System Restoration Using Remotely Initiated Synchronizing

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Executive Summary

ITC Holdings Corp. is implementing a remotely initiated synchronization scheme in its ITC*Transmission* system in southeast Michigan. This new scheme will allow remote system synchronization across breakers, resulting in faster system restoration during islanding or blackout conditions.

In the past, a substation operator has synchronized across open breakers on the ITC system while onsite. The legacy synchronizing panel consisted of a synchroscope, voltmeter, selector switches, lights, and a synchronism verification (sync check) relay. In manual mode, the operator was required to select the breaker to be synchronized across using a selector switch, and then attempt to close the selected breaker with the aid of the synchroscope. In automatic mode, the operator was required to select the breaker to be synchronized across using the selector switch, and close the breaker with the supervision of the sync check relay.

The desire of being able to restore the system faster without the presence of an operator at each station prompted the idea for the remotely initiated synchronizing scheme. Using the latest Intelligent Electronic Devices (IEDs) and RTU technology, this concept became feasible. This new Supervisory Control and Data Acquisition (SCADA) integrated scheme will allow the ITC Control Center to choose from a list of pre-identified breakers with remote system synchronization capability. The Control Center personnel will initiate the scheme to sync-close the breaker from their console. This eliminates the need to send field operators to each station to perform this task. In return, a faster response can be accomplished, reducing and mitigating other transmission system operational constraints. The legacy function of onsite synchronizing has also been retained.

This scheme was developed in a coordinated effort between Operations, Relay Engineering, SCADA Engineering, and Substation Design groups. Conformance testing and designs have been completed for several locations with the first field implementation in February 2011. This paper will detail the design, technical considerations and implementation of the remotely initiated synchronizing scheme.

1. Company Background

ITC Holdings Corp. invests in the electricity transmission grid to improve electric reliability, expand access to markets, lower the overall cost of delivered energy and allow new generating resources to interconnect to its transmission systems. The largest independent electricity transmission company in the country, ITC currently operates high-voltage transmission systems and assets in Michigan's Lower Peninsula and portions of Iowa, Minnesota, Illinois, Missouri and Kansas, serving a combined peak load in excess of 25,000 megawatts through its regulated operating subsidiaries, ITC*Transmission*, Michigan Electric Transmission Company (METC), ITC Midwest and ITC Great Plains. ITC also focuses on further in expansion in areas where significant transmission system improvements are needed through ITC Grid Development and its subsidiaries.

2. Introduction

There are various methods of synchronizing. They can be broadly classified as manual and automatic. To close a breaker through manual synchronizing process the station operator makes the decision using the synchroscope, volt meters, and lights on the panel. Automatic synchronizing relies on a control processor to monitor the system conditions and executes closing of the breaker when all criteria are met.

When a severe power outage occurs, the main priority of the utility is to restore the system to its normal operating conditions. In a blackout condition this is achieved with the creation of system islands. Synchronizing is a process of tying together these system islands; each with its own combination of generation, buses, and load. This process connects the systems with minimal disturbance to the buses and generators, eventually resulting in several generators serving the same load.

The transmission system operations group is responsible for determining the logical path used in restoring the system from a blackout or severe power outage. The system restoration plan identifies the locations with breakers that need the sync close capability. The selection of breakers along the restoration path is studied considering voltage, frequency and phase angle of the predefined islands on either side of the breaker. To sync close, it is necessary to have a healthy voltage within a predefined tolerance. The phase angle difference between the two systems should be minimal. The frequencies of the system islands should be as close as possible with matching phase rotation. Once it is determined that all the system criteria are within an acceptable range, the breaker can be closed with the expectation that the two systems are joined with minimal disturbance.

3. Scheme Background

3.1. System Restoration Considerations

Restoring a system after a major event requires a great deal of consideration with respect to the characteristics of the system in question. Depending on the system being restored and the configurations available to the system operators, the task of restoring the system can vary in difficulty.

Certain systems have distribution load available very near to the generating units, which allow the generation plant operators to bring black start generators online with gradual increases in load through onsite efforts. Once these generators are brought online and loaded to the point of being stabilized, the system operators have the opportunity to establish connections to other areas of the system where non-black start generators can be brought online and stabilized. Other systems do not enjoy the benefit of local distribution load near the generators. These systems must rely on their ability to establish paths through the transmission system to distribution load that is available in other areas. This can present challenges as multiple entities can then become involved which hinders communication and response time. An additional challenge in this situation is the increased sensitivity to proper synchronization as the generation is loaded to a much lower level when it must be stretched onto the transmission system to reach the desired load.

Distribution load is preferred over industrial load for the purpose of bringing generation online and stabilizing it after a blackout. Distribution load tends to be more predictable and incremental in nature, making it easier to divide into the desired amount for loading up generation after a blackout. Restoring heavy industrial customers too early can cause problems if items such as large industrial motors or blast furnaces are brought online before the system is strong enough to absorb this disturbance. Even in areas where electrical service has been unavailable for extended periods of time and cold load pickup comes into play, distribution load is much more predictable when compared to industrial load.

3.2. Legacy Synchronizing Scheme

Legacy synchronizing schemes were manually operated by trained substation operators. These schemes were mainly comprised of electromechanical-type relays. Elements included a sync selector switch (25SS), an AC voltmeter, synchronism check relay, synchroscope, and incandescent light bulbs. For each breaker position, the 25SS was used to connect the potentials across the breaker to the sync scheme. A sync bypass switch (25BP) was available to bypass the sync check relay; this would allow the breaker to be closed with or without supervision of the sync relay. Once synchronism was achieved, an auxiliary relay would pick up the close coil of the breaker.

System restoration with the legacy synchronizing scheme would require substation operators to report to pre-determined transmission system substations. They would inspect the substation and report their findings to the system operators. The substation operators were also expected to perform other responsibilities such as starting up any emergency station service generators and cutting off reclosing on the relay schemes at the station.

The Northeast Blackout of 2003 provoked a review of the legacy synchronizing scheme. Small pieces of load could be closed into the system using SCADA control, but connecting the larger pieces of the energized system required trained substation operators to manually close breakers using the legacy synchronizing scheme as described previously. The review revealed that the scheme was not performing as necessary for modern restoration requirements.

3.3. SCADA Controlled Synchronizing Scheme Benefits

A new scheme utilizing modern SCADA technology would enable a faster system restoration time. System operators would only require a minimal amount of training to learn to use a visual interface in the control room. Substation operators would still report to key substations in the event of a system restoration, but their focus would be shifted from system restoration to substation inspection. The system operators would not need to wait for a substation operator to drive to the substation to synchronously close breakers at that substation. Establishing these critical connections as quickly as possible would provide greater operational flexibility to the system operators, which would allow for quicker system restoration.

4. Design & Scheme Details

Upon obtaining the operational requirements for the scheme the next step of the design and development process was to evaluate and select components that could satisfy the system application. The capabilities of the scheme needed to include: SCADA interfaces to select the position to be synchronized, selection of the correct potentials, feedback of system measurements, and acknowledgement of breaker closing both locally and remotely. The scheme also had to provide a reliable supervision of system conditions and include the ability to be manually defeated.

4.1. Scheme Components

A. Electrically Operated Selector Switch Relay

A switch was chosen that combines electrical and manual operation in a single unit for multi-position applications. It was to have at least ten decks of contacts to ensure that the requirements of the scheme could be fulfilled. Multiple switch positions allowed for a common design template to be created which could accommodate up to six breaker positions. Shown in Figure 1 is an example of an installed selector switch (25SS).

Figure 1: Electrically Operated Selector Switch

B. Voltage Meters and Synchroscope

AC Volt meters and a synchroscope were installed on the panel to provide a visual interface for manual operation. The AC Volt meters provide feedback on the magnitude of the voltage on either side of the breaker being synchronized while the synchroscope allows the operator to gauge the slip frequency of these two voltages. These components are shown installed on the panel in Figure 2.

Figure 2: AC Voltmeter Measuring Line-Side Voltage Shown Next to the Synchroscope

C. Auxiliary Potential Transformers

The transmission system in which this scheme is being applied has a variety of nominal secondary voltages available due to the various types of potential measurement devices used. Auxiliary potential transformers are required to provide a 120 Volt nominal secondary voltage to the synchronizing scheme. This requirement is based primarily on the specifications of the synchroscope that was selected.

D. Microprocessor-Based Synchronism Check Relay

It became apparent early in the design stage that the operational goals of the synchronizing scheme would best be met with a microprocessor based relay. A relay was identified that contained synchronism checking capability as well as the ability to interface with the SCADA system. The sync check functionality allows for closing control after the system conditions of voltage magnitude, phase angle, and frequency have been met. The ability of this relay to interface with SCADA fulfills two needs in the scheme. The first need is for remote position selection of the electrically operated selector switch relay via the output contacts of the microprocessor based relay. The second need is the ability to execute remote close commands under the supervision of the synchronism check functionality of the microprocessor based relay. Display LEDs were also programmed on the front of the microprocessor based relay to indicate when the voltage magnitude, phase angle, and frequency specifications have been met. The relay is shown installed on the panel in Figure 3.

Figure 3: Microprocessor-Based Relay Used for Synchronizing

4.2. Application of the Scheme

The remotely initiated synchronizing scheme is first enabled by the selection of a breaker position to be closed. The positive homing circuit of the selector switch allows the switch to travel to a desired position based on what input of the switch has a command signal. Each input on the switch is wired to an output contact on the relay allowing any position on the switch to be selected with a relay contact pulse. This arrangement is shown in Figure 4.

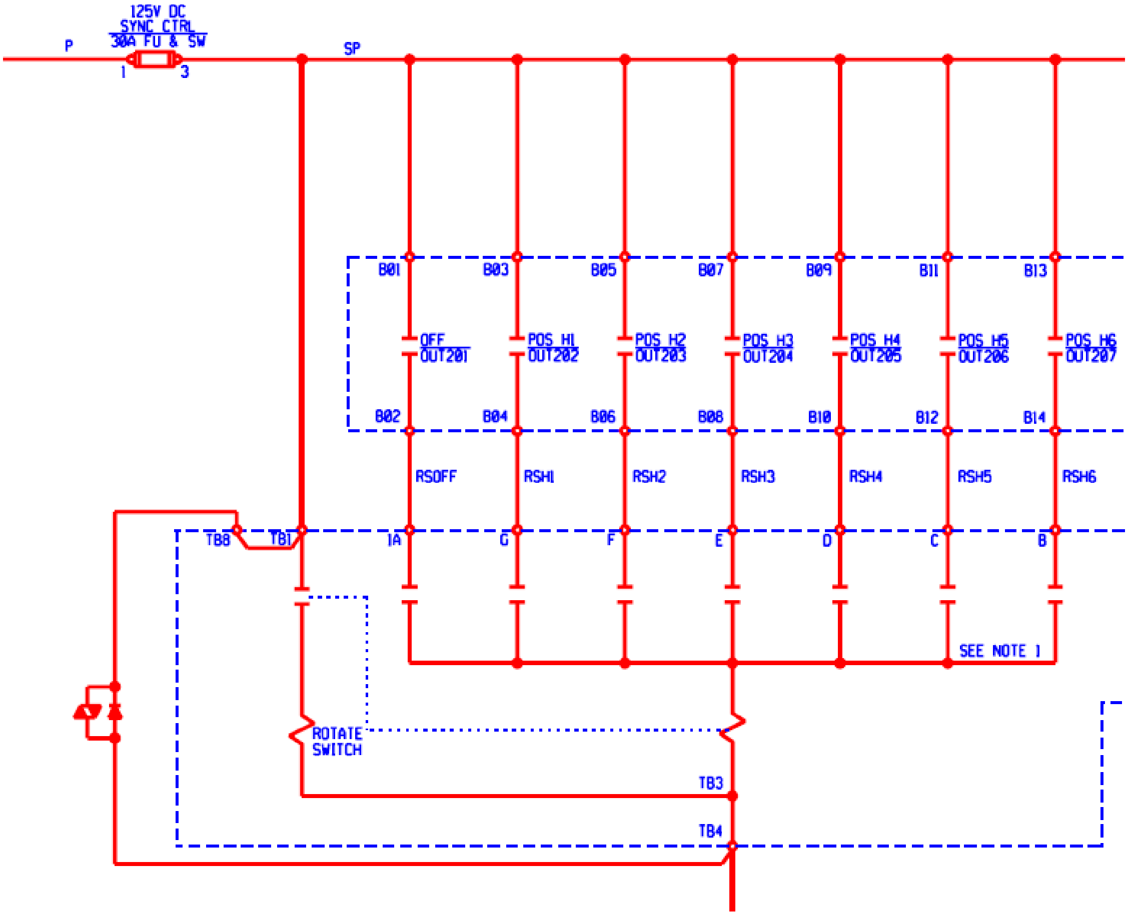


Figure 4: Outputs of the Microprocessor Relay
Used to Operate the Selector Switch

The pulsing of the relay contacts is controlled using the SCADA system and the relay's logic assignments. The pulsing time is constrained by the physical limitations of the electrical coil of the switch; in this case it was determined to be thirty cycles.

It is important to use a safe and secure communication protocol for this operation. ITC uses the industry standard Distributed Network Protocol (DNP) v3.0 communication protocol for SCADA communication and supervisory control. DNP allows for select before operate control. This is a security measure that allows the protocol to select a controllable point, and prior to sending an operate command ensures that the correct point is operated. DNP is also preferred as it is supported by multiple vendors and devices, from the master station computer to the end device. With no protocol translation being done at any level, the control signals are less likely to be compromised and less susceptible to delay.

The SCADA ‘close’ command is sent from the Control Center, and is routed to the station RTU. The RTU is configured to map this control request to a corresponding control output, in this case a DNP Binary Output. The RTU will send the command to the sync relay which then interprets the command using logic. When the relay takes action and moves the switch, the relay will report back to the RTU which position is selected. The SCADA system requires this feedback so that it confirms that the control indeed was received and implemented.

The control scheme is divided into two distinct operations due to available control logic points in the relay; Select Position and Operate Breaker. A system operator must first select a position to sync and wait for feedback. Once received there is a single control point mapped to a ‘Close Breaker’ command. The system operator can then issue this command, and the relay will begin the process of attempting to synchronously close the selected breaker. The system operator will then receive feedback as to whether or not the breaker indeed operated.

The position of the switch is fed back to the relay inputs using a contact deck on the switch. This switch position status is used in the settings of the relay to provide security to the scheme operation and is also provided to the SCADA system for remote position indication. See Figure 5.

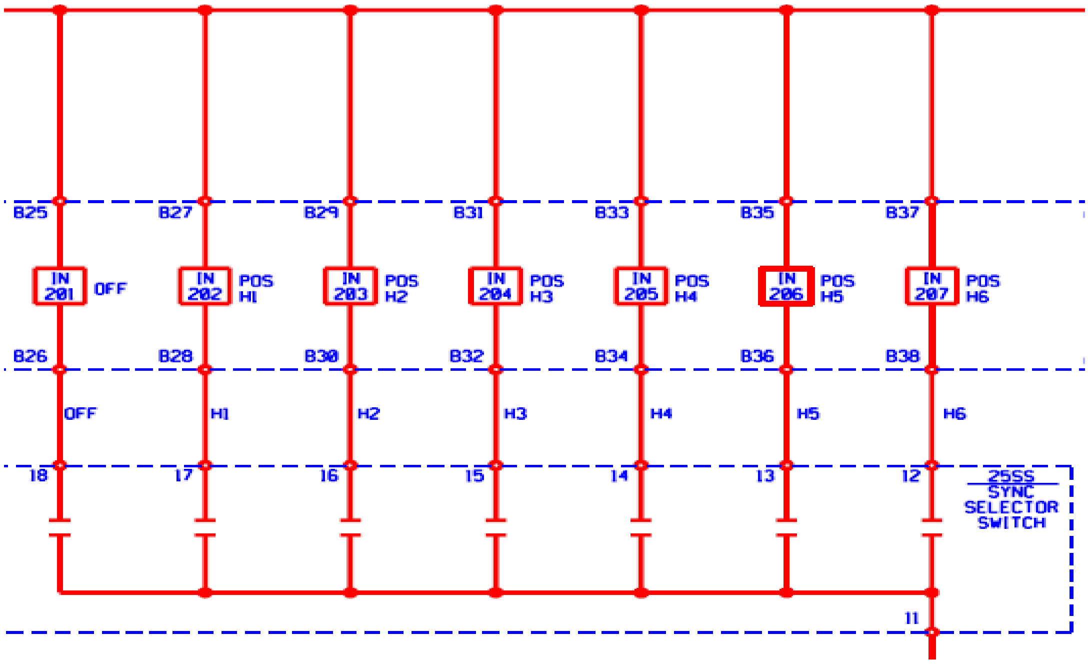


Figure 5: Selector Switch Inputs to the Relay

Selecting potential inputs and correcting their nominal secondary voltages requires eight contact decks of the selector switch. Four contact decks are required to select the phase and neutral voltages on each side of the breaker. This brings two sets of potentials into a shared set of secondary potential cutoff switches for the scheme. Four more contact decks are then used to select the appropriate auxiliary potential transformers. This ensures that the required nominal voltage is available to the relay, voltmeters and synchroscope. See Figure 6.

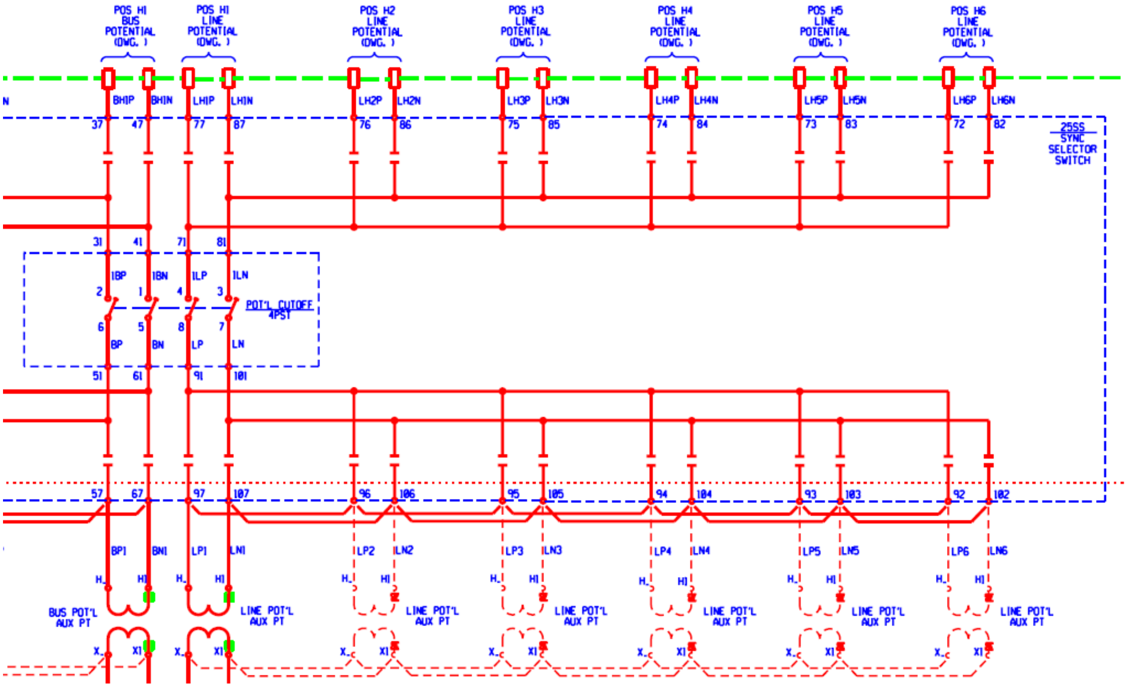


Figure 6: Wiring and Contact Arrangement
for Voltage Source Selection and Correction

Each breaker position to synchronize has a dedicated output contact on the relay. Settings in the relay dictate what output contact is made and when this should occur. In order to permit the closure of the selected breaker, one of three methods is used:

- Close by remote command with a standard closing tolerance
- Manual close by an operator with a standard closing tolerance
- Manual close by an operator with a 'bypass mode' closing tolerance

All closing conditions are programmed so that the output contact will only make for the breaker position that has been selected on the selector switch after the voltage specification is met. A standard voltage specification is programmed to be used for the remote closing and normal manual close. This specification allows for a voltage magnitude of ±15% of nominal, a slip frequency of 0.2 Hz, and a phase angle difference of ±20°. A 'bypass mode' voltage specification can be selected by station operators to provide more flexibility, allowing a phase angle difference of up to ±40°. This larger phase angle tolerance is only intended to be used when absolutely necessary. A full bypass of synchronizing relay supervision is not provided in the scheme; this prevents damage to system equipment in the case of operator error.

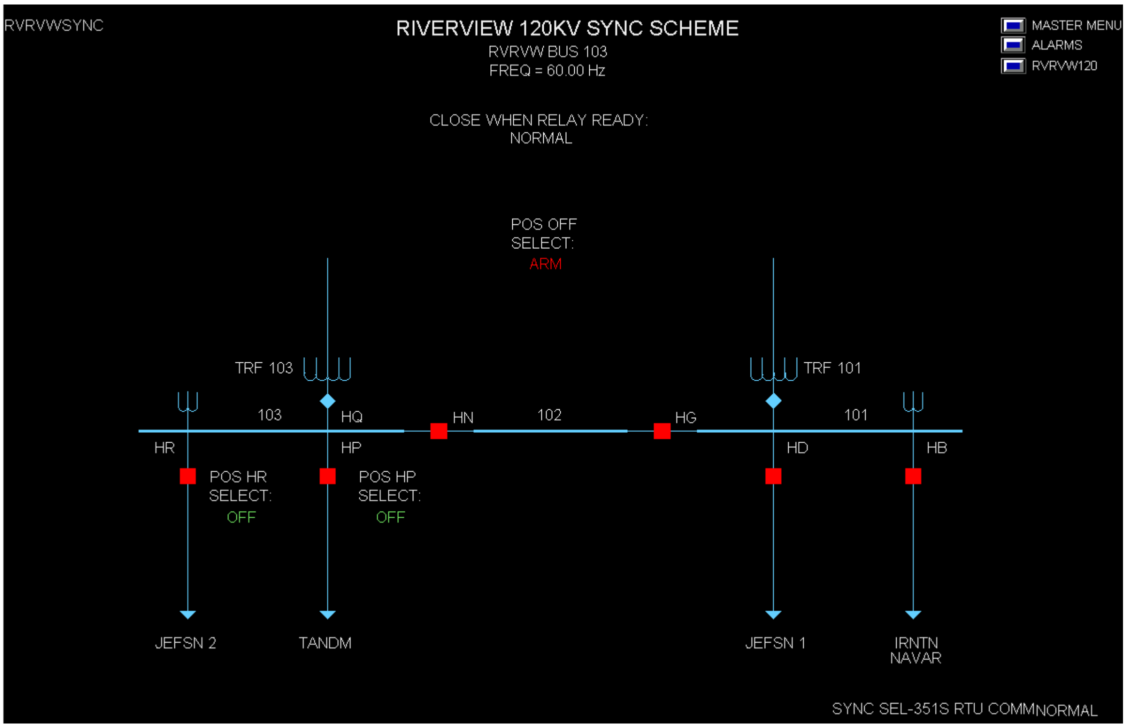
As mentioned previously, the status of the breaker selected is brought into a single input on the relay through a contact deck on the selector switch. This provides indication back to the control center as to the success or failure of a close attempt on the selected breaker position.

4.3. Telecommunications Infrastructure

ITC relies on a broadband network telecommunication backbone for its SCADA System. The redundant and diversified network connections to the primary and backup control centers increase the reliability to the remotely initiated sync scheme. The availability and speed of data transmission makes this application more accurate and time tolerant. The frequency of data update is standardized to five seconds although it could be increased with no harm to the existing SCADA system. The SCADA data communication is performed employing DNP over Transmission Control Protocol Internet Protocol (DNP TCP/IP).

4.4. TMS

The transmission management system (TMS) provides the master data collection for all substation assets. This is commonly known as the energy management system (EMS). With accurate information arriving from all substations it is easy to create a custom sync scheme operation display to make decisions remotely. The display consists of voltage and frequency values from both buses that are islanded. The display has control points for each breaker position allowing the operator to choose a position to sync. The system operator can make an informed decision to properly sync the two systems together. The system operator makes a control point selection, confirms his intention, and waits for the system to verify the action has gone through. The signal is sent to the remote sync relay and the scheme is armed. All control points are set with a timeout period. This is to ensure that if the end device doesn’t receive the command within a short period, the command is canceled and must be sent again. The ‘Operate Breaker’ command must be set at a longer than normal timeout duration due to the fact that it must wait for the relay to complete the synchronization procedure. This can take up to an extra sixty seconds. An example display screen is shown in Figure 7.



FREQ = 60.00 Hz

CLOSE WHEN RELAY READY: NORMAL

POS OFF SELECT: ARM

POS HR SELECT: OFF

POS HP SELECT: OFF

SYNC SEL-351S RTU COMM NORMAL

Figure 7: TMS Display Screen used to Control the Scheme

5. Implementation

5.1. Application Considerations

Implementing the synchronizing scheme requires a detailed assessment of the existing substation for deployment. This is to include the amount and type of breakers at each substation, the system restoration path, type of potential sources, the existing control schemes, and the SCADA interfaces available. The panel design, layout, and operational functions were tailored to address the majority of the cases.

This scheme can employ only six breaker positions due to the switch and relay that were chosen. The switch provides eight positions while only seven fulfill the technical specifications for this application. Feedback of status indication is required for proper implementation, reserving six positions of the switch for operations with the seventh being reserved for the deselected position.

To provide the appropriate situational awareness, information from remote substations shall be made available. This information is to include, but is not limited to, voltages and frequencies. These are necessary for each custom sync scheme substation display.

Physically, the scheme panel was designed to be of a width and height to allow for easy integration into existing control houses. The scheme panel layout places all switches and displays at a reasonable working height for the substation operators. In addition to this, potential cutoff switches were mounted to be accessible from the front of the panel while the breaker close cutoff switches were mounted onto the back of the panel. Figures 8, 9 and 10 show an example of this scheme installed in a substation.

[redacted]

Figure 8: Close-Up of Panel Layout

Figure 9: Synchronizing Panel Installed at the Substation

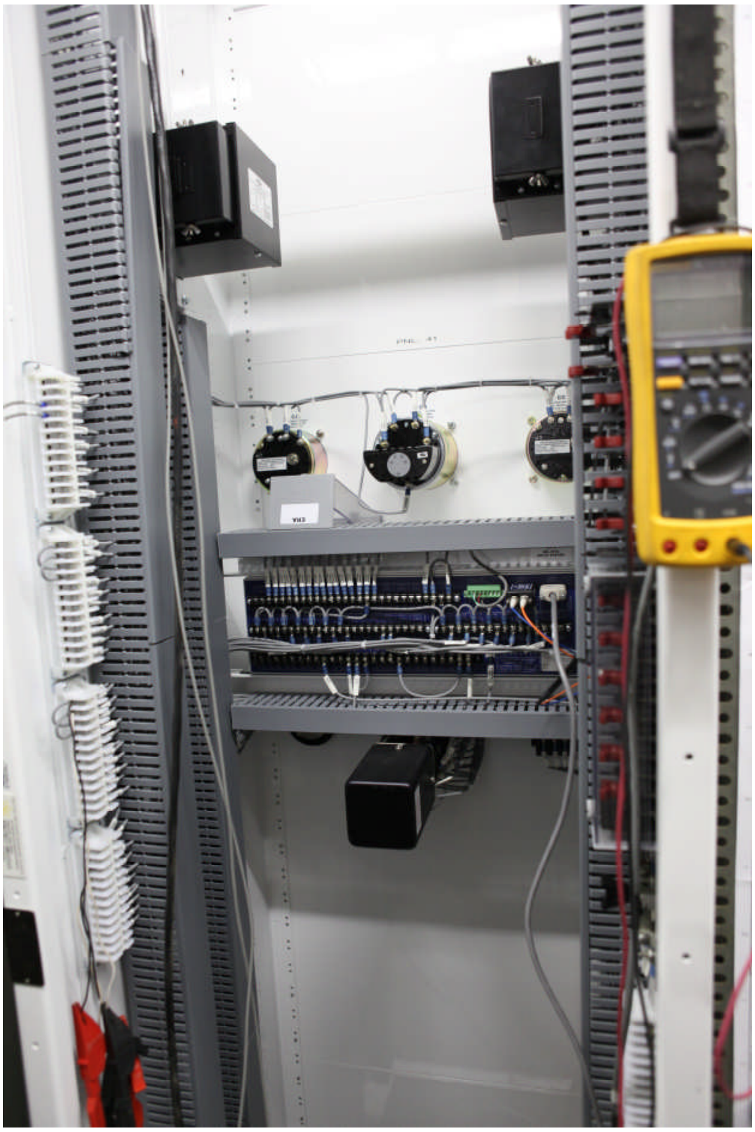


Figure 10: Rear View of Panel Layout

6. Testing

6.1. Application Testing

Before this scheme could be implemented in a substation environment the concept needed to be tested and accepted in a laboratory setting. This was done in the Engineering Lab at the headquarters of ITC Holdings. The components of the scheme were wired on the lab bench and connected to a relay test set which allowed for the variation of voltage magnitude, phase angle, and frequency. A test RTU was connected to the microprocessor relay which allowed for full SCADA control of the scheme through an interface into the TMS system. The close commands issued by the microprocessor relay were monitored by inputs of a relay test set as well. This testing method allowed for simulated inputs and outputs on the relay, with the entire SCADA and TMS interface being accounted for. This allowed realistic testing to be performed from both a SCADA and relay perspective. The controlled environment of the lab tests allowed for discussion and consideration of certain timers and settings that are critical to the proper function of the system.

6.2. Commission Testing

Once the concept had been proven and the panel had been physically installed at a 120 kV substation, the scheme needed to be commission tested. The standard testing philosophy employed by ITC was used, but additional tests were required as well. A relay test set was used to apply voltages of varying magnitude, phase angle, and frequency. These values were changed appropriately to prove out the various thresholds set in the relay. Once this had been accomplished, the commands that control this scheme were sent by a system operator to ensure that the switch moved to the proper positions, and the relay would only send a close command to the desired breaker during the expected conditions. A final proof of this was to close a 120 kV circuit breaker from the system operator’s desk while applying a slipping frequency with a test set to ensure the breaker would not be closed out of phase. This effectively proved the scheme from the system operator’s desk all the way to the closing coil of the circuit breaker.

After the relay had been tested satisfactorily with test voltages, actual system voltage was connected to the panel. A final check was performed of the system operator’s ability to move the selector switch, and the breaker was then closed by the system operator with the scheme connected to system voltage.

6.3. Procedural Considerations

A. Control Center Training & Simulation

As this scheme was developed and tested it became clear that like any other tool, it would only be effective if properly used. Shifting the responsibility of synchronizing from the substation operators to the system Control Center staff allowed for more centralized and frequent training. Efforts are underway to implement this system into the Control Center simulator that is used for regular training of the Control Center staff. This will allow for more detailed and realistic initial training, as well as give the control room staff the opportunity to refresh their knowledge of the scheme and its use.

B. Control Center Procedure

A procedure has been developed that can be followed by the control center staff for detailed instructions on how to use the interface provided by the TMS system. The procedure can be supplemented with regular training and system simulation (see previous section). A sample of the procedure wording is shown below:

Scheme Overview

The remote synchronizing scheme is intended to be used as a tool for synchronously closing transmission system breakers in the event of widespread outage or blackout. It allows *the Control Center to remotely close certain breakers at selected stations with the assurance that the voltages on either side of the breaker are of satisfactory magnitude, phase angle, and frequency. The voltage is monitored by a digital relay which is set to detect a satisfactory synchronizing condition.*

TMS Display

The remote synchronizing scheme is operated from a special TMS display screen, and all instructions given in this guide will assume the user is looking at this screen. The example that will be used in this guide is for Riverview substation. The TMS display screen for the synchronizing scheme is called 'RVRVWSYNC' and a link to this screen can be found on the upper right corner of the TMS one line for the station.

Position Selection

Only positions with the text 'POS XX SELECT' can be closed using the remote synchronizing scheme. At Riverview this includes positions HP and HR. These positions are selected via SCADA control that moves an electrically operated selector switch (see Figure 1). This switch has the breaker positions that can be selected for remote synchronization as well as the position 'OFF'.

To select a position to be closed, the word 'OFF' under the words 'POS XX SELECT' on the TMS display must be selected and commanded to 'ARM'. This causes the switch shown in Figure 1 to physically rotate to the position that was set to 'ARM'.

It is expected that this switch will be left in the 'OFF' position when this scheme is not in use. The terminology that is used with this switch dictates that 'ARM' is indicated on the TMS screen when the switch is in the associated position, and the other positions will be indicated as 'OFF' on the TMS screen. Using this convention, this scheme should be left with 'POS OFF SELECT' set as 'ARM' to denote that the switch is physically rotated to the off position. This turns off the sync scope and volt meters and removes breaker closing capability from the scheme.

Breaker Closing

Once a breaker position has been selected by the selector switch, this position can be closed by setting the 'CLOSE WHEN READY' point to 'OPERATE' (the normal state of this point is 'NORMAL'). Please note that this command is <u>not</u> a direct command to close the breaker. It merely arms the synchronizing relay to close the breaker that has been selected if the system conditions are correct. Once the relay receives this command it will observe the voltages on either side of the breaker for 30 seconds and close the breaker if the magnitude, phase angle, and frequency are satisfactory. At the time of this writing, satisfactory has been defined as ±15% of nominal magnitude, within ±0.2 Hz of nominal frequency, and ±20° of phase angle.

If the relay is unable to close the breaker, this will be indicated back through TMS as a control failure after approximately 60 seconds. If desired, additional 'CLOSE WHEN READY' commands can be sent. If the relay is able to close the breaker, the breaker will be indicated as closed in the TMS system.

After a breaker has been successfully closed or an unsuccessful attempt has been made, any other position can be selected and a close attempt can be made. There is no need to turn the switch 'OFF' for any period of time between position selections.

Local Application Notes

Crews working at the station should be aware that this scheme contains a relay contact with the ability to close the breakers that are listed on the selector switch. All necessary precautions should be taken when performing maintenance or service work on any of the breakers affected by this scheme, including but not limited to the use of the cutoff switches in the back of the synchronizing panel.

A substation operator can move the position selector switch manually if local synchronizing is desired. This switch only rotates counter-clockwise. The 'CLOSE' button of the digital relay (see Figure 3) will be used after verifying that the voltages are satisfactory and the needle of the synchroscope is at a satisfactory position and speed (see Figure 2). Note that the microprocessor relay will still supervise the system conditions before sending a close command to any breaker even when the 'CLOSE' button is pressed on the front of the relay.

If a substation operator desires to close the breaker with a less stringent phase angle restriction, the 25-BP switch can be set to 'BY-PASS' (see Figure 4). Setting the 25-BP to 'BY-PASS' changes the phase angle specification from ±20° to ±40°. Note that this does not remove the supervision of the digital relay. In no configuration will a close command be sent to the breaker unless the digital relay senses satisfactory voltage magnitude, phase angle, and frequency. The BY-PASS switch is not intended to be used unless absolutely necessary.

7. Future Enhancements

Throughout the development and implementation of this scheme, modifications and enhancements have been identified to improve its functionality. A variety of adjustments and corrections have been made to make this scheme as effective as possible. However, there are areas that can only be improved through future development and design of both this system and surrounding systems.

In speaking with Control Center staff about the required activities to restore the transmission system after a blackout, one of the key items that came up was the ability to gradually load the generators with distribution load. One of the concerns during this process is getting adequately small sections of load to place onto the generator to avoid tripping it back offline. Increased usage of SCADA at the distribution level would greatly assist the system restoration process in the fact that the distribution system operators could more accurately assess the amount of load that would be picked up by the island when breakers feeding load are closed back into the island.

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