Developing a new algorithm to participate power quality variations in tariff: an experience in Iran

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Keywords: Power Quality, Tariff, Economic Penalty, Voltage Sags, Harmonics, Flicker

Summary:
Many industrial and commercial electric customers require a higher level of power quality due to increasing sensitivity of sophisticated process controls and the growing reliance on computers. These customers are especially sensitive to momentary voltage sags caused by remote faults on the transmission system or on neighbor low voltage feeders. Customers are also applying more and more equipment that can cause harmonic distortion problems (e.g. adjustable speed drives). In this problem utilities and customers should clear some following important point:

• Who will be responsible for the quality of power being delivered in the regulated and deregulated utility industry?
• What is the base level of power quality that must be supplied by the utilities to the end use customers?
• What kinds of enhanced power quality services can be offers to the end use customers by utilities?
• What is the difference power quality concepts and requirement between regulated and deregulated networks?

The answers to all of these questions must be developed in terms of the contracts between utilities and customers or in other words in tariff.

This paper propose an efficient approach for power quality consideration in contract between customers and utilities in Iran regulated electric systems, however it could be implemented for the other countries by some little changes. Also results can be extended to deregulated systems. The more attention in this paper is voltage sags, harmonics and flicker.

The Proposed approach for consideration of tariff in PQ power quality:

The General algorithm of approach is as follows:

• Specification of Permissible Levels (PL) and Emission Limits according to standards (IEC-868, IEEE 1346 and IEEE 519).
• Specification of efficient indices for determination of power quality conditions for customer with respect to load sensitivity and importance.
• Classification of loads in customer groups according to load sensitivity and importance.
• Specification the damages for Permission Level (PL) violation for each customer groups.

The damage of customer groups is divided in two categories. First, damage of equipment caused by power quality variations, second, some kind of damages because of hardware, software, or control system malfunction or production line shutdown, etc.

• Specification the cost of power quality service. It must be paid by customers to utilities against economic penalty which must be paid by utilities for power quality permissible level violation.

By use of results of this procedure, utilities can design an efficient contract (or tariff).

This proposed algorithm for contract design have been implemented for some of large and small industries such as Iran Khodro Co., Pars Metal Co. in Tehran Regional Electric Company.
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Abstract: This paper describes an efficient algorithm to participate harmonics, flicker and voltage sags in developing tariff or contract between utilities and customers. It includes classification of loads, assessment of damages to load groups in power quality limits violations and therefore designing of contract. The proposed procedure is used in Iran for industrial and commercial customer but it is applicable for residential loads.

Keywords: Power quality, Tariff, Economic Penalty, Voltage Sags, Harmonics, Flicker

1. Introduction

A wide range of phenomena causes power quality problems. About two third of these are natural phenomena, such as lighting. Other sources of power quality disturbances, for example the operation of power system equipment (e.g., capacitor switching) may be found in industry, or within the power system itself, where faults may cause voltage sag at end user.

IEC 1000-2-2/4 and CENELEC (EN50160) standards define power quality at the physical characteristics of the electrical supply provided under normal operating conditions that do not disrupt or disturb the customer’s processes. UNIPEDE also includes the supply availability as part of this definition. Power consumers with sensitive or critical loads need a constant network supply voltage with a sinusoidal waveform at nominal frequency and magnitude. A power quality problem therefore exists if any voltage, current or frequency deviation results in maloperation or failure of a customer’s equipment [1,2,3].

The growing concern about power quality stem from:

- Consumer becoming increasingly aware of power quality issues and being better informed about the consequences of interruptions, sags, harmonics, flicker, etc. Motivated by deregulation, they are challenging the energy suppliers to improve the quality of power delivered.
- The proliferation of load equipment with microprocessor-based controls and power electronic devices, which are sensitive to many types of power quality disturbances.
- Economical damages are the most important reason. As a power quality may cause a malfunction of equipment, which production line will be shutdown, loss value is between hundred dollars up to millions.

With respect to above-mentioned, improvement power quality and specification of power quality requirements and responsibilities is clearly needed. In this paper a new algorithm to participate power quality variations in tariff that meet together the customer and utility is proposed.

2. Proposed Algorithm

General procedure to participate of power quality variations in tariff including five steps as follows:

- Classification of customers.
- Selection of efficient indices for power quality conditions for customer.
- Determination of Permissible Levels (PL) and emission limits according to standards.
- Specification of damages for PL violation for each customer.
- Determination of the cost of power quality service.

This proposed algorithm is for industrial and commercial customers. However nowadays the usage of computer in residential section is increasing and people are going to do their jobs at home, in the early future utilities should pay more attention to request of residential customers to provide better power quality. The main stages of proposed procedure are described in the following sections.

3. Customers Classification

Due to poor power quality, unscheduled shutdown of industrial processes or equipment failure can result in
substantial costs to many customers. The industries affected are many and varied and a partial listing is given in Table 1 [4].

As we are almost faced with these kinds of industry segment which are suffered from power quality problems, we put your customer in one of these category. Another reason to accept this division is most of loads and customer’s facilities belong to these segments.

This table is changeable and flexible according to situation, but the main point is that the table should included those customers that power quality variations has affected on them.

Table 1- Industries affected by power quality issues

<table>
<thead>
<tr>
<th>Industry Segment</th>
<th>Industrial process</th>
<th>Group Degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous process</td>
<td>1. Paper, fiber and textile factories</td>
<td></td>
</tr>
<tr>
<td>2. Plastic extruding or molding plants</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>Precision machining</td>
<td>1. Automotive parts manufacturing</td>
<td></td>
</tr>
<tr>
<td>2. Large pump forging factories</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>High technology products and research</td>
<td>1. Semiconductor manufacturing</td>
<td></td>
</tr>
<tr>
<td>2. Large particle physics research centers</td>
<td>B</td>
<td></td>
</tr>
<tr>
<td>Information technology</td>
<td>1. Data processing centers</td>
<td></td>
</tr>
<tr>
<td>2. Bank</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Telecommunication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Broadcasting</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Safety and security related</td>
<td>1. Hazardous process</td>
<td></td>
</tr>
<tr>
<td>2. Chemical processing</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. Hospitals and health care facilities</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. Military installations</td>
<td>A</td>
<td></td>
</tr>
</tbody>
</table>

4. Selection of power quality indices

Power quality encompasses a wide variety of conditions on the power system. Important disturbances can vary in duration from very high frequency impulses caused by a lightning stroke, to long-term over voltages caused by a regulator tap switching problem. The range of conditions that a power quality instrument must characterize creates problems both in terms of the monitoring equipment complexity and in the data collection requirements.

Table 2 provides a comprehensive list of indices have been used in power quality evaluation for Flicker, Harmonics, Voltage Sags, Voltage Swells and Interruptions [6,7,8].

The methods of characterizing are important for the monitoring requirements. For instance, Characterization of voltage sags involves a plot of the rms voltage versus time. Outages can be defined just by duration. Monitoring to characterize harmonic distortion levels and normal voltage variations requires steady-state sampling with trending of the results over time.

It may be prohibitively expensive to monitor all the different types of power quality variations at each location. The priorities for monitoring should be determined up front based on the objectives of the effort. Projects to benchmark system performance should involve a reasonably complete monitoring effort. Projects designed to evaluate compliance with IEEE Std. 519-1992 for harmonic distortion levels may only require steady state monitoring of harmonic levels. Other projects focused on specific industrial problems may only require monitoring of rms variations, such as voltage sags or momentary interruptions.

Table 2- Power quality indices

<table>
<thead>
<tr>
<th>Category</th>
<th>Index</th>
<th>Problem</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS Disturbance</td>
<td>SARFl, SIARFl, SMARFl, STARFl</td>
<td>Voltage Sags</td>
</tr>
<tr>
<td></td>
<td>DIPSore</td>
<td></td>
</tr>
<tr>
<td>Steady State</td>
<td>THD, TDD, TDD_{up}</td>
<td>Harmonics</td>
</tr>
<tr>
<td></td>
<td>P_{f}, P_{th}</td>
<td>Flicker</td>
</tr>
</tbody>
</table>

5. Determination of permission level and emission limits

- Permission level for harmonics (harmonics evaluations on utility system)

Harmonic evaluations on the utility system involve procedures to make sure that the quality of the voltage supplied to all customers is acceptable. IEEE 519-1992 provides guidelines for acceptable levels of voltage distortion on the utility system. Note that recommended limits are provided for the maximum individual harmonic component and for the Total Harmonic Distortion (THD) [9,10]. Table 3 reperesents permission limits for general systems for maximum individual harmonic and THD.
Table 3: Recommended Voltage Distortion Limits for General Systems.

<table>
<thead>
<tr>
<th>Bus Voltage</th>
<th>Maximum Individual Harmonic Component (%)</th>
<th>Maximum THD (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;69kV</td>
<td>3.0%</td>
<td>5.0%</td>
</tr>
<tr>
<td>115 kV to 161 kV</td>
<td>1.5%</td>
<td>2.5%</td>
</tr>
<tr>
<td>161kV&lt;</td>
<td>1.0%</td>
<td>1.5%</td>
</tr>
</tbody>
</table>

- Emission Limits for Harmonics (Harmonic evaluations for customer)

Most harmonic problems occur at the end user level, rather than on the utility supply system. Most nonlinear devices are located within end user facilities and the highest voltage distortion levels occur close to the sources of harmonics. The most significant problems occur when an end user has nonlinear loads and also has power factor correction capacitors that result in resonance conditions.

IEEE 519-1992 was developed to evaluate harmonic voltages and currents at a point of common coupling (PCC) between the end user and the utility supply system. The PCC is the location where another customer can be served from the system. The standard allows for the same procedure to be applied by the customer at other locations within a facility but different current limit values could apply in these cases.

Table 4: Harmonic Current Limits for Individual End Users from IEEE 519-1992.

<table>
<thead>
<tr>
<th>User load rated current (A)</th>
<th>Pst</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>1.08</td>
</tr>
<tr>
<td>45</td>
<td>1.42</td>
</tr>
<tr>
<td>60</td>
<td>1.72</td>
</tr>
<tr>
<td>75</td>
<td>2.00</td>
</tr>
</tbody>
</table>

The flicker Emission Limit is set to a Pst defined as a function of the current of the user (Table 5) and measured on the same reference impedance established for users whose rated current are lower than 16A. This criterion is based on the recommendation given in Technical Report IEC 1000-3-5 for electrical equipment with rated current lower than 75A [12].

Table 5 Flicker Emission Limits

<table>
<thead>
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<th>User load rated current (A)</th>
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<tr>
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<td>1.72</td>
</tr>
<tr>
<td>75</td>
<td>2.00</td>
</tr>
</tbody>
</table>

For user who’s rated current is more than 75A, the Emission must be verified by measuring the level of injected by the user installation on equivalent impedance which represent the actual network impedance at point of supply [13].

- Characterizing equipment sensitivity to voltage sags

Voltage sags are the most important power quality variation affecting many types of industrial customers. As industrial processes have become more automated, the equipment has become increasingly sensitive to these momentary under voltages. If the voltage sag affects a single piece of equipment in the process, the entire process can be interrupted.

Since we characterize the voltage sags with a magnitude and duration, it is useful to describe equipment sensitivity in the same manner. This is done with a magnitude/duration plot (Figure 1). The Computer and Business Electronics Manufacturers Association (CBEMA) was the first to use this concept to describe equipment sensitivity. They came up with the “CBEMA curve” that has become the benchmark for describing equipment susceptibility. The curve is reproduced in IEEE Standard 446 (The Orange Book).

Unfortunately, equipment doesn’t behave according to the CBEMA curve. Some equipment is less sensitive and some equipment, like the ASD in Figure 1, is much more sensitive. A working group in IEEE (IEEE P1346) is currently working on guidelines for compatibility of industrial process equipment [14].

- Emission Limits for voltage Fluctuations

The flicker emission limit is set to Pst measured on reference impedance. This criterion is the same that established by the Standard IEC 1000-3-3 for electrical equipment with rated current lower than 16A [11].
- Characterizing system performance

End users can evaluate the economics of power conditioning equipment if they have information describing the expected system voltage sag performance. There are currently no standards describing how to provide this information to customers.

6. Specification of damages for PL violation and Economical Penalty

Exceeding PL in more than a 5% of the ten-minute interval of a weekly control yields an Economic Penalty, which is calculated with following formula:

\[ \text{PCF} = K_1 \times \text{CES} + K_2 \times \text{IDC} + K_3 \times \text{LPV} + K_4 \times \text{EWC} + K_5 \times \text{HWC} + K_6 \times \text{HD} \]  

(1)

With:

- PCF: Penalty Cost Function
- CES: Cost of Extra Shift
- IDC: Instruments Damage’s Cost
- LPV: Loss Productions Value
- EWC: Extra Work Cost
- HWC: Halt Work Cost
- HD: Humanity Damages

Table 6- Weighting factors for various load group

<table>
<thead>
<tr>
<th>Group Degree</th>
<th>K_1</th>
<th>K_2</th>
<th>K_3</th>
<th>K_4</th>
<th>K_5</th>
<th>K_6</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>OR</td>
<td></td>
<td></td>
<td>OR</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>D</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

* 1 is for industrial segments

6. Emission Control and cost of power quality service.

For users already connected to network, for whom a possible violation of the emission limit is suspected, the distribution company should verify the actual emission by implementing a set of disturbance measurements. The minimum recommended period for measurement is a week. During this period the emission limits must be met during at least 99% of time. The measurement equipment used in this control must follow the international recommendations given in References [10,15].

If the disturbance injected by the user installation does not comply with the emission limits, the following type of solutions are envisaged:

- The distribution company, checking that the network PL are not exceeded, offers an agreement to the user by increasing the emission limits assigned to that user.
- The user must adopt counter-measures to reduce the emission.
- If the user still does not proceed to reduce the emission below its emission limits in a specified period of time, for instance 6 months, the user is economically penalized according to (Table 7), if the user remains without solving the emission problem, the distribution utility could ask TREC for the user disconnection [16].

Table 7-Payment for customer Emission Limits violations

<table>
<thead>
<tr>
<th>Segment</th>
<th>$/Kwh</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large industry segment</td>
<td>7.15</td>
</tr>
<tr>
<td>Industry Segment</td>
<td>2.87</td>
</tr>
<tr>
<td>Commercial segment</td>
<td>3.17</td>
</tr>
</tbody>
</table>

In case of applications for connection of new users to the network, several criteria for evaluating the acceptance of the connection are given. In first stage, simple but restrictive rules allow direct acceptance of those users with equipment whose disturbing effect are considered to be admissible. If this first stage is not satisfied, an individualized study is performed taking into account the technical characteristics of user equipment and point of study. The result of this evaluation process should be finished with an agreement of connection when the required emission limits are satisfied, or alternatively, the proposal by the distribution company of special conditions of acceptance. A description of this type of procedure can be found in [17].

7. Conclusion

Distribution companies are responsible for the quality of power delivered to customer with respect to
Permission Levels (PL) and customer should be control the injected disturbances to network according to Emission limits. Otherwise both side are faced with Economic Penalty. In this paper an efficient algorithm for participate power quality variations in tariff or contracts for industrial and commerical loads are proposed.

In Iran many companies especially car production companies such as IRAN-KHODRO and SAIPA encounter power quality problems. Now monitoring devices were installed in all companies and utilities and ministry of industries negotiate for consideration of power quality in contracts.

8. References

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