

# A Case Study of Corrective Action Plan to Meet PRC-026-1 Compliance

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## Abstract:

The purpose of NERC standard PRC-026-1 is to ensure that load-responsive relays do not trip under stable power swing conditions [1]. If a violation of the standard exists, a Corrective Action Plan (CAP) must be developed timely to meet the compliance requirement. Generally, the compliance of a load responsive relay is evaluated at a local terminal only. In a POTT or DCB scheme, zone 2 phase distance relay (Z2P) in a remote terminal may mitigate or correct the violation of a local Z2P. However, the characteristics of a Z2P which is completely contained within the Unstable Power Swing Region (UPSR) may not be completely contained within the UPSR of its remote terminal. This paper discusses evaluation and CAP of a local relay at a remote terminal in meeting PRC-026-1 compliance.

## I. Introduction of PRC-026-1

Phase distance relays are most common load responsive relays in BES. Evaluation and Corrective Action Plan (CAP) of phase distance relay associated with communication schemes is the focus of this paper.

Figure 1 is captured from the standard [1], which illustrates a phase distance relay is completely contained within the unstable power swing region (UPSR). UPSR is defined by the PRC-026-1 standard. If evaluation finds any violation to the standard requirements, a CAP needs to be developed timely.

National Grid USA has 116 BES Elements identified to comply with the standard. Violations in 25 BES Elements were found during R2 evaluation. This paper will draw on the author's work and lessons learned in spearheading PRC-026-1 compliance efforts at National Grid. This paper shares a few examples with utility engineers in meeting PRC-026-1 compliance. All the examples in the paper are real-life examples.

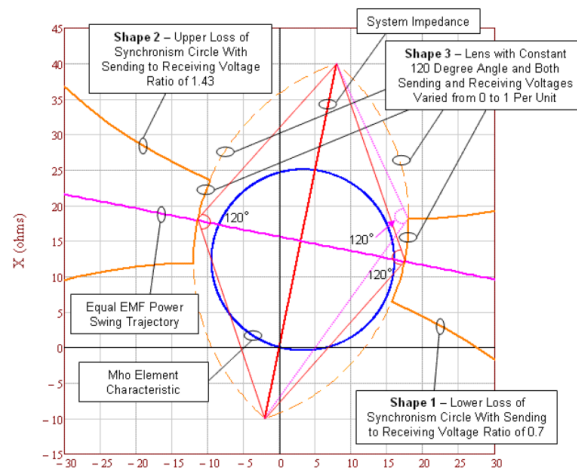


Figure 1 The UPSR (unstable power swing region) [1]

## II. Evaluation of a POTT scheme with supervision from remote terminal(s)

Zone 2 phase distance relay (Z2P) is excluded from the compliance requirement if the time delay is 15 cycles or larger. However, if Z2P is used in communication scheme, is subject to compliance requirement due to its high-speed operation. In this paper, Z2P, zone 2, phase distance zone 2 are used interchangeably.

Compliance evaluation is generally performed at a local terminal and using local information only. If a violation of Z2P exists, the actual violation is generally less severe and occasionally non-existing with the supervision from its remote terminal(s). A permissive tripping (PT) signal in POTT may be initiated from remote Z2P. Supervision of a remote PT signal will probably mitigate the violation level. Figure 2(a) is an example 3-terminal line with high speed POTT protection. To do the evaluation at WH terminal, it is necessary to do another network reduction to get a two-bus equivalent, as shown in Figure 2(b). Z2P used in communication scheme is high speed and thus subject to the compliance requirement. Figure 2(c) shows Z2P at WH terminal is not compliant. Operation of communication scheme needs remote supervision, which helps mitigate the severity of violation or even remove the violation completely. Figure 2(d) is the two-bus equivalent with fictitious remote buses added. The fictitious remote buses are added to the two-bus equivalent model to plot the remote Z2P Mho circle. It is to be noted that dashed line in Figure 2(b) is temporary for the plotting of a remote Z2P Mho circle and should be put out of service after plotting. Otherwise, the UPSR will be displayed incorrectly.

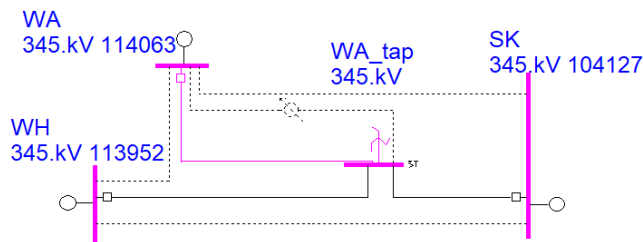


Figure 2(a) A 3-terminal line with POTT

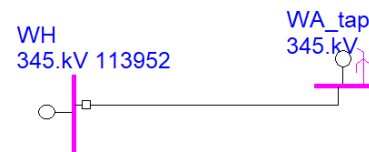


Figure 2(b) Two-terminal equivalent

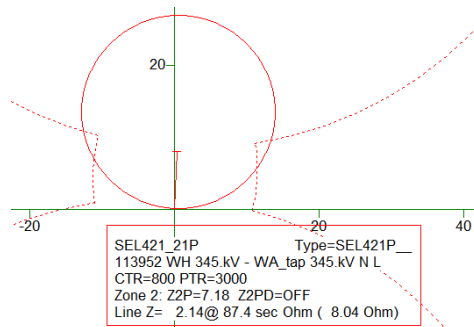


Figure 2(c) A sample three-terminal line

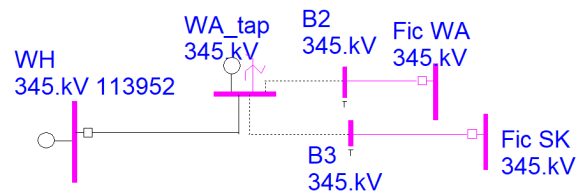


Figure 2(d) Model with fictitious buses

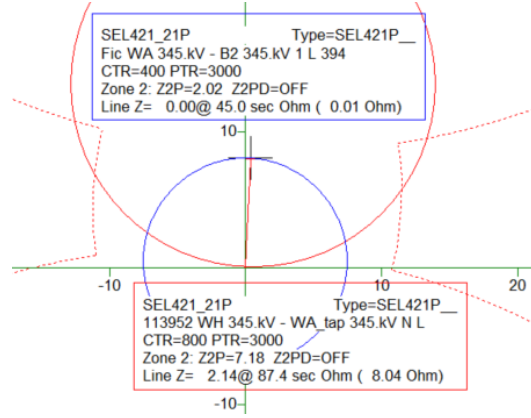
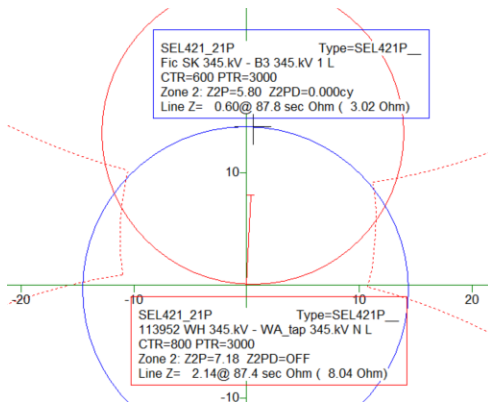


Figure 2(e) Minor violation with PT from SK supervision      Figure 2(f) Compliance with PT from WA supervision

Figure 2(e) illustrates most of the violation region is now compliant, with the PT supervision from terminal SK. However, a small area of violation still exists. Figure 2(f) illustrates that protection scheme is compliant with the PT supervision from WA terminal. Since operation of WH terminal POTT needs PT received from both SK and WA terminals, the WH terminal Z2P associated with POTT scheme is compliant with the standard. There is no CAP needed. It should be noted that the evaluation discussed here is at local terminal only.

### III. CAP of a DCB scheme with zone 2 violation

This section discusses a CAP for a 3-terminal line as shown in Figure 3(a) and Figure 3(b). There are two high speed protection system DUTT and DCB. Both schemes protect the whole line. DUTT is initiated by zone 1 protection. Zone 1 overlaps each other. MM and NL zone 1 can reach point S in Figure 3(b). In DCB scheme, Z2P trips in high speed if a block tripping signal (BT) is not received from either of its remote two terminals. Since a BT signal is initiated by a reverse looking protection, a BT signal in DCB does not help mitigation of the violation to a level a PT signal in POTT does. Discussion of evaluation and CAP in this section is limited to local terminal only.

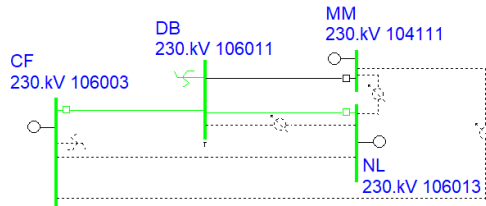


Figure 3(a) 3-terminal line with DCB and DTT

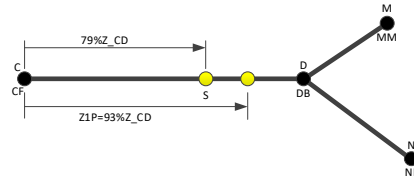


Figure 3(b) One-line diagram

Table 1 Line segment impedance

	Primary Impedance	CTR/VTR	Secondary
CF-DB	74.44@81.6Ohm	240/2000	8.93
NL-DB	11.20@81.6Ohm	400/2000	2.24
MM-DB	7.18@81.8Ohm	240/2000	0.86

Table 2 Line impedance and settings

Terminal (CRT/VTR)	Line	Primary	Secondary	Z1P	Z2P	Z1P %
CF (240/2000)	CF-NL	85.64@81.6	10.28@81.6	8.3	20	Z1P/Z_CD
	CF-MM	81.61@81.6	9.79@81.6			93%
NL (400/2000)	NL-CF	85.63@81.6	17.13@81.6	3.13	42	Z1P/Z_ND
	NL-MM	18.38@81.7	3.68@81.7			140%
MM (240/2000)	MM-CF	81.61@81.6	9.79@81.6	1.87	32.4	Z1P/Z_MD
	MM-NL	18.38@81.7	2.21@81.7			217%

### 3.1 CAP of CF phase zone 2 DCB (local evaluation)

Figure 4(a) is a capture of compliance evaluation of protection at CF terminal and a potential CAP.

Without a CAP, both zone 1 and zone 2 violate the standard requirement since they are not completely contained within the UPSR.

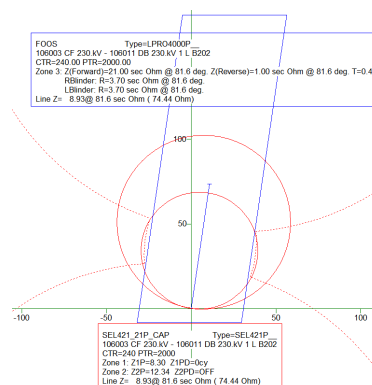
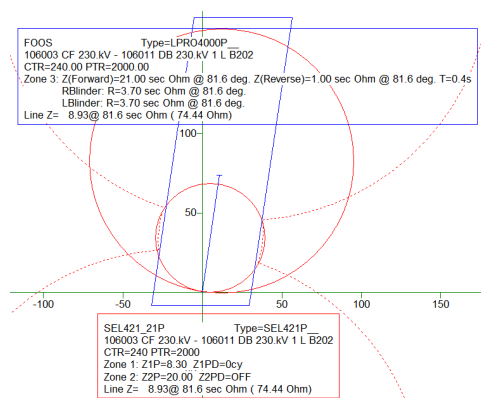


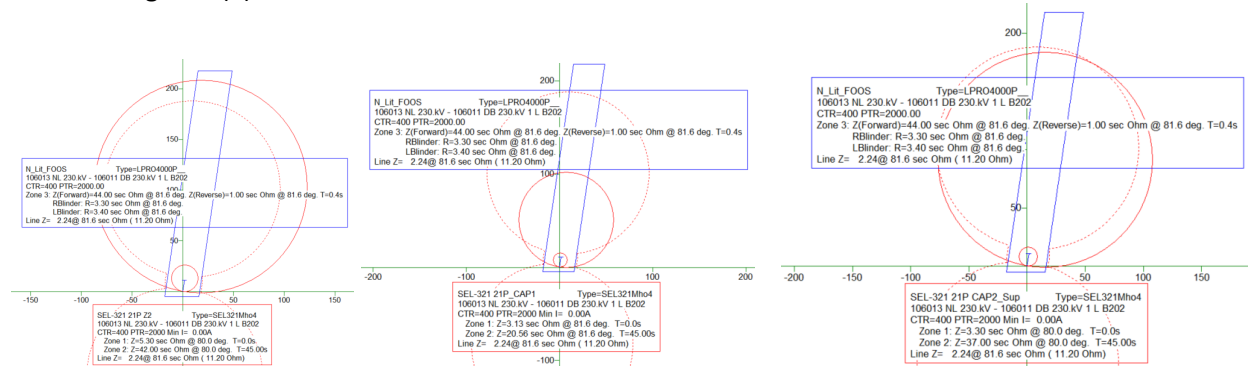
Figure 4(a) CAP with supervision      Figure 4(b) CAP with reduced zone 2 reach & supervision

Figure 4(a), a part of OOS function, i.e., the parallelogram, is used to supervise both zone 1 and zone 2 to meet the compliance requirement. A large portion of zone 2 circle is blocked from tripping. This may cause some concern of protection dependability.

Zone 2 was set to overreach the line significantly due to infeed effect. If sequential tripping is allowed, Z2P reach can be reduced to 120% of the line CF-NL, as shown in Fig 4(b). The supervision blocks only a small portion of the Z2P circle which may appear to be better. After one-terminal is out, relay calculated distance is more accurate and any three-phase fault should be close to the line in the impedance plan. The parallelogram supervision should not affect the protection dependability. If there is no dependability concern on a CAP with shorter zone 2 reach, there should be no dependability concern on a CAP with the original zone 2 reach. Although Figure 4(b) appears to be more dependable compared to Figure 4(a), CAP in Figure 4(a) is more dependable and was implemented.

### 3.2 CAP of NL phase zone 2 DCB (local evaluation)

Figure 5(a) is a capture of compliance evaluation of NL protection. The upper half of the UPSR is completely within the Z2P characteristics, which is just the opposite to the standard requirement. Zone 2 initiated DCB scheme violates the standard and there does not appear to be a good CAP with parallelogram supervision only. Unlike the CAP in Figure 4(a), the parallelogram used to supervise the zone 2 in Figure 5(a) does not correct the violation.



If sequential tripping is accepted, zone 2 reach setting can be reduced to 120% of NL-CF line impedance. The CAP in Figure 5(b) is acceptable to provide dependable line protection, with a 3 cycle or so delay for a 3-phase fault at some portion of the line due to sequential tripping. It is possible to make the protection slightly more dependable. A reduced zone 2 reach and supervision, as shown in Figure 5(c), relies less on sequential tripping and thus provides better protection dependability.

### 3.3 CAP of MM phase zone 2 DCB (local evaluation)

Figure 6(a) illustrates that the majority of zone 2 stays outside of the UPSR. Violation shown in Figure 6(a) appears to be uncorrectable with any supervision. If sequential tripping is acceptable, zone 2 reach can be reduced to 120% of impedance of line MM-CF, as shown in Figure 6(b). Zone 2 shown in Figure 6(b) has a minor violation which can be easily corrected by load encroachment.

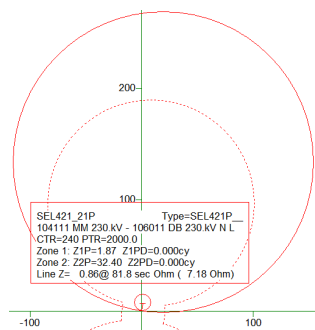


Figure 6(a) Severe violation

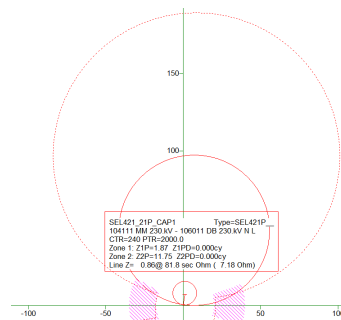


Figure 6(b) CAP with reduced zone 2

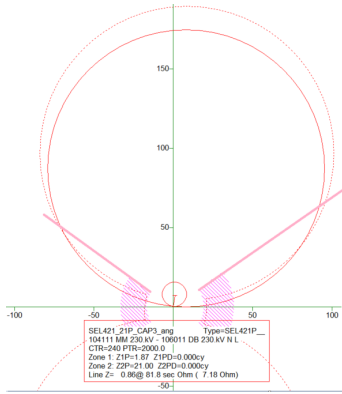


Figure 6(c) CAP with reduced zone 2 & supervision 1

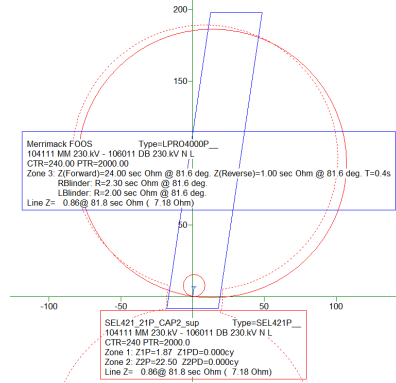


Figure 6(d) CAP with reduced zone 2 & supervision 2

Figure 6(c) and 6(d) illustrates variations of CAP. Figure 6(c) has zone 2 torque angle adjusted and supervised with load encroachment. Figure 6(d) has a slightly larger zone 2 reach and supervised with parallelogram.

It is to be noted that all the three CAPs mention in this section need sequential tripping for 3-phase faults near remote end of terminal CF. The CAP described in Figure 6(b) depends more on sequential tripping.

#### IV. Discussion of potential violation of zone 2 communication scheme at a remote terminal

It may be debatable whether a load responsive relay needs to be completely contained within the UPSR of its remote terminal. The standard does say load responsive relays are expected not to trip under stable swing condition. It would be safe if a load responsive relay can be completely contained within the UPSR of its remote terminal. It may be uncommon for a PRC-026-1 compliance study to cover zone 2 (if used in a scheme) at a remote terminal. The zone 2 at CF terminal for the system in Figure 3, even with supervision of parallelogram in Figure 4(a), is not completely inside the UPSR at terminal NL. Figure 7(a) illustrates the violation.

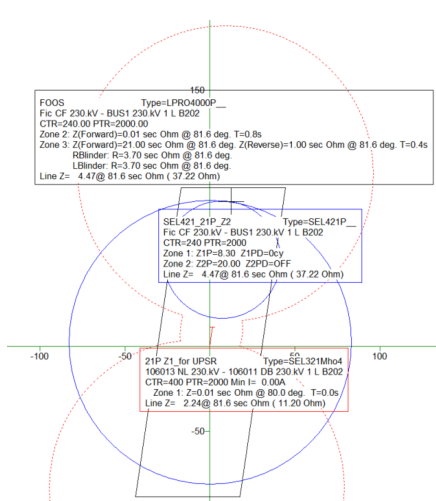


Figure 7(a) Z2P violation at CF against the UPSR at NL

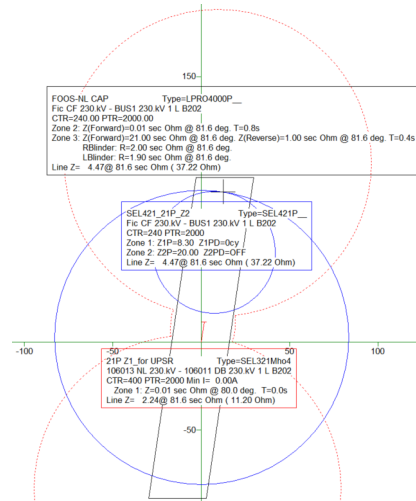


Figure 7(b) CAP at CF against the UPSR at NL

Figure 7(b) shows a narrowed parallelogram can correct the violation. There is some concern of its dependability when the apparent fault impedance is large. If sequential tripping is acceptable, the CAP may be acceptable since there will be no infeed and a 3-phase fault impedance angle close to the line angle.

When there is an opportunity, it would be desirable to replace the DCB protection with line differential protection, if a system study indicates two high speed protections are essential for system stability.

## V. Violation of DUTT scheme at a remote terminal

Like the DCB scheme discussed in section IV, phase distance zone 1, if used in a DUTT scheme, needs to be evaluated whether the zone 1 characteristics is completely contained within the UPSR at a remote terminal.

In National Grid system, there is another two-terminal line CF-NL with zone 1 DUTT scheme. Figure 8 illustrates that zone 1 characteristics at CF terminal is not completely contained within the UPSR at NL terminal. The violation shown in Figure 8 is very moderate and can be easily corrected. It is possible that the violation has been corrected in the local evaluation and CAP at CF terminal. The CAP can be a slightly reduced zone 1 reach, supervision with parallelogram, or using lens shape of zone 1. This real-life example shows there is a need to evaluate zone 1, if used in DUTT scheme, at its remote terminal.

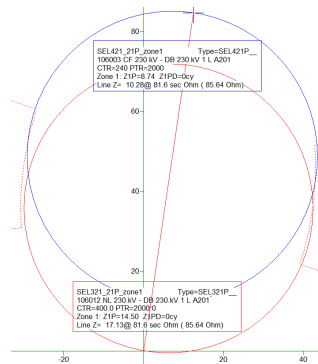


Figure 8 Evaluation of Z1P of CF terminal at NL terminal

## VI. Conclusions

This paper presents comprehensive exams on phase distance relays used in various communications schemes. Phase distance zone 2 in a communication aided scheme is high-speed and subject to meet PRC-026-1 compliance requirement. Permissive tripping supervision from a remote terminal will mitigate or correct a violation. With high speed scheme, evaluation of phase distance zone 2 protection is needed at both local and remote terminals. Similarly, phase distance zone 1, if used in DUTT scheme, needs to be evaluated at both local and remote terminals.

## **VII. References:**

1. NERC PRC-026-1 "*Relay Performance During Stable Power Swings*", North American Electric Reliability Corporation, Version 1, March 17, 2016
2. John Wang & Thanh C. Nguyen, *Understanding and Complying with PRC-026-1: Transmission Relay Performance During Stable Power Swings*, 2019 Western Protective Relay Conference, Spokane, Washington

## Biography

John Wang received his B.S. and M.S. in electrical engineering from Zhejiang University in 1985 and 1988 respectively. He earned a second M.S. in electrical engineering from University of Missouri-Rolla in 1997. He was an assistant professor in Zhejiang University from 1988 to 1994. He joined Basler Electric in 1998, was a principal engineer and had 12 years of experience designing protective relays and supporting customer relay applications. In September 2010, he joined Xcel Energy as a Principal Engineer in System Protection Engineering. Since March 2015, he has been a Principal Engineer at Protection Policy and Support at National Grid. He is a registered professional engineer, a senior member of IEEE, a member of the IEEE Standard Association and IEEE Power Engineering Society.