華中科技大學
Huazhong University of Science and Technology

2009-2010学年度第一学期

2009.11.08—2010.01.30

《电力系统分析》（I）

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第八章 电力系统不对称故障的分析和计算

8-1 简单不对称短路的分析

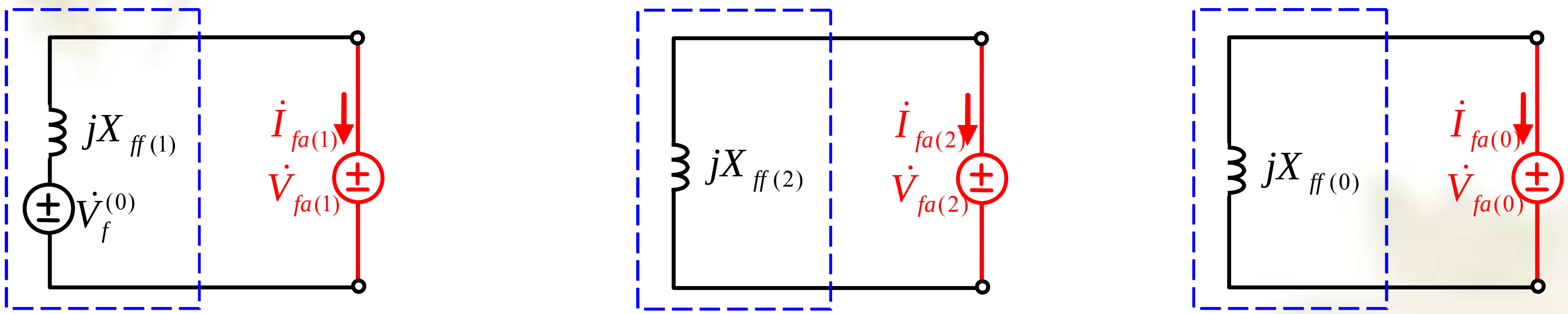
8-2 电压和电流对称分量经变压器后的相位变换

8-3 非全相断线的分析

8-4 应用节点阻抗矩阵计算不对称故障

8-1 简单不对称短路的分析

序网方程



$$\dot{V}_{fa(1)} = \dot{V}_f^{(0)} - jX_{ff(1)}\dot{I}_{fa(1)}$$

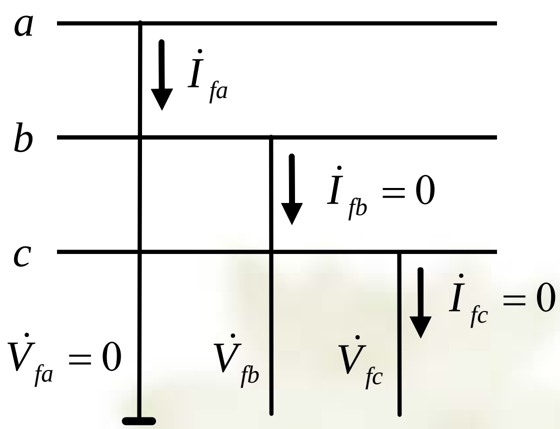
$$\dot{V}_{fa(2)} = -jX_{ff(2)}\dot{I}_{fa(2)}$$

$$\dot{V}_{fa(0)} = -jX_{ff(0)}\dot{I}_{fa(0)}$$

8-1 简单不对称短路的分析

1. 单相(a相)接地短路——序分量边界条件

(1)相量表示的边界条件：$\dot{V}_{fa}=0,\ \dot{I}_{fb}=0,\ \dot{I}_{fc}=0$



(2) 对称分量表示的边界条件

$$\dot{V}_{fa}=\dot{V}_{fa(1)}+\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=0$$
$$\dot{I}_{fb}=\dot{I}_{fb(1)}+\dot{I}_{fb(2)}+\dot{I}_{fb(0)}=0$$
$$\dot{I}_{fc}=\dot{I}_{fc(1)}+\dot{I}_{fc(2)}+\dot{I}_{fc(0)}=0$$

(3) 以*a*相为参考相

$$\dot{V}_{fa}=\dot{V}_{fa(1)}+\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=0$$
$$\dot{I}_{fb}=\alpha^2\dot{I}_{fa(1)}+\alpha\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$
$$\dot{I}_{fc}=\alpha\dot{I}_{fa(1)}+\alpha^2\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$

(4) 序分量边界条件：

$$\left.\begin{aligned}&\dot{V}_{fa(1)}+\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=0\\&\dot{I}_{fa(1)}=\dot{I}_{fa(2)}=\dot{I}_{fa(0)}\end{aligned}\right\}\ (8\text{-}2)$$

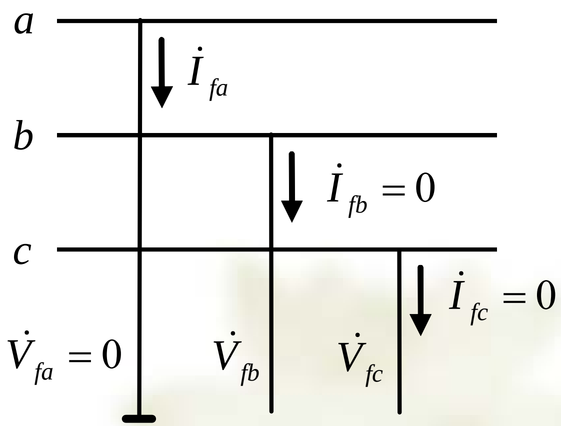
8-1 简单不对称短路的分析

1. 单相(a相)接地短路——联立方程求解

$$\left.\begin{aligned}\dot{V}_{fa(1)} &= \dot{V}_f^{(0)} - jX_{ff(1)}\dot{I}_{fa(1)}\\ \dot{V}_{fa(2)} &= \quad\;\; - jX_{ff(2)}\dot{I}_{fa(2)}\\ \dot{V}_{fa(0)} &= \quad\;\; - jX_{ff(0)}\dot{I}_{fa(0)}\end{aligned}\right\}(8-1)$$

$$\left.\begin{aligned}&\dot{V}_{fa(1)} + \dot{V}_{fa(2)} + \dot{V}_{fa(0)} = 0\\ &\dot{I}_{fa(1)} = \dot{I}_{fa(2)} = \dot{I}_{fa(0)}\end{aligned}\right\}(8-2)$$

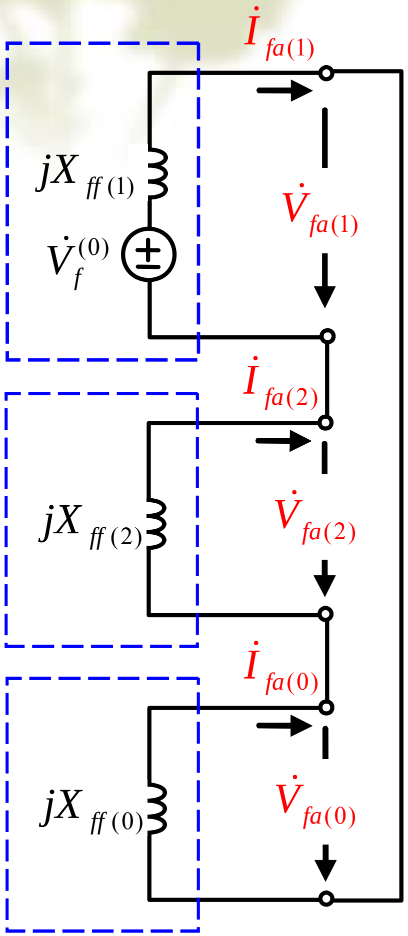
$$\dot{I}_{fa(1)} = \frac{\dot{V}_f^{(0)}}{j(X_{ff(1)} + X_{ff(2)} + X_{ff(0)})} \quad (8-3)$$



$$\left.\begin{aligned}\dot{V}_{fa(1)} &= \dot{V}_f^{(0)} - jX_{ff(1)}\dot{I}_{fa(1)}\\ &= j\left(X_{ff(2)} + X_{ff(0)}\right)\dot{I}_{fa(1)}\\ \dot{V}_{fa(2)} &= -jX_{ff(2)}\dot{I}_{fa(2)}\\ \dot{V}_{fa(0)} &= -jX_{ff(0)}\dot{I}_{fa(0)}\end{aligned}\right\}(8-4)$$

8-1 简单不对称短路的分析

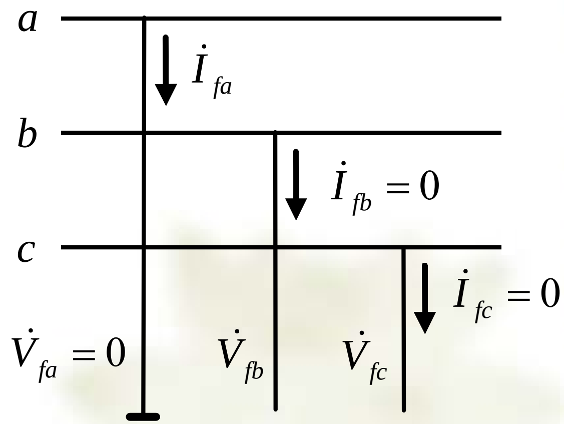
1. 单相(a相)接地短路——复合序网



$$\left.\begin{aligned}&\dot{V}_{fa(1)}+\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=0\\&\dot{I}_{fa(1)}=\dot{I}_{fa(2)}=\dot{I}_{fa(0)}\end{aligned}\right\}(8-2)$$

$$\left.\begin{aligned}\dot{V}_{fa(1)}&=\dot{V}_f^{(0)}-jX_{ff(1)}\dot{I}_{fa(1)}\\&=j\left(X_{ff(2)}+X_{ff(0)}\right)\dot{I}_{fa(1)}\\\dot{V}_{fa(2)}&=-jX_{ff(2)}\dot{I}_{fa(2)}\\\dot{V}_{fa(0)}&=-jX_{ff(0)}\dot{I}_{fa(0)}\end{aligned}\right\}$$

$$\dot{I}_{fa(1)}=\frac{\dot{V}_f^{(0)}}{j(X_{ff(1)}+X_{ff(2)}+X_{ff(0)})}\quad(8-3)$$



8-1 简单不对称短路的分析

1. 单相(a相)接地短路——故障点各相电流电压

$$\dot{I}_f^{(1)} = \dot{I}_{fa} = \frac{3\dot{V}_f^{(0)}}{j(X_{ff(1)} + X_{ff(2)} + X_{ff(0)})}$$

$$\dot{I}_{fb} = 0, \quad \dot{I}_{fc} = 0$$

$$\dot{I}_{fa} = \dot{I}_{fa(1)} + \dot{I}_{fa(2)} + \dot{I}_{fa(0)}$$

$$\dot{I}_{fb} = \alpha^2 \dot{I}_{fa(1)} + \alpha \dot{I}_{fa(2)} + \dot{I}_{fa(0)}$$

$$\dot{I}_{fc} = \alpha \dot{I}_{fa(1)} + \alpha^2 \dot{I}_{fa(2)} + \dot{I}_{fa(0)}$$

$$\dot{V}_{fa} = 0$$

$$\dot{V}_{fb} = \alpha^2 \dot{V}_{fa(1)} + \alpha \dot{V}_{fa(2)} + \dot{V}_{fa(0)} = j\left[(\alpha^2 - \alpha)X_{ff(2)} + (\alpha^2 - 1)X_{ff(0)}\right]\dot{I}_{fa(1)}$$

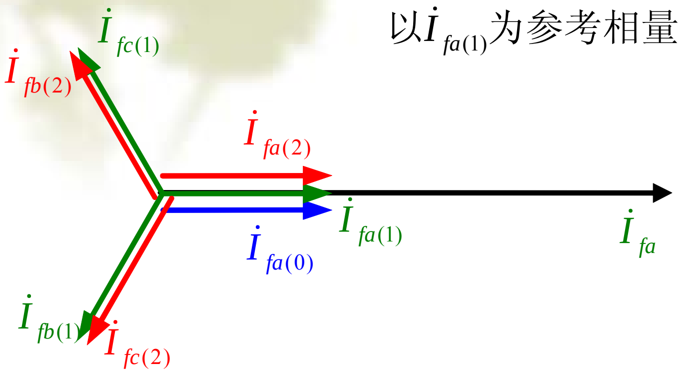
$$\dot{V}_{fc} = \alpha \dot{V}_{fa(1)} + \alpha^2 \dot{V}_{fa(2)} + \dot{V}_{fa(0)} = j\left[(\alpha - \alpha^2)X_{ff(2)} + (\alpha - 1)X_{ff(0)}\right]\dot{I}_{fa(1)}$$

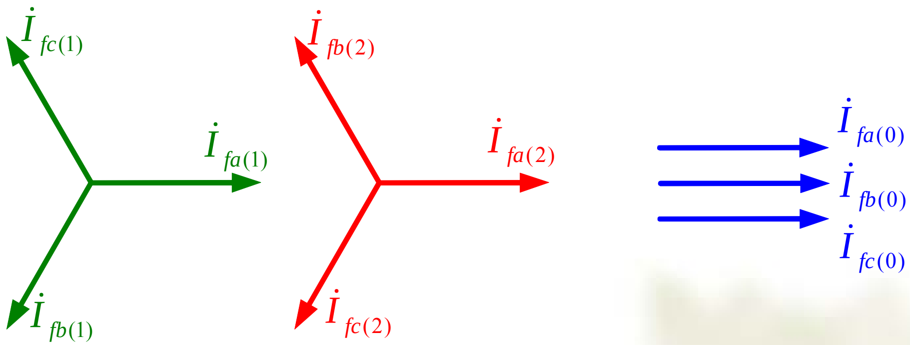
$$\dot{V}_{fa(1)} = j\left(X_{ff(2)} + X_{ff(0)}\right)\dot{I}_{fa(1)}, \quad \dot{V}_{fa(2)} = -jX_{ff(2)}\dot{I}_{fa(1)}, \quad \dot{V}_{fa(0)} = -jX_{ff(0)}\dot{I}_{fa(1)}$$

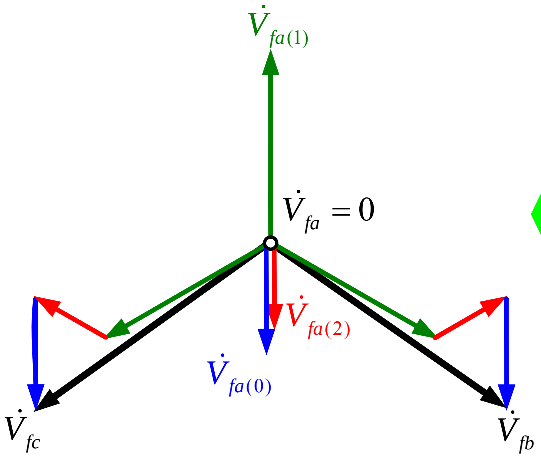
8-1 简单不对称短路的分析

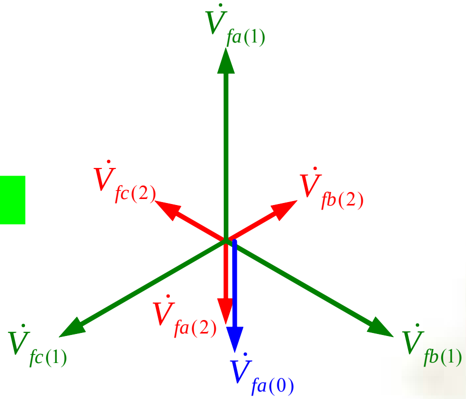
1. 单相(a相)接地短路——相量图

以$\dot{I}_{fa(1)}$为参考相量









$$\dot{V}_{fa(1)} = j\left(X_{ff(2)} + X_{ff(0)}\right)\dot{I}_{fa(1)}$$

$$\dot{V}_{fa(2)} = -jX_{ff(2)}\dot{I}_{fa(1)}$$

$$\dot{V}_{fa(0)} = -jX_{ff(0)}\dot{I}_{fa(1)}$$

8-1 简单不对称短路的分析

1. 单相(a相)接地短路——特例分析(I&II)

$X_{ff(1)} \approx X_{ff(2)}, X_{ff(0)}$：与系统中性点接地情况有关

Case I：$X_{ff(1)} > X_{ff(0)} \Rightarrow \dot{I}_f^{(1)} = \dot{I}_{fa} = \dfrac{3\dot{V}_f^{(0)}}{j(X_{ff(1)} + X_{ff(2)} + X_{ff(0)})} > \dot{I}_f^{(3)} = \dfrac{\dot{V}_f^{(0)}}{jX_{ff(1)}}$

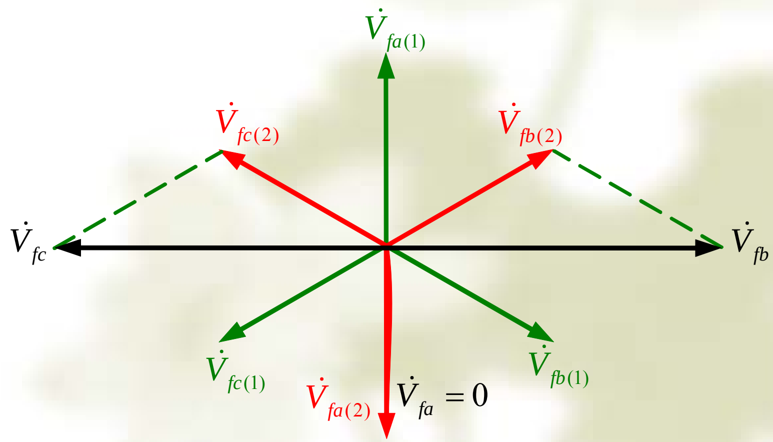
Case II：$X_{ff(0)} \to 0$，短路点靠近中性点直接接地点

$V_{fa} = 0,\ V_{fb} = V_{fc} = \sqrt{3}/2V_f^{(0)}$

$$\dot{V}_{fa(1)} = j\left(X_{ff(2)} + X_{ff(0)}\right)\dot{I}_{fa(1)}$$

$$\dot{V}_{fa(2)} = -jX_{ff(2)}\dot{I}_{fa(1)}$$

$$\dot{V}_{fa(0)} = -jX_{ff(0)}\dot{I}_{fa(1)} \approx 0$$



8-1 简单不对称短路的分析

1. 单相(a相)接地短路——特例分析(III)

$X_{ff(1)} \approx X_{ff(2)}, X_{ff(0)}$：与系统中性点接地情况有关

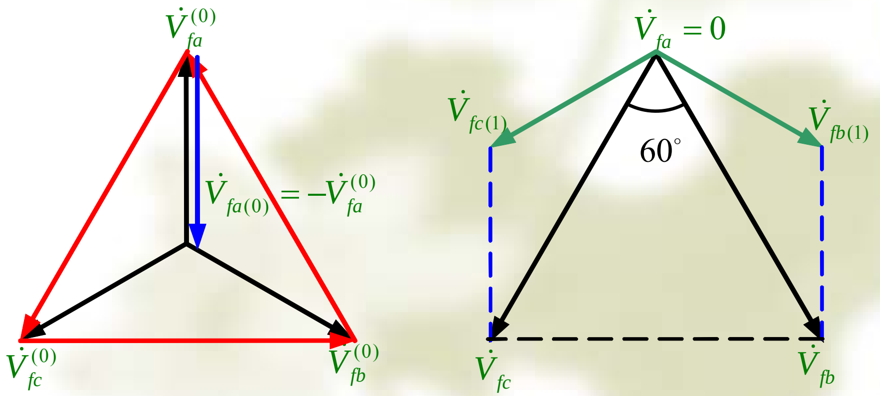
Case III：$X_{ff(0)} \to \infty$，中性点不接地系统

$V_{fa} = 0,\ V_{fb} = V_{fc} = \sqrt{3}V_f^{(0)} = V_{ab}^{(0)}$

$\dot{V}_{fa(1)} = \dot{V}_{fa}^{(0)},\quad \dot{V}_{fa(2)} = 0,\quad \dot{V}_{fa(0)} = -\dot{V}_{fa}^{(0)}$

$$\dot{V}_{fa} = \alpha^2\dot{V}_{fa(1)} + \alpha\dot{V}_{fa(2)} + \dot{V}_{fa(0)} = 0$$
$$\dot{V}_{fb} = \alpha^2\dot{V}_{fa(1)} + \alpha\dot{V}_{fa(2)} + \dot{V}_{fa(0)} = (\alpha^2 - 1)\dot{V}_{fa(1)}$$
$$\dot{V}_{fc} = \alpha\dot{V}_{fa(1)} + \alpha^2\dot{V}_{fa(2)} + \dot{V}_{fa(0)} = (\alpha - 1)\dot{V}_{fa(1)}$$

$$\dot{V}_{fa(1)} = j\left(X_{ff(2)} + X_{ff(0)}\right)\dot{I}_{fa(1)}$$
$$\dot{V}_{fa(2)} = -jX_{ff(2)}\dot{I}_{fa(1)}$$
$$\dot{V}_{fa(0)} = -jX_{ff(0)}\dot{I}_{fa(1)}$$



8-1 简单不对称短路的分析

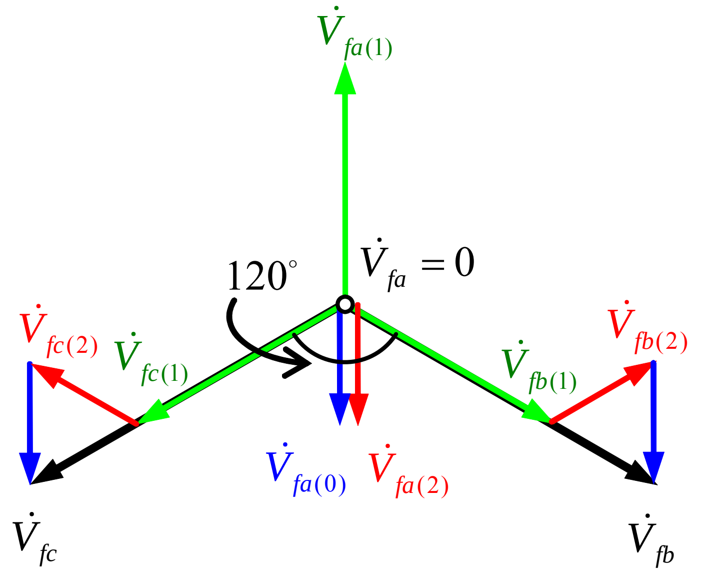
1. 单相(a相)接地短路——特例分析(IV)

$X_{ff(1)} \approx X_{ff(2)}, X_{ff(0)}$：与系统中性点接地情况有关

Case IV ：$X_{ff(2)} = X_{ff(0)} \Rightarrow \dot{V}_{fa(2)} = \dot{V}_{fa(0)} = -\frac{1}{2}\dot{V}_{fa(1)}$

$$\dot{V}_{fa(1)} = j\left(X_{ff(2)} + X_{ff(0)}\right)\dot{I}_{fa(1)}$$
$$\dot{V}_{fa(2)} = -jX_{ff(2)}\dot{I}_{fa(1)}$$
$$\dot{V}_{fa(0)} = -jX_{ff(0)}\dot{I}_{fa(1)}$$

$$\dot{I}_{fa(1)} = \frac{\dot{V}_f^{(0)}}{j(X_{ff(1)} + X_{ff(2)} + X_{ff(0)})} = \frac{1}{3}\dot{V}_f^{(0)}$$

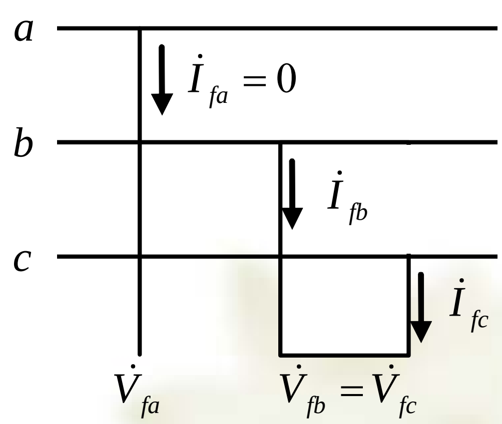


$$\dot{V}_{fa(1)} = j\left(X_{ff(2)} + X_{ff(0)}\right)\dot{I}_{fa(1)} = \frac{2}{3}\dot{V}_f^{(0)}$$
$$\dot{V}_{fa(2)} = -jX_{ff(2)}\dot{I}_{fa(1)} = -\frac{1}{3}\dot{V}_f^{(0)}$$
$$\dot{V}_{fa(0)} = -jX_{ff(0)}\dot{I}_{fa(1)} = -\frac{1}{3}\dot{V}_f^{(0)}$$

8-1 简单不对称短路的分析

2. 两相(b相和c相)短路——序分量边界条件

(1)相量表示的边界条件：$\dot{V}_{fb}=\dot{V}_{fc},\ \dot{I}_{fa}=0,\ \dot{I}_{fb}+\dot{I}_{fc}=0$



(2) 对称分量表示的边界条件

$$\dot{V}_{fb(1)}+\dot{V}_{fb(2)}+\dot{V}_{fb(0)}=\dot{V}_{fc(1)}+\dot{V}_{fc(2)}+\dot{V}_{fc(0)}$$

$$\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$

$$\dot{I}_{fb(1)}+\dot{I}_{fb(2)}+\dot{I}_{fb(0)}+\dot{I}_{fc(1)}+\dot{I}_{fc(2)}+\dot{I}_{fc(0)}=0$$

(3) 以a相为参考相

$$(\alpha^2-\alpha)\dot{V}_{fa(1)}+(\alpha-\alpha^2)\dot{V}_{fa(2)}=0$$

$$\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$

$$(\alpha^2+\alpha)\dot{I}_{fa(1)}+(\alpha^2+\alpha)\dot{I}_{fa(2)}+2\dot{I}_{fa(0)}=0$$

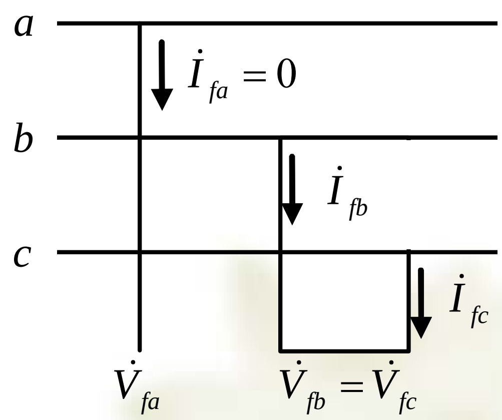
(4) 序分量边界条件：

$$\left.\begin{aligned}&\dot{V}_{fa(1)}=\dot{V}_{fa(2)}\\&\dot{I}_{fa(1)}+\dot{I}_{fa(2)}=0\\&\dot{I}_{fa(0)}=0\end{aligned}\right\}\quad(8\text{-}7)$$

8-1 简单不对称短路的分析

2. 两相(b相和c相)短路——联立方程求解

$$\left.\begin{aligned}\dot{V}_{fa(1)} &= \dot{V}_f^{(0)} - jX_{ff(1)}\dot{I}_{fa(1)}\\ \dot{V}_{fa(2)} &= \quad\; - jX_{ff(2)}\dot{I}_{fa(2)}\\ \dot{V}_{fa(0)} &= \quad\; - jX_{ff(0)}\dot{I}_{fa(0)}\end{aligned}\right\}(8-1)$$



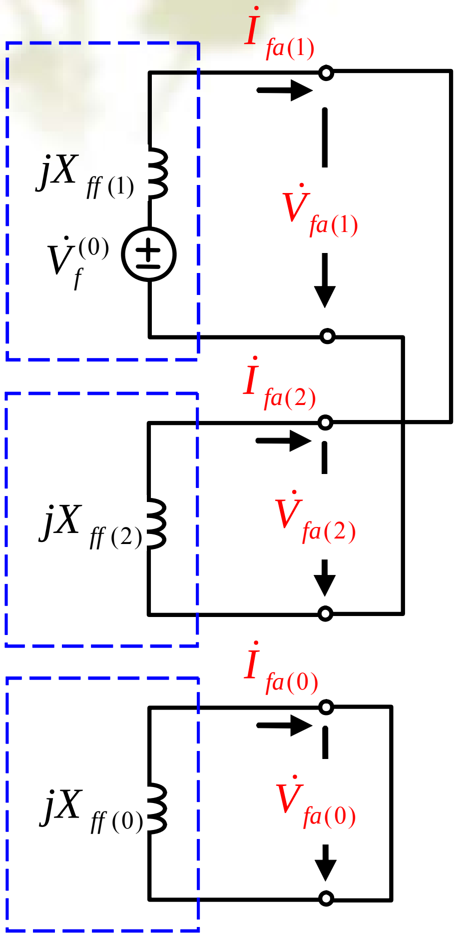
$$\left.\begin{aligned}&\dot{V}_{fa(1)} = \dot{V}_{fa(2)},\\ &\dot{I}_{fa(1)} + \dot{I}_{fa(2)} = 0\\ &\dot{I}_{fa(0)} = 0\end{aligned}\right\}(8-7)$$

$$\dot{I}_{fa(1)} = \frac{\dot{V}_f^{(0)}}{j(X_{ff(1)} + X_{ff(2)})} \quad (8-8)$$

$$\left.\begin{aligned}&\dot{I}_{fa(2)} = -\dot{I}_{fa(1)}\\ &\dot{V}_{fa(1)} = \dot{V}_{fa(2)} = -jX_{ff(2)}\dot{I}_{fa(2)} = jX_{ff(2)}\dot{I}_{fa(1)}\\ &\dot{V}_{fa(0)} = -jX_{ff(0)}\dot{I}_{fa(0)} = 0\end{aligned}\right\}(8-9)$$

8-1 简单不对称短路的分析

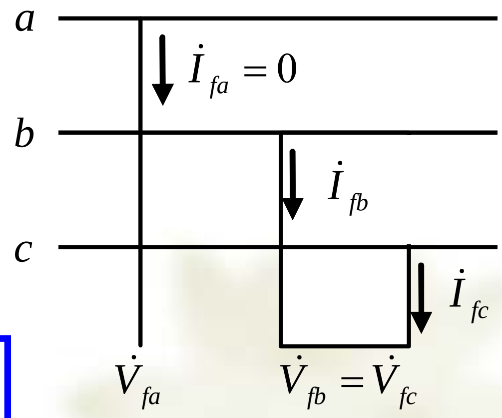
2. 两相(b相和c相)短路——复合序网



$$\left.\begin{aligned}&\dot V_{fa(1)}=\dot V_{fa(2)},\\&\dot I_{fa(1)}+\dot I_{fa(2)}=0\\&\dot I_{fa(0)}=0\end{aligned}\right\}(8-7)$$

$$\dot I_{fa(1)}=\frac{\dot V_f^{(0)}}{j(X_{ff(1)}+X_{ff(2)})}\quad(8-8)$$

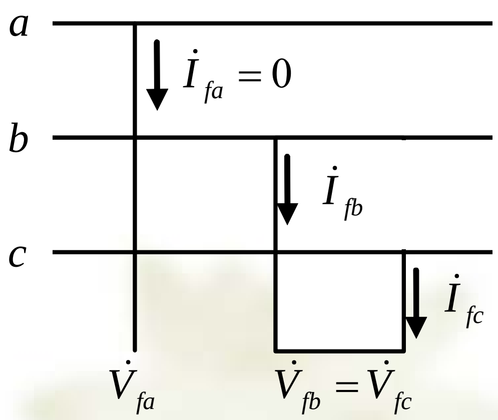
$$\left.\begin{aligned}&\dot I_{fa(2)}=-\dot I_{fa(1)}\\&\dot V_{fa(1)}=\dot V_{fa(2)}=jX_{ff(2)}\dot I_{fa(1)}\\&\dot V_{fa(0)}=-jX_{ff(0)}\dot I_{fa(0)}=0\end{aligned}\right\}(8-9)$$



8-1 简单不对称短路的分析

2. 两相(b相和c相)短路——故障点各相电流电压

$$\dot I_{fa}=\dot I_{fa(1)}+\dot I_{fa(2)}+\dot I_{fa(0)}=0$$
$$\dot I_{fb}=\alpha^2\dot I_{fa(1)}+\alpha\dot I_{fa(2)}+\dot I_{fa(0)}=(\alpha^2-\alpha)\dot I_{fa(1)}=-j\sqrt{3}\dot I_{fa(1)}$$
$$\dot I_{fc}=-\dot I_{fb}=j\sqrt{3}\dot I_{fa(1)}$$

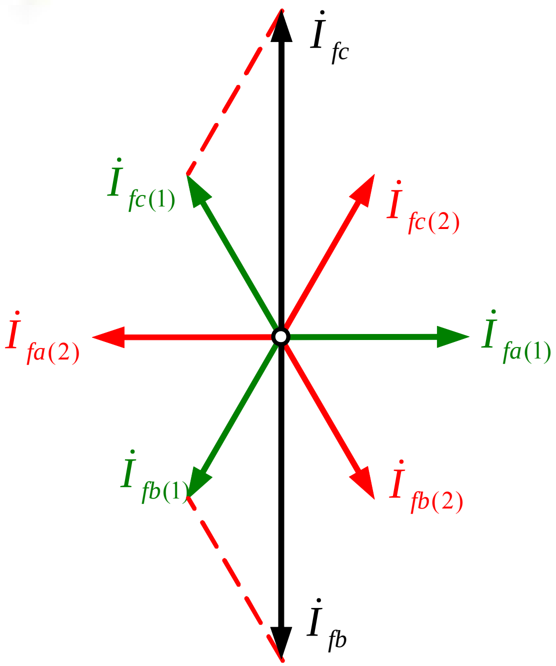


$$\dot V_{fa}=\dot V_{fa(1)}+\dot V_{fa(2)}+\dot V_{fa(0)}=2\dot V_{fa(1)}=j2X_{ff(2)}\dot I_{fa(1)}$$
$$\dot V_{fb}=\alpha^2\dot V_{fa(1)}+\alpha\dot V_{fa(2)}+\dot V_{fa(0)}=-\dot V_{fa(1)}=\dot V_{fa}/2$$
$$\dot V_{fc}=\alpha\dot V_{fa(1)}+\alpha^2\dot V_{fa(2)}+\dot V_{fa(0)}=-\dot V_{fa(1)}=\dot V_{fa}/2$$

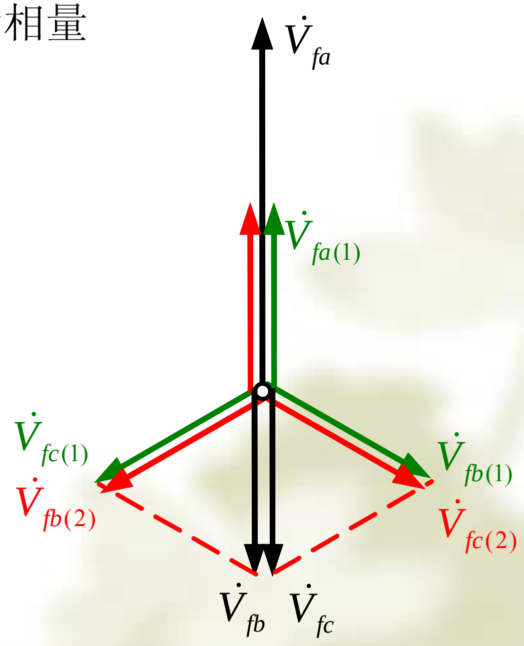
$$\dot I_{fa(2)}=-\dot I_{fa(1)},\ \dot I_{fa(0)}=0,\ \dot V_{fa(1)}=\dot V_{fa(2)}=jX_{ff(2)}\dot I_{fa(1)},\ \dot V_{fa(0)}=-jX_{ff(0)}\dot I_{fa(0)}=0$$

8-1 简单不对称短路的分析

2. 两相(b相和c相)短路——相量图



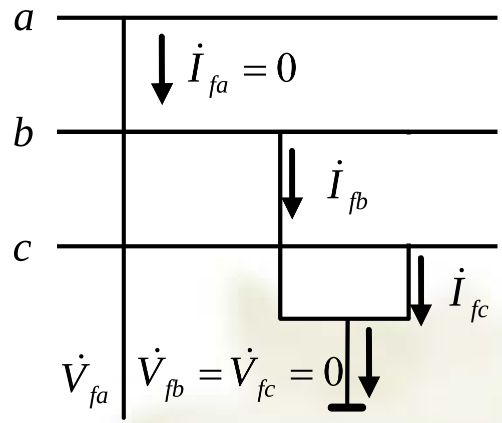
以$\dot{I}_{fa(1)}$为参考相量



8-1 简单不对称短路的分析

3. 两相(b相和c相)短路接地——序分量边界条件

(1)相量表示的边界条件：$\dot{V}_{fb}=\dot{V}_{fc}=0,\ \dot{I}_{fa}=0$



(2) 对称分量表示的边界条件

$$\dot{V}_{fb(1)}+\dot{V}_{fb(2)}+\dot{V}_{fb(0)}=0$$
$$\dot{V}_{fc(1)}+\dot{V}_{fc(2)}+\dot{V}_{fc(0)}=0$$
$$\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$

(3) 以a相为参考相

$$\alpha^2\dot{V}_{fa(1)}+\alpha\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=0$$
$$\alpha\dot{V}_{fa(1)}+\alpha^2\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=0$$
$$\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$

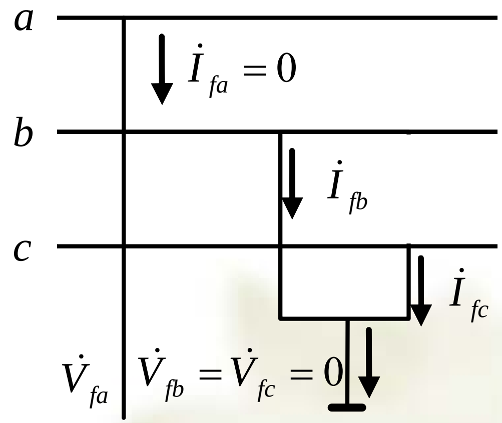
(4) 序分量边界条件：

$$\left.\begin{aligned}&\dot{V}_{fa(1)}=\dot{V}_{fa(2)}=\dot{V}_{fa(0)}\\&\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0\end{aligned}\right\}\quad(8\text{-}13)$$

8-1 简单不对称短路的分析

3. 两相(b相和c相)短路接地——联立方程求解

$$\left.\begin{aligned}\dot V_{fa(1)} &= \dot V_f^{(0)} - jX_{ff(1)}\dot I_{fa(1)}\\ \dot V_{fa(2)} &= -jX_{ff(2)}\dot I_{fa(2)}\\ \dot V_{fa(0)} &= -jX_{ff(0)}\dot I_{fa(0)}\end{aligned}\right\}(8-1)$$



$$\left.\begin{aligned}&\dot V_{fa(1)} = \dot V_{fa(2)} = \dot V_{fa(0)}\\ &\dot I_{fa(1)} + \dot I_{fa(2)} + \dot I_{fa(0)} = 0\end{aligned}\right\}(8\text{-}13)$$

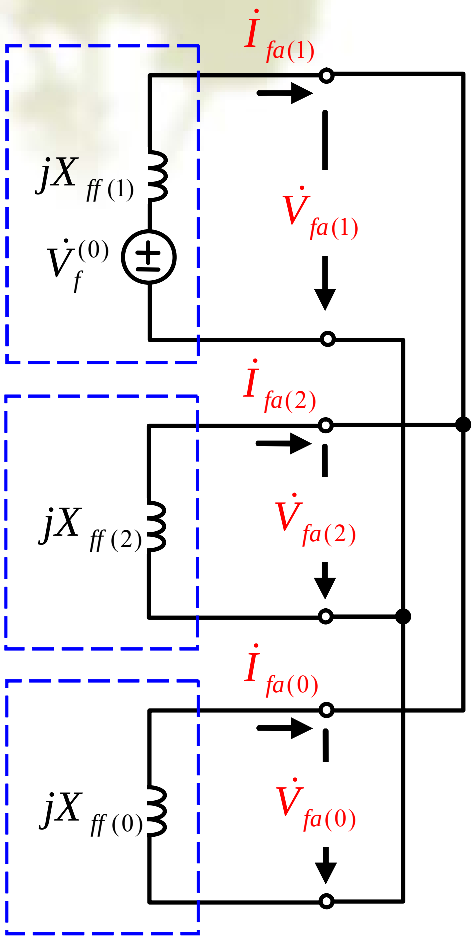
$$\dot I_{fa(1)} = \frac{\dot V_f^{(0)}}{j(X_{ff(1)} + X_{ff(2)} // X_{ff(0)})} \quad (8-14)$$

$$\dot V_{fa(1)} = \dot V_{fa(2)} = \dot V_{fa(0)} = j\frac{X_{ff(2)}X_{ff(0)}}{X_{ff(2)} + X_{ff(0)}}\dot I_{fa(1)}$$

$$\left.\begin{aligned}\dot I_{fa(2)} &= -\frac{X_{ff(0)}}{X_{ff(2)} + X_{ff(0)}}\dot I_{fa(1)}\\ \dot I_{fa(0)} &= -\frac{X_{ff(2)}}{X_{ff(2)} + X_{ff(0)}}\dot I_{fa(1)}\end{aligned}\right\}(8-15)$$

8-1 简单不对称短路的分析

3. 两相(b相和c相)短路接地——复合序网

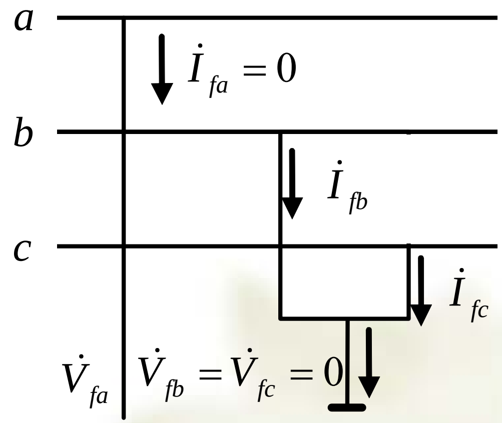


$$\left.\begin{aligned}\dot{V}_{fa(1)} = \dot{V}_{fa(2)} = \dot{V}_{fa(0)} \\ \dot{I}_{fa(1)} + \dot{I}_{fa(2)} + \dot{I}_{fa(0)} = 0\end{aligned}\right\} \quad (8\text{-}13)$$

$$\dot{I}_{fa(1)} = \frac{\dot{V}_f^{(0)}}{j(X_{ff(1)} + X_{ff(2)} // X_{ff(0)})}$$

$$\left.\begin{aligned}\dot{I}_{fa(2)} = -\frac{X_{ff(0)}}{X_{ff(2)} + X_{ff(0)}}\dot{I}_{fa(1)} \\ \dot{I}_{fa(0)} = -\frac{X_{ff(2)}}{X_{ff(2)} + X_{ff(0)}}\dot{I}_{fa(1)}\end{aligned}\right\}$$

$$\dot{V}_{fa(1)} = \dot{V}_{fa(2)} = \dot{V}_{fa(0)} = j\frac{X_{ff(2)}X_{ff(0)}}{X_{ff(2)} + X_{ff(0)}}\dot{I}_{fa(1)}$$



8-1 简单不对称短路的分析

3. 两相(b相和c相)短路接地——故障点各相电流电压

$$\dot{I}_{fa}=\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$

$$\dot{I}_{fb}=\alpha^2\dot{I}_{fa(1)}+\alpha\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=\left(\alpha^2-\frac{X_{ff(2)}+\alpha X_{ff(0)}}{X_{ff(2)}+X_{ff(0)}}\right)\dot{I}_{fa(1)}$$

$$\dot{I}_{fc}=\alpha\dot{I}_{fa(1)}+\alpha^2\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=\left(\alpha-\frac{X_{ff(2)}+\alpha^2 X_{ff(0)}}{X_{ff(2)}+X_{ff(0)}}\right)\dot{I}_{fa(1)}$$

$$\dot{V}_{fa}=\dot{V}_{fa(1)}+\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=3\dot{V}_{fa(1)}=j\frac{X_{ff(2)}X_{ff(0)}}{X_{ff(2)}+X_{ff(0)}}\dot{I}_{fa(1)}$$

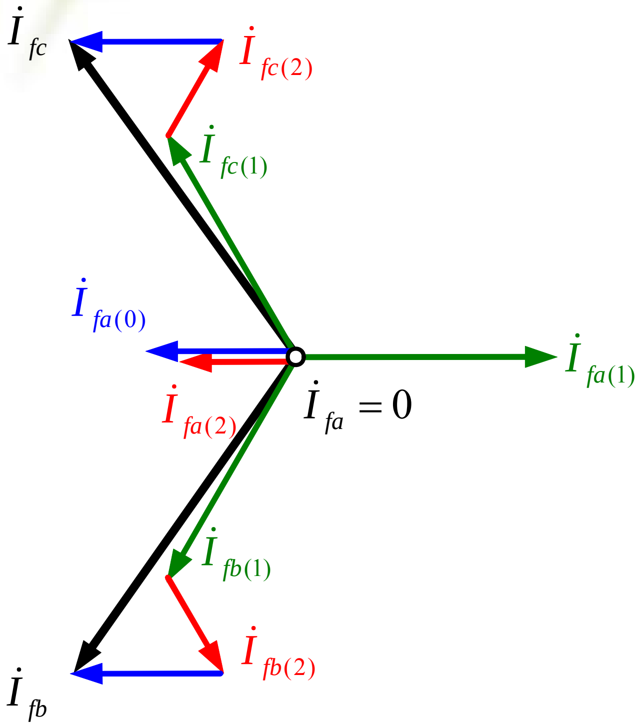
$$\dot{V}_{fb}=\dot{V}_{fc}=0$$

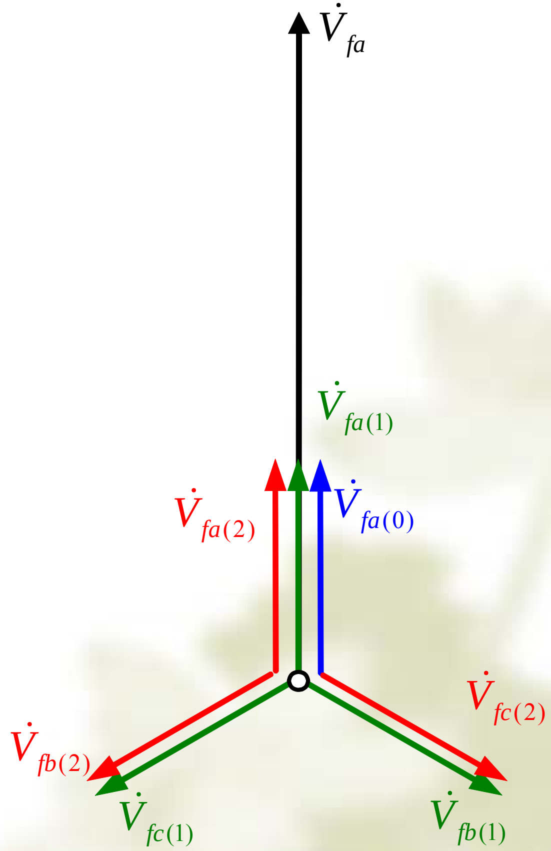
$$\dot{I}_{fa(1)}=\frac{\dot{V}_f^{(0)}}{j(X_{ff(1)}+X_{ff(2)}//X_{ff(0)})}$$

$$\dot{V}_{fa(1)}=\dot{V}_{fa(2)}=\dot{V}_{fa(0)}=j\frac{X_{ff(2)}X_{ff(0)}}{X_{ff(2)}+X_{ff(0)}}\dot{I}_{fa(1)}$$

8-1 简单不对称短路的分析

3. 两相(b相和c相)短路接地——相量图

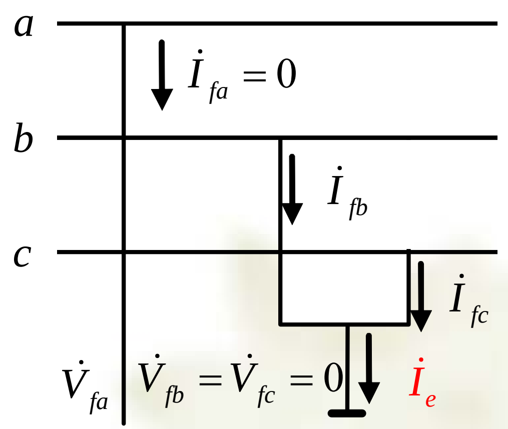




3. 两相(b相和c相)短路接地——故障点入地电流

$$\dot{I}_e = 3\dot{I}_{fa(0)} = \dot{I}_{fb} + \dot{I}_{fc} = -3\frac{X_{ff(2)}}{X_{ff(2)} + X_{ff(0)}}\dot{I}_{fa(1)}$$

$$\dot{I}_e = 3\dot{I}_{fa(0)} = j\frac{3\dot{V}_f^{(0)}}{X_{ff(1)} + X_{ff(0)} + X_{ff(1)}X_{ff(0)}/X_{ff(2)}}$$



$$\dot{I}_{fa(1)} = \frac{\dot{V}_f^{(0)}}{j(X_{ff(1)} + X_{ff(2)} // X_{ff(0)})}$$

$$\dot{V}_{fa(1)} = \dot{V}_{fa(2)} = \dot{V}_{fa(0)} = j\frac{X_{ff(2)}X_{ff(0)}}{X_{ff(2)} + X_{ff(0)}}\dot{I}_{fa(1)}$$

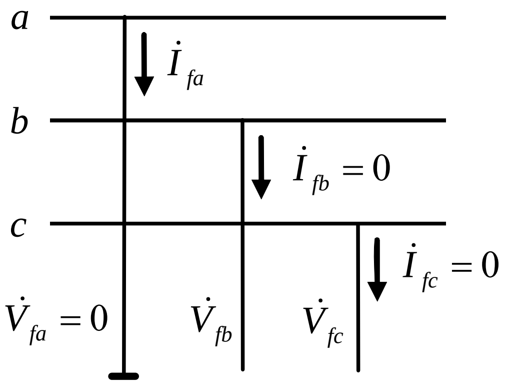
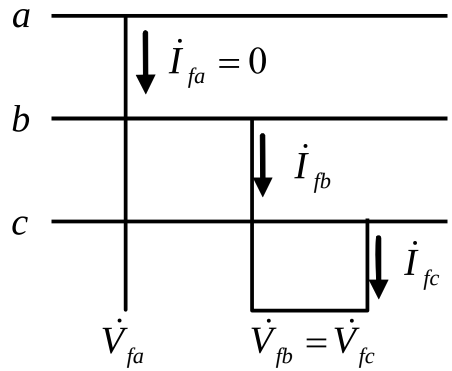
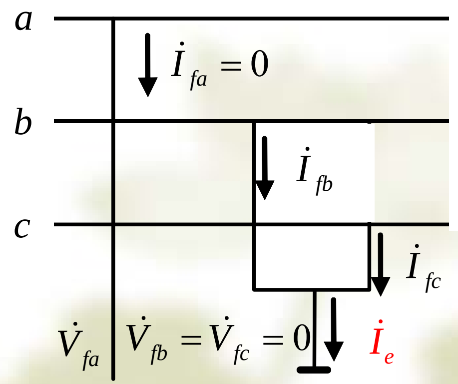
8-1 简单不对称短路的分析——小结

简单不对称短路的分析方法小结

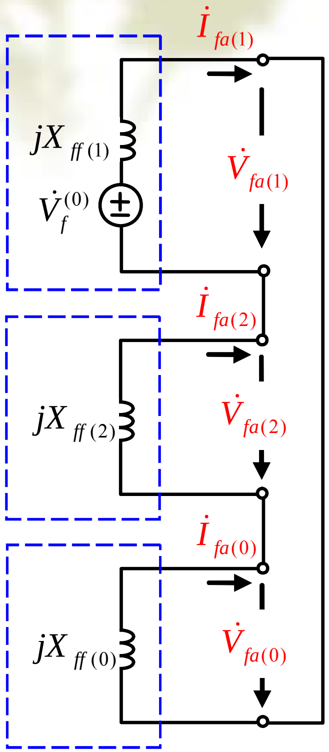
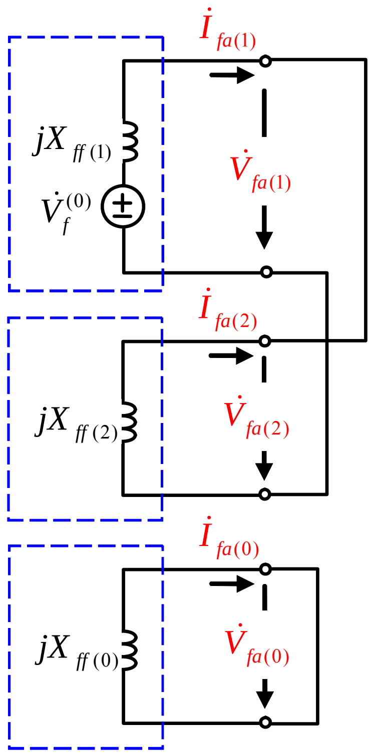
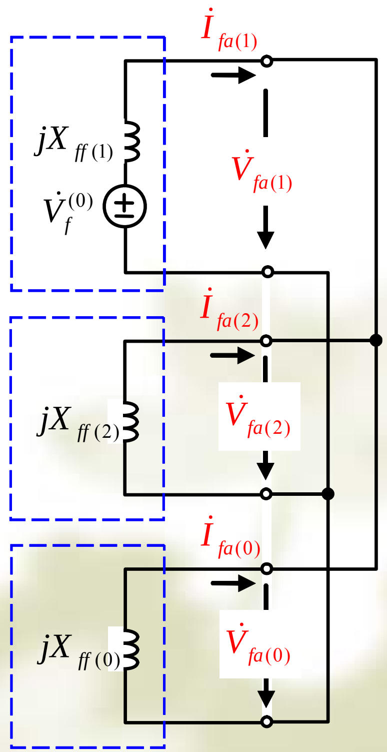
- 制定**各序网络**；根据系统运行方式确定故障口正常电压、各序输入阻抗，建立**序网方程**；(Chapter 7)
- 根据故障情况选取参考相，确定用**序分量表示的边界条件**；
- 由序网方程和序分量边界条件求解**故障口电流电压各序分量**(**复合序网**、方程求解等)；
- 对电流电压各序分量进行综合即可得到**故障口的电流和电压相量**。

8-1 简单不对称短路的分析——序分量边界条件

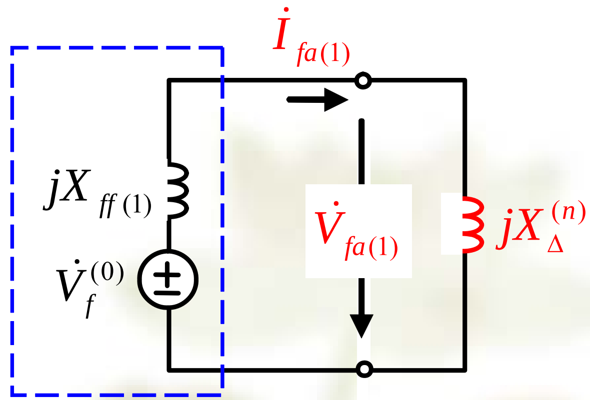
(1)关于故障特殊相和参考相——使序分量边界条件表达式简单

$f^{(1)}$	$f^{(2)}$	$f^{(1,1)}$
		
$\left.\begin{aligned}\dot V_{fa(1)}+\dot V_{fa(2)}+\dot V_{fa(0)}=0\\ \dot I_{fa(1)}=\dot I_{fa(2)}=\dot I_{fa(0)}\end{aligned}\right\}$	$\left.\begin{aligned}\dot V_{fa(1)}=\dot V_{fa(2)}\\ \dot I_{fa(1)}+\dot I_{fa(2)}=0, \dot I_{fa(0)}=0\end{aligned}\right\}$	$\left.\begin{aligned}\dot V_{fa(1)}=\dot V_{fa(2)}=\dot V_{fa(0)}\\ \dot I_{fa(1)}+\dot I_{fa(2)}+\dot I_{fa(0)}=0\end{aligned}\right\}$

8-1 简单不对称短路的分析——复合序网

<table>
<tr><th>$f^{(1)}$</th><th>$f^{(2)}$</th><th>$f^{(1,1)}$</th></tr>
<tr>
<td>
</td>
<td>
</td>
<td>
</td>
</tr>
<tr>
<td>$\dot{I}_{fa(1)}=\dfrac{\dot{V}_f^{(0)}}{j(X_{ff(1)}+X_{ff(2)}+X_{ff(0)})}$</td>
<td>$\dot{I}_{fa(1)}=\dfrac{\dot{V}_f^{(0)}}{j(X_{ff(1)}+X_{ff(2)})}$</td>
<td>$\dot{I}_{fa(1)}=\dfrac{\dot{V}_f^{(0)}}{j(X_{ff(1)}+X_{ff(2)}//X_{ff(0)})}$</td>
</tr>
</table>

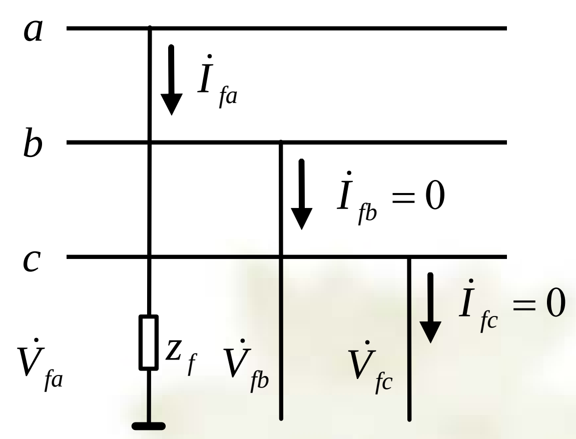
8-1 简单不对称短路的分析——正序等效定则

故障类型	附加电抗 $X_{\Delta}^{(n)}$	复合序网
$f^{(3)}$	0	
$f^{(1)}$	$X_{ff(2)} + X_{ff(0)}$	
$f^{(2)}$	$X_{ff(2)}$	
$f^{(1,1)}$	$X_{ff(2)} // X_{ff(0)}$	$\dot{I}_{fa(1)}^{(n)} = \dfrac{\dot{V}_f^{(0)}}{j(X_{ff(1)} + X_{\Delta}^{(n)})}$

8-1 简单不对称短路的分析——非全属性短路

(1) 单相(a相)非全属性接地短路——序分量边界条件

(1)相量表示的边界条件：$\dot{V}_{fa}=z_f\dot{I}_{fa},\ \dot{I}_{fb}=0,\ \dot{I}_{fc}=0$



(2)对称分量表示的边界条件

$$\dot{V}_{fa}=\dot{V}_{fa(1)}+\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=z_f(\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)})$$
$$\dot{I}_{fb}=\dot{I}_{fb(1)}+\dot{I}_{fb(2)}+\dot{I}_{fb(0)}=0$$
$$\dot{I}_{fc}=\dot{I}_{fc(1)}+\dot{I}_{fc(2)}+\dot{I}_{fc(0)}=0$$

(3)以a相为参考相

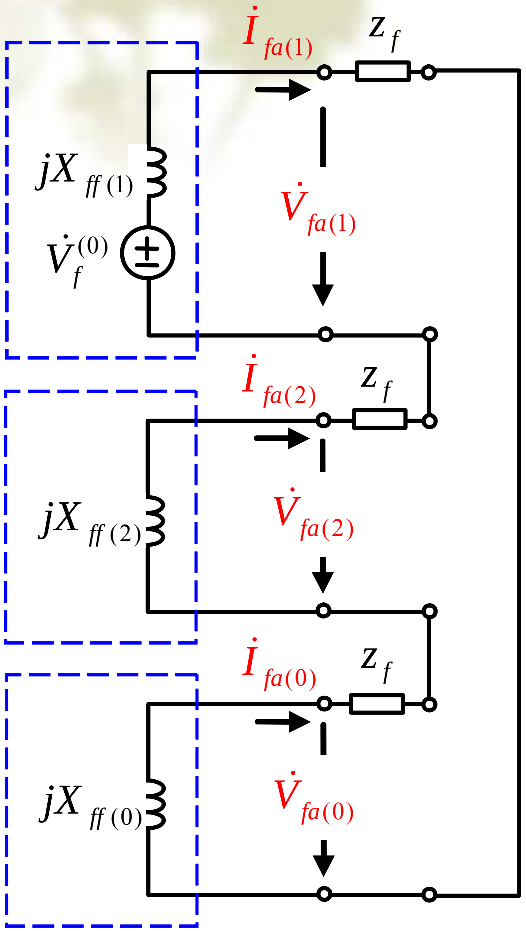
$$\dot{V}_{fa}=\dot{V}_{fa(1)}+\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=z_f(\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)})$$
$$\dot{I}_{fb}=\alpha^2\dot{I}_{fa(1)}+\alpha\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$
$$\dot{I}_{fc}=\alpha\dot{I}_{fa(1)}+\alpha^2\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$

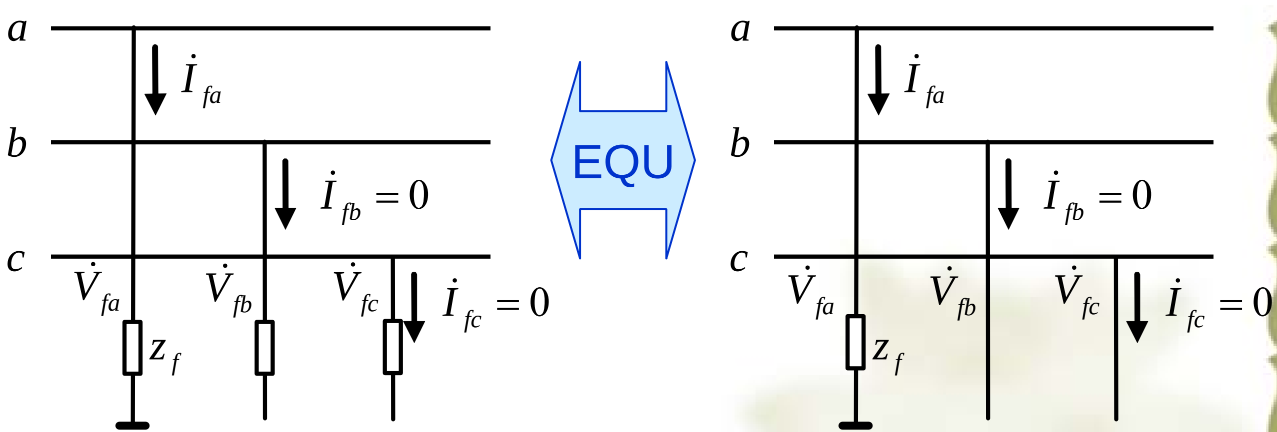
(4)序分量边界条件：

$$\left.\begin{aligned}&\dot{V}_{fa(1)}+\dot{V}_{fa(2)}+\dot{V}_{fa(0)}=3z_f\dot{I}_{fa(1)}\\&\dot{I}_{fa(1)}=\dot{I}_{fa(2)}=\dot{I}_{fa(0)}\end{aligned}\right\}$$

8-1 简单不对称短路的分析——非金属性短路

(1) 单相(a相)非金属性接地短路——复合序网



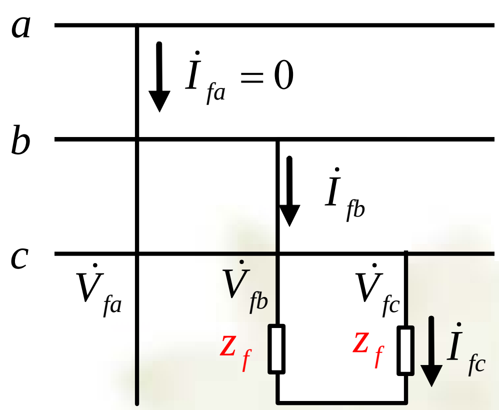


$$\left.\begin{array}{l}\dot V_{fa(1)}+\dot V_{fa(2)}+\dot V_{fa(0)}=3z_f\dot I_{fa(1)}\\ \dot I_{fa(1)}=\dot I_{fa(2)}=\dot I_{fa(0)}\end{array}\right\}$$

8-1 简单不对称短路的分析——非全属性短路

(2) 两相(b相和c相)非全属性短路——序分量边界条件

$$\dot{V}_{fb}-z_f\dot{I}_{fb}=\dot{V}_{fc}-z_f\dot{I}_{fc},\ \dot{I}_{fa}=0,\dot{I}_{fb}+\dot{I}_{fc}=0$$



$$\dot{V}_{fb(1)}+\dot{V}_{fb(2)}+\dot{V}_{fb(0)}-z_f(\dot{I}_{fb(1)}+\dot{I}_{fb(2)}+\dot{I}_{fb(0)})$$
$$=\dot{V}_{fc(1)}+\dot{V}_{fc(2)}+\dot{V}_{fc(0)}-z_f(\dot{I}_{fc(1)}+\dot{I}_{fc(2)}+\dot{I}_{fc(0)})$$
$$\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$
$$\dot{I}_{fb(1)}+\dot{I}_{fb(2)}+\dot{I}_{fb(0)}+\dot{I}_{fc(1)}+\dot{I}_{fc(2)}+\dot{I}_{fc(0)}=0$$

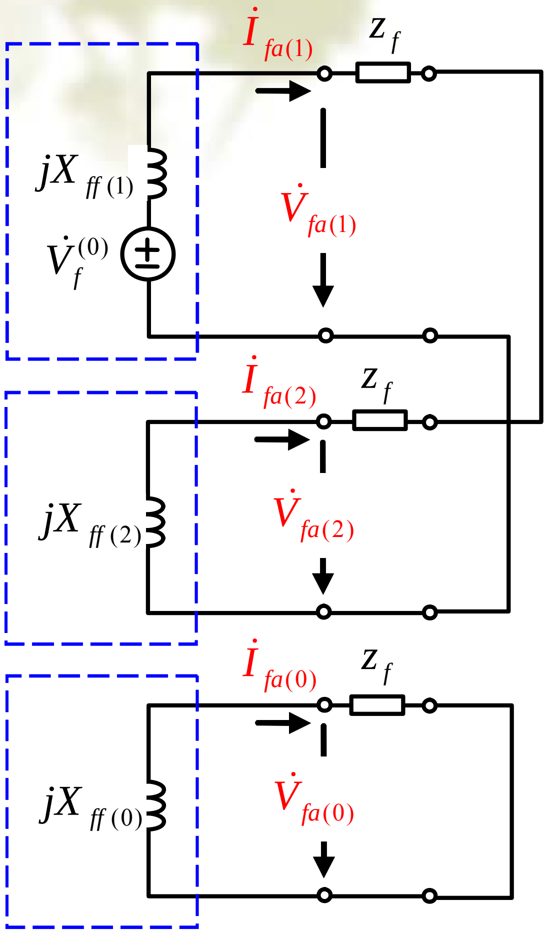
$$(\alpha^2-\alpha)\dot{V}_{fa(1)}+(\alpha-\alpha^2)\dot{V}_{fa(2)}$$
$$=z_f\left[(\alpha^2-\alpha)\dot{I}_{fa(1)}+(\alpha-\alpha^2)\dot{I}_{fa(2)}\right]$$
$$\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$
$$(\alpha^2+\alpha)\dot{I}_{fa(1)}+(\alpha^2+\alpha)\dot{I}_{fa(2)}+2\dot{I}_{fa(0)}=0$$

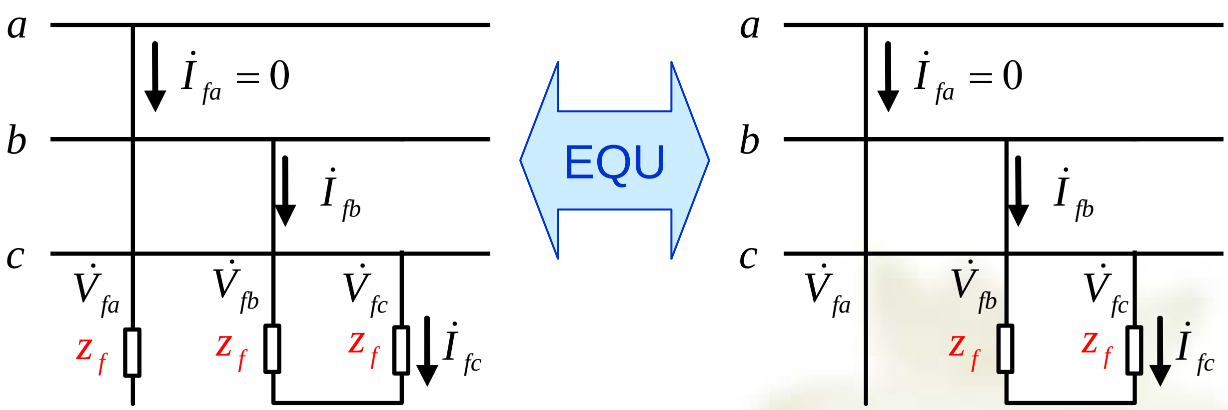
(4) 序分量边界条件：

$$\left.\begin{array}{l}\dot{V}_{fa(1)}-z_f\dot{I}_{fa(1)}=\dot{V}_{fa(2)}-z_f\dot{I}_{fa(1)}\\ \dot{I}_{fa(1)}+\dot{I}_{fa(2)}=0,\dot{I}_{fa(0)}=0\end{array}\right\}$$

8-1 简单不对称短路的分析——非全属性短路

(2) 两相(b相和c相)非全属性短路——复合序网



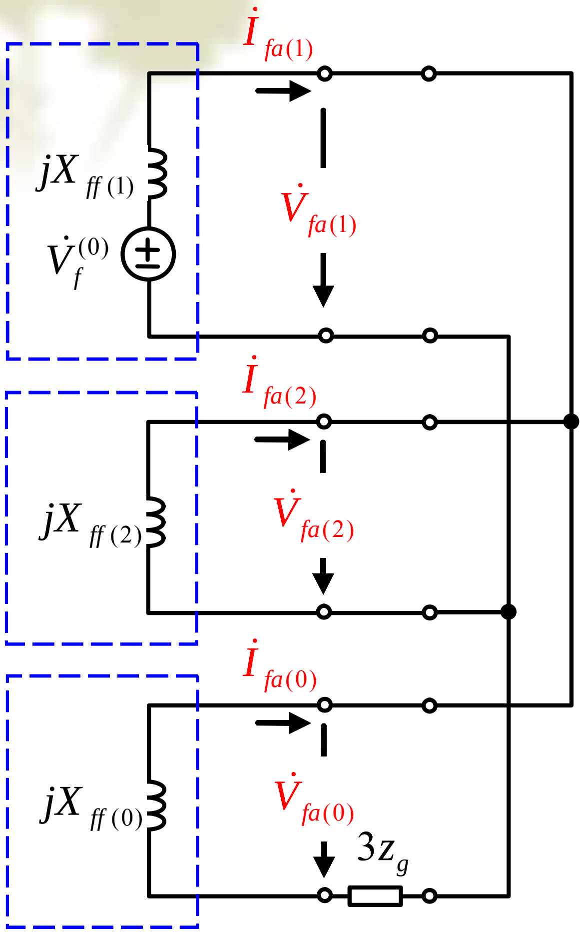


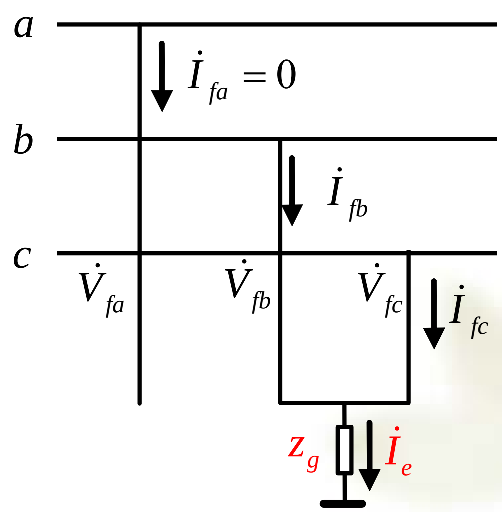
序分量边界条件：

$$\left.\begin{aligned}&\dot{V}_{fa(1)}-z_f\dot{I}_{fa(1)}=\dot{V}_{fa(2)}-z_f\dot{I}_{fa(2)}\\&\dot{I}_{fa(1)}+\dot{I}_{fa(2)}=0,\dot{I}_{fa(0)}=0\end{aligned}\right\}$$

8-1 简单不对称短路的分析——非金属性短路

(2) 两相(b相和c相)非金属性短路接地——复合序网



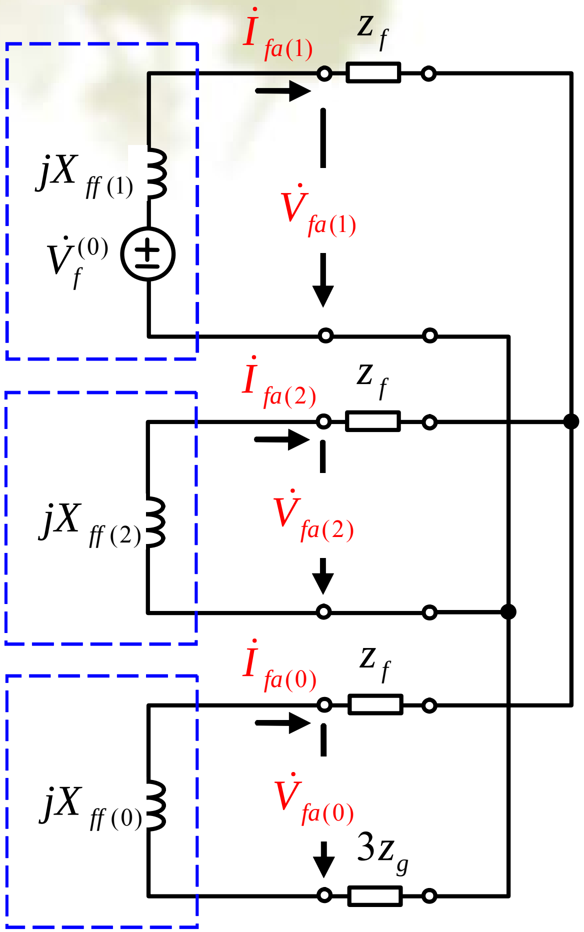


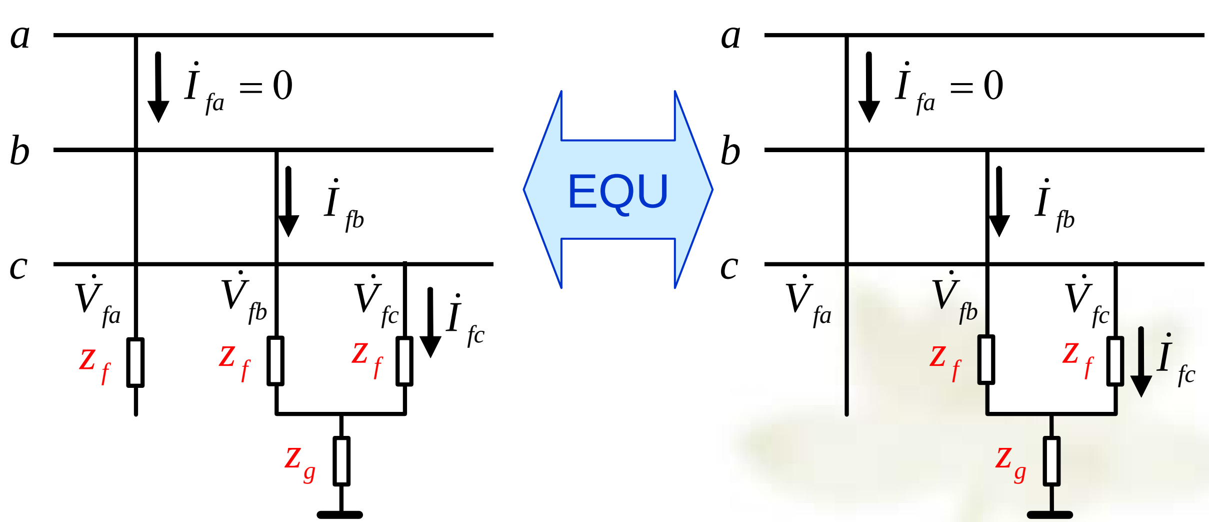
序分量边界条件：

$$\left.\begin{aligned}&\dot{V}_{fa(1)}=\dot{V}_{fa(2)}=\dot{V}_{fa(0)}-3z_g\dot{I}_{fa(0)}\\&\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0\end{aligned}\right\}$$

8-1 简单不对称短路的分析——非金属性短路

(3) 两相(b相和c相)非金属性短路接地——复合序网



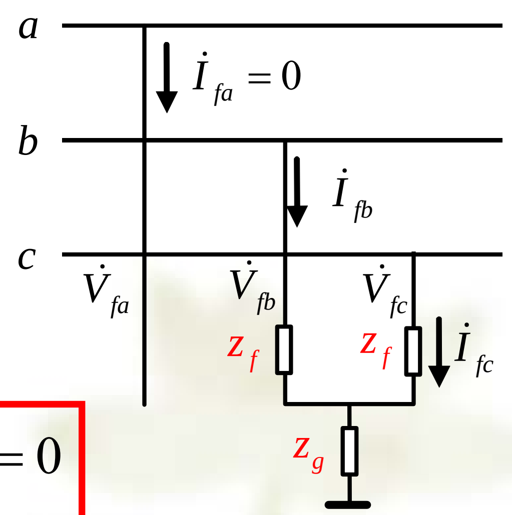


序分量边界条件：

$$\left.\begin{aligned}&\dot V_{fa(1)} - z_f \dot I_{fa(1)} = \dot V_{fa(2)} - z_f \dot I_{fa(2)} = \dot V_{fa(0)} - (z_f + 3z_g)\dot I_{fa(0)} \\ &\dot I_{fa(1)} + \dot I_{fa(2)} + \dot I_{fa(0)} = 0\end{aligned}\right\}$$

8-1 简单不对称短路的分析——非全属性短路

(3) 两相(b相和c相)非全属性短路接地——序分量边界条件



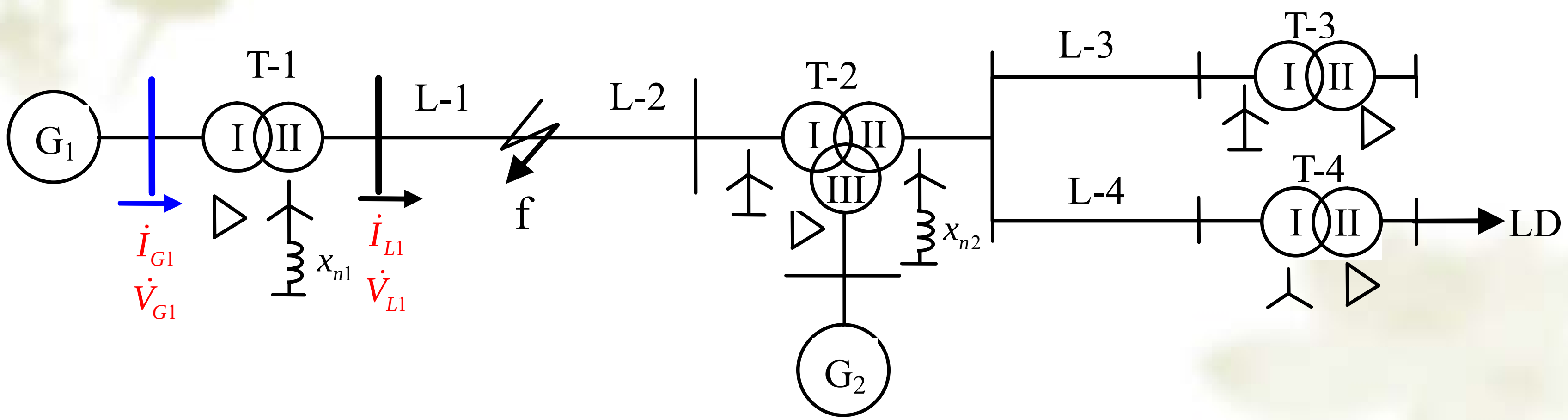
$$\dot{I}_{fa}=0$$
$$\dot{V}_{fb}-z_f\dot{I}_{fb}-z_g(\dot{I}_{fb}+\dot{I}_{fc})=0$$
$$\dot{V}_{fc}-z_f\dot{I}_{fc}-z_g(\dot{I}_{fb}+\dot{I}_{fc})=0$$

$$\alpha^2\dot{V}_{fa(1)}+\alpha\dot{V}_{fa(2)}+\dot{V}_{fa(0)}-z_f(\alpha^2\dot{I}_{fa(1)}+\alpha\dot{I}_{fa(2)}+\dot{I}_{fa(0)})-3z_g\dot{I}_{fa(0)}=0$$
$$\alpha\dot{V}_{fa(1)}+\alpha^2\dot{V}_{fa(2)}+\dot{V}_{fa(0)}-z_f(\alpha\dot{I}_{fa(1)}+\alpha^2\dot{I}_{fa(2)}+\dot{I}_{fa(0)})-3z_g\dot{I}_{fa(0)}=0$$
$$\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0$$

$$\left.\begin{aligned}&\dot{V}_{fa(1)}-z_f\dot{I}_{fa(1)}=\dot{V}_{fa(2)}-z_f\dot{I}_{fa(2)}=\dot{V}_{fa(0)}-(z_f+3z_g)\dot{I}_{fa(0)}\\&\dot{I}_{fa(1)}+\dot{I}_{fa(2)}+\dot{I}_{fa(0)}=0\end{aligned}\right\}$$

8-2 电压和电流对称分量经变压器后的相位变换

1. 不对称故障电压电流分布计算——举例

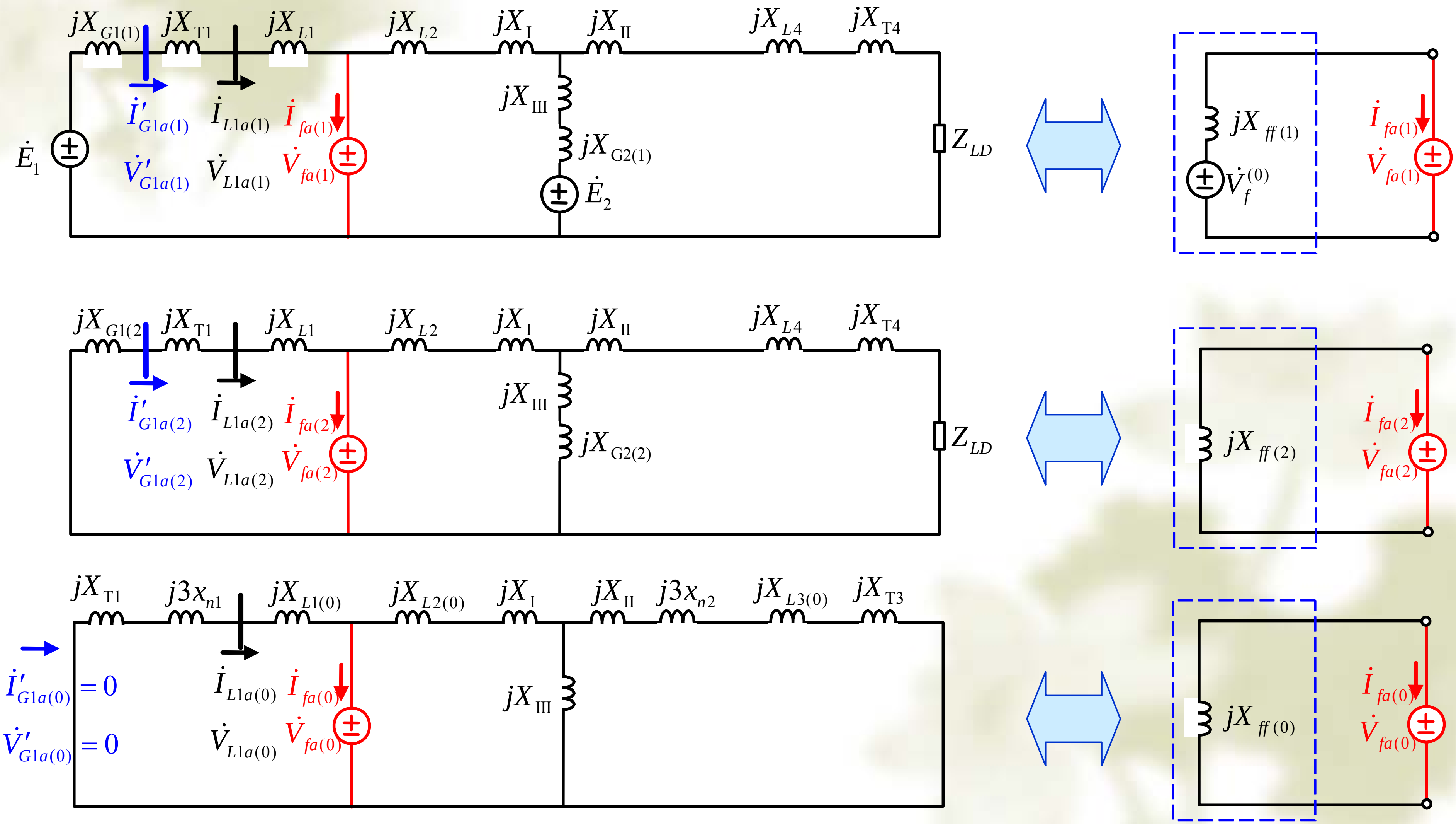


$$\dot{V}_{G1A}=\dot{V}_{G1A(1)}+\dot{V}_{G1A(2)}+\dot{V}_{G1A(0)}$$
$$\dot{V}_{G1B}=\dot{V}_{G1B(1)}+\dot{V}_{G1B(2)}+\dot{V}_{G1B(0)}$$
$$\dot{V}_{G1C}=\dot{V}_{G1C(1)}+\dot{V}_{G1C(2)}+\dot{V}_{G1C(0)}$$

$$\dot{I}_{G1A}=\dot{I}_{G1A(1)}+\dot{I}_{G1A(2)}+\dot{I}_{G1A(0)}$$
$$\dot{I}_{G1B}=\dot{I}_{G1B(1)}+\dot{I}_{G1B(2)}+\dot{I}_{G1B(0)}$$
$$\dot{I}_{G1C}=\dot{I}_{G1C(1)}+\dot{I}_{G1C(2)}+\dot{I}_{G1C(0)}$$

$$\dot{I}_{L1a}=\dot{I}_{L1a(1)}+\dot{I}_{L1a(2)}+\dot{I}_{L1a(0)}$$
$$\dot{I}_{L1b}=\dot{I}_{L1b(1)}+\dot{I}_{L1b(2)}+\dot{I}_{L1b(0)}$$
$$\dot{I}_{L1c}=\dot{I}_{L1c(1)}+\dot{I}_{L1c(2)}+\dot{I}_{L1c(0)}$$

1. 不对称故障电压电流分布计算——举例



1. 不对称故障电压电流分布计算——基本特点

不对称故障电压电流对称分量分布的特点

- 电源点负序电压为零；
- 正序电压在电源点最高，短路点最低；
- 故障点零序和负序电压最高；
- 变压器三角侧零序电压为零；
- 网络中各点三相电压不对称程度主要决定于负序分量，负序分量愈大，电压愈不对称。

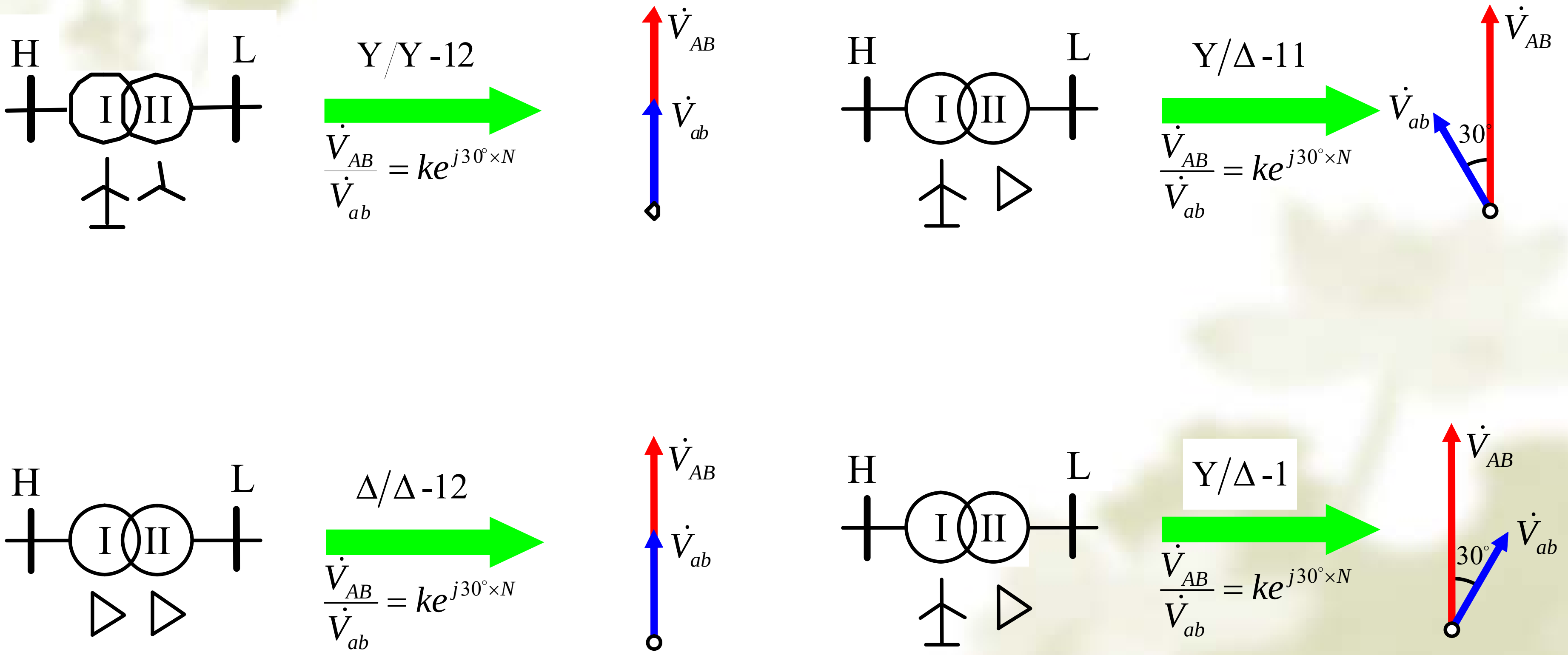
1. 不对称故障电压电流分布计算——基本步骤

不对称故障电压电流分布计算

- 由序网方程和序分量边界条件求解故障口电流电压各序分量(复合序网、方程求解等)；
- 由各序网络计算电流电压各序分量的分布情况；
- 对某一节点各序电压分量或者支路各序电流分量进行综合即可得到相应的电压和电流相量；
- 必须注意对称分量经过变压器后的相位变换问题。

2. 电压电流对称分量经变压器后的相位变换

(1) 变压器绕组联结组别及时钟定则



2. 电压电流对称分量经变压器后的相位变换

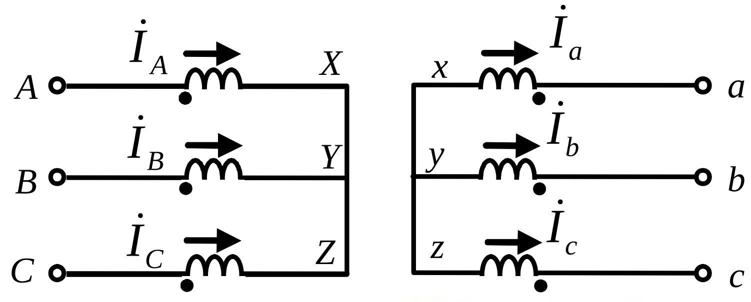
(2)对称分量经变压器后的相位变换

绕组联结组别：Y/Y−12

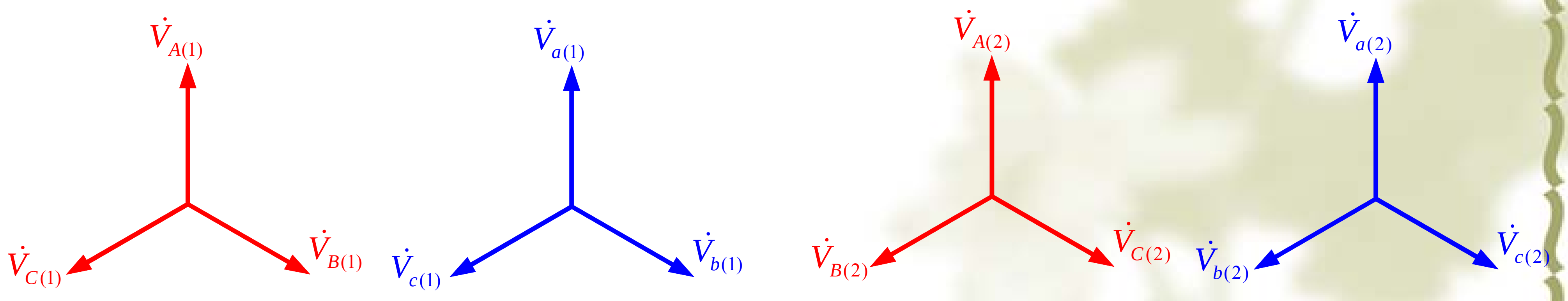
变比：$k = V_{1N}/V_{2N}$，$k' = k$

$$\dot{I}_A = \frac{1}{k}\dot{I}_a,\ \dot{I}_B = \frac{1}{k}\dot{I}_b,\ \dot{I}_C = \frac{1}{k}\dot{I}_c$$

$$\dot{V}_A = k\dot{V}_a,\ \dot{V}_B = k\dot{V}_b,\ \dot{V}_C = k\dot{V}_c$$



Y/Y-12



2. 电压电流对称分量经变压器后的相位变换

(2)对称分量经变压器后的相位变换

绕组联结组别：Y/Δ−11

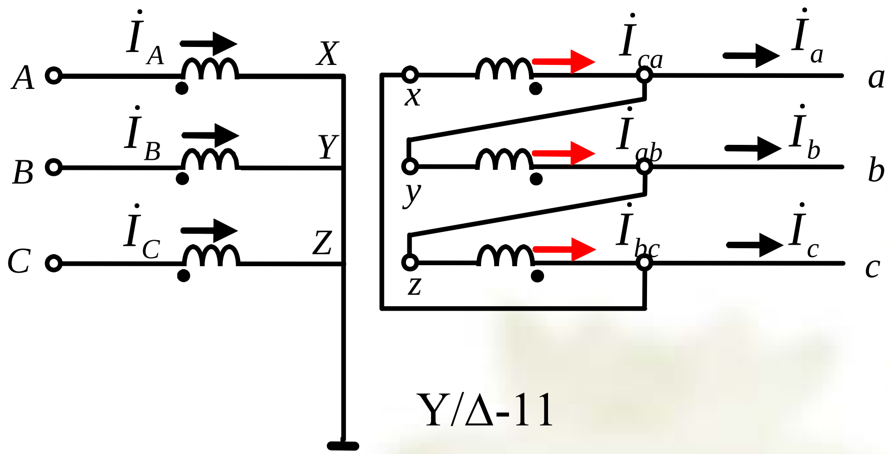
变比：$k = V_{1N} / V_{2N}$，$k' = k/\sqrt{3}$

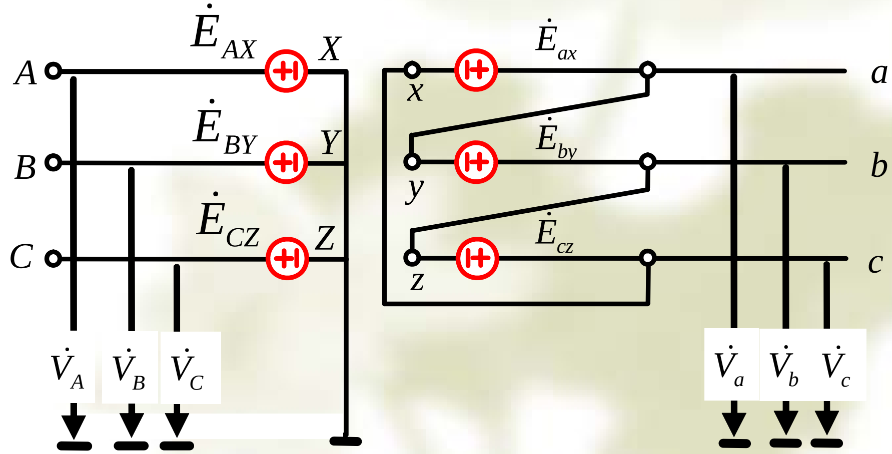
$$\dot I_A = \frac{1}{k'}\dot I_{ca},\quad \dot I_B = \frac{1}{k'}\dot I_{ab},\quad \dot I_C = \frac{1}{k'}\dot I_{bc}$$

$$\dot V_A = \dot E_{AX} = k'\dot E_{ax} = k'\dot V_{ac} = -k'\dot V_{ca}$$

$$\dot V_B = \dot E_{BY} = k'\dot E_{by} = k'\dot V_{ba} = -k'\dot V_{ab}$$

$$\dot V_C = \dot E_{CZ} = k'\dot E_{cz} = k'\dot V_{cb} = -k'\dot V_{bc}$$





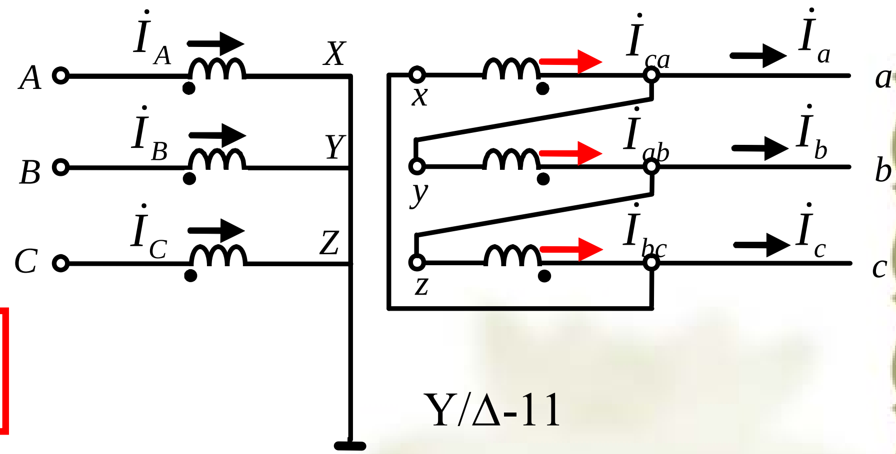
2. 电压电流对称分量经变压器后的相位变换

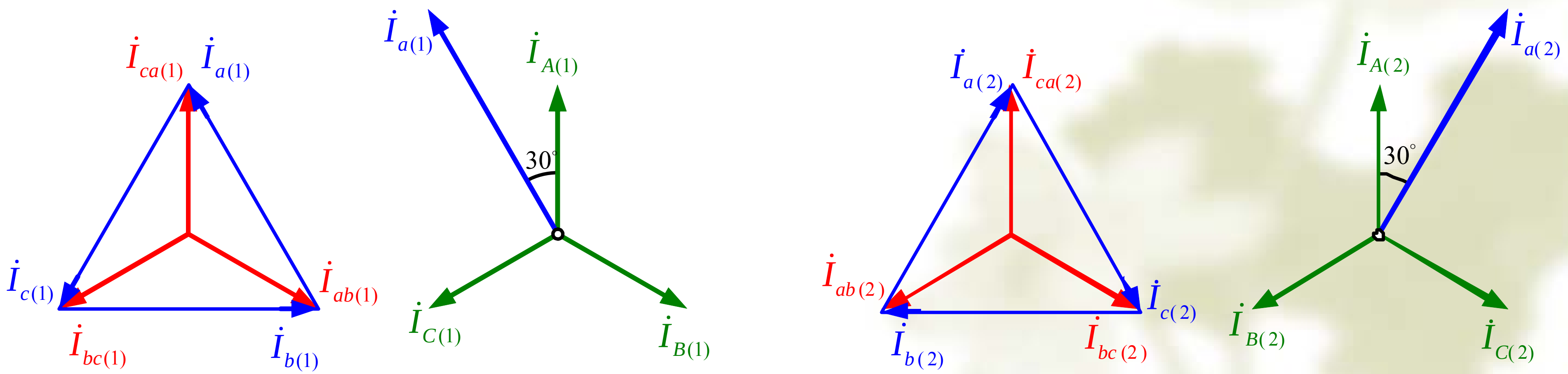
(2)对称分量经变压器后的相位变换——电流序分量

$$k = V_{1N} / V_{2N}, \quad k' = k / \sqrt{3}$$

$$\dot{I}_A = \frac{1}{k'}\dot{I}_{ca}, \quad \dot{I}_B = \frac{1}{k'}\dot{I}_{ab}, \quad \dot{I}_C = \frac{1}{k'}\dot{I}_{bc}$$

$$\dot{I}_a = \dot{I}_{ca} - \dot{I}_{ab}, \quad \dot{I}_b = \dot{I}_{ab} - \dot{I}_{bc}, \quad \dot{I}_c = \dot{I}_{bc} - \dot{I}_{ca}$$



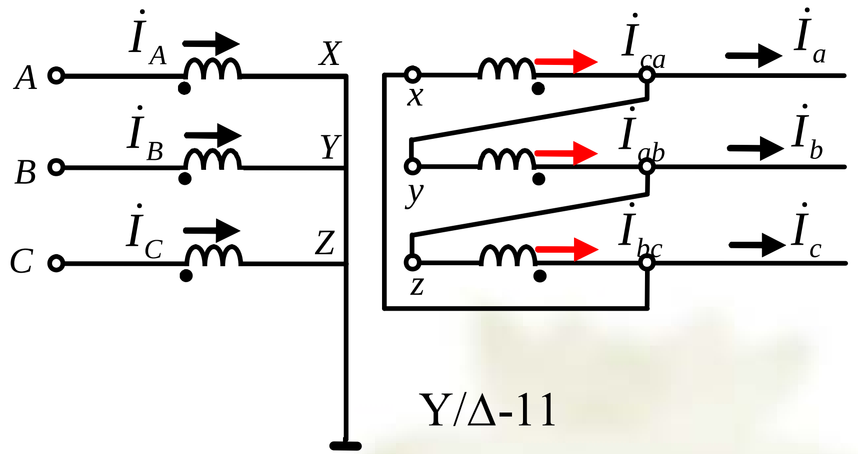


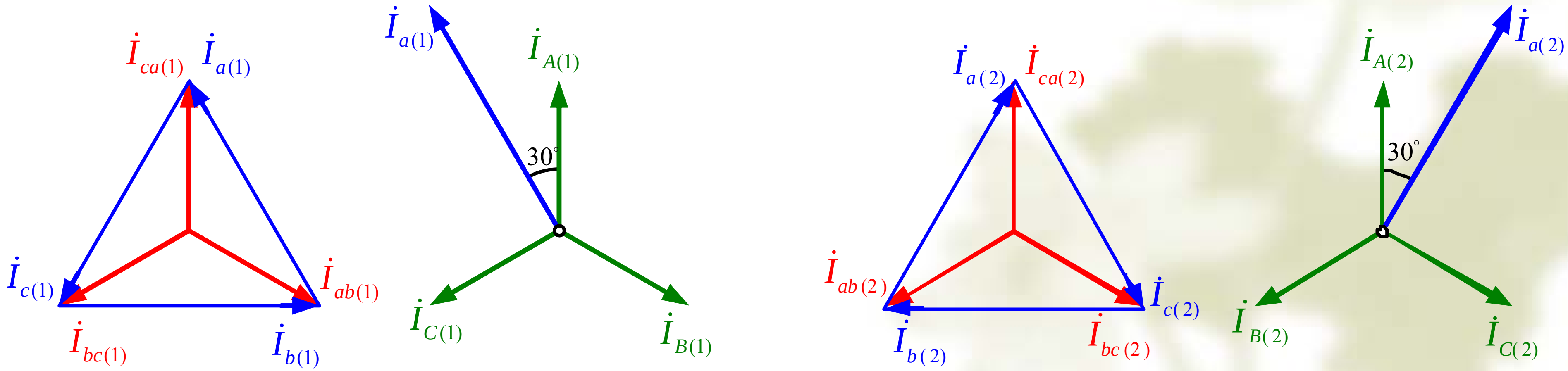
2. 电压电流对称分量经变压器后的相位变换

(2)对称分量经变压器后的相位变换——电流序分量

$$\dot{I}_{a(1)} = ke^{j30^0}\dot{I}_{A(1)}$$

$$\dot{I}_{a(2)} = ke^{-j30^0}\dot{I}_{A(2)}$$

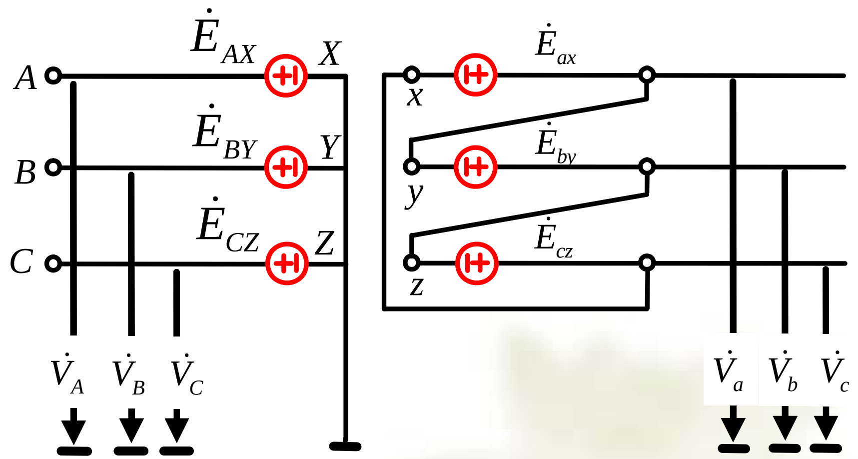


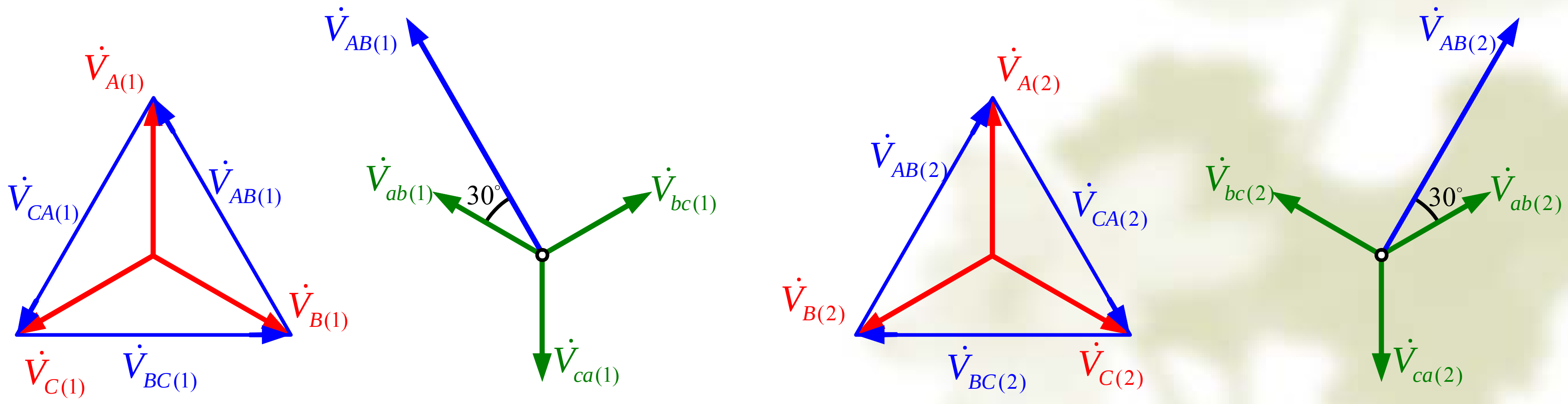


2. 电压电流对称分量经变压器后的相位变换

(2)对称分量经变压器后的相位变换——电压序分量

$$\dot{V}_A = \dot{E}_{AX} = k'\dot{E}_{ax} = k'\dot{V}_{ac} = -k'\dot{V}_{ca}$$
$$\dot{V}_B = \dot{E}_{BY} = k'\dot{E}_{by} = k'\dot{V}_{ba} = -k'\dot{V}_{ab}$$
$$\dot{V}_C = \dot{E}_{CZ} = k'\dot{E}_{cz} = k'\dot{V}_{cb} = -k'\dot{V}_{bc}$$





2. 电压电流对称分量经变压器后的相位变换

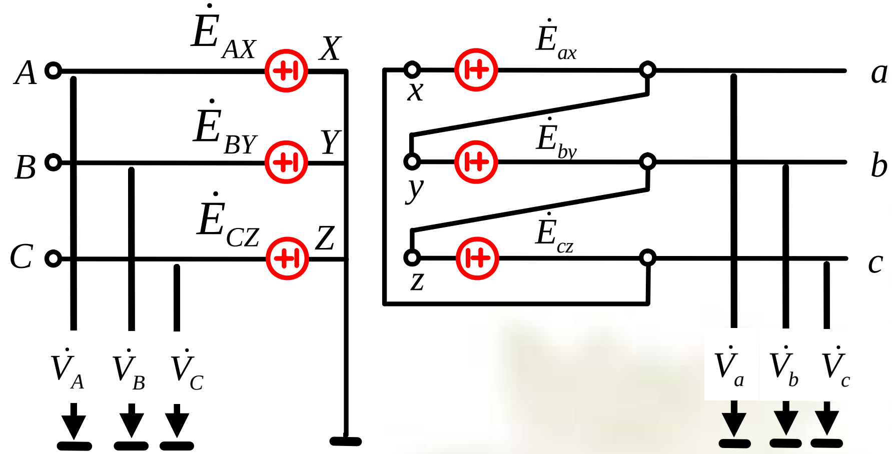
(2)对称分量经变压器后的相位变换——电压序分量

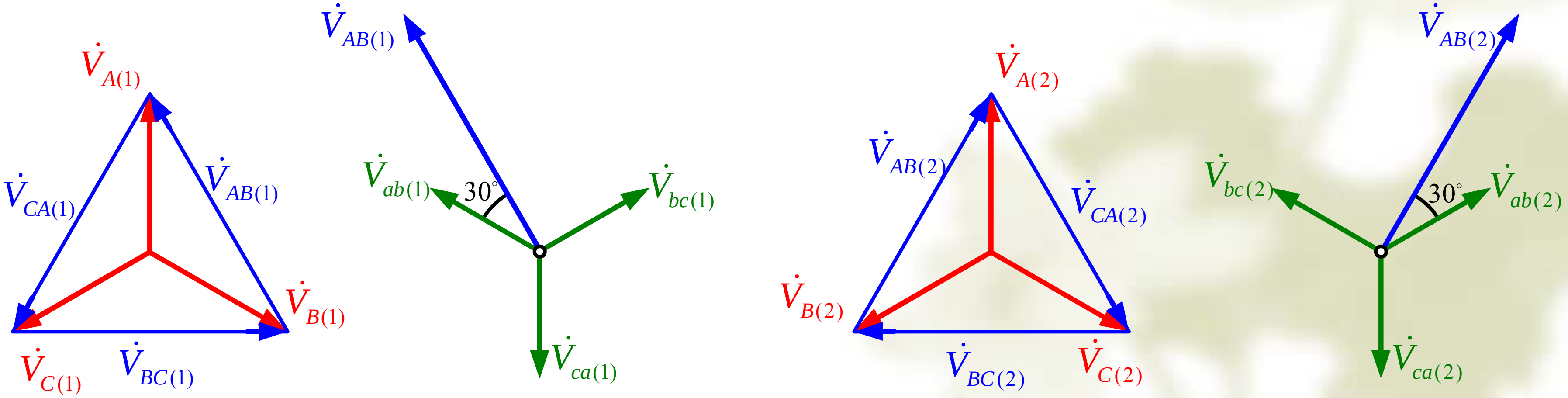
$$\dot{V}_{ab(1)}=\frac{1}{k}e^{j30^{\circ}}\dot{V}_{AB(1)}$$

$$\dot{V}_{ab(2)}=\frac{1}{k}e^{-j30^{\circ}}\dot{V}_{AB(2)}$$

$$\dot{V}_{a(1)}=\frac{1}{k}e^{j30^{0}}\dot{V}_{A(1)}$$

$$\dot{V}_{a(2)}=\frac{1}{k}e^{-j30^{0}}\dot{V}_{A(2)}$$





(2)对称分量经变压器后的相位变换——应用举例

Step 1:作各序网络：$X_{ff(1)} = X_{ff(2)} = 0.26, X_{ff(0)} = 0.48$

Step 2:计算故障口电流正序分量

$$\dot{I}_{fA(1)} = \frac{\dot{V}_f^{(0)}}{j(X_{ff(1)} + X_{ff(2)} + X_{ff(0)})} = \frac{j1.0}{j(0.26+0.26+0.48)} = 1.0$$

Step 3:计算故障口电流各序分量

$$\dot{I}_{fA(2)} = \dot{I}_{fA(0)} = \dot{I}_{fA(1)} = 1.0,\quad \dot{V}_{fA(1)} = j(X_{ff(2)} + X_{ff(0)})\dot{I}_{fA(1)} = j0.74$$

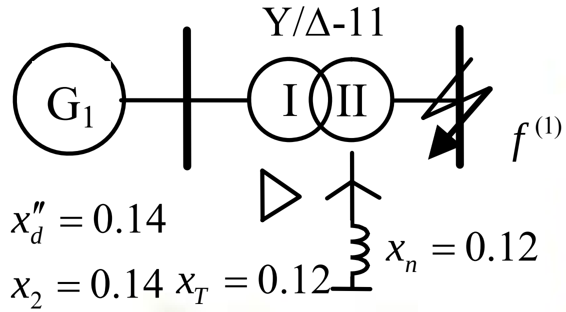
Step 4:计算发电机端电流各序分量

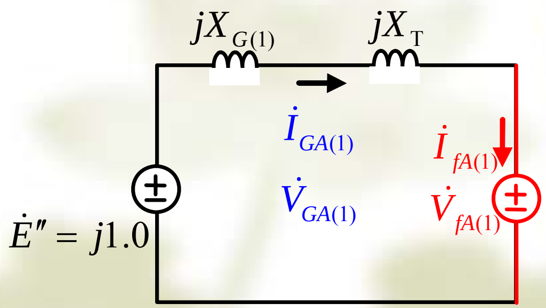
$$\dot{I}_{Ga(1)} = \dot{I}_{GA(1)} e^{j30^\circ} = \dot{I}_{fA(1)} e^{j30^\circ} = e^{j30^\circ}$$

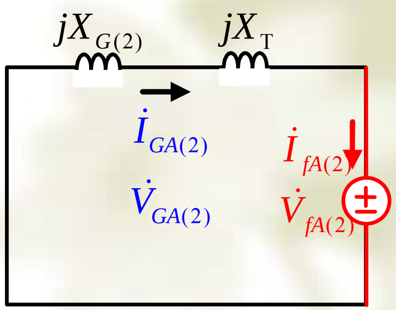
$$\dot{I}_{Ga(2)} = \dot{I}_{GA(2)} e^{-j30^\circ} = \dot{I}_{fA(1)} e^{-j30^\circ} = e^{-j30^\circ}$$

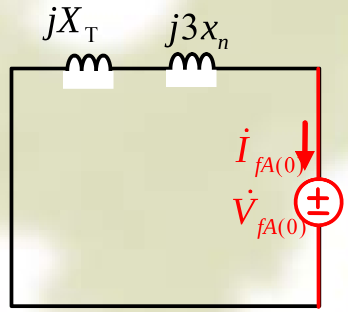
$$\dot{I}_{Ga(0)} = 0$$

计算发电机各相电流









(2)对称分量经变压器后的相位变换——应用举例

Step 5:计算发电机端各相电流

$$\dot I_{Ga}=\dot I_{Ga(1)}+\dot I_{Ga(2)}+\dot I_{Ga(0)}=\dot I_{GA(1)}e^{j30^\circ}+\dot I_{GA(2)}e^{-j30^\circ}=\sqrt{3}$$

$$\dot I_{Gb}=\alpha^2\dot I_{Ga(1)}+\alpha\dot I_{Ga(2)}+\dot I_{Ga(0)}=\dot I_{GA(1)}e^{j90^\circ}+\dot I_{GA(2)}e^{-j90^\circ}=0$$

$$\dot I_{Gc}=\alpha\dot I_{Ga(1)}+\alpha^2\dot I_{Ga(2)}+\dot I_{Ga(0)}=\dot I_{GA(1)}e^{j150^\circ}+\dot I_{GA(2)}e^{-j150^\circ}=-\sqrt{3}$$

Step 6:计算故障口电压各序分量

$$\dot V_{fA(1)}=j(X_{ff(2)}+X_{ff(0)})\dot I_{fA(1)}=j0.74$$

$$\dot V_{fA(2)}=-jX_{ff(2)}\dot I_{fA(1)}=-j0.26,\quad \dot V_{fA(0)}=-jX_{ff(0)}\dot I_{fA(1)}=-j0.48$$

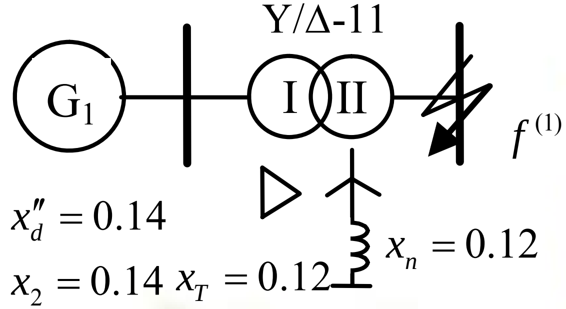
Step 7:计算发电机端电压各序分量

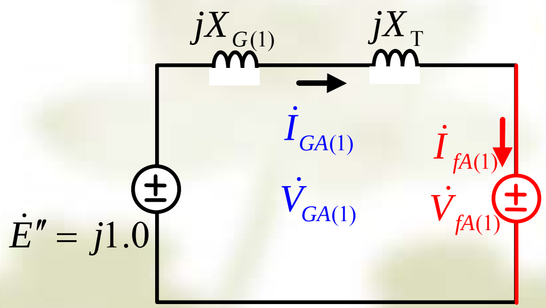
$$\dot V_{GA(1)}=\dot V_{fA(1)}+jX_T\dot I_{fA(1)}=j0.74+j0.12=j0.86$$

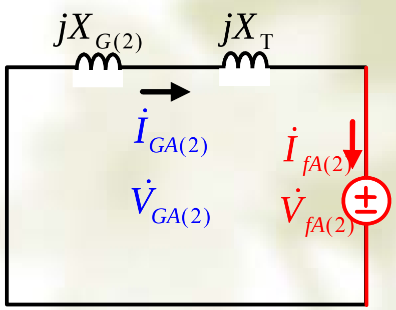
$$\dot V_{GA(2)}=\dot V_{fA(2)}+jX_T\dot I_{fA(2)}=-j0.26+j0.12=-j0.14$$

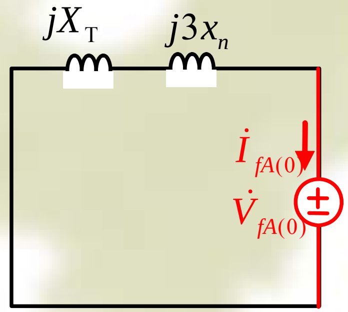
$$\dot V_{GA(0)}=0$$

计算发电机各相电流









(2)对称分量经变压器后的相位变换——应用举例

Step 7:计算发电机端电压各序分量

$$\dot{V}_{GA(1)}=\dot{V}_{fA(1)}+jX_T\dot{I}_{fA(1)}=j0.74+j0.12=j0.86$$

$$\dot{V}_{GA(2)}=\dot{V}_{fA(2)}+jX_T\dot{I}_{fA(2)}=-j0.26+j0.12=-j0.14$$

$$\dot{V}_{GA(0)}=0$$

$$\dot{V}_{Ga(1)}=\dot{V}_{GA(1)}e^{j30^\circ},\dot{V}_{Ga(2)}=\dot{V}_{GA(2)}e^{-j30^\circ},\dot{V}_{Ga(0)}=0$$

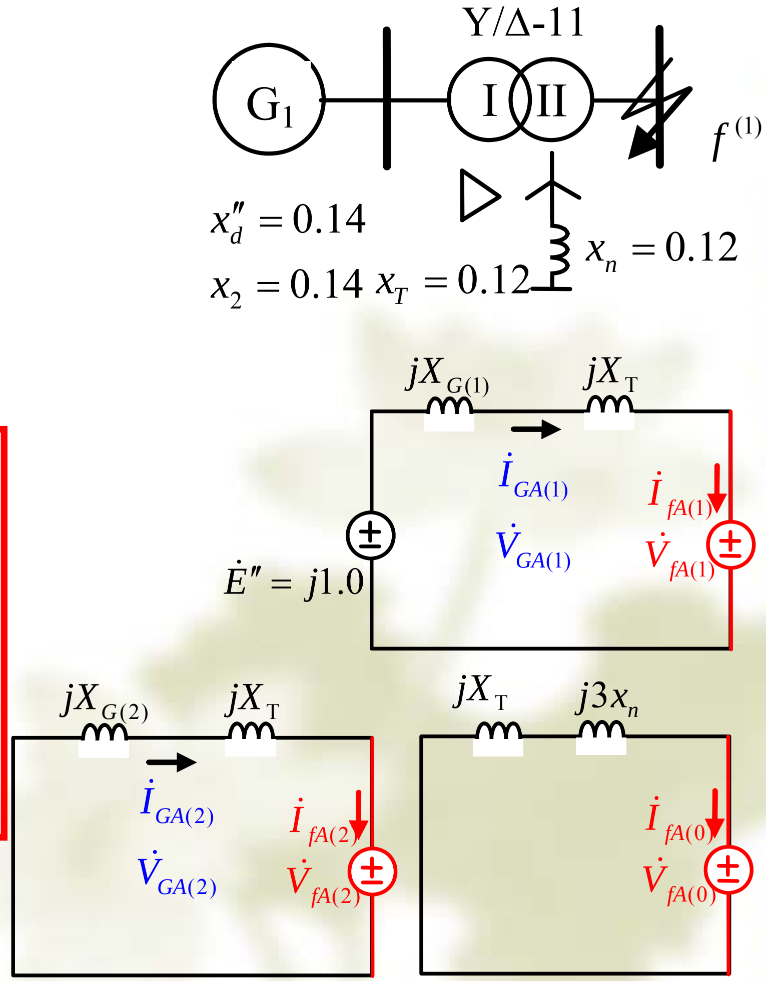
Step 8:计算发电机端各相电压

$$\dot{V}_{Ga}=\dot{V}_{Ga(1)}+\dot{V}_{Ga(2)}+\dot{V}_{Ga(0)}=\dot{V}_{GA(1)}e^{j30^\circ}+\dot{V}_{GA(2)}e^{-j30^\circ}$$

$$\dot{V}_{Gb}=\alpha^2\dot{V}_{Ga(1)}+\alpha\dot{V}_{Ga(2)}+\dot{V}_{Ga(0)}=\dot{V}_{GA(1)}e^{-j90^\circ}+\dot{V}_{GA(2)}e^{j90^\circ}$$

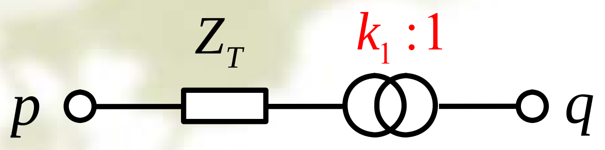
$$\dot{V}_{Gc}=\alpha\dot{V}_{Ga(1)}+\alpha^2\dot{V}_{Ga(2)}+\dot{V}_{Ga(0)}=\dot{V}_{GA(1)}e^{j150^\circ}+\dot{V}_{GA(2)}e^{-j150^\circ}$$

计算发电机各相电流

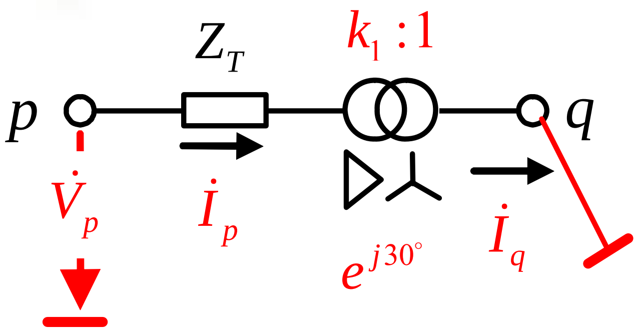


(2)对称分量经变压器后的相位变换——说明

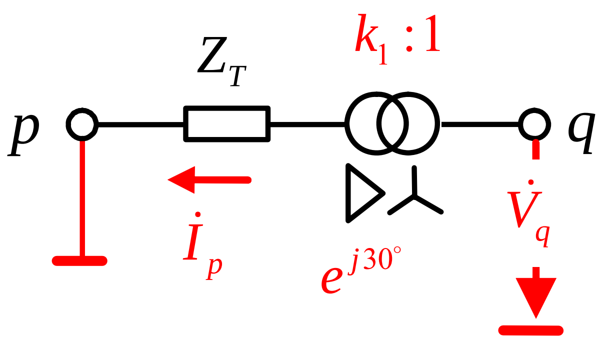
（1）变压器一相等值电路不考虑相移的原因：→ Y阵对称性



$$\Delta Y_{pq} = \Delta Y_{qp} = -k_1 / Z_T$$



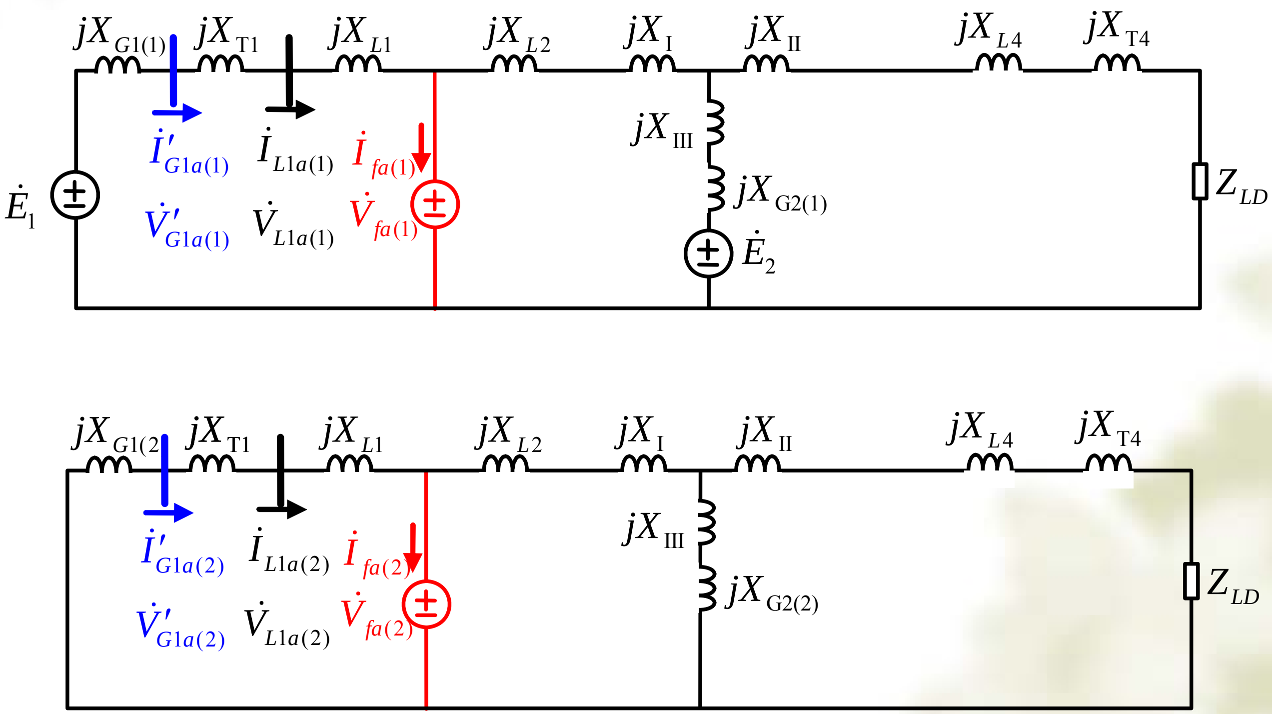
$$\Delta Y_{pq} = -\frac{\dot{I}_q}{\dot{V}_p} = -\frac{\dot{I}_p k_1 e^{-j30^\circ}}{\dot{V}_p} = -\frac{k_1 e^{-j30^\circ}}{Z_T}$$



$$\Delta Y_{qp} = -\frac{\dot{I}_p}{\dot{V}_q} = -\frac{\dot{V}_q k_1 e^{j30^\circ} / Z_T}{\dot{V}_q} = -\frac{k_1 e^{j30^\circ}}{Z_T}$$

(2)对称分量经变压器后的相位变换——说明

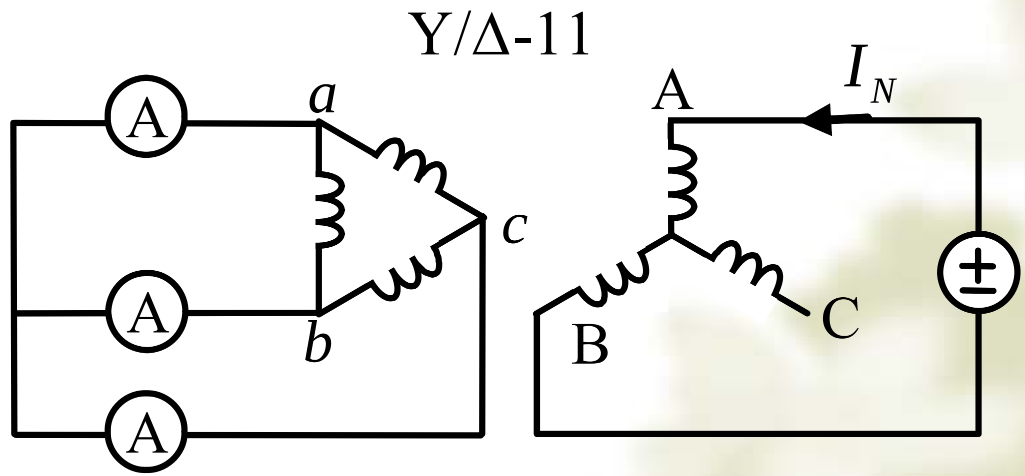
（2）各序一相等值电路不考虑相移对计算结果的影响：→ 没有因为同一序的电压和电流分量经过变压器后的相移相同.



(2)对称分量经变压器后的相位变换——应用举例

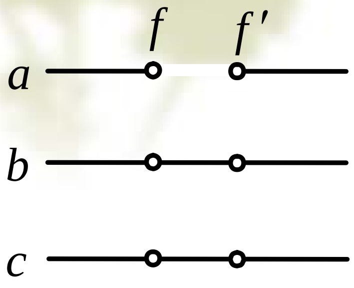
思考题：

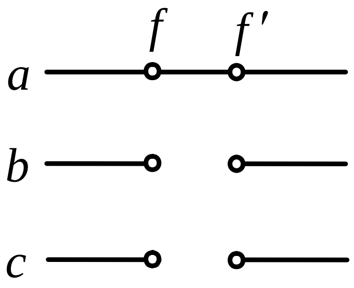
变压器绕组联结组别为$Y/\Delta-11$，Y侧AB相间施加电压至产生额定电流，试问：Δ侧各电流表读数应为多少？

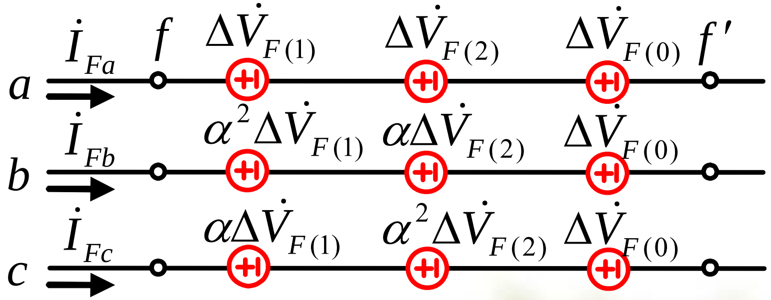


8-3 非全相断线的分析计算

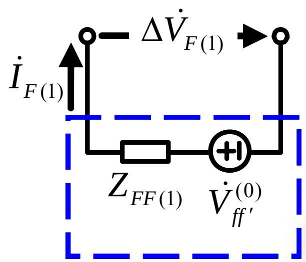
1. 对称分量法分析非全相断线——序网方程

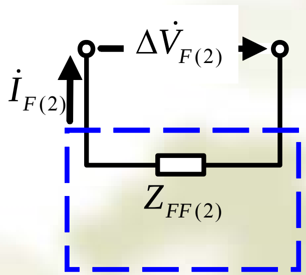


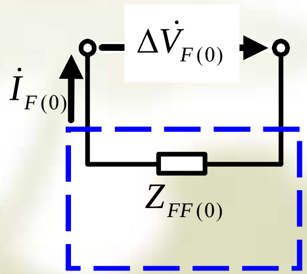




$$\left.\begin{aligned}\Delta\dot{V}_{F(1)} &= \dot{V}_{ff'}^{(0)} - Z_{FF(1)}\dot{I}_{F(1)}\\ \Delta\dot{V}_{F(2)} &= \quad\; - Z_{FF(2)}\dot{I}_{F(2)}\\ \Delta\dot{V}_{F(0)} &= \quad\; - Z_{FF(0)}\dot{I}_{F(0)}\end{aligned}\right\}(8-24)$$





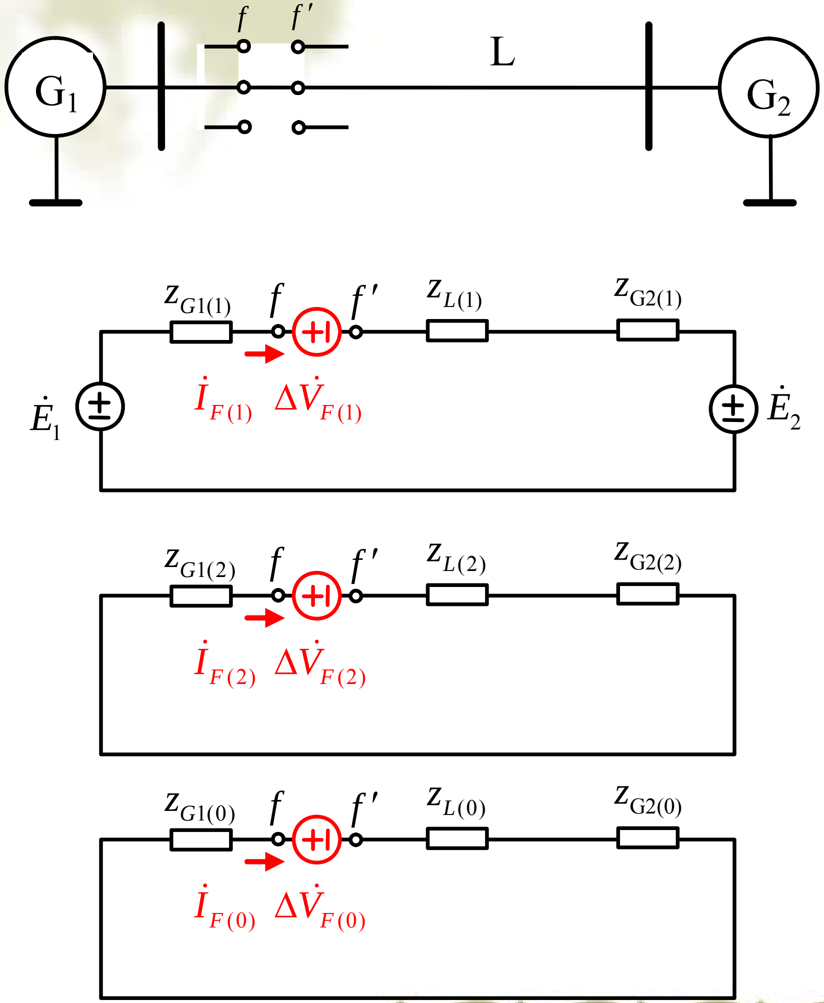


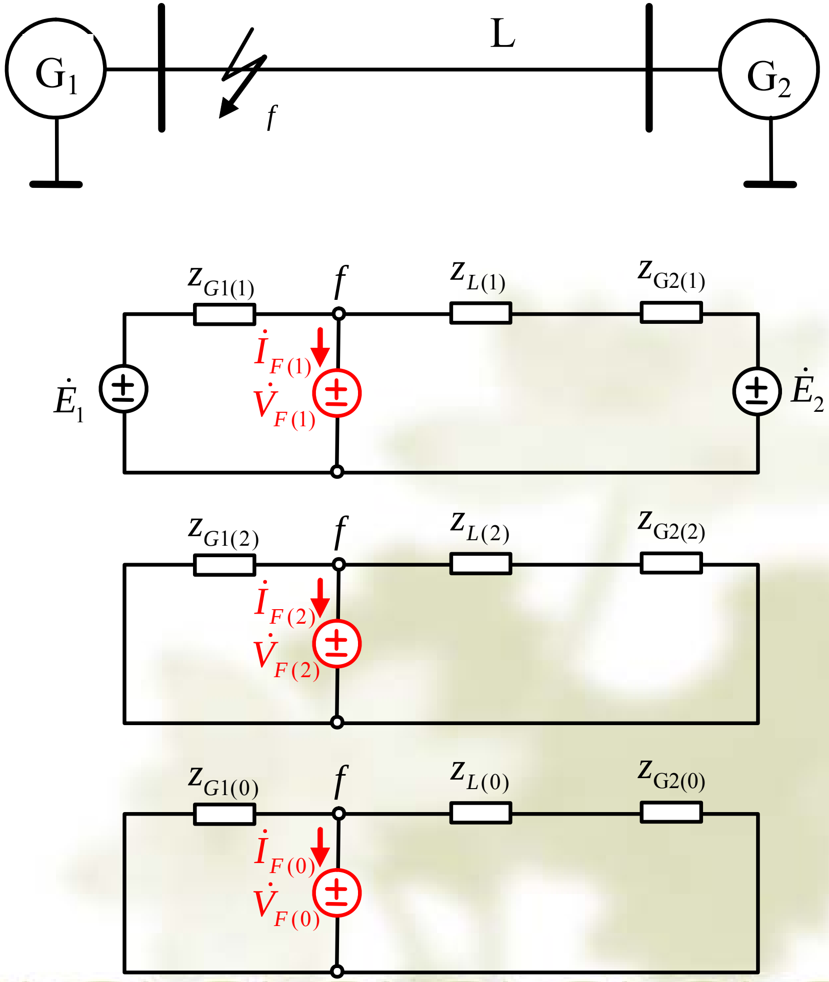
$\dot{V}_{ff'}^{(0)}$:故障口ff'的开路电压,即当ff'两点间三相断开时,网络内电势源在端口ff'产生的电压

$Z_{FF(1)}$、$Z_{FF(2)}$、$Z_{FF(0)}$:故障口ff'的各序输入阻抗

8-3 非全相断线的分析计算

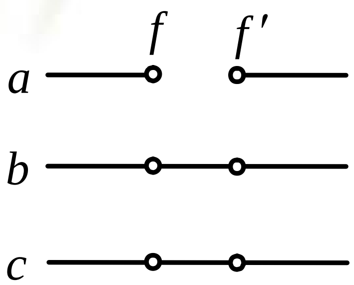
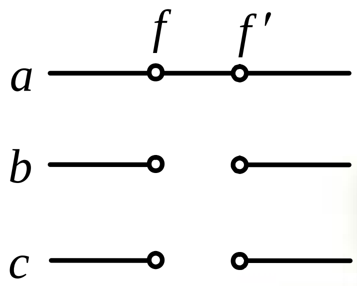
2. 非全相断线与不对称短路的区别





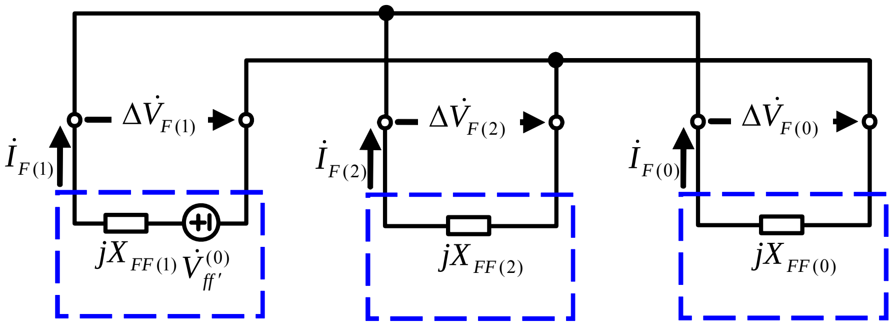
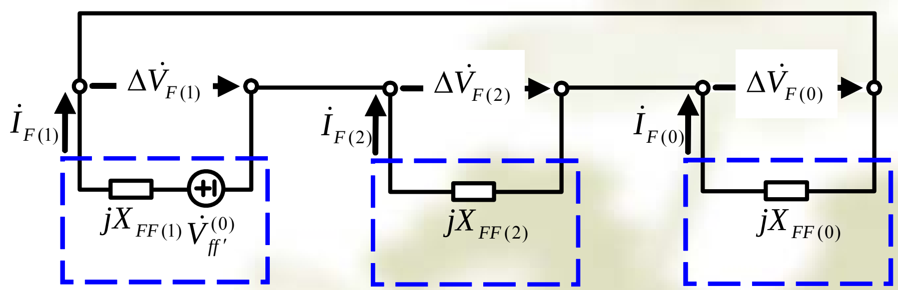
8-3 非全相断线的分析计算

3. 非全相断线的故障边界条件

单相(a相)断线	两相(b相和c相)断开
	
$\Delta\dot{V}_{Fb}=\Delta\dot{V}_{Fc}=0,\ \dot{I}_{Fa}=0$	$\Delta\dot{V}_{Fa}=0,\ \dot{I}_{Fb}=\dot{I}_{Fc}=0$
$\left.\begin{array}{l}\Delta\dot{V}_{F(1)}=\Delta\dot{V}_{F(2)}=\Delta\dot{V}_{F(0)}\\ \dot{I}_{F(1)}+\dot{I}_{F(2)}+\dot{I}_{F(0)}=0\end{array}\right\}$	$\left.\begin{array}{l}\Delta\dot{V}_{F(1)}+\Delta\dot{V}_{F(2)}+\Delta\dot{V}_{F(0)}=0\\ \dot{I}_{F(1)}=\dot{I}_{F(2)}=\dot{I}_{F(0)}\end{array}\right\}$

8-3 非全相断线的分析计算

3. 非全相断线的复合序网

单相(a相)断线	两相(b相和c相)断开
$\left.\begin{aligned}\Delta\dot{V}_{F(1)}=\Delta\dot{V}_{F(2)}=\Delta\dot{V}_{F(0)}\\ \dot{I}_{F(1)}+\dot{I}_{F(2)}+\dot{I}_{F(0)}=0\end{aligned}\right\}$	$\left.\begin{aligned}\Delta\dot{V}_{F(1)}+\Delta\dot{V}_{F(2)}+\Delta\dot{V}_{F(0)}=0\\ \dot{I}_{F(1)}=\dot{I}_{F(2)}=\dot{I}_{F(0)}\end{aligned}\right\}$
	
$\dot{I}_{F(1)}=\dfrac{\dot{V}_{ff'}^{(0)}}{j(X_{FF(1)}+X_{FF(2)}//X_{FF(0)})}$	$\dot{I}_{F(1)}=\dfrac{\dot{V}_{ff'}^{(0)}}{j(X_{FF(1)}+X_{FF(2)}+X_{FF(0)})}$

8-3 非全相断线的分析计算

4. 非全相断线的故障口电压电流各序分量

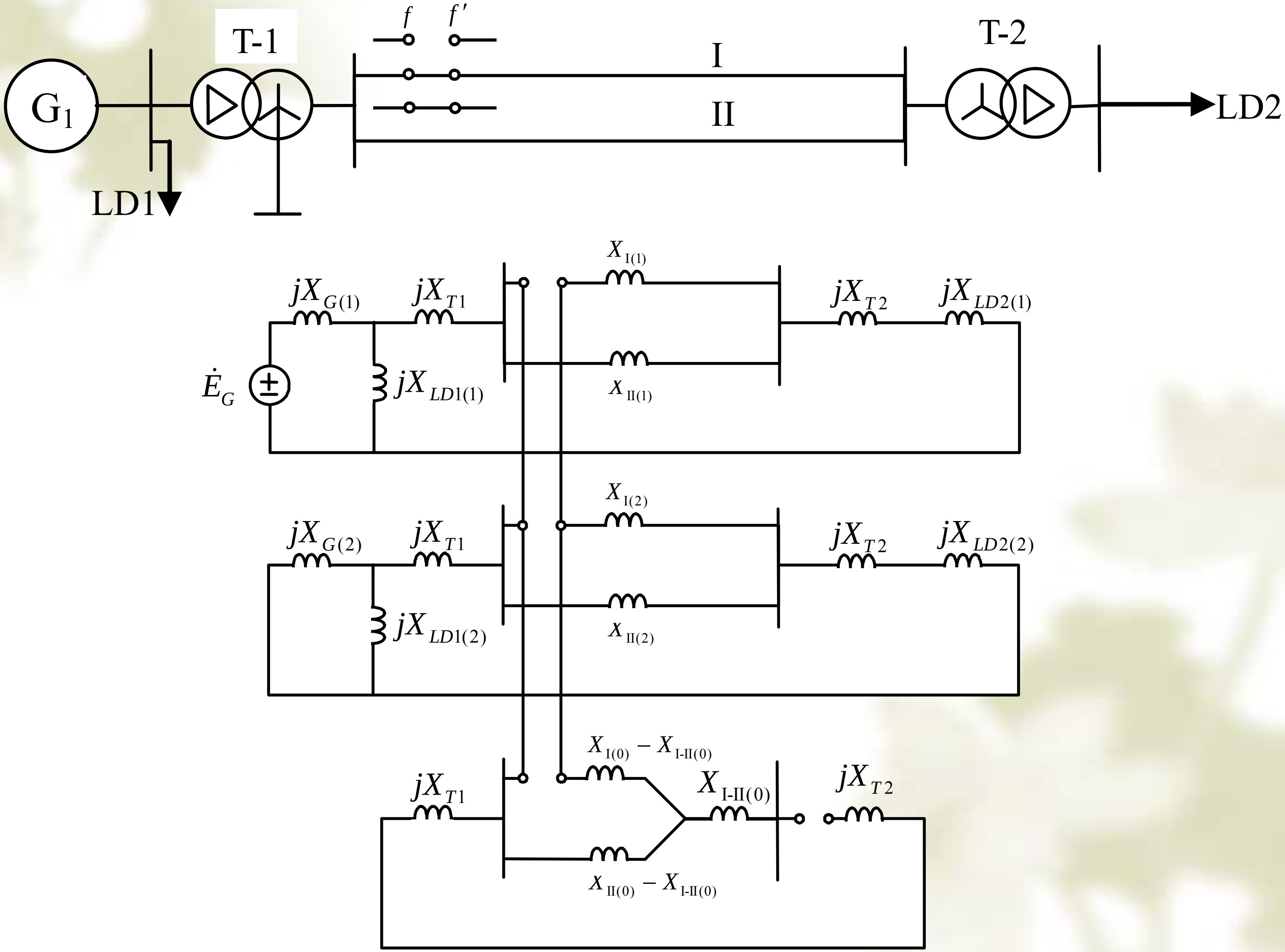
单相(a相)断线	两相(b相和c相)断开
$\left.\begin{array}{l}\Delta\dot{V}_{F(1)}=\Delta\dot{V}_{F(2)}=\Delta\dot{V}_{F(0)}\\ \dot{I}_{F(1)}+\dot{I}_{F(2)}+\dot{I}_{F(0)}=0\end{array}\right\}$	$\left.\begin{array}{l}\Delta\dot{V}_{F(1)}+\Delta\dot{V}_{F(2)}+\Delta\dot{V}_{F(0)}=0\\ \dot{I}_{F(1)}=\dot{I}_{F(2)}=\dot{I}_{F(0)}\end{array}\right\}$
$\dot{I}_{F(1)}=\dfrac{\dot{V}_{ff'}^{(0)}}{j(X_{FF(1)}+X_{FF(2)}//X_{FF(0)})}$	$\dot{I}_{F(1)}=\dfrac{\dot{V}_{ff'}^{(0)}}{j(X_{FF(1)}+X_{FF(2)}+X_{FF(0)})}$
$\dot{I}_{F(2)}=-\dfrac{X_{FF(0)}}{X_{FF(2)}+X_{FF(0)}}\dot{I}_{F(1)}$	$\Delta\dot{V}_{F(1)}=j(X_{FF(2)}+X_{FF(0)})\dot{I}_{F(1)}$ $\Delta\dot{V}_{F(2)}=-jX_{FF(2)}\dot{I}_{F(1)}$ $\Delta\dot{V}_{F(0)}=-jX_{FF(0)}\dot{I}_{F(1)}$
$\dot{I}_{F(0)}=-\dfrac{X_{FF(2)}}{X_{FF(2)}+X_{FF(0)}}\dot{I}_{F(1)}$	

8-3 非全相断线的分析计算

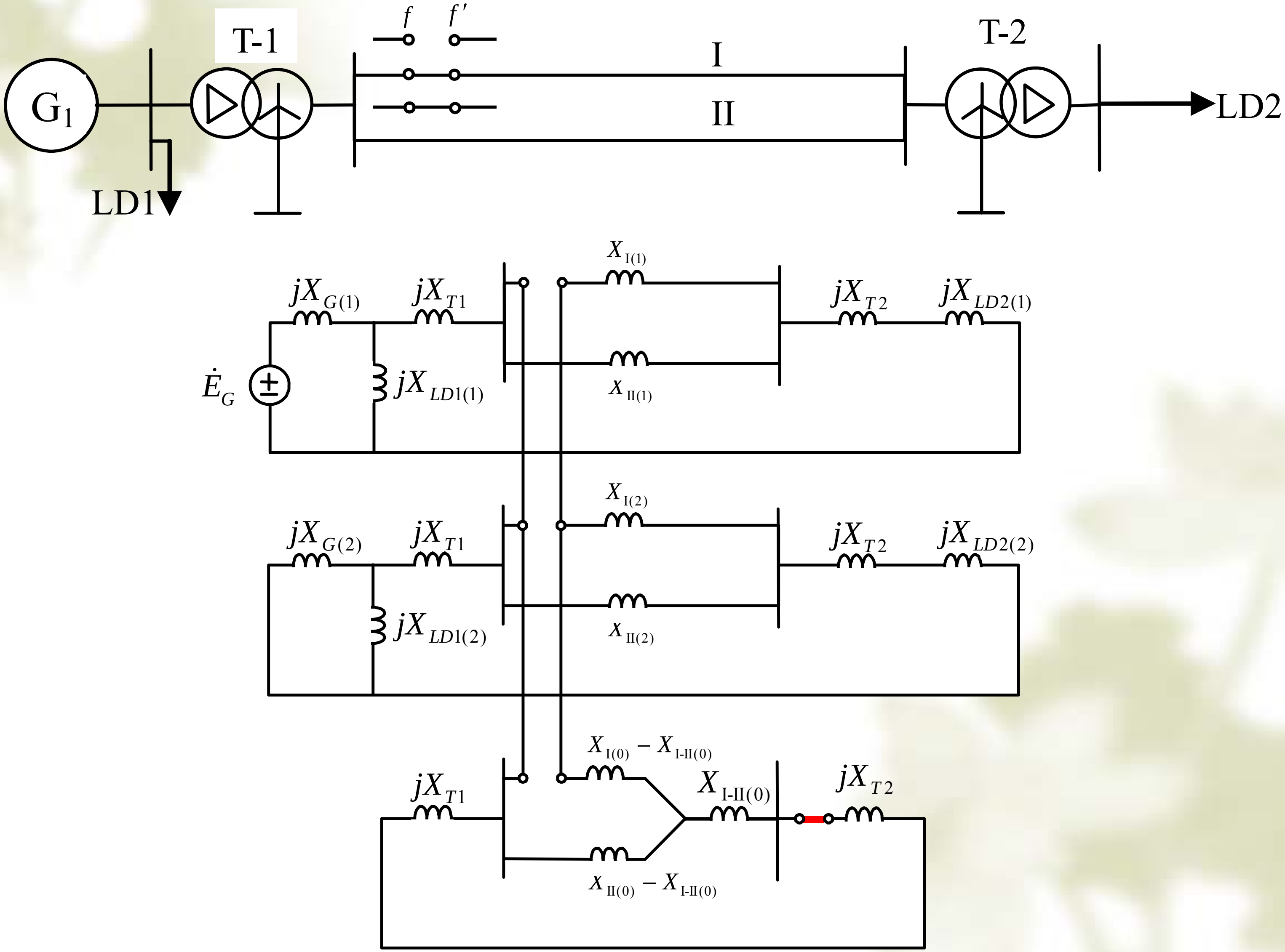
5. 非全相断线的故障口电压电流相量

单相(a相)断线	两相(b相和c相)断开
$\dot{I}_{F(1)}=\dfrac{\dot{V}_{ff'}^{(0)}}{j(X_{FF(1)}+X_{FF(2)}//X_{FF(0)})}$	$\dot{I}_{F(1)}=\dfrac{\dot{V}_{ff'}^{(0)}}{j(X_{FF(1)}+X_{FF(2)}+X_{FF(0)})}$
$\dot{I}_{Fb}=\left(\alpha^2-\dfrac{X_{FF(2)}+\alpha X_{FF(0)}}{X_{FF(2)}+X_{FF(0)}}\right)\dot{I}_{F(1)}$	$\dot{I}_{F}=\dfrac{3\dot{V}_{ff'}^{(0)}}{j(X_{FF(1)}+X_{FF(2)}+X_{FF(0)})}$
$\dot{I}_{Fc}=\left(\alpha-\dfrac{X_{FF(2)}+\alpha^2 X_{FF(0)}}{X_{FF(2)}+X_{FF(0)}}\right)\dot{I}_{F(1)}$	$\Delta\dot{V}_{Fb}=j\left[(\alpha^2-\alpha)X_{FF(2)}+(\alpha^2-1)X_{FF(0)}\right]\dot{I}_{F(1)}$
$\Delta\dot{V}_{F}=3\Delta\dot{V}_{F(1)}=j\dfrac{3X_{FF(2)}X_{FF(0)}}{X_{FF(2)}+X_{FF(0)}}\dot{I}_{F(1)}$	$\Delta\dot{V}_{Fc}=j\left[(\alpha-\alpha^2)X_{FF(2)}+(\alpha-1)X_{FF(0)}\right]\dot{I}_{F(1)}$

8-3 非全相断线的分析计算——举例

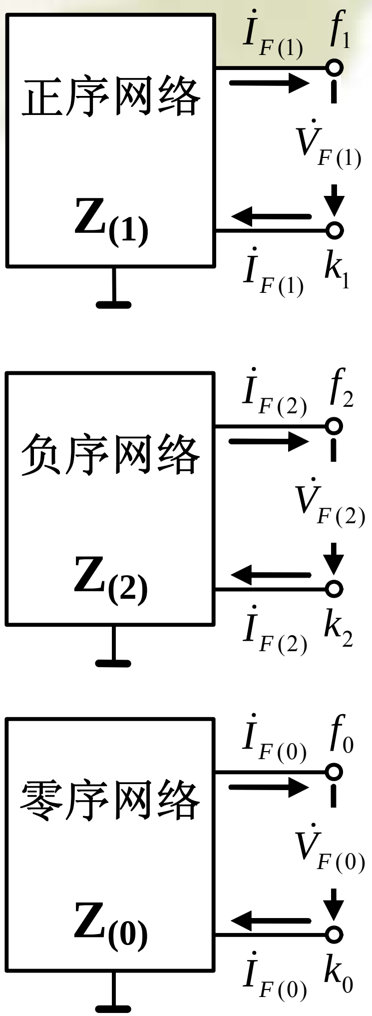


8-3 非全相断线的分析计算——举例



8-4 应用节点阻抗矩阵计算不对称故障

1.各序网络的电压方程式



(1)正序网络任意点电压

$$\dot{V}_{i(1)}=\sum_{j\in G}Z_{ij(1)}\dot{I}_j-Z_{if(1)}\dot{I}_{F(1)}+Z_{ik(1)}\dot{I}_{F(1)}=\dot{V}_{i(1)}^{(0)}-Z_{iF(1)}\dot{I}_{F(1)}$$

电压正常分量：$\dot{V}_{i(1)}^{(0)}=\sum_{j\in G}Z_{ij(1)}\dot{I}_j$

故障口$f-k$与节点i之间的互阻抗：$Z_{iF}=Z_{if}-Z_{ik}$

(2)正序网络故障口的电压方程

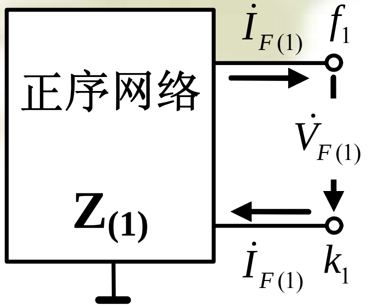
$$\dot{V}_{F(1)}=\dot{V}_F^{(0)}-Z_{FF(1)}\dot{I}_{F(1)}$$

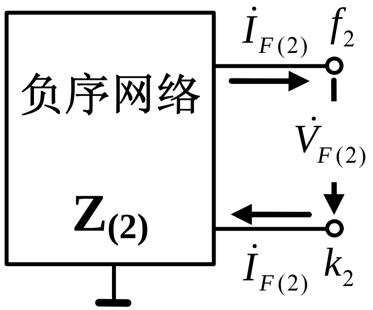
$$\dot{V}_{f(1)}=\dot{V}_f^{(0)}-Z_{fF(1)}\dot{I}_{F(1)},\dot{V}_{k(1)}=\dot{V}_k^{(0)}-Z_{kF(1)}\dot{I}_{F(1)}$$

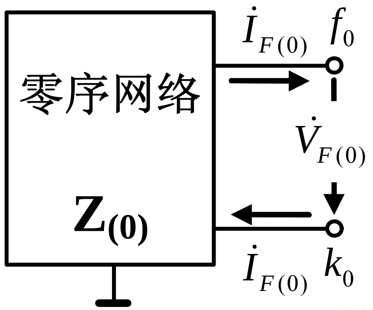
$$\dot{V}_{F(1)}=\dot{V}_{f(1)}-\dot{V}_{k(1)}=(\dot{V}_f^{(0)}-\dot{V}_k^{(0)})-(Z_{fF(1)}-Z_{kF(1)})\dot{I}_{F(1)}$$

8-4 应用节点阻抗矩阵计算不对称故障

1.各序网络的电压方程式







(3)负序和零序网络任意点电压

$$\dot V_{i(2)} = -Z_{if(2)}\dot I_{F(2)} + Z_{ik(2)}\dot I_{F(2)} = -Z_{iF(2)}\dot I_{F(2)}$$

$$\dot V_{i(0)} = -Z_{if(0)}\dot I_{F(0)} + Z_{ik(0)}\dot I_{F(0)} = -Z_{iF(0)}\dot I_{F(0)}$$

$$\dot V_{f(2)} = -Z_{fF(2)}\dot I_{F(2)}, \dot V_{k(2)} = -Z_{kF(2)}\dot I_{F(2)}$$

$$\dot V_{F(2)} = \dot V_{f(2)} - \dot V_{k(2)} = -(Z_{fF(2)} - Z_{kF(2)})\dot I_{F(2)}$$

$$\dot V_{f(0)} = -Z_{fF(0)}\dot I_{F(0)}, \dot V_{k(0)} = -Z_{kF(0)}\dot I_{F(0)}$$

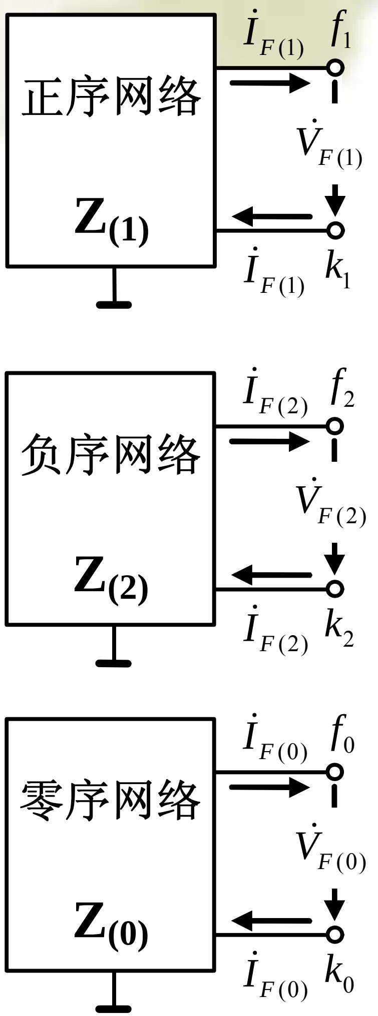
$$\dot V_{F(0)} = \dot V_{f(0)} - \dot V_{k(0)} = -(Z_{fF(0)} - Z_{kF(0)})\dot I_{F(0)}$$

(4)负序和零序网络故障口的电压方程

$$\dot V_{F(2)} = -Z_{FF(2)}\dot I_{F(2)}, \quad \dot V_{F(0)} = -Z_{FF(0)}\dot I_{F(0)}$$

8-4 应用节点阻抗矩阵计算不对称故障

1.各序网络的电压方程式——小结



故障口通用序网方程

$$\left.\begin{aligned}\dot{V}_{F(1)} &= \dot{V}_F^{(0)} - Z_{FF(1)}\dot{I}_{F(1)}\\ \dot{V}_{F(2)} &= \quad - Z_{FF(2)}\dot{I}_{F(2)}\\ \dot{V}_{F(0)} &= \quad - Z_{FF(0)}\dot{I}_{F(0)}\end{aligned}\right\}$$

各序网络任意点电压

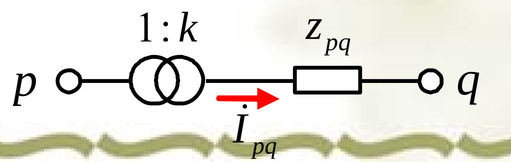
$$\left.\begin{aligned}\dot{V}_{i(1)} &= \dot{V}_{i(1)}^{(0)} - Z_{iF(1)}\dot{I}_{F(1)}\\ \dot{V}_{i(2)} &= \quad - Z_{iF(2)}\dot{I}_{F(2)}\\ \dot{V}_{i(0)} &= \quad - Z_{iF(0)}\dot{I}_{F(0)}\end{aligned}\right\}$$

故障口开口路电压：$\dot{V}_F^{(0)} = \dot{V}_f^{(0)} - \dot{V}_k^{(0)}$

故障口的自阻抗：$Z_{FF} = Z_{ff} - Z_{fk} - Z_{kf} + Z_{kk}$

故障口对节点i的互阻抗：$Z_{iF} = Z_{if} - Z_{ik}$

（3）支路电流：$\dot{I}_{pq(i)} = \dfrac{k\dot{V}_{p(i)} - \dot{V}_{q(i)}}{z_{pq(i)}}$, (i=1,2,0)



8-4 应用节点阻抗矩阵计算不对称故障

2.各种故障边界条件

$f^{(1)}$	$\dot{V}_{Fa} - z_f \dot{I}_{Fa} = 0,\ \ \dot{I}_{Fb} = \dot{I}_{Fc} = 0$
$f^{(2)}$	$\dot{V}_{Fb} - z_f \dot{I}_{Fb} = \dot{V}_{Fc} - z_f \dot{I}_{Fc},\ \ \dot{I}_{Fa} = 0,\ \dot{I}_{Fb} + \dot{I}_{Fc} = 0$
$f^{(1,1)}$	$\dot{V}_{Fb} - z_f \dot{I}_{Fb} - z_g(\dot{I}_{Fb} + \dot{I}_{Fc}) = 0$ $\dot{V}_{Fc} - z_f \dot{I}_{Fc} - z_g(\dot{I}_{Fb} + \dot{I}_{Fc}) = 0,\ \ \dot{I}_{Fa} = 0$
单相断线	$\Delta\dot{V}_{Fb} - z_f \dot{I}_{Fb} = 0,\ \Delta\dot{V}_{Fc} - z_f \dot{I}_{Fc} = 0,\ \ \dot{I}_{Fa} = 0$
两相断线	$\Delta\dot{V}_{Fa} - z_f \dot{I}_{Fa} = 0,\ \ \dot{I}_{Fb} = \dot{I}_{Fc} = 0$

8-4 应用节点阻抗矩阵计算不对称故障

2.各种故障序分量边界条件

$f^{(1)}$	$\left.\begin{array}{l}(\dot{V}_{F(1)}-z_f\dot{I}_{F(1)})+(\dot{V}_{F(2)}-z_f\dot{I}_{F(2)})+(\dot{V}_{F(0)}-z_f\dot{I}_{F(0)})=0\\ \dot{I}_{F(1)}=\dot{I}_{F(2)}=\dot{I}_{F(0)}\end{array}\right\}$
$f^{(2)}$	$\left.\begin{array}{l}\dot{V}_{F(1)}-z_f\dot{I}_{F(1)}=\dot{V}_{F(2)}-z_f\dot{I}_{F(2)}\\ \dot{I}_{F(1)}+\dot{I}_{F(2)}=0,\quad \dot{I}_{F(0)}=0\end{array}\right\}$
$f^{(1,1)}$	$\left.\begin{array}{l}\dot{V}_{F(1)}-z_f\dot{I}_{F(1)}=\dot{V}_{F(2)}-z_f\dot{I}_{F(2)}=\dot{V}_{F(0)}-(z_f+3z_g)\dot{I}_{F(0)}\\ \dot{I}_{F(1)}+\dot{I}_{F(2)}+\dot{I}_{F(0)}=0\end{array}\right\}$
单相断线	$\left.\begin{array}{l}\dot{V}_{F(1)}-z_f\dot{I}_{F(1)}=\dot{V}_{F(2)}-z_f\dot{I}_{F(2)}=\dot{V}_{F(0)}-z_f\dot{I}_{F(0)}\\ \dot{I}_{F(1)}+\dot{I}_{F(2)}+\dot{I}_{F(0)}=0\end{array}\right\}$
两相断线	$\left.\begin{array}{l}(\dot{V}_{F(1)}-z_f\dot{I}_{F(1)})+(\dot{V}_{F(2)}-z_f\dot{I}_{F(2)})+(\dot{V}_{F(0)}-z_f\dot{I}_{F(0)})=0\\ \dot{I}_{F(1)}=\dot{I}_{F(2)}=\dot{I}_{F(0)}\end{array}\right\}$

8-4 应用节点阻抗矩阵计算不对称故障

3.正序等效定则

	$\dot{I}_{F(1)}=\dfrac{\dot{V}_F^{(0)}}{Z_{FF(1)}+Z_{\Delta}}$	$\dot{I}_{F(2)}=K_2\dot{I}_{F(1)}$	$\dot{I}_{F(0)}=K_0\dot{I}_{F(1)}$
	Z_{Δ}	K_2	K_0
$f^{(1)}$	$Z_{FF(2)}+Z_{FF(0)}+3Z_f$	1	1
$f^{(2)}$	$Z_{FF(2)}+2Z_f$	-1	0
$f^{(1,1)}$	$z_f+\dfrac{(Z_{FF(2)}+z_f)(Z_{FF(0)}+z_f+3z_g)}{Z_{FF(2)}+Z_{FF(0)}+2z_f+3z_g}$	$-\dfrac{Z_{FF(0)}+z_f+3z_g}{Z_{FF(2)}+Z_{FF(0)}+2z_f+3z_g}$	$-\dfrac{Z_{FF(0)}+z_f+3z_g}{Z_{FF(2)}+Z_{FF(0)}+2z_f+3z_g}$
单相断线	$z_f+\dfrac{(Z_{FF(2)}+z_f)(Z_{FF(0)}+z_f)}{Z_{FF(2)}+Z_{FF(0)}+2z_f}$	$-\dfrac{Z_{FF(0)}+z_f}{Z_{FF(2)}+Z_{FF(0)}+2z_f}$	$-\dfrac{Z_{FF(0)}+z_f}{Z_{FF(2)}+Z_{FF(0)}+2z_f}$
两相断线	$Z_{FF(2)}+Z_{FF(0)}+3Z_f$	1	1

本章小结

- 各种故障序分量边界条件
- 复合序网的概念和正序等效定则
- 电压电流对称分量经过变压器后的相位变换
- 利用阻抗矩阵计算不对称故障的原理和方法

习 题

Ex 8-3, 8-8, 8-10 , 8-11

華中科技大學

Huazhong University of Science and Technology

The End

Thank You