ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 2, February 2014

SERIES COMPENSATED TRANSMISSION LINE PROTECTED WITH MOV

Neha Khanzode[1], Snehal Nemade[2], Neetin Punse[3], Vivek Akarte[4], Ankush Dhanorkar[5]

PG Student, Electronics and Power, Padm. Dr. V.B. Kolte college of Engineering, Malkapur, India[1,2]

PG Student, Electronics and Telecommunication Engineering, Padm. Dr. V.B. Kolte college of Engineering, Malkapur, India[3]

PG Student, Electronics and Telecommunication Engineering, G. H. Raisoni College of Engineering & Management, Amravati, India[4]

PG Student, Electrical and Electronics Engineering, Prof. Ram Meghe College of Engineering. & Management, Badnera, India[5]

Abstract: This paper presents an analysis of the effects of series line compensation levels on the transmission line voltage profile, transferred power and transmission losses for different static load models. For this purpose, a simple model is developed to calculate the series and/or shunt compensated transmission line load voltage. Consequently, different shunt and series compensation levels are used with several voltage sensitive load models for two different line models. It is observed that the compensation level is significantly affected by the voltage sensitivities of loads. Moreover, the voltage level of the transmission is an important issue for the selection of the shunt and series capacitor sizes when load voltage dependency is used. Rapid load growth and low water levels of the reservoirs create much stress on the power balance problem and on the existing transmission lines. In paper, a protection system for transmission lines using series capacitors is discussed in detail.

I. INTRODUCTION

Increasing demand of electric power and addition of new generation capacity to meet the demand, necessitate enhancement of large transmission capacity between generation and bulk consumption points. This can be achieved either by development of new transmission corridor or by enhancing the power transfer intensity of existing transmission assets. In India, major energy resources like coal and hydro potential are confined to a few pockets and located far-off distance from the load centers. In addition, to achieve economies of scale in the cost of delivered power, it was found that transportation of power from these pit-head generating stations to the distant load centers is always cheaper option than transportation of fuel near to load centers. This calls for development of transmission network by establishment of large number of long distance transmission lines and interconnection of different regional grids. While developing such type of network, various aspects like Right of- Way and other environmental problems, reduction of transmission cost etc. need to be considered. To take care of these aspects, power system planners are imparting great emphasis towards enhancement of transmission capacity of the existing assets to the extent feasible through application of emerging technologies.

II. POWER COMPENSATION

Figure 1 shows the simplified model of a power transmission system. Two power grids are connected by a transmission line which is assumed lossless and represented by the reactance X_L. 11δ∠V and 22δ∠V represent the voltage phasors of the two power grid buses with angle $\delta = \delta_1 - \delta_2$ between the two. The corresponding phasor diagram is shown in Figure 2.

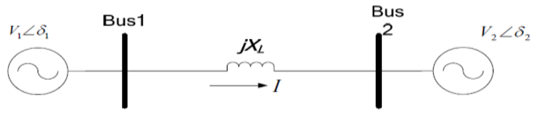

Fig1.1: Power transmission system: simplified model

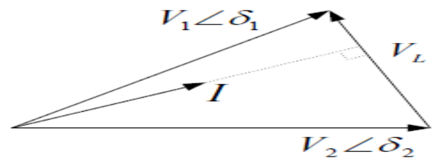

Fig 1.2: Power transmission system: Phasor Diagram

The magnitude of the current in the transmission line is given by

IL= VL/XL
=IV1δ1-V2δ2 I/XL

The active and reactive components of the current flow at bus 1 are given by

I d1 = V2 Sin δ/ XL,
Iq1 = V1- V2 Cos δ/ XL

The active power and reactive power at bus 1 are given by

P = V1 V2Sinδ / XL
Q = V1(V1-V2Cosδ) /XL

Similarly, the active and reactive components of the current flow at bus 2 can be given by

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526
INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 2, February 2014

$$I_{d2} = V1 \sin\delta / XL, \quad I_{q2} = V2 - V1 \cos\delta / XL \qquad (4)$$

The active power and reactive power at bus 2 are given by

$$P = V1\, V2 \sin\delta / XL, \quad Q = V2(V2 - V1\cos\delta) / XL$$

Equations (1) through (5) indicate that the active and reactive power/current flow can be regulated by controlling the voltages, phase angles and line impedance of the transmission system. From the power angle curve, the active power flow will reach the maximum when the phase angle δ is 90º. In practice, a small angle is used to keep the system stable from the transient and dynamic oscillations.

Generally, the compensation of transmission systems can be divided into two main groups: shunt and series compensation.

III. SERIES COMPENSATION

Series compensation plays the vital role in modern heavily loaded grid transmission lines. The series capacitor makes sense because it is simple and could be installed for 15 to 30% of the cost of installing a new line. Series compensation in modern power systems influences the power flow in particular network segment, reduces active power losses prevents system and sub synchronous oscillations, and connects more robustly different subsystems to stronger integrated network .The introduction of series compensation in existing networks requires not only extensive studies into the expected performance of the new system but also into the influence of its introduction on the operation of existing protection control and monitoring systems. The introduction of the capacitance in series with the line reactance adds certain complexities to the effective application of impedance based distance relays. The protective distance relays, which make use of impedance measurements in order to determine the presence and location of faults, are "fooled" by installed series capacitance on the line when the presence or absence of the capacitor in the fault circuit is not known priori.

Series Capacitors(SCs) and their overvoltage protection devices (typically Metal Oxide Varistors (MOVs) and/or air gaps), in spite of their beneficial effects on the power system performance, introduce additional problems and make the operating conditions unfavorable for the protective relays that use conventional techniques and include phenomena such as voltage and/or current inversion, subharmonic oscillations, and additional transients caused by the air gaps triggered by thermal protection of the MOVs. The apparent reactance and resistance seen by the relay are affected due to the variation of series compensation voltage during the fault period. As in all relaying, if the problem areas are anticipated and understood, the solution to the problem is achieved with comparative ease. In particular to series compensated lines the problems faced by the distance relay and some of the solution to these problems are researched and published. Reach settings for the zones of protection with respect to some of the typical problems and adaptive approach. Relay design progressing is concerned with the improvement of conventional relay algorithms based on phasor concepts.

IV. SERIES CAPACITORS

Series capacitors are applied to negate a percentage of and hence reduce the overall inductive reactance of a transmission line. The benefits of applying series capacitors on a transmission line include improved stability margins, better load division on parallel paths, ability to adjust line load levels, reduced transmission losses, and reduced voltage drop on the system during severe disturbances. The application of series capacitors is normally economical for line lengths greater than 200 miles.

A. Effects of Series Capacitor

- **Power Frequency**

The reduction of the series inductance of the transmission line by the addition of the series capacitor provides for increased line loading levels as well as increased stability margins. This is apparent by reviewing the basic power transfer equation for the simplified system.

The power transfer equation is:

$$P = E1 * E2 * \sin(a12)/XL - XC$$

where P is the power transfer, a12 is the angle between the E1 and E2 voltages,

- **Subharmonics**

The series combination of the capacitor and the inductance of the system sets up a series resonant circuit, the natural frequency of which (neglecting resistance) can be calculated by

$$fe = 1 / 2\pi\sqrt{LC}$$
$$= f * \sqrt{XC/XL}$$

where, f is the power system frequency and XL is the total system reactance. Since XC/XL is typically in the range of 0.25 to 0.75, fe will be a subharmonic of the power frequency. Any system disturbance, including faults, insertion of the capacitor, switching of any series element, etc., will result in the excitation of the system at the subharmonic frequency which in turn can give rise to transient currents. These transients are typically damped out after a few cycles, but may last significantly longer. In some cases, the subharmonic transient currents may interact with the generators on the system.

The presence of the transients in the generator(s) appears as a negative slip frequency on the rotor which is then reflected into the system as a net negative impedance. If this negative impedance becomes larger than the net positive impedance of the system, then the transient currents may grow to intolerable levels unless corrective actions are taken. As for the series capacitor, it will be protected once the current levels increase beyond the protective level of the bypass equipment.

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 2, February 2014

- **Subsynchronous Resonance**

The presence of the transients may also excite one or more of the natural torsional frequencies of the mechanical shaft system of the generator(s). This complex phenomena is known as subsynchronous resonance (SSR). Depending upon the degree of damping and resonance, the torsional oscillations may be severe enough to cause damage to the shaft. Large steam turbine generators are most susceptible to SSR due to their having 2 to 5 torsional modes that are typically in the frequency range of 5 to 55 Hz. Usually, the potential for subharmonic transients and SSR are investigated and corrective action is taken to mitigate their effects .Protective Equipment as mentioned earlier, protective equipment is applied to the series capacitor to protect it from the excessive voltages which can occur during faults. This equipment takes one of two basic forms: a parallel power gap or a metal-oxide varistor (MOV).

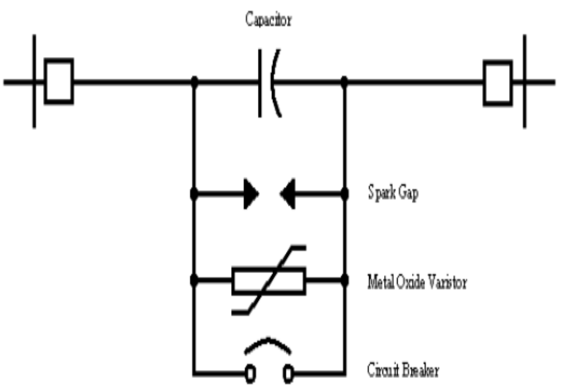

Fig 3.1: Series compensated line with MOV

V. MOV PROTECTION

A series capacitor bank consists of the capacitors and their protective system. MOV's provide overvoltage protection for the capacitors and are a significant member of the protection system. The general purpose of these banks, are to increase the power flow on an existing system by reducing the line impedance.

A. Series Capacitor Banks Overview

When capacitors are inserted in a transmission line, the series capacitance effectively compensates for the inherent inductance in the line to lower the total impedance. This in effect allows the circuit to transfer more energy with less heating of the lines. The series banks are generally located at either end of the section of the transmission line in one of the existing substations. However, sometimes they are located near the middle of the transmission line section which reduces the worst case potential fault current. With lower potential fault current, the MOV bank can be designed smaller.

In today's world the increasing difficulty in obtaining right-of-way for new power lines coupled with the rising cost of new power lines, are making the use of a series capacitor bank a favorable option for utilities. For long transmission lines where the source and load are separated by hundreds of km, the use of Fixed Series Compensation (FSC's), another common name for this device, is almost a necessity.

The typical protective bypass system consists of a metal oxide varistor, bypass gap, damping reactor, and bypass circuit breaker. The varistor serves to provide overvoltage protection of the series capacitor during power system faults. The bypass gap is controlled to spark over in the event of excess varistor energy. The bypass breaker closes automatically in the case of prolonged gap conduction or other platform contingencies. The breaker also allows the operator to insert or bypass the series capacitor. The damping reactor limits the capacitor discharge resulting from gap sparkover or bypass breaker closure. The communication of platform connection to the ground is accomplished using fiber optics.

The varistor and the triggered gap operate independently on each phase. The bypass breaker operates on a three-phase basis. The bypass system is capable of operating with single-pole or three-pole tripping and reclosing schemes employed on the transmission lines

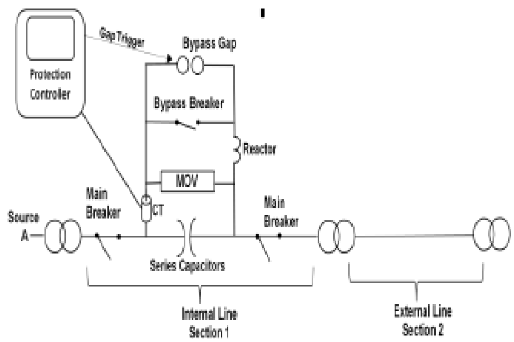

Fig 4.1 : Series Capacitor Bank

In Figure 4.2 a three phase fault is modeled and shows the current through the MOV and capacitors during the event. Note that the capacitor bank conducts the current for the first half cycle, and the MOV conducts the current for the second half. This is due to the nonlinearity of the MOV.

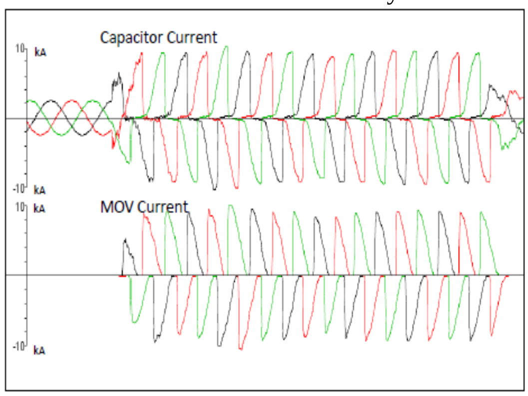

Fig 4.2 Phases of MOV and Capacitor Current during a fault

During a fault event, the MOV conduction results in adsorption of energy as shown in Figure 6 This energy absorption is constantly monitored and is used as the basis of triggering the bypass gap.

ISSN (Online) 2321 – 2004
ISSN (Print) 2321 – 5526

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH IN ELECTRICAL, ELECTRONICS, INSTRUMENTATION AND CONTROL ENGINEERING
Vol. 2, Issue 2, February 2014

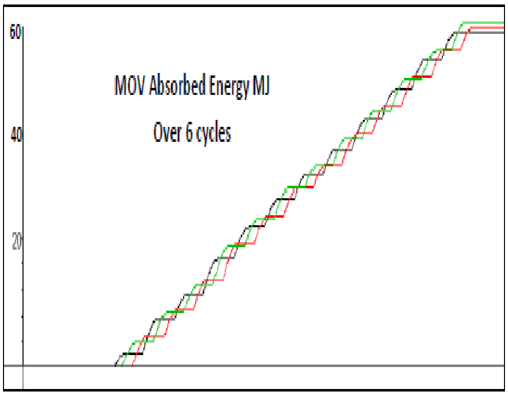

Fig 4.3: MOV Energy Absorption during a 3 phase fault

There are basically two types of faults of concern for series capacitor installations. If the fault occurs within the section of transmission line where the series cap bank is located, it is referred to as an internal fault . If the fault occurs on another section of the transmission line, it is considered an external fault. The difference between the two is only the magnitude of the fault. A nearby internal fault will result in significant fault current and significant duty on the varistors. A distant fault on an external section can result in a few percent higher than the normal maximum rated current of the cap bank. These two faults are handled differently by the control system and the MOVs. If the control system senses a high current internal fault it sends a signal to the triggered gap to bypass immediately. This pulls the MOVs out of the circuit before any significant accumulation of energy takes place. When an external fault occurs, the protection controls are all the MOVs have between operation and overload. If the control system fails, it is likely that the MOVs would too.

VI. CONCLUSION

In general, the problems associated with the protection of series compensated lines become less and less significant as the fault capacity on the bus increases. Thus testing under minimum system conditions will tend to provide more onerous test cases than would testing under maximum system conditions. The better the appreciation of the problems of series compensated lines, the more likely evaluation tests on a model power system will yield meaningful results. When the relaying system has been properly developed on a model power system, field experience indicates the presence of series capacitors will have an insignificant effect on overall system reliability when compared with other factors, most notably channel performance The completion of this research has led to potential solutions to three of the problems in impedance based capacitor compensated transmission line protection schemes.

While these three steps still do not provide for a universally applicable computer algorithm, they are a step in the right direction. Further, these techniques, particularly those dealing with the Fast Fourier Transform (FFT) and its application, may prove helpful in solving other problems unrelated to power system protection. 1) Determination of a method capable of resolving two very closely spaced frequencies from the voltage and current waveform data collected following a fault. This is an important concept for analyzing the subsynchronous frequency which is present in the “post fault domain” (caused by the presence of the capacitor on the line). The capacitor causes the natural frequency of the line to be less than the fundamental frequency of 60Hz. Therefore once the magnitude and frequency of the subsynchronous voltage and current signals is determined, as well as 60Hz synchronous component, then we can determine the L and C of the line as separate quantities.

REFERENCES

[1] P. Kundur, Power System Stability and Control. New York: Mc-Graw Hill, 1994.

[2] “Power System Relaying”, Stanley H. Horowitz and Arun G. Phadke, (book), Second edition, Research Studies Press Ltd., England, 1995, pg. 116,132.

[3] Stan Wilkinson, GE Power Management Ontario, Canada; “Series Compensated Line Protection Issues, GER 3972, pp 1-22.

[4] Series Compensated Line protection: A Practical Evaluation, G.E. Alexander, J.G. Andrichak, S.D.

[5] Rowe, S.B. Wilkinson, a paper presented to the Western Protective Relay Conference, October,1988.

[6] A. Guzman, J. Mooney, G. Benmouyal, and N. Fischer, “Transmission Line Protection for Increasing Power System Requirements,” in *55th Annual Conference for Protective Relay Engineers,* Texas A&M University.

[7] “Overview of Series-Compensated Line Protection Philosophies”, Finn Andersson, and Walter A. Elmore,Western Protective Relay Conference October 23-25, 1990, pg. 2-3

[8] S. Henschel, L. Kischner, and M. C. Lima, "Transient Recovery Voltage at Series Compensated Transmission Lines in Piauí, Brazil," Proceedings of the International Conference on Power System Transients (IPST'05), pp. 1-6, June 2005.