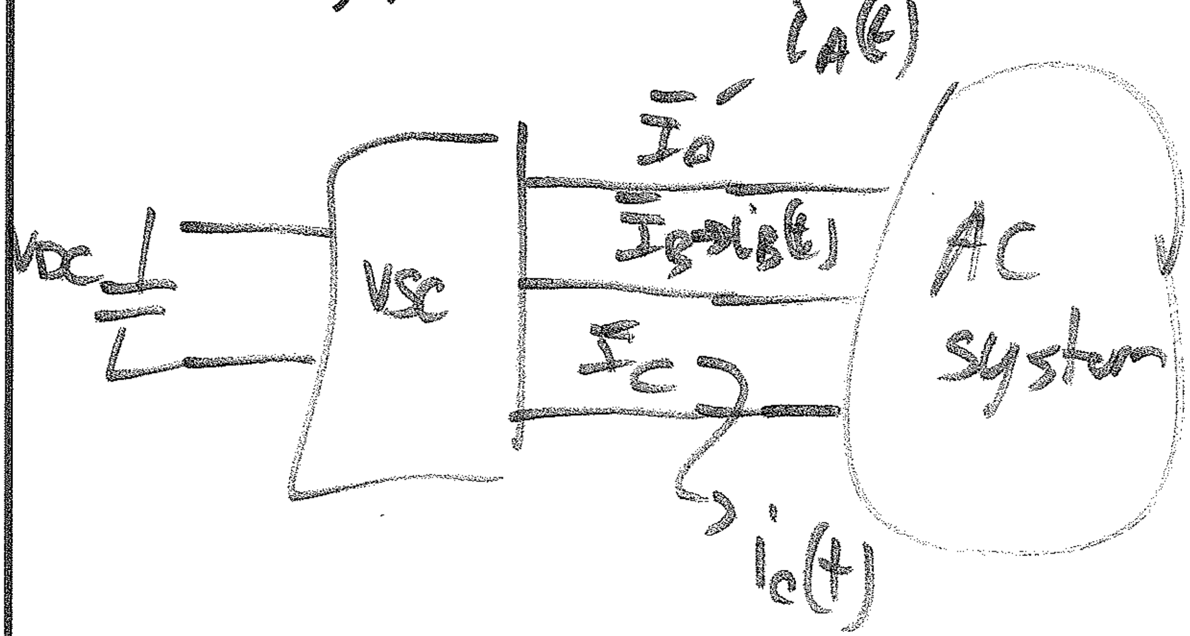
ECE 404-TD / 504-TD

ST: T&D APPLICATIONS OF VOLTAGE SOURCE CONVERTERS

SESSION no. 30



→ 3ϕ system

→ ① AC current reference tracking → controller design
→ switching frequency

② 3 currents → 2 are independent
→ 3 controllers

- Typically controllers work in reference frame transformed ~~to~~ from ABC domain

→ many way to implement transformations and choose references

→ Two axis transformations

→ Related to the Park's Transformation

→ really are instances of applying it

L31 3/13

Two Axis Transformation

Imitation Measured Currents:

Define array of time and define angular frequency:

$$t := 0\text{sec}, 0.0001\text{sec} .. \frac{6}{60\text{Hz}}$$

Δt

$$\omega_0 := 2\cdot\pi\cdot 60\text{Hz} \qquad \omega(t) := \omega_0$$

Voltage as a function of time

$$V_{mag} := 15\text{kV}$$

$$v_a(t) := \sqrt{2}\cdot V_{mag}\cdot\cos(\omega(t)\cdot t)$$

$$v_b(t) := \sqrt{2}\cdot V_{mag}\cdot\cos(\omega(t)\cdot t - 120\text{deg})$$

$$v_c(t) := \sqrt{2}\cdot V_{mag}\cdot\cos(\omega(t)\cdot t + 120\text{deg})$$

Transform measured ~~currents~~ voltages to the stationary dq0 (αβ) reference frame:

- Use equations from the Clarke Transformation instead of matrix for now

or the αB transform

$$v_{ds}(t) := \frac{2}{3}\cdot\left(v_a(t) - 0.5\cdot v_b(t) - 0.5\cdot v_c(t)\right)$$

$$v_{qs}(t) := \frac{\left(v_b(t) - v_c(t)\right)}{\sqrt{3}}$$

Q axis 180 out of phase with some definitions

or d axis

$$V_{os} = \left(V_a(t) + V_b(t) + V_c(t)\right)\cdot k = 0$$

Option I: for a 3Ø current regulation

use $\alpha\beta$ transformation

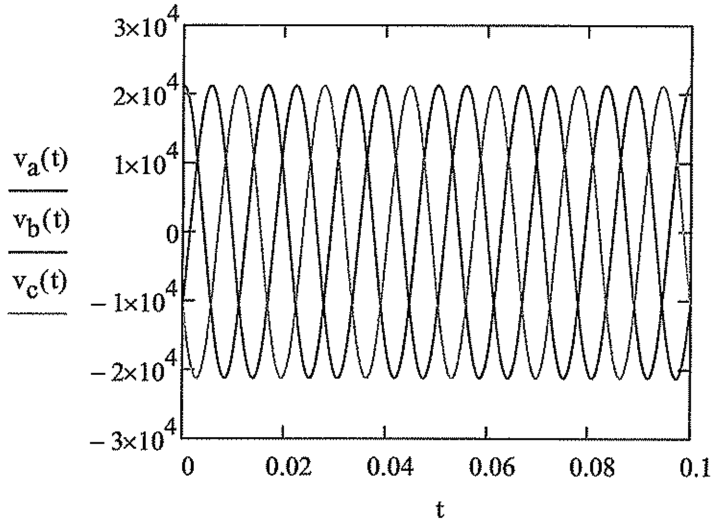
→ Regulator for $i_\alpha(t)$
and $i_\beta(t)$
β

- 2 controllers
- 2 independent variables

→ $i_0 = 0$ since no ground connection

→ Disadvantage - requires AC signal tracking

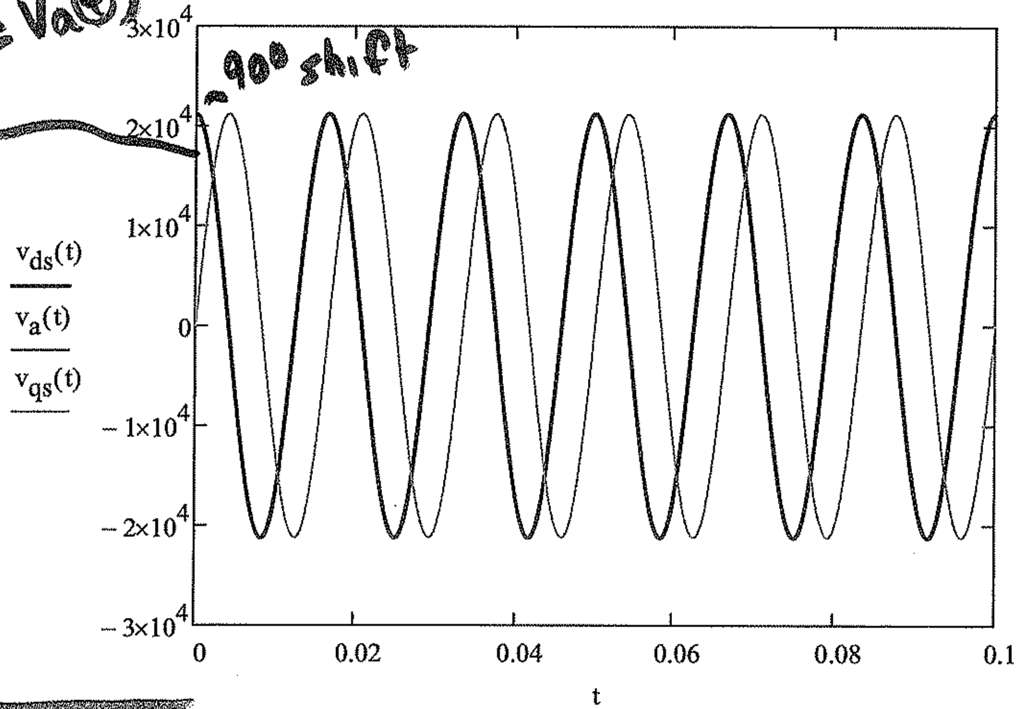
L31



Transformed voltages (not that $v_{ds}(t)$ in phase with $v_a(t)$

$V_{ds}(t) = V_a(t)$

~90° shift



Both 60Hz

$\theta r(t) := 2\cdot\pi\cdot 60.0\text{Hz}\cdot t$ → typically this is calculated from measurements on AC system

- Now apply rotating reference frame transformation in steps

$v_{dr1}(t) := v_{ds}(t)\cdot\cos(\theta r(t))$

→ Phase locked loop to track AC system frequency

L31 6/17

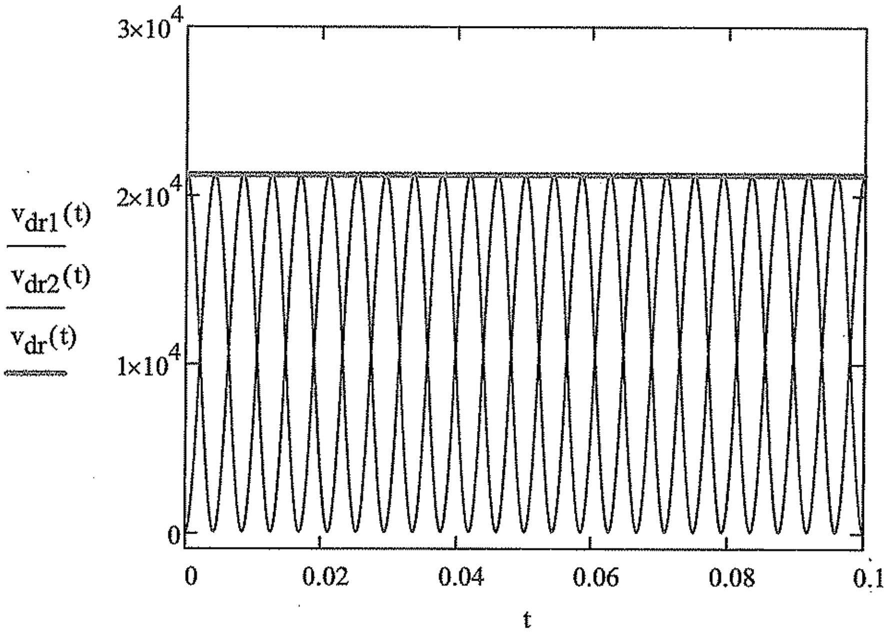
$$v_{dr2}(t) := v_{qs}(t)\cdot\sin(\theta r(t))$$

$$v_{dr}(t) := v_{dr1}(t) + v_{dr2}(t)$$

$$v_{qr1}(t) := v_{ds}(t)\cdot\sin(\theta r(t))$$

$$v_{qr2}(t) := v_{qs}(t)\cdot\cos(\theta r(t))$$

$$v_{qr}(t) := -v_{qr1}(t) + v_{qr2}(t)$$



~~Best~~ can control constant terms for V_{dr}, V_{qr}, i_{dr}, i_{qr}

→ 2 control loops

→ one for i_{dr} } transform reference & measurements for feedback control

one for i_{qr}

control loop output will be converted back to ABC frame for input to ~~firing~~ firing pulse circuit

$\left.\begin{array}{l}\text{d - axis}\\ \text{q - axis}\end{array}\right\}$ - mostly decoupled in controller

- If you have 2 control objectives in outer control converter controls

$|V| \rightarrow$ balanced $3\phi \xrightarrow{\text{or}} Q_{inj}$

and P_{inj}

$\rightarrow Q_{inj}$ (or $|V|$) generate i_{dref}

$i_{\alpha ref}$

P_{inj} generate i_{qref}

$i_{\beta ref}$

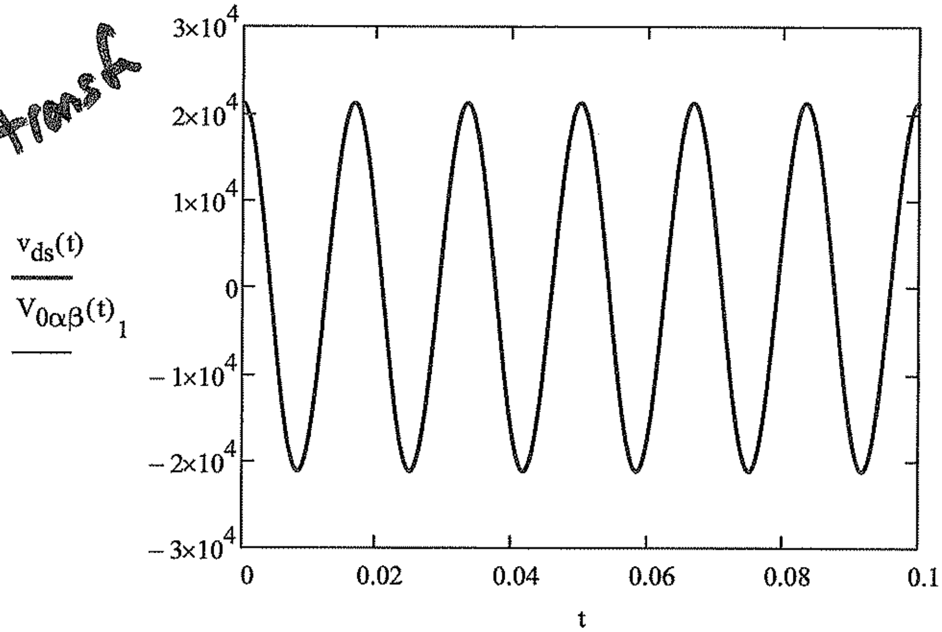
outer control

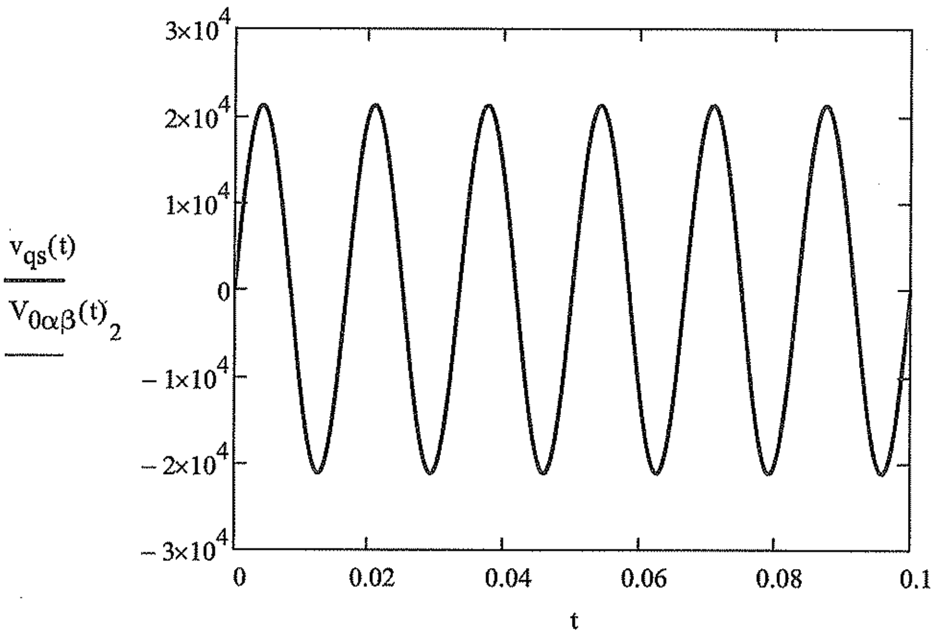
L31 9/8/12

Or if we redefine or reference angle:

$$V_{0\alpha\beta}(t) := P(0)\cdot\begin{pmatrix} v_a(t) \\ v_b(t) \\ v_c(t) \end{pmatrix}$$

α-β transf





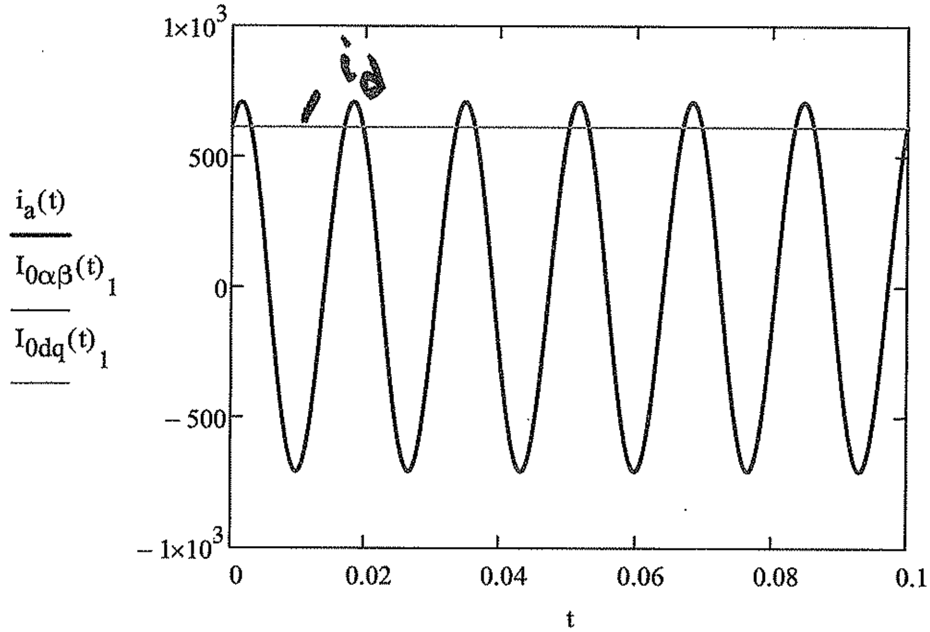
Now add some currents:

$$I_{mag} := 500A \qquad i_a(t) := \sqrt{2}\cdot I_{mag}\cdot\cos(\omega(t)\cdot t - 30deg)$$

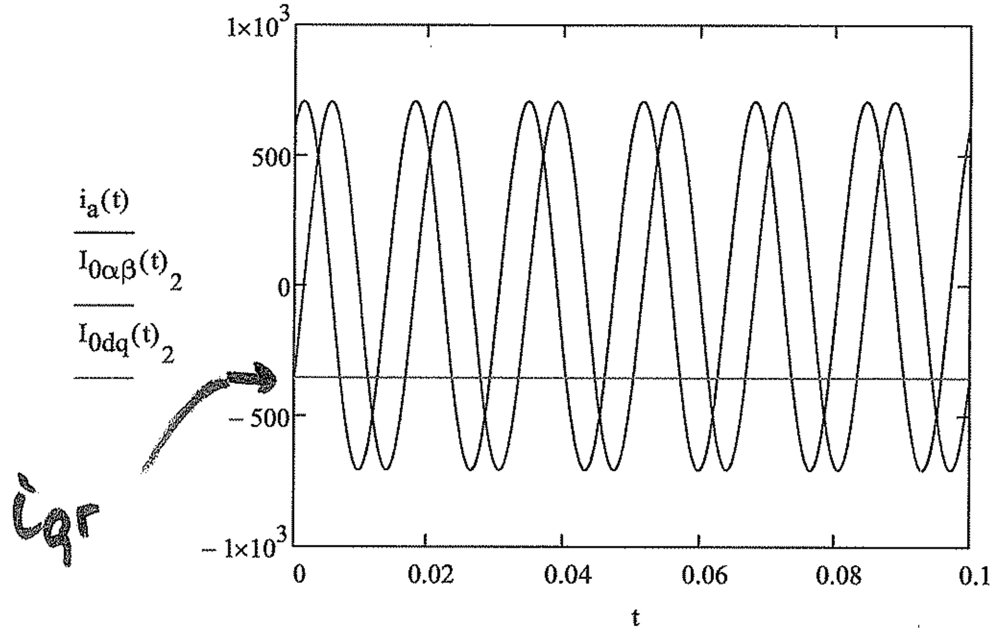
$$i_b(t) := \sqrt{2}\cdot I_{mag}\cdot\cos(\omega(t)\cdot t - 150deg)$$

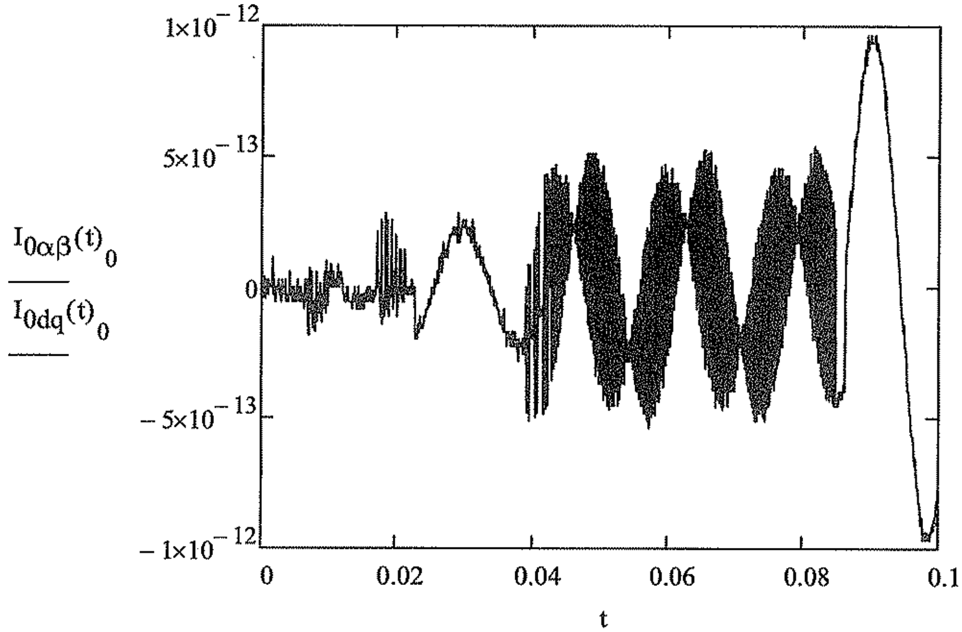
$$i_c(t) := \sqrt{2}\cdot I_{mag}\cdot\cos(\omega(t)\cdot t + 90deg)$$

$$I_{0dq}(t) := P(t)\cdot\begin{pmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{pmatrix} \qquad I_{0\alpha\beta}(t) := P(0)\cdot\begin{pmatrix} i_a(t) \\ i_b(t) \\ i_c(t) \end{pmatrix}$$



L31 10/17


1×10^{3}
500
0
-500
-1×10^{3}
0
0.02
0.04
0.06
0.08
0.1
t
$i_a(t)$
$I_{0\alpha\beta}(t)_2$
$I_{0dq}(t)_2$
i_{qr}


1×10^{-12}
5×10^{-13}
0
-5×10^{-13}
-1×10^{-12}
0
0.02
0.04
0.06
0.08
0.1
t
$I_{0\alpha\beta}(t)_0$
$I_{0dq}(t)_0$

L31 12/13

Now calculate real and reactive power

$MW := 1000kW \qquad MVA := MW \qquad MVAR := MW$

- Phasor form first:

$$V_a := V_{mag} \cdot e^{j \cdot 0deg}$$

$$I_a := I_{mag} \cdot e^{-j \cdot 30deg}$$

$$P_{3ph} := 3 \cdot \mathrm{Re}\left(V_a \cdot \overline{I_a}\right) \qquad P_{3ph} = 19.486\,MW$$

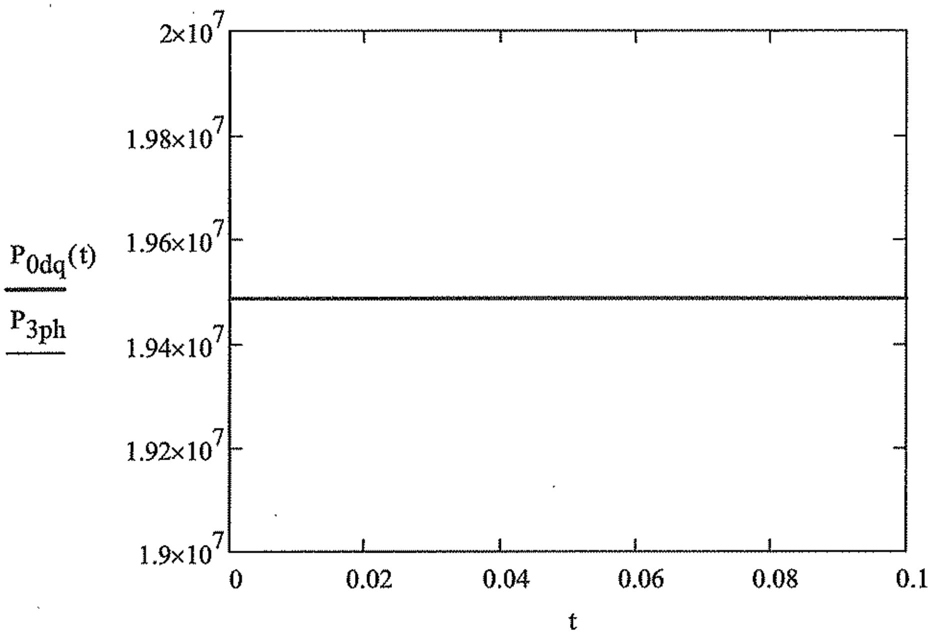
$$Q_{3ph} := 3 \cdot \mathrm{Im}\left(V_a \cdot \overline{I_a}\right) \qquad Q_{3ph} = 11.25\,MW$$

- Now in DQ reference frames:

$v_0 i_0 \qquad v_d \, i_d \qquad v_q \cdot i_q$

$$P_{0dq}(t) := \frac{3}{2} \cdot \left(V_{0dq}(t)_0 \cdot I_{0dq}(t)_0 + V_{0dq}(t)_1 \cdot I_{0dq}(t)_1 + V_{0dq}(t)_2 \cdot I_{0dq}(t)_2\right)$$

  - Note: we need the 3/2 term because of 2/3 constant in transformation matrix.
  - This will differ if use SQRT(2/3)



L31 2/1/13

$V_q \cdot i_d - V_d \cdot i_q$

$$Q_{0dq}(t) := \frac{3}{2}\cdot\left(V_{0dq}(t)_2 \cdot I_{0dq}(t)_1 - V_{0dq}(t)_1 \cdot I_{0dq}(t)_2\right)$$

- Note: we need the 3/2 term because of 2/3 constant in transformation matrix.
- This will differ if use SQRT(2/3)