Wroclaw University of Science and Technology

Diploma Seminar

Power System Faults

16/3/2023

Content:

Introduction:

- The power system items are designed to perform continuously a required function, except when undergo preventive maintenance or other planned actions, or due to lack of external resources.

- A fault implies any abnormal condition which causes a reduction in the basic insulation strength between phase conductors or phase conductors and earth, or any earthed screens surrounding the conductors.

- faults in the power system may occur because of the number of natural disturbances like lightning, high-speed winds It may also occur because of some accidents like falling off a tree, vehicle colliding, etc.

- The fault can be minimized by improving the system design, better quality of the equipment and maintenance. But the fault cannot be eliminated completely.

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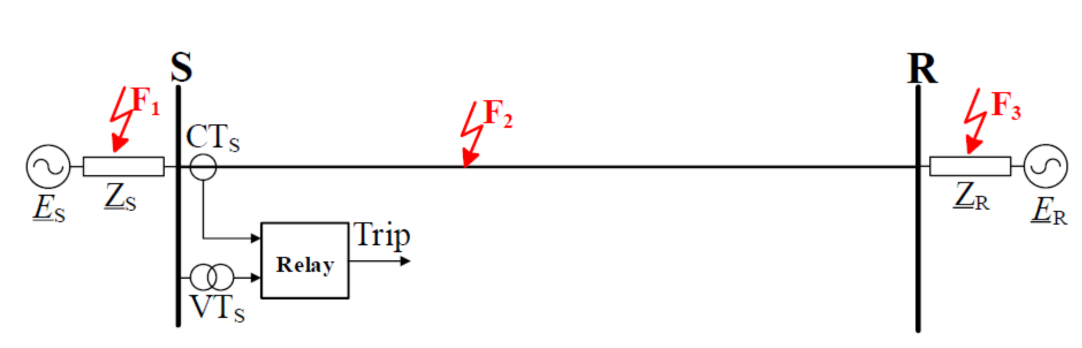
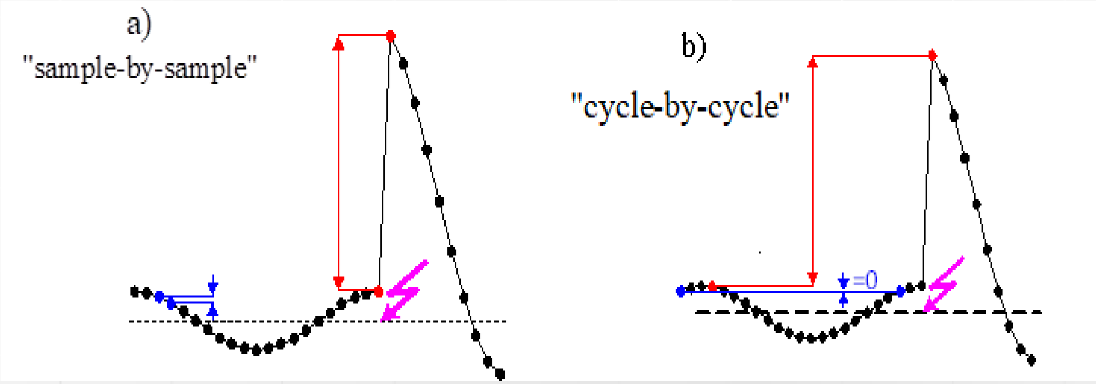
Fault identification:

- **Fault identification is performed in terms of :**
- **Fault detection**: fault detection can be treated as distinguishing the fault interval from the pre-fault interval.
- **Fault direction discrimination**: whether a considered fault is forward or backward with respect to the direction at which the protective relay is design to respond
- **Phase selection**: is aimed at identifying the fault type, i.e. which phases are involved in a considered fault and whether it is an earthed fault or isolated one.



Fault Detection algorithms:

- The abnormal conditions (not necessarily faults) are detected by watching the phase impedances and/or phase-current amplitudes and/or phase-voltage amplitudes and/or zero-sequence current amplitude.
- Disregarding a particular solution, two algorithms are commonly applied in contemporary digital protective relays:
- **Sample by Sample**: method computing numerically the first derivative of a watched signal. If this derivative overruns a pre-set value, an auxiliary counter starts to count. This counter is incremented by the absolute value of the derivative. When it reaches another pre-set threshold, a fault is confirmed.
- **Cycle by Cycle**: algorithm compares a present sample with the sample one cycle back. When the absolute value of the defined difference overruns its threshold. The detection is when the counter increased by the successive differences overreaches the second threshold.



Fault Detection algorithms:

- The condition for fault detection using **the sample-by-sample method**:

$$\Delta_{S\text{-}S} = | i(n) - i(n-1) | > \text{threshold}$$

- Where Threshold = $k_s \cdot 2 \cdot I_{pre} \sin(0{,}5\omega_1 T_s)$

k_s – safety factor accounting for possible increase of load current (for example: k_s=1.1),
I_{pre} – magnitude of pre-fault (load current) (A),
w_1=2pif_1 – fundamental frequency pulsation (w_1=2pi50 (1/s)),
T_s – sampling period (note: if the sampling frequency is f_s=1000 Hz then T_s=0.001 s),

- The condition for fault detection using **the cycle-by-cycle method**:

$$\Delta_{C\text{-}C} = | i(n) - i(n-N) | > \text{threshold}$$

- where: N – number of samples in a single fundamental cycle (*note that if the sampling frequency is* f_s=1000 Hz (as in all projects on Fault Calculations) then N=20 samples).
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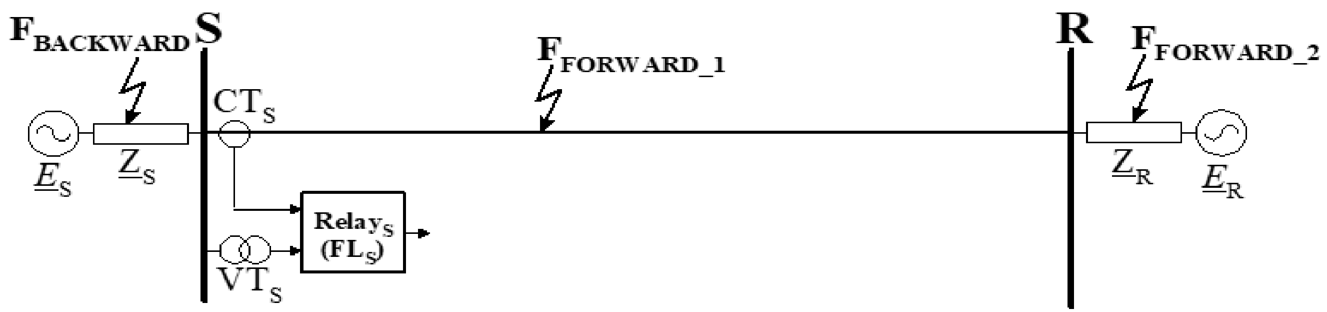
- To have **reliable fault detection**, the condition must be satisfied for 3 consecutive samples

Direction Discrimination:

- Is based on computing the increments in positive-sequence voltage and current (by subtracting the pre-fault positive sequence quantities from the fault ones).
- The impedance resulting from the increments of positive-sequence current, and voltage (measurements at the bus S) is calculated as follows:

$$\Delta \underline{Z}_1 = \Delta R_1 + \mathrm{j}\Delta X_1 = \frac{\Delta \underline{V}_1}{\Delta \underline{I}_1} = \frac{\underline{V}_1 - \underline{V}_1^{\mathrm{pre}}}{\underline{I}_1 - \underline{I}_1^{\mathrm{pre}}}$$

- Where $\underline{V}_1^{\mathrm{pre}}$, $\underline{V}_1$ are positive-sequence voltages from pre- and fault intervals, and similarly for currents .



One-line circuit diagram of transmission network showing three hypothetical fault positions.

- within the equivalent source behind bus S ($F_{BACKWARD}$)
- on the transmission line ($F_{FORWARD\_1}$)
- within the equivalent source behind bus R ($F_{FORWARD\_2}$)

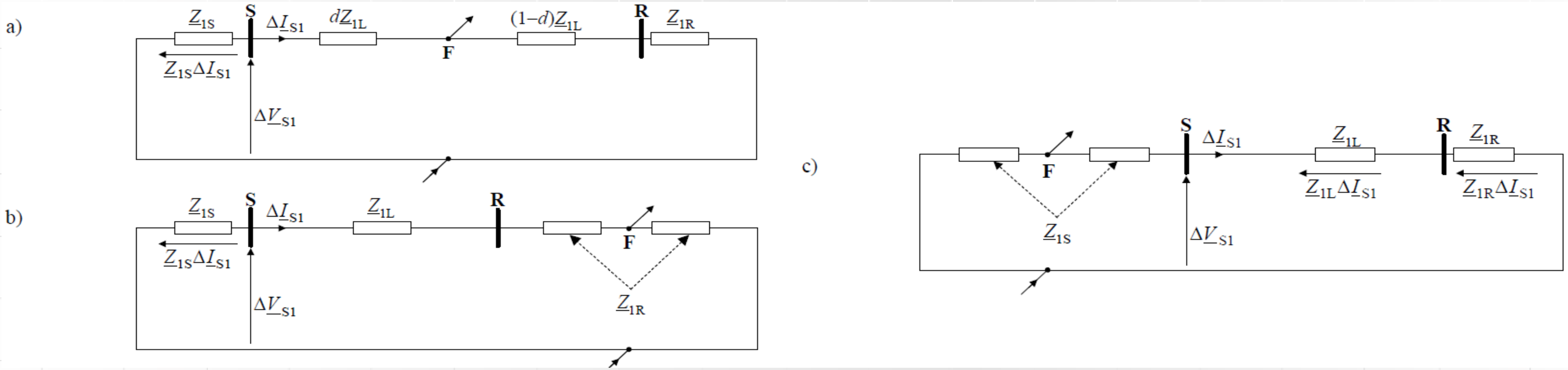
Direction Discrimination:

- For forward faults, the incremental positive-sequence impedance is at the third quadrant of the complex plane and is represented as follows:

$$\Delta \underline{Z}_1 = -\underline{Z}_{1S}$$

- For backward faults, the incremental positive-sequence impedance is at the First quadrant of the complex plane and is represented as follows:

$$\Delta \underline{Z}_1 = \underline{Z}_{1L} + \underline{Z}_{1R}$$



- Fig: Equivalent circuit diagrams for deriving the incremental positive-sequence impedance (a) forward fault on line S–R, (b) forward fault within system R, (c) backward fault within system S

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PHASE SELECTION (*FAULT CLASSIFICATION)*

- **The method of symmetrical components**:
- Three-phase quantities (a, b, c) are resolved into symmetrical components:
- positive-sequence components (1),
- negative-sequence components (2),
- zero-sequence components (0).
- positive-sequence is present for all fault types,
- negative-sequence is present under unsymmetrical faults,
- zero-sequence is present under unsymmetrical faults involving earth.

Fault type	Positive-sequence	Negative-sequence	Zero-sequence
a-E, b-E, c-E	+	+	+
a-b, b-c, c-a	+	+	–
a-b-E, b-c-E, c-a-E	+	+	+
a-b-c, a-b-c-E	+	–	–

PHASE SELECTION (*FAULT CLASSIFICATION*)

- Depending on fault type the following angles are of interest:
- All faults except three-phase balanced faults:

$$\alpha = \text{angle}\left(\frac{\underline{I}_2}{\underline{I}_1}\right) \quad (3) \qquad \text{or better:} \qquad \alpha_\Delta = \text{angle}\left(\frac{\underline{I}_2}{\Delta \underline{I}_1}\right) \quad (4)$$

- unsymmetrical faults with earth involvement:

$$\beta = \text{angle}\left(\frac{\underline{I}_2}{\underline{I}_0}\right) \quad (5)$$

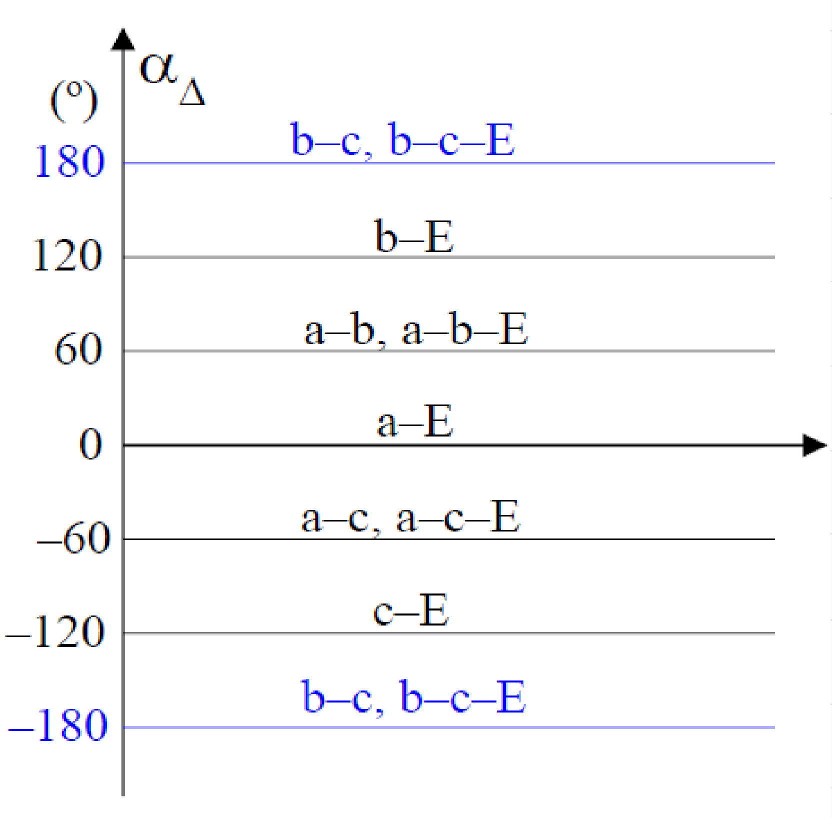


Fig :Values of criteria angles for different fault types negative vs incremental positive-sequence

PHASE SELECTION (FAULT CLASSIFICATION)

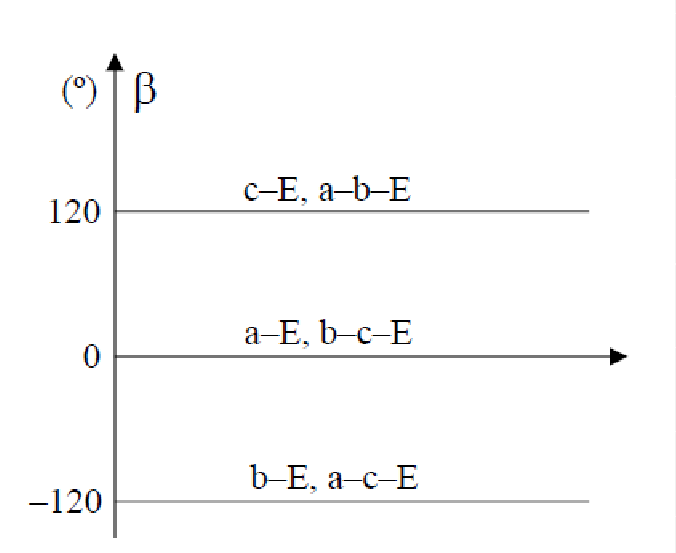


Fig. Values of criteria angles for different fault types negative vs zero-sequence

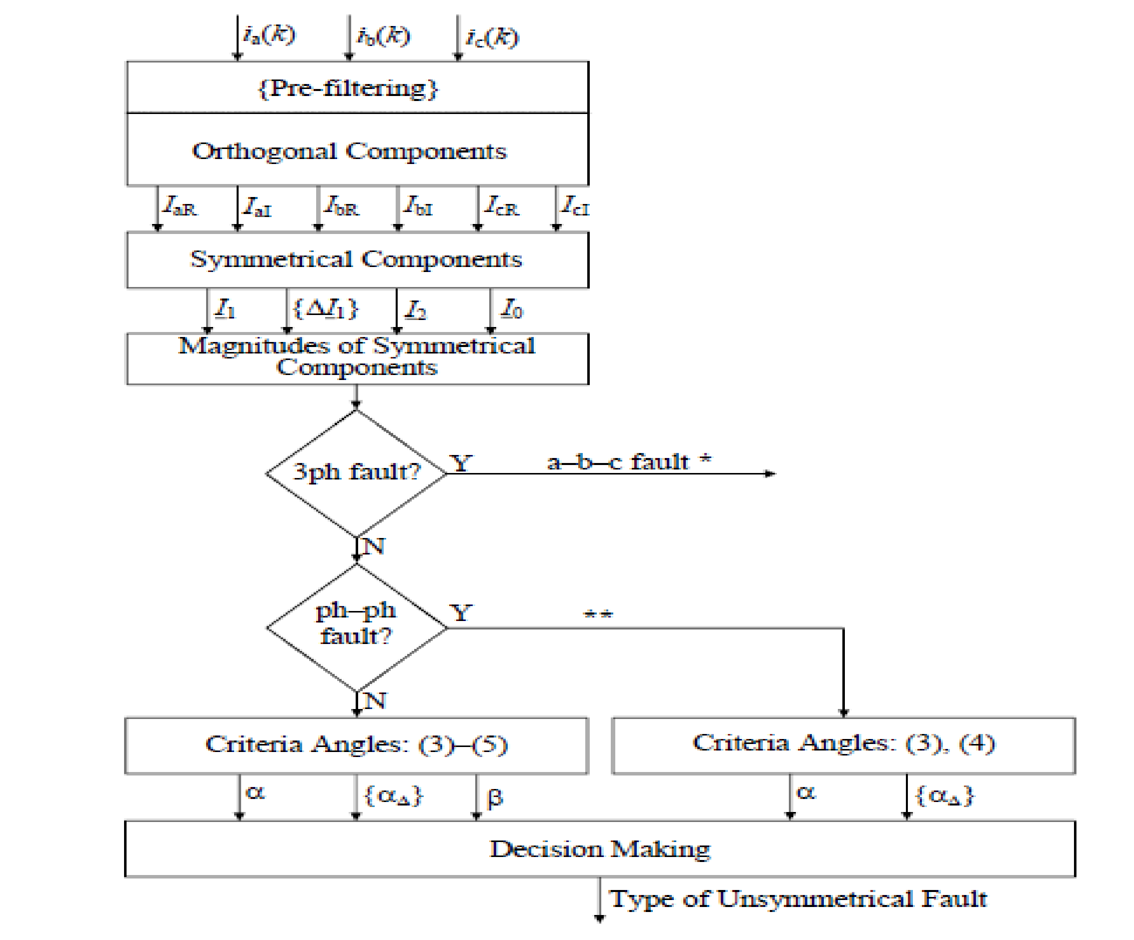
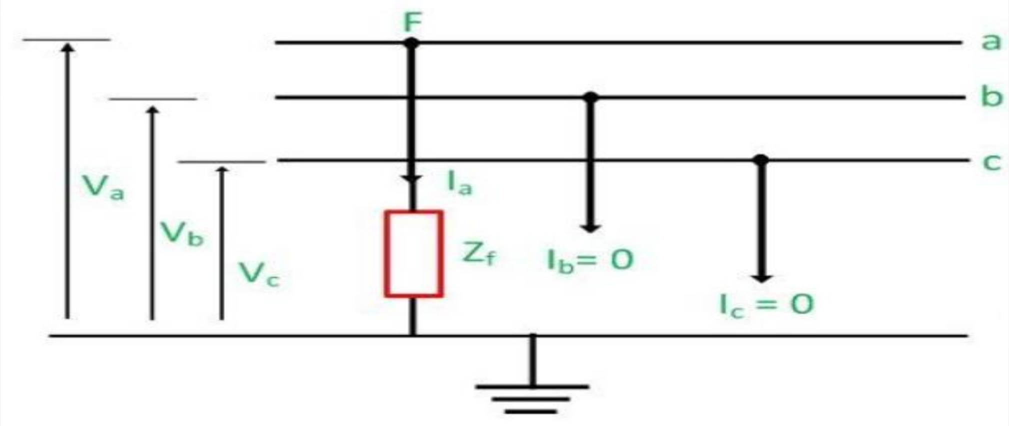


Fig. Block diagram of signal processing for making phase selection

Analysis of single phase-to-ground faults in high voltage networks:

- Suppose the phase **a** is connected to ground at the fault point F, I_a, I_b and I_c are the current and V_a, V_b and V_c are the voltage across the three-phase line a, b and c respectively. The fault impedance of the line is Z_f.



- Since only phase **a** is connected to ground at the fault, phase b and c are open circuited and carries no current; i.e fault current is I_a and $I_b = 0$, $I_c = 0$. The voltage at the fault point F is $V_a = Z_f I_a$
- The symmetrical component of the fault current in phase “a” at the fault point can be written in matrix form as:

$$\begin{bmatrix} \underline{I}_0 \\ \underline{I}_1 \\ \underline{I}_2 \end{bmatrix} = \frac{1}{3} \begin{bmatrix} 1 & 1 & 1 \\ 1 & \underline{a} & \underline{a}^2 \\ 1 & \underline{a}^2 & \underline{a} \end{bmatrix} \cdot \begin{bmatrix} \underline{I}_a \\ 0 \\ 0 \end{bmatrix}$$

Analysis of single phase-to-ground faults in high voltage networks:

- In the case of a single line-to-ground fault, the sequence currents are equal:

$$I_0 = I_1 = I_2 = \frac{1}{3} I_a$$

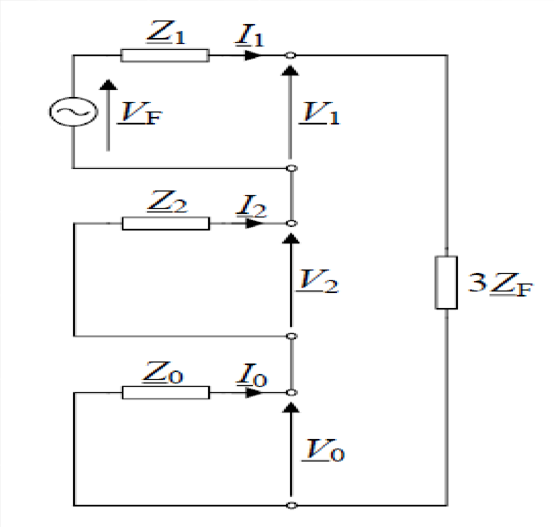
- We know that:

$$V_{aE} = (V_0 + V_1 + V_2) = Z_F (I_0 + I_1 + I_2)$$

$$(V_0 + V_1 + V_2) = (3Z_F) I_0 = (3Z_F) I_1 = (3Z_F) I_2$$

- Equations can be interpreted with the sequence networks (for positive-, negative- and zero-sequence) interconnected in series with the fault impedance 3ZF.
- From the sequence circuit of we have:

$$I_0 = I_1 = I_2 = \frac{V_F}{Z_0 + Z_1 + Z_2 + 3Z_F}$$



- In phase domain:

$$I_a = I_0 + I_1 + I_2 = 3I_1 = \frac{3V_F}{Z_0 + Z_1 + Z_2 + 3Z_F}$$

$$I_b = I_0 + a^2 I_1 + a I_2 = (1 + a^2 + a) I_0 = 0$$

$$I_c = I_0 + a I_1 + a^2 I_2 = (1 + a + a^2) I_0 = 0$$

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Thank you