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Fault Location Detection on Tapped Transmission Lines

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SUMMARY

Locating faults on a transmission line with multiple line taps and then isolating the effected section of the transmission line, to reduce outage time, is a significant challenge for operators of power transmission grids. This contrasts with distribution circuits where faulted circuit indicators on radial lines have been effectively utilized to locate faults allowing automated (SMART GRID) system sectionalizing and providing a reduction in SAIDI (**S**ystem **A**verage **I**nterruption **D**uration **I**ndex), minutes. Current solutions being applied for the location and isolation of a faulted transmission lines include the building of additional substations at or near critical tap points, utilization of distance relays and complex algorithms, and multiple reclosing schemes. Each of these solutions has potential drawbacks as they may be very expensive, lack accuracy, or potentially shorten the life of capital equipment. The described solution eliminates the need to add substations, increases accuracy of fault locating, and does not impact the life of the existing capital assets while at the same time provides an enhanced level of reliability. This approach, named SMART TAP™, uses light weight non-contact current measuring CT's or sensors, with fault directional intelligence, mounted on disconnect switches. SMART TAP™ will identify the location of and isolate faults, reducing outage durations. By locating and isolating the fault, the transmission company can reduce customer downtime and for the first time have a system that makes it possible to show an improvement in SAIDI minutes for the transmission system.

KEYWORDS

CMD™ II, Fault detection, Non-contact CTs, SAIDI, SCADA, RTU, Smart Grid, Smart Tap™, Tapped transmission lines, Transmission Reliability.

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1. THE PROBLEM

It is quite common for utility networks to have transmission lines with one or more taps on them between substations. In an ideal world, there would be a substation with protection and isolating devices at each tap. Unfortunately, the cost to site and build a new substation is prohibitive and in some cases the right of way to build the substation cannot be obtained. As a result, most transmission lines have been built with multiple taps that may or may not have a disconnect switch for isolation.

In our current environment, reliability and continuity of service have become extremely important to customers. This reliability performance is tracked by SAIDI minutes. While faults on the transmission system contribute only about 15% of these minutes, when they do, the numbers escalate quickly as many customers are connected to these taps. When a fault occurs, these customers are disconnected from the network and can be without power for extended times while the fault condition is being corrected.

2. TRADITIONAL SOLUTIONS

There are two traditional solutions for finding faults on these multiple tapped transmission lines. One uses distance relays and complex algorithms [1,2,3,4] and the other uses multiple reclose operations on lines closing into faults to locate their precise location. Both of these approaches work in the ideal case but their complexity increases exponentially [7,8,9,10,11] as the number of taps on a circuit increases. Conventional line distance relays [5,6] have had issues with the complexity of this problem as relay underreach and overreach combined with multiple possible fault points challenge the reliability and accuracy of this approach which often requires visual confirmation of the fault location before isolation. Complex solutions with multiple reclose operations and precise timing used in conjunction with switches to pick up circuits can be problematic and shorten the life of capital equipment as they require closing into faults multiple times to locate the fault through a pre planned trial and error solution. Many utilities find that these fault locating methods for multiple tap lines are not performing efficiently and result in extended outages to isolate and correct the fault. This contributes to a poor reliability image and a high SAIDI number.

3. A NEW SOLUTION

The application of lightweight non-contact, real time current sensors to existing disconnect switches on the transmission network can identify the faulted line segment in real time. Intelligent algorithms in the control system will isolate these faults without the need for trial and error fault closing operations to test the line. This approach, named SMART TAP™, also eliminates the issue of distance relays becoming confused with changing line impedance that occurs at tap points. Once the SCADA/EMS system operator determines that the fault circuit is not self-restoring, the approach will isolate and restore power to de-energized line segments with no faults and isolate faulted line segments from the network. A switching plan can be generated to provide the operator the proper switching steps to isolate the faulted section.

If desired, a fully automated isolation scheme could be implemented. This would automatically identify the fault location and reconfigure the disconnect switches to isolate the fault and reenergize unfaulted sections.

The principal advantage of this approach is that increasing the number of line taps does not make the problem any more difficult to solve (no complex algorithms to modify). This approach also makes it easy to apply to existing disconnect switches on existing right of ways. The result is a very economical way to reduce SAIDI minutes.

4. IMPLEMETATION DETAILS

SSI Power calls this application “SMART TAP™ ”. The objective of this system is to improve the SAIDI minutes and system reliability on transmission networks with taps. The diagram below (Fig. 1) is an example of a tapped transmission line network. The switching station for the tap can be in a substation or anywhere along the transmission line.

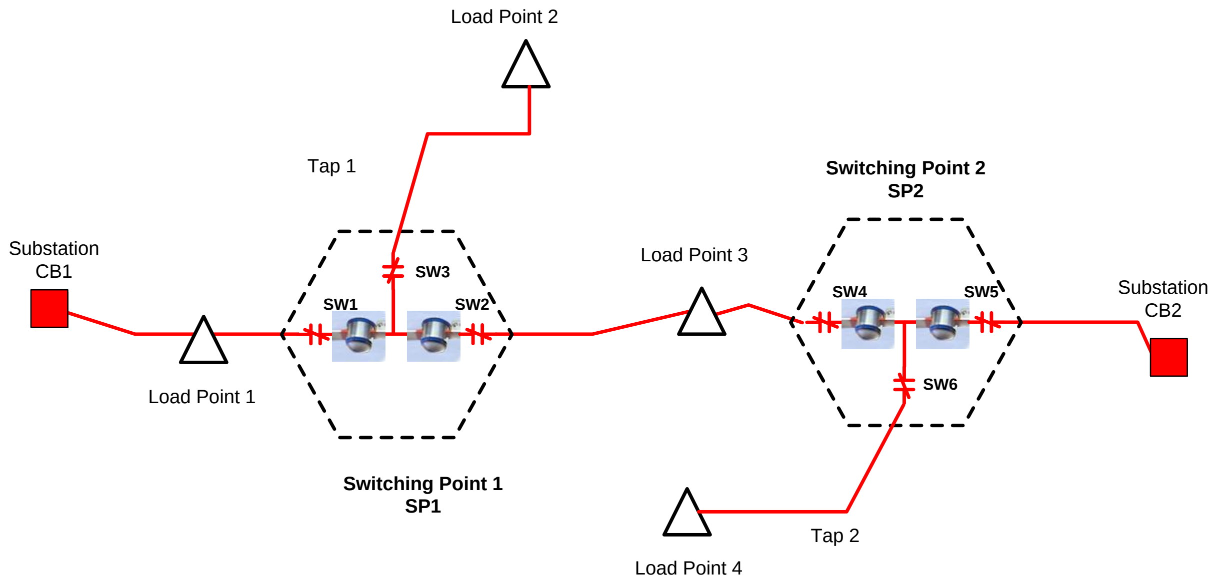


Figure 1: Network example in energized state

This local network has two supply points through CB1 and CB2. There are two switching points for a transmission line tap. In this example, each switching point is configured for three way switching. Configurations that are more complex can be implemented utilizing the same principals. Each is also equipped with a lightweight non-contact current measuring device for measuring current and fault conditions if they occur.

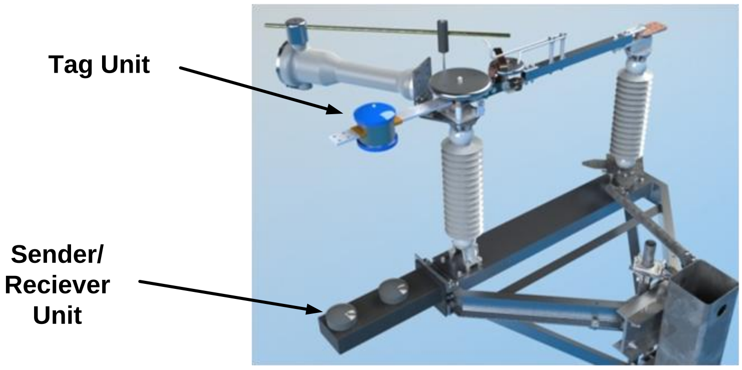
Presently (systems without the current measuring device) when a fault occurs on one of these tapped lines, it cannot be immediately determined which portion of the network experienced the fault. The approach to fault location is frequently a trial and error method of opening one of the switches at the station and reclosing the breaker. If the proper switch was opened, the breaker holds and the fault is isolated. If the wrong switch is opened, the breaker trips again. At this point, the operator knows the fault is on one of the other two possible sections. A second attempt is then made. If this one isolates the fault, the breaker holds, and the fault is cleared. If not, a third attempt is required.

The objective of the fault detection and isolation solution is to provide the operator information about which section is faulted and information as to which switch to open to isolate the fault the first time. This solution is implemented at the switching point to provide intelligence to the SCADA/EMS operator to avoid the necessity of trial and error sectionalizing switch reclosing to locate the fault by identifying the fault location and recommending the proper switch operation.

5. NON CONTACT CURRENT SENSOR

A lightweight current sensing device is an important part of the solution. Often tapped transmission lines are connected though disconnect or load break switches installed on a pole or tower. Pole mounting of conventional CTs is not practical and traditional ground mounted CTs would be very expensive to install and would most likely require additional right of way and a substation type of installation. Non-contact CTs can be mounted on the same structure as the switch and require no additional ground mounting of equipment. SSI Power offers the CMD™ II with fault detection and direction sensing to meet this need (see photo and description below).

CMD II mounted on a Southern States TLSwitcher®



The CMD™ II measures current on high voltage systems with zero footprint, no solid insulation to ground and no batteries. It uses 5.8 GHz communication technology to transfer data securely and reliably from the high voltage system to ground potential in real time. The compact design enables current measurement applications at locations that were previously prohibitive due to space and economic constraints.

The CMD™ II uses a backscatter communications system to communicate real time current measurements. The low energy requirements for backscatter data transmission allows the line mounted current sensor to operate without a line mounted power source. There are no batteries or solar panels to maintain at line potential on the high voltage system. The line-mounted sensors are able to harvest the necessary energy for the electronics of the line mounted current sensor by induction from the line.

The ground based electronics provide the fault indication and direction intelligence. The conditions for identifying a fault can be remotely programmed into the unit with different current time settings for determination of the fault conditions. An output indicating fault direction is also available to the SCADA/EMS system or the intelligent fault isolation system. This unit also provides standard RTU interfaces to the switch and the communications network.

6. EXAMPLE OF OPERATION

The principle of operation is illustrated below. By sensing fault direction in the CMD™ II, and logically combining the results, the fault location can specifically determined.

Figure 1 above, illustrates the network in the normal energized state. When a fault occurs anywhere on the network, the breakers, CB1 and CB2 will trip and the entire network is de-energized as in Figure 2.

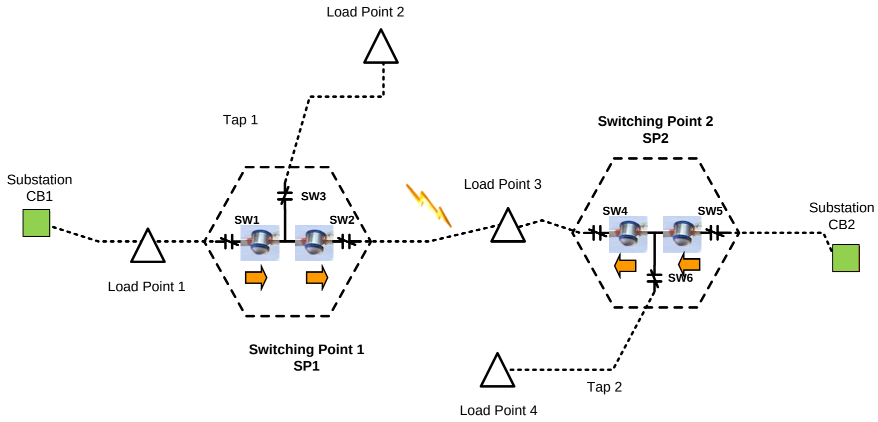


Figure 2: Case A ➔ Fault between SP1 and SP2

In this case, the fault direction detection arrows as measured by the non-contact CT are both pointing towards a point between SP1 and SP2. With the fault data, the operator can open SW2 and SW4; reclose CB1 and CB2. These switching actions re-energize the circuits as shown below in Figure 3.

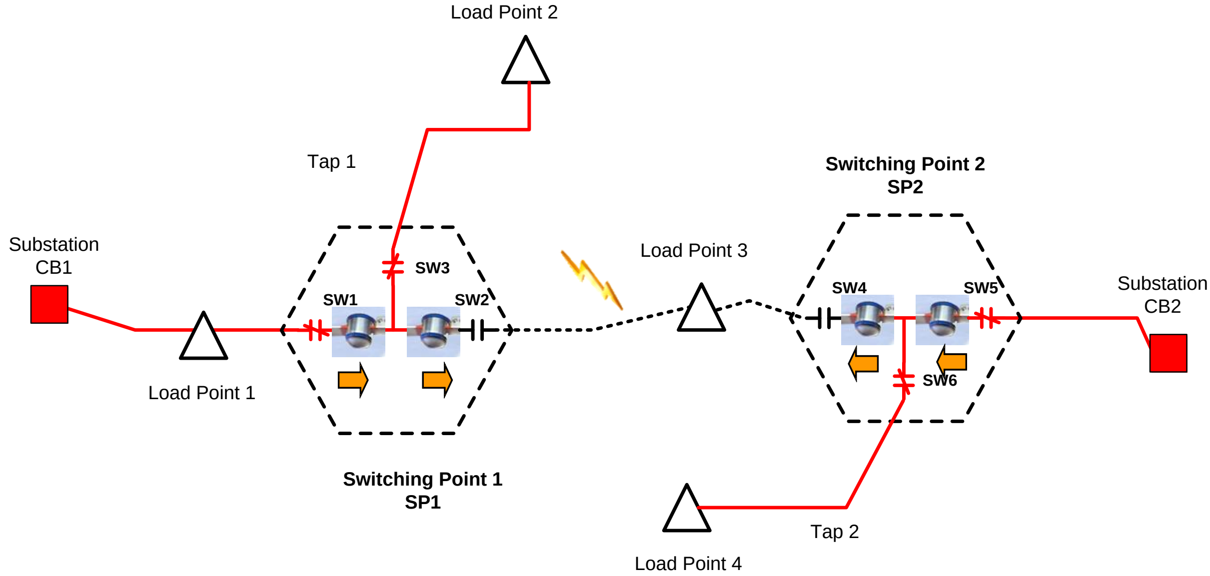


Figure 3: Case A ➔ Fault between SP1 and SP2, Service restored to Load Points 1, 2, and 4

This significantly reduces outage time and as a result, SAIDI minutes for Load Point 1, 2 and 4 and the entire system. Load Point 3 remains out of service until the fault is located and cleared. If the system is configured to operate automatically, it is feasible to avoid SAIDI minutes entirely for Load Points 1, 2, and 4 since the power would be restored in under 5 minutes (trigger time for starting to record SAIDI minutes).

A second case, Case B, is shown below in Figure 4. In this case, the fault arrows point toward CB1. The operator opens SW1 and recloses CB2. In this case Load Points 2, 3, and 4 are back on line. Load Point 1 is out of service until the fault is located and repaired.

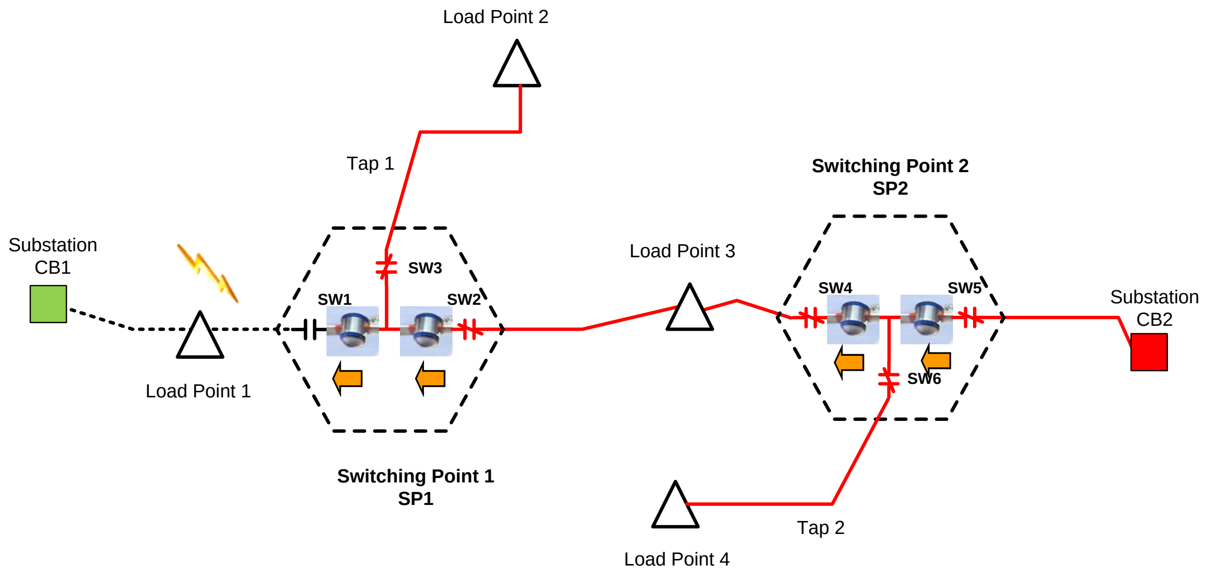


Figure 4: Case B ➔ Fault between CB1 and SP1, Service restored to Load Points 2, 3, and 4

In Case C, as shown below, the fault is on Tap 1. In this case, Load Points 1, 3, and 4 are quickly restored to service. Load Point 2 will be out until the fault is located and cleared for resumed service.

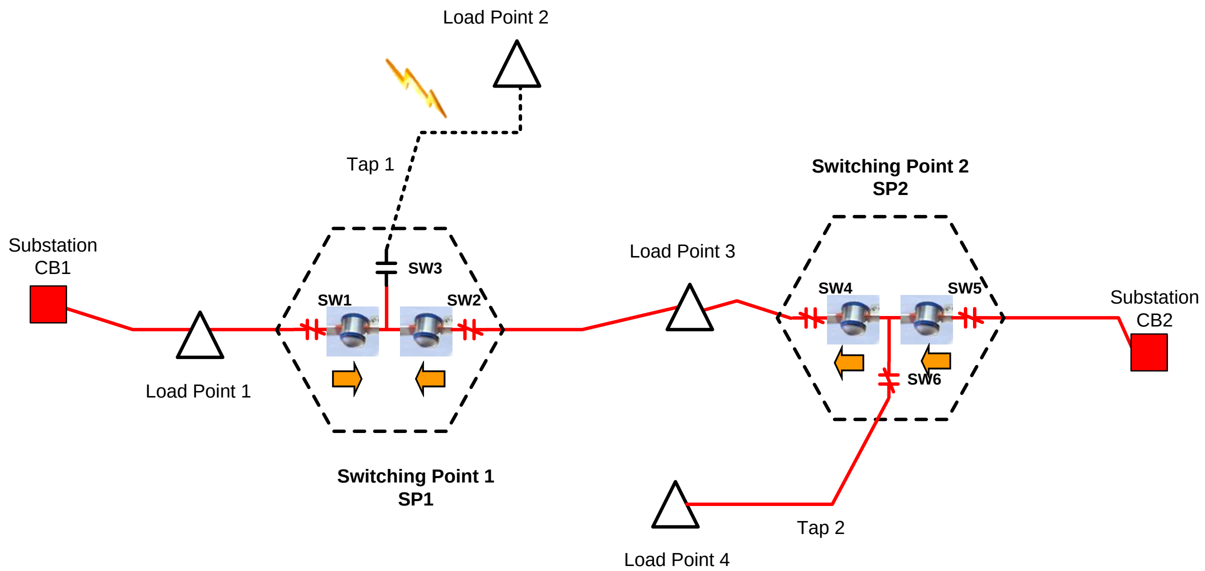


Figure 5: Case C ➔ Fault on Tap1, Service restored to Load Points 1, 3, and 4

In all of these cases, SAIDI minutes are significantly reduced or avoided by quickly restoring the fault without unnecessary closures into a fault to find it. Another aspect is safety, as after lock out, there is no reclosing into a faulted line, which could create unknown hazards with a down line.

In order to assist the operator a simple script can be set up in the SCADA/EMS system to describe the truth table. An example of the truth table set up is below.

Fault Scenario	SW1	SW2	SW4	SW5	Action
Case A: Between SP1 and SP2	⇨	⇨	⇦	⇦	Open SW2 and SW4; Reclose CB1 and CB2
Case B: CB1 and SP1	⇦	⇦	⇦	⇦	Open SW1; Reclose CB2; CB1 remains locked out
Case C: Tap 1	⇨	⇦	⇦	⇦	Open SW3; Reclose CB1 and CB2
Case D: Tap 2	⇨	⇨	⇨	⇦	Open SW 6; Reclose CB1 and CB2
Case E: Between SP2 and CB2	⇨	⇨	⇨	⇨	Open SW5; Reclose CB1; CB2 remains locked out

Table 1: Fault Direction Truth Table

7. SYSTEM DESCRIPTION

The following block diagram describes the system operation.

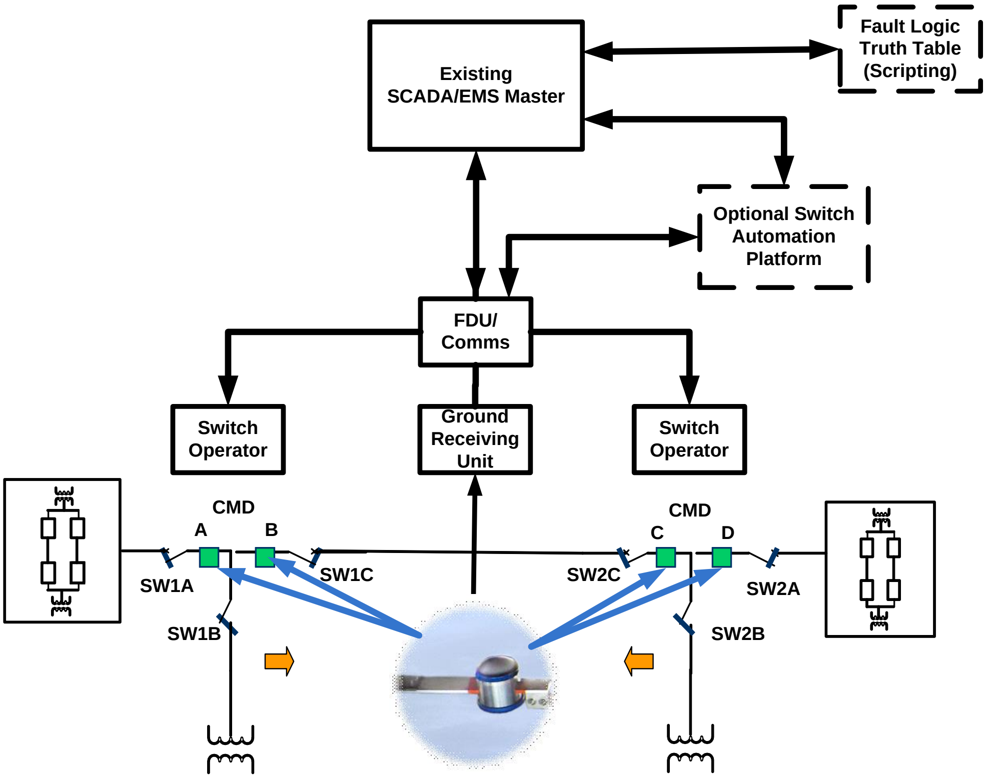


Figure 6: System Block Diagram

The ground based receiving unit for the non-contact CT interfaces with a Fault Detection Unit (FDU). This unit detects fault magnitude and fault direction.

The FDU detects and measures fault magnitude and direction. The FDU also processes the current wave form signals generated by the CT, measures line voltages from a PT, calculate RMS and average values, phase angle between voltage and current. Through a communications interface, the FDU provides this information to the SCADA/EMS. It will interface to any communication media, including fiber optics and radio. The FDU has local DC analog and binary inputs as well as control and analog set point output capability.

This system either can provide information to the system operator to take the corrective fault clearing action, or it can automatically clear the fault based on local logic. The following block diagram illustrates these two options. In both cases, the resulting switching actions are monitored by the SCADA system.

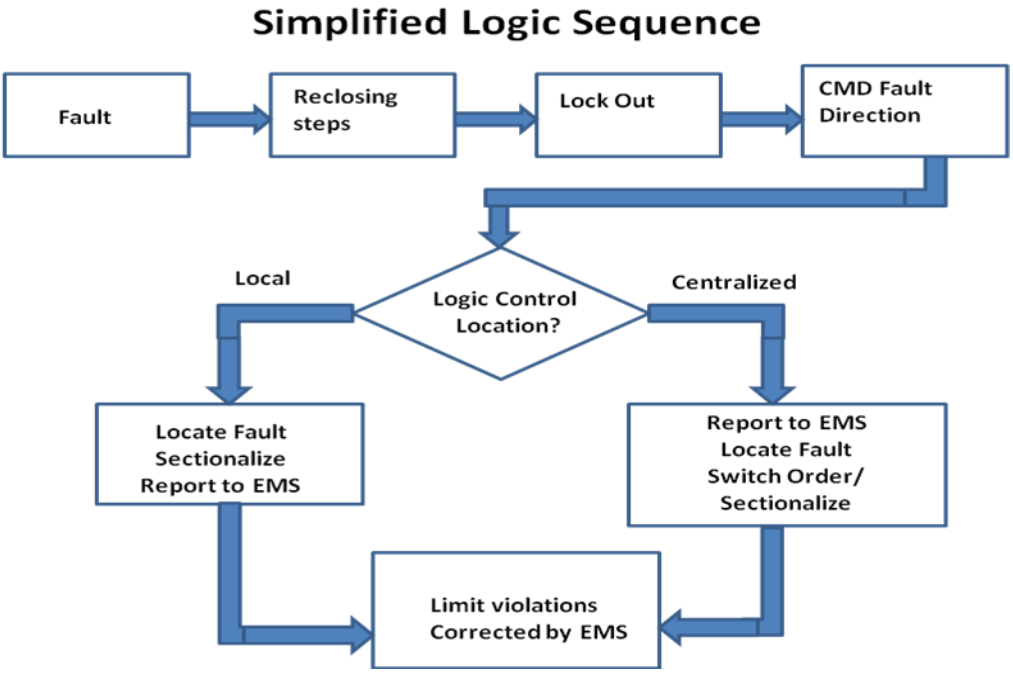


Figure 7: Logic Sequence – Local and Centralized Switching

If centralized control is used, the fault direction is reported to the SCADA/EMS and the switching recommendations are created via scripting in the SCADA system. If the local option is used, the opening of the switches to isolate the fault is automatic and the resulting switching operations are reported to the SCADA system. System limit violations caused by the switching actions are resolved by the EMS.

8. FIELD INSTALLATION EXAMPLES

The major advantage of this solution is the ease of field mounting and retrofitting existing switches with the intelligence to perform the fault isolation and detection function. Since a non-contact CT requires no separate foundation for mounting and is lightweight, they can be mounted to almost any switch configuration that may be encountered. Below are some installation photos of non-contact CTs utilizing the SSI Power CMD™ II.

The Tag Unit is mounted on the high voltage bus and is isolated from ground. It has no battery or super capacitor elements and requires no maintenance. The ground based transmitter and receiver unit is mounted on the frame of the switch below the Tag Unit. It is powered by the same 24 volt power supply utilized for the switch operator and RTU.

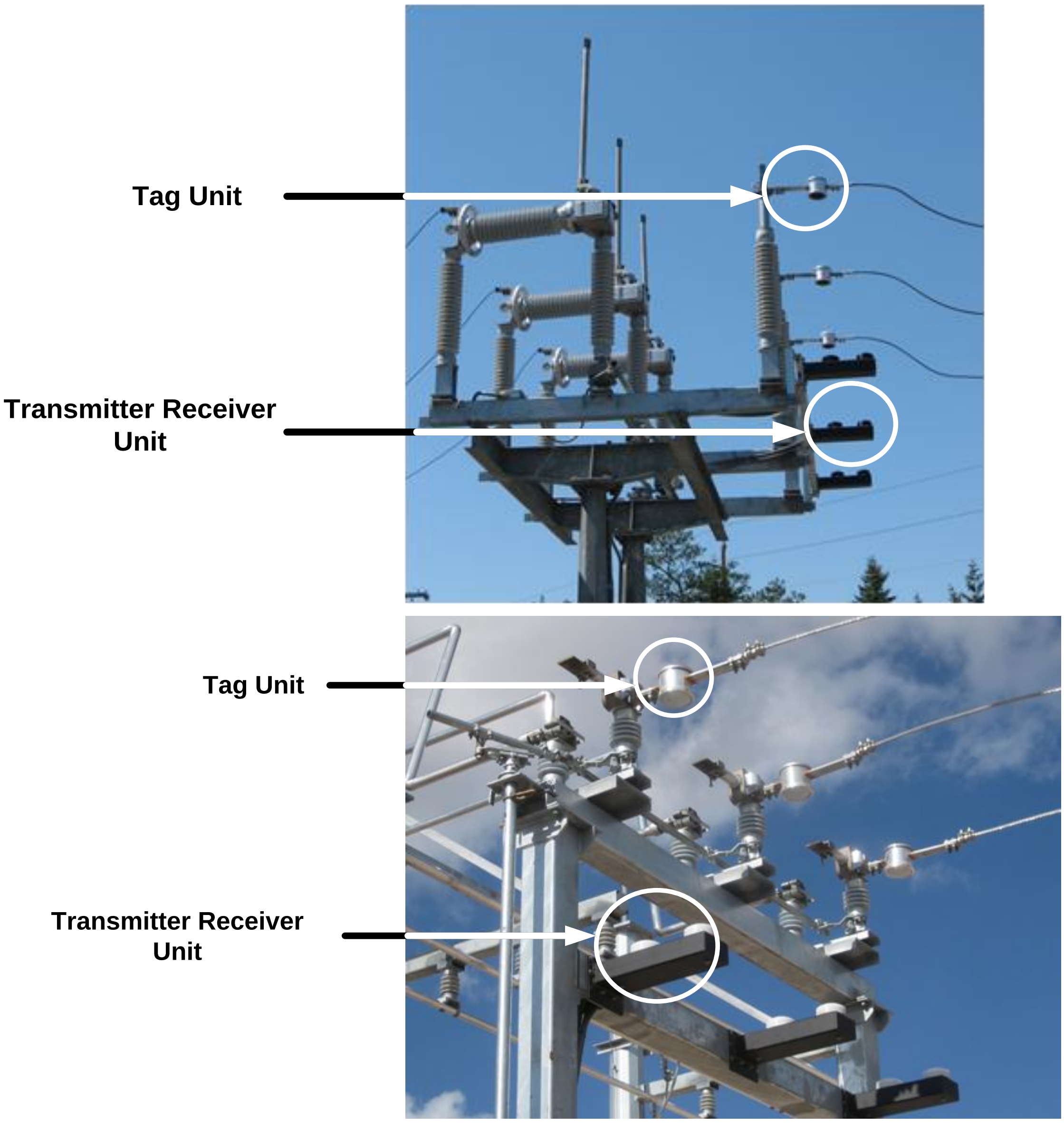


Figure 8: Installation Examples

From these photos, it can be seen that the installation of the CMD™ II can be accomplished without any ground-mounted equipment on the switch itself. This is a practical method to add intelligence to the switch.

9. CONCLUSIONS

Recently developed non-contact current sensors, such as the CMD™ II, which provide real time current information, have opened the door to implementation of more reliable fault locating and isolating solutions for transmission line systems. The SMART TAP™ fault direction sensing solution, using distributed line current sensors and intelligence, allows implementation of a revolutionary way to dramatically improve system reliability on transmission lines with multiple taps. This solution is the first to provide a reliable method for reducing SAIDI minutes on a transmission line system.

BIBLIOGRAPHY

[1] Sukumar M. Brahma, "Fault Location scheme for a Multi-Terminal Transmission Line Using Synchronized Voltage Measurements", IEEE Transactions on Power Delivery, Vol. 20, No. 2, April 2005, pp. 1325.

[2] Ying-Hong Lin, Chih-Wen Liu, Joe-Air Jiang, Jun-Zhe Yang, "An Adaptive Fault Locator for Transmission Lines Tapped with a Source of Generation – Using Synchronized Voltage and Current Phasors", Power Engineering Society Summer Meeting, 2000, IEEE. Vol. 3, July 2000, pp. 1379-1383

[3] M. Abe, T. Emura, N. Otsuzuki, and M. Takeuchi, "Development of a new fault location system for multi-terminal single transmission lines," IEEE Trans. Power Del., Vol. 10, No. 1, pp. 159-168, Jan. 1995.

[4] T. Nagasawa, M. Abe, N. Otsuzuki, T. Emura, Y. Jikihara, and M. Takeuchi, "Development of a new fault location algorithm for multi-terminal two parallel transmission lines, " IEEE Trans. Power Del., Vol. 7, No.3, pp. 1516-1992.

[5] M. Sachdev and R. Agarwal, "A technique for estimating transmission line fault location from digital impedance relay measurement" IEEE Transaction on Power Delivery, Vol.3, No.1, January 1988, pp. 121-129.

[6] D.J. Lawrence, L. Cabeza, and L, Hochberg, "Development of an Advanced Transmission Line Fault Location System Part II- Algorithm Development and Simulation, " IEEE Transaction on Power Delivery, Vol.7, No.4, October 1992, pp. 1972-1983.

[7] A.A. Girgis, D.G. Hart, and W. Peterson, "A new fault location technique for two- and three terminal lines", IEEE Transaction on Power Delivery, Vol.1, No.1, January 1992, pp. 98-107

[8] T.T. Takagi, et al, "Development of a New Fault Locator using the One-Terminal Voltage and Current Data," IEEE Transaction on PAS, Vol. PAS-101, No. 8, August 1982, pp. 2892-2898

[9] J.V.H. Sanderson, R.G.R. Santana, and B. Al-Fakri, "Improved directional comparison based algorithm for protection of multi-terminal transmission lines," in Proc. 5th Int. Conf. Developments in Power System Protection, Vo.368, 1993, pp.153-156.

[10] A. Girgis, D. Hart, and W. Perterson, "A new fault location technique for two-and three-terminal lines," IEEE Trans. Power Del., Vol.7, No.1, pp. 98-107, Jan. 1992.

[11] J. Minambres, I. Zamora, A. Mazon, M. Zorrozua and R. Alvarez-Isasi, "New technique, based on voltages, for fault location on three-terminal transmission lines," Electric Power Systems. Res., Vol.37-2, pp. 143-151, May 1996.