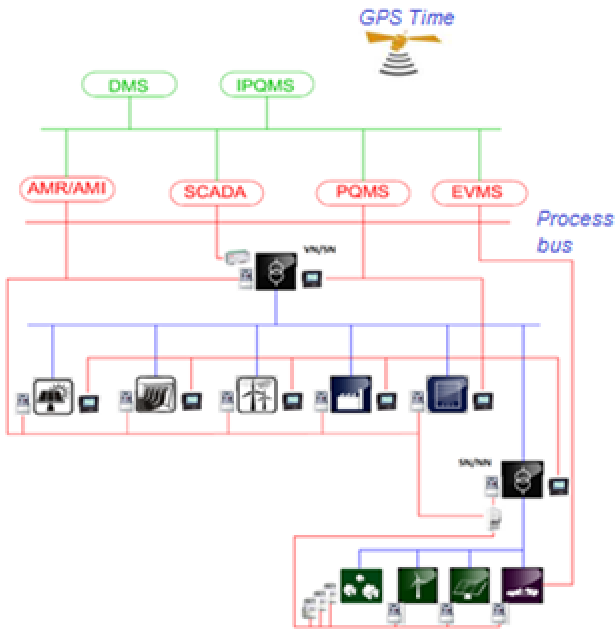

Figure 2: Principled IPQMS architecture [12]

The fundamental idea of IPQMS is to utilise all devices and systems useful for PQ monitoring in smart distribution grids, in order to complement data received from a limited number of purpose-built devices for PQ monitoring (PQ monitors). Figure 2 showed that the integration of data is carried out at the level of communication between individual systems, such as AMR/AMI, SCADA, PQMS, EVMS and others, with IPQMS. This means that the IPQMS uses the existing infrastructure of AMR/AMI, SCADA, PQMS, EVMS and other systems (data concentrators, communication infrastructure, software, etc.) for collection of PQ data. This also means that IPQMS uses the existing communication protocols used by the systems from which IPQMS collects the PQ data. Nonetheless, all individual systems must have the possibility of automatic data export into a single power quality data interchange format (PQDIF) [17]. This is a preferred format of data in IPQMS databases. Time synchronisation in all the devices is necessary for the purpose of comparing data from different systems and devices. Process bus, given in Figure 2, presents the future expected development of communication between individual devices of different application-specific uses, based on IEC 61850.

PQ monitoring has a potential to generate significant amounts of data, primarily due to number of norm defined PQ parameters, and number of potential measuring points in the network. Other systems serving as an additional source of information for IPQMS, such as AMR/

AMI, SCADA, EVMS, etc. (except PQMS), have not been designed for continued transfer of large amount of data. Nonetheless, satisfactory evaluation and analysis of PQ is only possible with sufficiently large PQ databases of these systems. The volume of collected data depends on the functionalities of systems and devices being the source of data for IPQMS, which varies from continual trends of smart meters and PQ monitors to voltage and electricity waveforms sampled with high frequency from PQ monitor and SCADA. IPQMS is usually implemented in a way that it firstly analyses alarm on violated PQ parameter, forwarded from measurement sensor through their corresponding system to IPMQS. Then, based on the kind and type of alarm, collection of necessary data required for analysis of the event is done from databases of each individual system. Therefore, when any of the sensors (PQ monitor, smart meter, protective relay and other instruments) detects a disturbance, i.e. violation of any of the PQ parameters, an alarm is forwarded through the corresponding system to the IPQMS. Based on topology (GIS database), and network topology (database available in SCADA), and the available measurement functionalities of individual instruments in the area, the IPQMS "issues" a request for collection of necessary data from all available sources (AMR/AMI, PQMS, SCADA, EVMS, etc.), required for PQ evaluation for the area in the observed time. Additionally, depending on functionalities and performances of the available measuring devices, IPQMS can request an additional data collection for the observed area, with the aim to complete the data needed by DSO for a quality disturbance analysis, detection of sources, and defining of mitigation or prevention measures.

Therefore, advanced software tools of IPQMS need full interoperability with other systems installed in the electricity distribution network or those currently under development, being a part of the future smart distribution grid, thus providing preventive actions on mitigation of network disturbances.

1.3. Advanced IPQMS

Each notification on PQ disturbance provides for timely elimination of the detected disturbance, by which a direct financial benefit is also provided. Accordingly, IPQMS not only provides DSO with continued PQ data collection from electricity distribution networks and a large number of points, interpreting them into practical and useful data, but it can also reduce financial loses users experience due to poor PQ and bring significant savings to the DSO itself (predictive actions, proactive management of PQ, or optimisation of funds intended for PQ improvement in the electricity distribution networks).

Introduction of an advanced IPQMS in current circumstances, using all available data on PQ and resources within the distribution network for PQ management, not only provides DSO with possibility to fulfil its obligations (determined through DSO licences), being responsible for PQ monitoring and management in the electricity distribution network, but it also brings financial benefit to both DSO and the community overall.

A contemporary or advanced IPQMS should primarily provide the following:

- detecting disturbances, i.e. violation of any PQ parameter,
- PQ evaluation in the observed area and defined time,
- detecting the source of disturbance,
- proposing mitigation measures or prevention of disturbance repetition.

The key difference between IPQMS and advanced IPQMS is that IPQMS solely collects and analyses the PQ data, while the advanced IPQMS should provide for detection of disturbances and propose measures for mitigation or prevention of disturbance repetition. Detection of causes of disturbances is possible only with application of advanced algorithms suitable for different disturbances, i.e. PQ parameters. Additionally, future smart distribution grids will have much more controllable devices in the network, of which some can directly influence PQ, providing elimination of PQ disturbances and prevention of their repetition.

Principal architecture of an advanced IPQMS is shown in Figure 3. This architecture is rather similar to IPQMS architecture, save the differences given further in text. System for registration of atmospheric discharges and meteorological data, with using correlation, can be used to detect sources and location of disturbance. An example of such available atmospheric discharge registration system covering Bosnia and Herzegovina is LINET. This system provides for registration of all atmospheric discharges with a rather precise geographical location and time of occurrence, which can be precisely correlated with disturbances in the distribution network (registered using PQMS, SCADA, AMR/AMI etc.), under the requirement of knowing the exact distribution line corridors. Furthermore, database of technical and geo-location characteristics of the

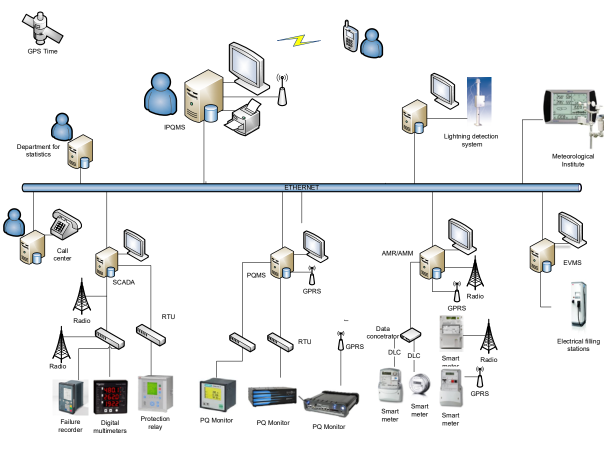

Figure 3: Principal architecture of advanced IPQMS [15]

distribution network of EPBiH - DEEO (Distributivni ElektroEnergetski Objekti, in English: Database of geo-referenced and technical data of electricity distribution system elements) should be used as a source of topology and network parameters data, required for PQ evaluation on the observed area and detection of disturbance sources and proposal of mitigation measures. Advanced disturbance source detection algorithms will be carried out at the software level, within the advanced IPQMS. Elimination of disturbances or prevention of their repetition must be implemented through interaction with other systems used to manage existing and future elements of smart distribution grids (e.g. SCADA for network management, AMR/AMI for demand management, EVMS for management of electric vehicle charging, etc.).

2. ADVANTAGES OF INTEGRATED PQ MONITORING AT JP ELEKTROPRIVREDA BIH D.D. - SARAJEVO

2.1. Description of pilot project of integrated PQ monitoring at JP ELEKTROPRIVREDA BIH D.D. - SARAJEVO

The possibility to use the available PQ information from the existing systems installed for other application-specific uses in the electricity distribution networks of EPBiH (AMR/AMI and SCADA) was assessed in parallel to implementation of pilot testing PQMS project in distribution networks of EPBiH, with the primary goal to test PQMS (different sites for installation of PQ monitors in the electricity distribution network, suitable communication and IT infrastructures, and suitable software tools for reporting and analysis of collected data). The PQ devices of Class A, based on [16], were used for additional verification of PQ data collected from the systems not primarily designed for the needs of PQ monitoring. Furthermore, justifiability and possibility of establishing IPQMS was also assessed during the testing on the real part of electricity distribution network. The goal of the pilot project was not to do a detailed PQ analysis in the sense of detecting sources of disturbances. Therefore, the impact of individual users and distributed generators on PQ was not analysed in detail.

A part of the electricity distribution network supplying a central area of the town of Bihac was selected for the analysis of possibilities to establish IPQMS and to verify the necessity for exchange and integration of all available PQ data and information into a single system. This area is supplied with electricity from the transformer station (TS) TS 35/10 kV Bihać, connected through a 35 kV transmission line with transmission network through transformer station TS 220/110/35/10 kV Bihac 1 and with Hydro Power Plant (HPP) Una (as shown in Figure 4).

During the period of testing at the selected area, a total of 6,866 users were connected to the electricity distribution network (6,831 users connected to low voltage (LV) network and 35 users connected to medium voltage (MV) network). Electricity is distributed through 36 secondary transformer stations TS 10(20)/0.4 kV (Figure 5).

— *35kV overhead line*

Figure 4: Geographic illustration of the observed 35 kV network [15]

—— *10 kV overhead line,* ----*10 kV cable line,*

10(20)/0,4 kV substation

Figure 5: Geographic illustration of 10 kV network of primary TS 35/10 kV [15]

Tested PQMS was based on architecture shown in Figure 1. Two fixed PQ monitoring devices were installed at the beginning and at the end of the 35 kV line TS 220/110/35/10 kV Bihac 1 - HPP Una, while the third device was installed at TS 35/10 kV Bihac, also located on this 35 kV line. Nonetheless, PQ monitoring was performed on 10 kV side (as shown in Figure 6). With the aim to assess the possibility of using PQ information from AMR/AMI system, an additional 5 smart multifunctional meters were installed within this pilot project (with new firmware installed, improved based on experiences from laboratory tests) along with an existing meter with an old firmware, used as control meters at sites and transformer station areas shown in Figure 6. All AMR/AMI system meters were connected through GRPS connection. Access to meters, needed meter parametering and collection of data were done remotely. Furthermore, data from numeric relays installed on sites shown in Figure 6 were used with the aim to assess the possibilities to use information from the installed SCADA system in the area for the future IPQMS uses.

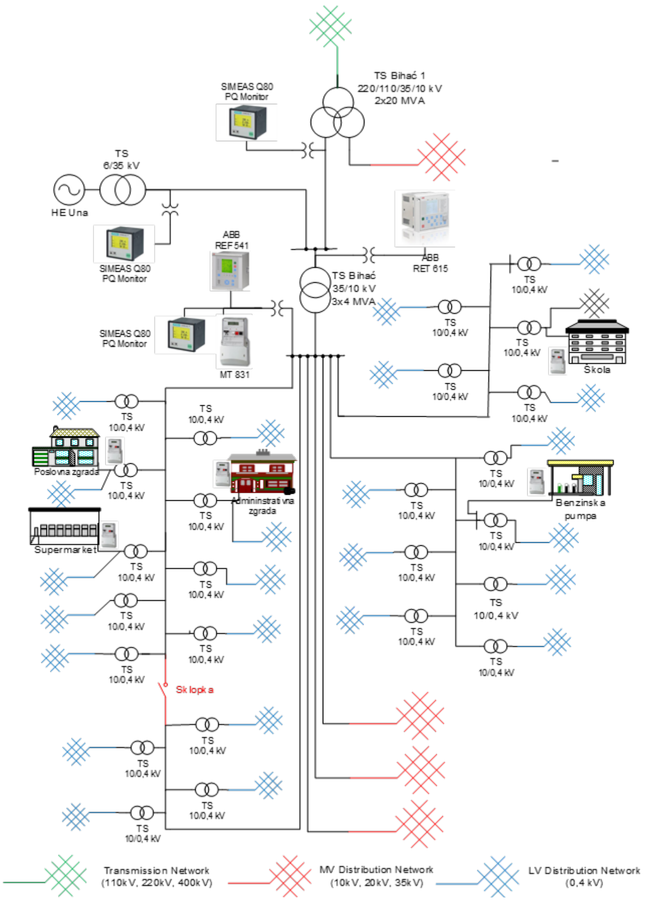

Figure 6: Principled distribution of equipment used in the observed area [15]

2.2. Advantages of PQ data integration

The following diagrams show the advantages of integrated use of data from these devices/systems for a more complete PQ information in the given area. Accordingly, the following graphs verify that DSO can have a more precise and complete information on distributed electricity to users in the area through use of information from all available devices in the given electricity distribution area (PQ monitors Class A, smart meters and numerical relays). Using only a part of the available equipment installed in the selected area (Figure 6) can show advantages of establishing a singular IPQMS. Here are several particular cases:

a) In order to carry out effective voltage quality monitoring in the selected 35 kV network, two PQ monitors were installed. Data from PQMS provided for monitoring of all PQ parameters in PQ meter installation points, i.e. this system provides information on effective voltage value on 35 kV busses in TS 110/35/10 kV Bihac 1 and HPP Una. Nonetheless, use of data from the existing SCADA system (from a numerical relay, Figure 6), installed at TS 35/10 kV Bihac, provides information on this parameter also in this point of the 35 kV network, in addition to a full information on effective voltage value in the observed network (Figure 7).

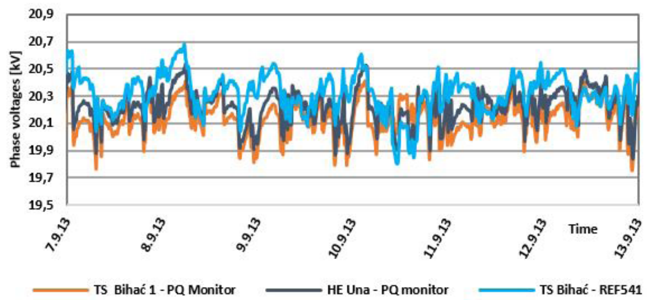

Figure 7: Voltage values in the 35 kV network of the observed area [15]

b) Use of PQ monitor installed at 10 kV measuring module of Ring Main Unit (RMU) at the TS 35/10 Bihac facility, and smart meter installed at MV customer (Fuel station), it is possible to secure a more complete/accurate information on effective voltage value in this part of the 10 kV network (feeder Bahovo). Figure 8 shows results of phase voltage measurements using PQ monitor (installed at 10 kV measuring module of TS Bihac), smart meter (installed at MV customer at 10 kV network) and control meter in 10 kV facility of TS Bihac).

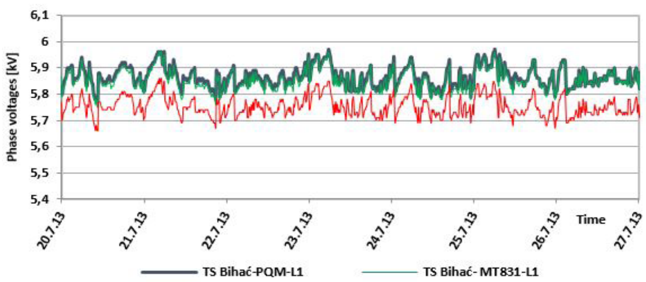

Figure 8: Voltage values in the 10 kV network of the observed area [15]

c) Use of data from smart meters installed in points of customer connection in LV network for the purpose of this research, can provide the DSO with a more complete information on specific PQ parameters of distributed electricity. Figure 9 clearly shows the advantage of using the available data from AMR/AMI systems for the purpose of PQ monitoring in LV electricity distribution networks. This advantage is rather important, because these parts of the electricity distribution network do not expect installation of a higher number of PQ monitors, nor electronic devices installed within SCADA system, while the PQ information about distributed electricity in LV network is very valuable.

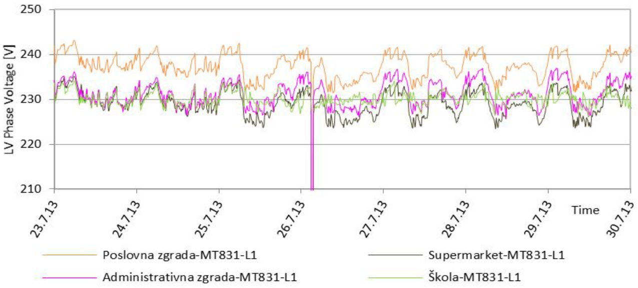

Figure 9: Voltage values in the LV network of the observed area [15]

d) Use of data on the effective voltage value from the available devices, installed on all voltage levels, can easily show the trend of voltage changes in this part of the distribution network.

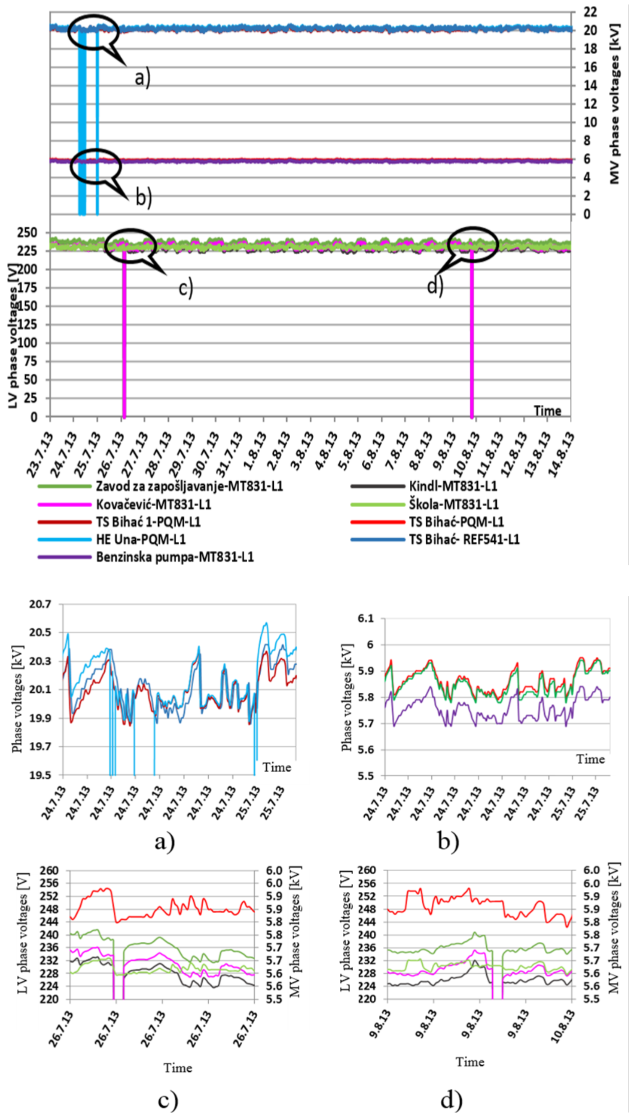

Figure 10: The trend of effective voltage value at the observed area of electricity distribution network [15]

Figure 10 shows that monitoring in all significant points of the electricity distribution network is required for a complete monitoring of voltage values. Namely, the loss of voltage at 35 kV bus of HPP Una does not mean the loss of voltage at the 35 kV busses of TS Bihac and TS Bihac 1 (detail a). Therefore, disconnection at HPP Una did not have a more significant impact on voltage valies in 10 kV network of TS Bihac (detail b). Also, voltage disturbance occured due to repair of a cable in LV network (detail c - disconnection and network reconfiguration, and d - connection and normal service restoration) was registered only at a part of customer locations in LV network.

e) Using the meters with new, upgraded firmware provides for monitoring of the voltage THD (Total Harmonic Distortion) trend in the whole observed area, as shown in Figure 11. Figure 11 clearly shows that the voltage THD values are somewhat higher in LV networks compared to MV networks, as well as that the trend of voltage THD change in LV networks does not accompany the trend of voltage THD change in MV networks (this can be explained by neutral point connection type of secondary transformer stations TS 10(20)/0.4 kV - Dyn5, acting as filters of the third harmonic). Taking into account the complexity of estimation of voltage THD value through the network, and the importance of voltage THD measurement data, monitoring of this parameter comes as a necessary and significant element of the future IPQMS.

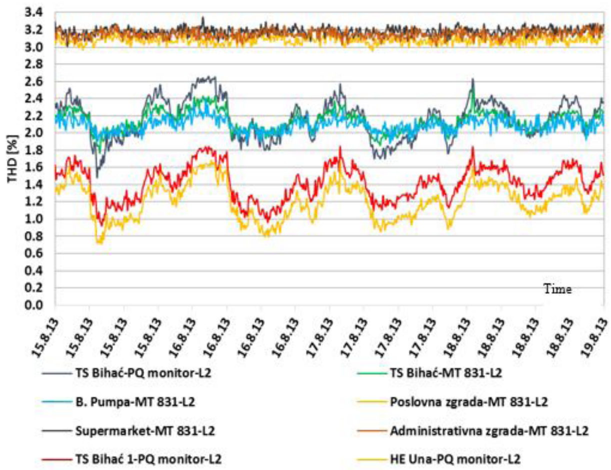

Figure 11: Mean 10-minute value of voltage THD on the observed area [15]

f) Data from the smart meter event logbook (Table I) provides for a significant source of information for the DSO on PQ of distributed electricity. The information on precise time of disconnection and reconnection of customer supply, loss and return of voltage of each phase, registration of time of voltage sags and swells are of specific importance. The information on disconnection of customers, taken from smart meters of the observed area, clearly shows that the information gained from PQ monitors only (installed, in this case, only at the MV network) does not provide the DSO with accurate data on PQ of electricity delivered to the end user in the LV network. Advanced IPQMS should carry out automated correlation of events from smart meters and events registered using other systems, as given in Chapter 1.3.

Table I: List of some events from smart meters on observed area during the research [15]

	TS Bihac	Škola	Zavod za zapošljavanje	Pumpa	Doo Kindl	Kovačević
30/05/2013 10:42	Over-voltage phase L1					
30/05/2013 10:47	Over-voltage phase L1					
...						
11/06/2013 13:37			Power down			
11/06/2013 13:42			Power up			
12/06/2013 06:03	Power down	Power down	Power down	Power down	Power down	Power down
12/06/2013 06:03	Power up	Power up	Power up	Power up	Power up	Power up
30/06/2013 16:14				Power down		
30/06/2013 16:18				Power up		
1/7/2013 9:01:23				Power down		
1/7/2013 9:05:15				Power up		
9/7/2013 14:56:14	Power down	Power down	Power down		Power down	Power down
9/7/2013 15:13:32	Power up	Power up	Power up		Power up	Power up
14/07/2013 05:56			Power down		Power down	Power down
14/07/2013 05:58			Power up		Power up	Power up
14/07/2013 06:29		Power down				
14/07/2013 06:30		Power up				
14/07/2013 08:02	Power down					
14/07/2013 12:45	Power up					
14/07/2013 14:14		Power down				
14/07/2013 14:16		Power up				

2.3. Necessity of integrated PQ monitoring through analysis of key measurement results

Necessity of integrating all available PQ data with the aim of more complete and accurate PQ information in distribution network (from energy received from transmission network - primary TS, to the place of electricity supply to the end user - metering point) can be observed from the following cases:

- Detected disturbances (voltage interruption) on 35 kV busses of HPP Una (Figure 10 - detail a), due to disconnection at HPP Una, do not significantly impact the PQ of delivered electricity at the observed transformer station area of TS 35/10 kV Bihac, in view of effective voltage value (Figure 10 - detail b), and THD voltage (Figure 12). In other words, using the data from smart meters installed at the points of common coupling, and data from the numeric relay at 35 kV bus TS 35/10 kV Bihac, one can justifiably presume that the electricity delivered to consumers in this part of the electricity distribution network was of satisfactory quality. Therefore, within the viewed parameters, DSO can determine that the disconnection and reconnection of HPP Una (as distributed generator) has no significant impact on PQ of distributed electricity to the consumers connected in the observed area of electricity distribution network, using only a small number of PQ monitors installed in the area.
- Voltage interruptions due to failure on Harmani feeder led to interrupted supply for 1,919 users in the following periods:
    - from 26/07/2013 at 02:44h to 26/07/2013 at 03:26h - period of network reconfiguration to establish alternative supply (Figure 10 - detail c),
    - from 9/8/2013 at 18:43h to 9/8/2013 at 19:28h - period of establishing the optimal network configuration (Figure 10 - detail d).

  Considering the fact that the test PQMS used instruments only at only three selected points in MV network (Figure 6), the information is available only using and integrating data from AMR/AMI and SCADA systems.
- Clear verification of advantages of integrating data available from AMR/AMI system is visible in Table I. Analysis of collected information on voltage interruptions, stored in the meter events logbook, leads into conclusion that the interruptions in the LV network are

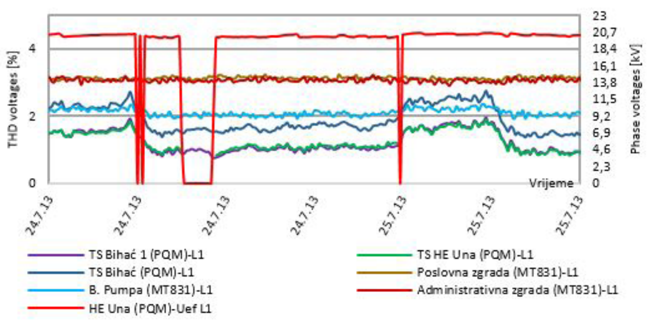

Figure 12: Voltage THD trend in the observed area at the moment of HPP Una disconnection [15]

frequently only of local character, at the following level: one MV feeder (e.g. registered interruptions on Harmani feeder, in the period 15/07/2013 - 06/09/2013), transformer station area of secondary TS 10(20)/0.4 kV, LV feeder of secondary TS 10(20)/0.4 kV, one customer (e.g. registered interruptions with Fuel station user, in the period 13/09/2013 - 18/09/2013), or just one phase.

3. CONCLUSION

From the above presented characteristic cases (although a small number of devices was used) it is easy to conclude that use of all intelligent electronic measurement sensors in the distribution network and integration of their PQ data into a single system (IPQMS) presents a necessity should one want to have precise and accurate information on PQ in the area. Using the data, DSO can identify areas with eventual PQ violations in a more precise and accurate manner, and carry out necessary checks through additional measurements (using portable PQ monitors Class A).

Several analysed characteristic cases lead to conclusion that the preciseness of PQ monitoring in distribution network depends on the possibility of exchanging all available PQ information. Therefore, full information and PQ analysis in distribution network requires establishment of a single IPQMS using all available data on PQ from smart distribution grids. Performed analyses show that the integration of PQ data received from modern electronic devices (smart meters and numerical relays installed in the network for the needs of AMR/AMI and SCADA systems) into a single IPQMS, provides DSO the possibility to overcome problems of insufficient number of PQ monitors installed within PQMS.

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