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Improvement of Power System Operation by Reducing the Switching Transient

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ABSTRACT

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. Inductive loads to operate requires re al and reactive power. Reactive power is required to provide the electromagnetic field necessary to operate an induction motor. 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.

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

I. INTRODUCTION

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 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 as close to 1.0 as possible, which implies that the flow of reactive power should be as kept to a mini mum. 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. Reduced system voltages often result when an electrical utility distribution system operates at a lower (poor) 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. It is in the best interest of both the electrical utility and industrial customers to maintain a high power-factor. 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.

II. 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 Figure 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[14]; pre-insertion resistors[9], pre-insertion inductors[9], fixed inductors[18], MOV arresters[9], series inrush-current-limiting reactors, dividing the capacitor bank[19] 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.

III. PRE-INSERTION IMPEDANCE

Circuit Breakers with Pre-Insertion Resistors

The insertion transient typically lasts for less than one cycle of the system frequency. The performance of pre-insertion impedance is evaluated using both the insertion and bypass transient magnitudes, as well as the capability to dissipate the energy associated with the event, and repeat the event on a regular basis. Pre-insertion resistors are one of the most effective means for controlling capacitor energizing transients; however, reliability issues have often caused utilities to select other means. For similar levels of transient suppression, the pre-insertion resistor can be physically smaller than the equivalent pre-insertion inductor. Transients associated with the energization of capacitor banks can be reduced by the application of pre-insertion resistors into the capacitor-energizing circuit 10 to 15 milliseconds through the closing of an additional set of contacts prior to the closing of the main contacts. The insertion of the resistor is a two-step process. The initial circuit is made through the pre-insertion resistor in an SF6 environment. The resistor is then shunted as the main contacts close. Synchronization is required between the resistor and main contacts and is usually achieved by connecting the resistor contact rod directly to the main contact control rod [14]. Various values of pre-insertion resistors are available. Pre-insertion resistors have been used in combination with circuit breakers and circuit switchers, as well as in a new device called Cap Switcher designed specifically for switching capacitors. Worst -case transients occur when the initial switch closing occurs at a voltage peak and when the bypassing of the inserted device occurs at a current peak.

Vacuum Switches

Vacuum switches and breakers are general purpose devices that have been used for shunt capacitor switching at medium voltage for many years. A vacuum is an ideal switching medium as it provides the high dielectric strength needed for capacitor switching and an environmentally friendly insulating medium.

ABB manufactures the PS15 and PS25 capacitor vacuum switches. The switches have been specifically designed and tested in accordance with ANSI C37.66 for heavy-duty operation in capacitor-switching applications for the harshest climatic conditions. Figure 1 shows the ABB vacuum switch PS15.

Figure 1: ABB Vaccum Switch PS15 for 15.5kV – 27kV

The PS15 is a solid dielectric single-phase vacuum switch suitable for use in distribution systems up to 15.5kV ungrounded (27kV grounded), whereas the PS25 is suitable for use in distribution systems up to 25kV ungrounded (and 43kV grounded). Figure 2 shows the ABB vacuum switch PS25.

Figure 2: ABB Vaccum Switch PS25 for 25kV – 43kV

Use of series reactors creates need for capacitors or arrestors to protect contacts

- Typically limited to medium voltage applications
- Inrush currents likely to damage interrupter contacts over time causing pre-mature failure or increased maintenance
- Full interrupter ratings (breaker only)
- Bushing mounted current transformers (breaker only)
- Lowest First Cost
- Capable of a high number of operations
- Vacuum Switch can mount in the rack at 38 kV and below They also have the following disadvantages:

Cap Switcher

The Cap switcher is an application-specific SF6 capacitor switching device equipped with pre-insertion resistors designed specifically for capacitor switching duty. The closing resistors are in the circuit for 5-15ms. The main contacts then shunt the current by the resistor. Its closing resistors provide transient suppression to minimize the detrimental effects of voltage transients on sensitive equipment such as computers, CNC machines, and variable speed drives and to minimize the detrimental effects of current transients on utility equipment such as circuit breaker contacts, power transformer cores and coils, etc. The Southern States Cap switcher high voltage capacitor switching device has been specifically developed to mitigate transients associated with capacitor bank switching. Eliminates the need of reactors previously used to limit the inrush currents. A key feature of the design of the Cap switcher is that it can be used to energize a capacitor bank at any point on the voltage wave and still provide the transient suppression required. The device eliminates the need for inrush current reactors that are used with breakers and other devices. Figure 3 shows Southern States Cap switcher.

Figure 3: Southern States Capacitor switching device 15kV - 38kV

Switching Control Sentinel

When a trip command is received the unit determines at what point in time the contacts would open if the trip coils were immediately energized. The SCS then calculates the time from this point until the target point. ABB, manufactured the Switching Control Sentinel (SCS) device for high-voltage circuit breakers. SCS is a microprocessor-based control device, which enables synchronized closing or opening of independent pole operated (IPO) circuit breakers. The SCS continuously acquires the phase voltage waveforms.. This is the delay time that has to be inserted to make the contacts separate at the target time. The SCS delays the trip command by exactly that time and then energizes the trip coil.

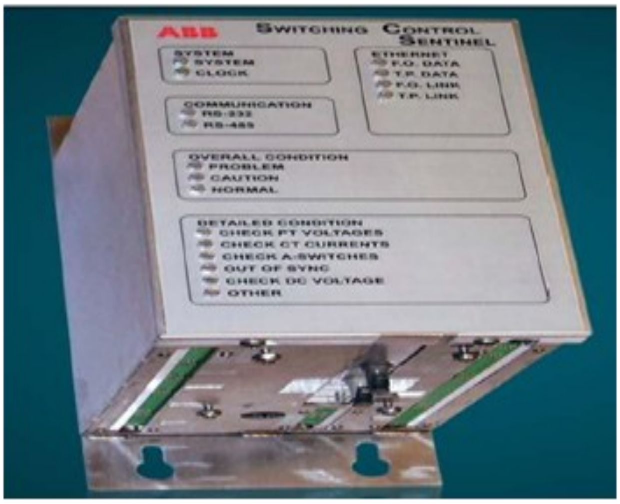

Figure 4: ABB Switching Control Sentinel

All the above mentioned techniques which are in the market today are designed specifically for mitigating switching transients associated with high-voltage or medium voltage transmission systems. Adapting these techniques in the distribution system is cost effective.

IV. 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.

The code has been tested digitally with several different sampling times to observe the closing time of the switch does not cross the acceptable time limit that is obtained by the sensitivity analysis conducted on the model. The resulting waveforms are compared with the signals that are not monitored for voltage zero. As the three phases are equally displaced by an angle 120°, synchronous closing can be obtained when the vacuum switch closes at 120° out of time with respect to each phase.

As for the follow up, the future research will be focused on developing the algorithm and practically implementing in the field, taking into consideration the repetitive capability of the switching mechanism, condition of the interrupting medium and the contacts, the control voltage, and the ambient temperature at the time of operation.

It should be noted that the switch is a mechanical device and wears out with time. Closing the switch at voltage-zero is practically possible only when all the above mentioned factors are taken into consideration. The switching tolerance times that are obtained by the sensitivity analysis can be used to adjust the closing time of the switch accordingly.

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