Analysis of the misoperation of DCB scheme for transmission line protection

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Introduction:

In the modern society, electricity is indispensible to our daily life. A fault in the power system could result in power quality issues and service interruptions in a large area. Power outage minimization and correct and prompt fault isolation are of concerns to utilities. Protection schemes shall work properly to identify and isolate faults quickly and minimize the impact on interrupting service to customers. The pilot protection schemes or communication aided schemes can help transmission line isolate faults in a timely, effective and selective manner. Based on three (3) real cases occurred in National Grid system, this paper presents an analysis of the repeated misoperations on Directional Comparison Blocking (DCB) scheme of an 115kV line by using fault records from digital relays at the surrounding substations. The analog and digital data of fault records facilitate an efficient investigation and accurate analysis of these events. The root causes of the DCB misoperations were identified with the help of fault records.

After reviewing this paper, readers would be reminded that periodical inspection of power line carrier (PLC) communication components is highly recommended and static end to end test may not be able to find the root cause of DCB scheme misoperations.

System Overview:

Two key Bulk Power System (BPS) substations (MB2 & WCH) are inter-connected by 115kV parallel lines (1 & 2) at National Grid system. Each line is divided into three sub-sections (1w, 1, 1s for line 1 and 2w, 2, 2s for line 2) with in-line breakers in between, where step-down distribution transformers are tapped at the in-line breaker stations. The simplified system one line is shown in Figure 1.

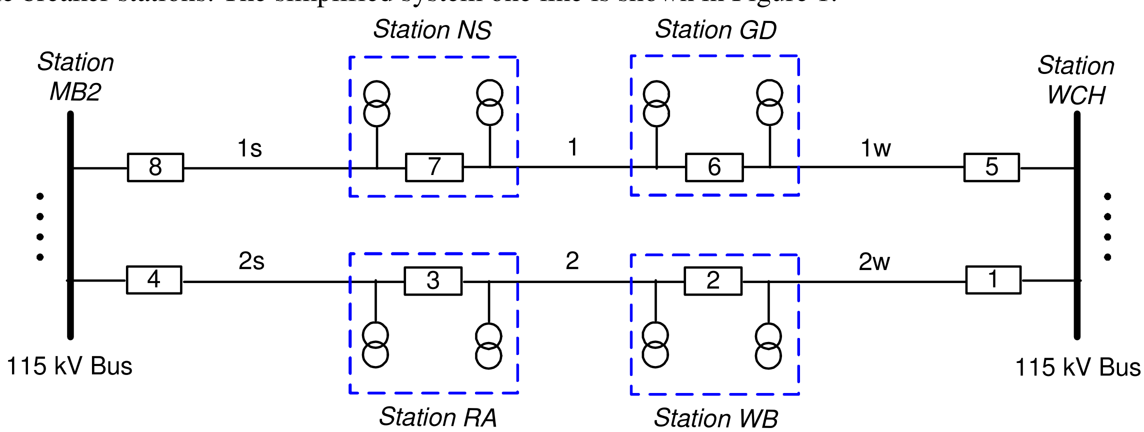

Figure 1: The simplified system one line

Per system stability study result, each section of the lines is protected by the communication aided permissive over-reaching transfer trip (POTT) & directional comparison blocking (DCB) schemes. The digital relays are provided for each line and the dedicated digital fault recorders (DFR) are installed at substations MB2 and WCH. The communication channel of DCB scheme is PLC. Since the DCB communication channels utilize ON/OFF type signaling, which is not continuously monitored, the daily automatic channel testing is performed to ensure the integrity of the channel and provide alarm in case of loss of the required functions. In addition to PLC channel daily automatic channel check back, the monthly maintenance test is performed on DFR to ensure functionality.

Over a two-year period, communication issues of carrier hole or momentary carrier blocking signal interruption have consistently been of the cause of line 2w over-trip by DCB scheme during the external ground faults. Although all possible efforts have been made to explore the root cause, no progress was made until each of the components in the PLC communication system was thoroughly inspected and tested.

Incident Summary:

On July 3rd of 2014, a ground fault occurred on 2s line and the faulted line was correctly isolated from both line terminals MB2 & RA respectively. In the event of line 2s trip, line 2w breaker 1 at WCH station was unexpectedly over-tripped by DCB scheme of line 2w, resulting in the loss of the power supply at the tapped station WB. Since there were two in-line breaker stations between the faulted line 2s and the WCH station, the trip of line 2w line breaker at WCH was definitely undesired and should have been avoided. See Figure 5.

On May 29 of 2013, a momentary ground fault, caused by lightning stroke, was on line 1s between stations MB2 and NS. The line 1s was tripped from both ends and then successfully reclosed. However, in the mean time, in-line breaker 2 at WB station (see Figure 2) was single ended tripped by line 2w DCB scheme.

On April 21 of 2013, line 2 between stations RA & WB was tripped correctly due to a failure of A-phase on the line CCVT at RA station. Almost the same time, line 2w was also tripped out from station WCH by the line 2w DCB scheme.

Up to this point, a question brought the investigation team attention. Why the line 2w was always over-tripped on the external zone ground fault by the DCB scheme only. Right after the over-trip, the static end to end relay tests were performed with no relay and communication channel problems being found. However, as a matter of fact, the similar line 2w DCB scheme improper operation repeated.

Investigation and Analysis:

Event on May 29th of 2013

First, by using the event on May 29 of 2013 as an example, the investigation team analyzed what happened to the DCB protection scheme based on the captured fault data. Figure 2 reproduces the fault location and breaker operation status during the fault isolation.

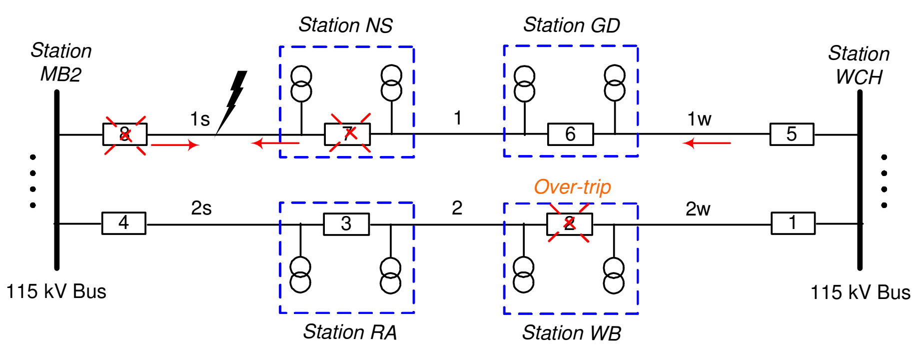

Figure 2: Fault on line 1s on May 29 of 2013 and breaker Status

Line 2w relay records of DCB scheme at WB station are reviewed and shown in Figure 3.

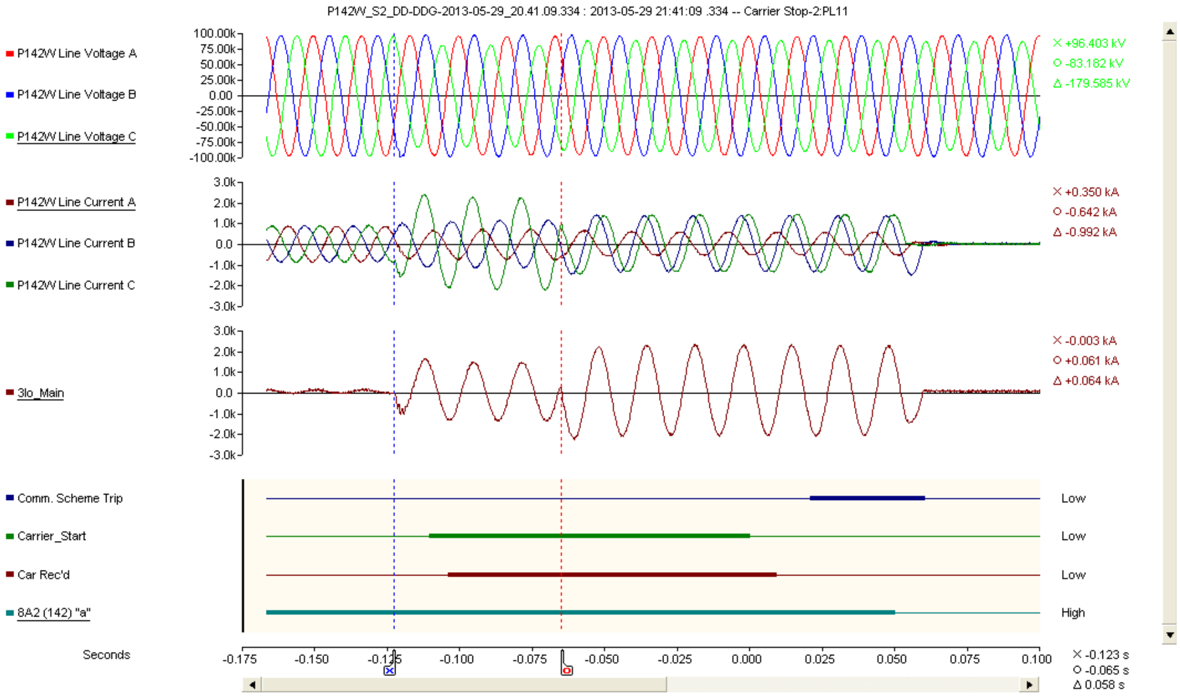

Figure 3: Line 2w relay record of DCB scheme at WB station

Line 2w relay record from station WCH is shown in Figure 4 below.

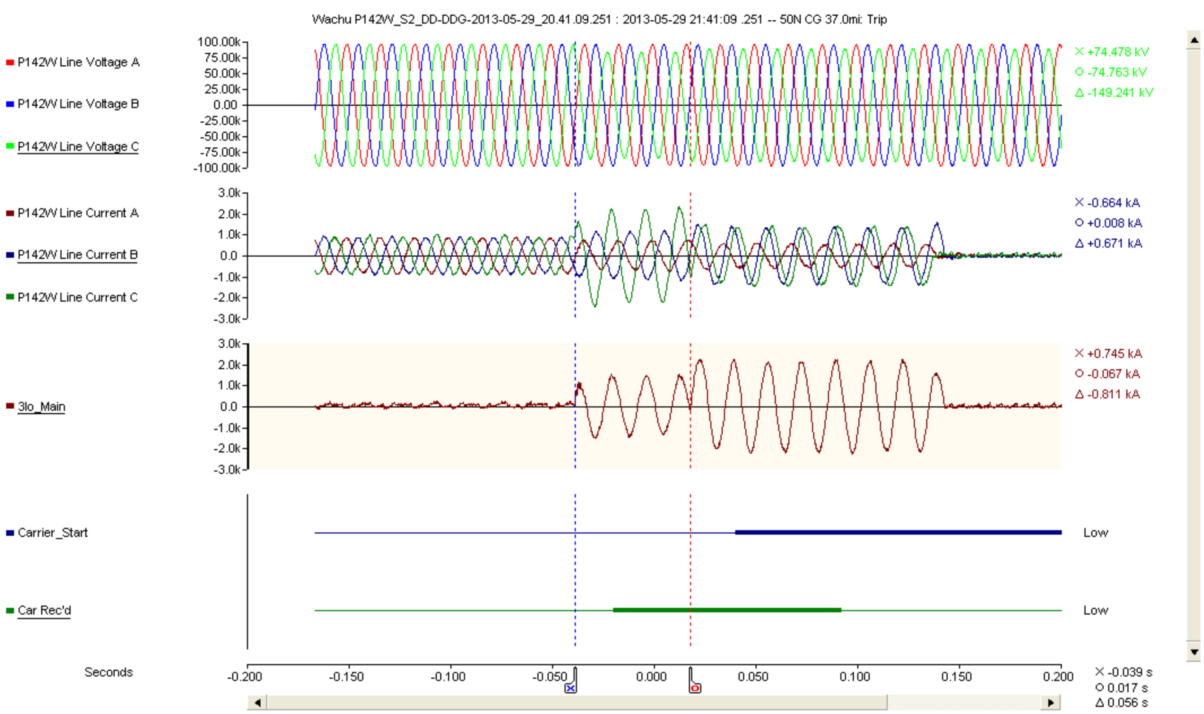

Figure 4: Line 2w relay record of DCB scheme at WCH station

As per relay records, the following findings and sequence of operations can be summarized as:

1) The original fault current flow direction on line 2s, 2, and 2w was from WCH to MB2, which can be confirmed by the assertion of "Carrier Start" in the digital trace of the line 2w relay records at WB (see Figure 3)

2) The line 1s breaker 8 at MB2 tripped correctly prior to the line 1s in-line breaker 7 at NS station. Open of the breaker 8 resulted in the current reversal on line 2s, 2 and 2w. The current reversal occurred in 58ms after the original line 1s fault (see Figure 3 & 4).

3) After the current reversal, the fault current flow direction on line 2s, 2, and 2w was then reversed from MB2 to WCH. The relay of line 2w at WB now sensed the fault as in forward direction and carrier directional ground OC trip element (CDG) of the DCB scheme would make a trip if the blocking signal from the remote terminal was not present.

4) In-line breaker 2 at station WB was tripped by the CDG element of the line 2w DCB scheme due to the early dropout of the received carrier blocking signal from the remote terminal WCH (see Figure 3 & 4).

Event on July 3rd of 2014

On July 3rd of 2014, a ground fault occurred on line 2s. The line 2w breaker 1 at WCH station was over-tripped by line 2w DCB scheme on the fault prior to the in-line breaker 3 trip at station RA (see Figure 5). As a result, the whole station WB lost the power supply. The line 2w relay record of DCB scheme from station WCH is shown in Figure 6.

Prior to the in-line breaker 3 open, the carrier signal of the line 2w DCB scheme from WB had been continuously sent to the remote station WCH as the relay of line 2W at station WB sensed this reverse fault. However, line 2w breaker 1 at station WCH was inadvertently over-tripped by DCB scheme due to a carrier hole (see Figure 6).

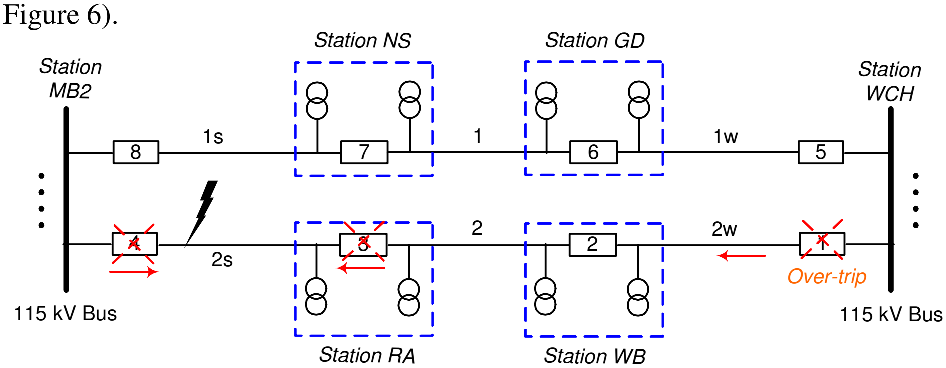

Figure 5: Fault on line 2s on July 3rd of 2014 and breaker trips

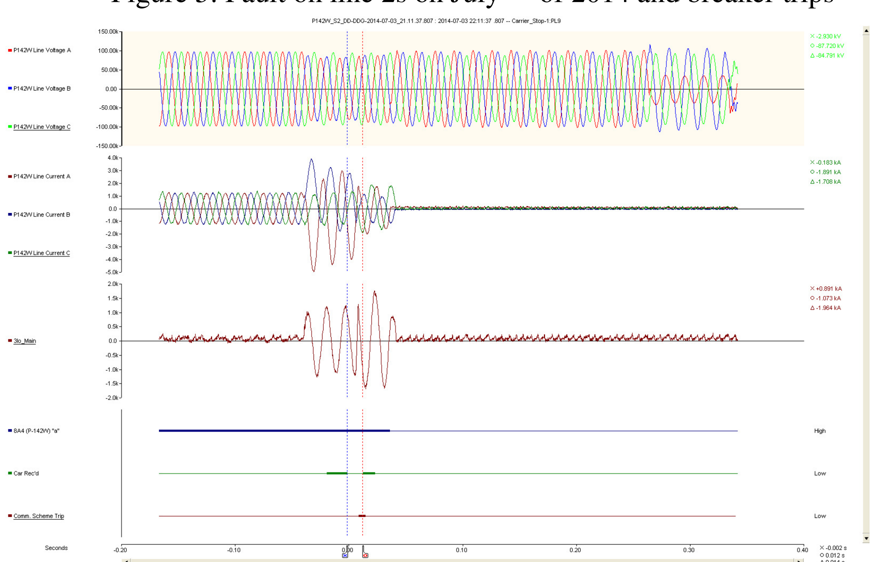

Figure 6: Line 2w relay record of DCB scheme at WCH station on July 3 2014

Per relay record in Figure 6, the duration of 14ms carrier hole was present prior to the DCB scheme operation. The combination of the relay target of the line 2w carrier directional ground OC trip (CDG) and momentary missing of blocking carrier signal resulted in the line 2w trip from WCH terminal only for the line 2s fault.

The static end to end field tests were performed for DCB scheme relays for the line 2w following the misoperations in June 2013 and July 2014, but no problems were found. The hi-frequency signal db losses were within the accepted range during the communication tests. The protection relay settings for the line 2w DCB schemes at WB and WCH were also re-reviewed with no improper protection and logic settings being discovered as well.

What could be the root cause for the momentary loss of the blocking signal (i.e. carrier hole) on the line 2w during external ground faults? Up to this point, it is necessary to have more detailed review of each carrier equipment and devices of this DCB system at both WB and WCH stations.

DCB scheme with power line carrier communication:

The DCB pilot scheme is the one of oldest type of protection systems and it is still widely used in the power industry. At National Grid, typically, DCB scheme is one of dual communication aided protection schemes in addition to POTT when optical fiber and line differential protection is not available.

In DCB scheme, both the forward overreaching elements (Zone 2) and reverse elements (Zone 3) are required at each line terminal. Zone 2 and zone 3 elements may consist of phase distance, ground distance and/or directional ground overcurrent element to provide the phase and ground fault detection. Ideally, the blocking signal should be sent to remote end only when the fault is out of the protected line and in the reverse direction. DCB scheme is highly dependable because the relaying system can still trip on internal fault even without the communication channel.

If the relay detects the fault in the reverse direction, Zone 3 elements would immediately pickup and transmit a blocking signal to block the remote trip. If zone 2 elements pickup and no blocking trip signal is received after the elapse of coordination timer, a trip will be initiated to trip the local breaker to isolate the in-zone fault. In this sense, the reach of the local reverse elements must be set be greater than the remote forward overreaching elements for tripping.

The classic DCB scheme utilizes power line carrier (PLC) communication channel with amplitude modulation. The same frequency can be used for the carrier signal at all line terminals. The power-line carrier AM ON/OFF type of channel is widely used. Figure 7 shows the typical power line carrier channel components.

The ON/OFF type carrier telecommunication equipment is OFF in the normal state and in-zone line fault. However, it is turned on to send blocking carrier signal to the remote to block tripping on the revere direction fault. Therefore, DCB scheme requires the blocking functions at all terminals. Loss of communication channel or momentary carrier signal interruption (carrier hole) in DCB schemes could cause a line over-trip on an external fault as the blocking signal is not received from the remote end.

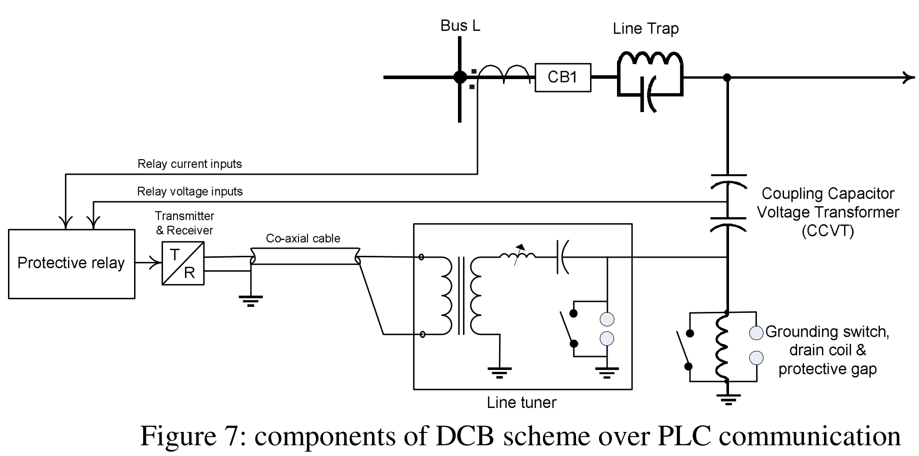

Figure 7: components of DCB scheme over PLC communication

As shown in Figure 7, any deterioration of communication path could lead to a carrier hole which could be at transmitting or receiving end. The presence of carrier hole would indicate the too much signal attenuation from bad line trap, the insulation break-down of coaxial cable, the flash-over of protective gap, and/or excessive external electromagnetic interferences.

Since the hi-frequency signal level was normal at both terminals during the tests, the issue of transmitter/receiver and line trap can be excluded; otherwise significant of signal attenuation would be observed.

Field investigations and findings:

In fall 2014, comprehensive tests and inspections were made on line tuner, CCVT and communication cables at both WB and WCH stations. Two major issues were found at WB station on the shield layer grounding of communication cable and the protective gap in CCVT.

1. Protective gap in Line 2w CCVT:

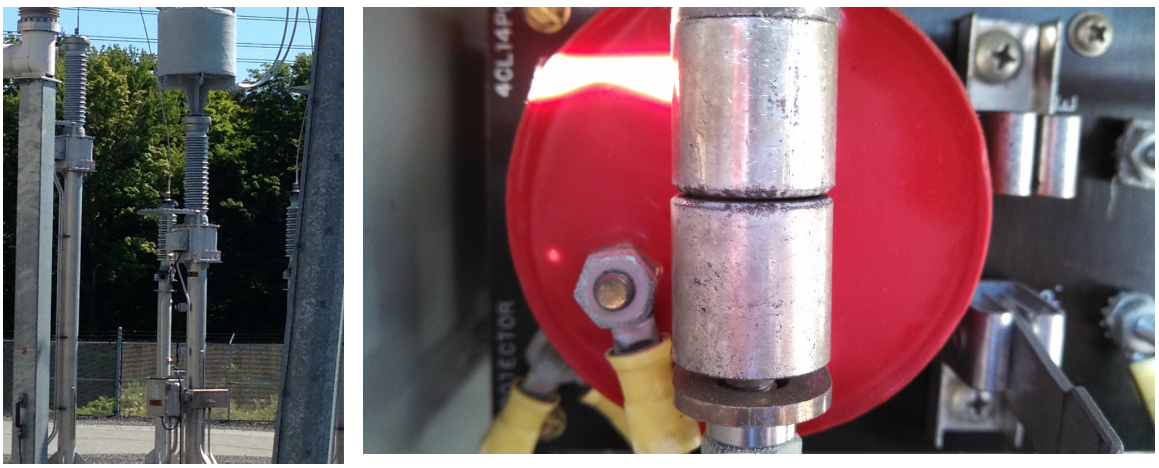

Figure 8: CCVT installation & the protective gap in CCVT with burning marks at WB

Figure 8 indicates the bad status of gap in the line 2w CCVT at WB. As seen in the figure, many burning marks were on the tip or edge of the gap and black color carbons were built-up, which reduced the effective distance of the gap and decreased the threshold of flash-over voltage.

2. The grounding of shield layer of communication cable:

Since line tuner is installed in the field and transmitter/receiver is installed in the relay room, the coaxial or triaxial cable is required to provide a low impedance path for the carrier signal between the equipment. The coaxial cable has a center conductor surrounded by a tubular insulating layer and the mesh conducting shield surrounds the insulation layer. The outer most of the cable is insulating jacket. Coaxial cable provides protection of the signal from external electromagnetic interference. Triaxial cable is similar to coaxial cable and provided with the addition of an extra layer of insulation and a second conducting sheath, which has better interference rejection capability than coaxial cable. Figure 9 shows the typical coaxial & triaxial cable.

Figure 9: coaxial cable (left) & triaxial cable (right)

The tri-axial cable is used at WCH station while co-axial is installed at WB station. However, the shield layers of the cable are grounded at both ends at WB station. This is improper application for co-axial cable, where the fundamental frequency ground current could flow through the shield due to different ground potential rises (GPR) at locations during the ground fault and the electromagnetic interferences can be imposed on the center conductor. The induced voltage on the center conductor from the shielding layer of the communication cable could saturate the isolation transformer in the line tuner and the inputs of the receiver; thus result in the momentary loss of the received blocking signal.

Based on above mentioned findings, the combinations of reduced protective gap in CCVT and improper shield layer grounding of the communication cable were the root cause of the carrier hole. Thus, the protective gap in CCVT was cleaned and re-adjusted; the additional grounding on co-axial cable shield in the field at WB was removed.

In addition to the corrections in the communication system, the relay and logic settings were reviewed. By re-reviewing the past twenty years of DCB misoperations due to carrier hole at National Grid New England region, it seems the typical length of the hole is between 8 - 16 ms. Therefore, the setting of 16 ms, i.e. one cycle, for carrier hole extension timer should be able to satisfy most of operational scenarios. Given that the carrier hole extension timer setting on the line 2w was reset from half cycle to one cycle.

Until now, the misoperation of line 2w DCB scheme has never repeated since the field fixes and setting changes made in September 2014.

Conclusions & recommendations:

The communication aided scheme over PLC is one of the oldest pilot protection schemes and still being widely used in the US. The misoperations related to PLC communication are not uncommon; however, the root cause of the misoperations was not sometimes timely and easily identified. The correction through relay and logics settings, such as increasing the carrier hole timer setting to a proper length, can avoid some of over-trips. To find the root cause of the issue and the corresponding correction shall be the correct methodology.

The equipment failure and the maintenance issues could be the cause of PLC communication related misoperations. It is recommended the components be inspected following a major misoperation. The maintenance intervals may be shorter than that of relays.

The components should be installed as per engineering design. For example, the engineering design at WB requires the shield layer grounding of co-axial communication cable be grounded only at protection panel. However, the cable shield layer was grounded at both ends during the construction.

As mentioned before, the protective gaps are provided in CCVT and line tuner. The protective gap in line tuner is normally a sealed, non-translucent gas tube device which corresponds to the insulation level of the line tuner. (Refer to the contents in the red circle in Figure 10)

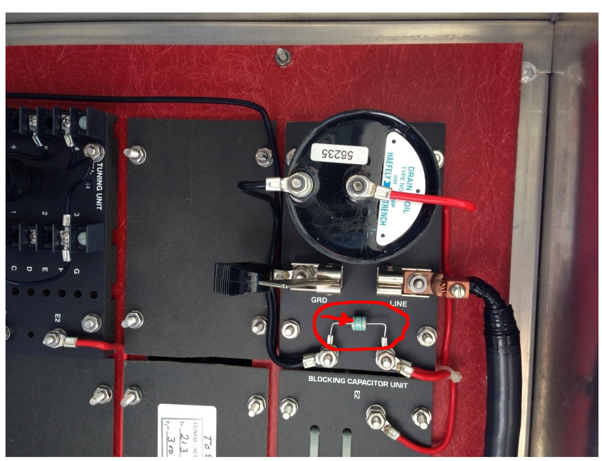

Figure 10, Line tuner and its protective gap

It is difficult to identify the working status of this tube gap and know whether it has previous discharges due to its non-translucent nature. A vendor in power line carrier industry recently released an innovative spark gap retrofit kit to replace the gas tube gap in the line tuner as shown Figure 11 below.

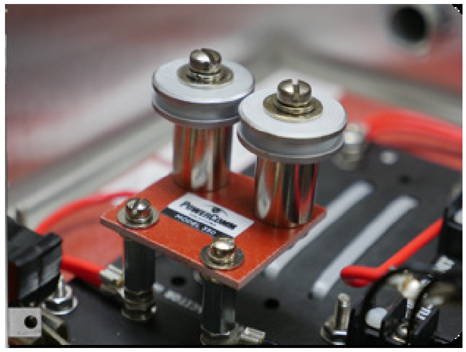

Figure 11: Gas tube gap retrofit kit

It should be noted that the gap setting should be based on the BIL of line tuner. Therefore, the previous discharge or flashover can be easily identified when using the new adjustable air gap. By adjusting the gap distance, the insulation coordination can be maintained between protective gaps in CCVT and line tuner. If the gap distance in the line tuner is set shorter/sensitive than that of gap in CCVT, the gap in line tuner would discharge first. The obvious advantage of method is the gap in the line tuner is more accessible than CCVT as power outage is required for gap checks in CCVT for safety reasons. When carrier hole is present in the high frequency communication system, it is easy to inspect the status of the protective gap in the line tuner without requesting the power outage of the line.

References:

1. IEEE 643 Std. Guide for Power Line Carrier Applications;

2. 2016 Georgia Tech Relay conference paper “The complications of DCB scheme for 3-terminal line protection”, *Song Ji, Yujie Irene Lu & Michael Gregg, National Grid USA*

3. Power Line Carrier Application Engineering training material by PowerComm solutions

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