ANALISA GANGGUAN SISTEM TENAGA LISTRIK

TEK 156117 (2SKS)

ANALISA GANGGUAN SISTEM TENAGA LISTRIK

- **Tujuan :**
- Mahasiswa mampu memodelkan dan menganalisa arus gangguan hubung singkat, dengan menggunakan metode Thevenin maupun dengan menggunakan bus impedance matrix. Mampu menerapkan komponen simetri untuk menghitung impedansi urutan pada beban, saluran transmisi dan mesin sinkron, transformator dan generator berbeban. Mampu menganalisa gangguan hubung singkat satu phasa ketanah, antar phasa dan dua phasa ketanah, gangguan satu phasa lepas (hubung terbuka), gangguan dua phasa lepas (hubung terbuka).
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- **Pokok Bahasan :**
- Membuat pemodelan dan menganalisa arus gangguan hubung singkat, menganalisa arus gangguan dengan menggunakan metode Thevenin, menghitung kapasitas hubung singkat pada bus yang terganggu, menganalisa gangguan 3 phase seimbang dengan menggunakan bus impedance matrix, membentuk bus impedance matrix dengan menggunakan metode step by step. Mengenal komponen simetri, menerapkan komponen simetri untuk menghitung impedansi urutan pada beban, saluran transmisi dan mesin sinkron, menerapkan komponen simetri untuk menghitung impedansi urutan pada transformator dan generator berbeban. Menganalisa gangguan hubung singkat satu phasa ketanah, antar phasa dan dua phasa ketanah, menganalisa apabila terjadi gangguan satu phasa lepas (hubung terbuka) dan gangguan dua phasa lepas (hubung terbuka).

- **Kepustakaan :**
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- Hadi Saadat, *Power System Analysis*, 3rd Edition, McGraw-Hill, 2011.
- John J. Grainger, William D. Stevenson, Jr., *Power System Analysis*, McGraw-Hill, Inc, 1994.
- C.J. Das*, Power System Analysis*, Marcel Dekker, Inc. 2002
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- Berdasarkan ANSI/IEEE Std. 100-1992 gangguan didefenisikan sebagai suatu kondisi fisis yang disebabkan kegagalan suatu perangkat, *komponen* atau suatu elemen untuk bekerja sesuai dengan fungsinya. Gangguan hampir selalu ditimbulkan oleh hubung singkat antar fase atau hubung singkat fase ke tanah. Suatu gangguan hampir selalu berupa hubung langsung atau melalui impedansi. Istilah gangguan identik dengan hubung singkat, sesuai standart ANSI/IEEE Std. 100-1992.

Tujuan menganalisis gangguan :

1. Untuk menentukan arus maksimum dan minimum hubung singkat tiga fasa
2. Untuk menentukan arus gangguan tak simetris bagi gangguan satu dan dua line ke tanah, gangguan line ke line, dan rangkaian terbuka.
3. Penyelidikan operasi rele-rele proteksi
4. Untuk menentukan kapasitas pemutus dari circuit breaker
5. Untuk menentukan distribusi arus gangguan dan tingkat tegangan busbar selama gangguan

Gangguan yang mengakibatkan hubung singkat dapat menimbulkan arus yang jauh lebih besar dari pada arus normal. Bila gangguan hubung singkat dibiarkan berlangsung dengan lama pada suatu sistem daya, banyak pengaruh-pengaruh yang tidak diinginkan dapat terjadi :

1. Berkurangnya batas-batas kestabilan untuk sistem daya.
2. Rusaknya perlengkapan yang berada dekat dengan gangguan yang disebabkan oleh arus tak seimbang, atau tegangan rendah yang ditimbulkan oleh hubung singkat.

3. Ledakan-ledakan yang mungkin terjadi pada peralatan yang mengandung minyak isolasi sewaktu terjadinya suatu hubung singkat, dan yang mungkin menimbulkan kebakaran sehingga dapat membahayakan orang yang menanganinya dan merusak peralatan – peralatan yang lain.

4. Terpecah-pecahnya keseluruhan daerah pelayanan sistem daya itu oleh suatu rentetan tindakan pengamanan yang diambil oleh sitem – sistem pengamanan yang berbeda – beda; kejadian ini di kenal sebagai “*cascading*”.

Membuat pemodelan dan menganalisa arus gangguan hubung singkat

Consider the series R–L circuit shown in Figure 7.1. The closing of switch SW at $t = 0$ represents to a first approximation a three-phase short circuit at the terminals of an unloaded synchronous machine. For simplicity, assume zero fault impedance; that is, the short circuit is a solid or "bolted" fault. The current is assumed to be zero before SW closes, and the source angle α determines the source voltage at $t = 0$. Writing a KVL equation for the circuit,

$$\frac{L\,di(t)}{dt} + Ri(t) = \sqrt{2}V \sin(\omega t + \alpha) \quad t \geqslant 0 \qquad (7.1.1)$$

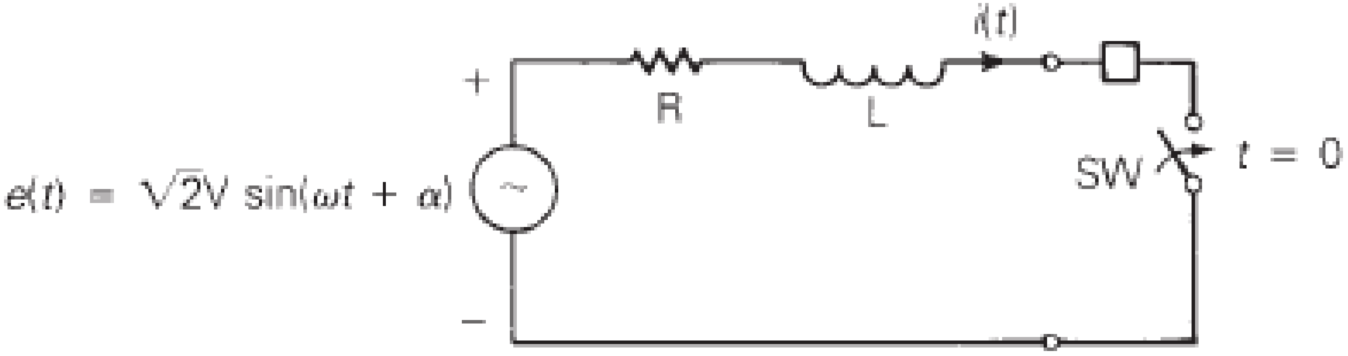


FIGURE 7.1

Current in a series R–L circuit with ac voltage source

$$\frac{L\,di(t)}{dt} + Ri(t) = \sqrt{2}V\sin(\omega t + \alpha) \quad t \geqslant 0 \tag{7.1.1}$$

The solution to (7.1.1) is

$$i(t) = i_{\mathrm{ac}}(t) + i_{\mathrm{dc}}(t)$$

$$= \frac{\sqrt{2}V}{Z}\left[\sin(\omega t + \alpha - \theta) - \sin(\alpha - \theta)e^{-t/T}\right] \quad \mathrm{A} \tag{7.1.2}$$

asymmetrical fault current

$$i_{\mathrm{ac}}(t) = \frac{\sqrt{2}V}{Z}\sin(\omega t + \alpha - \theta) \quad \mathrm{A} \tag{7.1.3}$$

symmetrical or steady-state fault current

$$i_{\mathrm{dc}}(t) = -\frac{\sqrt{2}V}{Z}\sin(\alpha - \theta)e^{-t/T} \quad \mathrm{A} \tag{7.1.4}$$

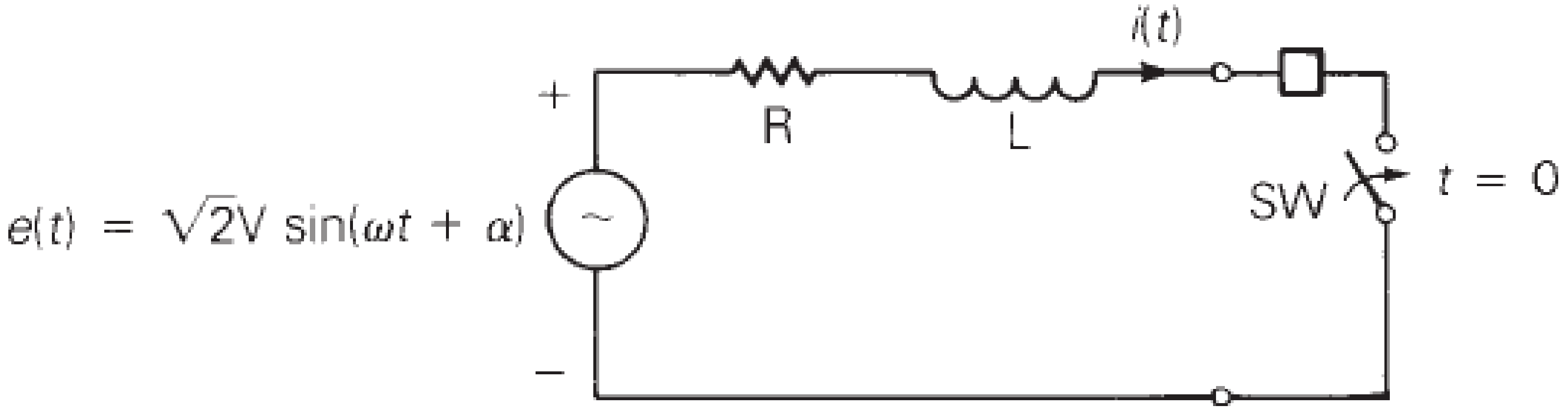
dc opset current

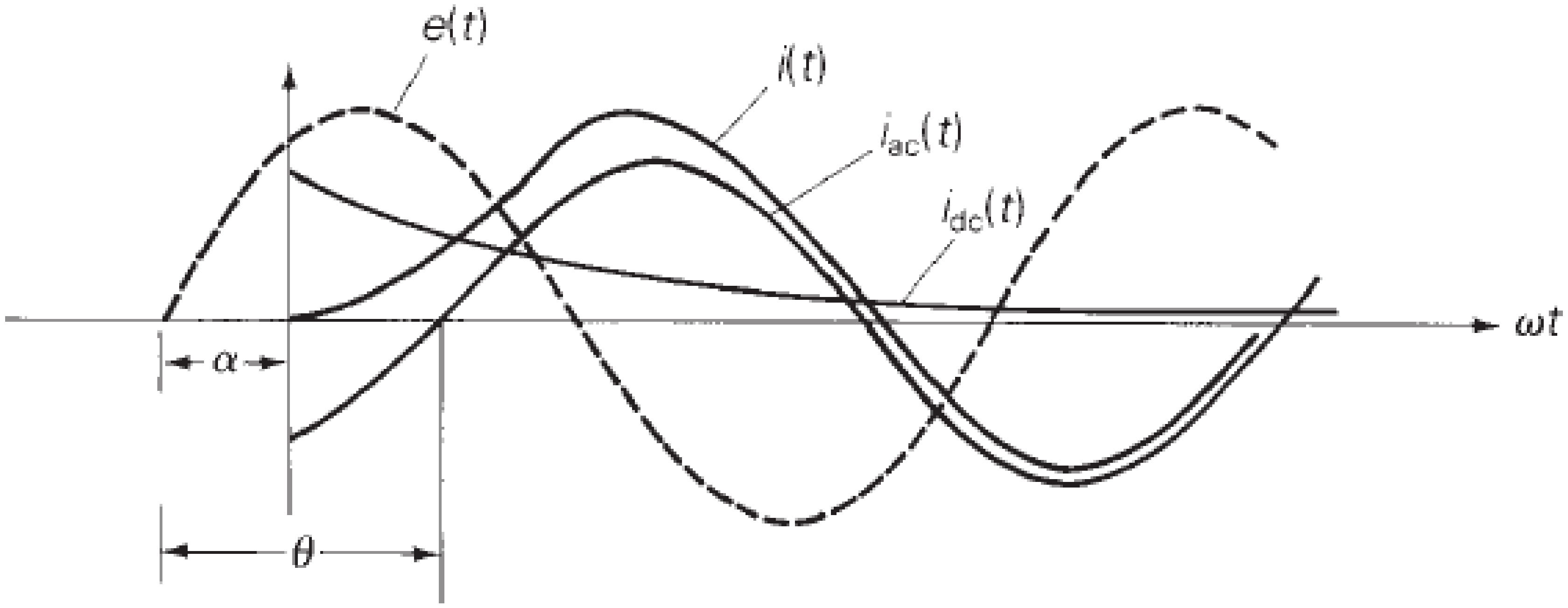
$$Z = \sqrt{R^2 + (\omega L)^2} = \sqrt{R^2 + X^2} \quad \Omega \tag{7.1.5}$$

$$\theta = \tan^{-1}\frac{\omega L}{R} = \tan^{-1}\frac{X}{R} \tag{7.1.6}$$

$$T = \frac{L}{R} = \frac{X}{\omega R} = \frac{X}{2\pi f R} \quad \mathrm{s} \tag{7.1.7}$$

time constant


$e(t) = \sqrt{2}V \sin(\omega t + \alpha)$
+
−
R
L
$i(t)$
SW
$t = 0$


$e(t)$
$i(t)$
$i_{ac}(t)$
$i_{dc}(t)$
ωt
α
θ

The total fault current in (7.1.2), called the *asymmetrical fault current*, is plotted in Figure 7.1 along with its two components. The ac fault current (also called *symmetrical* or *steady-state fault current*), given by (7.1.3), is a sinusoid. The *dc offset current*, given by (7.1.4), decays exponentially with time constant $\mathrm{T} = \mathrm{L}/\mathrm{R}$.

The rms ac fault current is $\mathrm{I}_{\mathrm{ac}} = \mathrm{V}/\mathrm{Z}$. The magnitude of the dc offset, which depends on α, varies from 0 when $\alpha = \theta$ to $\sqrt{2}\mathrm{I}_{\mathrm{ac}}$ when $\alpha = (\theta \pm \pi/2)$. Note that a short circuit may occur at any instant during a cycle of the ac source; that is, α can have any value. Since we are primarily interested in the largest fault current, we choose $\alpha = (\theta - \pi/2)$. Then (7.1.2) becomes

$$i(t) = \sqrt{2}\mathrm{I}_{\mathrm{ac}}[\sin(\omega t - \pi/2) + e^{-t/\mathrm{T}}] \quad \mathrm{A} \tag{7.1.8}$$

where

$$I_{ac} = \frac{V}{Z} \quad A \tag{7.1.9}$$

The rms value of $i(t)$ is of interest. Since $i(t)$ in (7.1.8) is not strictly periodic, its rms value is not strictly defined. However, treating the exponential term as a constant, we stretch the rms concept to calculate the rms asymmetrical fault current with maximum dc offset, as follows:

$$\begin{aligned} I_{rms}(t) &= \sqrt{[I_{ac}]^2 + [I_{dc}(t)]^2} \\ &= \sqrt{[I_{ac}]^2 + [\sqrt{2}I_{ac}e^{-t/T}]^2} \\ &= I_{ac}\sqrt{1 + 2e^{-2t/T}} \quad A \end{aligned} \tag{7.1.10}$$

It is convenient to use $T = X/(2\pi f R)$ and $t = \tau/f$, where τ is time in cycles, and write (7.1.10) as

$$I_{\mathrm{rms}}(\tau) = K(\tau)I_{\mathrm{ac}} \quad \mathrm{A} \tag{7.1.11}$$

where

$$K(\tau) = \sqrt{1 + 2e^{-4\pi\tau/(X/R)}} \quad \text{per unit} \tag{7.1.12}$$

From (7.1.11) and (7.1.12), the rms asymmetrical fault current equals the rms ac fault current times an "asymmetry factor," $K(\tau)$. $I_{\mathrm{rms}}(\tau)$ decreases from $\sqrt{3}I_{\mathrm{ac}}$ when $\tau = 0$ to I_{ac} when τ is large. Also, higher X to R ratios (X/R) give higher values of $I_{\mathrm{rms}}(\tau)$. The above series R–L short-circuit currents are summarized in Table 7.1.

TABLE 7.1

Short-circuit current—series R–L circuit*

Component	Instantaneous Current (A)	rms Current (A)
Symmetrical (ac)	$i_{ac}(t) = \frac{\sqrt{2}V}{Z} \sin(\omega t + \alpha - \theta)$	$I_{ac} = \frac{V}{Z}$
dc offset	$i_{dc}(t) = \frac{-\sqrt{2}V}{Z} \sin(\alpha - \theta) e^{-t/T}$	
Asymmetrical (total)	$i(t) = i_{ac}(t) + i_{dc}(t)$	$I_{rms}(t) = \sqrt{I_{ac}^2 + i_{dc}(t)^2}$ with maximum dc offset: $I_{rms}(\tau) = K(\tau) I_{ac}$

EXAMPLE 7.1 Fault currents: R–L circuit with ac source

A bolted short circuit occurs in the series R–L circuit of Figure 7.1 with $V = 20$ kV, $X = 8\ \Omega$, $R = 0.8\ \Omega$, and with maximum dc offset. The circuit breaker opens 3 cycles after fault inception. Determine (a) the rms ac fault current, (b) the rms "momentary" current at $\tau = 0.5$ cycle, which passes through the breaker before it opens, and (c) the rms asymmetrical fault current that the breaker interrupts.

SOLUTION

a. From (7.1.9),

$$I_{ac} = \frac{20 \times 10^3}{\sqrt{(8)^2 + (0.8)^2}} = \frac{20 \times 10^3}{8.040} = 2.488 \quad \text{kA}$$

b. From (7.1.11) and (7.1.12) with $(X/R) = 8/(0.8) = 10$ and $\tau = 0.5$ cycle,

$$K(0.5\ \text{cycle}) = \sqrt{1 + 2e^{-4\pi(0.5)/10}} = 1.438$$

$$I_{\text{momentary}} = K(0.5\ \text{cycle})I_{\text{ac}} = (1.438)(2.488) = 3.576 \quad \text{kA}$$

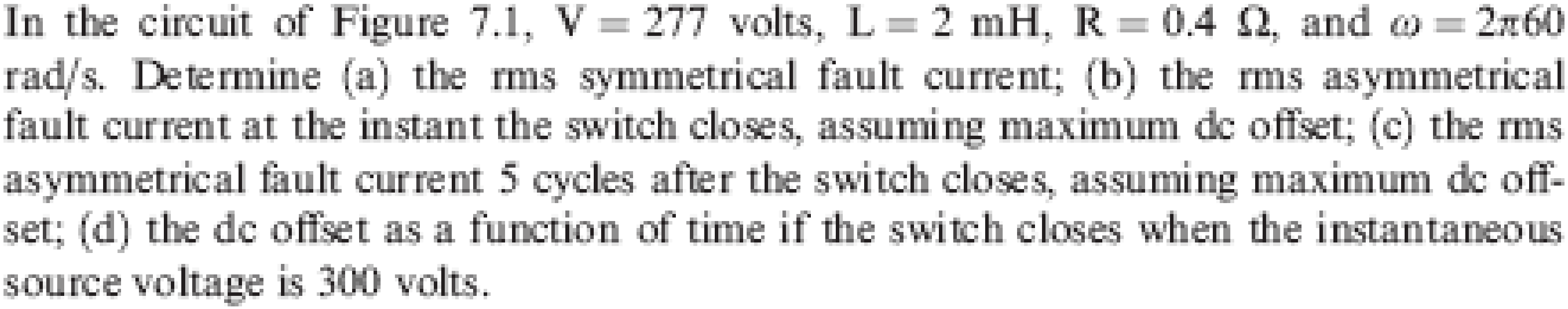
c. From (7.1.11) and (7.1.12) with $(X/R) = 10$ and $\tau = 3$ cycles,

$$K(3\ \text{cycles}) = \sqrt{1 + 2e^{-4\pi(3)/10}} = 1.023$$

$$I_{\text{rms}}(3\ \text{cycles}) = (1.023)(2.488) = 2.544 \quad \text{kA}$$

■

TUGAS 1



In the circuit of Figure 7.1, $V = 277$ volts, $L = 2$ mH, $R = 0.4\ \Omega$, and $\omega = 2\pi 60$ rad/s. Determine (a) the rms symmetrical fault current; (b) the rms asymmetrical fault current at the instant the switch closes, assuming maximum dc offset; (c) the rms asymmetrical fault current 5 cycles after the switch closes, assuming maximum dc offset; (d) the dc offset as a function of time if the switch closes when the instantaneous source voltage is 300 volts.

FIGURE 7.1

Current in a series R–L circuit with ac voltage source