AUTOMATED ASSESSMENT OF VOLTAGE SAG PERFORMANCE AT LOW VOLTAGE BUSES

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ABSTRACT

The paper describes the software for the assessment of voltage sag performance at low voltage buses based on available sag performance at point of common coupling (PCC). The sag performance at the PCC can be obtained either through computer simulations or from long term measurements. The software takes into account the influence of downstream transformers and induction motors and correspondingly accounts for the changes in sag characteristics per phase. In this way, more realistic characteristics of sags at equipment terminals can be determined.

INTRODUCTION

Assessment of Power Quality (PQ), especially at the PCC is gaining attention with sharp rise in sensitive equipment installations across the network. Among various power quality events and disturbances, voltage sags and short interruptions are seen as the most frequent cause of nuisance tripping or damage of sensitive equipment and process disruptions leading often to substantial financial losses, especially to the process industry. In recent years, the power quality responsibilities are increasingly shared among utilities, equipment manufacturer and end customers. The responsibilities include providing continuous power supply and waveform distortions within the standards set (or recommended by the regulating bodies) to develop reliable and robust systems and to procure products that are immune to PQ problems, respectively. A utility would be inclined to assess the investments required based on the system's voltage sag and short-interruption performance through fault analysis, their propagation to low voltage buses, and corresponding areas of vulnerability to sag characteristics. A customer however, would be more interested in the number of sags at the point of common coupling and at the point of connection of critical processes within the plant. It is therefore, essential to establish variation in the utility bus voltage sag profile while propagating through transformers or other heavy dynamic loads connected within customer facility. Based on these studies the equipment manufacturers can also benefit by optimising their products customised to local or global immunity requirement standards accordingly.

With this in mind, an MS Access based modular software, Automated Voltage Sag Assessment Software (AVSAS), was developed for the assessment of the voltage sag performance beyond the service entrance. It uses Structured Query Language (SQL) for filtering the information and dynamic record-sets for reducing the memory requirements. This paper describes the software and demonstrates its capabilities on a simple case study.

DESCRIPTION OF AUTOMATED VOLTAGE SAG ASSESSMENT SOFTWARE (AVSAS)

The AVSAS uses a modular approach, ensuring module independence and expandability of the entire package. The basic structure, composition and modular blocks are shown in Fig.1, illustrating various modules included within, for voltage sag assessment at both system level and low voltage level.

It consists of five application modules: Calculation of number and characteristics of voltage sags; Identification of the area of vulnerability and the area affected by the fault; Voltage sag propagation through transformers; the effect of induction motor(s) dynamic responses on voltage sag characteristics, and the user interface.

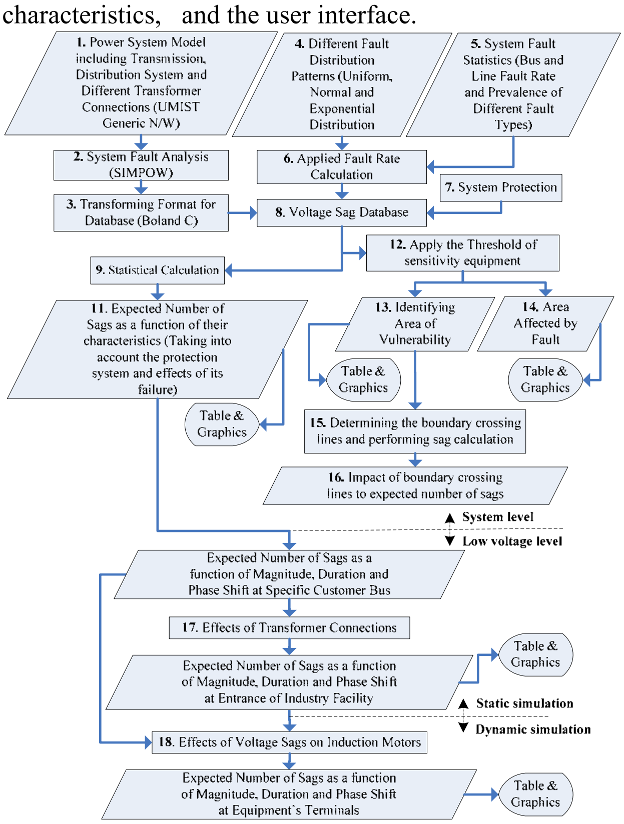

Fig.1 AVSAS flow chart

At the heart of the software is a dedicated voltage-sag database which systematically stores system and low voltage buses sag data such as magnitude, duration, phase angle, phase shift, type of faults, fault-location and fault-rate in corresponding table-type record-sets. The voltage-sag data in this particular case is obtained from fault calculations using commercially available SIMPOW software. The data obtained from long term measurement at system buses however, could be equally well used.

Number and characteristics of voltage sags

In this module, different fault distribution patterns (with different distribution parameters) are considered in the calculation of fault rates at fault locations along the line (refer blocks 4-6 in Fig.1). The module (block 9 & 11 in Fig.1) calculates the number of sags contributed by each voltage level and aggregates them to provide the total number of sags as a function of voltage magnitude, duration and phase shift for the entire network. Its working principle

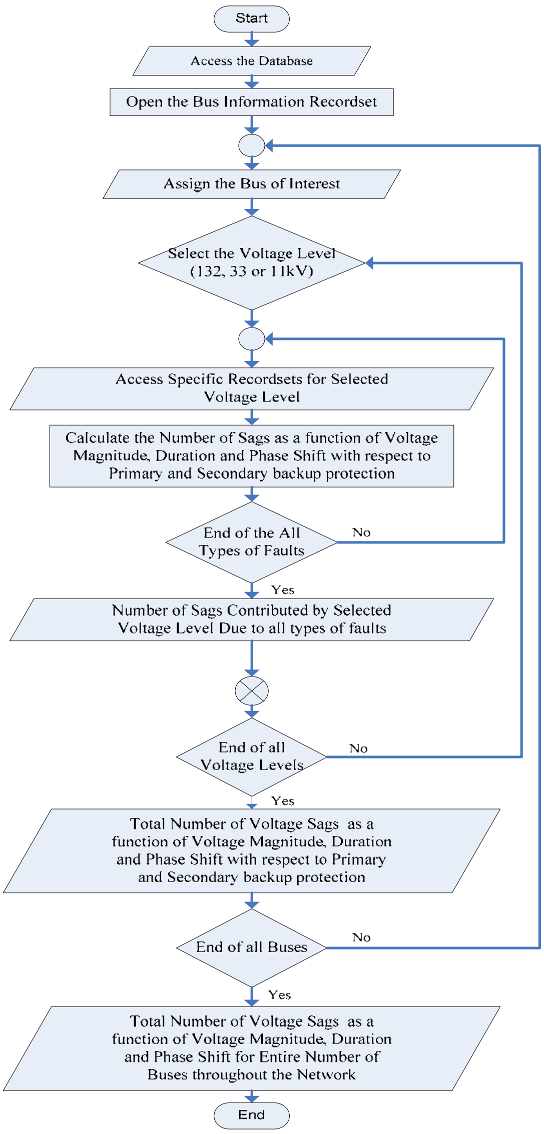

Fig.2 Calculation of number and characteristics of sags

is illustrated in Fig.2 The module starts with accessing the voltage-sag database and opens the bus information record-set, which contains bus number (or bus name) and voltage level. Once the bus of interest is defined by the user, the module pulls up all the corresponding sag information including the fault rate for each of those particular sag events. This data is further filtered using pre-defined criteria, i.e., voltage threshold, phase shifts, duration. The filtered information along with the fault rate for each of record-sets enables a statistical representation of voltage sag number distributed on voltage-sag magnitude-duration plane and phase-jump-duration plane at the bus of interest. This is performed by a sub-block within the 'Calculate the Number of Sags' block in Fig.2. Its principle is further elaborated in Fig.3.

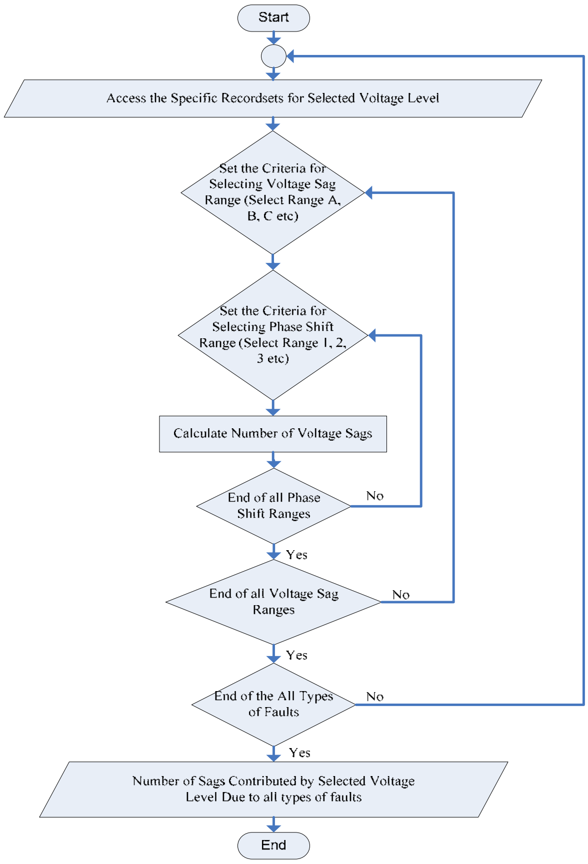

Fig.3 Filtering criteria for statistical representation of sag profile at bus of interest

Fault and sag propagation through the network

The module facilitates the automated visualization of the area of vulnerability and its associated boundary crossing lines. Block 13 in Fig.1 represents this feature and is further elaborated using a flow chart in Fig.4. It allows the user to specify the voltage threshold, phase shift range, and fault types on the Graphical User Interface (GUI). This data is passed to the event procedure block to be used as a filtering criterion to obtain specific record-sets for the area of vulnerability, and when stored in corresponding tables, it dynamically updates the GUI to show the area of vulnerability.

In contrast to the area of vulnerability, the area affected by the fault is the area of the network that would see voltage-sags below the specified voltage threshold and/or phase-jump range following a particular type of fault occurring at the specified bus. The calculation procedure is similar to that illustrated in Fig.4, except that the area affected by the fault on bus of interest is shown instead.

Sag propagation through transformers

The theory presented in [1] forms the backbone of this module and is represented by the block 17 in Fig.1. The module accounts for the influence of transformer winding connections on propagation of voltage sags, and calculates the change in voltage sag characteristics on the transformer secondary. It is designed to perform voltage sag propagation

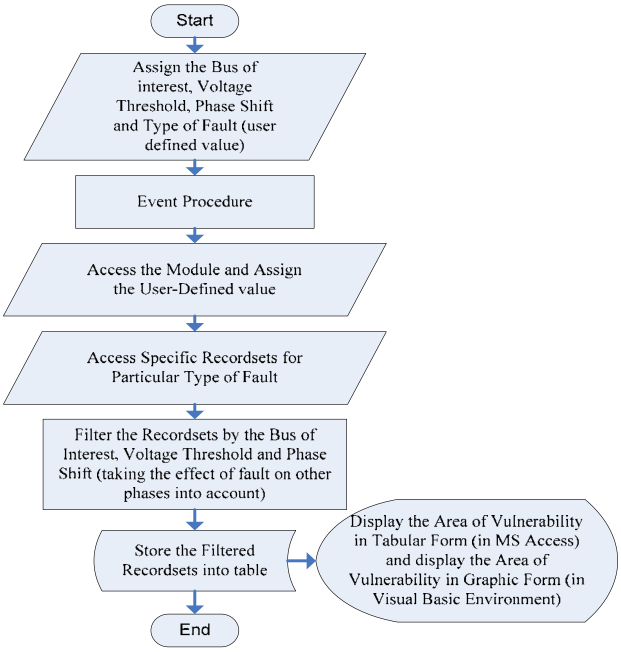

Fig.4 Area of vulnerability identification module

analysis on any transformer connected at low voltage level. The working principle is illustrated in Fig.5. The bus of interest and vector group of transformer connected at PCC are chosen by the user in order to access the specific record-set (primary side voltage and load current information) related to that particular bus, and to perform required calculations. The module then manipulates transformer primary phase voltages and currents to obtain corresponding sequence quantities, which are then used in a matrix (specific for chosen transformer type) operation to obtain respective secondary sequence quantities and corresponding phase quantities. This operation is repeated for all the faults, yielding corresponding change in sag number and characteristics at the equipment or plant connection.

Influence of induction motor dynamics on sags

This module is illustrated in Fig.6, and is based on the work presented in [2]. Once the sequence quantities are obtained from corresponding phase quantities, the influence of induction motor dynamics on sag during and after fault clearing are calculated individually and aggregated at the end. Both during sag and post sag conditions involve speed and slip estimation at each integral time step, which dictates the currents drawn by the motors, affecting the motor terminal voltages eventually. For the purpose of voltage sag number estimation, the non-rectangular voltage sags due to induction motor dynamics are converted to rectangular voltage sags based on voltage sag lost energy equation [3].

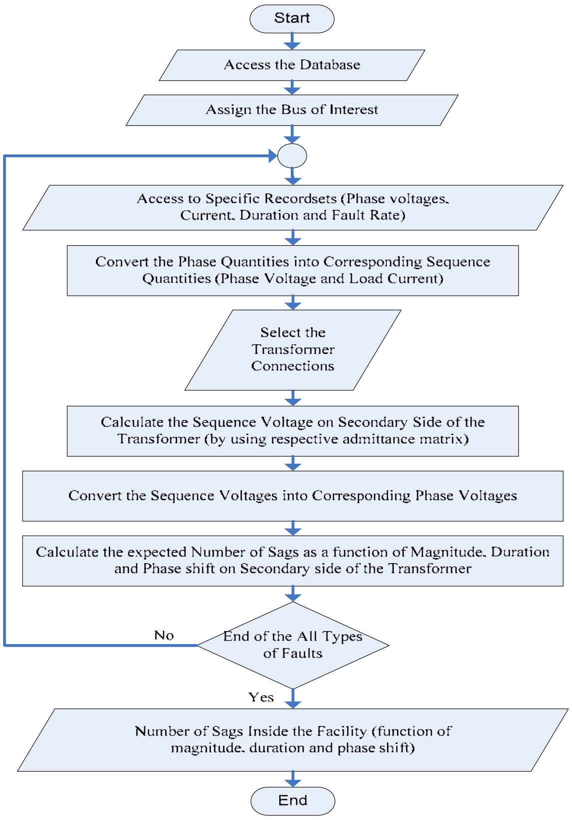

Fig.5 Voltage sag propagation through transformer

User interface

The main interface prompts for user-inputs and provides buttons that link to various modules previously mentioned. Some buttons are designed to analyse piece-by-piece effect, while others analyse a collective effect of certain features. For example, the influence of transformer winding connections on sag characteristics can be analyzed separately or with the effects of primary protection failure included. The results are either displayed in tables, 3D histograms, or as a combination of the above.

ILLUSTRATIVE EXAMPLE

In order to illustrate sag propagation and corresponding change in characteristic from PCC to low voltage equipment terminals an arbitrary bus (bus no. 100 from generic distribution network [4]) was selected and entered in main user interface (Fig.7). 'Raw sag data extraction' key organises all the voltage information relevant to the bus of interest and plots the number of voltage sags in different cells on magnitude–duration and phase-jump-duration planes (Fig.8, upper left). While executing the 'Effect at transformer' (with user defined transformer type), it plots the number of sags seen on the transformers secondary (Fig.8, upper right). 'Effect of induction motor' (with user defined individual motor size, applied load and inertia and their number connected at the bus), results in the plot (Fig.8, lower left) of the number of sags as a consequence of the induction motor dynamics effect. Finally 'Effect of transformer and induction motor' key accounts for both previous effects simultaneously (Fig.8, lower right).

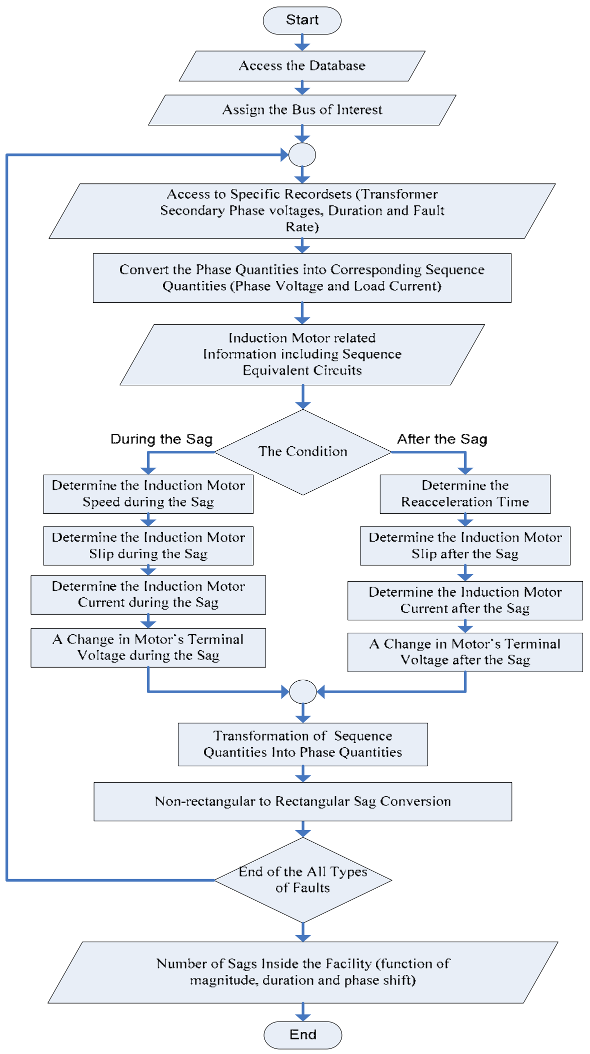

Fig.6 Influence of induction motor dynamics on sags

SUMMARY

A comprehensive, expandable, and complete AVSAS is briefly described with illustrated capabilities. It could be used by utilities to assess the existing system performance, required investments at specific locations (area of vulnerability and area effected by the fault) and to suggest locations for connection of sensitive customers; by their customers (industrial plant owners) to procure equipment or solutions that will tolerate the voltage sag specification at the PCC and by the manufacturers of sensitive equipment to develop customised products for specified locations.

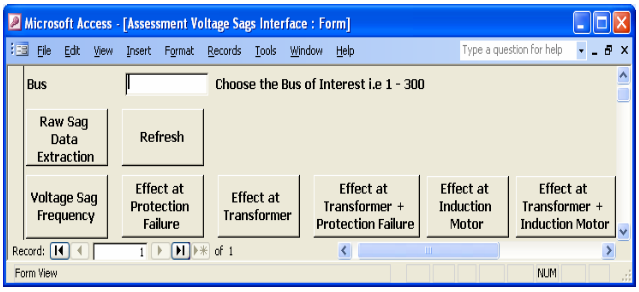

Fig.7 AVSAS main user interface

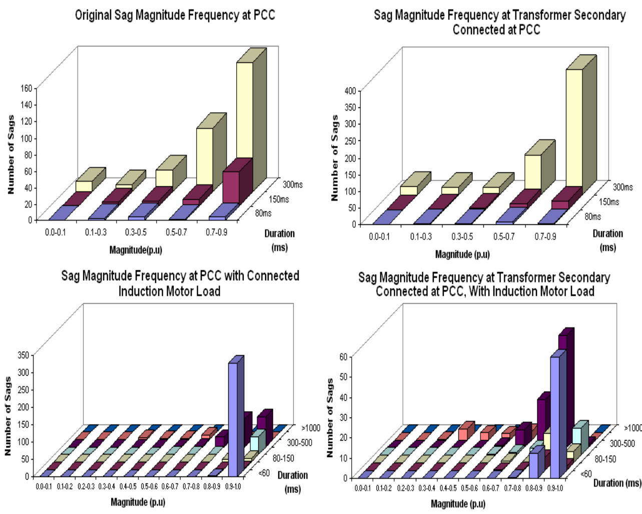

Fig.8 Effect of transformer winding connections, induction motor dynamics and their combinations on sag propagation beyond PCC

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