Study Committee B5 Colloquium
October 19-24, 2009
Jeju Island, Korea

204

Protection of Static VAR Compensator

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Summary

Static Var Compensator (SVC) protection is presented. SVC systems come in a wide number of arrangements, and are custom designed for specific applications. For SVC applications the control and protection system plays an essential role in the overall performance of the power system. From protection standpoint, an extensive protection system is generally required for SVCs to optimise the equipment operational limits for maximum utilisation.
This paper outlines the experience gained from, and design aspects of relay protection for SVC's. The paper analyzes different fault cases and describes different relay protection principles applicable to SVCs. It also includes an overview of SVC protection methods.
It covers the protection of the connection of the SVC to the substation busbars. For the SVC itself the power transformer, the SVC medium voltage busbar and the active branches, i.e. TCR, TSC and harmonic filters are of specific interest. These branches are exposed to severe current and voltage transient during system disturbances. Insensitivity to harmonics and DC current are essential.
SVCs are normally ungrounded on the MV bus and residual voltage protection is used to detect ground faults. If selective earth fault protection is required for the SVC, this can be accomplished by using either a grounding transformer or an automatic reclosure scheme.
Special protection functions are integrated in the SVC control system to detect abnormal operating conditions and to react rapidly to avoid damage and unnecessary tripping by the plant protection system. Those protection functions and their interaction with power system is an important criterion for selection and application of each protection device are covered in the paper.

Keywords
Static Var Compensator (SVC), Protection System

1. Introduction

The SVC (Static Var Compensator) is a member of the FACTS (Flexible AC Transmission System) family. By means of thyristor control of reactive power, it enables dynamic voltage control at the point of common connection with a grid. The fast response of an SVC makes it highly suitable for fulfilling functions such as steady-state as well as dynamic voltage stabilisation, meaning power transfer capability increases, reduced voltage variations, and flicker reduction at industrial arc furnaces. SVCs are special in the sense that they are needed the most during network disturbances. At these occasions they may make the difference between a network collapse and successful continued operation. It is therefore imperative that they do not trip when they are needed the most. Security is the number one requirement on SVC protections, given reasonable dependability is maintained. The way to achieve high security is to minimise the number of relays and protective functions used in a plant [2].

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2. Transformer and Busbar Protection

Utility SVCs normally make use of a power transformer between the power grid and the SVC medium voltage (MV) busbar. On this bus harmonic filters, thyristor controlled reactors and capacitors are connected. In many cases, an auxiliary power transformer is also connected to this bus. It is important to note that the power transformer is the only connection of this bus to the mains. There are never several infeeds or more than one power transformer in the circuit.
SVC transformers are, like generator transformers, made with a large turn ratios. The voltage on the SVC MV bus is typically in the span of 15-30 kV irrespective of the voltage level on the mains. A very normal transformer turn ratio is 400/25 kV. This large ratio results in very high short circuit currents on the MV bus, it is frequently in the range of 50-90 kA (rms symmetrical). The transformer current in its MV bushings also become large due to large power and low voltage, 5-15 kA are normal values. The large fault and load current currents must be considered when designing the protection system.

High load currents (>10 kA depending on transformer brand) makes it impossible to use the concept of bushings connected directly on the transformer tank, instead special high current hoods have to be uses. These hoods are of non magnetic material. They are quite narrow and cannot fit current transformers (CTs). Instead external current transformers have to be used. The high short circuit current excludes post type CTs leaving bushing type CTs as the only choice. The largest current ratings available is 8000 A, therefore two CTs have to be connected in parallel in many cases. Considering the fact, the connection of the SVC MV busbar to the mains is made by one single power transformer and the very large load current makes it reasonable to leave the standard protection concept with a differential current relay connected directly across the power transformer. The better design is to extend the protection zone to also include the SVC MV busbar. In this design the CTs in all the other SVC branches are used to close the differential zone.

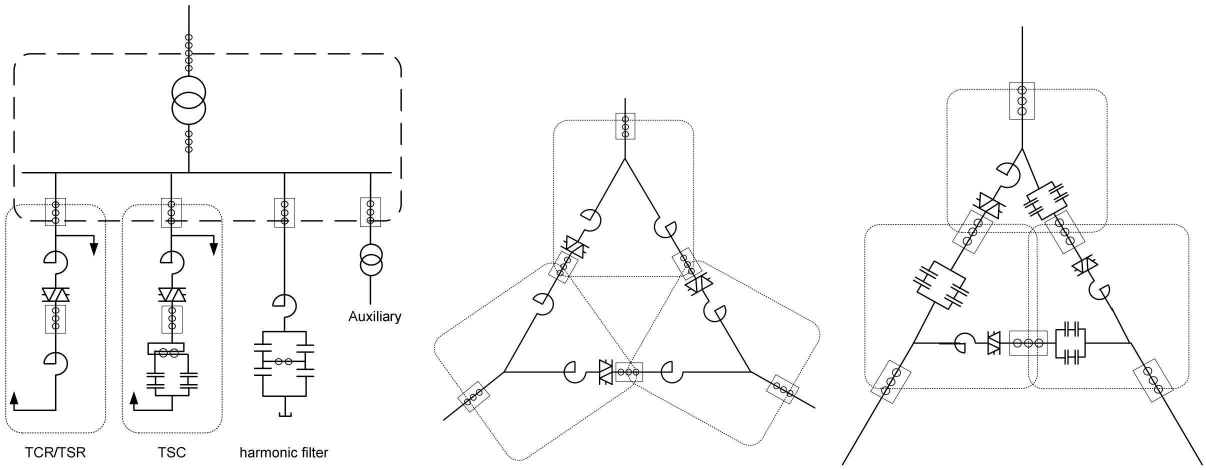

Figure 1: Typical arrangements for transformer and SVC bus (left), TCR/TSR (middle) and TSC (right) differential zones.

Standard transformer protective functions shall be used, differential current, restricted earth fault current and overcurrent functions are recommended.

When it comes to overvoltage protection, it is important to note that SVC transformers are made with large magnetic cores. The saturation voltage is typically as high as 120-125% of nominal voltage. This figure is derived from the large voltage variation on the SVC MV bus. The transformer impedance is normally close to 15% on its power rating. As the current through the transformer is purely reactive (inductive or capacitive) the voltage on the MV bus will vary +/- 15% when the SVC goes from fully capacitive to fully inductive operation. Typically the voltage reference for the SVC controller is settable between 100% and 110% voltage on the mains. Totally the voltage on the MV bus will vary from +25% to -15%. The power transformer must be designed not to saturate at maximum continuous voltage on this bus.

Overexcitation of a transformer can damage the transformer if it persists. Overexcitation results in excessive core flux resulting in high interlamination core voltage, which may result in iron burning. At high flux levels, the transformer saturates since flux begins to flow in leakage paths not designed to carry it, again causing damage. The normal power transformer design is to have the winding with the lowest voltage closest to the core. For an SVC it is the winding connected to MV bus. This winding determines the magnetisation of the core, one can therefore say that an SVC transformer is magnetised from the SVC MV bus! Over excitation relays, if used, shall be connected to the MV bus, it is almost impossible to saturate an SVC power transformer from the high voltage side. The protection is not used as standard protection since overvoltage protection on secondary side will prevent high voltage resulting in overflux.

Customer usually specifies what kind of transformer guards he requires in his protections solution. Commonly used transformer guards are; Buchholz function, sudden pressure function, high oil temperature, high winding temperature, low oil level.

3. TCR Protection

A TCR or TSR branch is delta connected where each phase consists of a thyristor valve and two reactor stacks. The thyristor valve is electrically located between the reactors. By combining one line Current Transformer (CT) with two branch CTs, a protective zone encompassing two reactor halves and a thyristor valve is created in a main differential protection. By permutation, three such zones are aggregated in the TCR to provide detection and clearance of inter-zone faults. Time delayed overcurrent relays, with an added instantaneous step sensing the branch currents are generally used as back-up. The reactors are protected by thermal overload relays. The split arrangement of the reactors in each phase provides extra protection to the thyristors in event of a reactor fault, i.e. fault current is limited and the risk for steep front voltage surges eliminated. The valves are also protected against thermal overload by a specific function (TCR current limiter) in the SVC control system, see section 9.

Differential protection can be of high or low impedance type. The protection serves as the main protection for short circuits between the different protective zones. The protection is unaffected by SVC energization and any valve misfiring. Differential protection of low impedance type will have higher requirements on CT’s compared to high impedance types. Low impedance types of differential protection needs to be blocked during SVC energisation, if energisation is performed with fully conducting TCR valves. Large DC components, with long time constant will be present in the TCR current at full conduction. Due to the large DC component and very long primary time constant false differential current exists. Restraint criteria’s are generally not fulfilled and will not stabilize the protection.

Unsymmetrical TCR operation and turn to turn faults can also be detected by a negative phase sequence protection. However, turn to turn faults are extremely difficult to detect. The small unbalances and sequence currents associated with turn to turn faults generally are smaller than the existing tolerable unbalances in the system, i.e. unbalances due to negative sequence, component tolerances, etc. Consequently there seems to be no reliable handle to distinguish between the intolerable and tolerable conditions. As the turn to turn fault spreads to more turn, the current will increase. Negative sequence relays must consider conditions mentioned above, the settings are generally high which makes the relay insensitive. The relay should be time delayed to avoid operation on system transients and external faults.

The valves are also protected against thermal overload by a specific function (TCR current limiter) in the SVC control system, see section 9. The selective protection simulates the temperature inside the reactor and works with the time constant of the reactors. For some installations this protection is installed in the SVC control system. Experience from hundreds of SVC’s has also shown that it is very rare that this protection operates since the TCR current will be limited by protective control features implemented in highly reliable SVC control systems.

4. TSC Protection

A TSC is delta connected where each phase consists of a thyristor valve, a reactor and a capacitor bank. The thyristor valve is electrically located between the reactor and the capacitor. The capacitor bank is generally divided into two parallel halves with a number of capacitor units connected in series and parallel. The differential protection scheme is described in section 4 (TCR protection). An overcurrent relay sensing the line currents in the TSC provides backup. Unbalance protection function supervises the voltage across capacitor by measuring unbalance current. Unbalance current can be measured in different configurations as indicated in Figure 1 and 2. Two overvoltage criterion are used: One overvoltage criterion for the unit and one criterion for internal elements. In case of excessive capacitor voltage, an alarm or a trip command is issued.

In the TSC branches the thyristors are protected by arresters across the valve. Arresters shall preferable be located so that a current flow in an arrester will not be seen as a transient fault by the differential relay and cause false tripping. In TSC topologies where currents are bypassed from differential CT's, extra time delays must be added to avoid false tripping.

Negative sequence protection may be added if requested by customer, see section 3.

5. Harmonic Filter Protection

For most SVC installations harmonic filters are connected. Harmonic filters perform the dual task of providing reactive power generation at fundamental (grid) frequency and performing the harmonic filtering needed to take care of the harmonics generated by the TCR. Filter banks for SVC applications are generally divided into two parallel banks in Y-Y connection with ungrounded neutrals tied together. Internal fuses protect the capacitor units.

Differential protections are not to be preferred in harmonics filter since complicate bus arrangement will apply. Harmonics filters are generally ungrounded and double wye connected. This means that the two strings in the capacitor bank is tied together internally in the capacitor bank, see figure below. Differential protections for filter banks will require CT's with high current rating in the neutral.

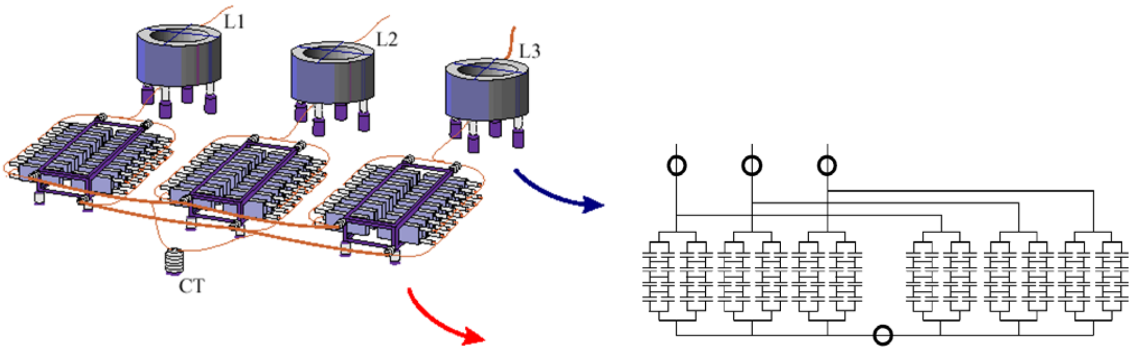

Figure2: Unbalance current measured in double Y-Y filter capacitor bank

Harmonics generated by the system and the TCR are important when designing small capacitor banks and shall be considered in rating calculations as well as for the protection of the capacitors [1]. Overload protection functions shall supervise the voltage across capacitors by measuring branch currents and calculation the resulting capacitor voltage, including the effects of harmonic frequencies. Relays that are designed to operate for fundamental component shall not be used.

Unbalance protection function supervises the voltage across capacitor by measuring unbalance current. Unbalance current can be measured in different configurations as indicated in Figure 1 and 2. Two overvoltage criterion are used: One overvoltage criterion for the unit and one criterion for internal elements. In case of excessive capacitor voltage, an alarm or a trip command is issued.

6. Auxiliary Transformer Protection

It is quite common to use the SVC MV bus for one source of auxiliary power to the SVC. The high short circuit power on the bus makes it difficult to trip the aux power transformer in case of a fault, not fuses nor circuit breakers would do. Fuses are for maximum 40 kA short circuit power and circuit breakers for maximum 63 kA. Tripping the complete plant to disconnect the aux power is bad for the forced outage availability. The best way to overcome the difficulties is to install a series reactor in front of the aux power transformer. It should be designed to bring down the fault current below 40 kA. Current limiting fuses are the fastest and best means to minimise damage to the aux power transformer. In order to be able to replace the fuses or to avoid unsymmetrical operation after a fault a disconnector is also needed.

The aux power transformer shall be protected by means of overcurrent relays, tripping the complete plant in case the fuse operation fails. Load current is very low, typically in the range of 10 A. A protection scheme is needed to detect current slightly above the max load for overload purpose and at the same time being able to detect short circuit current in the range of 40 kA. This can be done by two different overcurrent relays, one connected to a CT with a turn ratio matching the load current and a second one having a turn ratio selected for short circuit current.

7. Ground Fault Detection

Ground faults within an SVC are extremely rare. Overhead lightning protection of the complete SVC yard is provided. The medium voltage (downstream the main power transformer) electrical circuit is built with relative large clearances/creepage distances. The thyristor branch circuits/equipment are fenced in. The environment is considered clean, the pollution level is low. Surge arresters are provided on the SVC medium voltage circuit. The key to avoid ground faults is to keep animals and forgotten tools out of the energized areas.

ABB has for a few customers recently proposed and delivered an alternative solution related to ground fault location within the SVC. The philosophy is to increase the reliability of the SVC by eliminating the grounding circuit. With the grounding transformer removed the ground fault has to be detected by a voltage relay sensing a zero-sequence voltage. Since the ground fault now will not be selective detected, it will instead be located by an automatic reclosing sequence. Upon SVC trip, all the branch disconnectors will be opened. The SVC breaker is then reclosed. Two scenarios are to be considered:

a) If the ground fault remains, the SVC main circuit breaker is tripped again and it is concluded that the ground fault is on the common SVC bus, or within the main power transformer. Filters installed without disconnectors will be included in the energisation sequence. The SVC is then put into lock-out condition.
b) If the ground fault remains but the SVC is not tripped, the fault has to be in one of the SVC branches. These are then closed in one-by-one, using their motor-operated disconnectors, until we get a ground fault trip again. The branch that initiates this second ground fault tripping is then isolated using its motor-operated disconnector. Finally the SVC main circuit breaker is closed in again and the SVC resumes operation in degraded mode, if allowed. SVC operation without harmonic filters is generally not recommended.

The above-described auto-reclose sequence will take somewhat (say one minute) longer time to complete, than a normal start sequence. It also will involve one additional (no load) transformer energisation. The energisations of the thyristor branches, using their motor-operated disconnectors is not noticeable as the thyristor valves are blocked and no “charging current” will develop. The arcing at the disconnector will be completely negligible. The additional closing in of the transformer, which could have a medium voltage ground fault, constitutes no risk for the transformer.

The traditional way to provide ground fault location within an SVC, has been to provide a medium voltage grounding transformer (z-connection) [1]. Grounding transformers are not recommended since there are concerns around the “grounding circuit” within an SVC. First there is a prospective resonance between the grounding transformer and (part of) the TSC capacitor bank. Secondly the fault current on the SVC medium voltage bus may be very high. Fuses are needed to protect the grounding transformer in case of an internal fault, but fuse selection is difficult with this combination of high fault current and relatively high voltage. Additional components are introduced and these in their turn shall be protected. This will have a negative effect on the SVC reliability and availability.

8. Protective Control Features in SVC control system

Fundamental frequency current or voltage overload in any branch in the SVC is prevented by the control system. There are control functions making sure that the total SVC current i.e. the current through the power transformer or the current in the TCR cannot become higher than the component ratings. The voltage on the SVC MV bus is also controlled to make sure it cannot exceed its design value.

DC current in the TCR is actively suppressed by a control function manipulating the thyristor firing instants.

When it comes to detecting malfunctions in the plant the most important function is to compare the actual currents in thyristor controlled branches with currents simulated in the control system. The simulation is based on measured system voltage and actual firing orders to the thyristors. In case there is a deviation between the two values exceeding a limit the plant is considered faulty. There are also a number of self supervision functions and hardware checks making sure the control system is working properly.

In case of a detected faulty control system the operation will automatically be transferred to a redundant system, in case such a system is not available the SVC will trip.

9. Conclusion

Security takes precedence over dependability in the protection system for an SVC. The plants are installed to improve the voltage stability in the grid during and following major network disturbances. They must not trip when they are needed the most unless major faults appear in the main circuit. Only required protective functions, such as short circuit detection shall be employed. In case other functions are added they should be significantly time delayed.
Overload of SVC components is not possible unless the control system is faulty. Self supervision detects control system failures. Time delayed overcurrent and overvoltage protection may be used to further enhance control system failure detection.

Bibliography

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