

## The design of a modern protection system for a Static Var Compensator.

Wikström, K\*. Gajic, Z. and Poulsen, B  
ABB AB, FACTS  
Sweden

### Summary

SVC equipment includes several high voltage objects such as a Power Transformer, Thyristor Controlled Reactors (TCR), Thyristor Switched Capacitors (TSC) and harmonic filters. Multi-object capability of protection IEDs has changed the way of designing the SVC protection system. Modern multifunctional IEDs include all needed functionality to enable complete protection solutions based on functional integration. Only a few IEDs are needed to protect a complete SVC installation. The protection system is main and backup scheme with a design based on a single failure criteria. The paper will give guidelines on which protective functions to be included in the main and backup protection system.

### Keywords

Static Var Compensator (SVC), Protection system, functional integration.

### 1. Introduction

SVC installation, figure 1 shows a typical configuration, is a major component in a utility transmission system. Main tasks for a SVC could be to improve steady state voltage quality, increase power transfer capabilities, and give reactive support during power system faults. Important factors such as high availability during steady state conditions and the need for robust operation during major network event give stringent requirements on the SVC protection system reliability.

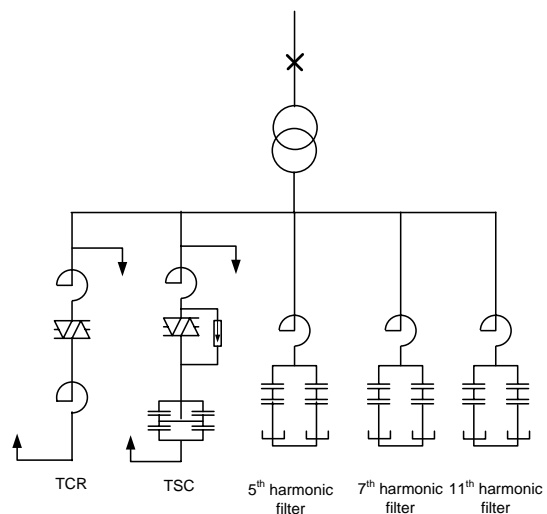


Figure 1: Showing a simplified single line diagram for a typical SVC configuration. Configuration consists of SVC main breaker, power transformer, thyristor controlled reactor (TCR), thyristor switched capacitor (TSC) and harmonic filters (5:th, 7:th and 11:th).

## 2. General requirements on a SVC fault clearing system.

The basic task of the SVC fault clearance system is to detect a specified class of power system faults and abnormalities and to disconnect the associated item of plant from the rest of the power system. By definition the protection system consists of instrument transformers, protection equipment, auxiliary supply, tripping circuit including the circuit breaker trip coil and all necessary wiring. The fault clearance system is the protection system together with circuit breakers. Independent of the high performance and quality the protection equipment may have, it is of no use if any of the other components in the fault clearance system fails. The fault clearance system in the station must fulfil certain basic requirements originating from the power system. Simplified the requirements can be expressed as follows. The fault clearance system shall perform with high reliability, speed, selectivity and sensitivity. The faulty power system component shall be disconnected as fast as possible with no damage to other components and equipments in the power system. Of major importance is of course to prevent or limit people from injuries. The fault clearance system shall also make it possible to continue the operation of the power system with a minimum disturbance to the customers. The reliability is probably the most fundamental and important property of the fault clearance system.

The *reliability of protection* includes *dependability of protection* and *security of protection*.

Dependability of protection is the probability for a protection to operate under given failure conditions for a given time interval. High dependability is the same as the function really will be executed correctly when wanted.

Security of protection is the probability for a protection of not having an unwanted operation for a given time interval. High security is the same as the function will not result when unwanted.

## 3. Single failure criteria

We cannot assume that all components in the fault clearance system always will operate correctly. As each of the components in the fault clearance system has a low risk of failure it has become a common practice among utilities to apply the single-failure criterion in the planning and design of the fault clearance system.

The single-failure criterion requires that the failure of any one component in a fault clearance system should not result in a complete failure to clear a power system fault.

When a power system fault occurs it must be possible to clear it in an acceptable way, even if there is one failure in the fault clearance system. The following failures shall be considered:

- Loss of input from a voltage/current transformer
- A failure to operate of a protection equipment or a protection function
- An interruption of the DC supply/tripping circuit/other secondary circuits
- A failure to operate a switching device

It is a relatively common situation that the fault clearance system does not completely fulfil the single-failure criterion conceivable faults. It is obvious that some kind of back-up protection is necessary to be able to fulfil the single-failure criterion, and the back-up must cover the complete fault clearance system.

These principles are based on the power system requirements and must be fulfilled.

#### **4. SVC protection system.**

It is advisable to use a circuit local back-up protection system to fulfil the single-failure criterion for a SVC protection system. The protection system A will then clear the fault in the SVC if the protection system B failures to operate or vice versa.

The two systems sense the same currents and voltages. In principle all components in the fault clearance system are duplicated in some way. The currents are supplied from different current transformer cores to the two protection systems. The voltage transformer is normally not duplicated but the supply to each protection system shall be separately fused. The protection equipment, DC supply, secondary wires and trip coils including the trip circuits are duplicated. The circuit breaker itself is expensive and is not duplicated. Instead a breaker failure protection is used.

A circuit local back-up protection system has several advantages. The performance of a back-up operation can in many cases be the same as for a main fault clearance. The back-up fault clearance is selective. This will limit the negative effect on the power system and minimize the outage. Continued SVC operation when having redundant high voltage equipments (TCRs, TSCs or filters) is possible even for backup clearance. The back-up clearance operates fast. In many cases the fault clearance time will be the same as for operation of the main protection.

The thermal stress on high voltage equipment will be reduced. Therefore, the thermal dimensioning fault clearance time can be decreased which leads to the possibility to use less expensive high voltage equipment or postpone reinforcements of the high voltage equipment in existing stations. A circuit local back-up protection system is a complicated system and a clear separation between the two systems is of vital importance for the performance.

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 protection system. These protections are a vital part of the complete SVC protection system.

#### **5. Tripping scheme and breaker failure**

All faults internal to the SVC will isolate the SVC from the network by tripping the SVC main circuit breaker. It is not recommended to have any breakers to trip individual branches of the SVC as this will give a more complex tripping scheme and by this jeopardizing the protection system security. Even if action of the protection trip always is to open the main SVC breaker it is of extreme importance to have selective object trip indication in order to be able to prepare for an auto reclosing with the faulty object disconnected. The selective indication will also decrease the outage time of the faulty object. To ensure the necessary performance, special care has to be taken when dimensioning the current transformers.

The breaker failure protection is a part of the local back-up protection system and shall be able to detect if the main breaker has failed to disconnect the fault. In such case the breaker failure protection shall trip all adjacent breakers to be able to clear the fault. As security is extremely important, a high performance breaker failure protection is advisable to be used. This function uses two methods for detecting unsuccessful opening of the breaker, contact based detection of breaker opening when current is low or a dedicated overcurrent function when current is high. This breaker failure protection has high security and it is possible to clear a fault within 250 ms or less even in case of a breaker failure. The breaker failure function should always be configured for immediate retrip of the SVC main breaker to further increase the protection system security.

## 6. Customer requirements.

Many customers have the following requirements on the protection system.

1. Different manufacturers for protection system A and B.
2. Different measuring principle in protection system A and B.
3. Only one protected object/cubicle or IED.
4. Separated differential zones for the power transformer and SVC MV bus

As indicated in the chapters above, high priority should be given to protection security for the SVC protection system. This means that protection system A and B should be as identical as possible but still fulfil the dependability requirements.

1. It is preferable to have the same manufacturer for both protection system A and B.
2. It is preferable to have identical protection functions in protection system A and B from a security perspective, however to increase the performance/cost ratio it is recommended to use a current differential function in system A and a overcurrent function in system B to detect short circuits.
3. To increase the availability of the SVC installation and performance/cost ratio for the protection system it is better to integrate as many functions as possible in one cubicle/IED as long as the single failure criteria are still fulfilled.
4. Commonly used differential zones configurations for a SVC installation is shown in figure 2 and 3 below. The possibility for auto reclose is equal in the two solutions as auto reclose is not performed for a fault in the power transformer and/or on the SVC bus. One argument in favour for the solution with separated differential zones is selective fault indication but remember that other protections such as transformer guards have selective indication. The solution with an overall differential will increase both the performance/cost ratio as well as the security for the protection system. Recommendation in [2] is to use an overall differential zone that covers both the power transformer and the SVC MV bus.

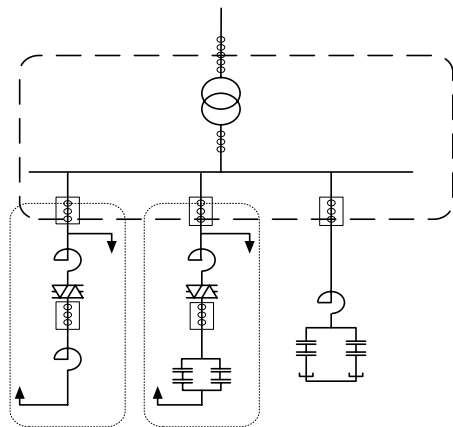


Figure 2: Overall differential zone for power transformer and SVC MV bus.

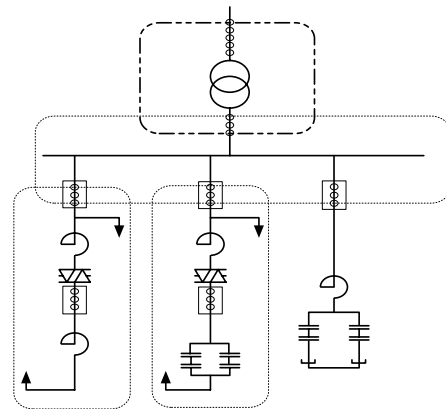


Figure 3: Separate differential zones for power transformer and SVC MV bus.

## 7. Additional functionality.

To enable fault analysis it is very important to record all currents, voltages, controls and protection signals from the SVC. This information is normally recorded both in the control system and the protection system. To be able to use the information all transient recorders must be mutually triggered for a primary event.

## 8. Protections functions

In general, current differential protections with overlapping protection zones and over current protections are used as short circuit protection for all SVC components. Time delayed residual overvoltage protection is used as earth fault protection for the SVC busbar and all SVC medium voltage components. A special auto reclose scheme can be implemented to achieve selective indication for earth faults. Current unbalance protection is employed for the capacitor banks in TSCs and filters. A special capacitor overload protection is used on the filters to protect against low order harmonics from the system. Recommendation for protection allocation for protection system A and B is shown in figure 4 below.

Other used protection functions if requested by customers are restricted earth fault, negative sequence current protection and overexcitation. For more details of protection functionality see [1] and [2]. However these functions can be seen as optional; they will increase the dependability of the protection system but at the same time decrease the security.

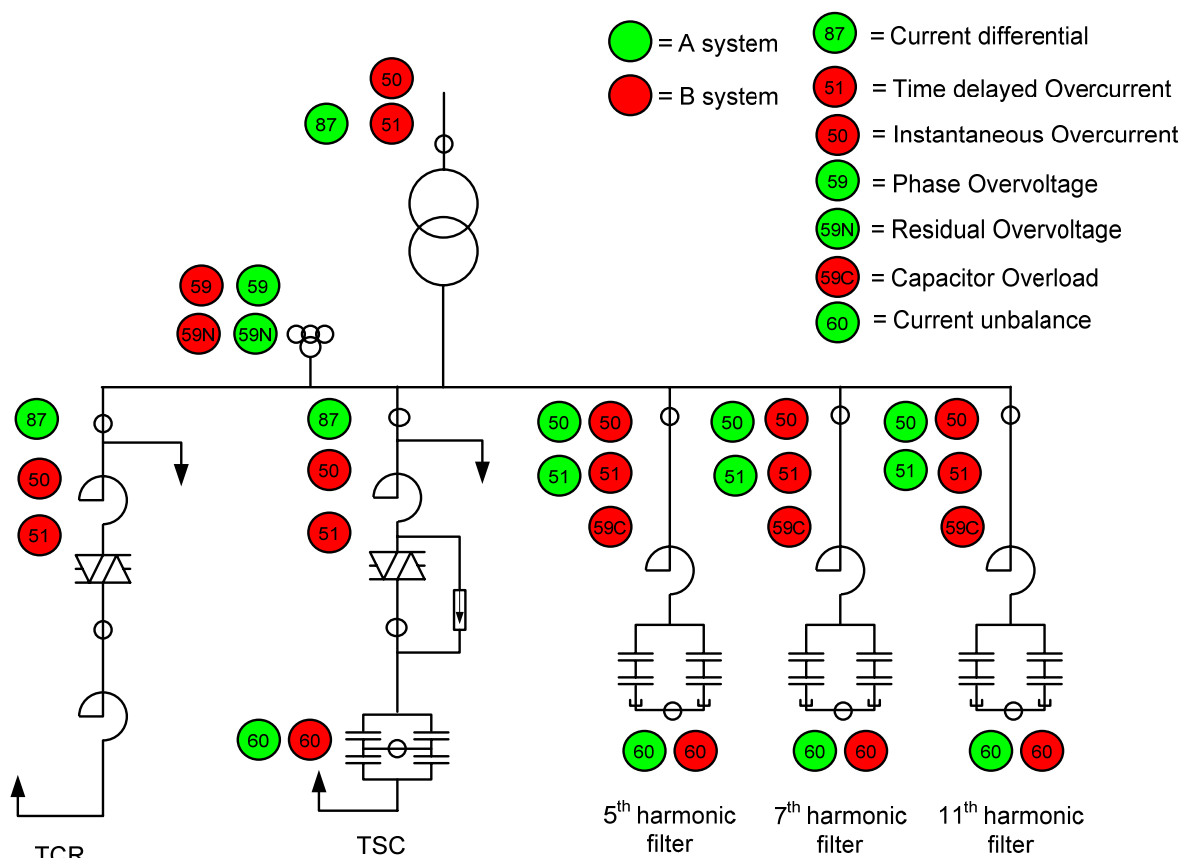


Figure 4: SLD for a SVC including protection function allocations.

To illustrate the possibilities using an IED with multi object capabilities a comparison has been made by studying two protection configurations from the field with a SLD according to figure 4. Both protection configurations are fulfilling all power system requirements but they are based on different technologies.

### Protection Configuration 1:

Conventional approach with the following individual protections.

- Current differential protections. (87)
- Phase and residual over voltage protection. (59N and 59)
- Overcurrent protection with 4 analogue inputs. (50/51 or 60)

## Protection Configuration 2:

IEDs with multi object capabilities and with the following attributes/IED.

- 24 analogues inputs. (AI)
- 2 low impedance current differential functions. (87)
- 2 high impedance current differential functions. (not used in the comparison)
- 6 over current functions. (50/51)
- 6 residual over current. (60)
- 6 capacitor overload functions. (59C)
- 1 phase over voltage function. (59)
- 1 residual over voltage function. (59N)

Protections used in configuration 1	IEDs used in configuration 2	Protected object(s)	Function(s)	Number of AI
A1 <sup>a</sup>	X1 <sup>c</sup>	Transformer and SVC bus	87	18
A2	X1	SVC bus and branches	59N and 59	3
A3	X2	TCR	87	6
A4/A5	X2	TSC	87 and 60	6/3
A6/A7/A8	X3	5 <sup>th</sup> / 7 <sup>th</sup> /11 <sup>th</sup> filter	50/51 and 60	3*(3/1)
B1 <sup>b</sup>	Y1 <sup>d</sup>	Transformer and SVC bus	50/51	3
B2	Y1	SVC bus and branches	59N and 59	3
B3	Y1	TCR	50/51	3
B4/B5	Y1	TSC	50/51 and 60	3/3
B6/B7/B8	Y2	5 <sup>th</sup> / 7 <sup>th</sup> /11 <sup>th</sup> filter	50/51 and 60	3*(3/1)
B6/B7/B8	Y2	5 <sup>th</sup> / 7 <sup>th</sup> /11 <sup>th</sup> filter	59C	-

Table 1: Function allocation for protection configuration 1 and 2.

- a) A1=Protection number 1 in protection system 1, main  
b) B1=Protection number 1 in protection system 1, backup  
c) X1=IED number 1 in protection system 2, main  
d) Y1=IED number 1 in protection system 2, backup

Protection configuration 1 use in total 16 protections and protection configuration 2 use 5 IEDs. Protection configuration 2 will decrease the number of protection cubicles to a minimum. Additionally there is only need for one type of IED spare. Totally this will increase the performance/cost ratio for the protection solution.

## 9. Conclusion

It is today possible to protect a complete SVC installation with a limited number of protection IEDs without any decrease in protection system reliability. Additionally numerical technology with improved communication facilities and transient fault recording will improve the access to information both during normal operation and for fault analysis.

## Bibliography

- [1] Working Group of Substation Protection Subcommittee of IEEE "Static Var Compensator Protection" (IEEE Transactions on Power Delivery, Vol. 10. No 3 July 1995, page 1224 – 1233.  
[2] M. Halonen, B. Thorvaldsson, K. Wikström "Protection of Static Var Compensator" (Cigré, October 19-24, 2009, Jeju Island, Korea)