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ANALYSIS ON DETECTION OF POWER GRID HARMONIC POLLUTION BASED ONALLOCATING POWER QUALITY MONITORS IN ELECTRICAL DISTRIBUTION SYSTEMS –A REVIEW

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ABSTRACT

The core issue that prevents finding the overall solution to this problem lies in divergence within the power engineering community on the best definition of the harmonic pollution level The growth of non-linear devices has increased the harmonics pollution in distribution systems. Under industrial competition, the concern over power quality, especially harmonic distortion, has increased due to the new generation of load equipment. This equipment has been fully automated electronically, so it is very sensitive to any power quality disturbances. Electrical power organizations have set standards to limit the harmonics pollution in the distribution systems; however, the enforcement of the standards has to be disciplinal, by applying a penalty fee for any customer or utility that exceeds the standard limits. In order to apply the penalty fee properly, precise detection of harmonics pollution sources must be considered. The bus voltages and the line currents in the entire system have to be known in order to obtain accurate identification, which can be achieved by monitoring the distribution system. The large number of sensors needed to monitor the distribution system increases the cost of the monitoring system; therefore, the sensors have to be installed in an optimum way that decreases their quantity and their construction fixed costs. This thesis offers a new optimization approach for allocating the monitors in the distribution system. The Vertex-Colouring approach reduces the monitoring system cost by placing the harmonics pollution monitors in minimum cost locations where they can observe all the buses and branches of the distribution system. The number of monitors is affected by the percentage of nonlinear loads in the distribution network; thus, investigations on lightly polluted systems, medium polluted systems, and heavily polluted systems have been presented. The relation between the harmonics pollution level from one side, and the nonlinear load types, power ratings, and voltage levels from the other side has been highlighted as important observations of the polluted systems investigation. The Total Harmonic Powers (THP) method has been used to identify the harmonics pollution sources. In addition to its simplicity, The THP method is efficient, and requires the network voltage and current values which can be provided by the proposed monitoring system. The ability to apply the THP method on any distribution system has been scrutinized in order to confirm its validity for distribution systems.

Key words: Harmonics Pollution, Monitors, Electrical and Computer Engineering

I INTRODUCTION

Most of electronic devices and apparatus operate with DC supply in contrary; the common power grid provides AC voltage. Consequently, every electronic equipment connected to the mains requires AC to DC converter. Today they are the most common loads at power grid. In recent years, the traditional power systems' structures have been changed, and the electrical system can no longer be handled as a single entity. The conventional way of transporting electric power via transmission networks, unidirectional from generators to end users, is not adequate for the deregulated systems, so the transmission networks have to be able to support transferring energy between customers and companies [1]. The customers have options to buy the electricity from various providers, and the energy price, reliability, and quality play the main roles in the electricity market. As a result, the customers will purchase the cheapest energy that meets their needs within acceptable reliability and quality ranges [2, 3]. Under industrial competition, the concern over power quality has increased due to the new generation of load equipment. This equipment has been fully automated electronically, so it is very sensitive to any power quality disturbances [1]. Indeed, power quality disturbances may cause malfunctions in the equipment, which leads to higher production costs due to decreased production efficiency. Moreover, the electronic converters in these loads produce harmonic currents that increase current distortion. Eventually, the impact of electronic converters on power quality will be increased proportional to the converters' lifetime; therefore, maintaining power quality levels above specific baselines will be an essential requirement in future decades [3]. Customers connected to the electrical network are no longer classified only as consumers, since they can also generate and sell power via the deregulated system. Recently, the number of installed distributed generators (DGs) has risen, and connecting a new DG to the network has to meet power quality conditions that guarantee the security of the system during any power quality disturbances, especially voltage dips [1]. DGs create additional power quality disturbances, such as waveform distortion, voltage fluctuation, and flicker. In addition, the new transmission technologies, combined with electronic converters, FACTs, and HVDCs, produce harmonic currents in the high-frequency order which cause current quality distortion [4]. The restructuring of power systems raises the concerns over power quality problems resulting from harmonics distortion. Electrical power organizations have proposed some standards in order to protect their electrical power systems from the consequences of harmonics pollution. When a customer or utility produces harmonics pollution above the limits, the cost of the harmonics pollution consequences should be paid by the responsible party; the customer or the utility. Due to the highly complex interconnected networks in the distribution systems, identifying the sources that cause harmonics pollution is a hard task to achieve.

II METHOD AND METHODOLOGY

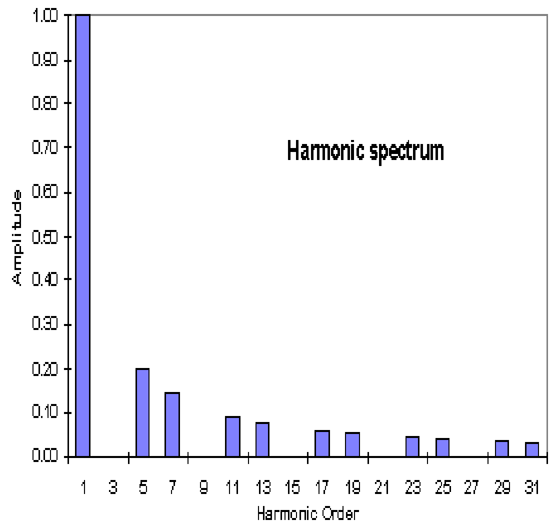
The impacts of harmonic voltage and current on distribution electrical equipment are highlighted .however; their consequences have also been explained in great detail in many publications [26–28]. The currents injected by nonlinear devices can degrade the voltage waveforms in the distribution power system, which causes misoperation or damage to the customers' equipment. Moreover, harmonics current flow in the distribution network causes electrical losses. These losses are small compared to the fundamental losses due to the small magnitude of the harmonics currents; however, because of their continuity in the system, the cost of these losses is tangible. Indeed, the increase in use of electronic power devices and the augmented use of sensitive equipment in the distribution system can make the consequences of the harmonics pollution significantly costly [29]. For instance, according to Barry Kennedy in his book "Power Quality Primer", there is a case study of a building with 240 dispersed computers and other electronic equipment working 4,380 hours per year with a load of 60 kW; the harmonics flow in the system increased losses by 4802 W at a cost of $2,101 per year (based on a cost of energy of $0.10/kWh) [15]. The cost of harmonics pollution consequences and the harmonics pollution mitigation costs should be regained. One way of getting these back is increasing the price of electricity in order to cover all additional costs; however, the main drawbacks are, first, that increasing the price of electricity will affect the electric companies' profits under deregulation systems, and second, it would force innocent customers (non-harmonics-producing customers) to pay an extra fee not related to their own usage [16]. As mentioned before, an incentive scheme should be considered as a solution for controlling harmonics pollution in the distribution systems.Thus, the identification of harmonics pollution sources is the first step toward controlling and solving the problem. The dynamic nature of the distribution system and the difference in features from one distribution network to another, such as the voltage level, load density, and the supplied customers' types – residential, commercial or industrial – makes the identification process a hard task. The harmonics currents produced by different types of customers have distinct characteristics. Hence, the identification method has to be valid for different types of harmonics pollution.

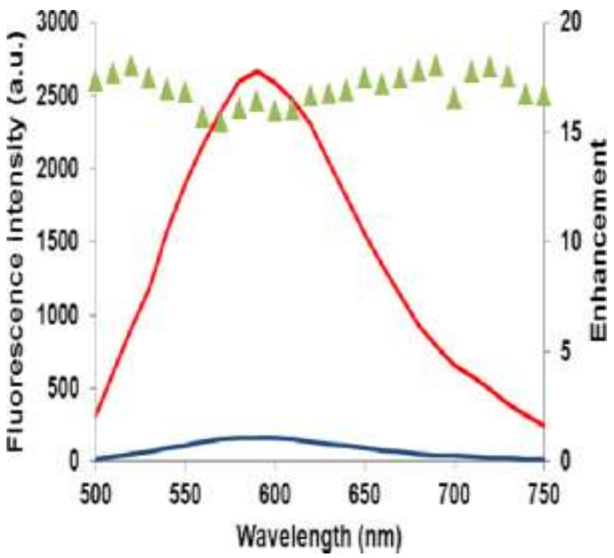
III ANALYSIS AND ASSESSMENT

Chapter Assessment Electrical power organizations set standards to limit harmonics pollution in their distribution systems, and an incentive-based regulation has been proposed to force customers and utilities to follow these standards. If any customer or utility exceeds the standards' limits, they must pay a fee related to their harmonics pollution levels. To apply the incentive regulation properly, accurate identification of harmonics pollution sources is necessary. In order to get accurate identification, the bus voltages and the line currents in the entire system have to be known. This can be achieved by monitoring the distribution system. The number of monitors needed and the cost of the monitors themselves increase the cost of the monitoring system; therefore, the monitors have to be installed in an optimum way that decreases the number of monitors needed and the cost of the monitors. The cost of the monitors varies from one location to another, depending on the number of current transducers and DAQs required. So, the monitors should be installed in strategic locations that reduce the monitors' number and cost due to the decreasing of transducers and DAQs used. Several optimization techniques have been applied to monitor allocation problems; however, the purpose of the monitoring system, such as characterizing system performance, characterizing specific problems, or enhancing power quality services, plays the main role in choosing the proper optimization techniques for the allocation problem. The vertex-colouring (VC) method has been applied for the harmonics pollution monitoring allocation problem in order to measure or calculate all the bus voltages and line currents of the system under monitoring. Each bus in the system is represented by a vertex, and each line is represented by an edge in the VC. The optimum solution using the VC method is when all buses and lines have been coloured at minimum monitoring system cost. This can be achieved by minimizing the number of monitors used and minimizing the cost of the monitors themselves. The VC method is applied to different-sized systems, and the fundamental advantage of the VC method is the low input data required: only the existence matrix. In addition, the monitors' number and cost and the data redundancy factor shows better results using VC compared to the results of the packing and covering method. In order to identify the sources of harmonics pollution in the distribution system, the customers' buses and loads should be monitored. If the bus under monitoring was a known bus, different loads' currents can be calculated easily using basic circuit analysis rules; however, if the customer's bus was an unknown bus, the loads connected to that bus should be measured, because the basic circuit rules cannot be applied for nonlinear loads. As a result, the percentage of nonlinear loads in the distribution system affects the cost of the harmonics pollution monitoring system used to identify the sources of harmonics in the system. Thus, different combinations of loads in the IEEE 40-Bus will be discuss in detail in Chapter Five before illustration of the methods of identifying the harmonics-producing devices in the system.

1. Single-phase switching device

Single phase Diode Bridge Rectifiers (DBR), Switch Mode Power Supplies (SMPS), and Phase Angle voltage controllers (PAVC) are examples of devices of this type. These devices are the most popular choice for low-power applications.





2. Three-phase switching devices

Three-phase rectifiers, Variable-Frequency drives (VFD), and typical IEEE 6 and

12 pulse converters are example of this category. Pulse Width Modulation (PWM) is used in these converters for controlling the output voltage. The ratio between the switching frequency FS and fundamental frequency F1 determines the configuration of the converters. For instance, if (FS/F1) equals 6, then the converters are 6–pulse converter.

IV DISCUSSION

The correct modelling of the harmonic-producing devices is an important step that
Leads to not only understanding the devices' behaviour, but also to finding the best way for detecting the device. The nonlinear devices are divided into two groups: nonlinear magnetic devices and nonlinear switching devices. Several examples from both groups have been highlighted with their current waveforms and spectrums. After looking at the harmonic producing devices as standalones, an investigation into how these devices can interact in the distribution system is demonstrated. Different polluted distribution systems are categorised into lightly polluted systems, medium polluted systems, and heavily polluted systems. The ratio of the nonlinear loads to the total system load decides the category of the polluted system. Moreover, the nonlinear loads can be connected in one place, or they can be distributed in the entire system. Both cases have been investigated for all polluted systems categories. How the harmonics pollution level changes when the rating power, the voltage level, the type of nonlinear load, and the network impedance are changed was the most important observation from the investigation. The last section in this chapter focused on the identification methods used to locate harmonics pollution sources in distribution systems. The total harmonic powers (THP) method was proposed method for detecting the harmonics sources. The THP method is a simple method that uses the sign of the THP at a specific bus to nonlinear are connected upstreaor downstream with respect to that bus. Two obstacles can limit using the THP method in detecting the nonlinear loads for distribution systems: the high degree of accuracy in calculation, and that the method cannot detect by using only the sign a nonlinear load connected to a bus that has another nonlinear load connected to one of its downstream buses.

V CONCLUSIONS

The conclusions derived from the investigation conducted throughout this thesis are as follows: The harmonic currents consequences appear in electrical systems as voltage distortion due to the interaction between the harmonic currents and the network impedance. for high-order harmonics or from harmonic resonance phenomena. • Distribution of harmonic pollution monitors in the network limits the system impedance variation impact on assessing the harmonic pollution level. • The monitor cost fall into two parts: the first part is the fixed cost, which includes the analysing data unit (typical PC) and the transferring data means; the second part is the location cost, which includes the transducer and DAQ costs. • Reducing the monitoring system cost can be done by minimizing the number of monitors used and by placing the monitors in the least costly locations. The packing-covering optimization approach minimizes monitoring system cost by
reducing the number of monitors used; however, the proposed vertex-colouring approach minimizes monitoring system cost by reducing the number and location cost of monitors. • The main advantage of the proposed vertex-colouring approach is the low required input data; only the Existence Matrix, which is an integer representation of the Y-Bus matrix, is required as input. The elements in the main diagonal of the Existence Matrix represent the number of current branches of each bus; however, the non-diagonal elements represent the connections between buses. • The vertex-colouring reduces the number of current branches monitored; therefore, data redundancy is reduced using the proposed method, which leads to reduction of the media to store

the data as well as the bandwidth for sending and receiving the measuring data. • In order to keep the accuracy of the monitoring system within an acceptable limit, the increase of nonlinear loads in a distribution system will force the monitoring system to install extra monitors to provide the required measuring data. • The correct modeling of the harmonics-producing devices is an important step that leads to not only understanding the device behaviour, but also to finding the best way for detecting the device. • When the distance between the harmonics-producing bus and the bus under study is short, the susceptibility and capability of being polluted is high. The distance in the distribution system can be representative of the network impedance. • Operating at high voltage levels increases the load impedance; therefore, the ability of being polluted from nearby buses that have lower voltage levels decreases due to harmonic currents attempting to find shorter paths and lower impedance. However, the amount of power loss resulting from harmonic currents is increased due to the increase in the loads' impedance. • When a nonlinear, heavily loaded bus, and a linear, lightly loaded bus share the same PCC, both buses account for the harmonics pollution produced to the PCC from IEEE standards point of view.

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