FIELD MEASUREMENTS, MODELLING AND SIMULATION FOR HARMONIC ANALYSIS OF A LARGE INDUSTRIAL POWER SYSTEM

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ABSTRACT

Harmonic distortion problems due to non-linear loads can have a significant impact on industrial customers. Voltage and current distortion levels must satisfy limits set out by Grid Code requirements. This paper details the harmonic analysis of a large mine in Ireland which is currently undergoing an extensive expansion. As part of the expansion two existing 2MW synchronous motors are to be replaced by two new 4MW asynchronous motors. As the synchronous motors also act as reactive compensation for the plant it is planned to install two sets of capacitors banks on the main 6.6kV busbar to help maintain a high power factor.

As many of the motor loads around the plant are fed through Variable Speed Drives there is existing harmonic distortion currently at the plant. Also depending on their size, installation of PFC capacitor banks may cause a resonance condition to exist. This resonance condition could magnify any harmonic currents present at the resonant frequency. As part of the application for the increase in load the harmonic emission levels of the plant have to be assessed. The results of site measurements, system simulations and possible corrective actions are outlined in this paper.

INTRODUCTION

Harmonic distortion can have a significant impact on industrial customers such as additional losses and heating of certain network equipment, faulty operation of control equipment, and interference in neighbouring telecommunication systems [1]. To ensure compliance with the Grid Code [2] voltage and current distortion levels must satisfy limits set out by IEC 61000-3-6 [3]. This paper details the on site measurements and computer modelling carried out as part of the harmonic analysis of a large mine in Ireland undergoing expansion. The aim of the study was to improve the power factor, maintain harmonic distortion within acceptable levels and reduce possible resonance problems at the plant.

The plant is currently connected to the transmission system via two 110kV/6.6kV 12.5MVA transformers. The existing plant has four synchronous motors installed as part of its milling process. These synchronous motors also act as reactive compensation for the plant by supplying MVARs and thus reducing the plants MVAR consumption from the transmission system and increasing the overall plant power factor. A simplified one line diagram of the plant is shown in Figure 2.

Due to an increase in load demand the connection to the transmission system is being upgraded to two 25MVA transformers. One of the factors behind the predicted increase in load demand is the replacement of two of the 2MW synchronous motors (as shown in Figure 1) with two new 4MW asynchronous motors. To cater for the reactive power loss of two of the synchronous motors, it is planned to install two sets of capacitors banks on the main 6.6kV busbar to help maintain a high power factor.

Fig. 1 - Existing 6.6kV 2MW Synchronous Motors

Two system computer models were developed using the ATP software for the harmonic analysis. Firstly, a model of the existing plant was created. The results of this model were then compared to harmonic measurements taken to check all system parameters were accurately represented. A model of the future plant was developed by reconfiguring the existing network model to allow for the addition of the two new asynchronous 4MW motors, the retirement of the two 2MW synchronous motors, uprating of the 110kV/6.6kV transformers and reconfiguration of the loads on the main 6.6kV busbar. The post expansion harmonic levels were then compared to the limits set out by Grid

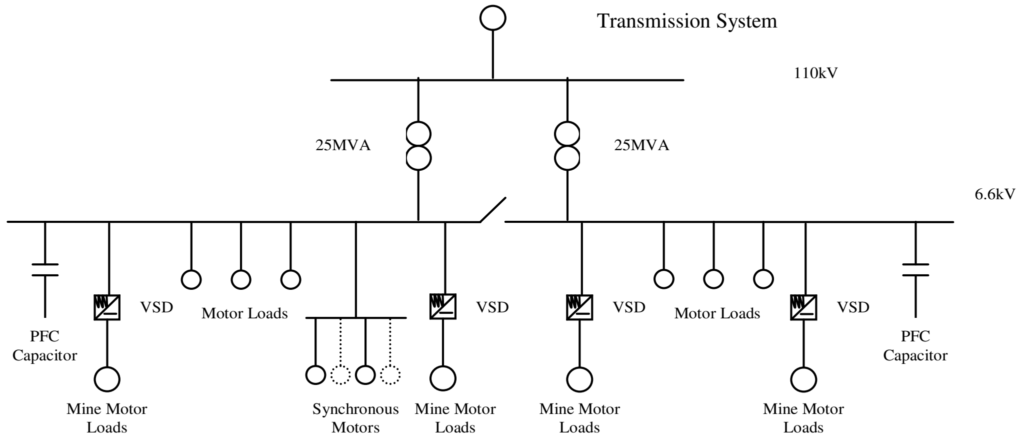

Fig. 2 - Single Line Diagram for overall Plant

Code [2].The effect of the installation of the Power Factor Correction (PFC) capacitor banks was then examined to determine if a resonance condition existed that could lead to a magnification of current harmonic components thus causing increased voltage distortion levels. Finally conversion of the PFC capacitor banks into simple shunt filters was examined to reduce the Total Harmonic Distortion (THD) of the plant to within Grid Code [2] limits.

EXISTING PLANT

A harmonic model of the existing plant was created to establish existing harmonic levels at the site. This was then compared to THD measurements taken.

Existing Plant Measurements

Several harmonic measurements were taken to verify the model of the existing plant. Due to physical constraints these measurements were taken at the line bay at the remote end of the 110kV feeder feeding the plants own 110kV station. These measurements were taken using the Unipower Unilyzer 902 power quality meter which recorded both voltage and current waveforms and harmonic components from the fundamental through to the 50^{th}. The measurements were used to determine the dominant harmonics across the frequency spectrum. In both the voltage and current spectrums the significant harmonics were the 5^{th} and 7^{th}. The maximum measured voltage THD recorded over a one week period was 1.25%. A graph of the values over a full week is shown in Figure 3.

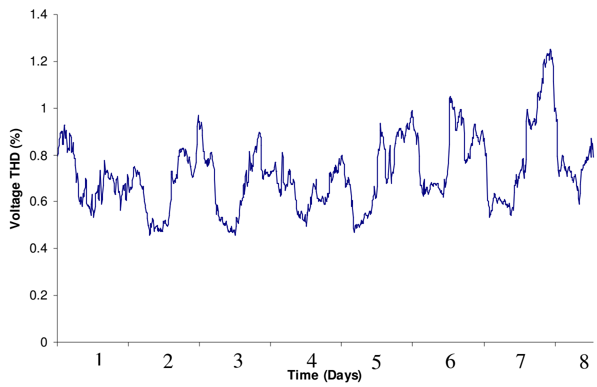

Fig. 3 – Voltage THD (%) for overall plant measured over 1 week period

Existing Plant Model

An existing plant model was created by modelling the transmission network back to 220kV stations, the two 12.5MVA transformers and all 6.6kV loads fed from the main 6.6kV busbar. The overhead lines of the transmission network were modelled as PI equivalent RLC models. All reactive compensation connected to the surrounding transmission network was included in the model. The harmonic currents injected by each 6.6kV load were represented as harmonic current sources in the software model. The input values used in the harmonic current sources are based on harmonic measurements taken on each 6.6kV feeder. These measurements were taken over a period of 24 hours coinciding with a period of full production for the specified load. The current harmonic spectrum and phase voltage and current waveforms from one of the loads are illustrated in Figures 4 and 5 respectively.

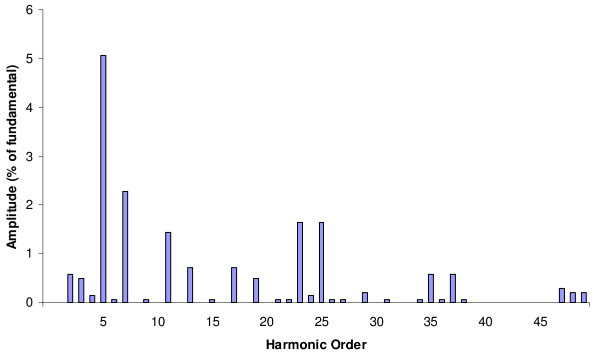

Fig. 4 – Measured Current Harmonics of a 6.6kV feeder

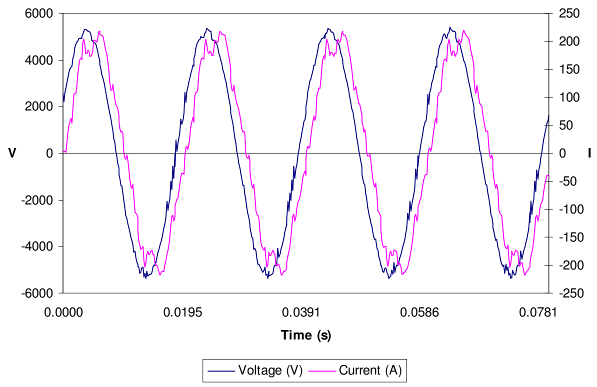

Fig. 5 – Measured Phase Voltage and Current Waveforms of a 6.6kV feeder

For illustrative purposes the fundamental is excluded. As can be seen the 5th and 7th harmonic frequencies produce the largest harmonic currents.

Simulations were carried out in the time domain and the frequency domain to determine the THD and any resonant conditions which may exist. The maximum modelled voltage THD using the existing plant model was 1.17% with the largest harmonics being the 5th and 7th which correlates well with the field measurements of the overall plant. A frequency scan is shown in Figure 6 below showing a resonance condition near the 7th harmonic.

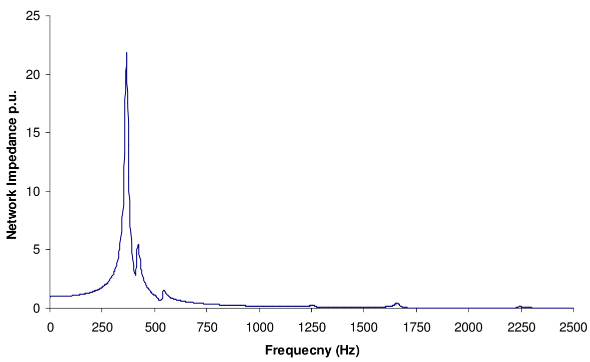

Fig. 6 – Resonance condition (Network Impedance vs. Frequency) for existing plant model

FUTURE PLANT

A harmonic model of the future plant was created by adjusting the existing plant model to represent the changes happening on site during the expansion. Firstly the two new 25 MVA transformers were modelled instead of the existing 12.5MVA transformers. The harmonic current sources representing the four synchronous motors were adjusted to represent the future plan of only two synchronous motors. New harmonic sources were added to represent the two new asynchronous motors fed through 12 - pulse Variable Speed Drives (VSD). These harmonic sources were modelled using the harmonic content of the motors and drive system supplied by the manufacturer. Some loads were being transferred from one side of the old busbar to the opposite side of the new busbar during the refurbishment, this was also taken account for in the model. All new cable runs were also modelled in the new plant model.

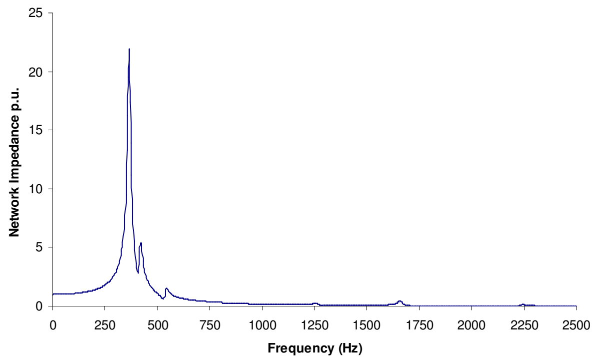

Fig. 7 – Resonance condition for future plant model

The results of the future plant model show that the harmonic levels are not significantly increased due to the refurbishment. The maximum modelled voltage THD was 1.20% with both the 5th and 7th harmonics again dominating. The main reason for this is due to the fact that the 2 new 4 MW asynchronous motors are fed through 12 - pulse VSD's. The effect of the 12 - pulse VSD's can be seen in the increase in the 11th and 13th harmonic voltage levels from 0.19% and 0.04% to 0.28% and 0.06% respectively due to harmonic currents being injected into the system by the converters at orders 12N±1. The harmonic impedance of the network also remains unchanged as can be seen in Figure 7 above.

INSTALLATION OF PFC CAPACITORS

The installation of the PFC capacitors was investigated due to the potential creation of or shift in resonant frequency due to the introduction of an extra parallel capacitance. The results of a separate study showed the required size of the PFC capacitors to be 10 MVAR (5MVAR on each side of the new 6.6kV busbar). The future plant model was updated to include these two 5MVAR capacitors and the impact of their installation was examined. Figure 8 illustrates that for the operating condition of both capacitor banks switched in harmonic order near the 5^{th} dominate with an increase in the 9^{th} harmonic order.

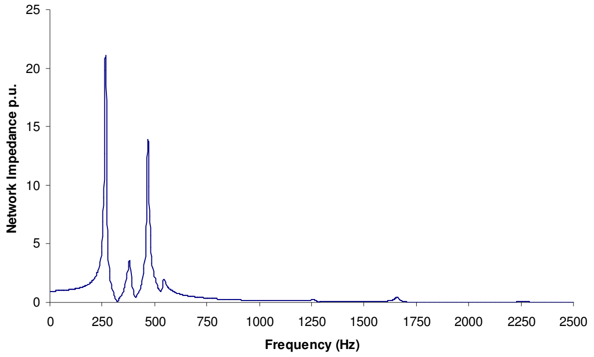

Fig. 8 – Resonance condition for future plant model after the installation of the PFC capacitors

The maximum voltage THD after the installation of the PFC capacitors was modelled as 3.69%. This exceeds the limits set out in the Grid Code [2].

PRELIMINARY FILTER DESIGN

Conversion of PFC capacitor banks into harmonic filters is an effective method to provide the required power factor correction while ensuring harmonic levels are maintained to within planning levels [4]. Due to the dominance of the 5^{th} harmonic tuning of the PFC capacitor banks to the offending 5^{th} harmonic was investigated.
Examination of a simple shunt filter, providing the required reactive compensation, under normal operating conditions was carried out and the effect of the tuned bank on the frequency response is shown in Figure 9. The harmonic impedance versus frequency without filters is also shown. It is found that the impedances at the 5^{th} harmonic order have been reduced and the overall voltage THD has been reduced to 0.36% which is well within the limits set out in the Grid Code [2].

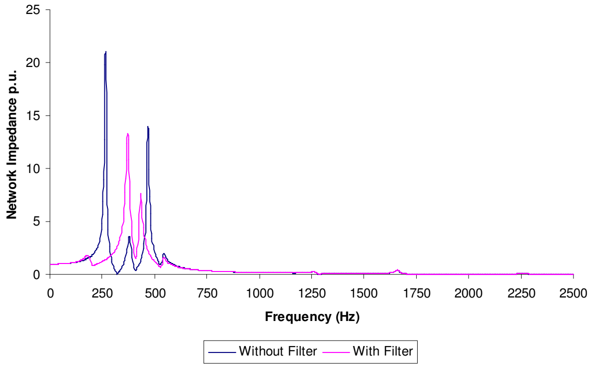

Fig. 9 – Effect of filter on resonance condition

CONCLUSIONS

The use of non-linear loads in industrial systems can result in unacceptable levels of harmonic distortion. The results of this paper show the existing harmonic distortion levels of the industrial plant in question to be within Grid Code requirements. However, post expansion the levels of harmonic distortion are modelled to exceed limits. It is also shown in this paper that the proposed PFC capacitor banks can be tuned to act as harmonic filters and operate to reduce the harmonic distortion to acceptable levels. It is recommended that the PFC capacitor banks be tuned to act as harmonic filters and also that upon completion of the plant expansion harmonic measurement are taken to verify Grid Code compliance.

REFERENCES

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[2] Eirgrid Grid Code, V.3.1.

[3] IEC 61000-3-6 - Electromagnetic compatibility (EMC) - Part 3-6: Limits - Assessment of harmonic emission limits for the connection of distorting installations to MV, HV and EHV power systems.

[4] Mark McGranaghan, Scott Peele and Dan Murray, “Solving harmonic resonance problems on the medium voltage system”, Paper 0737, CIRED – Vienna, May 2007