4. Fault Indicators

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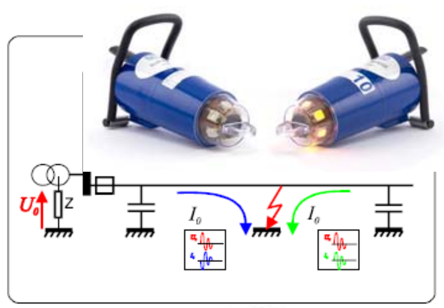
Fault Indicators



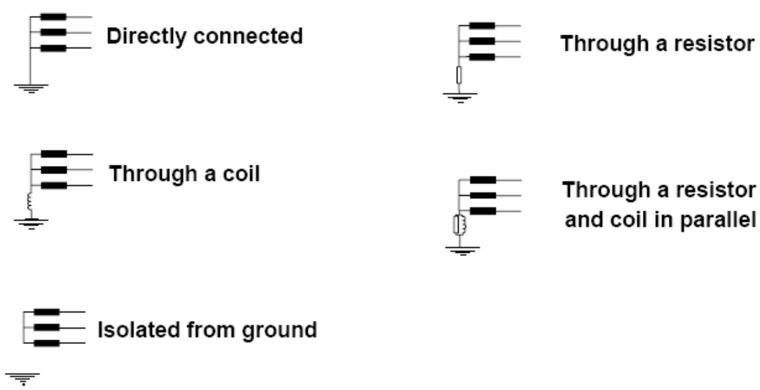

Clip-on mounted Flite 110


Pole mounted Flite 210

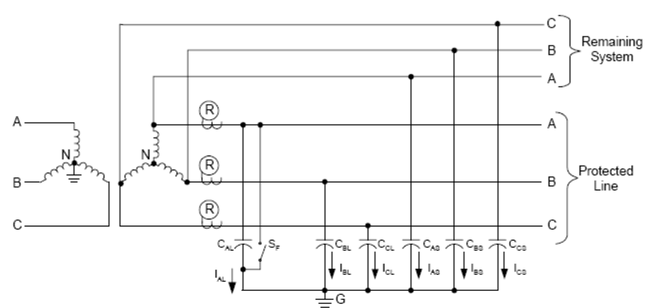

Easergy T200I

Grounding Conditions

- Affects the fault current



Ungrounded Network



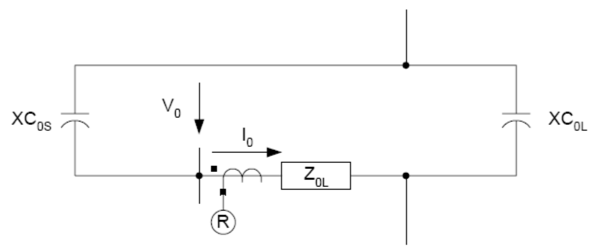
Three-Phase Simplified Representation of an Ungrounded Network

$$\vec{I}_{AL} + \vec{I}_{BL} + \vec{I}_{CL} + \vec{I}_{AS} + \vec{I}_{BS} + \vec{I}_{CS} = 0$$

$$3\vec{I}_{0L} = \vec{I}_{AL} + \vec{I}_{BL} + \vec{I}_{CL} = -(\vec{I}_{AS} + \vec{I}_{BS} + \vec{I}_{CS})$$

$$I_F = \vec{I}_{AL} = -(\vec{I}_{BL} + \vec{I}_{CL} + \vec{I}_{AS} + \vec{I}_{BS} + \vec{I}_{CS})$$

Ungrounded Network – Sequence Analysis

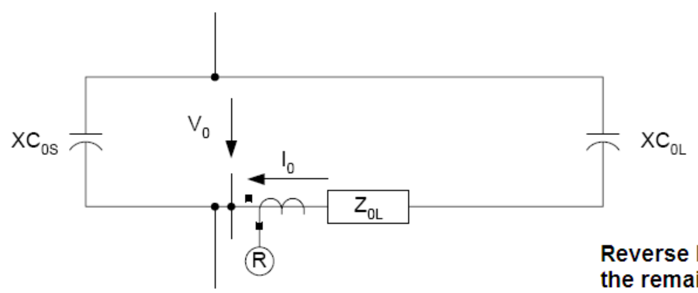


Foreward Fault (Sf closed)

$V_O = -I_O * (-jXC_{OS}) = j\,XC_{OS}\,I_O$

Therefore, for forwarding fault: $Z_O = V_O / I_O = +XC_{OS}$

Reverse Fault



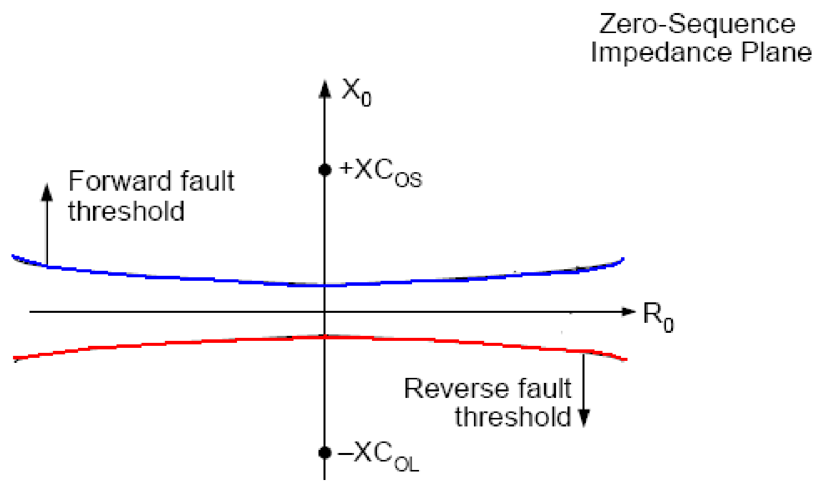
Reverse Fault (Fault at the remaining ssytem)

$-V_O = -I_O\,(Z_{OL} - j\,X\,C_{OL}) = -I_O\,Z_{OL} + j\,X\,C_{OL} * I_O$

$V_O = -j\,X\,C_{OL} * I_O$ ← Considering XC ol >> Z oL

Therefore, for reverse fault: $Z_O = V_O / I_O = -XC_{OL}$

Zero-Seq Impedance Plane Directional Element

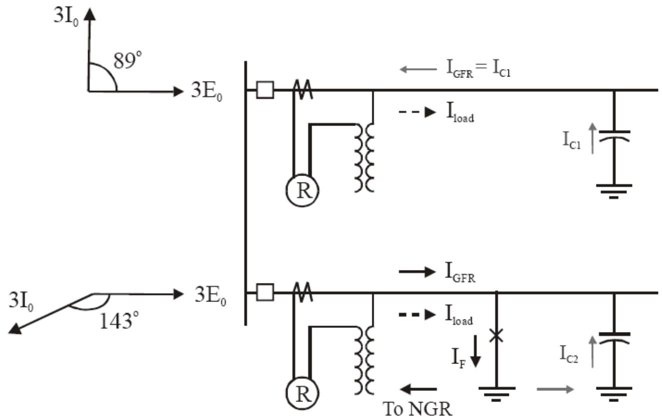


Fault Detection/Direction Method for Compensated Networks

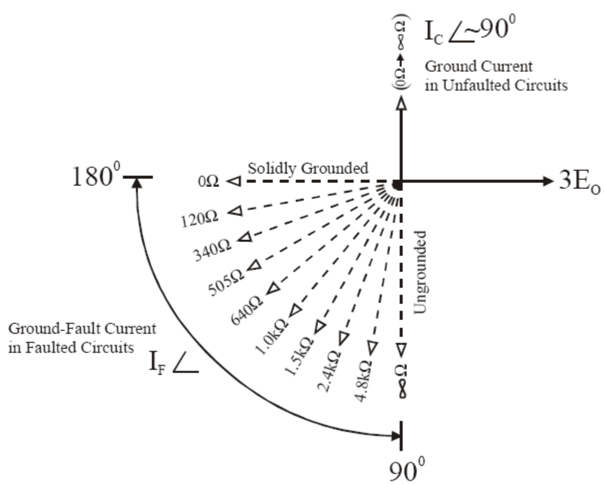
- Voltage Detection
  - Zero-Sequence Voltage (V_0)
  - Phase-to-Ground Voltage
  - Incremental Zero-Sequence Voltage (ΔV_o)
- Wattmetric Method (Real Current)
- Zero Sequence Directional Relay Approach
- Conductance Method

Zero Sequence Directional in Iº and Vº Plane

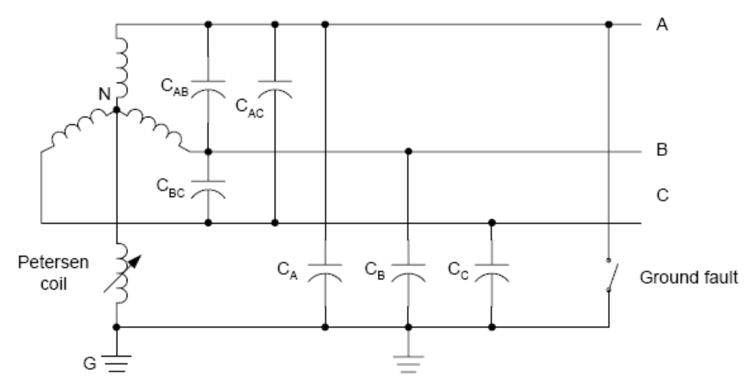
- Zero-Sequence Directional Relay – classical solution



Forward Fault dependence on grounding type



Compensated System Network – Analysis



Compensated System

Patented Idea

(12) **United States Patent**
Roberts et al.

(10) **Patent No.:** **US 6,573,726 B1**
(45) **Date of Patent:** **Jun. 3, 2003**

(54) **SENSITIVE GROUND FAULT DETECTION SYSTEM FOR USE IN COMPENSATED ELECTRIC POWER DISTRIBUTION NETWORKS**

(75) Inventors: **Jeffrey B. Roberts**, Viola, ID (US); **Daqing Hou**, Pullman, WA (US); **Hector Altuve-Ferrer**, Nuevo Leon (MX)

(73) Assignee: **Schweitzer Engineering Laboratories, Inc.**, WA (US)

5,455,776 A * 10/1995 Novosel 364/492
5,694,281 A * 12/1997 Roberts et al. 361/80
6,229,679 B1 * 5/2001 Macbeth 361/42

* cited by examiner

Primary Examiner—Safet Metjahic
Assistant Examiner—Etienne LeRoux
(74) *Attorney, Agent, or Firm*—Jensen & Puntigam, P.S.

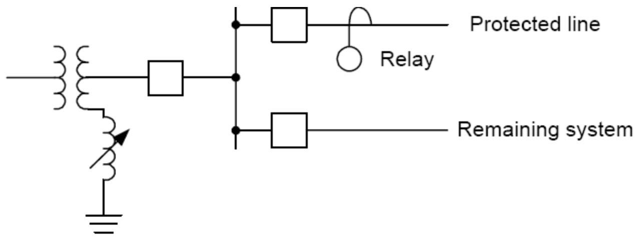
(57) **ABSTRACT**

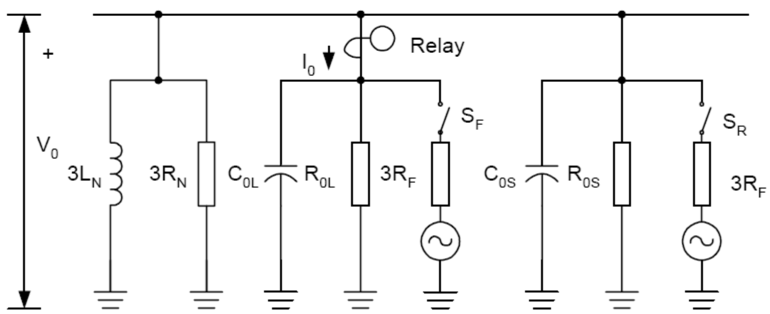
...tem for detecting ground faults in a compensated ...c power distribution network includes the determina... ...f zero sequence voltage (V_0) and zero sequence current ...n a power line and calculating the zero sequence ...ctance (G_0) therefrom. The operation of the conduc... calculation circuit occurs only under selected power ...nditions involving minimum values of zero sequence

What is claimed is:

1. A system for detecting ground faults in a compensated distribution network, comprising:
   - means for determining the zero sequence voltage (V_0) and zero sequence current (I_0) on a power line;
   - a calculation system for calculating therefrom a conductance or resistance value from the real parts of said zero sequence voltage and zero sequence current;
   - circuitry for enabling the operation of the calculating system for only preselected power line conditions; and
   - means for comparing the conductance or resistance value against a first threshold value to determine a forward fault and a second threshold value to determine a reverse fault.

Single-Line and Sequence Diagrams

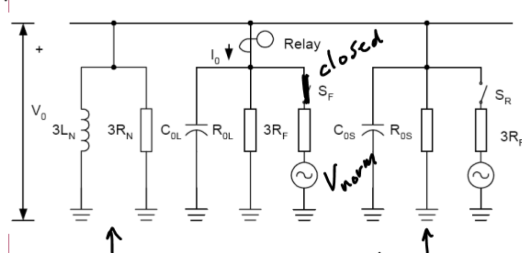




Compensated Network (Forward Fault)

Forward Fault Case:

$\bar{I}_0$ is divided into 2 branches.



$$Z_N = \frac{j9R_N\omega L_N}{3R_N+3j\omega L_N} = \frac{j3R_N\omega L_N}{R_N+j\omega L_N}$$

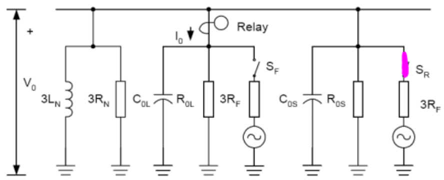
$$Z_S = \frac{-j\frac{R_{0S}}{\omega C_{0S}}}{R_{0S}-j/\omega C_{0S}}$$

$$V_0 = -I_0\left(\frac{Z_S}{Z_N+Z_S}\right)\cdot Z_N = -I_0\frac{Z_S\cdot Z_N}{Z_N+Z_S}$$

$$\rightarrow I_0 = -V_0\left[\left(\frac{1}{R_{0S}}+\frac{1}{3R_N}\right)+j\left(\omega C_{0S}-\frac{1}{3\omega L_N}\right)\right]$$

Compensated Network (Reverse Fault)

Reverse Fault Case:



I_0 flows through C_{0L} and R_{0L}.

$$Y_L = \frac{1}{R_{0L}} + j\omega C_{0L}$$

$$I_0 = V_0\left[\frac{1}{R_{0L}} + j\omega C_{0L}\right] \quad \text{(Reverse fault)}$$

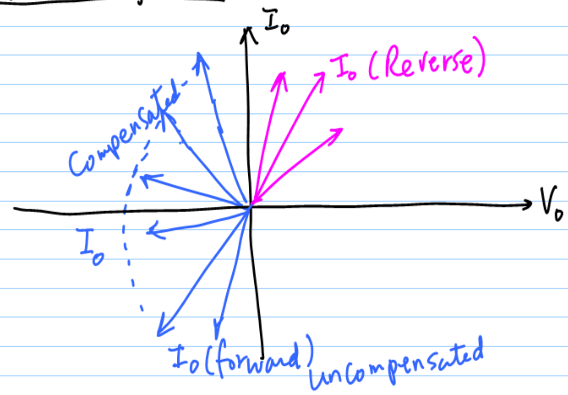
cf) $R_N = L_N \to \infty$ in forward fault.

$$\rightarrow I_0 = -V_0\left[\left(\frac{1}{R_{0S}} + \frac{1}{3R_N}\right) + j\left(\omega C_{0S} - \frac{1}{3\omega L_N}\right)\right]$$

$$= -V_0\left[\frac{1}{R_{0S}} + j\omega C_{0S}\right]$$

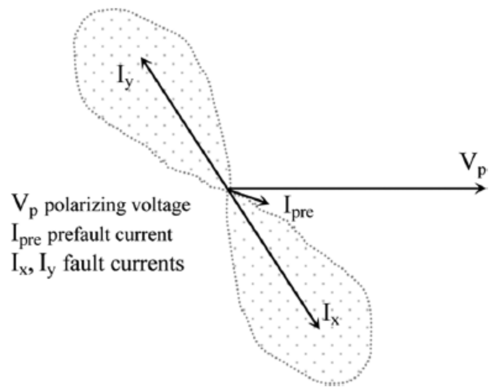
Directionality Phasor Diagram

Phasor Diagram



Sequence Current Phase-Change Method

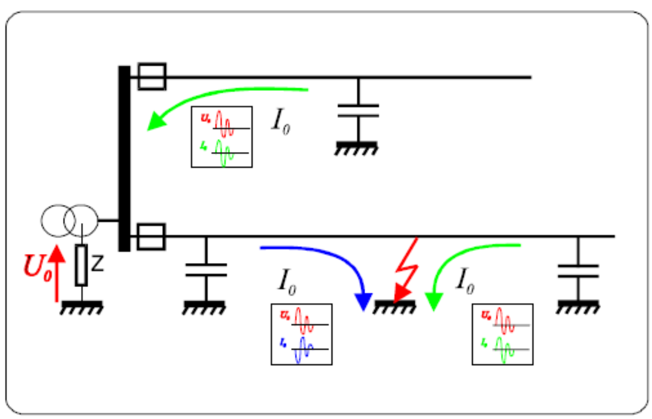
- Phase voltage and current



Fault current regions for directional comparison.

Zero-Sequence Phase Change

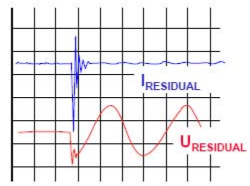
- Fault Direction



Fault Direction Indicator

PTG FAULT AND ANALYZING OF THE DIRECTION

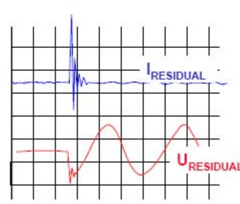
If the PTG fault occurs 'upstream' the LineTroll 3500 we may have residual figures as shown in the next figure



FI

PTG FAULT AND ANALYZING OF THE DIRECTION

If the PTG fault occurs 'downstream' the LineTroll 3500 we may have residual figures as shown in the next figure



Wattmetric Relay Element

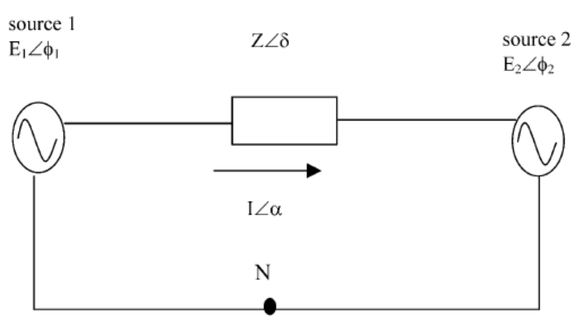
$$W = Re[V_0 \cdot I_0^*] = V_0 I_0 \cos\phi$$

with positive threshold & negative threshold

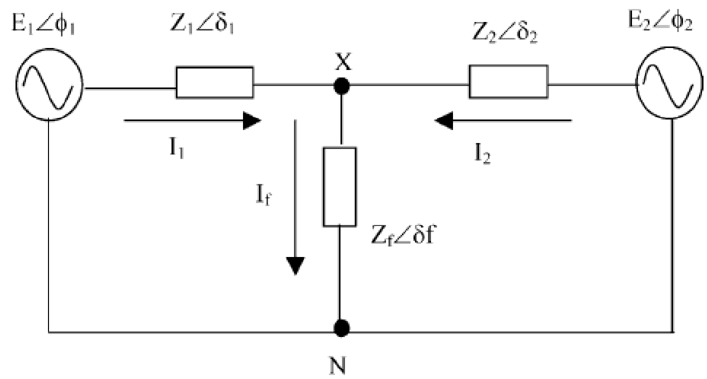
- Has been used for many years for compensated networks.
- Simple, secure, dependable (for low resistance faults)
- The requirement of sensitive detection of V_o is a limit for high resistance faults.
- Dependent on CT accuracy

Real Current Component Method

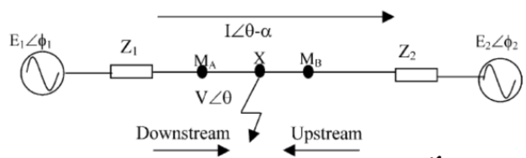
- Determination of voltage sag source by the phase angle difference between current and voltage.
- Two Source System at Pre-fault condition



At Fault Condition



Equivalent Circuit (Rf=0)



M_A, M_B : measuring points

$$\bar{V}_{M_A} = \bar{E}_1 - \bar{I}\,\bar{Z}_1 \xrightarrow{I^*} \bar{V}_{M_A}\bar{I}^* = \bar{E}_1\bar{I}^* - |I|^2\bar{Z}_1$$

Real Part: $VI\cos(\theta-\alpha) = E_1 I\cos(\phi_1-\alpha) - I^2R_1$

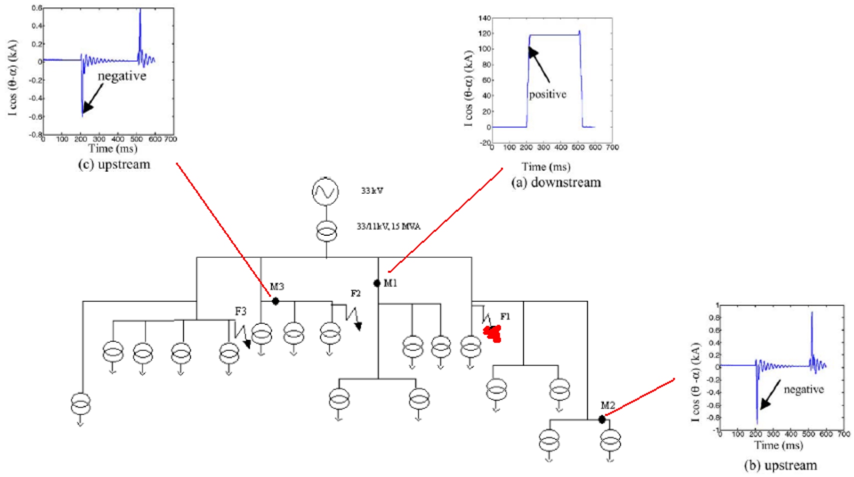
θ : phase angle for voltage @ M_A

α : phase angle of current @ M_A

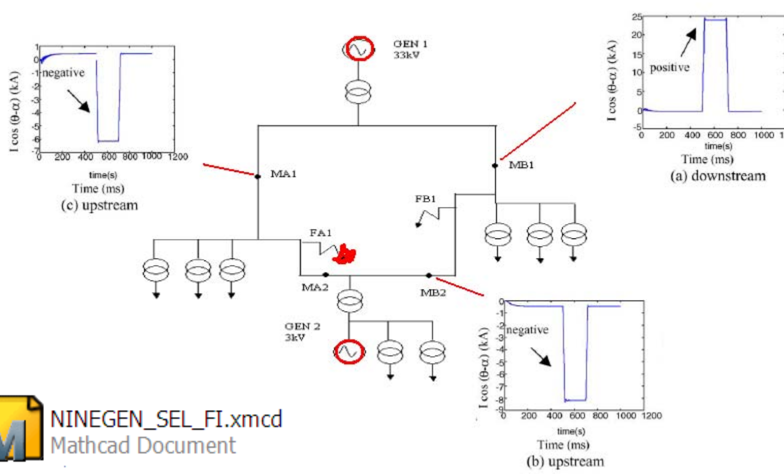
Downstream $I\cos(\theta-\alpha) > 0$. Power flow →

Upstream $I\cos(\theta-\alpha) < 0$. power flow ←

Example 1



Example 2

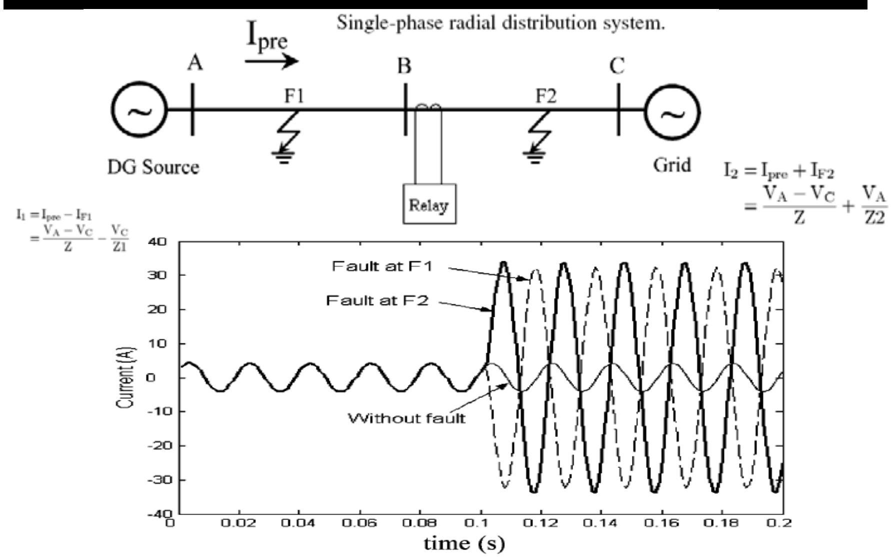


NINEGEN_SEL_FI.xmcd
Mathcad Document

Phase Current Phasor Change Approach -Principle

- A directional relay algorithm for radial systems using current signals only – phasor change in current between normal and fault
- The direction of a fault can be determined by finding the difference in angle of positive-sequence current phasors from fault and pre-fault data.
- Voltage information (at the **relay point**) is required.

Phase Current Phase Change Approach-Example



Different current waveforms at the secondary of CT.

Example Case

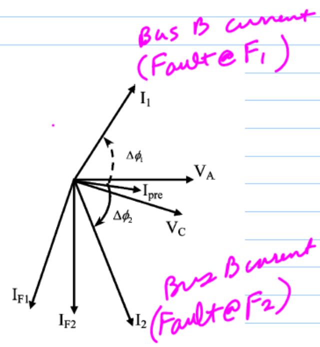


TABLE I
CURRENT PHASOR DATA FOR SINGLE-PHASE SYSTEM, FAULT AT 0.1 s

Fault position	Fault		Prefault		Difference	
	Mag (A)	Angle (rad)	Mag (A)	Angle (rad)	Mag (A)	Angle (rad)
F1	11.6	0.25	1.4	-1.34	10.2	**1.59**
F2	11.9	-2.11	1.4	-1.34	10.5	**-1.37**

TABLE II
CURRENT PHASOR DATA FOR THE SINGLE-PHASE SYSTEM, FAULT AT 0.11 s

Fault position	Fault		Prefault		Difference	
	Mag (A)	Angle (rad)	Mag (A)	Angle (rad)	Mag (A)	Angle (rad)
F1	11.6	-2.89	1.4	1.80	10.2	**1.59**
F2	11.9	0.43	1.4	1.80	10.5	**-1.37**

How about this patented method?

US005796259A

United States Patent [19]
Dickmander

[11] **Patent Number: 5,796,259**
[45] **Date of Patent: Aug. 18, 1998**

[54] **METHODS AND APPARATUS FOR DETECTION OF FAULT DIRECTION**

[75] Inventor: **David L. Dickmander**, Cary, N.C.

[73] Assignee: **ABB Power T&D Company, Inc.**, Raleigh, N.C.

[21] Appl.
[22] Filed:
[51] **Int. C**
[52] **U.S. (**
[58] **Field**
[56]

Primary Examiner—Glenn W. Brown
Attorney, Agent, or Firm—Woodcock Washburn Kurtz Mackiewicz & Norris LLP

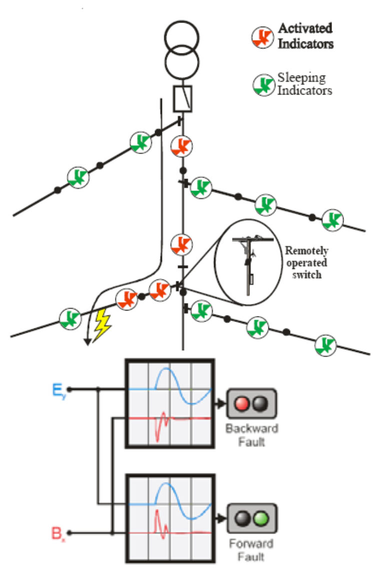
[57] **ABSTRACT**

Apparatus and methods for detecting the direction of a fault in relation to a switch connected between a source and a load ...r for generating ...nd power cycles. ...e current during ...or compares the ...current samples ... the sign of the ...comparator com-...cycle to the sign ...first comparator ...ion in relation to ...des a fault incep-...tion indication in ...first and second ...omparator which

Generally, the invention determines fault direction based on observations of the voltage and current conditions at the fault inception instant. More particularly, the invention determines that fault direction is downstream if at the fault instant the polarity of the current deviation between the present cycle and the prior cycle is in the same direction as the measured voltage. For example, if the voltage has a positive polarity, a downstream fault will cause the present cycle current to deviate from the prior cycle current in the positive direction. If the voltage has a negative polarity, a downstream fault will cause the present cycle current to deviate from the prior cycle current in the negative direction.

Electric/Magnetic Field of Transient Wave from Earth Fault

- Discharging/Recharging transients during the initiation of the fault are used to detect the direction to the fault in compensated and isolated networks.
- Peterson coil acts as high impedance to the transients, making the transients intact, not affected.
- E (~voltage)
- B (~Current)

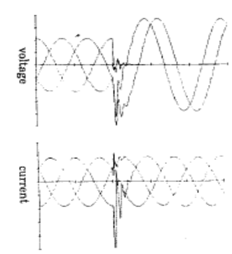


Transient Measurement

- Earth fault traveling wave has long been recognized for fault detection.
- Utilized by so-called "Wischer relay" (Transient Measurement) when all other detection methods have failed in compensated networks.
- Indicator: transients due to phase-to-ground fault. Redistribution of the phase-to-ground voltage is forced throughout the whole system.
- Make use of slower subsequent transient oscillations.
- Two types of transients
  - Discharge Transient (of the faulty conductor)
  - Recharging Transient (of the healthy conductor)

Using the EMTP and the Omicron for Developing and Testing a Transient Based Digital Ground-Fault Relay for Isolated or Compensated Networks

J. Coemans J.-C. Maun
Electrical Engineering Department
Free University of Brussels (ULB)
Belgium



: Typical voltage and current waveforms during an earth fault

A transients based directional function is already available in SIEMENS 7SN71 relay. The behaviour of this static non digital relay can be summarized as follows :

- startup condition : a fault is detected if 50Hz zero-sequence voltage is present for more than 70 milliseconds.
- directional checking : basically, the directional function relies on the transient behaviour of the zero-sequence voltage and current after the fault inception; indeed, the fault direction is determined by the sign of the power flow $I_0(t)*V_0(t)$ during the first alternance of the induced transients.

Discharging Transient

- Discharging transient
  - On faulty conductor
  - Charge is drained off
  - Ground is conducted to its entire length
  - Initial part of this charge is the traveling wave that passes along the faulty conductor and discharges it to ground.
  - The termination of the line ends determines the degree of reflection and damping
  - This transient is effectively damped out by skin-effect in cables and lines and by the load of the connected distribution transformer along the line.

Recharging Transient

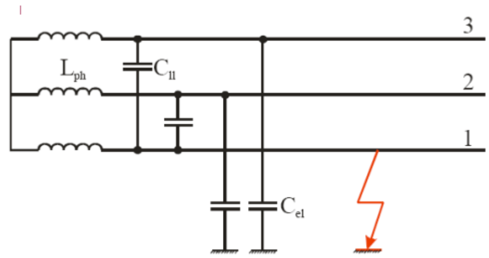
- Recharging transient
  - Recharging of the healthy conductors
  - The transport of the charge from the ground to the healthy conductors is established through the inductance/windings of connected equipment (transformers).
  - This becomes much lower frequency than the discharging transient
  - This charge will initiate a damped oscillation into the steady state fault situation.

Natural frequency of recharging transient

$$\omega_n = \sqrt{\frac{1}{L_{tot} \cdot C_{tot}}}$$

L_{tot} : Total inductance of network

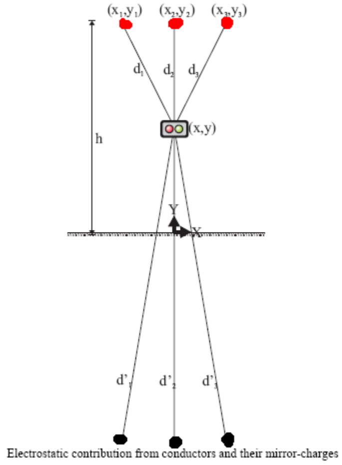
C_{tot} : Total capacitance (Inter-phase C's are ignored)



Equivalent circuit for the recharging transient

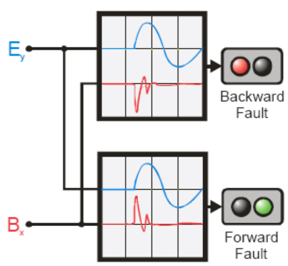
A new measurement method for a FI

- Electromagnetic field below the line (in order to distinguish faults from other switching operations.)
  - Horizontal component of magnetic field (substitute for zero sequence current)
  - Vertical component of electric field (substitute for zero sequence voltage)
- Contribution from each conductor is summed up to calculate the total electric field and magnetic field in the position of the fault indicator.

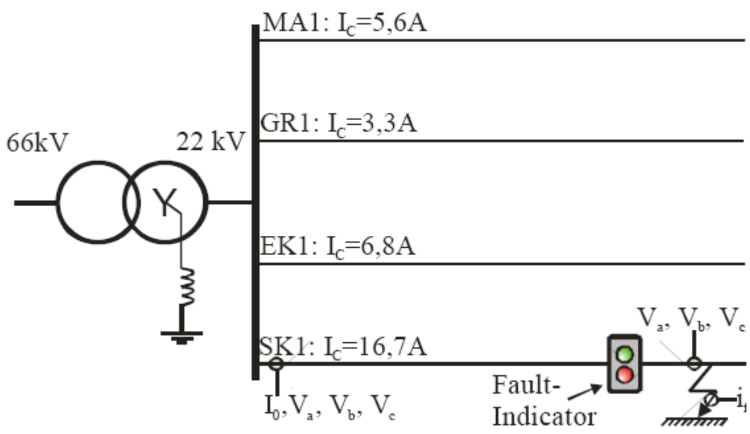


Fault Indication/Direction

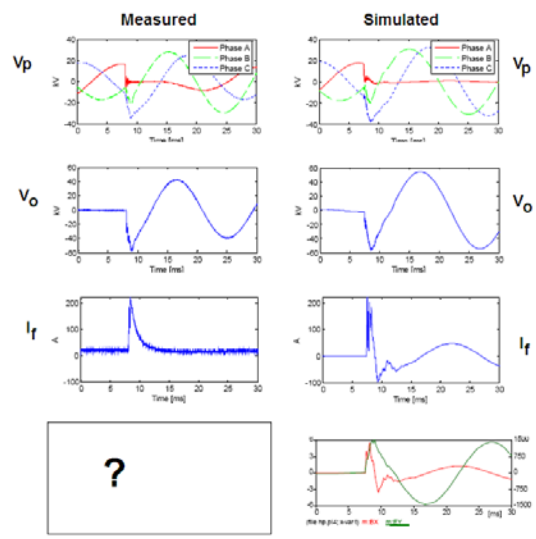
- Comparison of the polarity between the measured voltage-(vertical component of electrical field: Ey) and current transient (horizontal component of flux density: Bx).
- If the two transients are in phase, the fault is considered to be a forward fault (downstream if the indicator is facing the feeder), and if the two transients are in opposite phase, the fault is considered a backward fault (upstream).



Field Test



Measurement/Simulation at Fault Site



Forward Fault

Surge Based Direction Discrimination

United States Patent [19]
Johns

[11] **Patent Number:** **4,922,368**
[45] **Date of Patent:** **May 1, 1990**

[54] **METHOD AND APPARATUS FOR DETECTING AND DISCRIMINATING FAULTS IN TRANSMISSION CIRCUITS**

[75] Inventor: **Allan T. Johns,** Swindon, England

[73] Assignee: **National Research Development Corporation,** London, England

[21] Appl. No.: **275,723**

[22] Filed: **Nov. 23, 1988**

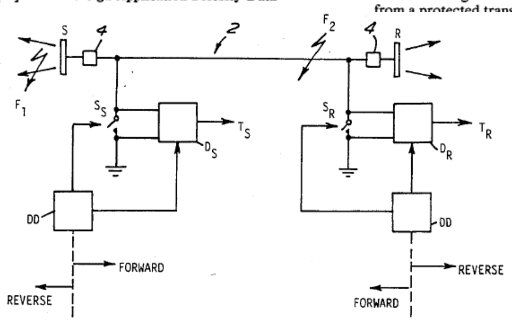
[30] **Foreign Application Priority Data**

tions on Power Delivery, vol. PWRD-1, No. 3, Jul. 1986.
Aucoin et al., "Distribution Impedance Fault Detection Utilizing High Frequency Current Components", IEEE Transactions of Power Apparatus and Systems, vol. PAS-101, No. 6, Jun. 1982.

Primary Examiner—Derek S. Jennings
Attorney, Agent, or Firm—Cushman, Darby & Cushman

[57] **ABSTRACT**

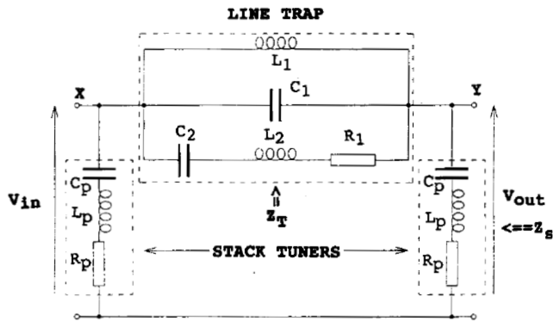
Discriminating circuits are coupled to receive signals from a protected transmission circuit. Each discriminat- ... from a direction detector sig- ... any fault which occurs is for- ... predetermined point. The dis- ... ranged to produce an output ... eaker of the protected circuit ... in the protected circuit. In this

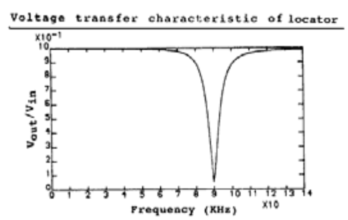


Surge (Traveling Wave) Based Scheme

- Use of high frequency components to determine the faulty section of an overhead power distribution feeder.
- Try to determine the faulty section of a distribution system by detecting fault-induced high frequency components on the line.
- Principle
  - Tuned Circuits to receive high frequency components on the line due to faults (Stack Tuners)
    - High-Z for power frequency
    - Effective Impedance that matches the line characteristic impedance at the center frequency
  - Line trap that is tuned at the center frequency so that it becomes a virtual short circuit at the frequency
    - Impedance Zt at the center frequency

Locator Arrangement





Typical parameters of locator components

L_1 = 0.1 mH, (Q = 30 at 50 Hz)
C_1 = 32 nF
L_2 = 3 mH
C_2 = 1 nF
R_1 = 10 KΩ
L_p = 16 mH, (Q = 30 at 50 Hz)
R_p = 500 Ω
C_p = 201 pF

- Center Frequency at 90kHz

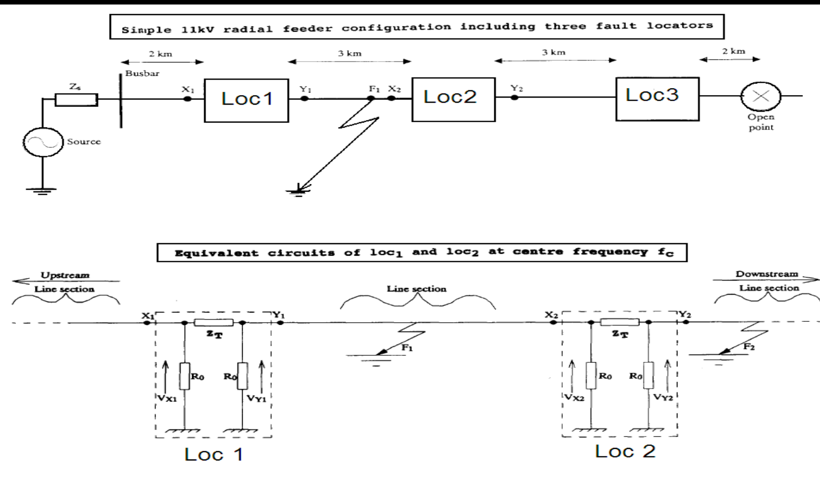
Details of the Stack Tuners

- Stack Tuners
  - At center frequency = 90kHz, the stack tuner has about 500 ohm, which is close to the typical 11kV characteristic impedance
  - The shunt path formed by each stack tuner correctly terminates the line
  - Ensures that standing wave patterns at the centre frequency are minimized.
  - The impedance of each stack tuner rises rapidly outside the narrow band of frequencies around the center frequency
  - Each stack tuner is an open circuit at power frequency.

Details of the Line Trap

- Frequency response such that, its impedance peaks at a value approaching 10 kohm at the centre frequency.
- The line trap circuit at the centre frequency, acts as an attenuator
- Its impedance falls to a very low value at or around power frequency (of order of 0.03 ohms at 50 Hz)
- Completely transparent at power frequency but otherwise acts as a barrier between each stack tuner circuit at the center frequency.
- Frequencies outside the band immediately adjacent to the center frequency provide a voltage transfer ratio of almost unity.

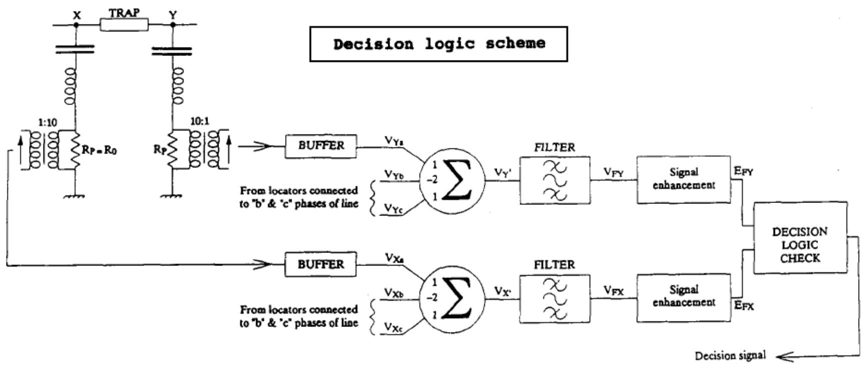
Operation Principle



$|V_X| - |V_Y|$ = +ve quantity, upstream

$|V_X| - |V_Y|$ = -ve quantity, downstream

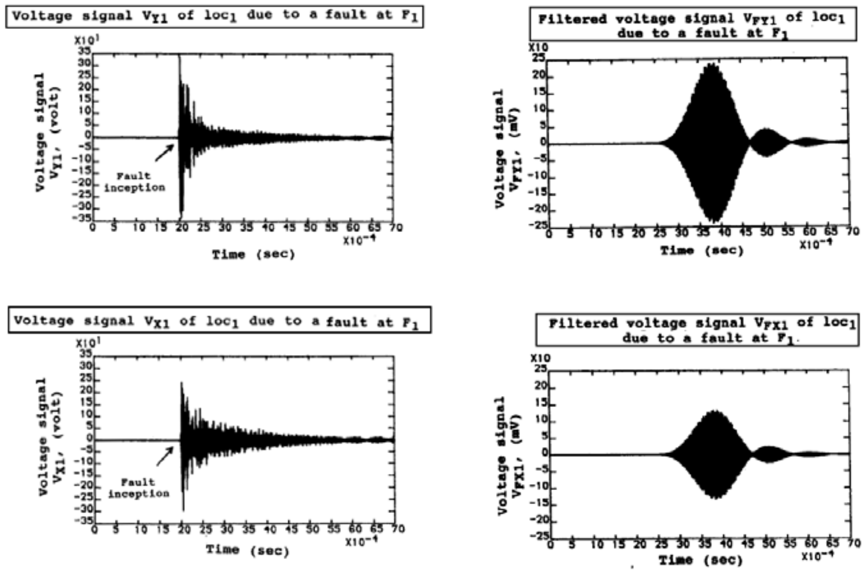
Decision Logic



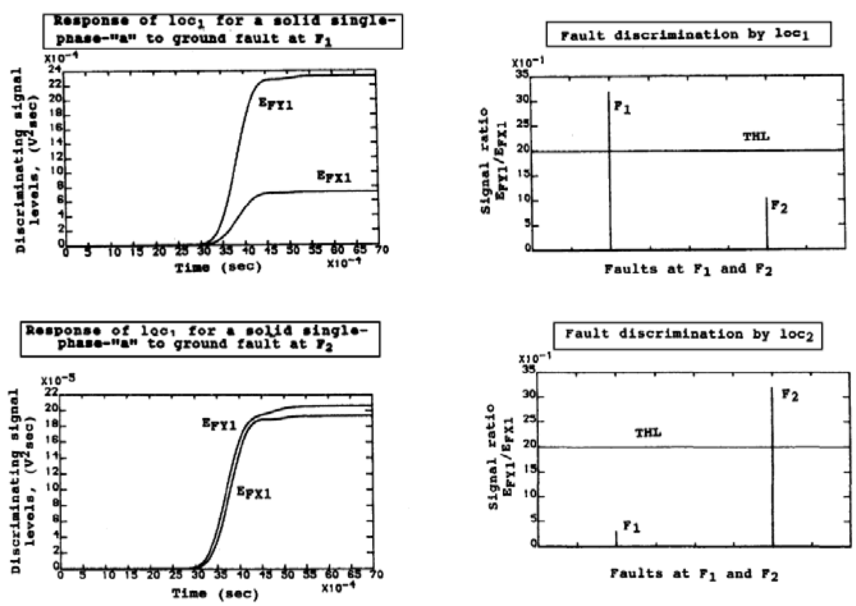
Simulation

- Data
  - The source was represented by a simple lumped equivalent circuit with parameters set to produce a given symmetrical short circuit level at the bus-bar and a reactance to a resistance ratio of 30 at power frequency (50Hz).
  - The ratio of the source zero to positive sequence impedance is unity and the equivalent power frequency impedance of the line is
    - 0.54 + j0.64 ohms per Km (positive phase sequence)
    - 0.69 + j2.02 ohms per Km (zero phase sequence)
  - The sampling frequency was set at approximately 200 kHz thereby enabling the response of the locator to be examined for a center frequency of 90 kHz.

Simulation Results



Fault Discrimination



Operational Variables

- Type of faults
- Fault resistance
- Fault Inception Angle
- Short Circuit Capacity of Bus-Bar (kVA level)
- Suggested Works
  - PSpice Simulation
  - Matlab/Simulink
  - MathCad Practice

Reference

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