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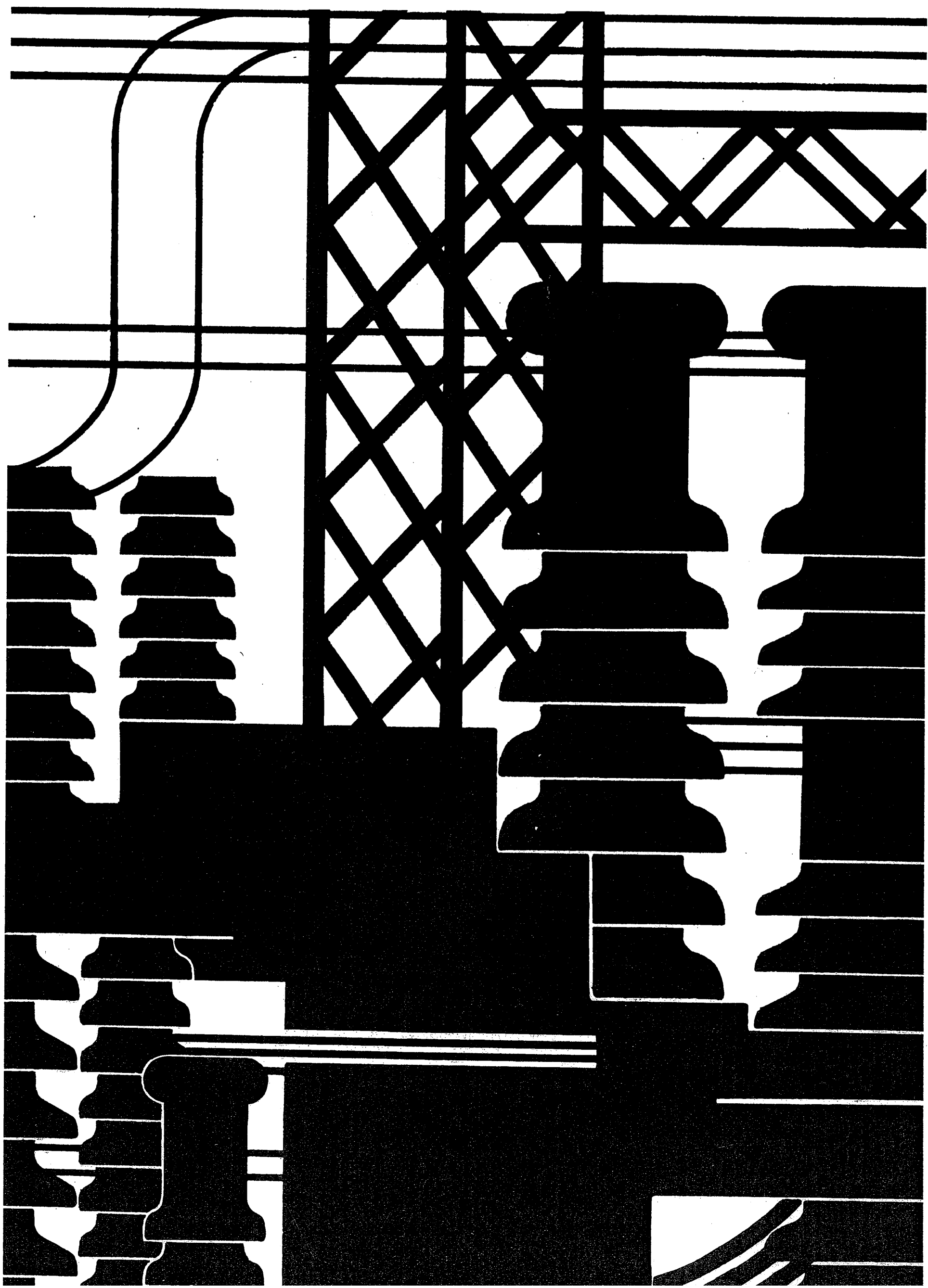

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HARMONIC DISTORTION IN MACEDONIAN POWER SYSTEM, THE NEEDS FOR ADEQUATE STANDARDS AND MEASUREMENTS UNDER DEREGULATION

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Summary: This paper is consisting from several parts. The first part of the paper, after the introduction, discus for the harmonic measurements performed in the Macedonian power distribution network according national and international standards. In the second part of the paper are presented the existing situation of the Macedonian metering system in the distribution network and where is the State owned Public Enterprise Electric Power Company of Macedonia (ESM) in the restructuring, privatization and deregulation process? The responsibility for harmonics under deregulation is discussed. Based on the power quality (PQ) existing standards is presented the needs for adequate standards and measurements in a deregulated process and its economic impact based. The PQ resulting from deregulation and harmonic distortion measurements results are presented and discus. At the end of the paper are made conclusions for the topics discuss in the paper

Keywords: **Harmonics, Deregulation, Power Quality**

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1. INTRODUCTION

Power electronics control at distribution level may mitigate voltage variations, harmonics and voltage sags. However, the increased use of power-electronics controllers may introduce new problems like additional harmonic voltage distortion, especially for higher order harmonics. In a competitive market, equipment manufacturers build the conversion elements in these systems only up to minimum acceptable levels, thus putting the burden upon the end user to either pay a premium for a higher quality conversion element or go without. We must understand that you can have harmonics and still have good PQ. Moderate levels of harmonics do not affect most equipment. While the presence of harmonics in the power systems of the contemporary commercial workplace cannot be denied, harmonics cause far fewer PQ problems than they are often blamed for. The proliferation of adjustable-speed drives (ASDs) and the presence of other non-linear electrical loads in distribution systems can cause significant degradation of PQ. They generate harmonics and subharmonics of the 50Hz or 60Hz power frequency. These unwanted frequencies distort the power waveforms and can interfere with the operation of sensitive electronic equipment, both in other parts of the plant generating the harmonics and in the distribution system. Filipski and Arseneau have measured various types of watt-hour meters and watt-hour meters and have demonstrated that errors exceeding 1 percent in induction watt-hour meters can occur with waveforms typical of those measured for ASD loads [9]. They recommend avoiding the use of inductive meters in nonsinusoidal situations, both for this reason and because of possibility of mechanical damage, which can occur when the meter is subjected to a change in the direction of energy flow several times per minute.

Today, electricity is generally sold from one supplier to one costumer, with ownership changing hands at only one physical point: the revenue meter. In contrast, after deregulation we can expect that the ownership of the commodity will be exchanged at several points along the generation/transmission/distribution chain. Like all other commodities for electric power there will be quality issues at each physical location where ownership is transfered. A variety of active equipment is now commercially available covering the full range of power ratings, from HVdc links and flexible ac transmission systems (FACTS) to custom power devices, and their role is likely to increase in the deregulated environment. Deregulation disperses responsibility for PQ, in the past it was clear, for the most part, that the utility was responsible for delivering some level of PQ to the customer. After deregulation, however, who is responsible for the customer's PQ? Also the increasing trend use of power electronic control at the generation, transmission and distribution systems following deregulation has PQ implications that will affect the standards and monitoring tools. Is there are adequate industry and utility – oriented PQ standards?

2. HARMONIC DISTORTION IN THE MACEDONIAN DISTRIBUTION NETWORK (FIELD MEASUREMENTS)

The objective in the present work was to perform a series of PQ measurements at metering points of different consumers to determine the levels of generated distortion. This paper presents the results of harmonic distortion surveys performed at six different locations, in the Macedonian distribution network. The sites were selected, based on the suspicion that these sites could be generating high amount of distortion. The characteristics of the six industrial locations are listed on Table 1.

Table 1. Sites location of the PQ surveys.

City	Type of load	Location
Skopje	Electronic equipment	Aerodrome
Bitola	Electronic equipment	Substation B
Ohrid	Welding equipment	A.D. EMO
Gostivar	Electronic equipment	Substation G
Prilep	Electric motors	Tobacco Factory
Skopje	Electric furnace	Steel Factory

The "NRM III" (German measurement system) was designed to evaluate different parameters from the voltage and current waveforms. The current circuits of the measurement system NRM III are connected in serial with watt-hour meter input current, but the current transformers connections has to be connected on the short-circuit bridges, used only for temporary bridges of the clamps that bring the current in and out the watt-hour meter. These bridges are removed as soon as the measurement instrument "NRM III" is inserted in the circuit. The measurements were carried out within a period of 5 to 8 days. The parameters evaluated were: voltage and current rms values; total harmonic distortion in voltage and current (THDV and THDI); and detection of the three most significant harmonics in voltage and current. This measurement system is based on the notebook computer with program for measurement control, measurement results processing, statistic processing of the results and review, as well as circuits for entering and processing of measurement signals, and adapting to enter in the computer for further processing. This instrument makes complete measurement each second and it always finds the average value of the measurement results in longer time intervals i.e. in one minute or in ten minutes. The sum of the voltage and current harmonics in the power system is accidental dimension which change from second to second, but still depends mostly on the "time of the day" and the voltage level. The measurement results are processed again statistically and subordinated in a curve of summation frequency or internal distribution curve, out of which 99% of 95% of the sum can be determined and evaluated. These sings mean that the certain sum of the harmonic included in that sum or smaller in 99% (or 95%) that the total measurement time. The largest sum of the harmonics which duration was very short in comparison to the total measurement interval (i.e. were larger only in 1% or 5% of the total measurement time) is rejected.
The total harmonic distortion in voltage and current were evaluated, based on the following expressions [13]

$$\% \mathrm{THDI} = \frac{\sqrt{\sum_{i=2}^{n} I_i}}{I_1} 100; \quad \% \mathrm{THDV} = \frac{\sqrt{\sum_{i=2}^{n} V_i}}{V_1} 100 \qquad (1)$$

where:
THDI, THDV = total harmonic distortion in current and voltage;
I_1, V_1 = rms fundamental current and voltage
I_i, V_i = rms i_{th} harmonic current and i_{th} harmonic voltage

Analysis of the acquired voltage and current waveforms would allow knowing the distortion levels in the Macedonian distribution network.

3. DESCRIPTION OF THE EXISTING SITUATION OF THE METERING SYSTEM IN MACEDONIAN DISTRIBUTION NETWORK

Residential customers require the largest number of points of delivery, followed by commercial customers, and then industrial customers. Approximately 650,000 induction watt-hour meters are in service in the Republic of Macedonia. Thus, the relative growth in the residential and commercial sectors suggests that the suppliers of electricity must concern themselves with such key issues as equity in metering, and efficiency and load management, at a much larger number of delivery points. The measuring sets installed in ESM's system belong to the older generation and they lack the possibility of objective reading of the engaged power, which amounts to approximately half of the invoice value submitted to the electric power consumer. Some of the measuring sets are so old-fashioned that, at their periodical calibration, they cannot be repaired, as the manufacturer has long ceased to produce the corresponding spare parts. Beside these consequences, which may result from both objective and subjective reasons, the problem of the measuring transformers (current and voltage) should also be pointed out, as they are, among other purposes, used for supplying the measuring sets. Namely, the positive legal regulations require their check every 10 years. According to the present conditions it has been concluded that a number of measuring transformers needs to be replaced, i.e. overhauled. This situation highly influences the correctness of electric energy and power registering and objective determination of electric energy losses. Having this situation the State owned Public Enterprise Electric Power Company of Macedonia (ESM) has to replace the metering system in the distribution network for many reasons: more accurate and simultaneous registration of the produced and taken over electric energy; remote reading of energy and power and energy within the distribution network and the interconnecting lines; adjustment of measuring points in EES of Macedonia into the future restructuring of ESM and improvement of PQ as one of the important issue.

4. THE DERGULATION PROCES IN THE ELECTRIC POWER COMPANY OF MACEDONIA

The ESM is closely following the restructuring and privatisation processes all around Europe. It is already identified that the needs for restructuring of the current monopoly is necessary to improve the overall performance and cash flow of the ESM and the entire energy sector in the country. For that purpose, few renown foreign consulting companies have already prepared several restructuring and privatisation strategies for ESM.

Additionally, having in mind that ESM has to operate in the common EU and Balkan Electricity Market, the restructuring of ESM must be done in the strong correlation with the EU Directives, especially Directive 96/92. A special Committee for Restructuring of ESM was established with main task to define the frameworks for future transformation and restructuring of ESM.

Taking into account the size, the current structure of the sources, fuels, transmission network and the large number of the existing distribution companies, it is envisaged that the best option for restructuring of ESM is its organization as a Vertically Integrated Company with different accounts for production, transmission and distribution of the electricity. Transformation of ESM into a Holding Company with various production branches is also one of the possible solutions for improving the business effects of the company.

For the privatisation purposes, ESM together with the German Consulting Company CONSULECTRA developed a Master Plan, which will be used as a model document during the coming privatisation.

The tender for selection of the so-called Promoter or Consultant for the privatisation with task to assist ESM and the Government of Macedonia through the privatisation process, has already been carried out. As a first step toward privatisation, ESM initiated its transformation from Public Enterprise into the Joint Stock Company with 100 % of the shares owned by the Government. Finally, as one of the necessary conditions for successful privatisation of ESM, it is establishing of so-called Regulatory Commission or Agency which will be responsible for issuing electricity licenses, definition of the tariff structure for production, transmission and distribution of the electricity, and for setting all kind of disputes between parties in the fully liberalized electricity market in the Macedonia and wider. The first draft documents for establishing of the Regulatory Agency are already prepared by the American Consulting Company, Pierce & Atwood.

Having all said above in mind, one can see that ESM strongly committed itself to move in the direction of establishing a new market oriented power company which will be strong partner to the neighboring power companies in near future. With the help and support from the Government, it is estimated that the Macedonian energy market will be 30 % liberalized by 2003, and fully liberalized by 2006, for which Macedonia already signed a Protocol with all neighbouring countries on September 1999, in Thessalonica, Greece.

5. HARMONICS UNDER DEREGULATION

In a deregulation the ownership of commodity will be exchanged at several points along the generation/ /transmission/distribution/end user chain. Like all other commodities for electric power there will be quality issues at each physical location where ownership is transferred, at the point of common coupling (PCC). As the utilities deregulate, the electricity sold on the market needs to be clean (no excessive harmonics). The price and terms of the electric service will be determined in the competitive market place and will be negotiated on case-by-case basis. To avoid the "not paying something that you did not order" the contracts between different entities involved in a deregulation will have to address issues of PQ requirements with energy service company (ESCo) or at PCC with special contracts. Figure 1 illustrates the important relationship where harmonics considerations will be included in the contracts.

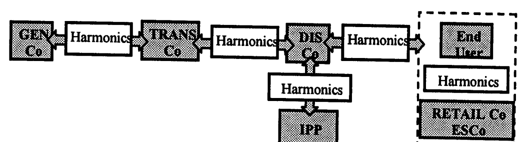

Figure 1. The PCC in a deregulated power system

The typical hydro and thermal generation company (GenCo) use synchronous machines, which normally produce pure sinusoidal current. Non-conventional GenCo like wind and solar power usually uses dc generators with inverters to gain in efficiency. The process of dc to ac conversion leads to harmonic generation. At the network connection point, the fundamental power as well as harmonic powers will flow towards the network. The transmission company (TransCo) is responsible for the voltage being supplied. The distribution company (DistCo) or customer (EndUser) is responsible for harmonic loading of their

systems, created by nonlinear loads with the facility. The small IPP may be located on the distribution system, creating a need to define the PQ requirements for the interface. One of the important requirements to consider for the IPP is the harmonic characteristic of the generated current.
This all will typically be defined in terms of harmonics current limits at the PCC, as described in [1], or in the PQ standards under development.

6. NEEDS FOR ADEQUATE STANDARDS AND MEASUREMENTS TO SUPPORT DEREGULATIONS

Standards are related directly to the measurement requirement. Although systems operation and market transactions concerns differ in many import aspects, they are also insupportable and often complementary.
There is tide connection between the Energy Service Company (ESCo) cost of power supply and its PQ.

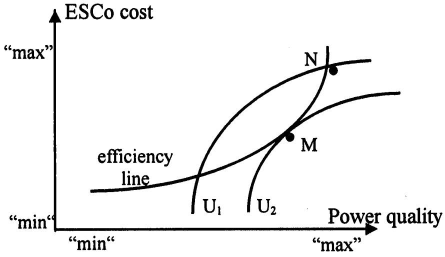

Fig. 2. Cost that provide a given level of utility

Figure 2 shows the indifference map for a single consumer. It represents the preferences of the consumer between power cost and PQ. The consumer's economic well-being or "utility" is constant along each curve: higher numbered curves have higher levels of utility, U_1, U_2, The point, (M), where the consumer's utility curve and the efficiency curve are tangent represents the cost/quality combination with the highest possible utility given the present technology and market structure embedded in the efficiency curve. Historically, utilities have had incentives to invest in capital assets to maintain reliability potentially beyond the point that is economically efficient from a social planner's perspective. For example, they may be operating at point N in Figure 2. With deregulation suppliers are expected to conduct an explicit assessment of the trade-off between the cost and quality of electricity service. Measurement and standards have the potential to contribute to the outward shift of the efficiency curve. Without adequate measurement and standards, the full shift in the efficiency curve envisioned for deregulation may not be realized. Figure 3 illustrates the potential impact of measurements and standards. For example, without adequate measurement and standards, additional cost may be needed to maintain the PQ of the system (S_1), or, without adequate measurements and standards; the quality of electricity service may decrease given available costs (S_2).

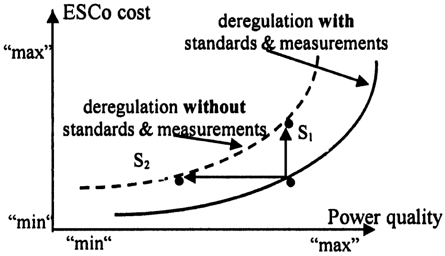

Fig. 3. The deregulation with and without standard and measurements

In the [1] have been some significant changes made since it was first published in 1981. The main emphasis in these changes has been to establish an approach to set harmonic limits on individual power consumers that will result in reasonable harmonic voltage distortion on the utility power system. An overview of the major changes to these harmonic standard follows. The major difference in the recommended practices is the introduction of current distortion limits. There are different current distortion limits depending on which categories the particular power system falls into. On the one extreme of this spectrum is a power system that seizes 1 or 2 large customers. The other end of the spectrum is a power system that serves many small customers. Different current distortion limits are assigned based on which category a particular power system falls into. The idea behind this is to allow individual power consumers their fair share of harmonic current distortion while assuring that voltage distortion at the PCC does not exceed 5% THD (barring a significant parallel resonance at a harmonic frequency). Utility-oriented PQ standards are under continuous development [2]-[7]. These types of standards can be used to set a common quality basis for competition between suppliers, and they should create a minimum-acceptable level of PQ. The European standard already contains some well-defined margins for harmonic distortion and other variations [6]. Industry needs to establish uniform and complete PQ measurement standards so that data can be compared (over location, over time, etc.) and disputes resolved. Standards such as IEC 61000-4-7, which cover harmonics measurements, are a good mode, but only in quasi-stationary waveforms can be used. In the categories indicated in the standard and at points of power interchange between different companies it is necessary to perform real-time continuos measurement. IEC 77A Working Group 09 has made enormous progress in his area [11]. It is far less expensive to inform manufacturers about the real level of PQ that is available than it is to attempt to improve the level of PQ. Some industries, such as the semiconductor industry, have already developed their own standards [12]. Next to these industrial initiatives, a serious effort is needed from standard setting organizations like IEC and IEEE, to publish requirements for equipment immunity against voltage sags and short interruptions. Some of key areas where standards may contribute to the needs of deregulation include the following: measurement and communication of transmission system dynamic performance (e.g. system transient behavior, and monitoring of voltage collapse) to system operators; more frequent measurement and communication of distributed generator output (aggregated) to system operators. For example, standards are needed to increase the amount information returned from generation. In particular, system operators need better information of the timing of loads being generated;

Standards are needed to establish a minimum set of functionality. Establishing functionality standards will promote competition and lower barriers to entry. Standards will be needed to provide proper pricing signals for transmission services. For example, new tools/procedures are needed to help the market value power at bulk transmission interfaces. These include new measurement and reporting procedures to collect and distribute information on utilization of these interfaces. More precise measurement of PQ, especially harmonics, flicker, sags, and surges to support contracts that were previously not in place or that were not explicit if they were in place.

From the above explanation we can see that measurements and standard are needed to support the deregulation and more work is needed on PQ standards that can be used by utility, industry and equipment manufacturers.

7. PQ RESULTING FROM DEREGULATION

The Table 2 identifies key concerns associated with deregulation of the electric power industry. The impacts of high/medium/low presented in Table 2 are based on information obtained from the literature revue, through e-mail and telephone interviews with many world-vide industry experts.

Table 2. Impact areas associated with deregulation

Concerns associated with deregulation	Potential economic impact	Importance of measurement and standards	Variation in opinion
Power quality resulting from deregulation	High	High	Low

About the impact measurement and standards may have on PQ to end-users or on the development of markets for differentiated PQ-hence the variance for the impact area is "high". For each economic impact area presented in Table 2, we discuss the potential economic impact, the importance of measurement and standards and the variance of response opinion below.

Potential Economic Impact (High). PQ issues will become increasingly important with the increase use of sensitive electrical equipment. The cost of poor PQ includes equipment failures and lost productivity of labor and capital. The cost of poor PQ includes equipment failures and lost productivity of labor and capital. That is the reason that companies wont to have a PQ SMCs[13], or additional and more specific standards associated with PQ under deregulation.

Importance of Measurement and Standards (High). Increasing use of power electronics (electronic ballast and adjustable speed drives) is increasing the injection of harmonics and flicker into the power system and creating problems for loads susceptible to PQ problems. Standards governing acceptable power performance and measurements to locate the source of problems are needed to maintain or increase PQ.

Variation in Responses (Low). Respondents indicated that may PQ problems be able to be solved with improved measurement capabilities, which could then help move the development of standards forward, and that the potential benefits are large, and the opinion of the interviewers was similar.

8. HARMONIC MEASUREMENTS RESULTS

The THDI values in general exceeded the 5%, as expected. From Table 3, it can be seen that in some locations (Aerodrome, Substation B, A.D. EMO, Tobacco Factory and Steel Factory) the recorded $THDI_{max}$ was high.

Table 3. Minimum, maximum, average THDI values.

	Phase A			Phase B			Phase C		
Location	min	max	avg	min	max	avg	min	max	avg
Aerodrome	3,02	12,3	6,63	3,31	12,4	6,58	3,18	11,7	6,55
Substation Bitola	1,52	8,44	3,45	1,45	8,82	3,49	1,65	9,54	3,88
A.D. EMO	0,78	37,5	5,12	0,96	42,3	4,59	0,70	45,7	5,49
Substation Gostivar	0,00	3,98	2,74	0,00	3,99	2,85	0,00	3,87	2,63
Tobacco Factory	0,00	14,1	2,24	0,00	26,3	1,88	0,00	31,2	4,52
Steel Factory	0,00	740	31,1	0,00	424	19,5	0,00	230,	19,6

Table 4 shows that only one location, Aerodrome, had HDV_{max} above 5%. All the other locations presented acceptable THDV values (less than 5%).

Table 4. Minimum, maximum, average THDV values.

	Phase A			Phase B			Phase C		
Location	min	max	avg	min	max	avg	min	max	avg
Aerodrome	1,33	5,99	2,43	1,41	4,25	2,39	1,35	110	2,55
Substation B	1,01	2,89	1,99	1,10	3,30	2,26	1,07	3,38	2,26
A.D. EMO	0,40	3,69	1,29	0,59	3,98	1,43	0,37	4,21	1,31
Substation G	0,49	1,80	1,22	0,73	2,11	1,51	0,43	1,76	1,16
Tobacco Factory	0,26	3,21	1,28	0,20	3,21	1,16	0,26	2,94	1,13

Steel Factory	0,30	3,94	0,99	0,41	2,67	1,09	0,46	3,43	1,18

However, the $THDI_{max}$ occurred only at some particular samples. Therefore, THDI average values represented a more realistic behavior of the current distortion.

From these average values, it can be observed that only Substation G, Substation B and Steel Factory presented less than 5% in THDI.

9. CONCLUSIONS

At the measured locations of the distribution network in the Macedonia, the percentage THD average value was not equal to or below than 5%. This is not agrees with the standards established [1].

Even when in all locations the THDImax values were much higher than 5%, they should not be considered as the most representative values because they are instantaneous values. Instead, THDI average values must be taken as the most significant values. Three locations (Aerodrome, A. D. EMO and Steel Factory) presented a THDI average high above the allowed 5%. The nature of the loads, (arc furnace, motor drives, and variation of solid state and power electronic equipment) confirms the high distortion produced to the current.

The dominant harmonics found in the current harmonics content at max THDI were mostly the 3rd, 5th, 7th, and 9th in different percentages depending on the location. From all this conclusions, it can be established that the induction watt-hour meters installed at industrial locations are actually working under different distorted conditions and have to be replaced.

If ESM has to operate in the common EU and Balkan Electricity Market, the restructuring of ESM must improve the measuring system and PQ issue, you can't control if you can't measure and monitor.

The deregulation of the power system affects PQ at two major aspects. Firstly, deregulation brings more PQ problems. For example, under deregulation, distribution generation will contaminates the power grid as a whole. A large amount of FACTs equipment applied to facilitate or realize the deregulation process may greatly deteriorate PQ. Secondly, in a deregulated power system, PQ becomes more important to both the energy supplier and the energy consumer. At the mean time, both the utilities and the end users are responsible to the PQ. The responsibility should be distributed fairly. Deregulation is not expected to increase the harmonic distortion problems but is likely to highlight the existing one.

Measurement requirements and related needs for standards development is, or needs to be, underway in several areas to help secure the benefits that are potentially available in a deregulated electric industry. A decision on whether to pursue standards in any area requires a prospective assessment of the benefits and costs of standards for that area. Retrospective assessment of the benefits and costs of standards for that area. Retrospective assessment of these benefits and also valuable, not so much to affirm or withdraw the original decision, but to help refine the techniques and areas of investigation in assessments that will be made in the future.

Estimating that PQ problems cost U.S. industry about $26 billion a year in lost production or equipment damage, with the single shutdown costing as mush as $500,000 per hour [13].

PQ problems that are currently costing European businesses are more than 10 billion Euros per year. In the year 2000, 50% of buildings in Germany were found to suffer from data loss in information technology equipment and computer lockup [14].

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