Review of Current Harmonic Voltage Simulation and Allocation Methods

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***Abstract* - Current standards defining harmonic voltage emission levels and network planning levels are defined within the AS61000 series standards. AS61000.3.6 defines methods for electrical utility suppliers to allocate harmonic voltage distortion limits to customers connecting to the network. This is aimed at limiting the voltage distortion to below the network planning levels. However AS61000.3.6 does not investigate low fault level networks or SWERS (Single Line Earth Return). This paper investigates harmonic voltage simulation methods along with an investigation into current harmonic voltage allocation methods.**

I. INTRODUCTION

Harmonic distortion is becoming a greater problem for utility suppliers with ever growing demand on electrical networks, increased requirements for efficiency and continuity of supply. Couple this with the increased connection of distorting loads and distributed generation, a greater understanding and better facilities are needed to manage voltage distortion into the future.

Analysis software such as PSS/Sincal can be used to simulate harmonic distortion and system resonances throughout large electrical networks if configured properly. In light of this the main objectives of this paper were to:

- Investigate methods for streamlined conversion from DINIS to Sincal
- Document the simulation of harmonic voltage allocation within Sincal
- Asses the appropriateness of current allocation methods

DINIS to Sincal conversion software had already been developed for Ergon Energy, but was not in use because of a variety of issues with the output. An Automated Program Interface (API) was developed to facilitate the streamlined conversion of DINIS models to Sincal.

This API performs the following functions on the output Sincal model:

- Modification of the graphical layout to allow for the interpretation and modification of the model
- Translation of two and three winding transformer data from DINIS to Sincal
- Transfer of Layer settings between views within Sincal
- Connection of MV/LV transformers to LV loads on SWER lines
- Re-allocation of phases and loading to SWER lines
- Adjustment of Resistance and Reactance values for link cables within substations
- Configuration of system frequency dependencies within the model
- Configuration of harmonic sources within the model

Using the API it is possible to recreate large network models within SINCAL and conduct detailed harmonic simulations.

To fully understand the effect of distorting loads on a network multiple distorting loads must be simulated. A harmonic voltage allocation tool which allocates loads as per AS61000.3.6 and HB264 has been developed to accommodate this. The tool uses Sincal as a slave to find short circuit and load flow data and configure harmonic load profiles within the model. Once this is complete full harmonic simulations can be calculated on network segments from data extracted from DINIS.

To improve the accuracy of harmonic simulations with multiple distorting loads phase angles must be taken into consideration for distorting loads. An investigation into the effects of modelling phase angles in Sincal was conducted which limited the effect of summating voltages from nearby loads.

II. BACKGROUND

A. Harmonic Distortion

Harmonic voltage distortion is caused by the connection of non linear loads. Such loads draw current unlike the sinusoidal waveform expected from linear loads. As such their input current waveform is a combination of the fundamental frequency and a number of harmonic frequencies as shown in **Error! Reference source not found.** [1]

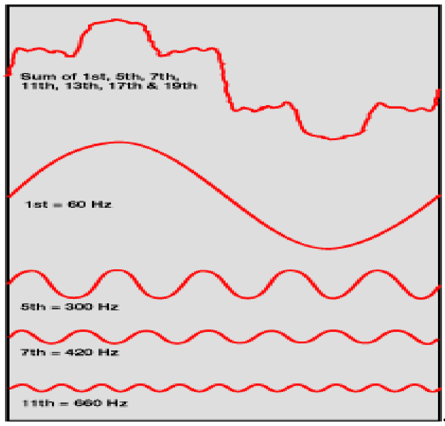


Figure 1: Example of current drawn from non linear load

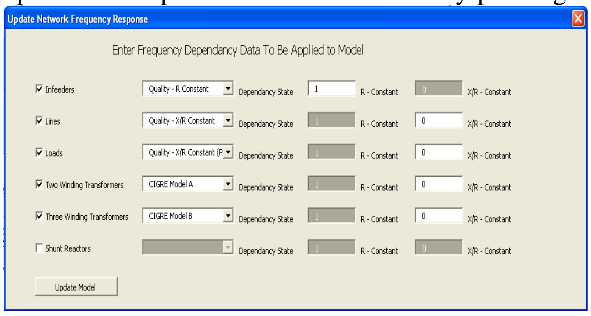
These harmonic currents are not consumed by connected equipment and as a result are dissipated as excess heat. This reduces the life of nearby connected equipment, overheating of cables, false tripping of protection and in severe cases damage to sensitive equipment.

Harmonic currents can also have even more damaging effects if a case of resonance exists. Resonance is brought about through the change in capacitive and inductive reactance with frequency. As frequency increases inductive reactance increases while capacitive reactance decreases. At the resonant frequency the magnitudes of inductive and capacitive reactance are equal.
Resonance causes an amplification of current at and around the resonant frequency as the overall reactance at that frequency approaches zero. If the resonant frequency is equal to a harmonic frequency present on the network the harmonic distortion can rise to unacceptable levels. Resonance can occur when Power Factor Correction (PFC) capacitors or transmission lines with high capacitance are connected.

B. Output from DINIS to Sincal Converter
The DINIS to Sincal converter takes a selected network section from within DINIS and converts it to a Sincal file. However the output Sincal file is not functional as the converter does not convert three winding transformers, regulation data and sites. There are also a number of other problems with converted files that have been overcome with the APIs. These include the modification of the graphical display within the Sincal model so it can be viewed by the user.

Once the output Sincal file is reconstructed with the API the model is as accurate as the original DINIS model. Therefore any inherent errors in the DINIS model will be translated to the Sincal model. However if the DINIS model is accurate than the calculations made by Sincal will also be accurate giving a strong foundation for harmonic simulations.

C. API Development
The API was developed to streamline the conversion process and to assist in the simulation of harmonic conditions on Ergon Energys network. The API was written using Visual Basic Applications (VBA) through Microsoft Excel. While it may have been more appropriate to write the APIs in Visual Basic (VB), VBA is more readily available meaning future modifications can be easily made to the program.
Another benefit of VBA over other coding languages was the ease of which it can read and write to the Microsoft Access database. As Sincal uses an Access or Oracle database to store all information relative to a model this was a major advantage. All API functions utilize forms in VBA to simplify their operation and provide a more aesthetically pleasing interface.



below shows an example of the interface used by the API.

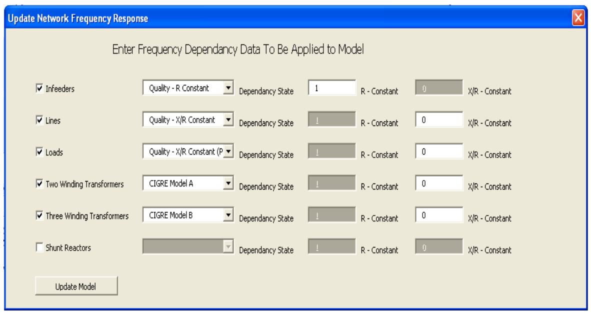


Figure 2: Example of API Interface

Sincal also includes functionality which allows external code to run functions from within Sincal. This was used to run simulations and read or manipulate the results and other data within the model as required.
D. Allocation Tool Development
As with the APIs the allocation tool was written in VBA. The accessibility of VBA made it an obvious choice for the design of the allocation tool as changes can be easily made by Ergon Energy without the need to acquire additional software. As with the API the allocation tool utilizes forms for its interface.

The allocation tool can perform manual allocations, whereby the program calls for the required inputs user. Constants defined within AS61000.3.6 or HB264 are stored within the program to limit the number of user required inputs.

Auto allocation of a Sincal model can also be performed using the allocation tool. The user selects the layer assigned to the loads to be allocated in Sincal and the allocation method. The allocation tool uses Sincal as a slave to perform calculations and extracts the necessary data from the model. The tool then establishes harmonic load profiles within Sincal and attaches the profile to the corresponding load.

III. METHOD

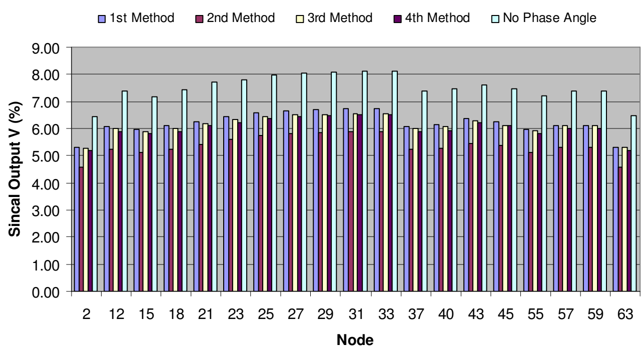
AS61000.3.6 accounts for summation of distorting loads using the second summation law shown in Equation 1 **Error! Reference source not found.**. This summation law utilizes a summation factor α which is dependant upon the harmonic order being allocated. The second summation law was used during this investigation to validate proposed simulation methods for phase angels

$$U_h = \sqrt[\alpha]{\sum_i U_{hi}^{\alpha}} \qquad \textbf{Equation 1}$$

The output phase angle of harmonic voltages is dependent upon the firing angle of distorting loads which changes with equipment make and model. To account for this the phase angle of loads in PSS/Sincal was distributed over 135° to provide diversity.

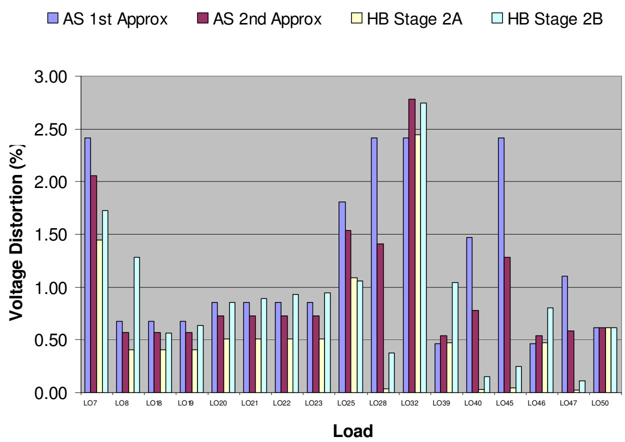
Error! Reference source not found. Error! Reference source not found. shows the overall harmonic voltage levels through a test network developed within PSS/Sincal when the phase angle of distorting loads were distributed over 135° using four different methods as well as no consideration to phase angle. It can clearly be seen that the distribution of phase angles causes a reduction in harmonic voltage compared to the voltage levels seen with no consideration to phase angle. The overall reduction seen through the distribution of phase angles was compared to what would be expected using Equation 1 **Error! Reference source not found.** to determine the most appropriate method.

Graph 1: Sincal Derived Harmonic Voltage Distortion Levels Modelling All Loads with Phase Angle Distribution over 135°



Using network models recreated in Sincal and phase angle distribution a review into the appropriateness of current harmonic voltage allocation methods was conducted. This was achieved by allocating harmonic voltage using AS61000.3.6 1st and 2nd approximations and HB264 Stage 2A and Stage 2B approximations.

Graph 2: Emission Limits Derived from Current Harmonic Voltage Allocation Methods



As it can clearly be seen in

Graph 2 there is a large amount of variation between each allocation method. These variations are brought about through the electrical location of the loads, their size and the system capacity at their point of common coupling.

This highlights the issues which are arising for utility suppliers with a diverse range of fault levels throughout their network and varying load types.

IV. RECOMMENDATIONS

The final recommendations of this project are as follows:

- Further refinement of conversion process to improve automation
- Further refinement of allocation tool to reduce risk of misinterpretation/calculation during allocation

- More detailed investigation of allocation methods
- Development of allocation method for LV and HV for use within Australia
- Possible refinement of MV allocation method considering standard data availability
- Investigation into the effects of harmonic distortion on SWER

V. CONCLUSION

The main objectives of this project were met with the development of both the API and Allocation tool. As a result of this DINIS to Sincal conversion is now both a practical and time effective solution to detailed network modelling.

This has also seen the commencement of harmonic voltage simulations which has the potential of yielding further improvements to allocation techniques. This will prove to be critical in the future management of harmonic distortion on electrical networks.

The recommendations given will provide further improvement to conversion and allocation techniques. They will also lead to detailed investigation into both the effects of harmonic voltage distortion levels throughout Ergon Energys network and improvement on allocation techniques.

This project has provided the author with technical insight into harmonic voltage distortion and groundwork for further development in this field. A practical solution to harmonic voltage distortion in electrical networks within Australia is possible in the near future and this project has provided a strong foundation for its development

Acknowledgment

The authors would like to thank Ergon Energy and CQ University for their support and assistance with this project.

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