POWERFACTORY

PowerFactory 2021

Technical Reference

Voltage Transformer

StaVt, TypVt

PF2021

POWER SYSTEM SOLUTIONS

MADE IN GERMANY

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Contents

1 General Description

The *VT* block simulates the behavior of a voltage transformer.

The voltage transformer does not have any impact on the network since the model is written in such a way that only the voltage signals are used as signals (it does not influence the voltage of the connected terminal).

Three different voltage transformer models are available in *PowerFactory* :

- Ideal voltage transformer;
- Detailed voltage transformer;
- Capacitive voltage transformer.

The "detailed" model simulates the core saturation effect accordingly with the parameters defined by the IEC and the ANSI standards. Two different types of VT block are available: the three phase VT and the single phase VT. Each type has different input and output signals.
The single phase VT is activated when the *Secondary Connection* setting ("cstapcon", see §3.2.1) is *O*.

2 Integration in the relay scheme

The VT type class name is TypVt and the VT class name is StaVt. The VT block represents in the relay model scheme the voltage signals entry point. Usually the VT block is connected to the measurement block. In figure 2.1 the typical connection scheme of a three phase VT block is shown, in figure 2.2 the same scheme for a single phase VT .
In both cases the VT is connected to the Measurement block inputs.

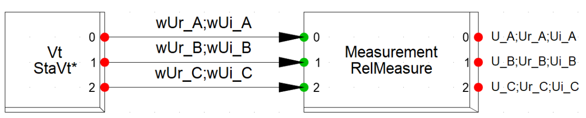

Figure 2.1: *Voltage Transformer* three phase connection scheme with measurement element

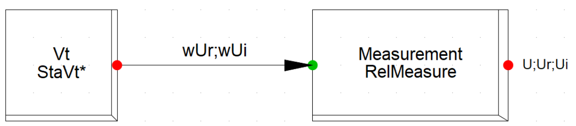

Figure 2.2: *Voltage Transformer* single phase connection scheme with measurement element

The available signals list and decsription can be found at §7.

3 Features and User interface

3.1 Voltage Transformer Type (TypVt)

The *Voltage Transformer Type* dialog consists of five tab pages

- Basic Data
- Transformer Data
- Additional CVT Data
- Description
- Version

3.1.1 Basic Data

The “Basic Data” tab page allows to define:

- The model name (“loc_name” parameter)
- The model type (*Ideal Voltage Transformer*, *Voltage Transformer*, *Capacitive Voltage Transformer*).
- The available transformer primary taps in terms of Line to Line voltages (“primtaps” parameter).

3.1.2 Transformer Data

The “Transformer Data” tab page contains the settings which define the Voltage Trasformer model when in the “Basic Data” tab page the *Voltage Transformer* or the *Capacitive Voltage Transformer* model type has been selected.
For more details regarding such settings please refer to §5.

The “Transformer Data” tab page graphical controls are not displayed when in the “Basic Data” tab page the *Ideal Voltage Transformer* model type has been selected.

3.1.3 Additional CVT Data

The “Additional CVT Data” tab page contains the settings which define the Capacitive Voltage Trasformer model when in the “Basic Data” tab page the *Capacitive Voltage Transformer* model type has been selected.
For more details regarding such settings please refer to §6.

The “Transformer Data” tab page is not displayed when in the “Basic Data” tab page the *Ideal Voltage Transformer* or the *Voltage Transformer* model type has been selected.

3.1.4 Description

The *Description* tab page can be used to insert some information to identify the VT element (both with generic strings containing the manufacturer name ("manuf" parameter) and a *characteristic name* ("chr_name" parameter) for the item and with an unique *Foreign Key* textual string ("for_name" parameter) similar to the approach used in the relational databases) and to identify the source of the data used to create it.

The *Description* edit box allows to insert a long text description of the VT.

The *Rated Burden* frame allows to insert burden impedance data and the *Accuracy Class* information; both information are not used in the VT model calculation but have a documentation purpose only.

3.1.5 Version

The *Version* tab page is used by the PowerFactory library version system to manage the library database element versions. Both the *Version* and the *Change Log* edit box can be manually edited even if it's normally not required.

3.2 Voltage Transformer (StaVt)

The user can change the block settings using the "Voltage Transformer"dialogue ("StaVt" class). The dialog consists of three tab pages: *Basic data*, *Additional Data*, and *Description*. The main settings are located in the *Basic data* tab page.

3.2.1 Basic Data

The "Basic Data" tab page of the VT dialog ("StaVt" class) is used to set

- the Voltage Transformer name ("loc_name" parameter).
- the type (*Type* control, "typ_id" parameter).
- the measurement position (*Location* control, "pbusbar" parameter).
- the primary phase-phase rated voltage level (*Tap* control, "ptapset" parameter).
- the primary winding connection (*Connection* control, "cptapcon" parameter).
- the secondary winding type (*Type* control, "staptyp" parameter).
- the secondary phase-phase rated voltage level (*Tap* control, "stapset" parameter).
- the secondary winding connection (*Connection* control, "cstapcon" parameter).

The block can be disabled using the *Out of service* check box ("outserv" parameter)).
The *Ratio* blue text provides additional info regarding the voltage ratio and the *Busbar* and *Branch* control point to the busbar element and to the branch element where the VT is located.

The secondary winding type ("TypVtec" class, see §3.3) allows to define the secondary winding impedance in terms of magnitude (*Impedance* control, "Zb" parameter) and angle (*Power factor* control, "cosb" parameter).

Please note that the *Location* control can point to another Voltage Transformer. In this way the other VT output signals can be used as input signals of the VT block. The *Location* control can point also to a cubicle("StaCubic" class), to a Terminal("ElmTerm" class) or to a Busbar ("StaBar" class).

3.2.2 Additional Data

The *Additional Data* tab page graphical controls are displayed only if in the "Basic Data" tab page of the *Voltage Transformer Type (TypVt)* dialog (see §3.1) the *Voltage Transformer* or the *Capacitive Voltage Transformer* model type has been selected.
Please refer to table 5.1 for the *Voltage Transformer* model type setting, to table 6.1 for the *Capacitive Voltage Transformer* model type.

3.2.3 Description

The *Description* tab page contains the same information available in relevant tab page of the *Voltage Transformer Type (TypVt)* dialog (see §3.3.3) and some additional edit boxes and graphical controls which allow to define

- The *Commissioning Date* ("iComDate" parameter).
- The *Owner* ("pOwner" parameter).
- The *Operator* ("pOperator" parameter).
- The *Approval Status* ("appr_status" parameter).

3.3 Voltage Transformer Secondary Type

The *Voltage Transformer Seconday Type* dialog consists of three tab pages

- Basic Data
- Description
- Version

3.3.1 Basic Data

The "Basic Data" tab page allows to define:

- The model name ("loc_name" parameter).
- The available transformer secondary taps in terms of Line to Line voltages ("sectaps" parameter).

The *Rated Burden* frame allows to insert the burden impedance data ("Zb" and "cosb" parameter); such impedance is used in the secondary winding burden calculation in the *Detailed Voltage Transformer* model (see §5) and in the *Capacitive Voltage Transformer* model (see §6).

3.3.2 Description

The *Description* tab page can be used to insert some information to identify the VT element (both with generic strings containing the manufacturer name ("manuf" parameter) and a *characteristic name* ("chr_name" parameter) for the item and with an unique *Foreign Key* textual string ("for_name" parameter) similar to the approach used in the relational databases and to identify the source of the data used to create it.

The *Description* edit box allows to insert a long text description of the VT.

3.3.3 Version

The *Version* tab page is used by the PowerFactory library version system to manage the library database element versions. Both the *Version* and the *Change Log* edit box can be manually edited even if it's normally not required.

3.4 Voltage Transformer Secondary

The *Voltage Transformer Secondary* dialog ("StaVtsec" class) is used to set

- the Voltage Transformer Secondary name ("loc_name" parameter).
- the type (*Type* control, "typ_id" parameter).
- the Primary Voltage Transformer object at which the Secondary Winding belongs ("cPriVt" parameter).
- the secondary phase-phase rated voltage level (*Tap* control, "stapset" parameter).
- the secondary winding connection (*Connection* control, "cstapcon" parameter).

The block can be disabled using the *Out of service* check box ("outserv" parameter)).
The *Ratio* blue text provides additional info regarding the voltage ratio.

4 Ideal voltage transformer

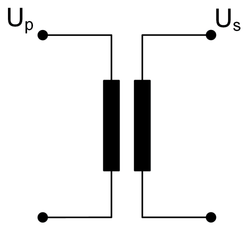

Figure 4.1: Equivalent circuit of the ideal VT model

The *Ideal voltage transformer* model implements a simple ratio between the primary and the secondary voltage values. It takes care of winding connection type (*Y* or *D*).
No other additional effect is considered.

4.1 Input parameters

Part of the parameters required for the *Ideal Voltage Transformer* model is entered in the element (*StaVt*) dialog and part in the type (*TypVt*) dialog. These parameters are listed in Table 4.1 and Table 4.2. An additional object, the Voltage Transformer Secondary Type ("TypVtsec") (see §3.3), must be created to store the Secondary Winding Tap values. At least one Voltage Transformer Secondary must be present but multiple secondary windings can be created and associated to the *Voltage transformer* using the list object displayed by the "Additional Secondary Windings" button available at the bottom of the *Basic Data* tab page in the Voltage Transformer (*StaVt*) dialog.

Table 4.1: *Ideal Voltage Transformer* Input parameters defined in *StaVt*

Name	Unit	Description	Base
$ptapset$		Primary Tap	
$cptapcon$		Primary Connection ("YN" or "D" or "V")	
$staptyp$	Object	Secondary Type	
$stapset$		Secondary Tap	
$cstapcon$		Secondary Connection ("YN" or "D" or "O")	

Table 4.2: *Ideal Voltage Transformer* Input parameters defined in *TypVt*

Name	Unit	Description	Base
$primtaps$	V	Primary Taps (L-L) V	Primary Voltage

The required parameter are at least one voltage tap in the *Primary Taps (L-L) V* listbox in the *Basic Data* tab page in the Voltage Transformer Type (*TypVt*) dialog and one in the *Basic Data* tab page in the Voltage Transformer Secondary Type (*TypVt*) dialog. The *Rated Output* parameter ("Snom" parameter) present above the *Primary Taps (L-L) V* listbox n the Voltage Transformer Type (*TypVt*) dialog is not used in the calculation and is available for documentation purpose only.

4.2 Transfer functions

The following transfer formulas are applied:

- When the primary connection is *Y* and the secondary connection is *Y*:

$$U\_xsecondary = U\_xprimary/ratio \tag{1}$$

where:
$ratio =$ the VT transformer ratio
$x =$ phase a,b,c

- When the primary connection is *Y* and the secondary connection is *D*:

$$U\_xsecondary = (U\_xprimary - U\_yprimary)/ratio \tag{2}$$

where:
$ratio =$ the VT transformer ratio
$x =$ phase b,c,a
$y =$ phase a,b,c

5 Detailed voltage transformer

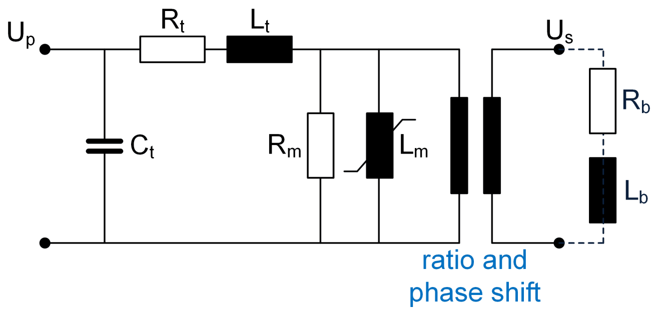

Figure 5.1: Equivalent circuit of the detailed VT model

The *Detailed voltage transformer* model is the more complete Voltage Transformer model available. It consists of the transfer function of the *Ideal Voltage Transfomer* (see §4.2) and of the equations solving the equivalent circuit represented in Figure 5.1.Only for the EMT simulation it includes a saturation model.

5.1 Input parameters

Part of the parameters required for the *Detailed Voltage Transformer* model is entered in the element (*StaVt*) dialog and part in the type (*TypVt*) dialog. These parameters are listed in Table 5.1 and Table 5.2.

Table 5.1: *Detailed Voltage Transformer* Input parameters defined in *StaVt*

Name	**Unit**	**Description**	**Base**
Ct	nF	Stray capacitance of the transformer	Uinom
Rb	Ω	Burden Resistance	sec. voltage
Lb	H	Burden Inductance	sec. voltage

Table 5.2: *Detailed Voltage Transformer* Input parameters defined in *TypVt*

Name	**Unit**	**Description**	**Base**
Rt	Ω	Transformer leakage resistance	Uinom
Lt	H	Transformer leakage inductance	Uinom
Rm	Ω	Transformer Magnetizing resistance	Uinom
Lm	H	Transformer Magnetising inductance	Uinom
$itrmt$		Saturation Mode(*Piecewise Linear*, *Polynomial*)l	/
$psi0$	$p.u.$	Ψ_0 Knee Flux	Uinom
$Lmsat$	H	Saturated Magnetising Inductance	Uinom
$ksat$		Exponent for the polynomial saturation model	/

5.2 Two slope and polynomial characteristic Saturation Model

Figure 5.2 shows the magnetizing current-flux plots for the two slopes characteristic and the polynomial characteristic. The input parameters of both plots are the same except for the saturation exponent, which only applies to the polynomial characteristic. The input parameters are listed in Table 5.3.

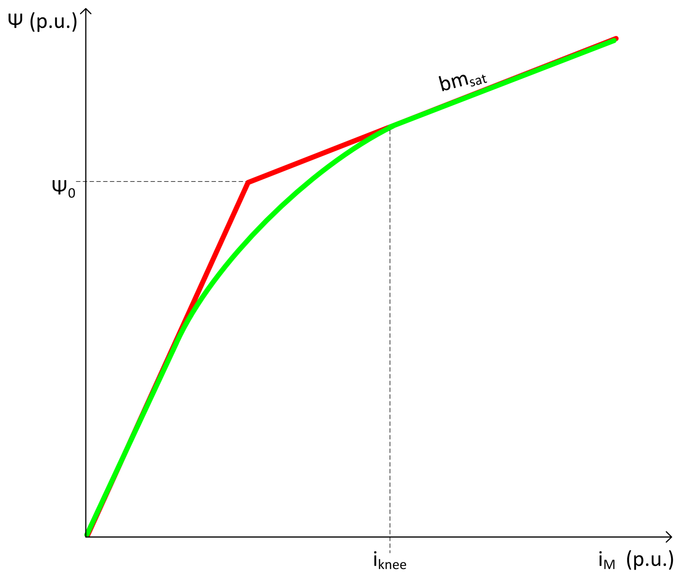

Figure 5.2: Two slope and polynomial saturation curves

Table 5.3: Two-slope and polynomial saturation characteristic input parameters

Parameter	**Description**	**Unit**
Ψ_0 *Knee Flux*	Knee-point of asymptotic piece-wise linear characteristic. Typical value around 1.1 to 1.2 times the rated flux.	p.u.
Lm *Linear (unsaturated) reactance*	Magnetising reactance for unsaturated conditions L_{unsat}. In p.u. values, the linear reactance is equal to the reciprocal of the magnetising current (reactive part of the exciting current).	p.u.
$Lmsat$ *Saturated reactance*	Magnetising reactance for saturated conditions L_{sat}.	p.u.
Saturation exponent	Exponent of polynomial representation (k_{sat}). Typical values are 9, 13, 15. The higher the exponent the sharper the saturation curve.	-

5.2.1 Piecewise Linear Saturation model

In the non-saturated condition $\Psi m_x < \Psi m_{knee}$ the excitation current is calculated by the following equation:

$$I_{ex} = \frac{B_m}{\omega_N} \cdot \Psi m_x \tag{3}$$

In the saturated condition where $\Psi m_x > \Psi m_{knee}$ by the following equation:

$$I_{ex} = I_{knee} + \frac{B_{msat}}{\omega_N} \cdot (\Psi m_x - \Psi m_{knee}) \tag{4}$$

with:

$$\begin{aligned} I_{knee} &= \frac{B_m}{\omega_N} \cdot \Psi m_{knee} \\ \Psi m_{knee} &= \sqrt{2} \cdot V_s \end{aligned} \tag{5}$$

where
$V_s =$ is the *Saturation Voltage* (“Vs” variable in the “Excitation Parameter” frame in the Voltage Transformer dialogue (“StaVt” class)).

5.2.2 Polynomial Saturation model

When not saturated $\Psi m_x < \Psi m_{knee}$:

$$I_{ex} = \frac{B_m}{\omega_N} \cdot \Psi m_x \cdot \left(1 + \left|\left(\frac{\Psi m_x}{\Psi m_0}\right)^{ksat}\right|\right) \tag{6}$$

When saturated $\Psi m_x > \Psi m_{knee}$:

$$I_{ex} = I_{knee} + \frac{B_{msat}}{\omega_N} \cdot (\Psi m_x - \Psi m_{knee}) \tag{7}$$

with:

$$\begin{aligned} I_{knee} &= \frac{B_m}{\omega_N} \cdot \Psi m_{knee} \cdot \left(1 + \left(\frac{\Psi m_{knee}}{\Psi m_0}\right)^{ksat}\right) \\ \Psi m_0 &= \Psi m_{knee} \cdot e^{-\frac{\ln\left(\frac{\frac{B_{msat}}{B_m} - 1}{ksat + 1}\right)}{ksat}} \\ \Psi m_{knee} &= \sqrt{2} \cdot \left(\frac{K_{sat} + 1}{ksat}\right) \cdot V_s \end{aligned} \tag{8}$$

where:
$ksat$ is the *Exponent* (“Ksat” variable in the “Excitation Parameter” frame in the Voltage Transformer dialogue (“StaVt” class)).
$V_s =$ is the *Saturation Voltage* (“Vs” variable in the “Excitation Parameter” frame in the Voltage Transformer dialogue (“StaVt” class)).

6 Capacitive voltage transformer

It models a Capacitive Voltage transformer with ferro-resonance suppression.
The equivalent circuit of the capacitive voltage transformer model is shown in Figure 6.1. The model is based on [1], [2] and [3].

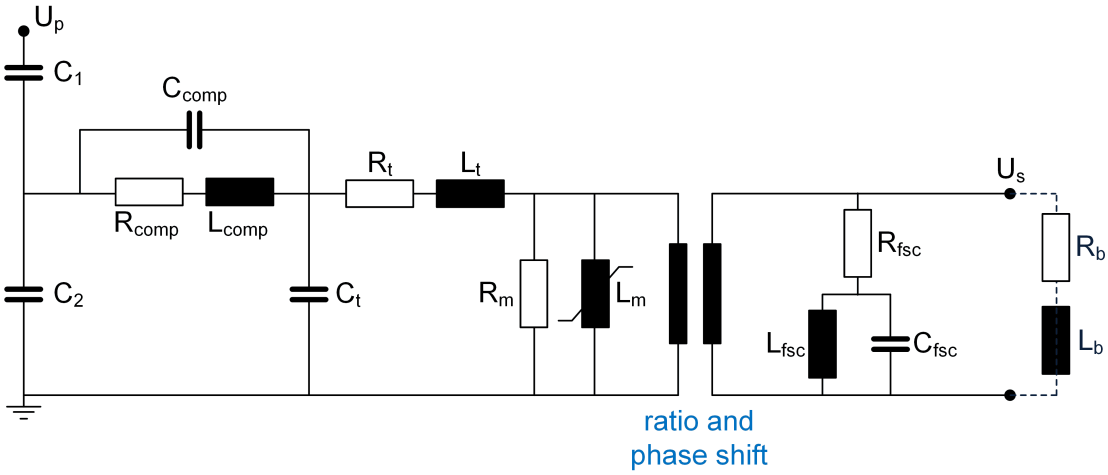

Figure 6.1: Equivalent circuit of the capacitive VT model

Saturation is used only in the EMT simulation model and is calculated same as for the detailed voltage transformer model.

6.1 Input parameters

Part of the parameters required for the capacitive voltage transformer model is entered in the element (*StaVt*) and part in the type (*TypVt*). These parameters are listed in Table 6.2 and Table 6.1.

Table 6.1: *Capacitive Voltage Transformer* Input parameters defined in *StaVt*

Name	**Unit**	**Description**	**Base**
Ct	nF	Stray capacitance of the transformer	Uinom
$Ccomp$	nF	Stray capacitance of the compensation coil	Uinom
Rb	Ω	Burden Resistance	sec. voltage
Lb	H	Burden Inductance	sec. voltage

Table 6.2: *Capacitive Voltage Transformer* Input parameters defined in *TypVt*

Name	**Unit**	**Description**	**Base**
Rt	Ω	Transformer leakage resistance	Uinom
Lt	H	Transformer leakage inductance	Uinom
Rm	Ω	Transformer Magnetizing resistance	Uinom
Lm	H	Transformer Magnetising inductance	Uinom
$psi0$	$p.u.$	Ψ_0 Knee Flux	Uinom
$Lmsat$	H	Saturated Magnetising Inductance	Uinom
$ksat$		Exponent for the polynomial saturation model	/
$Uinom$	V	Nominal intermediate voltage (L-L)	/
$C1$	nF	Capacitive divider primary capacitance	Uinom
$C2$	nF	Capacitive divider secondary capacitance	Uinom
$Rcomp$	Ω	Compensation coil resistance	Uinom
$Lcomp$	H	Compensation coil inductance	Uinom
$Rfsc$	Ω	Ferro-resonance suppression coil resistance	sec. voltage
$Lfsc$	H	Ferro-resonance suppression coil inductance	sec. voltage
$Cfsc$	nF	Ferro-resonance suppression coil capacitance	sec. voltage

If stray capacitances of the transformer Ct and compensation coil $Ccomp$ are set to 0, they are omitted by the model.

The default parameters used for the CVT are from a *PCA-5 Westinghouse Electric* device $(138kV(LL)/5kV(LN)/115V(LN), 60Hz)$.

7 Signal Definitions

7.1 Single phase

Table 7.1: Input/output signals of the single phase Voltage Transformer element (*CalVt1p*)

Name	Description	Unit	Type	Model
Ur_A	Vt block phase A primary side voltage real part	Primary Volts	IN	Any
Ur_B	Vt block phase B primary side voltage real part	Primary Volts	IN	Any
Ur_C	Vt block phase C primary side voltage real part	Primary Volts	IN	Any
Ui_A	Vt block phase A primary side voltage imaginary part	Primary Volts	IN	Any
Ui_B	Vt block phase B primary side voltage imaginary part	Primary Volts	IN	Any
Ui_C	Vt block phase C primary side voltage imaginary part	Primary Volts	IN	Any
U2r	Secondary side voltage real part	Secondary Volts	OUT	Any
U2i	Secondary side voltage imaginary part	Secondary Volts	OUT	Any
U0x3r	Zero sequence voltage real part (calculated internally)	Secondary Volts	OUT	Any
U0x3i	Zero sequence voltage imaginary part (calculated internally)	Secondary Volts	OUT	Any

7.2 3 phase

Table 7.2: Input/output signals of 3 phase Voltage Transformer element (*CalVt*, *CalVtcap*, *CalVt-det*)

Name	Description	Unit	Type	Model
Ur_A	Vt block phase A primary side voltage real part pu	Primary Volts	IN	Any
Ur_B	Vt block phase B primary side voltage real part pu	Primary Volts	IN	Any
Ur_C	Vt block phase C primary side voltage real part pu	Primary Volts	IN	Any
Ui_A	Vt block phase A primary side voltage imaginary part pu	Primary Volts	IN	Any
Ui_B	Vt block phase B primary side voltage imaginary part pu	Primary Volts	IN	Any
Ui_C	Vt block phase C primary side voltage imaginary part pu	Primary Volts	IN	Any
U2r_A	Phase A secondary side voltage real part	Secondary Volts	OUT	Any
U2r_B	Phase B secondary side voltage real part	Secondary Volts	OUT	Any
U2r_C	Phase C secondary side voltage real part	Secondary Volts	OUT	Any
U2i_A	Phase A secondary side voltage imaginary part	Secondary Volts	OUT	Any
U2i_B	Phase B secondary side voltage imaginary part	Secondary Volts	OUT	Any
U2i_C	Phase C secondary side voltage imaginary part	Secondary Volts	OUT	Any

8 References

[1] L. Kojovic, M. Kezunovic, and C. Fromen, “A new method for the ccvt performance analysis using field measurements, signal processing and emtp modeling,” *IEEE Transactions on Power Delivery*, vol. 9, no. 4, 1994.

[2] M. Kezunovic, L. Kojovic, V. Skendzic, C. W. Fromen, D. R. Sevcik, and S. L. Nilsson, “Digital models of coupling capacitor voltage transformers for protective relay transient studies,” *IEEE Transactions on Power Delivery*, vol. 7, no. 4, 1992.

[3] D. Fernandes Jr., W. L. A. Neves, and J. C. A. Vasconcelos, “Identification of parameters for coupling capacitor voltage transformers,” *Proceedings of IPST*, no. 01IPST080, 2001.

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