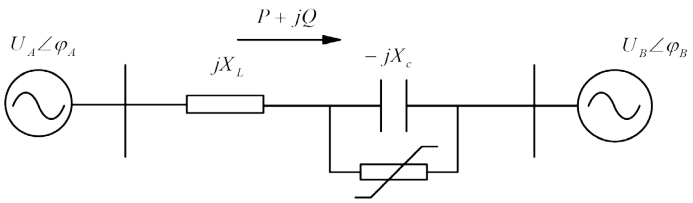
Fixed Series Compensation

High-reliable turnkey services for fixed series compensation

NR Electric Corporation

The Fixed Series Compensation (FSC) solution is composed of NR's PCS-9570 FSC control and protection system, and circuit breaker monitoring & control devices, that are used to achieve series compensation protection, spark gap trigger, and switching order of control.



$$P = \frac{U_A \cdot U_B \sin(\varphi_A - \varphi_B)}{X_L - X_C}$$

$$Q = \frac{k}{(1-k)^2} \frac{U_A^2 + U_B^2 - 2U_A U_B \cos(\varphi_A - \varphi_B)}{X_L}$$

Degree of compensation $k = \frac{X_C}{X_L}$

Configuration

The capacitor is connected in series with the transmission line to compensate the inductive reactance of the transmission line. The small change of transmission line equivalent inductance can significantly increase the transmission capacity.

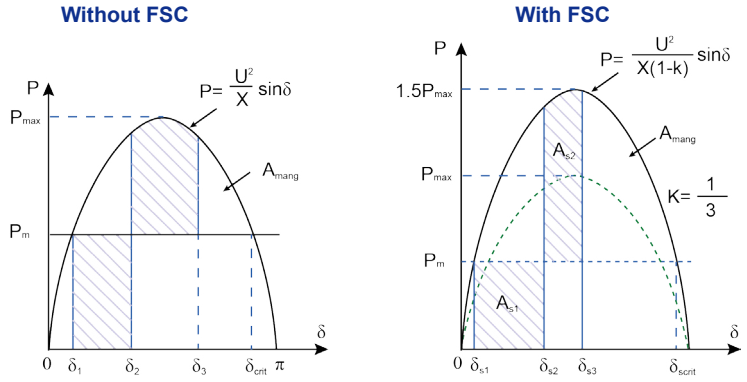


Figure 1. The transmission capacity increases with FSC

Another important benefit is to reduce transmission losses by optimizing the active power share between parallel lines.

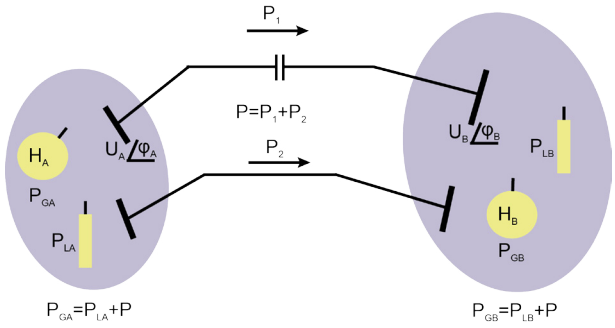


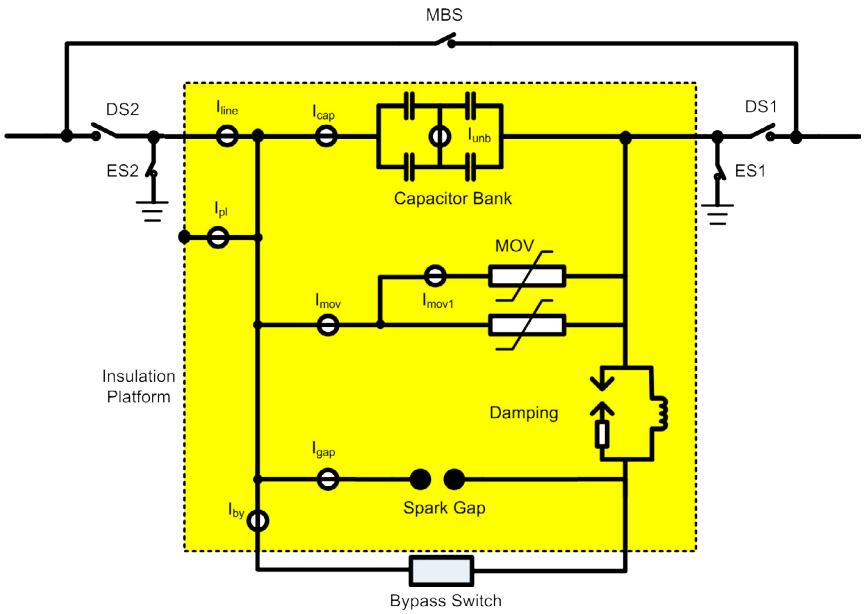
Figure 2. Balance power distribution with FSC

The fixed series compensation equipment is installed in the transmission line to achieve the following advantages:

- Improve the transmission capacity of lines
- Improve system transient stability
- Change system power distribution and reduce network losses
- Change voltage distribution

Configuration

NR's PCS-9570 series compensation solution includes capacitors, MOV, damping circuit, spark gap, bypass switch, series compensation platforms, electronic transformer, and protection and control system.



This unique solution is suitable for the series compensation of AC transmission lines with 66kV to 1000kV. The protection part integrates capacitor unbalance current protection, capacitor overload protection, arrester overload protection, arrester unbalance protection, platform flashover protection, sub-synchronous resonance protection, capacitor discharge protection, line current monitoring, gap protection, discharge trigger circuit supervision, three-phase position inconsistent protection, bypass breaker failure protection, device out-of-power protection, and fiber optic systems fault detection. The Control part includes sequence control function, screen monitor, alarm, switching disconnectors interlocking and remote upload information.

Configuration

FSC mainly consists of the following components:

- **Capacitor bank**

Capacitor banks are used to achieve the compensation for transmission line inductance so as to reduce the electrical distance between two substations and improve the system transient stability.

- **MOV**

MOV has good non-linear characteristic. It provides overvoltage protection for capacitor banks to limit the overvoltage cross capacitor bank at the protection level 2.0pu ~ 2.5pu (typically) or less, to ensure the safe operation of capacitor bank.

- **Spark Gap**

The duration from turn-on command issuing to completely spark gap conduction is less than 1ms. It prevents the MOV against damage due to the excessive absorption of energy.

- **Damping Circuit**

The damping device comprises damping reactors and linear resistor string gap (or non-linear resistance). When the series compensation device is in bypass state, the damping circuit can facilitate and speed up the energy storage in capacitor.

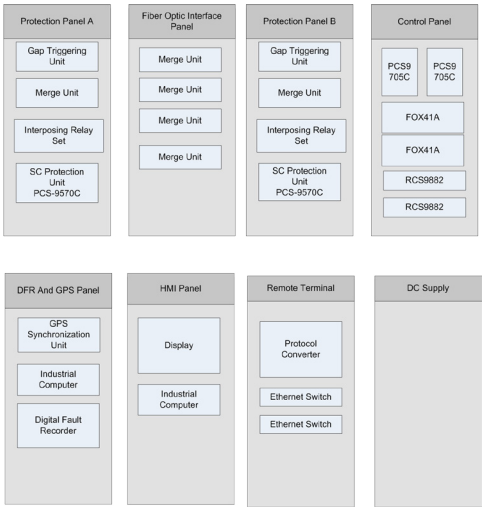
- **Bypass Switch**

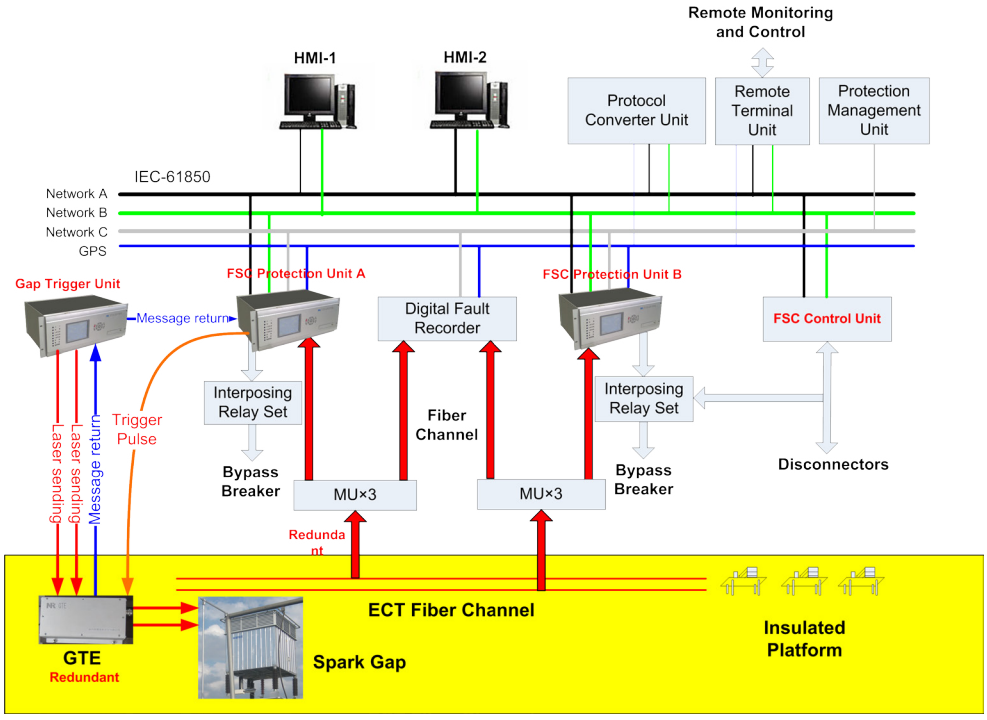
The closing time of bypass switch is longer than the conduction time of spark gap, but it can cause the spark gap interrupted. In addition, it provides normal operation and maintenance functions for series compensation devices.

Configuration

- **Control and Protection**

The typical configuration of series compensation is shown as below. Protection devices and trigger gap control are in reduendant design. The switching control device integrates conventional circuit breaker monitoring and control functions in one rack. The protocol converter and the remote device can be configured according to the actual situation. The remote control unit provides distant sequence control of series compensation to realize free-maintance station.





Functions

Protection Functions

Table 1 presents each function of capacitor bank protections PCS-9570C during its operation.

	Protection Function	Alarm	Bypass	Trigger Spark Gap	Permanent Lockout	Temporary Lockout	Permanent Bypass	Reinsert	Other
Capacitor	Capacitor Overload Alarm	√							
	Capacitor Overload Bypass	√	√			√	#1	#2	
	Capacitor Unbalance Alarm	√							
	Capacitor Unbalance Low-set Protection		√		√				
	Capacitor Unbalance High-set Protection		√		√				
MOV	MOV High current Protection		√	√		√		√	
	MOV Energy Low-set Protection		√	√		√		√	
	MOV Energy High-set Protection		√	√		√			
	MOV Temperature Protection		√	√		√			
	MOV Unbalance Protection		√	√	√				
Spark Gap	Gap Self Trigger Protection		√		#3			#4	
	Gap long Conduction Protection		√		√				Remote Trip Lines Breakers
	Refuse/Delay Trigger Protection		√		√				
Bypass Breaker	Breaker Close Failure Protection		√		√				Remote Trip Lines Breakers
	Breaker Open Failure Protection		√		√				
	Pole Disagreement Protection		√		√				
Other	Platform Flashover Protection		√		√				
	Cap Discharge Protection		√	#5		√		√	
	SSR Protection		√						
	Line Current Supervision	√							Lockout Reinsert
	Trigger Circuit Monitoring	√							

#1 Permanent bypass if the number of capacitor overload exceeds the setting.

#2 Reinsert if the number of capacitor overload is less than the setting.

#3 Permanent bypass if the number of gap self trigger exceeds the setting.

#4 3-phases reinserting if the number of gap self trigger exceeds the setting.

#5 The gap trigger optical pulse will be emitted if the capacitor instantaneous voltage exceeds the setting.

Functions

Control

- Temporary or permanent lockout.
- Support double bypass circuit breaker.
- Auto-reinserting (single-pole and/or three-pole).
- Trigger the spark gap. The maximum time delay from the point where MOV high-current and/or high-energy bypass threshold is exceeded to Spark Gap conduction shall not exceed 1 ms.
- Dual FSC protection system to avoid the failure of bypassing series capacitors.

Communication

- Merging unit communication to protection system based on IEC60044-8 protocol.
- Ethernet ports supporting IEC 61850 protocol.
- 2 RS-485 ports supporting IEC 60870-5-103 protocol and clock synchronization.
- 1 RS-232 ports or RS-485 for printer and 1 RS-232 frontpanel port for testing and setting.
- GPS clock synchronization.

Spark Gap

- The gap discharge voltage is set higher than that established by MOV protection. The gap receives forcing trigger command and is triggerred quickly. The gap can not be triggered without receiving the triggering command.
- The spark gap can withstand the discharging current of capacitor bank at a specified protection voltage level.
- The Gap Trigger Electronic (GTE) device uses dual laser energy to avoid EMI caused by high potential power supply. Low-power CPLD can realize trigger command processing, closed-loop power control and equipment self-test. The trigger command processing delay is about 20us. The entire conduction time of the spark gap (from GTE receiving the trigger command to the spark gap completely turn-on) is less than 100 μs.
- The ignition gap uses double seal structure with good immunity to wind speed and humidity. The ignition device has a special electrical discharge machine and a precise installation equipment to make the trigger voltage stable and accurate. Within the adjustment duration, the trigger voltage error is less than 5%.
- Each ignition gap has two GTEs to work with dual sets of protection to form a redundant configuration. Ignition pulse will be output if the trigger command is received by any GET.
- The trigger system has good anti-EMI capability in case of switching arc and gap conduction.

Features

The PCS-9570 series products are developed based on NR's solid AC high voltage protection principles and years' of experience. It provides protection and control solutions for AC transmission line capacitors in series compensation system. It features:

- Safe and reliable primary equipment
  The PCS-9570 system adopts safe and reliable primary equipment such as capacitors, MOV, spark gap, damping device, electronic transformer and protection & control system.

- Unified UAPC platform
  The self-developed UAPC platform has visual programming software and hardware modular configuration. It is flexible for expansion. Communications between hardware modules are fulfilled by internal high-speed bus.

- The operation of duplicated protections are fully independent. The starting components are combined with protection output to increase operation reliability.

- The use of electronic transformer greatly improves its anti-interference capability.

- Interposing relay sets are developed for the closing of series compensated bypass switch.

- The control and protection module can facilitate the realization of sequence characteristics of series compensation equipment.

- Measurement and control devices are fully complied with IEC61850. Operators can enable or disable dispatching of series compensation devices through the remote one-touch control function .

- Easy-to-use testing device.
  The conventional relay tester can ease the on-site inspection of series compensation system.

Case Study

HeChi Substation Series Compensation

Hechi series compensation is installed in Hechi substation of Southern Power Grid. its series compensation degree is 50%. The related parameters are shown in the table below.

Technical Parameters	Value
Rated voltage (kV rms)	525
Three-phase Capacity (MVA)	476.0
Compensation degree	50%
Rated current (A)	2400
Rated phase voltage (kV rms)	66.1
Each phase capacitance (μF)	115.6
Each phase series impedance (Ω)	27.55
Protection level (p.u.)	2.37

NR provides the following study and services in this project:

- Study series compensation voltage and check series compensation device parameters.
- Test the new gap trigger system to see if it can trigger the original seal gap, verify that the new gap trigger complies well with the original spark gap;
- Measure the thermal characteristics of original MOV devices curve. The MOV thermal protection simulation model remains the same as the actual cooling curve to ensure reliable operation of MOV;
- Perform the RTDS test for protection & control system to test the performance of series compensation.

After completing all equipment installation and commissioning, the manual ground short circuit test is executed to prove that the entire control and protection system can well meet the specified requirements.

BaiSe Substation Series Compensation

The technical data of 500kV BaiSe series compensation project is shown in the table below.

Technical Parameters	Value
Rate voltage (KVrms)	525
Three-phase rated capacity (MVA)	542
Compensation degree	50%
Rated current (A)	2400
Rated phase voltage (kV rms)	75.3
Each capacitance (μF)	101.47
Each series impedance (Ω)	31.37
Protection level (p.u.)	2.3

NR provides the follow study and services to ensure the reliable operation of series compensation in Baise project:

- Overvoltage simulation of power network including series compensation.
- Platform stress analysis and a variety of load checking.
- Insulation coordination study.
- Spark gap development and type test.
- RTDS test of control and protection system.

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