ISSN 2320-9984

Volume 9 Issue 4 | December 2021 ISSN: 2320-9984 (Online)

International Journal of Modern Engineering & Management Research

Website: www.ijmemr.org

Modeling and Simulation of Switching Transient in Power System by Capacitor

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Abstract—*Transmission lines are used for transporting energy from generating stations to distribution systems. A distribution system connects all the individual loads to the transmission lines. An electric power system is known to be comprised of electrical network components used to supply, transfer and use of electric power. The growth in size of power plants and in the higher voltage equipment has divided an electric power system into three principal divisions: Generating stations, the power delivery system and the load. The power delivery system is divided into two divisions: High voltage transmission and low voltage distribution system. An example of an electric power system is the network that supplies a region's homes and industry with power- for sizeable regions, smaller power systems are also found in industry, hospitals, commercial buildings and homes. The majority of these systems rely upon three phase ac power the standard for large- scale power transmission and distribution across the modern world.*

Keywords:— *Power Quality, Transients, Capacitor Switching, Zero-Crossing, Modeling and Simulations.*

1. INTRODUCTION

Generally, electrical systems are made up of three basic types of load: resistors, inductors, and capacitors. The industrial loads of the electrical system are highly inductive, which means that they require an electromagnetic field to operate. Reactive power is required to provide the electromagnetic field necessary to operate an induction motor. An inductive load to operate requires real and reactive power. Reactive power is required to provide the electromagnetic field necessary to operate an induction motor [4, 5]. For inductive loads to operate requires real and reactive power. Power factor is related to power flow in electric al systems and measures how effectively an electrical power system is being used. In order to efficiently use a power system we w ant power factor to be a s close to 1.0 as possible, which implies that the flow of reactive power should be as kept to a mini mum. Reduced system voltages often result when an electrical utility distribution system operates at a lower (poor) power-factor. Maintaining a high power factor is a key to obtaining the best possible economic advantage for both utilities and industrial end users. Operating a power system at a low power factor is a concern for both the electrical utility and the industry. The major cause of a poor power factor in a system is due to motors, which are inductive loads. It is in the best interest of both the electrical utility and industrial customers to maintain a high power-factor. Low-voltage results in dimming of lights and sluggish motor operation. In addition, it increases the current flow in the system, which may damage or reduce the life of the equipment Operating the power system at a higher power factor allows the system to maximize the capacity of the system by maximizing the delivery of real power. Commercial and industrial customers avoid utility charges by operating at an acceptable power factor.

Advantage of Improving Power Factor

By improving the power factor:

- The efficiency of the power system is increased because real power flow is maximized and reactive power flow is minimized.
- Voltage drop will be minimized. Voltages below equipment ratings cause reduced efficiency, increased current, and reduced starting torque in motors [4].
- Industrial and commercial customers avoid power factor penalty charges.
- Reduced currents results in reduced losses (I^2R)

Switched Capacitor and Fixed Banks

The amount of fixed capacitance to add to the system is determined by minimum reactive demand on a 24-hr basis as shown in Fig. (1). the curve represents the reactive energy requirement by the system on a 24-hr period. Note that the system draws 310kVr for every hour of the day. A fixed capacitor of 310kVAr can be installed to provide the required reactive energy by the system. Switched capacitors on the other hand are those that are not connected all of the time. Switched capacitors give added flexibility in the control of power factor correction, losses, and system voltage because they may be switched on and off several times during a day. Switched capacitor banks are applied with an automatic switch control, which senses a particular condition. There are two types of capacitor bank installations utilized today: Fixed and switched capacitor banks. Fixed capacitor bank installations are those that are continuously energized. Fixed capacitor banks are connected to the system through a disconnecting device that is capable of interrupting the capacitor current, allowing removal of the capacitors for maintenance purposes. Fixed capacitor banks are applied to provide reactive energy to the system, which results in a boost in the voltage. Caution must be used, however, to ensure that the power factor does not go leading, which can happen particularly during light load conditions. If the condition is within a preset level, the control's output level will initiate a trip or close signal to the switches that will either connect or disconnect the capacitor bank from the power system. Capacitor controls can be chosen to switch capacitors in and out of the system depending upon the desired control quantity, which are:

- Time Switch: VAr demand has a high degree of regularity with respect to time
- Reactive current controls: VAr demand.
- Temperature: Increase in VAr demand is closely related to temperature change [4].
- Voltage: Control or improvement of voltage regulation
- Current: Current magnitude

Capacitor bank switching is not based on power factor because both the voltage and current would have to be monitored and a microprocessor is required to calculate the power factor.

Switching Equipment and Capacitor Bank

Devices currently available for transient over-voltage control either attempt to minimize the transient over-voltage (or over-current) at the point of application or limit the over-voltage at remote locations. Some of the techniques employed at the utility's switched capacitor bank include[4]; pre-insertion resistors[9], pre-insertion inductors[9], fixed inductors[8], MOV arresters[9], series inrush-current-limiting reactors, dividing the capacitor bank[9] into smaller size banks, and avoiding the application[11] of capacitors at multi-voltage levels to eliminate the possibilities of secondary resonance. Another approach to reducing energizing transients is to time the switching device to close at the best possible time (when voltage across the switch is zero) rather than altering the circuit parameters.

Controlled Closing

In order to control the closing of the breaker/switch, alternatively simple algorithm is required to utilize all of the available information to predict when the signal to close should be given to insure a zero-voltage close operation. To accomplish closing at or near a voltage zero it is necessary that the breaker/switch consists of a zero detection module, a delay-time calculation module and a power module. The success of a synchronous closing scheme is often determined by the ability to repeat the process under various system and climatic conditions. Uncharged capacitors energized at zero volts should produce virtually no transients. The synchronous closing technique will lower peak transient voltages to about 1.1p.u. As a result, synchronous closing helps to increase equipment life, reduce ground transients and minimize capacitor inrush Zero-crossing switching, also called synchronous switching, represents a relatively new technology and a best means [2] of reducing capacitor switching transients. Synchronous switching, times the closing of each phase to correspond with the zero crossing of the phase voltage, thereby preventing the generation of switching transients. The proposed control unit receives the close command and sends a modified close signal to the switch close coil or open coil. It should be noted that the dielectric strength of the switch should be sufficient to withstand system voltages until its contacts touch. Closing the switch at or near voltage zero is not difficult to achieve and closing consistency of ±0.5 milliseconds should be possible. A comparison of the voltage transient for a non-synchronous closing and synchronous closing of a capacitor bank is shown in Figure 1.

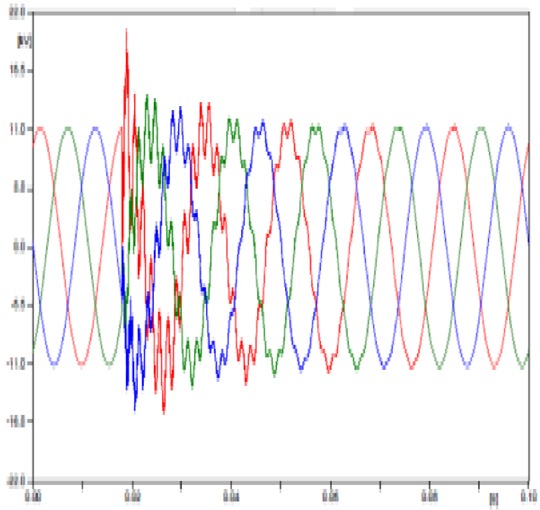

Figure 1: Voltage Corresponding to No-Synchronous Closing in a Capacitor Bank

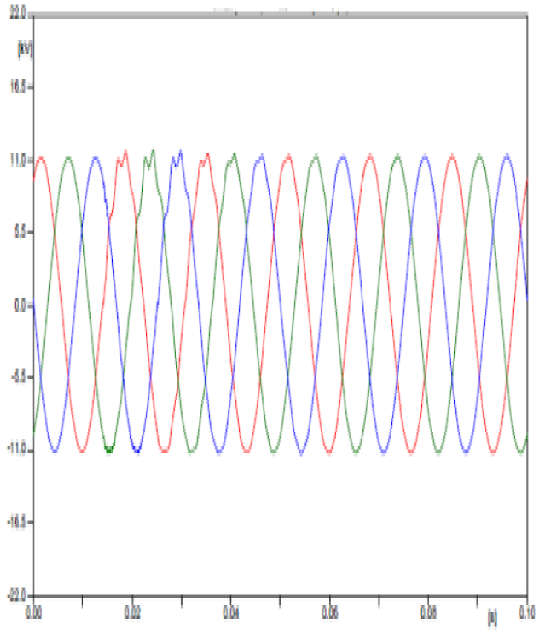

Figure 2: Voltage Corresponding to Synchronous Closing in a Capacitor Bank

Modeling

The power system under study is 220 KV Substation MPPTCL Narsinghpur. It is connected to 220kV on the high voltage side and is stepped down to 132kv on the distribution side. The distribution system has 3 feeders and 4 capacitor banks placed on all the feeders.

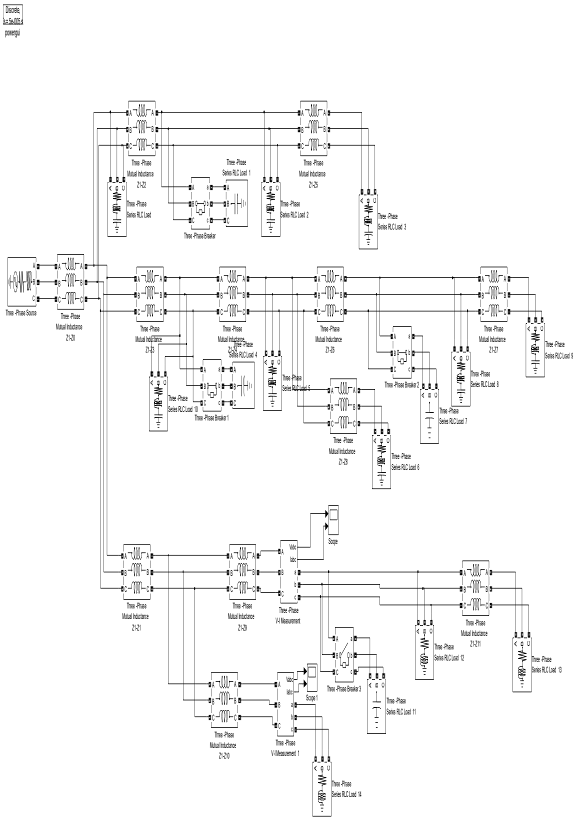

Figure 3: Simulink Model of the Sub-Station

The study has been performed on 150kVAr, 300kVAr, 600kVAr, 1200kVAr capacitor banks. This chapter presents the results obtained on a 300kVAr bank. After the model was built, simulation results were recorded. Simulation of the model has been done to analyze the response of the transients by switching the capacitor bank 'on' at different time intervals, taking phase A in control. Several switching time intervals of capacitor bank have been simulated using MATLAB/SIMULINK software to study the response of the transient over-voltages and currents and, the harmonic content present.

Response of transient at the capacitor bank. Fig. show the transient disturbance of the 3-phase voltage and current waveforms of all 3 phases. As the transient is characterized by a surge of current having a high magnitude and a frequency as high as several hundred Hertz, it can be noticed from the results that the voltage reaches 26% of its normal per-unit value and the current value reaches 300% its normal value when the switch is closed.

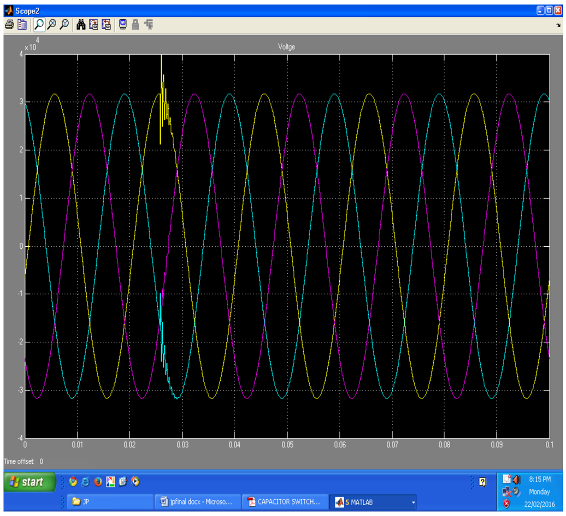

Figure 4: Transient Response of the Voltage Waveform

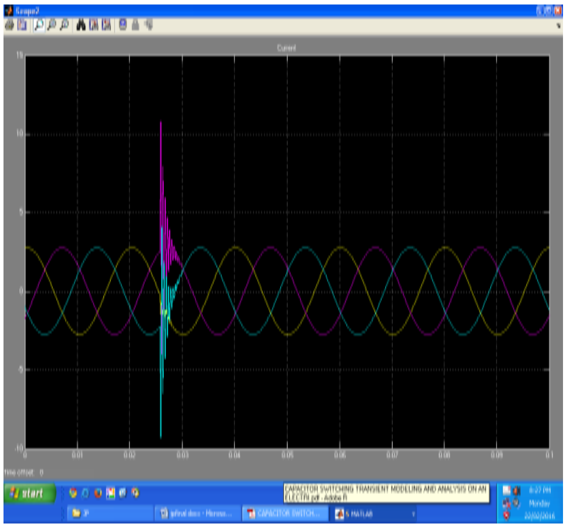

Figure 5: Transient Response of the Current Waveform

Figure 5 displays the disturbance created in phase A of the voltage and current waveforms

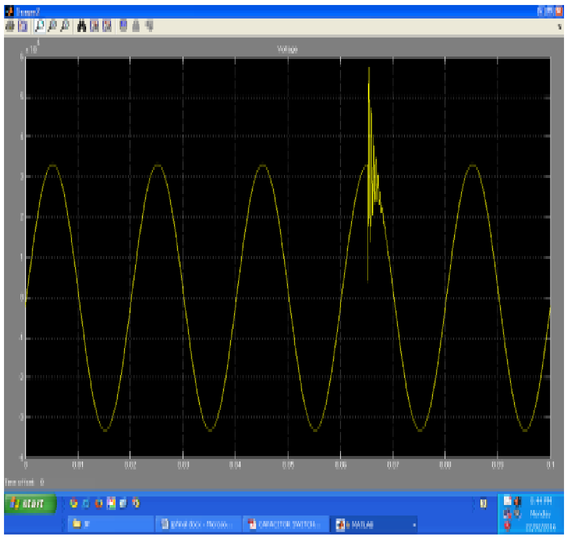

Figure 6: Transient Response of Phase A Voltage Waveform

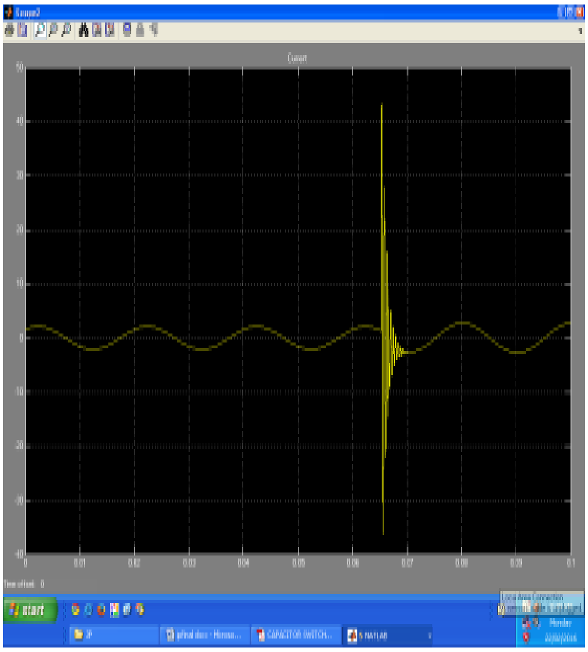

Figure 8: Transient response of Phase A current waveform

Response of the transient near the load

Fig. depicts the transient disturbance observed during the simulation of all phases A voltage and current waveforms. It can be noticed that the transient over-voltage remains almost the same. Table 4.3 gives the magnitude of peak values obtained by the voltage and current waveforms near the load center during the time of closing the switch.

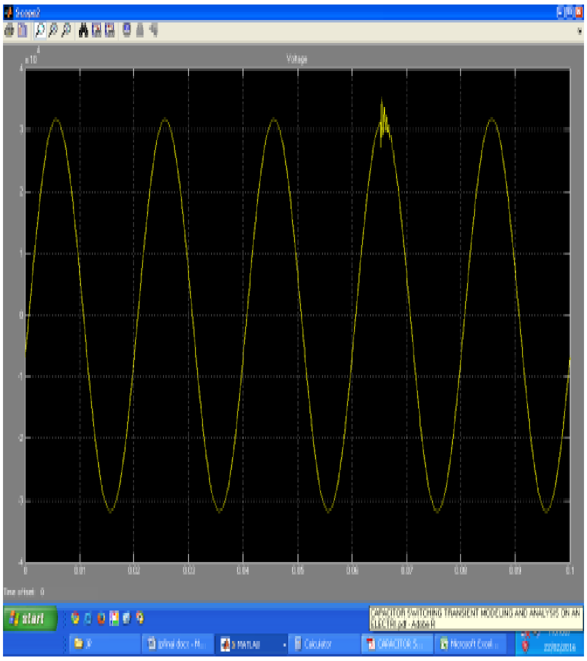

Figure 7: Transient Response of Phase A

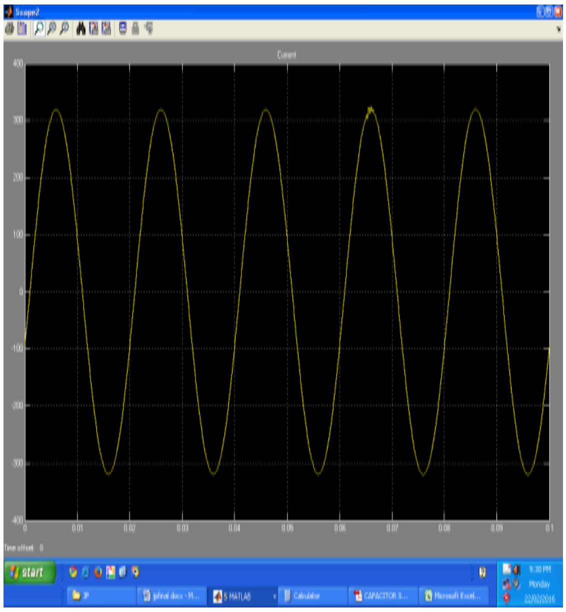

Figure 9: Transient Response of Phase A Current Waveform near Load

Response of transient at the capacitor bank

When the capacitor bank is switched at the zero-crossing of the voltage waveform the following transient disturbances are observed near the capacitor bank. It can be noticed that switching at the zero-crossing of the voltage waveform would result in transient free operation of the system. Fig. displays disturbance on phase A voltage and current waveforms.

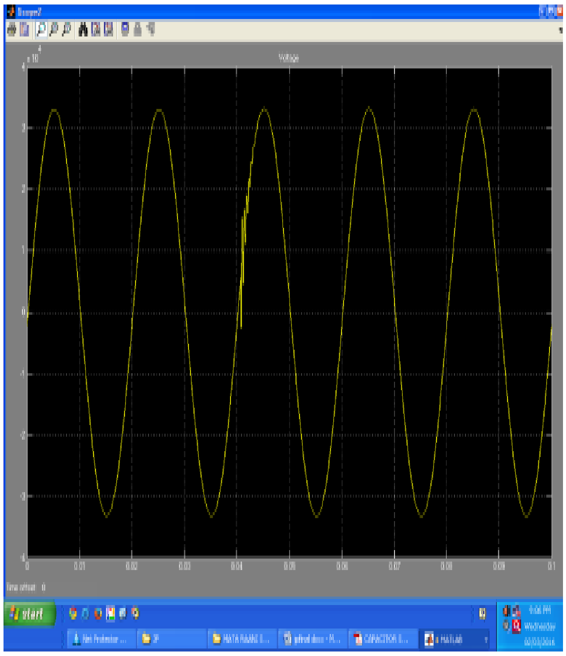

Figure 10: Transient Response of Phase

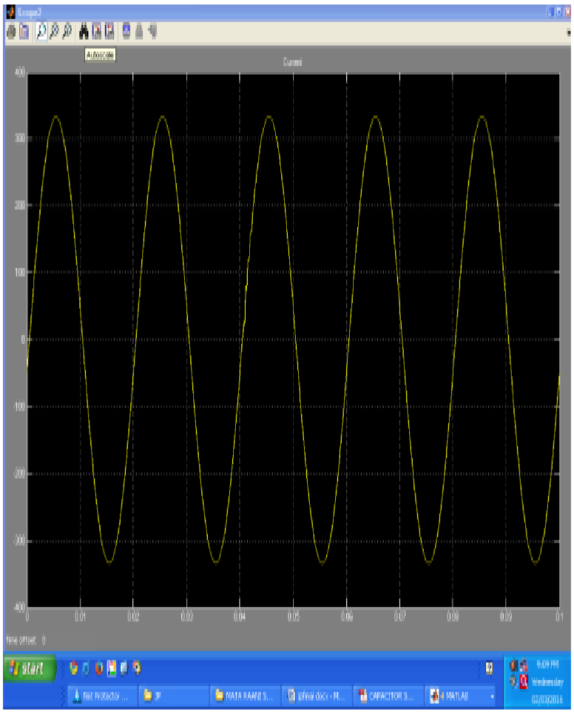

Figure 11: Transient Response of Current Waveform

Response of transient near the load

The following data is obtained near the load when the capacitor bank is switched at zero-crossing of the voltage. Fig. are the voltage and current waveforms obtained near the load.

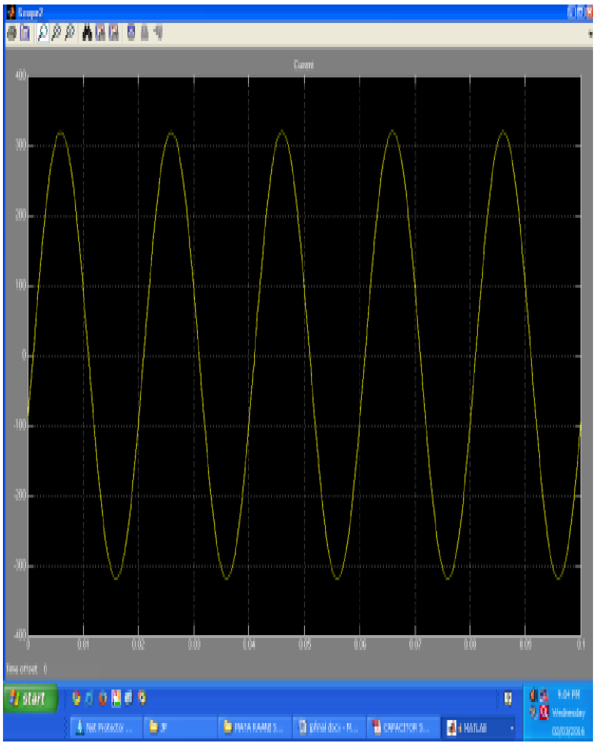

Figure 12: Transient Response of Voltage Waveform

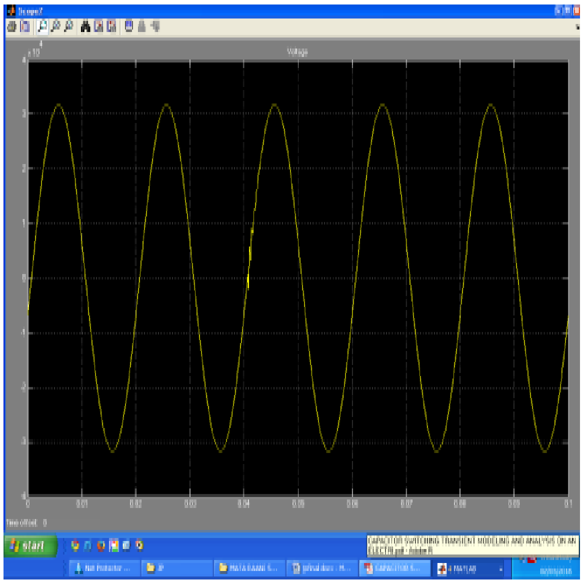

Figure 13: Transient Response of Current Waveform

Switching Time Control Technique

This chapter presents a Matlab based algorithm, which controls the switching time of the capacitor bank. provides a brief description of the practical systems used to connect capacitor banks to a distribution system. also underlines the logic behind a practical system that reduces capacitor bank switching transients. Section5.2 explains the Matlab/Simulink based algorithm to control the switching time of the capacitor bank. Section 5.3 presents the results obtained using the algorithm.

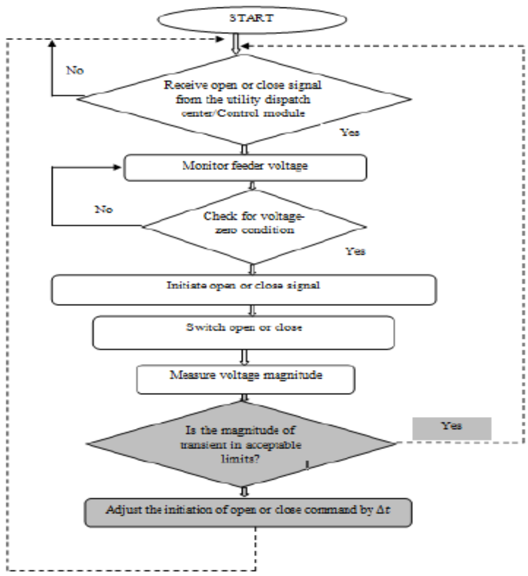

Figure 14: Flowchart Representation of the Algorithm

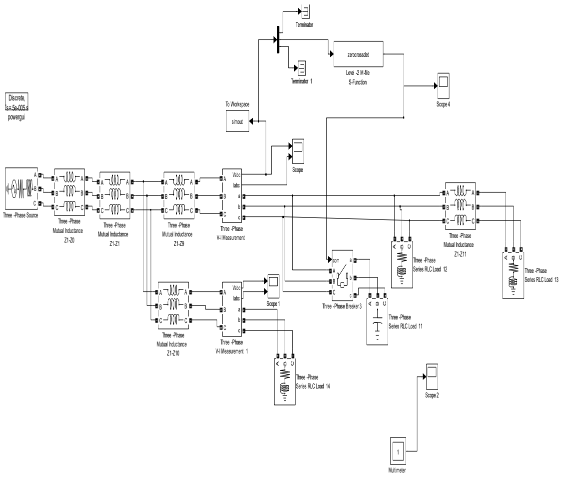

Figure 15: Feeder 3 of the Distribution System Model

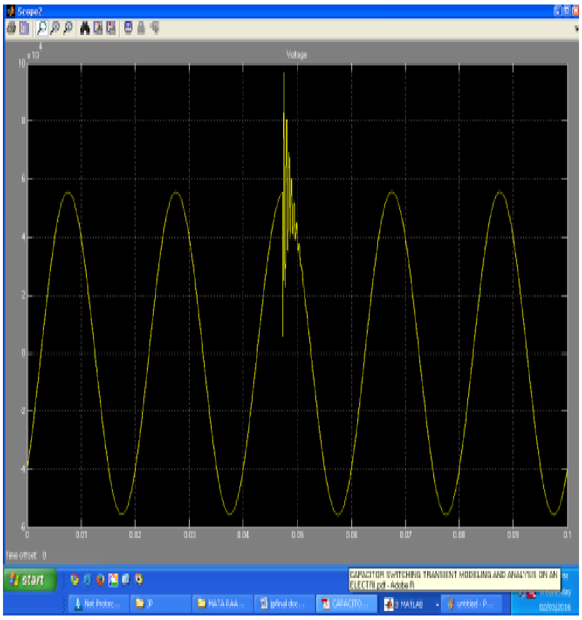

Figure 16: Response of the Switching Transient when the Closing Time is not Monitored

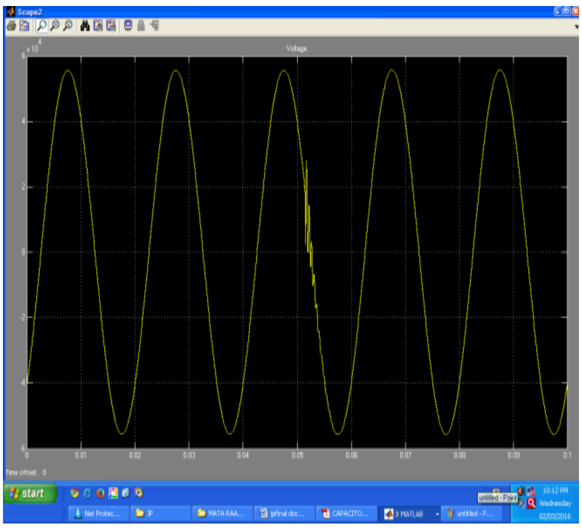

Figure 17: Response of the Transient when the losing Time is monitored

3. CONCLUSION

This thesis has discussed the importance of voltage zero-closing technique to mitigate the transients associated with the switching of capacitor banks. Sensitivity analysis is performed on the Simulink model of the distribution system to find the acceptable time range where the transients are acceptable. FFT analysis is carried out to check the harmonic distortion present in the Simulink model and the results obtain indicate that the model is free from harmonics. A MATLAB code is developed such that the vacuum switch interactively closes at voltage zero irrespective of the time given by the user. All of this analysis has done taking into account a real substation and modeling it using Simulink software.

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