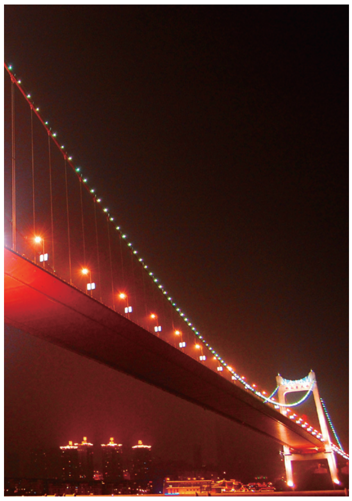
Power Stability Control System



Leading-Edge Solutions to Power Stability Control Worldwide

NR Electric Corporation

Practice, Improvement, Cooperation and Innovation

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1 Introduction of Power System Stability

Power system is a highly nonlinear system that voltage, current and frequency are changing all the time with the varying loads, generations and various disturbances. A large disturbance can result in an unbalance between the loads and the generations, and the system will maintain stable if the voltage and frequency can oscillate to a steady state after the disturbance. Power Stability is always considered as an important factor for system safe operation.

As indicated in Figure 1, the power system stability can be divided into three categories: Rotor Angle Stability, Voltage Stability, and Frequency Stability [1].

- Rotor Angle Stability refers to the ability of synchronous machines to remain in synchronism after a disturbance in an interconnected system. Instability can result in an increase in angular swings of some generators and will eventually lead to their loss of synchronism with other generators.

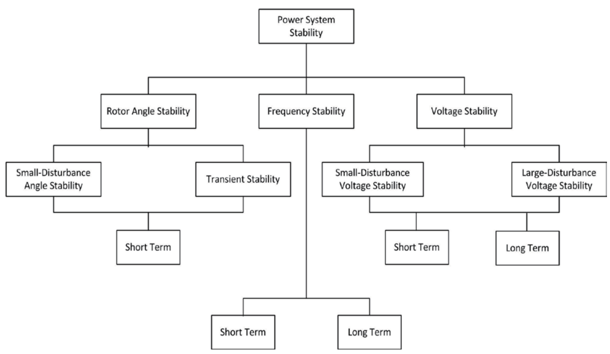

Figure 1. Power System Stability Categories

- Voltage Stability refers to the ability of a power system to maintain the voltages at all buses to a new steady state from an initial operating point after a disturbance. Instability will lead to a drastic fall or rise in the voltages of some buses.

- Frequency stability refers to the ability of a power system to maintain the frequency to a steady state after a severe unbalance between generations and loads. Instability can result in a sustained frequency oscillation which will lead to the generator shutdown or load shedding.

Generally, power generation is composed of large numbers of synchronous generators, which can be interconnected over thousands of kilometers in very large power systems. All generators must operate in a synchronised manner during both normal and disturbance conditions.

Loss of synchronisation of a generator or a group of generators with respect to another group of generators causes instability that could result in expensive widespread power blackouts.

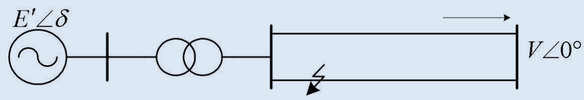

Figure 2. A simple conceptual transmission model

A simple ideal transmission model is introduced for stability analysis. As shown in Fig. 2, the ideal model is composed of a remote generator connected to a large power system via two parallel transmission lines with an intermediate switching station. Since speed changes are quite small, power is considered equal to torque in per unit. The generator can be considered as a constant voltage source E' behind a reactor, while the transformer and transmission lines can be considered as inductive reactance. Applying $S=E'xI^*$, the electrical power is thus obtained as below:

$$P_e = \frac{E'\,V}{X}\,\mathrm{Sin}\,\delta$$

where V is the voltage of the infinit bus and X is the total reactance of the transmission lines and the generator. The above equation shows that the power system is fundamentally a highly nonlinear system when large disturbances occur.

The relationship between P_e and δ can be described in a power angel curve as shown in Figure 3. The pre-fault operating point is at δ_0 where the mechanical power P_m is equal to the electrical power P_o.

During normal operation of a generator system without losses, the mechanical power and electrical power are equal and the generator oeprates at a constant frequency close to rating frequency which is 50 to 60Hz.

However, when a short circuit occurs on a transmission line, the electric power will be decreased which will lead to an increase in generator speed and angle. If the acceleration relative to other generators is too large, the synchronization will be lost. Loss of synchronisation is an unstable and uncontrollabe situation with large variations of voltages and currents that will normally cause separation of a generator or a group of generators. After the fault is cleared, the generator is decelerated as the electrical power output is larger than the mechanical power output. The angle continues to increase to δ_F when the energy lost during deceleration is equal to the energy gained during acceleration. If δ_F is smaller than (π - δ_0'), the system can remain stable at another operating point δ_0'. If δ_F is larger than (π - δ_0'), the rotor will accelerate again and δ will increase beyond recoery. The is a transient instability which will lead to a loss of synchronism.

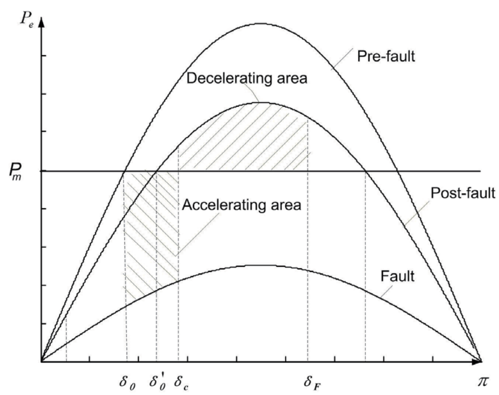

Figure 3. The relation between Pe and δ graphically

Figure 3. indicates the equal area criterion for "first swing" stability. If the decelerating area is larger than the accelerating area, the system can eventually goes back to stability with sufficent damping.

Stability control can help to increase stability by decreasing the accelerating area or increasing the decelerating area. It can be achieved during the forward angle swing by increasing the electrical power output, or by decreasing the mechanical power input, or by both.

Considering the power stability, it is essential to build a protection system to clear faults on transmission lines or other units at the first time. However, these protection devices are mainly responsible for preventing the components for being destroyed in the fault, but not focus on maintaining the electric generation and alleviating the widespread disturbances, which are both very important to the entire society.

A System Protection Scheme (short for SPS, named in 2001 by CIGRE) refers to a system that concentrates on the power system supply capability rather than certain equipment. NR's Power Stability Control System (PSCS) is fully complied with SPS and has been widely applied in China. Figure 4 shows how a PSCS works on power system.

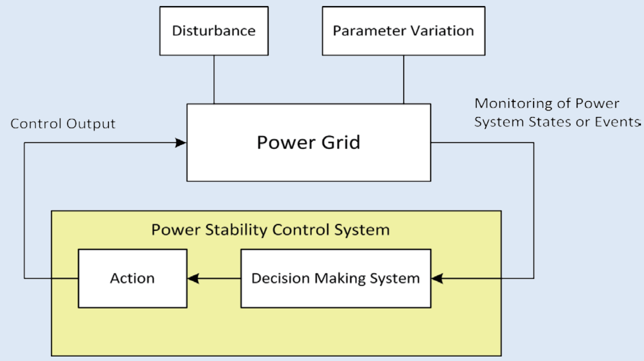

Figure 4. Work Flow of Power Stability Control System

The PSCS targets on maintaining the system voltage and frequency within an acceptable range and balance between loads and generation by load shedding, changing generation, or tripping transmission lines. First, the system will take measures to maintain system stability, including Rotor Angle Stability, Voltage Stability, and Frequency Stability. Second, if it fails and instability occurs, the system operation will focus on minimizing the affected area and avoiding the cascading instability.

In China, the unique Three-defense-Line principle is applied to ensure the stable and safe operation against various faults and disturbances. The First Defense Line mainly targets on the equipment protection, and the PSCS is used as the second and the third Defense Line. Over ten years' safe operation proves that the application of three-defense-line principle has significantly improves the stability condition in China and has effectively reduced the possibility of collapses.

2 Innovative Three-Defense-Line Solution

With the growth of loads and the increase in transmission distance and the composited structure of HVAC and HVDC system, the stability characteristics of modern power system have become more complicated.

Reasons leading to the blackout:

- Weak/imperfect Power grid structure: The irrational primary structure may lead to power transfer to LV grid when HV grid trips, and it will destroy the transient stability and the voltage instability. The transmission line will be severely overloaded and consequently a wildspread disaster may occur in the whole system.
- If the transmission capacity of the main line is small when one or two transmission lines trip, it can lead to residual T/L overload and sharp voltage drops which may lead to system instability.
- Incorrect operation of protective relay.
- Imperfect scheme and design of stability system.

NR has established the unique three-defense-line principle to protect the power system from blackout, and for the last 10 years, stability of the complicated China power system has been improved significantly.

Fault Clearing (The first defense line)

The first defense line consists of accurate and fast protective relays to ensure the fault can be quickly cleared to maintain stable and safe operation. NR provides reliable and high-speed protection products with innovative DPFC protection elements which can significantly reduce the pickup time to trip the fault. It guarantees that the fault is quickly cleared before the system loses its stability.

We strongly recommend that the islanding position should be prearranged based on the stability analysis to prevent mal-operate .

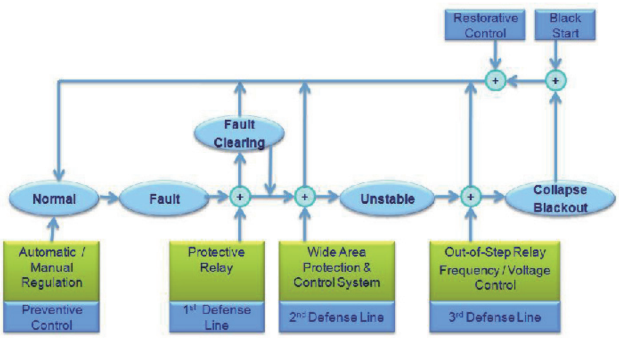

Figure 5 Three-Defense-Line Solution

Relevant Products:

Numerical protective relays:RCS-900 series

Load Shedding and Generator Shut-Down (The second defense line)

The second defense line is an emergency control which can effectively prevent and reduce the possibility of system oscillation. If the unbalance between generation and load arises, the power stability control system will take some measures including generator shut-down and load-shedding to bring the voltage and the frequency back to an acceptable value.

The control strategies can be either generated off-line or on-line based on the operation configuration and load flow condition. The control commands are sent to the executing device.

As the fiber optic network is widely used in the second defense line, the reliability of this control system has been gradually improved. Furthermore, with the application of online pre-decision technology, this control method becomes more and more applicable.

Relevant Products:

Power Stability Control System (PSCS): RCS-992

Out-of-Step Islanding (The third defense line)

The third defense line uses local corrective control such as out-of-step islanding and load-shedding for extremely severe contingencies. The third defense line aims at avoiding the system collapse and minimizing the loss of load. NR provides out-of-step protection and frequency/voltage control devices to keep the system stability when the second defense line can not restore the system to a normal operating state.

Relevant Products:

Out-of-Step Protection: RCS-993

Frequency and Voltage Control Device for Power Stability: RCS-994

3 NR’s Power Stability Control System (PSCS)

As the secondary and the third defense-line of a power system, the power stability control system has formed a complete and reliable solution to guarantee the stable operation of a power system.

Definitions of Stability Control

1. The stability control device is used in power plants or substations for generator tripping, load shedding, accelerated output cutting-off, and emergency run up/down of HVDC power so as to ensure the stability of power system when severe disturbances occur.
2. Stability control devices in more than two power plants or substations are connected by communication equipments to form a regional stability control or a large-scale power systems. Normally, it is composed of a master station, a slave station and executive stations.
3. Stability control strategy table is a logic control chart with detailed and predicted calculation and analysis. Both offline and online strategy tables can be provided.

The sub-tables can offer control methods and measures based on the fault element, fault type and power limit of associated transmission line interface. The operation mode of the strategy table should be integrated based on the severity of stability conditions rather than the power element status.

Online strategy table can form a control strategy relying on the current operation, concerning about the adaptability of power change of the transmission line interface.

Principle of Forming Control Strategy

- Focus on the adjustment of operation mode after fault.
- Generator shut-down shall be considered prior to islanding and load shedding .
- Safety of the control objective and the auxiliary power that the generation tripped in the power plant shall be considered.
- The same standard and principle should be applied to the power grids in the same region.

Stability Control Measures

- Generator should be shut-down at the source of the power system in order to reduce the accelerating energy at the source side.
- It is an effective method to keep the voltage stable in the load center by shedding load concentratively.
- Islanding tie line for interconnecting power grids is effective with the least loss of the total system since the weak connected tie line is the weakest point in the system.
- Regulating the power of the HVDC system is a useful measure for stability control with controlled serial compensation, serial capacitor compensation, and shunt capacitor compensation device so as to improve the transmission capacity.
- Margin should be preserved to avoid accidental spreading due to unsufficient control.

Architecture

A Power Stability Control System (PSCS) is composed of many control devices in several substations. All control devices can be connected to each other via communication channels. Figure 6 indicates a power stability control system with master-slave single layer structure. Communication between the master station and slave sub-stations is fulfilled by optical link channels and up to 30 sub-stations can be connected to the master station. However, as shown in Figure 7, a power stability control system also can adopt the composite structure which supports two or more master stations.

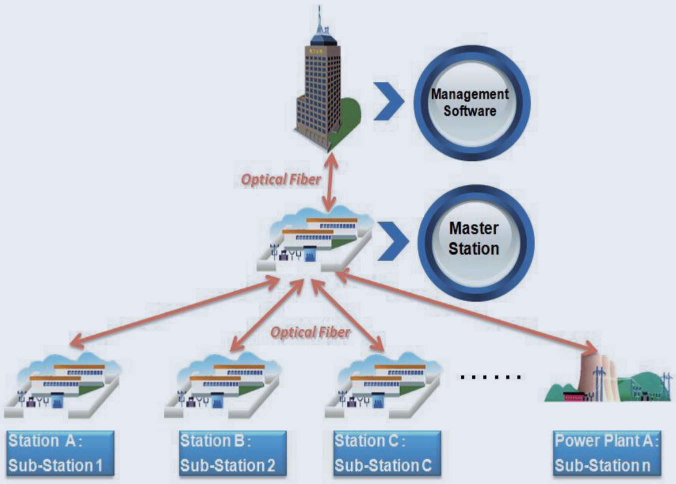

Figure 6 Master-slave single layer structure

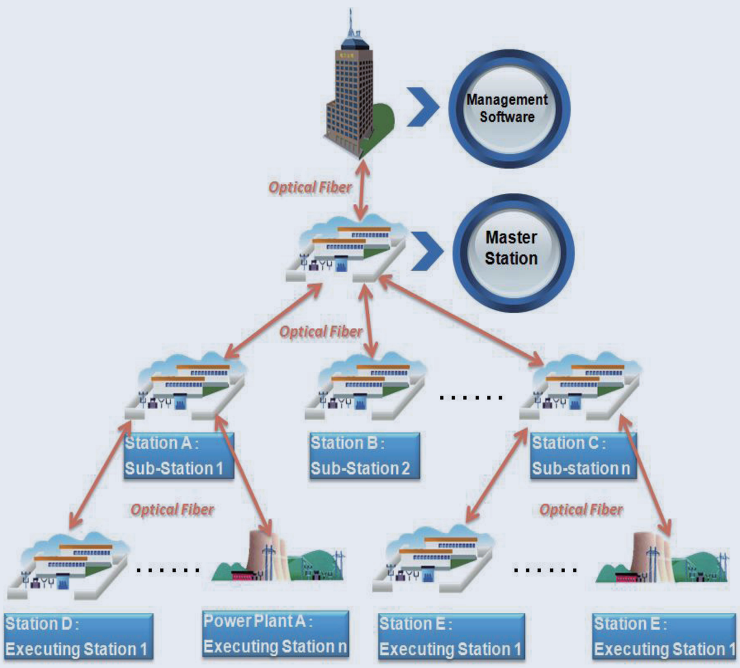

Figure 7 Composite multiple layer structure

Application of Power Stability Control System (PSCS)

Figure 9 shows a regional power grid, where the green lines refer to the 500kV transmission lines and the red lines indicates the directions of power flow. Assume that a fault occurs, how the power stability control system, RCS-993 out-of-step protection and RCS-994 frequency/voltage control device improve the stable operation of this system will be introduced briefly in the following.

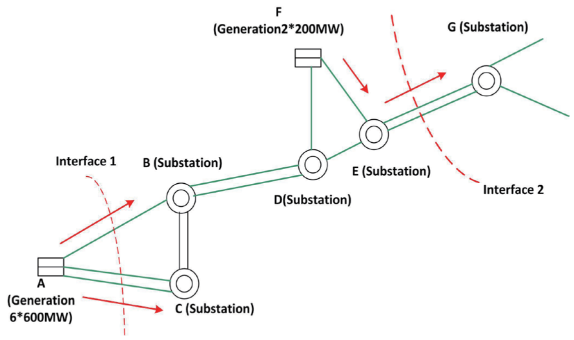

Figure 9 Network Layout of Region Power Grid

First, the stability analysis of this power system will be taken using a simulation program, including N-1 stability estimate (fault in one line), N-2 stability estimate (fault in two lines) and severel faults such as shut-down of all generations and mis-tripping of breaker. It is found that the stability problems exsit at both interface 1 and the interface 2

Interface 1:

If the double-line between A and C are both tripped, the line between A and B will be over-loaded. Furthermore, the system voltage will collapse if the both lines at interface 1 are all tripped or the generation at A is shut-down.

Interface 2:

During heavy load at interface 2, the transient stability can not be guaranteed if fault occurs in any line of interface 2. And over-frequency of power system will be caused if both lines of interface 2 are tripped.

Second, a control strategy can be generated by the dynamic simulation to solve the above stability problems. The detailed control measurements are listed below:

Interface 1:

When the double-line between A and C are both tripped, partial of generation at A shall be shut-down to avoid the overload on line AB.

When an overload occurrs on line AB, the generation of power plant A shall be partly shutdown according to the overload level.

When the lines at interface 1 are all tripped or the generation of power plant A are wholly shutdown, some load shall be shed to avoid the voltage collapse.

Interface 2:

When one of the lines at interface 2 is tripped, the generation of power plant A shall be reduced to avoid instability.

If both lines at interface 2 are tripped, part of the generation of power plant A shall be shutdown according to pre-fault power flow to avoid frequency collapse.

Third, the RCS-992 Power Stability Control System (PSCS) can be applied to this regional network and protection & control devices can be equipped in different substations and power plants. The power plant A and substation E are assigned as the Master Stations and the load center is allocated as the Executing Station for load-shedding.

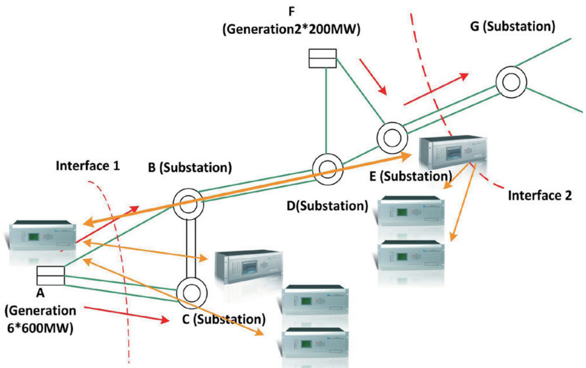

Figure 10 Stability Control Scheme in Region Network

The function of Host Unit in power plant A:

1) Monitor the open/close state and the power flow of Line AC and line AB, and send the information to the Host Unit in substation E.

2) Detect the fault and determin the fault type on line AB, line AC and power plant A. Calculate the generation/loads which need to be controlled and take the corresponding measures reference to the control strategy.

3) If needed, send the shut-down commands to the generation in power plant A and send load-shedding commands to the Executing Stations.

The function of Host Unit in substation E:

1) Send the information of open/close state of lines EG and the load flow condition to the Host Unit in power plant A.

2) Detect the fault and determin the fault type on the line EG, calculate the control capacity of generation/load and take control measures such as generation shutdown and load-shedding in accordance with the control strategy.

3) If needed, send generation shutdown command to power plant A and send load-shedding command to the Executing Station.

Meanwhile, the third defence line is applied to this regional network as a backup of Power Stability Control System (PSCS) so as to avoid any severe disturbance.

1) The Under Voltage Load-Shedding Device is applied to the system for load shedding when the system voltage is sharply dropped.

2) The Frequency Control Device in power plant A and power plant F can shut down generation step by step to avoid any over frequency.

3) The Out-of-Step Islanding Device at interface 2 is used to island it when the out-of-step situation occurs.

4) The black startup scheme is considered.

The innovative Three-Defense-Line solution used in this regional network has been successfully put into service for more than three years and has significantly improved the power stability.

4 NR's State-of-Art Products

Power Stability Control System

Application

The Power Stability Control System is a control system designed for power grid system stability control. If unbalance between generation and load arises due to some severe contingencies, the protection and control device will do some system analysis and take measures to avoid system collapse, including generator shut-down and load-shedding, to ensure the stable operation and protect power system against blackouts. This power stability control system is applicable to regional grids, interconnected grids, wide area networks, power plants and substations.

The software package of PSCS installed in dispatching center collects the system state information, load flow condition, event records and data records from master and slave stations through communication channels and send them to operators in the form of curve or report. The system can also send the control tactic table and setting value to stations. The communication channel is either fiber microwave or optic cable interface with 2M (64K) Ethernet using IEC 60870-5-103 or IEC 61850 protocol.

Features

- 2M,64kbps, Data exchanged in 1.66ms
- Distributed modular system
- Detect status and fault without BI (patent).
- HVDC pole blocking detecting scheme (patent).
- Universal control table

Control Device

As shown in Figure 11, each set of control device consists of one master unit and several slave units.

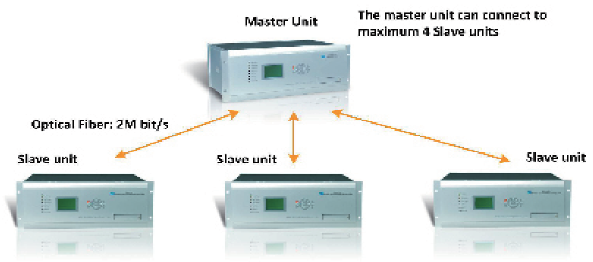

Figure 11 Components of Control Device

A slave unit can manage up to 36 channels for data sampling and sending the results to the master unit, including analog inputs, detecting binary inputs, calculating and determining the normal state and the faulty state of lines, transformers and generators.

A master unit is used to collect and receive the information from other stations to ensure the comprehensive processing, controling and external communications.

Functions of Host unit at master station

- Communicate with other stations.
- Receive results from the slave units in local stations.
- Determin the system normal state.
- Establish the required power transfer limits.
- Implement the stability control tactics.

Functions of Slave units at master station

- Acquire and calculates data.
- Discriminate whether the lines (transformers and generators) are in services.

- Identify the fault type if the transmission lines (or transformer-generator units/busbar) are tripped.
- Execute the commands received from the host unit.
- Implement the stability control tactics.
- Perform the control functions that are not related to the system operation modes e.g. overload discrimination of transformers or lines, etc.

Functions of Host unit at slave station

- Communicate with other stations.
- Acquire data from slave units and perform analysis
- Implement the stability control tactics.

Functions of Slave units at slave station

- Acquire and calculates data.
- Detect whether the lines (transformers and generators) are in service.
- Identify the fault type if the transmission lines (or transformer-generator units/busbar) are tripped.
- Execute the commands received from the host station.
- Implement the stability control tactics.
- Perform the control functions that are not related to the system operation modes e.g. discriminate overload of transformers or lines, etc.

Functions of Host unit at implementation station

- Communicate with other stations.
- Receive the acquired data discrimination results from slave units of local station.
- Implement the stability control tactics.

Functions of Slave units at implementation station

- Acquire and calculate data.
- Detect the status of transmission lines (transformers or generators) and identify the fault if it is not in service.
- Execute the commands received from host station.
- Implement the stability control tactics.
- Perform the control functions that are not related to the system operation modes e.g. discriminate overload of transformers or lines, etc.

Master station, sub-stations and implementation stations shall be assigned according to the actual conditions. A master station can be either a certain key power plant or an important substation, while other substations and power plants are the sub-stations and the implementation stations of the system respectively.

Functions

- Detect the operating conditions of the outgoing lines, transformers and generators.
- Transmit the status from a station to the relevant stations
- Automatically identify the on-line operation mode of the grid.
- Identify the fault types of the outgoing lines, transformers or busbars.
- According to load flow and fault type, calculate the fittest control strategy based on the stability analysis.
- Determine which measures should be taken, e.g. generators shutdown, load shedding, separating, modulating of DC power, quickly reducing output of generators, etc.
- Real-time control measures will be taken when the incidents independent from the network operation mode occur in the grid so as not to influence the voltage stability.
- Select the units to be shutdown in the most reasonable way according to pre-defined specific requirements.
- Deliver the control commands and the control values to other stations via a communication network.
- Check and confirm the control commands received from the master station before manipulation.
- Remote monitoring and setting modification.
- GPS clock synchronization.
- Event and data record.
- Self-checking, abnormality alarm, automatic display, and printing, etc.

RCS-993

Out-of-Step Relay

Application

Power system are required to remain stable after experiencing any size of disturbance caused by a fault, loss of a generator, or loss of a transmission line. Some severe disturbances may cause the loss of synchronism of the interconnected power systems, leading to cascading blackouts and equipment damages. The out-of-step protection relay RCS-993 can effectively prevent the whole system collapse caused by the out-of-step of the interconnected power systems. When the out-of-step condition has been detected, a host of normal open dry contacts of RCS-993 are energized to be closed. These contacts could be used to trip associated circuit breakers to separate the power system into two or more smaller islands at the pre-selected points, to shut down proper generators and shed appropriate loads and/or start other related synchronizer to prepare for the system synchronism after the system separation.

Out-of-step islanding is an essential measure to prevent cascading accident after losing synchronism. Proper islanding scheme should be established when processing the power structure design. It is preferred to establish the island scheme by analyzing the out-of-step oscillation mode considering the current operating condition.To restore the synchronization, it is necessary to shut-down part of the generation when the major power plant and main power grid are out of step.

The RCS-993 relay feature focused on digital out-of-step protection with initiated tripping for power grid which can avoid power system collapse. When an out-of-step fault occurs in the system, the relay isolates grid islands, and the power grid is separated into two independent synchronized systems to avoid large area blackouts.

Two tripping stages targets on the different oscillation cycles are provided. The fast tripping stage can measure an oscillation cycle equal to or larger than 200ms and initiate tripping command in one cycle after the system out-of-step oscillation is detected; while the slow tripping stage can measure an oscillation cycle equal to or longer than 100ms and the tripping command can be initiated in 2 to 15 cycles after the system out-of-step oscillation is detected.

Features

- Determine the out-of-step of power system based on the variation trace of and use the minimum voltage value measured at the place where the device is located to determine the operation region.
- The quick stage of out-of-step relay can measure the loss of synchronism which period is over 200ms and initiate tripping command in the first asynchronous cycle.
- The slow stage of out-of-step relay can measure the loss of synchronism which period is over 100ms and tripping time could be set between the second and the fifteenth cycle.
- The impedance sequence discrimination method is adopted to determin if the system loses synchronism
- The patented adaptive floating threshold method is insensitive to system unbalance and disturbance. Innovative technologies are adopted to prevent any undesired operation caused by component failures. The relay has two independent data acquisition paths, one for a fault detector and the other for protection and its

logic. Tripping outputs are supervised by the fault detector to prevent mal-operation.

- There are two alternative category options for wiring connectors, plug in/out wiring connector and crimp terminal connector.
- The relay provides GPS clock synchronization, including second pulse, minute pulse, and IRIG-B synchronization.
- The relay is compatible with multiple communication protocols- IEC61850 and IEC 60870-5-103. The RCS-993 provides networking interface such as RS485, RS232 and Ethernet port.

RCS-994
Frequency & Voltage Relay

Application

The frequency emergency control method is an effective way to prevent frequency collapsing. The RCS-994 relay is a Frequency & Voltage Control Device providing frequency and voltage protection for power system stability control. In the under-frequency condition, a generator will be initiated to balance the generation and load so as to increase the system frequency, while a generator will be shut down in the over frequency condition in order to decrease the system frequency.

Control Measurements

Control approach to under frequency

- The pump should be switched to generation mode, and the standby power supply should be put into service when the system frequency is reduced because of some disturbance.
- Load shedding is the best way to prevent the system frequency from collapse, and a proper load shedding scheme shall be formed considering the most severe fault based on the islanding scheme. Sufficient load shedding can help to rapidly maintain the balance of active power and frequency restoration.
- The load inter-trip measure shall work with load shedding devices to avoid a large drop in frequency.
- The low frequency islanding device is used as a backup protection for the auxiliary power supply and safe power supply of other important indstrial comsumers, so as to minimize the impact of weak-interconnection system when system frequency reduces.
- By using load shedding, the system frequency shall be controlled under 51 Hz.

Control approach to over frequency

- Over frequency control device can detect the excessive value and the gradient of frequency variation.
- The setting and the sequence of generation shut down are determined according to the overall network parameters. It is recommended that the hydropower and small capacity thermal power shall be shut down first.
- The over speed protection controller(OPC) of turbine is recommended to be blocked or coordinate with other turbines during over frequency control. The frequency shall

be kept lower than the pickup value of OPC to avoid undesired shutdown, and the excessive value and the duration of over frequency shall be controlled to meet the requirements of the turbine.

Control approach to under voltage

The voltage emergency control is used to restore voltage to an acceptable levels after disturbance in a power system. Lack/Surplus of reactive power will lead to a severe run up/down in voltage which may collapse the system and do harm to the safety of equipments.

- In a under voltage condition, reactive power should be increased by generator forced excitation using capacitor compensation devices and forced compensation; Meanwhile, if necessary, the demand of reactive power should be decreased by tripping shunt reactor and load shedding.
- Regulation of transformer OLTC should be blocked in the case of under voltage condition and the voltage of main grid can not restore rapidly after the fault is cleared.
- Static Var Compensator should be installed to provide reative power for voltage stability protection.
- Stability control system shall concerntrate on load shedding when massive loss of power source and low voltage load shedding cannot stop the severe voltage drop.
- Load shedding is an essential approach to restrict voltage drop and prevent voltage from collapse, the scheme of such devices shall sufficiently consider the analysis of voltage stability in certain regions where the problems occur.

- If the transmission line is overloaded when the tie line in entirely or partly tripped, the generator shut-down or load shedding command shall be issued to avoid voltage instability.

Control approach to over voltage

- Devices for restricting over voltage is necessary to avoid the busbar voltage rise to a unacceptable value caused by sudden load loss in distributed substation.

Features

- The RCS-994 will accelerate load shedding to prevent power system collapse when the system voltage or the frequency decreases sharply and bring the voltage back to the operation range.
- Power swing blocking function is based on the analysis of df/dt and du/dt to prevent mal-operation caused by short-circuit fault or abnormal conditions of voltage and frequency.
- Four basic stages and two special stages are provided respectively for the under frequency and under voltage load shedding. 14 sets of trip outputs can be flexibly configured to the corresponding steps.
- The reliable and fast patented adaptive floating threshold method is insensitive to system unbalance and disturbance.
- The innovative technology can effectively prevent any undesired trip caused by component failure. The relay has two independent data acquisition paths, one for the fault detector and the other for protection and its logic. Tripping outputs are supervised by the fault detector to prevent a mal-operation.
- There are two alternative category options for wiring connectors, plug in/out wiring connector and crimp terminal connector.
- The relay provides GPS clock synchronization, including second pulse, minute pulse, and IRIG-B synchronization.
- The relay is compatible with multiple communication protocols- IEC61850 and IEC 60870-5-103. The RCS-994 provides networking interface such as RS485, RS232 and Ethernet port.

5 Cases Study

1. A Power Plant in Myanmar

As shown in Fig.12, the Power Plant R in Myanmar consists of 5×100MW generators, and is connected to a 500kV substation via the 220kV double circuit transmission lines,

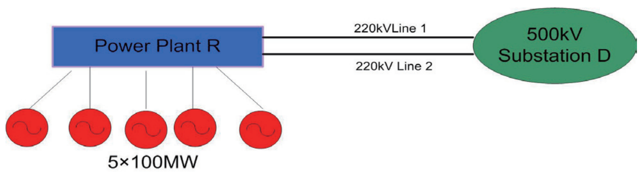

Fig.12 Introduction of Power Plant R

Control Measurements of PSCS in Power Plant R:

- Detecting the severe fault On Tie lines connected to Substation D: Selective Generator Tripping.
- Over frequency protection: Selective Generator Tripping.
- Send the remote command from Substation D to Selectively shut down the generator via a 2M fiber channel.
- Detecting oscillation center on the Tie line: Tripping the tie lines by out-of-step relay

Fig.13 shows the PSCS diagram in Substation R.

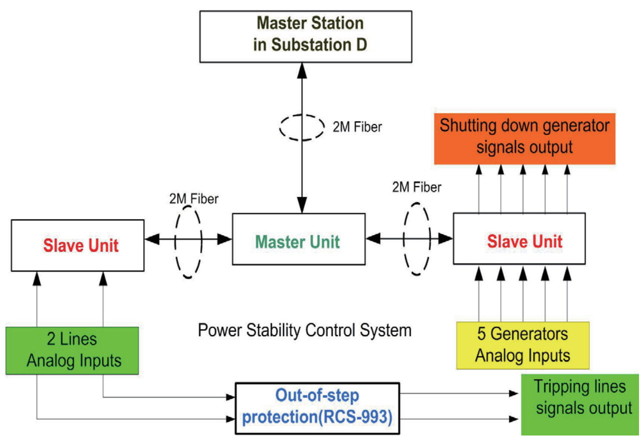

Fig.13 The PSCS diagram in Power Plant R

2. Region Network in Power Grid F

Character of the Grid

- Comparative Large Single Generator(Plant): Power Plant A 6*600MW
- High Proportion of Exporting Power (heavy Power Exporting)
- Weak Interconnection (interconnected)

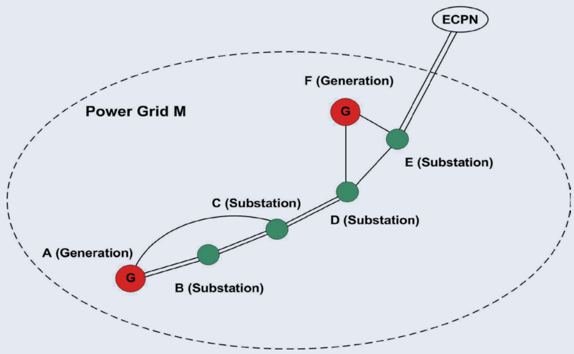

Fig.14 Introduction of Power Grid F

Control Measurements of PSCS in Regional Network:

- Detecting Severe fault On Tie line to East China: Selective Generator Tripping or Load Shedding
- Loss of Large Generator: Load Shedding

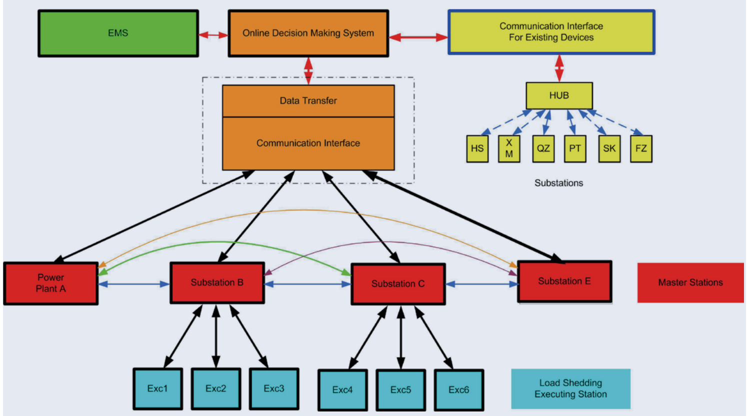

Fig.15 PSCS Configuration Diagram of Power Grid F

Operation Performance

At 13:31:01 On Jul 11, 2006, the double circuit tie-line between Power Grid F and ECPN were both tripped when the power flow on the tie-lines is 1,059MW. The PSCS operated correctly and sent the comand of shuting-down 759MW generation to power plant A; After 26ms, the devices in power plant A received this command, and 581ms after, the #2 and #3 generators were shut down by PSCS when it is detected that the system frequency had increased more than 0.2 Hz.

On Nov 25, 2006, the PSCS operated correctly when line DE was tripped due to a short circuit fault.

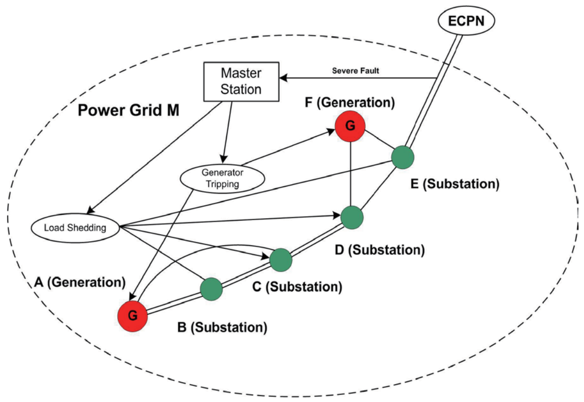

Fig.16 PSCS applied in Power Grid F

3. China Southern Grid

The Power Stability Control System for China Southern Power Grid is the most complex and largest system for AC-DC Hybrid Power Grid in the world. The PSCS devices are installed in about 250 plants/stations.

- Guizhou-Guangdong AC-DC Subsystem
- Tianshengqiao-Guangdong AC-DC Subsystem
- Yunnan-Guangdong AC Subsystem
- 3G-Guangdong DC Subsystem
- Guizhou Grid Subsystem
- Yunnan Grid Subsystem
- Guangdong Grid Subsystem

Control Measurements of PSCS

- HVDC Bi-pole blocking
- HVDC Single pole blocking
- loss of critical lines detecting
- Generator tripping and
- Load shedding

Operation Performance

At 19:00 On May 8, 2006, one HVDC bi-pole blocking operated when 3000 MW Power is transferred to another power grid. The system operated correctly that two generators in two different power plants were shut down by PSCS.

On Sep 24, 2007, one transmission line was tripped due to a short circuit fault. The system operated correctly that two generators in the power plant were shut down by PSCS as pre-established.

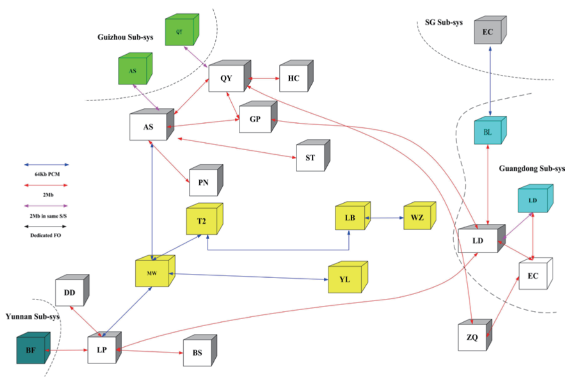

Fig.17 PSCS Diagram

Reference

[1]: The Stability definition and classification in power systems in an published IEEE report written by CIGRE Study Committee 38 and the IEEE Power System Dynamic Performance Committee, 2004.

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