Review Study on "Minimization of Switching Transient by capacitor bank in substation"

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***Abstract*- Power system has dynamic behavior as it faces various disturbances like sudden change in load, sudden change in generation and various faults. During transients parameters of power system has been changed and it is very necessary to measure and check these parameters for power system safety. There are several methods and tools to know the behavior of the system during transient. Some of are Runge-Kutta, Euler's, Modified Euler's methods. In this paper, the use of capacitor bank has been discussed to improve the efficiency by minimizing the transient response. A practical application of using capacitor Bank to reduce switching transients is presented. A model that represents a real distribution system 220kv from UPPTCL Shaktinagar sub-station was built and simulated using MATLAB/SIMULINK software for purposes of this study. A spectral analysis of voltage and current waves is made to extract the acceptable capacitor switching times by observing the transient over-voltages and, harmonic components. An algorithm is developed for practical implementation of zero-crossing technique by taking the results obtained from the SIMULINK model**

Index terms- Capacitor Bank, Transients response, Electric distribution, SIMULINK Model, Harmonic Component

1. INTRODUCTION

In early days there was little demand for electric energy so that small power station were build to supply lighting and heating loads, however the wide spread of electrical energy by modern civilization has necessitated to produce bulk electrical energy economically and efficiently.

The increase demand of electrical energy can be meeting by building big power station at favorable places. Large network of conductors between the power station and the consumers which continuously faces the disturbances like sudden change in load, sudden thrown of load, transient, switching etc.

The power delivery system is divided into two divisions: High voltage transmission and low voltage distribution system. 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. 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 .An electric power system is known to be comprised of electrical network components used to supply, transfer and use of electric power. 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.

2. POWER FACTOR

Power factor is the ratio of real power and reactive power as shown in equation (1)

Power Factor=COSØ=(Real power(KW))/(Apparent power (KVA))… (1)

Every electrical systems are made up of three basic types of load: resistors, inductors, and capacitors. The industrial load s of the electrical system is highly inductive, which means that they require an electromagnetic field to operate. For inductive loads to operate requires real and reactive power. 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 [4, 5].

Power factor is related to power flow in electrical systems and measures how effectively an electrical power system is being used. In order to efficiently use a power system we want 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 minimum. 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.

Benefits of Improving Power Factor

By improving the power factor: Industrial and commercial customers avoid power factor penalty charges.

Reduced currents results in reduced losses (I2R)

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]

Capacitor Banks

Installation of capacitor banks close to the load center will reduce the magnitude of reactive power drawn by the load from the utility distribution system. The most common method in practice today for improving power factor (correct to near unity) is the installation of capacitor banks. Capacitor banks are very economical and generally trouble free. Installing capacitors will decrease the magnitude of reactive power supplied to the inductive loads by the utility distribution system thereby improving the power factor of the electrical system. Supply of reactive power from the utility power system is now reduced.

Capacitor Size and Location

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Capacitor Size and Location

Capacitors are rated in “VArs”, which indicates how much reactive power is supplied by the capacitor. When dealing with a large scale distribution system containing several feeders and laterals, deciding on the size and installation location becomes an optimization problem. The placement of the capacitor bank should be such that it minimizes the reactive power drawn from the utility power system. Neagle and Samson (1956) developed a capacitor placement approach for uniformly distributed lines and showed that the optimal capacitor location is theperiod. 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. 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:

Voltage: Control or improvement of voltage regulation

Current: Current magnitude

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]

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.

Power Quality Problem

A power quality problem can be defined as:

"Any power problem manifested in voltage, current, or frequency deviations that result in the failure or mis-operation of customer equipment." [9]

The quality of electric power has been a constant topic of study, mainly because poor power quality can lead to economiclosses, especially in industrial processes, due to loss production. Due to increasing installations of power electronics based equipment, the power system disturbances depicted in Figure(2) has become a common phenomenon.

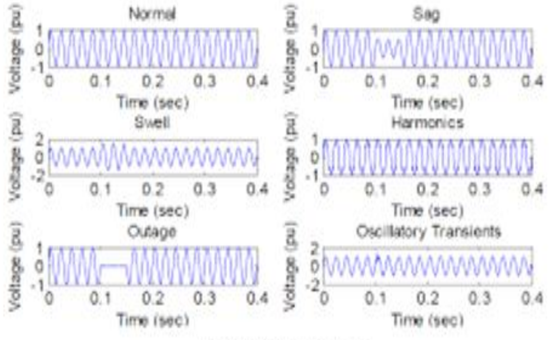
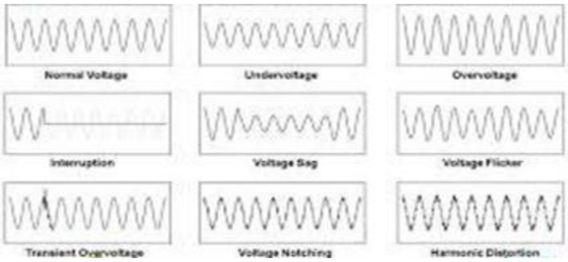


Fig. 1 Simulated disturbance signals

(2a)



(2b)

Figure2: Types of Power Disturbances

There are many reasons for power disturbance including Transients, Interruptions, Dip/ under voltage, Surge/overvoltage, Waveform distortion, Voltage fluctuations

First up are transients (that is our main focus of study), which have the potential to do the most damage of all disturbances and of which there are two types: impulsive and oscillatory. The impulsive variety is the most common type of power surge or spike and describes a sudden event that raises or lowers voltage and/or current levels. These may last no more than 50 ns, but often result in data corruption and physical damage to equipment. Impulsive transients are caused by lightning, poor grounding, the switching of inductive loads, fault clearing by the power company, and electrostatic discharge (ESD).Mitigating the risks posed to your server room from impulsive transients typically comes down to eliminating potential ESD and using surge suppression devices, also known as transient voltage surge suppressors (TVSS) or surge protective devices (SPDs). While SPDs are built into some electrical devices, standalone SPDs are more common. Taking this one step further, cascading SPDs and uninterrupted power supply (UPS) devices is an immensely effective means to protect electronic equipment against both impulsive transients and power interruptions. Oscillatory transients are what cause the power signal to alternately swell and shrink very quickly, usually when a load such as a motor or capacitor is suddenly turned off. When they occur on an energized circuit, typically as a result of switching operations by the power company, they can be fairly disruptive to electronic equipment. The tripping of adjustable speed drives (ASDs) is a common issue associated with capacitor switching and its resulting oscillatory transient. A solution can be found in installing line reactors or chokes ahead of the ASD or on the dc link. Some ASDs have these as a standard feature and others as an add-on option.

Transient Over-Voltages

A transient is defined in IEEE 1100-1999 as:

“A sub-cycle disturbance in the AC waveform that is evidenced by a sharp, brief discontinuity of the waveform”.

A transient is an outward manifestation of a sudden change in the system conditions, as when a switch opens and closes or when there is a fault condition in the system.[10] Transients can be caused by a number of power system switching events or faults such as lightning strikes, short circuits, or equipment failure. Utilitycapacitorpoint on the circuit where the reactive power flow equals half of the capacitor VAr rating. From this, they developed the 2/3 rule for selecting capacitor size and placement to optimally reduce losses. For a uniformly distributed load, the bankkVAr size should be two-thirds of the kVAr as measured at the substation, and the bank should be located two-thirds the length of the feeder from the substation. For this optimal placement of a uniformly distributed load, the substation source provides reactive energy for the first 1/3 of the circuit, and the capacitor provides reactive energy for the last 2/3 of the circuit [6].

A generalization of the 2/3 rule for applying n capacitors on a feeder is given in Eq. (2), (3) and (4),

$$\text{Size of each of n banks} = \frac{2}{2n+1} \ldots\ldots\ldots\ldots\ldots.. (2)$$

$$\text{Location} = \frac{2}{2n+1} \times \mathrm{L} \ldots\ldots\ldots.\ldots\ldots\ldots\ldots \quad \ldots (3)$$

$$\text{Total Vars supplied by capacitor}$$
$$= \frac{2}{2n+1} \text{of the circuit vars requirement} \qquad (4)$$

Where, L is the total length of the feeder. In general, the location that provides the maximum benefits of power factor correction is near the load. It is common to distribute capacitors throughout an industrial plant. Depending on the size of the motors, it may be more economical to place the capacitors in larger banks at, or near, the motor control centers. Fig. (1) Below shows how reactive energy requirement that has to be supplied by the system. As can be seen during peak load periods, the source is delivering approximately one-half of the reactive energy it would have had to supply if the capacitor banks had not been added [4, 7, 8].

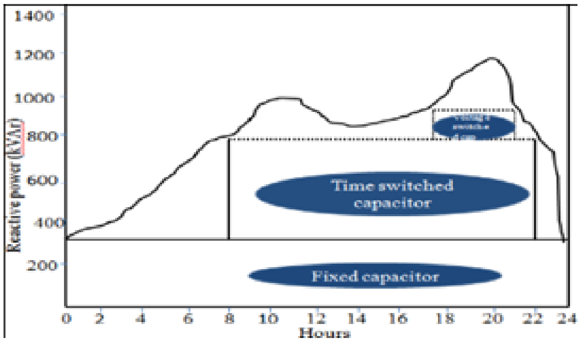


Figure 1: Daily kVAr Load Curve

In the case of concentrated industrial loads, there should be a capacitor bank, sized to almost equal the reactive load requirement, located as close to each load as practical. On a uniformly loaded feeder, greater savings can be achieved by using a number of banks distributed along the feeder so that the reactive load is compensated before travelling through much feeder conductor. With more banks on the feeder, the total capacitance can more closely equal the total reactive load.

Capacitors are intended to operate at or below their rated voltage and frequency and are suited for continuous operation at 135% of rated reactive power. Capacitors can operate continuously only when the following limitations are not exceeded.

- 110% of rated rms voltage
- 120% of rated crest voltage
- 135% of nominal rms current based on rated voltage and rated kVAr, including fundamental currents and harmonic currents.
- 135% of rated kVA [4].

Types of capacitor bank

1. Fixed Capacitor Banks
2. 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. 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-hrswitching receives special attention when it negatively impacts customer equipment. These transients may originate when a capacitor bank is switched in or out of the system. Capacitor switching is considered to be a normal event on a utility system and the transients associated with these operations are generally not a problem for utility equipment, since peak magnitudes are just below the level at which utility surge protection, such as arresters, begins to operate (1.8pu or above) [11].

A transient, from its point of origin, will propagate in either direction on the distribution feeder and may be transferred through transformer capacitive/inductive couplings to other voltage levels. Secondary over-voltages can cause voltage magnification and these can be quite severe as the energy associated with these events can damage power electronic motor drives. More commonly, nuisance tripping of adjustable-speed drives often occurs. Prior to switching on a capacitor, the voltage across the terminals is zero. Because capacitor voltage cannot change instantaneously, energizing a capacitor bank results in an immediate drop in system voltage toward zero, followed by a fast voltage recovery (overshoot) and finally an oscillating transient voltage superimposed on the 50 Hz fundamental waveform as illustrated below in Fig. (3).

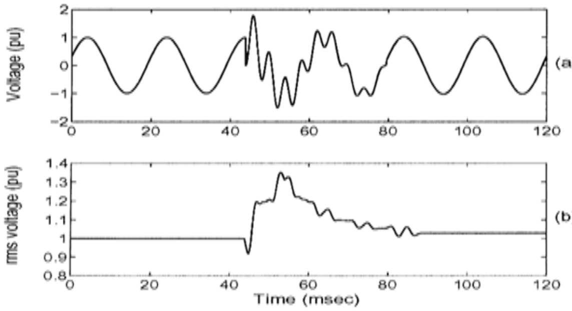


Figure 3: Switching Transient

The peak voltage magnitude of the transient depends on the instantaneous system voltage at the moment of energizing, and under worst-case conditions this can be 2.0 times greater than the normal system peak voltage. But the magnitude is usually less than this because of system loads and damping phenomenon due to resistive elements in the system [11]. Typical distribution system overvoltage levels range from 1.1 to 1.6pu [9]. In addition, to the transient over-voltage phenomenon, application of shunt capacitors can lead to the following side effects: Increased transient inrush current of power transformers, and prolonged decay rate of the transient [13]. Severe harmonic distortion and resonance with load-generated harmonics and capacitors can be stressed due to switching transients. In addition, adjustable-speed drives (ASD) are extensively used in industrial applications for improved motor speed control, energy efficiency, minimal space requirement, reduced noise levels, and reliability. Since ASDs are often applied in critical process control environments, nuisance tripping can be very disruptive with potentially high downtime cost implications [14]. Nuisance tripping refers to the undesired shutdown of an ASD's (or other power electronic devices) due to the transient overvoltage on the device's DC bus. Fig. (4) shows an example of a capacitor-switching transient causing the DC bus to exceed the overvoltage trip point.

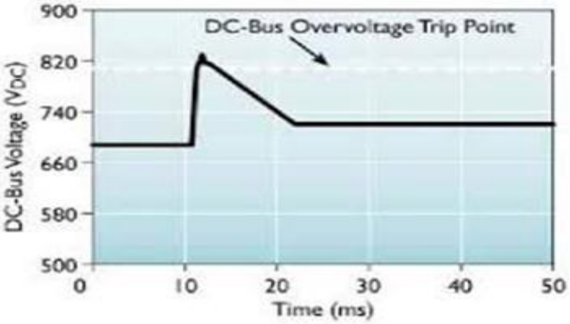


Figure 4: DC-Bus Voltage of Adjustable-Speed Drive During a Capacitor-Switching Transient

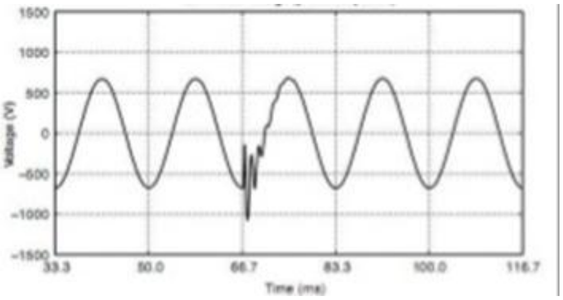


Fig -5 Switching transient problem with load

Without high-speed monitoring equipment, it can be difficult to be certain that the cause of an ASD trip was due to a capacitor-switching transient. However, there are two characteristics that can be clues that an ASD has tripped due to a capacitor switching transient. The first clue is that the ASD controls indicate that the drive tripped due to an overvoltage. The second clue is that an ASD has tripped due to a capacitor-switching transient is that a pattern of tripping has been noticed. Since utility capacitors are typically switched daily, any resulting nuisance tripping can potentially cause frequent disruptions at the same time every-day. The potential for nuisance tripping is primarily dependent on the switched capacitor bank size and location. It is important to note that nuisance tripping can occur even if the customer does not have power factor correction capacitors.

Harmonics:-

The benefits realized by installing capacitor banks include the reduction of reactive power flow on the power system. Therefore, the capacitor bank should be placed as close to load as possible for optimum results. However, this may not be the best engineering solution or the most economical solution due to interaction of harmonics and capacitors.[4]Harmonic distortion of the voltage and current in an industrial facility is caused by the operation of nonlinear loads and devices on the power system. Harmonic distortion can be transferred to the utility power system where its disturbance of the sinusoidal waveform is commonly referred to as noise. Power electronics is the major source of harmonic distortion. However, apart from power electronic devices there are other sources of harmonic distortion such as arcing devices and equipment with saturable -ferromagnetic cores. These loads draw non-sinusoidal currents, which in turn react with system impedance and produce voltage distortion. Application of capacitor banks can create series or parallelresonance, which magnifies the problem of harmonic distortion. If the resonant frequency is near one of the harmonic currents produced by the non-linear loads, a high-voltage distortion can take place. The total harmonic distortion (THD) of the current varies from some 200% at some load terminals to a few percent at transmission level. The total harmonic distortion THD of the voltage varies from 10% at some distribution transformers to about 1% at transmission level. Overheating of transformers is another problem associated with harmonic currents. ANSI/IEEE Standard C57 states that a transformer can only be expected to carry its rated current if the current distortion is less than 5%. If the current distortion exceeds this value, then some amount of de-rating is required. Another effect of harmonic currents on the power system is the overheating of neutral wires in wye-connected circuits. This effect occurs because the third harmonic and any multiples thereof do not cancel in the neutral as do the other harmonic currents. The result is a large 180-Hz current in the neutral conductor if there are significant nonlinear loads connected to the wye source. Usually the higher multiples of the third harmonic are of small magnitude. The increase in the RMS value of current, however, can cause excessive heating in the neutral wire. This potential for overheating can be addressed by over- sizing neutral conductors or reducing nonlinear currents with filters. Most utilities impose limits on the amount of harmonic current that can be injected onto the utility system. This is done to ensure that relatively harmonic-free voltage is supplied to all customers on the distribution line. IEEE Standard 519-1992 recommends limits for harmonics for both utilities and customers. At the point of common coupling between the utility and the utility customer, limits are recommended for individual harmonics as well as the total harmonic distortion of the current. The recommended levels varydepending on the size of the load with respect to the size of the power system, and also upon the voltage at the point of common coupling. The standard also recommends limits on the voltage harmonics supplied by the utility.

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