A COMPREHENSIVE MODELLING AND SIMULATION OF POWER QUALITY DISTURBANCES USING PSCAD

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Abstract : Power quality is an important measure to give standard quality of power supply to its customers. This paper presents a comprehensive set of PSCAD models used to simulate various power quality disturbances on linear and nonlinear loads. The models presented includes distribution of line faults, energization of transformer that are used to simulate voltage sag/swell. Capacitor bank switching model is used to simulate the oscillatory transient event, nonlinear load models to simulate triple harmonic and voltage notch generated from the load side and lastly electric arc furnace model used to simulate flicker disturbance are also presented. This paper presents simulation of each of the power quality disturbance using Power System Computer Aided Design (PSCAD) software.

Keywords: PSCAD, power quality disturbances, harmonics, line faults, voltage sag/swell, flicker, EAF, induction motor, capacitive transients.

I. INTRODUCTION

Power quality plays an important role in power system engineering. It tries to ensure quality of power being delivered to the consumer. A single power quality event such as voltage sag caused by a fault in transmission or distribution level may cost the affected industries up to millions of financial losses. Power quality disturbances are categorized into voltage sag, voltage swell, transient, harmonic, voltage notch, and flicker. Power quality research is the study of various phenomena that root power quality disturbance to occur and the advancement to eliminate them. These disturbances may be in the form of voltage sag, swells, voltage disproportions, transients, interruptions and harmonics which can cause problems to the industries ranging from malfunctioning of equipments to complete plant closures. Such disturbances occurring on high voltage end in distribution feeder will proliferate downstream to the low voltage ends where sensitive loads are connected. In an electrical power system, various types of faults, the dynamic operation of power equipment and amplified exploitation of nonlinear loads often create power quality disturbances.

The various simulation tools [1] available are MATLAB/ Simulink, PSCAD/EMTDC, ATP/EMTP, Power system Analysis Toolbox (PSAT) and EATP with each having merits and demerits [2]. In this work PSCAD is chosen as the simulation software for its easy to use interface and advantages as discussed in [3,4]. A comprehensive set of the models to demonstrate voltage sag/swell, voltage transient, notch and voltage flicker are presented in this paper.

II. MODELLING APPROACH:

The following circuits are developed and analyzed using the PSCAD software and they were also studied thoroughly under different circumstances. These models are also the basic depiction of larger power systems. The distribution voltage level used in the models is based on the Malaysia grid code.

III. ENERGIZATION OF TRANSFORMER

The transformer energizing model developed in PSCAD is shown in fig 1. It is used to simulate voltage swell caused by transformer inrush current and core saturation during energization. The model consists of an 11 kV, 0.75 MVA, 50 Hz three-phase source block feeding through a three-phase breaker block to a 11 kV/0. 415kV, 100 MVA saturable core transformer block to a 10 MW resistive and 100 KVAR inductive load. The measurements of instantaneous waveform and RMS are located at the 11 kV feeder bus.

This model enables the simulation of voltage swell caused by transformer energizing. The switchgear (which in case here is a capacitive bank) is set to open at initiate stage and close at 0.06 second during simulation to simulate voltage swell caused by transformer energizing. A 2 second simulation time is set and the capacitive switchgear opens at 1 sec.

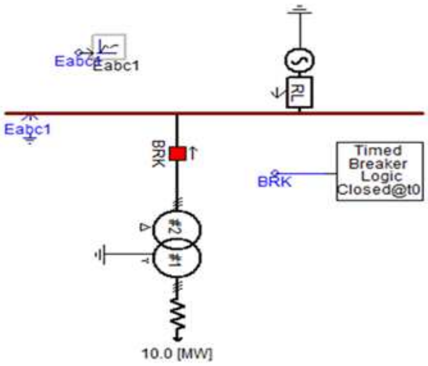

Fig1: Transformer Energization Model

The voltage waveform of the model is as shown in fig 2. The voltage swell can be clearly seen and the different values of load doesn't have much effect on the voltage waveform.

All three phases experience unbalanced voltage swell and gradually rise to its nominal voltage level. The sag magnitude of the transformer energizing voltage swell is dependent on the source feeder power rating and transformer power rating. The higher the transformer power rating, the lower the swell magnitude.

The voltage swell normally keeps between 1 to 10 cycles and the rise of voltage is up to 15 to 20% of the original voltage.

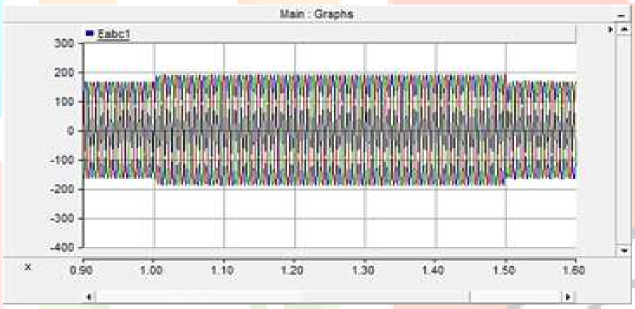

Fig 2: Simulated Voltage Swell Waveform

IV. LINE FAULTS WITH VOLTAGE SAG SWELL

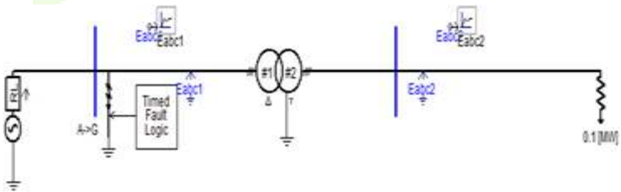

Fig3: Line fault model of the system

The line fault model depicted in fig 3, consists of 11 kV, 0.75 MVA, 50 Hz three-phase source block feeding through 11 kV/0.415 kV, 0.75 MVA delta/wye transformers to a kW resistive and 100VAR inductive load. There are instantaneous waveform measurement scopes located at 11 kV and 0.415 kV buses.

A voltage sag or voltage dip is a short duration reduction in rms voltage which can be caused by a short circuit, overload or starting of electric motors, single line to ground (SLG) faults, line-line and three phase (symmetrical) faults. Voltage sag happens when the rms voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute.

Depending on the type of fault the sag can be balanced or unbalanced. Naturally for Three phase to ground (ABC-G) fault the sag is symmetrical (balanced) in all the three phases whereas for unbalanced faults like A-G, B-C, BC-G the sag is unsymmetrical (unbalanced) in all the three phases.

The simulation time is approx. 2 sec and the fault occurs at 0.4 sec and the duration is approximately 0.3 sec. There are three kind of faults such as LG, LLG and LL faults going on.

The voltage waveforms are shown in the fig 4, fig5 and fig6 for an L-G, L-L and L-L-G faults respectively.

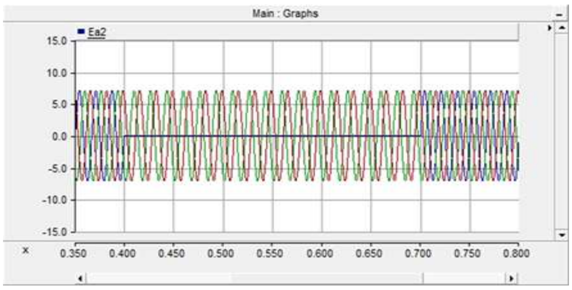

Fig4: Voltage Waveform For An LG Fault

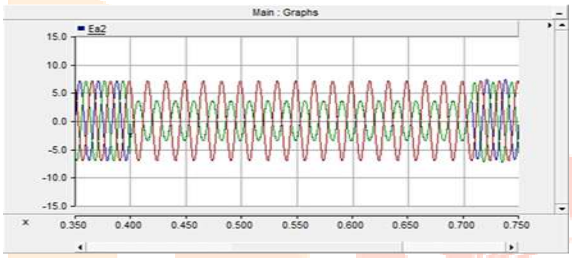

Fig5: Voltage Waveform For An LL Fault

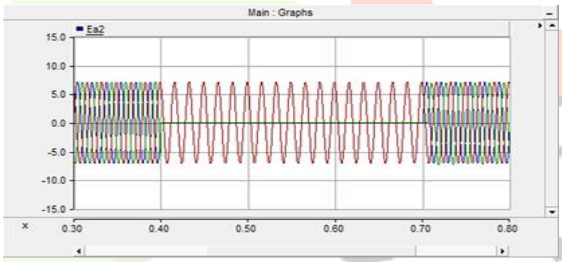

Fig6: Voltage Waveform For An LLG Fault

V. CAPACITOR BANK SWITCHING TRANSIENTS

Characteristics of electromagnetic transients originating from industry capacitor banks switching is studied in this paper. Moreover, factors that influence the intensity of such transients are investigated in order to identify the conditions in which these effects can be undermined. It should be pointed out that the electrical network which represents a real-life feeder of the typical 11 kV distribution system is inspected in this paper. The feeder supplies mining loads (total power is approximately 0.75 MVA) with installed three phase, star connected, capacitor banks (rated power 500 kVAr),

Phase to phase voltage waveforms are measured during energizing of three phase capacitor banks. Phase to phase voltage waveforms during energizing of one 600 kVAr capacitor bank and 25 kVar the 11 kV electrical network with isolated neutral point are presented below.

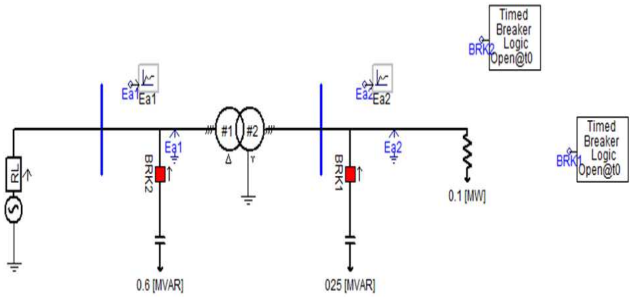

Fig 7: PSCAD model for the switching transient

Simulations of electromagnetic transient phenomena during energizing of capacitor banks are carried out in electrical networks of 11 kV. An equivalent three phase electrical model is implemented with usingthe PSCAD software as shown in fig 7.

The Model consists of power system equivalent, industrial Loads(LINEAR), distribution transformer, breaker, supply cable, capacitor banks equivalent and capacitive loads. Model comprises of 11kv, 50hz, three phase fixed source block feeding through an 11kv,415V, 0.75MVA delta –wye transformers to a 1kw resistive load.

The results of phase to phase voltage waveforms during energization of three phase capacitive banks in electrical networks of 11kV with isolated neutral point are depicted in fig 8. This circuit focuses on the sensitive analysis of influential parameters within a three phase system by observing characteristic parameters of phase transient currents and phase to phase transient voltage waveforms (amplitude, duration, frequency).

Influential parameters on a three-phase system are: initial conditions, impedance of system, consumers' characteristics, capacity of capacitor banks and moment of circuit breaker switching. Shunt Capacitor are always added in distribution system for power factor correction and feeder voltage correction.

Theoretically observing the transient overvoltage should reach twice of its steady value. However, in this simulated case study the voltage did not reach twice the peak steady voltage due to damping cause by impedance in the system. The speed of the transient settling down is dependent on the size of the load.

When loads are connected to higher KW ratings results in higher damping factor, hence leading to higher damping factor, hence leading to faster settlement of transient oscillation. It takes half a cycle before the oscillations appreciably damp out. The switching transient magnitude is reduced when propagated towards 11 kv bus.

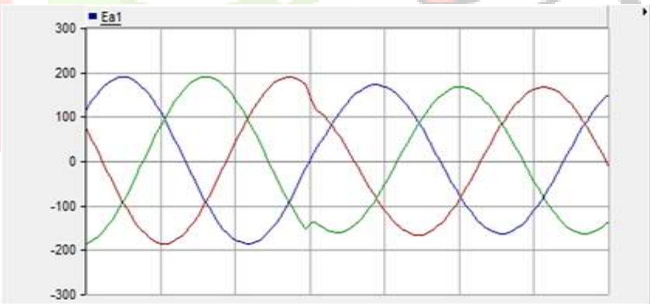

Fig 8 : Waveform of voltage transient due to capacitor bank switching

VI. SINGLE PHASE NON LINEAR LOAD:

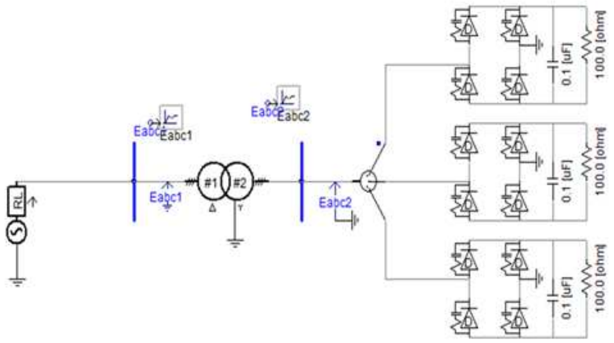

Fig 9: PSCAD Model of a single phase non- linear load

The model depicted in fig 9, consists of 11 kV, 0.75 MVA, 50 Hz three-phase source block feeding through a 11 kV/0.415 kV, 0.75 MVA delta/wye transformer to a 100 Ω resistive load, single-phase bridge with 0.1µF capacitive filter and 10 Ω resistive load for each phase. There are instantaneous waveform scopes located at 11 kV and 0.415 kV buses for measurement. A 2 second simulation time is set and waveform is obtained.

To visualize the harmonic distortion, the simulation time is set at 0.5 second so that 10 cycles will be simulated. The harmonics block clearly shows that at 0.415 kV, phase A consists of odd harmonic order with high 3rd order zero sequence harmonic, which is the unique characteristic of triple harmonic generated by the single phase nonlinear load. However, as the waveform propagates upstream to 11 kV it can be clearly see that all the triple harmonics 3rd, 9th, 15th, and 21st generated from the single phase nonlinear load has been suppressed by the delta/wye transformer. The harmonics generated in the three phases are measured using a polymeter which are shown in fig11, fig12 and fig13 respectively. The smaller harmonics have larger magnitude.

Harmonic distortions at 0.415 kV are still noticeable along 60° and 240° of each cycle waveform. However, at 11 kV bus harmonic distortion has be significantly suppressed by the delta/wye transformer.

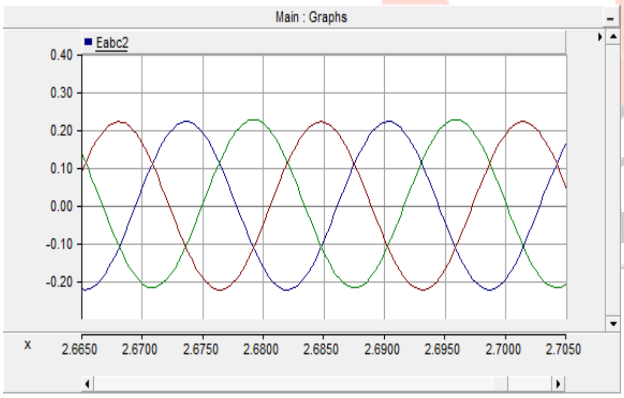

Fig 10: Voltage waveform due to single phase AC-DC diode circuit

Fig 11: Harmonic content of voltage in phase A

Fig 12: Harmonic content of voltage in phase B

Fig 13: Harmonic content of voltage in phase C

The capacitors are connected in parallel to the load for the purpose of filtering and energy storages. Having three loads connected turned ON, has resulted in significant flat toppings of the voltage waveforms.

VII.ARC FURNACE (FLICKER)

The circuit depicted in fig 14 is used to simulate flicker disturbance caused by the electric arc furnace. The model consists of 0.415 kV, 0.75 MVA, 50 Hz three-phase source block fed directly to an electric arc furnace block. There are instantaneous waveform scopes located at 0.415 kV buses for monitoring.

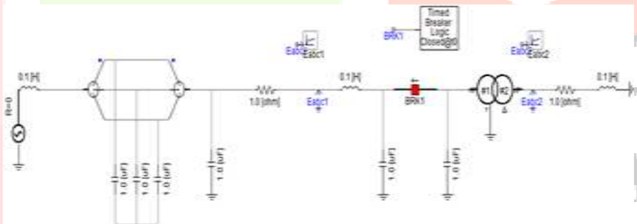

Fig 14: PSCAD Model of an electric Arc furnace

A controlled voltage source with resistive and inductive network is used to couple the generated flicker disturbance to a given phase of the power system line. For a three-phase system, three sets of measured voltage source and resistive and inductive networks are needed. The electric arc furnace model uses a hyperbolic model.

During the melting period, the consumption of reactive power by EAF becomes strongly fluctuating. The voltage drop caused by reactive power also fluctuates in an erratic way, giving rise to flicker. The frequency fluctuation of the EAF model in this simulation is at 8.8Hz.

There is swell in voltage for the time fault for the circuit breaker we have used in 0.5 sec. The waveform goes swelling for the faulty duration and the waveform the final waveform is shown below.

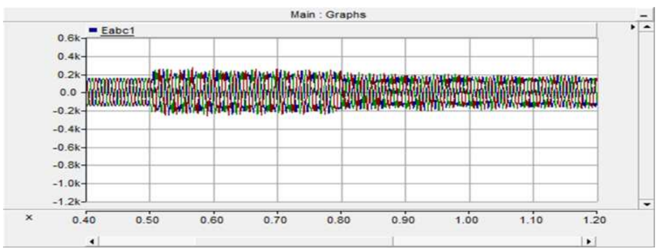

Fig 15: The voltage Fluctuation due to Flicker of an Arc Furnace

VIII. INDUCTION MOTOR

The model consists of a 11 kV, 0.75 MVA, 50 Hz three-phase source feeder block feeding through 11 kV/0.415 kV, 0.75 MVA delta/wye transformers, a three phase breaker as motor starting contactor, a three-phase induction motor, and 10 kW resistive load. There are instantaneous waveform scopes located at 11 kV and 0.415 kV buses for measurement.

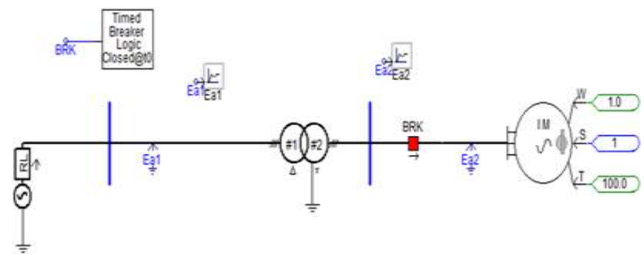

Fig 16: PSCAD model of an Induction Motor

The induction motor starting model is used to simulate voltage sag triggered by starting a high power industry induction motor. The induction motor which we are using here is in speed control mode. Figure 17 shows a three-phase voltage sag instantaneous waveform caused by a 75 kW (100 hp) induction motor starting upon closing of motor starting contactor at 0.1 second. The speed of the induction motor during starting is set at 1 rad/sec using the machine constsnt. The voltage sag at 0.415 kV bus propagates upstream through the transformer to the 11 kV feeder bus.

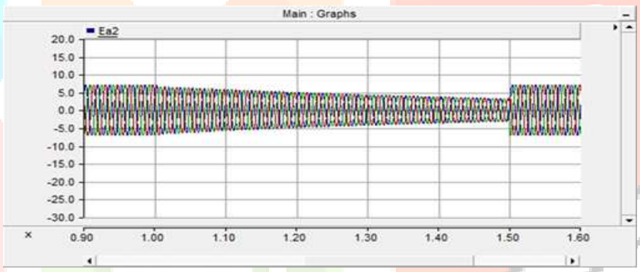

Fig 17: The waveform of Voltage Swell due to induction motor strating

The waveform registers the voltage sag of about 15 to 20 % of the drop in the waveform through the nonlinear load. A higher powered induction motor leads to higher voltage sag down the voltage waveforms. Since, it is a nonlinear load we used a polymeter to measure the harmonic waveforms The harmonic waveforms show the rise in the odd waveforms just like 3rd, 5th, 7th and 9th. The voltage sag magnitude reduces as it advances upstream toward the 11kV feeder where the voltage sag becomes irrelevant and not noticeable.

IX. CONCLUSION

The simulation approach provides the researcher the flexibility to create power system models to simulate power quality disturbance by connecting various functional building blocks in the simulation environment. It gives an insight on how power quality disturbance propagates and behaves within the simulated power system model. The limitation of the simulation approach is its reliance on the capability of the selected simulation software, basic information of power quality and the simulation software, and the accessibility of power system building blocks required to build the power system model to simulate the intended power quality disturbance. This paper presents simulation models that are able to simulate power quality disturbance, including voltage sag due to fault, induction motor starting, transformer energizing, voltage swell, oscillatory transient, impulsive transient, harmonic, voltage notch, and flicker. These simulation models contribute as basic models to the power quality study as well as the development of mitigating schemes for power quality disturbances.

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