COASTAL DISTRIBUTION NETWORK POWER QUALITY MEASUREMENT

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ABSTRACT

The paper presents description and results of power quality measurements in a typical coastal distribution network. The measurements are performed over a long period of time (from 2004 to 2012) at different connection points in existing distribution network. Significant and relevant details of the coastal network are described and discussed. The measurements are part of power system studies, in particular harmonic studies, for networks in coastal regions, including specific types of loads like hotels, resorts, marinas, airports, apartment buildings, market centres and moderate size industrial plants. Such aforementioned loads may be source of negative effects regarding power quality in public distribution network. Obtained results are analyzed and the most significant ones are shown in the paper. The harmonics level are generally below stipulated limits, although in some cases obtained values are very close to them, i.e. power quality is good, although some degradations are possible. Results of measurements will be used as basic investigations for developing a specific generic model.

INTRODUCTION

Typical coastal distribution network, a type of distribution network that can be found along the Mediterranean coast and similar coastal regions around the World, is characterized by radial structure with relatively long medium-voltage lines (10kV) and short high-voltage cables (35kV), dispersion of power consumption at low voltage level and relatively short low voltage lines (0.4kV). The main occupations of such a region are services in touristic and related industry. As a result, some of these networks have experienced significant changes, due to intensive tourism development and building. With deregulation and wide spread connections of renewable energy sources (PV, wind generators and similar) as distributed generation at low and medium voltage levels, such networks may increase its complexity even more.

The loads are mainly concentrated in individual buildings, big or small hotels, airports, commercial centers (shopping malls), marinas, light industry and other facilities. Their demand is variable during the year, mainly two-seasonal: during the summer there is very high demand, while during the winter these networks operate at low capacity (except for some exceptional days, like New Year eve or similar). Further typical characteristic of these networks are relatively high level of reactive power, low power factor (cosφ) and possible large unbalance.

Some of the loads typically found in these networks are highly nonlinear and well known as power system harmonic sources (air conditioning, public lighting, electric supply of yachts in marinas, commercial and entertainment centers, leisure facilities, low power electronics, audio and video devices, PCs and similar). They cause numerous undesirable effects, such as resonances, capacitor bank failures, insulation overheating, short-circuit in cables, etc. The situation may become even more challenging in the future due to expected large increase in the use of electric vehicles in urban transportation as those will require construction of fast charging battery stations along main traffic corridors and in car parks. These devices, being highly nonlinear, will contribute further to increase in network harmonic levels. To be able to analyze different scenarios in such networks, especially for power quality purposes, relevant measurement activities should be performed. Overall harmonic measurement activities have been performed over a long period of time (from 2004 to 2012), according to international standards (IEEE 519 Standard and EN 50160, and using verified measurement equipment. All measurement was performed in Montenegrin coastal region, mostly in Distribution Unit in Tivat Municipality, as part of Montenegrin Electric Enterprise.

MEASUREMENT METHOD

Measurement was performed with two power quality analyzers: METREL MI 2192 and FLUKE 434. They are portable multifunction instruments for measurement and analysis of three-phase power systems in accordance with EN 50160 standard.

Power quality analyzers were connected at the point of common coupling (PCC), i.e. common electrical grids (usually available in transformer stations) in the distribution network. They recorded all relevant parameters, using values from secondary coils of current and voltage measurement transformers already existing in the network for measurement on medium and high voltage. For measurement on low voltage, the measurement values are taken directly from the grid.

Usually measurements were lasting 7-10 days in order to cover all expected signal dynamics in one working week. Total of 135 days of measurements were performed at 15 characteristic locations:

C1. Mediterranean marine 8 days
C2. Hotel complex 10 days
C3. Business and residential complex 8 days
C4. Shopping center 8 days
C5. Airport 5+8 days (two times)
C6. Equivalent individual household 8 days

C7. Apartment (multi flat) building 8 days
C8. Industrial plant 12 days
C9. Sports hall 7 days
C10. A small hotel 8 days
C11. Business trade center 11 days
C12. School and kindergarten 8 days
C13. Administrative building 7 days
C14. Water supply plant 9 days
C15. Commercial port 10 days

Measurements are based on the digital sampling of the input signals. Each input (3 voltages and 3 currents) is sampled 128 times in each cycle. Duration of the cycle depends on the frequency at the synchronization input (one of the 3 voltage inputs or a current input). At 50 Hz, the input cycle period is 20 ms. Measuring samples were taken in 10 minute intervals, according to IEC 61000-4-7. Root mean square (RMS) values of phase (line) voltages and currents, neutral current, as well as active and reactive powers were measured and saved.
The values of important harmonic parameters (THD_U, THD_I, HD_U, HD_I), power factor and some other indices are calculated at the end of each sampling period and the results are available on the display or are recorded. Fast Fourier transform (FFT) based results are only calculated on every 8th input cycle (every 160 ms, 50 Hz).
In a 3 phase systems with a normal 3 wire connection, the following values are not available for displaying and recording:

- Neutral conductor current
- Phase voltage-current angle
- Phase power factor

Flicker measurements: according to IEC 61000-4-15.

RESULTS OF HARMONIC MEASUREMENTS

All measurements in the network were carried out according to IEC 61000 and EN 50160 and for each characteristic load separately. Based on measurements in real network and in real operating conditions, different specific load models have been identified. Notation C1 to C15 was used for labeling each of different load types. The key information about harmonic characteristics of these loads related to measurements performed in the field, are presented in the sequel. Special attention was paid here on customers C1, C2 and C8 as the most interesting and the most significant for considered coastal distributed network.

Mediterranean marine - C1

A complex of highly nonlinear loads considered here is a see-side marina. The boats and yachts represent specific combination of nonlinear loads like rectifiers for charging batteries, small navigation radars, TV, audio devices and other electronic equipment, lighting, navigation instruments etc. Besides that, there are some office buildings, shops, residential apartments, street public lighting, traffic installations and other linear and non-linear loads supplied from the same point of common coupling (PCC). In addition, new facilities or buildings construction may add some specific consumers like derrick, pumps, cement mixer, reflectors, etc. Earlier harmonics measurements in 2004 at different points of the distribution network showed existence of total harmonic distortion (THD) of grid voltage at 35kV between THDU=1-5% (2.8% in average, $THDU_{95\%}$=4.1%) and between THDU=3-7% (4.1% in average, $THDU_{95\%}$=6.2%) at 10kV level [1, 2]. At that time in the area where nowadays is the Mediterranean marine, existed a Military shipyard. Harmonic measurements at the 35kV PCC of the shipyard in the transformer station (TS) where other public consumers are also connected, showed total harmonic distortion between THDU=1.5-4% (2.8% in average, $THDU_{95}$%=3.6%) [1]. Measurement, in new operational conditions on this site, was performed from September 17-24, 2009, after the new marina was built [2]. Connecting point for the marine site is in TS 35/10 kV on 35 kV busbar (Figure 1). The same point was chosen for connection of measurement equipment. Measurements included individual and total harmonic distortion of both voltage and current at all three phases. Special attention was paid on low order harmonics, like the 3rd, the 5th and the 7th ones.

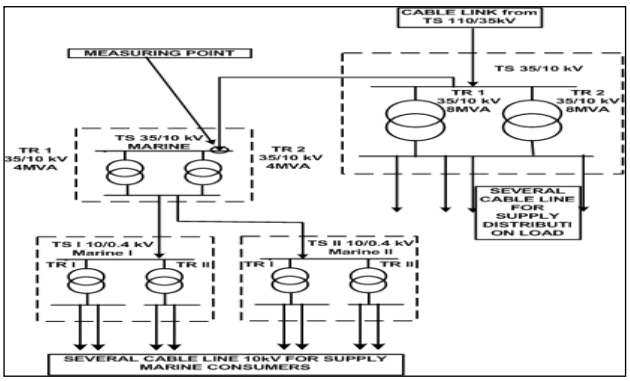

Figure 1 Single-pole scheme of marine supply

Measurement was performed by getting currents and voltages from secondary windings of current and voltage measuring transformers. Current measuring transformers have ratio 150/5 A, and voltages measuring transformers 35/0.1 kV. During the period of measurement, system was low load.

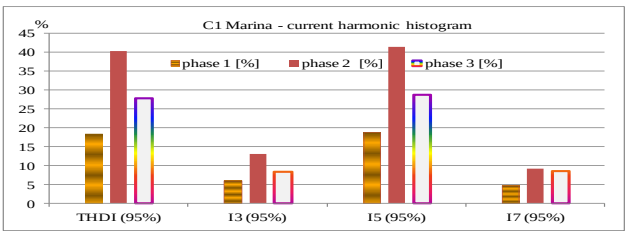

Figure 2 THDI and current harmonics of a Mediterranean marina

The results for each of three phases are shown in Fig 2. Total harmonic distortion of recorded current (THDI), as well as three dominant harmonics are presented. Measured values are given as 95% values (values which have not been exceeded during 95% of time). High percentage of the 5th harmonics and large unbalance can be noted.

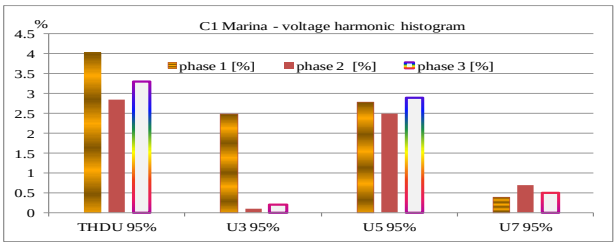

Figure 3 THDU and voltage harmonics of a Mediterranean marina

Figure 2 shows THDI, while Figure 3 THDU at the end of the cable line 35 kV for the marine supply. One of possible reasons for this situation may be connection of public (street) lighting solely on the phase "1", i.e. public lighting is the phase "1" dominant load. High current peaks in the phase "1" are happening during night hours (after 8:00h pm), and decrease in early morning hours. In addition, during working hours employees on building site do construction activities, using derricks and the other single-phase motor gadgets and some three-phase motor machines (big cement mixers e.g.). Also, it is possible that the 3rd voltages harmonic from 0.4 kV busbars Marine I and 0.4 kV busbars Marine II is flowing into higher voltage level network, due to winding of all transformers 10/0.4 kV are connected in Yy (Figure 1).
Therefore, all distribution consumers, connected on 35 kV busbar in TS 35/10 kV (Figure 1), may be exposed to negative impact of total activity on marine site.
It is very important fact to observe that measuring point is relatively far away from harmonic pollution source. Nevertheless, impact of the marine site activity was significant. During measurement period, overpassing THDU and THDI limits have been recorded. THDU is above limit in a very short period, so generally this is not a problem, as $THDU_{95\%}$=4.05%. However, THDI is over the 15% line in a long period. Based on statistics, problem exist in 12% measuring time (phase 1) up to 90% (phase 3).

Hotel complex - C2

This kind of hotel complex usually is equipped with high tech devices for air conditioning, video surveillance, smart lifts, smart rooms, modern kitchen equipment, internal TV system, etc. [3, 5]. The power quality measuring for a large hotel complex is realized because to establish waveform of hotel complex current is needed. In addition, very important think is getting information about the level of voltage and current distortions in the common point of access. Substation of 35/10 kV is electricity source for hotel complex. Part of capacity its available power transformers in substation 35/10 kV used by the operator of distribution for its consumers at low voltage.

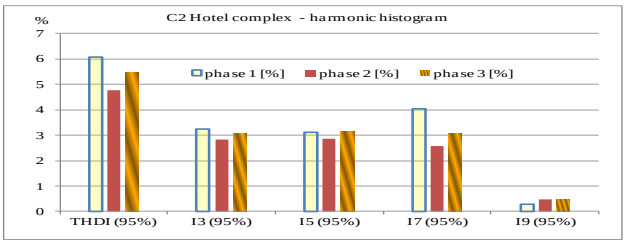

Figure 4 THDI and current harmonics of a group of hotels

Measurement was performed in the period from July 6th to 15th, 2009 and to fully according with EU standard EN 50160. The corresponding 10 kV cable, which connected on 10 kV busbar in substation 35/10 kV, is connection feeder for hotel complex substation 10/0.4 kV. This substation has four transformer units of the 1MVA, and because they usually connected in pairs of two, measurement was performed with two quality analyzers the Fluke 434. Figure 4 shows THDI as well as some individual harmonics. Single-pole schema of real distribution network with hotel complex position and measurement point is shown in Figure 5.

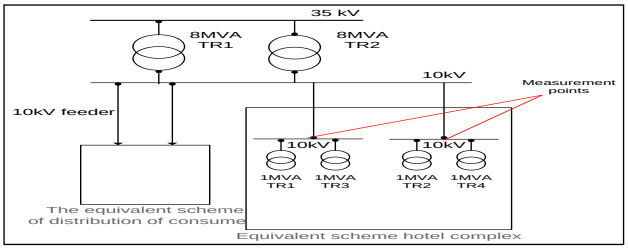

Figure 5 Single pole schema of the hotel complex connection

Load of TS 35/10 kV, in addition to this considered hotel complex, and make other distribution customers individually with less power, the household, as well as several markets and other retail outlets. Impact of a modern hotel complex on the real distribution network is significant. They all suffer, in greater or lesser extent, the consequences of a possible collapse of the parameters of quality in some conditions of the hotel complex. Measuring the place specified in the TS 10/0.4 kV in the hotel complex.
Generally, the consequences of the hotel do not feel the continuity, and cannot cause a disturbance in higher level than that stipulated in EN 50160. However, the default state of change short-circuit current on 10kV grid in substation in the hotel complex, it may further affect the variance of parameters. Dominant impact of the fifth harmonic of voltage on the THDU has been recorded. This is the recognizable characteristics of the distribution system.
Although the value THDU in accordance with the limits

defined in the aforementioned standards and not passed 5%, THDI in some phases passed values that are greater than limits. Namely, for 10 kV grid in consideration, the relationship between maximum current (load) and maximum short circuit current on the buses [3] is

$$20 < I_{sc}/I_L < 50 \qquad (1)$$

According (1) and results described in [3] is obviously that all values THDI greater than 8% could be problematic. This is especially emphasized for all days from July 11th, 2009 up to the end of measurement, especially for July 12th, 2009 after midnight, when the values reached level beyond 16%. Simultaneous activity of many nonlinear consumer in these hours (air conditioning, audio video equipment, a multitude of electronic devices for entertainment, etc.), which contemporary contribute to this effect, is obviously.

Industrial plant - C8

A large industrial plant has been picked for monitoring and taken into account for modeling of the network. It is a metal-refining factory that produces plain bearings for automotive industry, with electrolysis unit, electro-induction stove, press, bore unit and others. All measurements were performed from April 23rd to May 4th, 2004. Figure 6 represents the part of distribution network in consideration. Two Coastal Power Supply Units "ED Tivat" and "ED Kotor", both parts of Montenegrin Electric Enterprise, are connected at the transformer station TS 35/10 kV No.3.

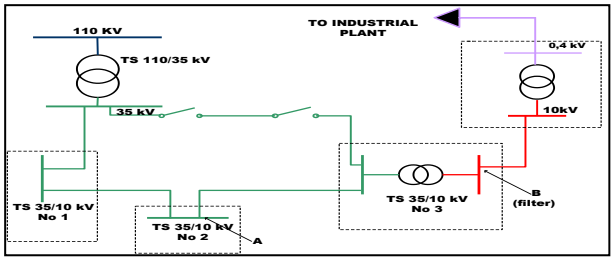

Figure 6 Supplying scheme-first case

Beside industrial plant into consideration the TS 35/10 kV No.3 substation supply other industrial facilities, individual households, a couple of warehouses and sales markets, too. All this consumers have constant problems during the operation hours of this industrial plant.

The prime reason for the measurements was rhythmic oscillation of ammeters needle during the day in all transformer station on 35 kV network. Further reason was consumer complains. The measurement site was selected to determine the cause and to follow the propagation of disturbance. Harmonic measurements were performed on two occasions and at two sites:

- at 35 kV voltage level in TS-35/10 kV No.2 at the point A, and
- at 0.4 kV PCC grid in TS 10/0.4 kV, from which the industrial plant is supplied.

Point A at 35 kV voltage level was selected as high voltage line, which supplies TS 35/10 kV No.3, as well as industrial consumer, is connected at this point. The transformers TS 35/10 kV No.1, No.2 and No.3 are connected in series regarding harmonic flow from the industrial consumers to the major TS 110/35 kV, which belongs to the "ED Tivat". Low voltage PCC at industrial plant was selected to determine which drive inside the plant is the main source of disturbance. In that sense several major units were selected and measured.

This highline connects two local distributive organizations and it transmits energy from transmitting network connected at TS 110/35 kV over TS 35/10 kV No.1 and TS 35/10 kV No.2 into TS 35/10 kV No.3. The largest consumers, which are supplied by TS 35/10 kV No.3, are induction stove, press, different frequency controlled drives and electrolysis systems. Method of measurement was indirect, by picking two phase currents and two line-voltages, from current and voltage 35 kV measurement transformers.

During the measuring period, an obtained harmonic current spectrum is presented on Figure 7. These results show that individual voltage harmonics at the point A are below, but close to the HDUnlim=3%, n≥3 limit according to IEEE-Standard 519 [8]. However, individual current harmonics (the 5th and the 7th) are above the IEEE limit (HDInlim=15%, n<11), while others are below. This shows that high distortion can be expected at point B, as 10 km of 35 kV highline, which connects TS No.2 and TS No.3, largely dumps this deformation.

More results are given in [4].

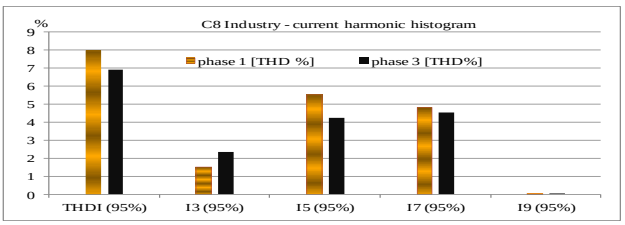

Figure 7 THDI and currents harmonics of an Industrial plant

It is clear that THDU reaches its maximum at night hours when majority of consumers are public lighting and households. Also, the 5th and the 7th harmonics have significant values during working hours of day when industrial plant is most active.

DISCUSSION

Many countries in political transition, due to insufficient or inadequate development has common problem in distribution system. Nowadays, we can see very intensive construction in Montenegro, especially in coastal distribution region with relatively weak network. Sometimes, this construction is not adequately supported with sufficient level of distribution network deployment.

Before the marina was built, the land belonged to a military shipyard, with specific loads, which generated certain level of harmonic distortion. At beginning of the marine constructing, part of loads were connected on existing distribution network. Based on measurement is obvious that existing network is not adequately for intended purpose.

To avoid further harmonic level increase, a new investor should built new, improved network for full capacity of load and for planed level of marine operation. Such conclusion is based on plans for intensive building of apartments, markets, modern hotels and the other supported objects in near future on this site. New network must be designed to provide the lowest occurrence of higher harmonics.

However, in the case that existing network remains in use with some improvements, than high level of harmonics can be expected. In that case, the problem can be solved by installing adequate filter or filters. However, installation and operation of filters are costly and in absence of national power quality standards there are no initiatives for situation improvement.

In addition, the problem of the appearance of the third voltage harmonic can be somewhat overcome by proper selection of a winding of transformer. With dominant load, such as shown industrial plant, power quality aggravates on the buses of coupling connection of high voltage lines. In this situation, neighboring consumers suffer the negative impact of industrial plants. It is questionable who and in which way should respond. Also, such negative effects produce untoward impact on the consumer itself, which results with frequent production breakdowns and production cost increasing. Before making reclamation to Power Company, this type of consumers, should analyze load characteristic of their own electrical devices. It is important for them to determine whether any device has negative impact to the other devices. Only after this reclamation to Power Company has its justification. The further open question is recompense of loses to consumers in one distributional company, which is made by consumer from other distributional company. Distributional company should make adequate regulations, which will determine conditions for connection of nonlinear consumers. In the conduction of deregulated market, it is clear that supplier is responsible for the power quality. In that sense, the largest consumers, which are significantly nonlinear, must be obliged to reduce level of harmonic distortion on the PCC.

CONCLUSION

Today, the simultaneous operation of many nonlinear devices in modern facilities in consideration, imposes the necessity of new ways of planning distribution networks, primarily it means the standard model of consumer adoption. Permanent measuring should be performed related to collecting all relevant information about network behavior. In countries with an attractive coastal environment and incomplete developed coastal distribution network, the challenges of modern construction can sometimes be high.

Results of long term measurement have shown, from power quality standard's point of view, relatively acceptable level. But, in certain situations, some of measuring values reached critical level (eg. *G. Apartment (multi flat) building-C7 when THDU passed 5% on certain day*). General conclusion is that obtained harmonics level are more or less below stipulated limits in standards, although in some cases they are very close to them (limits). The power quality is good, although some degradation is possible

All information collected by measuring are very significant for better understanding technical network behavior, especially if measuring period is as long as possible. From the other side, all of these data could be used for creating a simulation model - generic network for coastal distribution network, as a good tool for predicting the values of power quality indices and avoiding future possible negative effects [6,7].

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