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A Study on Protection of Cables by Solkor Differential Protection Relay with Fibre Optic Pilot Wireor Metallic Pilot Wire

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ABSTRACT
This paper intends to briefly compare the protection of buried three phase high voltage cable with Solkordifferential protection relay using metallic pilot wires orfibre optic pilot wires.
Dielectric property of the fiber optic provides complete electrical isolation as well as interference free signaling. This provides total immunity from GPR (ground potential rise), longitudinal induction, and differential mode noise coupling andhigh-voltage hazards to personnel safety.
So Fibre optic provides great advantage for Solkor differential protection relaying.
KEYWORDS: Fiber optic pilot wires, Metallic pilot wires, Solkor Differential Protection Relay

I. INTRODUCTION

Solkor Differential protection was developed and now progressed into a microprocessor controlled, differential feeder protection system providing complete protection for cable feeders. Induced voltage is generated on metallic pilot wire installed alongwith power cable. As the core of fibre optic pilot wire is made of glass, which is an insulator, no induced voltage is present.

II. Operation of the differential relay with fibre optic pilot wire

The relay compares magnitude and phase angle of measured currents at either end of protected feeder, it operates for faults detected within the protected Zone, indicated in Fig. 1.

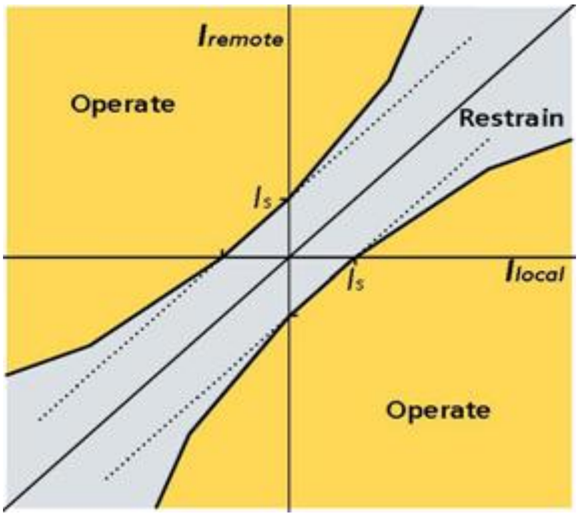


Fig. 1 Differential Protection Operating Characteristic

Thetheory of operation of the differential relay with fiber optic pilot wire isexplained with reference to the simplified schematic diagram inFig. 2.

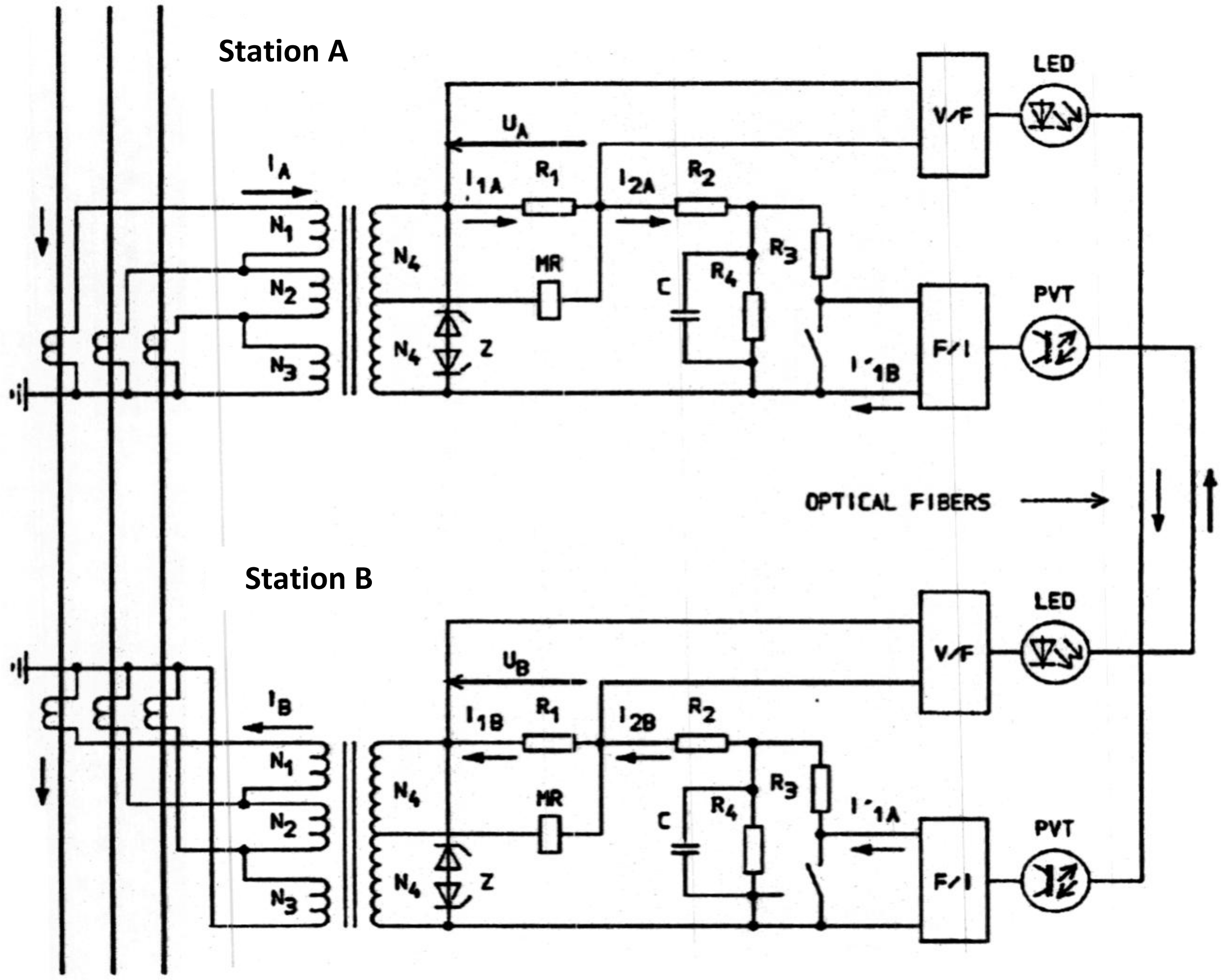


Fig. 2 Simplified schematic diagram

F/I Frequency to Current Converter
MR MeasuringRelay
R1Resistor 500 ohms
V/F Voltage to Frequency Converter
R2 Resistor 470 ohms
LED Light Source
R3 Resistor 30 ohms
PVT Light Sensing Detector
R4 Resistor 2.7 kohms
C Capacitor, 0.68 µF
TR Summation Transformer
Z Zener Diodes

A balanced 3-phase through current gives the following secondary currents:

$$I_{1A} = \bar{I}_{1B} = I_R \cdot \frac{NI + N2}{1920} + I_S . \frac{N2}{1920} + (\bar{I}_R + \bar{I}_s + \bar{I}_T) . \frac{N3}{1920}$$

$$\frac{N1 + N2}{1920} . \bar{I}_R + \frac{N2}{1920} . \bar{I}_S$$

Since $\bar{I}_R + \bar{I}_s + \bar{I}_T = 0$

The summation transformer with rated current $I_n = 5$ A has the following turn ratios:

$$N_1 = 4\ t\ , N_2 = 4\ t, N_3 = 12\ t, N_4 = 960\ t$$

Hence, for balanced 3-phase secondary current 5 A:

$$I_{1A} = I_{1B} = \frac{(4+4)\ .5}{1920} + \frac{4.5}{1920}(-0.5 - j\ 0.866) = 0.018\ A$$

The voltage to frequency converter (V/F) for relay in Station A receives a voltage which is proportional to the current I_{1A} via the optical fiber link and the frequency to current converter (F/I) of relay in Station B, the current I'_{1A}, equal to I_{1A} in magnitude and with only a small phase angle shift (~5°) is injected in relay for Station B. Similarly, a current I_{1B}, equal to I'_{1B} in magnitude and only with a small phase angle shift is injected in relay for Station A.

Hence, in case of through currents which are equal in Stations A and B, the secondary currents I_{1A} and I_{1B} are equal, and the currents I_{2A} and I_{2B} have the same magnitude and only a phase angle difference of about 5° relative the Currents I_{1A} and I_{1B}. The current through the measuring relay (MR) will be negligible.
The measuring relay (MR) operates when the relay current is 10-11 mA.

2.1 Requirements on the fibre optic wires

The protection relay is designed for 50 μm core, 125 μm cladding, graded index multi mode communication fiber with wavelength 850 nm or 1300 nm.

If the fiber is "double-window" (specified at both 850 nm and 1300 nm), then a Wavelength Division Multiplexing (WDM) application is possible. With optical couplers and decouplers, the protection relay can communicate via a direct, all-optical medium at 1300 nm while over the same fiber pair and at the very same time, non-protective functions, including very-high-bit-rate computer data, can be time division multiplexed at 850 nm wavelength.

For multi mode fibers, the following figures for coupled optical power (min value) and receiver sensitivity are valid:

850 nm:	Optical power coupled:	19 dB (80 μW)
	receiver sensitivity:	-5 dB 320 (nW)
	total system gain:	24 dB
1300 nm:	Optical power coupled:	15.4 dB (35 μW)
	receiver sensitivity:	-12.6 dB (55 nW)
	total system gain:	28 dB

A system margin of 5 dB is recommended.
Hence, the maximum permissible system loss is 19 dB for 850 nm multimode and 23 dB for 1300 nm multimode systems.

Examples on typical calculations are given below.
Ex. 1: Fiber Optic System Loss Tabulation for 850 nm System
LED optical power coupled (minimum) 80 μW= 19 dBμ

Connector loss = 2.0 dB
Fiber loss:

Attenuation 4.8 Km (3 Miles)

(3 dB/Km)	=	14.5 dB
Splices 3 x 0.5 dB	=	1.5 dB
Exit loss	=	0.2 dB
System Margin	=	5.0 dB
Total loss	=	23.2 dBμ
Received power	=	-4.2 dBμ
Receiver sensitivity	=	-5 dBμ
Excess power	=	0.8 dBμ

Ex. 2: Fiber Optic System Loss Tabulation for 1300 nm System
LED optical power coupled (minimum) 15.4 dBμ

Connector loss = 2.0 dB
Fiber loss:
Attenuation 20 Km (12.4 miles)

(1.0 dB/Km	=	20.0 dB
Splices 3 x 0.2 dB	=	0.6 dB

Exit loss	=	0.2 dB
System Margin	=	5.0 dB
Total loss	=	25.8 dBμ
Received power	=	- 10.4 dBμ
Receiver sensitivity	=	-12.6 dBμ
Excess power	=	2.2 dBμ

2.2Requirements on the current transformers

For stability in case of external faults with large through fault currents, the CT's at both line ends should be of the same type and have approximately the same saturation factor (ALF) at the actual secondary load.

The current transformer secondary limiting emf (E_{2max}) shall meet the requirement.

$$\geq I_{Kmax} \cdot a \cdot \frac{Isn}{Ipn} \cdot \frac{5}{I_N 2} + R_{CT} + R_L$$

where
a = 1 for 50 Hz
a = 1.6 for 60 Hz

I_{Kmax} = max. Fundamental frequency current fed into the line end in case of internal fault.
I_{sn} = rated secondary current of the CT
I_{pn} = rated primarycurrent of the CT
R_{CT} = CT secondary winding resistance
R_L = Secondary winding resistance (loop resistance for direct earthed systems) and additional load on the same core as protection relay.
For the above requirement, a dc time-constant of max 120 ms for the net is assumed.

III. Operation of the differential relay with metallic pilot wire

The theory of operation of the differential relay with metallic pilot wire (SolkorRf) isexplained with reference to the simplified schematic diagram in Fig. 3.

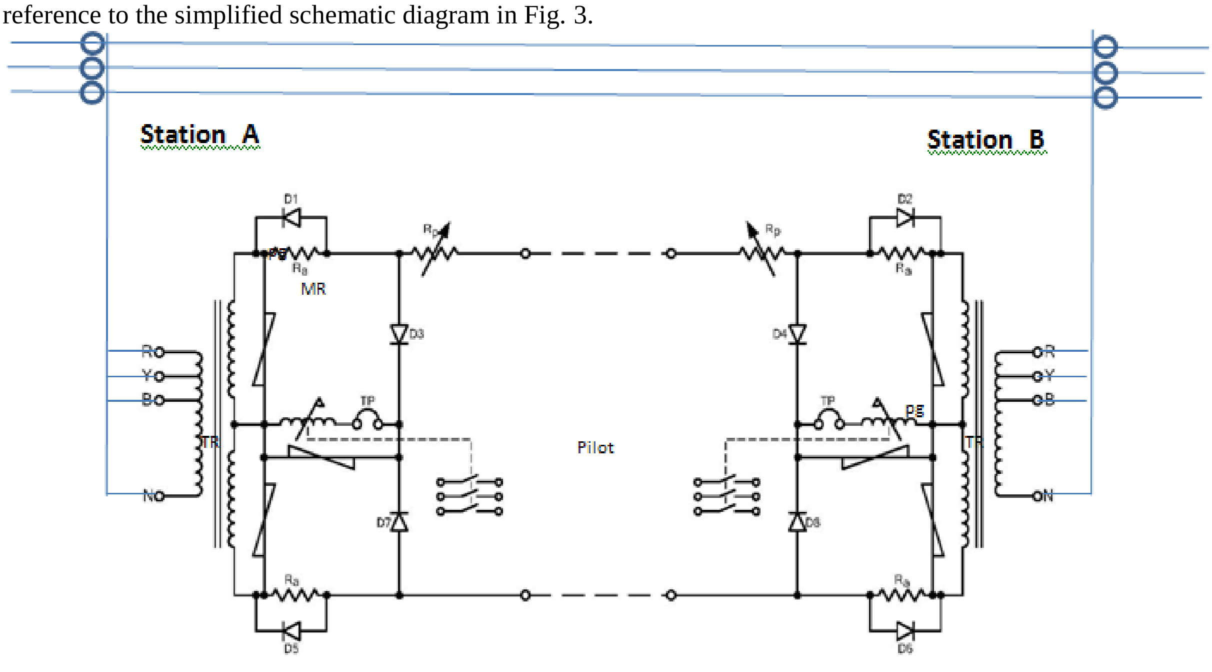


Figure 3.SolkorRf Schematic

D1,D2,D3,D4,D5,D6,D7,D8- DIODES
Pg- Non Leaners Resistor

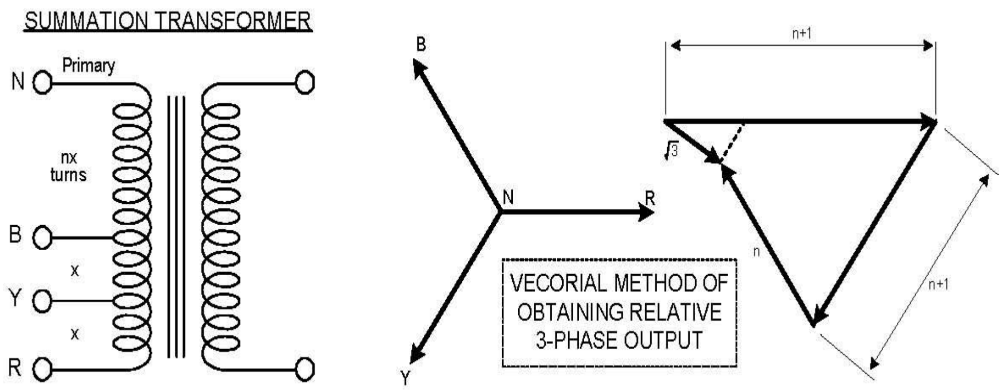
Ra - Fixed Standard Resistor.
Rp - Padding Resistor.
TR - Summation Transformer
MR - Measuring relay

In addition to the basic components there are at each end, three non-linear resistors, a tapped ‘pg’ resistor and three diodes. The non-linear resistors are used to limit the voltage appearing across the pilots and the operating element. The purpose of the ‘padding’ resistors at each end is to bring the total pilot loop resistance up to a standard value. The protection is therefore always working under constant conditions and its performance is to a large extent of the resistance of the pilot cable’ The ‘padding’ resistors comprise five series connected sections, each section having a short circuiting link. The values of the resistance on the sections are 35 ohms, 65 ohms, 130 ohms, 260ohms and 500ohms.

For SolkorRf without isolating transformers the value chosen should be as near as possible to ½(2000-Rp) ohms.

Referring to the basic circuit of SolkorRf as shown in Figure 3, the circulating current will flow from the summation transformer through the diode or the resistor depending on the polarity of the summation transformer output.

The main purpose of the summation transformer is to enable either balanced or unbalanced three phase currents to be re-produced as a single phase quantityas shown in Figure 4.
As this device is essentially a transformer it can also be used to reduce the burden imposed by the pilot circuit on the current transformers by changing the
impedance levels. it provides isolation between the current transformers and the pilot circuit.



Fault Type	Effective Primary Ampere-turns	Relative Output
R-E	I(nx + x + x) = Ix. (n+2)	n+2
Y-E	I(nx + x) = Ix. (n+1)	n+1
B-E	I(nx) = Ix. (n)	n
R-Y	I(x) = Ix. (1)	1
Y-B	I(x) = Ix. (1)	1
B-R	I(2x) = Ix. (2)	2
3P	I(√3x) = Ix. (√3)	√3

Figure 4.Summation transformer

Pilot wires are exposed to a number of hazards that can interfere with the proper operation of the scheme or cause damage to the pilot circuit and associated equipment. The most common hazards are:

1. Rise in station ground potential (GPR).

2. Induced voltages.
3. Lightning.

A substantial voltage rise can occur at the substation ground mat relative to the remote ground potential. This voltage rise can cause excessive insulation stresses on the pilot wire relay, the pilot wire monitoring relay, the pilot wires, and between pilot wires and other conductors in the same cable.

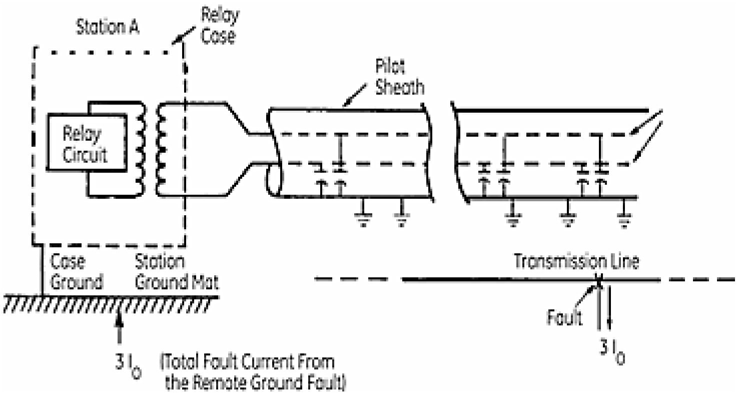


Fig 5. - *Station mat .ground potential rise*

As illustrated in Figure 4, the typical condition resulting in ground potential rise is a single-phase-to-ground fault on the power system. With ground current flowing through the Station A ground mat, there will be a voltage difference between this mat and the remote ground potential. The magnitude of this voltage depends on the magnitude of the current and on the impedance between the station ground and the remote ground. The value of the ground current is usually available from system fault studies. The impedance between the mat and the remote ground is determined by calculation or test.

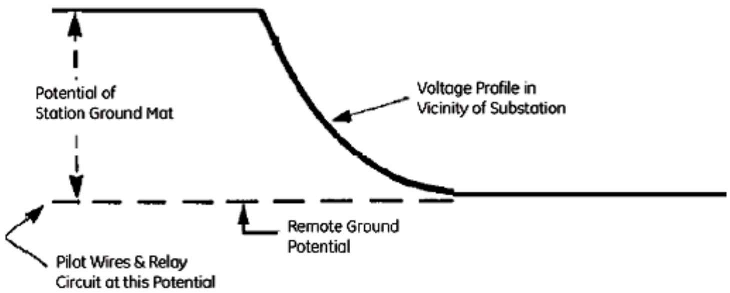


Fig 6.*Typical Ground Potential Profile During SLG Fault*

The diagram in Figure 5 represents a typical voltage profile of the potential difference between the pilot cable and ground during a single-phase-to-ground fault. As is apparent from the plot, the potential of earth near the pilot wire cable tends to be at the remote ground potential for most of the length of the pilot run. Hence, if the cable is not grounded, it will assume a potential near that of the remote ground because of the capacitive coupling. Thus, the potential rise of the station ground mat results in a significant voltage difference between the station ground mat and the pilot cable with its connected station equipment. If this voltage difference becomes too great, there is danger to personnel and the possibility of damage to the pilot wire relays, the connected equipment, and the pilot wire itself. If this voltage difference exceeds 600 volts, protection of the pilot wires is usually necessary since this is the continuous voltage insulation level of the connected relays, terminal boards, panels and standard telephone cables.

The value of the induced voltage in metallic pilot wires is calculated using the following formula.

$$V = C.L.i.K$$

Where: V induced longitudinal voltage [V]

C mutual impedance per unit length [ohm/km]

L length of exposure (between power and communication cable) [km]

i fault current [A]

K shielding factor {K-1 for no shielding}

The mutual impedance, C of two parallel circuits having earth returns is given by

$$C = 2\pi f \left| log_e(1 + \frac{6\,x10^5 p}{d^2 f}) \right| x10^{-4}\ [ohm/km]$$

Where: d geometric separation between earth return circuits in metres

p earth resistivity in ohm-metres

f system frequency in Hz

If the shield is not grounded on both ends the shield current is zero and the shielding factor K is 1.

IV. Comparison between SolkorR/RF relay uses metallic pilot wires&SolkorNrelay uses Fibre optic pilot wires

Table.1

S.NO.	DESCRIPTION	SOLKOR-R/RF WITH METALLIC PILOT WIRES	SOLKOR-N WITH FIBRE OPTIC PILOT WIRES
1)	Circuit type	Static / Electro-Mechanical	Numerical
2)	Barrier Transformer	Required for higher Voltage level	Not required
3)	CT Ratio both side	To be same	With Different CT ratio, it can be programmable to match with other END.
4)	Pilot Supervision	Separate relay required	Inbuilt
5)	Padding Resistance	To set value according to pilot resistance	Not required
6)	Pickup	Different Values for Each Phases	Same for all Phases
7)	Metering	Not possible	Measurement display available
8)	Trip circuit supervision	Not possible	Available
9)	Breaker failure	Not possible	Available
10)	Fault recorder	Not possible	Available
11)	Protection Signal Delay	Not possible	Available
12)	Programmable Out put	Not possible	Available
13)	Distance	Shorter	Longer
14)	Immunity, Reliability, Safety	Less	High

V. Comparison of Site Test Results between Solkor R/RF relay uses metallic pilot wires &Solkor Nrelay uses Fibre optic pilot wires

Site Test results are tabulated as below for Solkor R/RF relay uses metallic pilot wires &Solkor N relay uses Fibre optic pilot wires

5.1SolkorRf mode in 7PG21 relay of Siemens makeuses metallic pilot wires

Table.2

Phase	Injected Current (A)	Operating DC Current (mA)	Pilot AC Voltage(V)	Relay Operation	Pilot Circuit
R-N	0.125	11.35	45.22	TRIP	OPEN
Y-N	0.154	11.35	45.20	TRIP	OPEN
B-N	0.206	11.27	45.20	TRIP	OPEN
R-Y	0.616	11.27	45.12	TRIP	OPEN
Y-B	0.616	11.28	45.13	TRIP	OPEN
R-B	0.308	11.27	45.13	TRIP	OPEN
R-N	1.0	0	0	NO TRIP	SHORT
R-N	1.0	41.03	135.8	TRIP	OPEN

Operating Time at 1A: R-N : 28.9 mSec

5.2 Solkor N 7SG18 relay of Siemens make uses Fibre optic pilot wires

Idiff> Pick up Test: Diff. Setting=1.0

Table.3

Station	Phase	Pick-Up (A)	Drop-Off (A)
Station A	R	0.998	0.936
	Y	0.998	0.939
	B	1.003	0.939

Differential Biasing Characteristic Test:

Table.4

Ib/In	Calculated Id/In		Operated Id/In			
	Ph-E	3Ph	R	Y	B	RYB
1.0	1.250	1.250	1.247	1.247	1.247	1.235
2.0	1.750	1.750	1.618	1.618	1.627	1.618
3.0	2.750	2.750	3.00	2.994	3.00	3.00
4.0	4.250	4.250	4.433	4.637	4.645	4.552

Idiff> Timing Test:

Table.5

Station	Injected Current	Idiff> Operating Time (mSec)			
		R	Y	B	RYB
Station A	2*Idiff	47	45	48	47
	5*Idiff	36	38	36	39

VI. CONCLUSION

Protection of buried three phase High Voltage cable is studied with differential relay using metallic pilot wires and fibre optic pilot wires.

Fibre optic pilot wire provides total safety for operating personnel from High Voltage hazards due to induced voltages. In addition to this, the numerical relay which uses fibre optic has advanced features such as measurements with display, event records, fault records and compatibility for smart grid substations.Fibre optic pilot wire can be incorporated into network in planned upgrades.

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