Investigation And Mitigation Techniques Of Power Quality Problems In Nuclear Installations

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Received: 17/1/2012 Accepted: 19/2/2012

ABSTRACT

The electrical power systems are exposed to different types of power quality disturbances problems. Investigation and monitoring of power quality is necessary to maintain accurate operation of sensitive equipment especially for nuclear installations. The present research discusses investigation and monitoring of power quality problems for the electrical sources of nuclear installations. Field power quality data is collected by power analyzer and analyzed with reference to power quality standards. There were several disturbances exceeded the thresholds, they were voltage harmonics and voltage flicker. Mitigation techniques were suggested to install a passive filter at low voltage side and all sensitive and critical loads should be isolated and fed through uninterruptible power supply (UPS).

Keywords: power quality, harmonic distortion, voltage flicker, passive filter, uninterruptible power supply (UPS).

INTRODUCTION

Among all electrical power quality problems, harmonic distortion and flicker are the disturbances that cause most problems to sensitive loads. Due to the partial or total interruption of the industrial process [1]. Harmonics are sinusoidal components of a periodic wave having a frequency that is an integral multiple of the fundamental frequency. Thus for a power system with \( f_0 \) fundamental frequency, the frequency of the \( h \)-th order of harmonic is \( hf_0 \). Harmonics are often used to define distorted sine waves associated with currents and voltages of different amplitudes and frequencies. Distorted waveforms can be decomposed into the sum of the fundamental frequency and the harmonic components. Harmonic distortion levels are described by the complete harmonic spectrum with magnitudes and phase angles for each individual harmonic component. It is also common to use a single quantity, the Total Harmonic Distortion (THD), as a measure of the effective value of harmonic distortion. Harmonic distortion originates in the nonlinear characteristics of devices and loads in the power system. The most cost-effective filter is generally a single-tuned passive filter and this will be applicable for the majority of the cases. Filters must be carefully designed to avoid unexpected interactions with the system [2]. Voltage fluctuations are cyclical variations in the voltage rms values or a series of random voltage changes, whose magnitude does not normally exceed voltage ranges of 0.9 p.u. to 1.1 p.u. A common phenomenon of voltage fluctuations is the voltage flicker. Loads, which can exhibit continuous, rapid variations in the load current magnitude, can cause voltage fluctuations [3]. Uninterruptible power supplies in nuclear installations are designed to provide a stable, and uninterruptible vital AC power to the safety related and non-safety related instrumentation, and control systems. Uninterruptible power supplies are used to provide a reliable uninterruptible source of voltage and frequency regulated AC power to the vital loads required to maintain in a safe conditions. The on-line double conversion UPS technology offers highest security. Only this design offers absolutely uninterruptible power supply and equalizes all power disturbances such as voltage fluctuations, distorted voltage waveform, frequency fluctuations, voltage transients, short interruptions and long power outage. The nuclear research reactors has sensitive loads which are affected by disturbances occurring at some factories connected to the same feeder at the point of common coupling. The nuclear research reactor is the case study for power quality problems. The Unipower...
900F is chosen as a power quality analyzer instrument to satisfy the following specifications: long term measurements, measuring the main electrical quantities, all units must be measured simultaneously, able to capture voltage sags/swells and real-time measurements [4]. The electrical power of the nuclear research reactor is supplied to the installation via tow incoming feeders from tow different substations to keep good reliability. Each feeder is designed to carry the full load [5]. The monitoring investigations were performed at the nuclear research reactor for both feeders at different operation conditions. Measurements were carried for 7 days on the medium voltage side for each source separately.

MEASUREMENT RESULTS

2-1 - Measurement results of the first feeder:-

2.1.1- Harmonics

It is observed that all the three phases are being combined into one single plot for comparisons. As shown in fig. (1) The voltage total harmonics distortion (VTHD) levels did not exceed the acceptable tolerance of 5 % set by the IEEE standard, but the fifth harmonic exceeded the acceptable tolerance of 3 %. Fig. (2) Indicate that the current total harmonics distortion (ITHD) levels are not exceed the acceptable tolerance of 15 % set by the IEEE standard. However there are an immense increase in the ITHD levels at one point and this point is light load.

![Fig. (1) Voltage total harmonics distortion](image1)

![Fig. (2) Current total harmonics distortion](image2)
2.1.2- Flicker

The short time flicker (Pst) exceeds the limit as shown in fig. (3), it is indicated daily. Because of the substation feeds industrial loads and these loads are considered sources of voltage flicker. The long time flicker (Plt) exceeds the limit as shown in fig. (4) it is indicated daily. The long time flicker is calculated from a sequence 12 Pst – values over a two hours interval.

![Fig.(3) Short time voltage flicker](image)

![Fig.(4) Long time voltage flicker](image)

2.2- Measurement results of the second feeder:

2.2.1- harmonics

Generally as shown in fig. (5), the voltage total harmonics distortion (VTHD) levels are closed to the acceptable tolerance of 5% set by the IEEE standard. Whereas, there is an immense increase in the VTHD levels. Referring to the recorded data, this point is light load. And as shown in fig. (6) The current total harmonics distortion (ITHD) levels are closed to the acceptable tolerance of 15% set by the IEEE standard. But there is an immense increase in the ITHD levels at three points. Referring to the recorded data, the power is very low at these points, hence these points are considered light load.
2.2.2- Flicker
The short time flicker ($P_s$) exceeds the limit as shown in fig. (7). And the long time flicker ($P_l$) exceeds the IEEE limit as shown in fig. (8).
MITIGATION APPLICATION

Referring to the results of monitoring and according to the power quality solutions, mitigation techniques are suggested. Install passive filters at low voltage side and all sensitive and critical loads should be fed through uninterruptible power supply (UPS).

3-1- passive filter

From measurements, the fifth harmonic is considered a common feature in the system.

3.1.1- Design of fifth harmonic passive filter: [7]

Referring to the electrical system of the case study:
Harmonic order = 5
Three-phase capacitor bank rating = 500 kVAR
Capacity rating = 500 kVAR, 400 V
Nominal bus voltage = 400 V
Transformer rating = 2000 kVA, 6%
5th harmonic current = 40% of fundamental current (assumed)
Filter tuning harmonic = 4.7
Utility harmonic voltage source = 1%

The design of filter can be done by Harmonic Filter Calculation Spreadsheet which provides a convenient method for determining low voltage filter component values and duties. A computer program designs it for uses with Microsoft excel. The following table shows an example design calculations for 5th harmonic filter. Calculation including capacitor derating, filter component values, capacitor duty with respect to IEEE Std 18-2002. [8]
Table (1) calculations for 5th harmonic filter

<table>
<thead>
<tr>
<th>System Information</th>
<th>5th</th>
<th>Power System Frequency: 50 Hz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three-Phase Capacitor Bank Rating:</td>
<td>500 kVAR</td>
<td>Capacitor Rating: 400 kVAR</td>
</tr>
<tr>
<td>Nominal Bus Voltage:</td>
<td>400 V</td>
<td>Capacitor Frequency Rating: 50 Hz</td>
</tr>
<tr>
<td>Rated Capacitor Bank Current:</td>
<td>721.697395 Amps</td>
<td>Derated Capacitor Size: 500 kVAR</td>
</tr>
<tr>
<td>Filter Tuning Harmonic:</td>
<td>4.7 th</td>
<td>Total Harmonic Load: 500 kVAR</td>
</tr>
<tr>
<td>Capacitor Impedance (key):</td>
<td>0.32 Ω</td>
<td>Filter Tuning Frequency: 236 Hz</td>
</tr>
<tr>
<td>Capacitor Impedance (delta):</td>
<td>0.96 Ω</td>
<td>Capacitor Rating (key): 9943.1816 μF</td>
</tr>
<tr>
<td>Filter Reactor Impedance:</td>
<td>0.014463193 Ω</td>
<td>Capacitor Rating (delta): 331.439393 μF</td>
</tr>
<tr>
<td>Filter Full Load Current (actual):</td>
<td>755.9072392 Amps</td>
<td>Filter Reactor Rating: 0.046092432 mH</td>
</tr>
<tr>
<td>Transformer Nameplate Rating:</td>
<td>2000 kVA</td>
<td>Supplied Compensation: 623.7079194 kVAR</td>
</tr>
<tr>
<td>Transformer Nameplate Impedance:</td>
<td>6 %</td>
<td>Utility Side Voltage Distortion (Vh): 1 %</td>
</tr>
<tr>
<td>Load Harmonic Current:</td>
<td>40 %</td>
<td>(Utility Harmonic Voltage Source)</td>
</tr>
<tr>
<td>Utility Harmonic Current:</td>
<td>71.20975682 Amps</td>
<td>Load Harmonic Current: 286.6751345 Amps</td>
</tr>
<tr>
<td>Maximum Total Harmonic Current:</td>
<td>399.8948914 Amps</td>
<td></td>
</tr>
</tbody>
</table>

CAPACITOR DUTY CALCULATIONS:
- Filter RMS current: 637.2054316 Amps
- Harmonic Capacitor Voltage: 39.6939098 Volts
- RMS Capacitor Voltage: 420.6813741 Volts

FILTER REACTOR DESIGN SPECIFICATION
- Reactor Impedance: 0.014463193 Ω
- Fundamental Current: 755.9072392 Amps

Table (2) IEEE Std 18-2002

<table>
<thead>
<tr>
<th>Limits</th>
<th>Actual</th>
<th>value %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak Voltage</td>
<td>120%</td>
<td>458.8600254</td>
</tr>
<tr>
<td>RMS Current</td>
<td>135%</td>
<td>837.2054316</td>
</tr>
<tr>
<td>KVAR</td>
<td>135%</td>
<td>523.7079184</td>
</tr>
<tr>
<td>RMS Voltage</td>
<td>110%</td>
<td>420.8613741</td>
</tr>
</tbody>
</table>

3.1.2-Cost of Filter
The cost of fully automatic system is 60 $/ kVAR [9]
For 500 kVAR, which is required to case study, then, Cost = 500 * 60 = 30000 $, and it is very low compared with its benefits, it can protect the electrical system equipment from the harmonics effects.

3.2-Uninterruptible Power Supplies (UPS):
3.2.1-UPS capacity and cost [10]
All the critical and sensitive loads of the case study = 45 kVA
The grand total UPS = total loads * 1.2
(The factor 1.2, may be dynamic load at the system)
The grand total of UPS = 45 * 1.2 = 54 kVA
Hence, UPS with 60 kVA rated power was selected.
According to [11] the cost of UPS is (500$ / kVA)
The cost of UPS = (rated kVA) * 500 + 5% (running and maintenance)
The cost of UPS = (60 * 500) * 1.05 = 31500 $,
And it is very low compared with its benefits; however, it is related to the safety of nuclear installation.

CONCLUSION AND RECOMMENDATIONS

This paper presents the investigation and influence of power quality problems on the behavior of the electrical system of nuclear installations. The analysis of the recorded data at the point of common coupling yields that, fifth harmonics and flickers are the most severe events and should be taken in consideration for any evaluation. It is recommended that mitigation technique should be done to keep good performance of the electrical system and then void operation problems of the nuclear installations. The passive filters and uninterruptible power supply (UPS) are effective solutions to mitigate power quality problems.

REFERENCES

[5] Safety analysis report of nuclear research reactor,”SAR”.