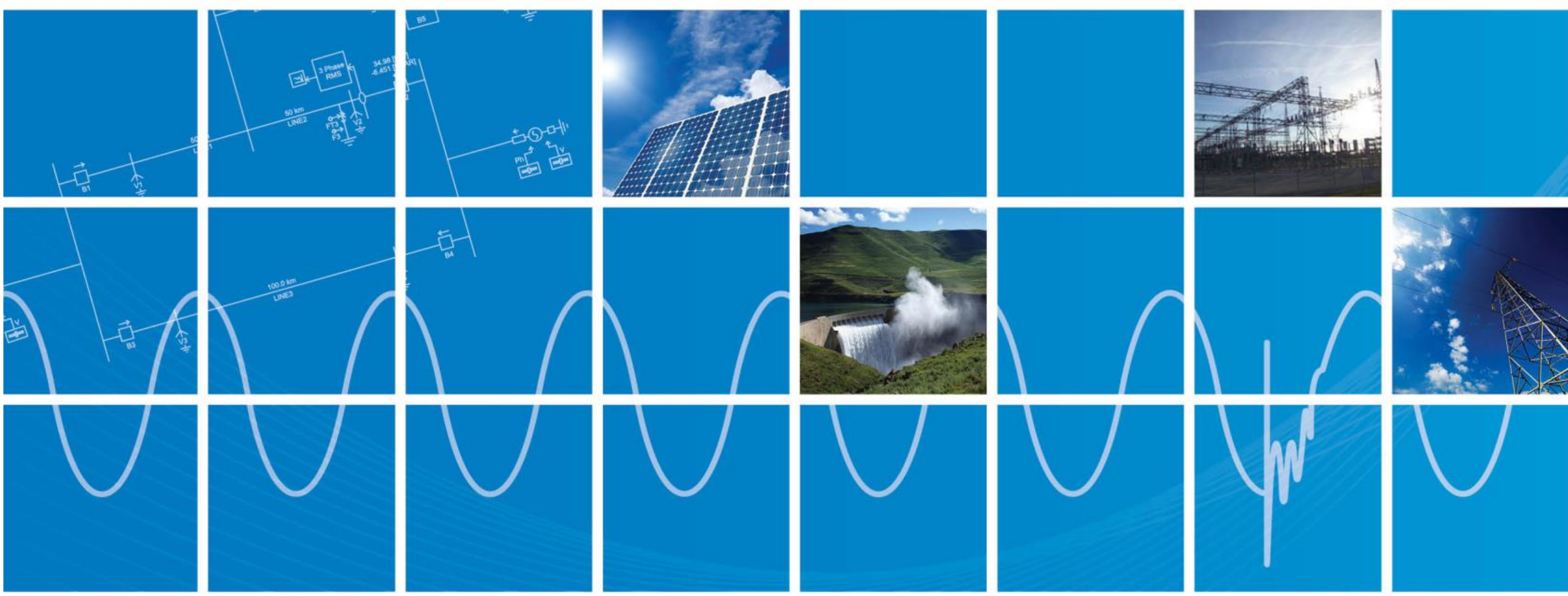
Three-Phase Voltage Source 1 Component

For PSCAD Version 5.0

January 30, 2020

Initial



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CONTENTS

1. OVERVIEW

This section provides additional details on three-phase voltage source 1 implemented in PSCAD/EMTDC.

1.1. Source impedance

The user can specify the positive sequence source impedance and the zero sequence source impedance in source 1.

1.1.1. Positive sequence source impedance

The positive sequence source impedance (Figure 1) can be represented as follows,

- R: Purely resistive
- L: Purely inductive
- R//L: Parallel RL
- R-R//L: Parallel RL in series with a resistance

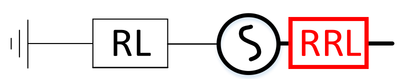

Figure 1: Source 1 Positive Sequence Impedance Highlighted

The positive sequence source impedance can be entered either as the physical values (Ohm / H) or as the impedance value (Magnitude/Angle).

R//L impedance format

When the source impedance is selected as R//L in impedance format ($Z\angle\theta$), the source physical quantities, i.e. L1 and R1 as shown in Figure 2, are calculated based on the impedance magnitude (Z) and its phase angle (θ) as shown in (1) to (3) and described in detail in Appendix A.

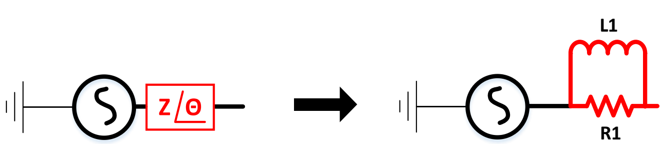

Figure 2: Impedance Value R//L Conversion

$$Z\angle\theta = R_1 // L_1 = \frac{R_1 \cdot j\omega L_1}{R_1 + j\omega L_1} \tag{1}$$

$$L_1 = \frac{Z}{\omega \cdot sin(\theta)} \tag{2}$$

$$R_1 = \frac{Z}{\cos(\theta)} \tag{3}$$

R-R//L impedance format

When the source impedance is selected as R-R//L in impedance format ($Z\angle\theta$), the source physical quantities, i.e. R1, L1 and R2 as shown in Figure 3, are calculated based on the impedance magnitude (Z), its phase angle (θ), and the harmonic number (n) as shown in (4) to (14).

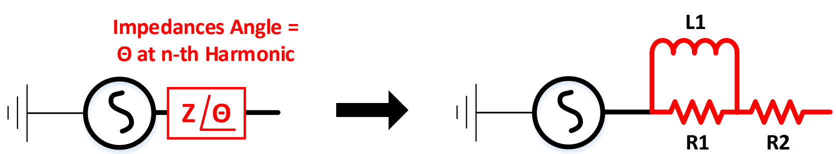

Figure 3: Impedance Value R-R//L Conversion

$$Z\angle\theta = R_2 + R_1 // L_1 = R_2 + \frac{R_1 \cdot j\omega L_1}{R_1 + j\omega L_1} \tag{4}$$

$$Var_1 = Z \cdot \sin(\theta) \tag{5}$$

$$Var_2 = \sqrt{Var_1} \cdot n \cdot (1 - n) \tag{6}$$

$$Var_3 = Var_1 \cdot \tan(\theta) \cdot (1 - n^2) \tag{7}$$

$$Var_4 = \sqrt[\frac{3}{2}]{Var_1} \cdot (n - 1) \tag{8}$$

$$Var_5 = \sqrt{{Var_3}^2 - 4 \cdot Var_2 \cdot Var_4} \tag{9}$$

$$Var_6 = \frac{-Var_5 - Var_3}{2 \cdot Var_2} \tag{10}$$

$$If\ Var_6 \leq 0, then\ Var_6 = \frac{Var_5 - Var_3}{2 \cdot Var_2} \tag{11}$$

$$L_1 = \frac{{Var_6}^2 + Z \cdot \sin(\theta)}{\omega} \tag{12}$$

$$R_1 = \omega L_1 \cdot \sqrt{\frac{Z \cdot \sin(\theta)}{\omega L_1 - Z \cdot \sin(\theta)}} \tag{13}$$

$$R_2 = \frac{\omega L_1 \cdot \frac{n}{R1 \cdot \tan(\theta)} - \left(\omega L_1 \cdot \frac{n}{R1}\right)^2}{1 + \left(\omega L_1 \cdot \frac{n}{R1}\right)^2} * R_1 \tag{14}$$

The harmonic number (n) of the frequency is defined as, where the phase angle of the impedance at that frequency is the same as that at the fundamental. Figure 4 illustrates the positive sequence impedance of the source where the harmonic number is set to three times of the fundamental frequency.

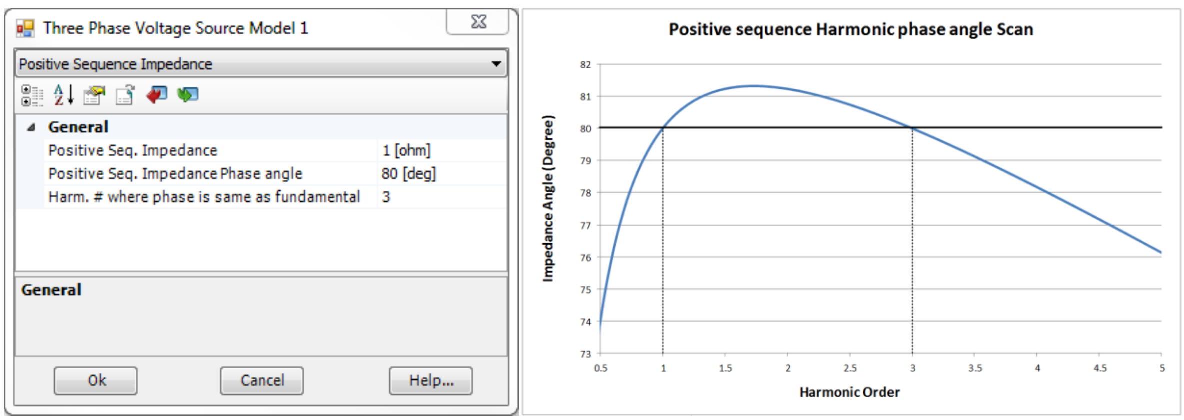

Figure 4: Positive Sequence Impedance Configurations and The Frequency scan Results

1.1.2. Zero sequence source impedance

The zero sequence source impedance (Figure 5) can be entered as parallel RL (R//L) or series RL (R-L).

The zero sequence source impedance can be entered either as the physical values (Ohm / H) or as the impedance value (Magnitude/Angle).

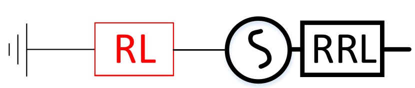

Figure 5: Source 1 Zero Sequence Impedance Highlighted

1.2. Voltage Source

There are three source control options available for selection, fixed, external, and auto mode as shown in Figure 6.

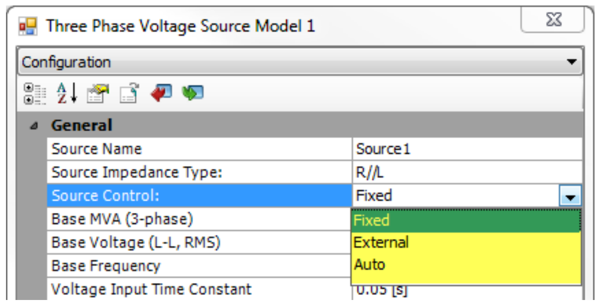

Figure 6: Source Control Options

1.2.1. Fixed control option

In fixed control option, the two different data formats can be selected to specify the source behind the impedance. This is controlled directly by the **Specified Parameters** input with options as shown in Figure 7.

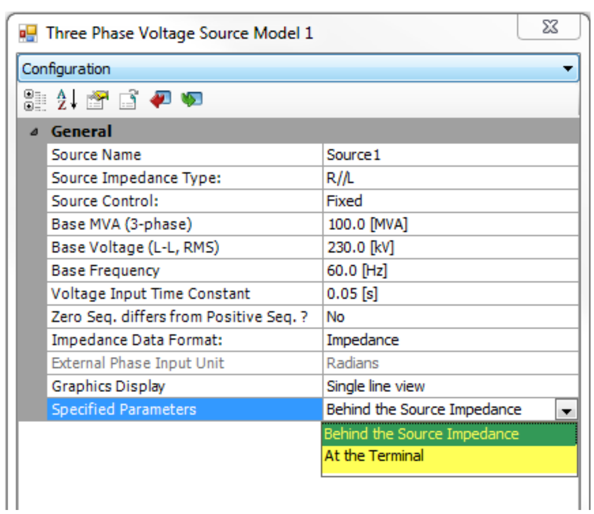

Figure 7: Specified Parameters

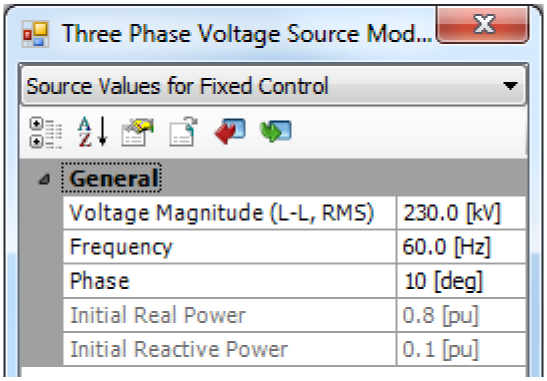

Figure 8: Behind the Source Impedance

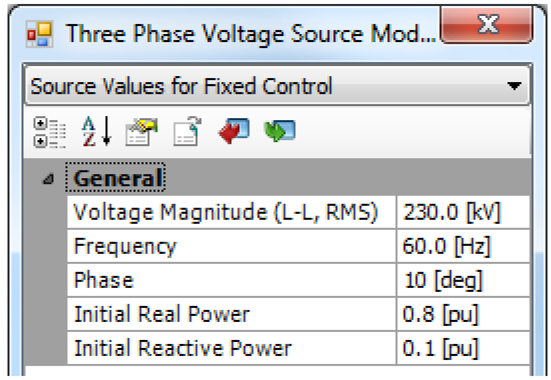

Figure 9: At the Terminal

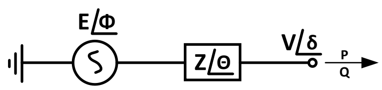

Figure 10: Equivalent Source and Impedance

Behind Source Impedance: When this option is selected, the source parameters are directly entered as frequency (f), voltage of the source behind the impedance (E) and the angle of the source behind the impedance (ϕ) as shown in Figure 8 and Figure 10. The source impedance (Z and θ) are derived from the source impedance specified by the user.

At the Terminal: When this option is selected, the terminal parameters are entered directly (i.e. frequency (f), terminal voltage (V), terminal phase angle (δ), terminal output active (P) and reactive (Q) power) as shown in Figure 9 and Figure 10. These quantities were used to determine the voltage magnitude (E) and phase angle (ϕ) behind the impedance and the angle of the source behind the impedance (15) and (16). The derivation details are depicted in Appendix B.

$$\phi = \delta + \theta - \tan^{-1}\left(\frac{Q + \frac{V^2}{Z}\cdot\sin(\theta)}{P + \frac{V^2}{Z}\cdot\cos(\theta)}\right) \quad (15)$$

$$E = \frac{\sqrt{\left(P + \frac{V^2}{Z}\cdot\cos(\theta)\right)^2 + \left(Q + \frac{V^2}{Z}\cdot\sin(\theta)\right)^2}}{\frac{V}{Z}} \quad (16)$$

1.2.2. External control option

In external control option, the voltage magnitude, frequency and the phase values of the source behind the impedance can be controlled externally as shown in Figure 11. The external values can be controlled manually by connecting a slider, or automatically through a control system output for dynamic adjustment. Table 1 summarized the external input signals unit.

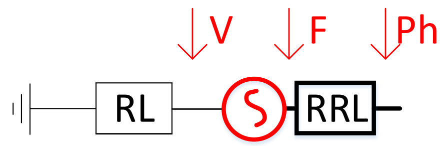

Figure 11: Voltage Source External Control

Table 1: External Input Signals Unit

Magnitude	kV, Line to Line, RMS
Frequency	Hz
Phase Angle	Degrees or radians

1.2.3. Automatic control option

In the automatic voltage and power control option, the voltage magnitude can be adjusted automatically to regulate the voltage at a selected bus and/or adjust the source phase angle internally to regulate the real power leaving the source. Figure 12 shows how the source is connected to allow automatic voltage control.

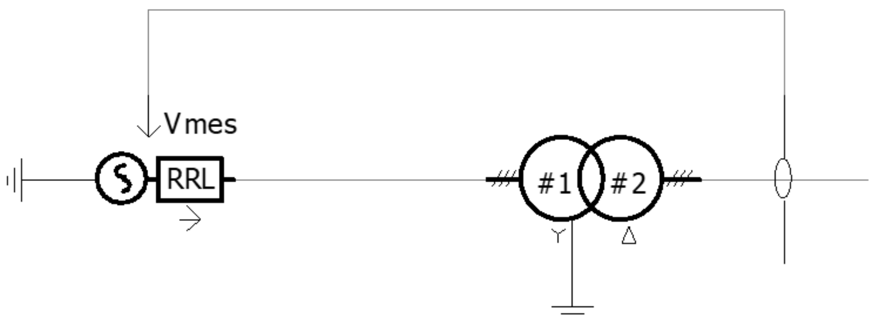

Figure 12: Automatic Voltage and Power Control

Figure 13 demonstrates the voltage control block diagram where T1 is the controller time constant and T2 is the measurement time constant as highlighted in Figure 14. VA, VB and VC are the instantaneous line to ground voltage (kV) measured at a selected bus.

Figure 15 demonstrates the power control block diagram where T1 is the controller time constant and T2 is the measurement time constant as highlighted in Figure 16. VA, VB and VC are the instantaneous line to ground voltage (kV) measured at voltage source terminal; IA, IB and IC are the instantaneous current (kA) measured leaving the terminal.

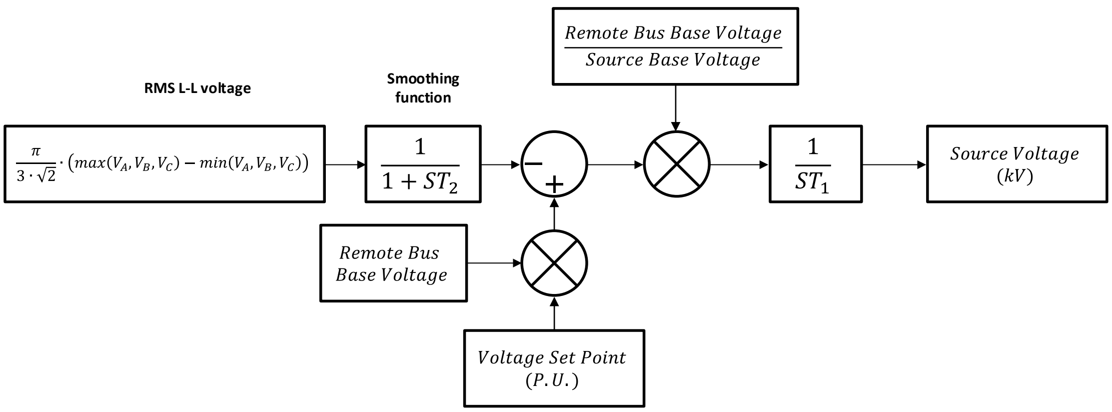

Figure 13: Automatic Voltage Control Configurations

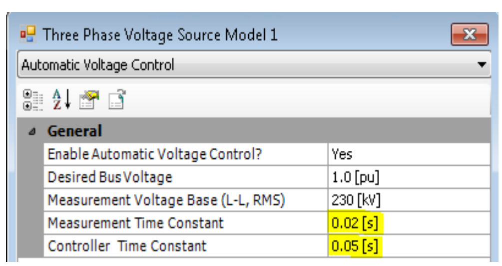

Figure 14: Voltage Control Block Diagram

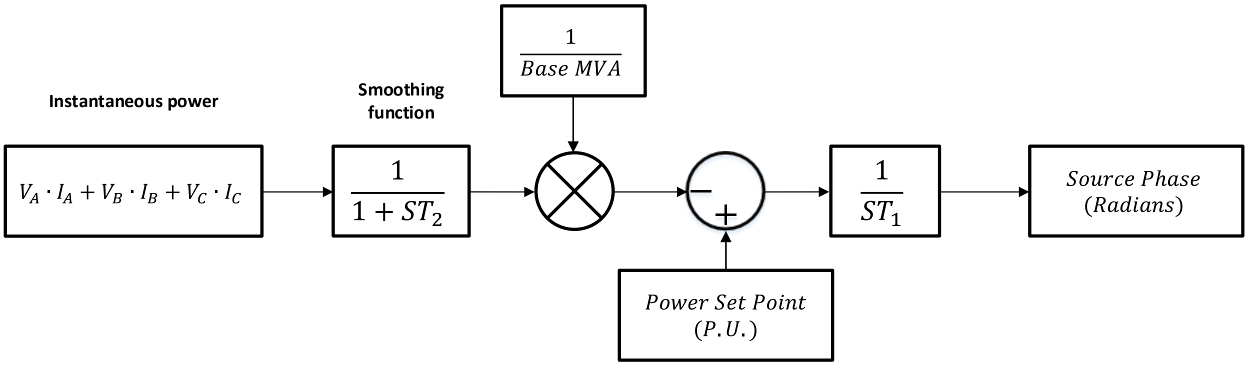

Figure 15: Automatic Power Control Configurations

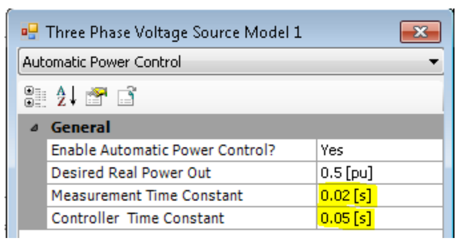

Figure 16: Power Control Block Diagram

2. PSCAD/EMTDC EXAMPLE DESCRIPTION

2.1. Example 1:

The objective of this example is to demonstrate how to specify the source impedance and voltage source parameters under fixed control mode. Circuitry 1 shows the different impedance format available in source 1 to specify the source impedance. Circuitry 2 shows that the source parameters can be entered directly or can be specified based on entered terminal conditions.

2.1.1. Circuitry 1: Impedance Format

The positive sequence source impedance can be entered as physical values (Ohm and H) or impedance value (Magnitude and Angle). Both sources have a positive sequence impedance of 10 ohms with an angle of 80°. Circuit 1a is specified by impedance magnitude and angle. Circuit 1b is specified by R and L physical values. Circuit 1c consists of an ideal voltage source and an R//L circuit. The physical values of the ideal source and the R//L circuit are configured as per (1)-(3) as shown in Figure 17. A permanent fault was applied at the source terminals at 0.5 seconds with fault impedance of 0.1 ohm, and the currents (I1a, I1b & I1c) are measured at the source terminals. As depicted in Figure 18, all circuits show identical results.

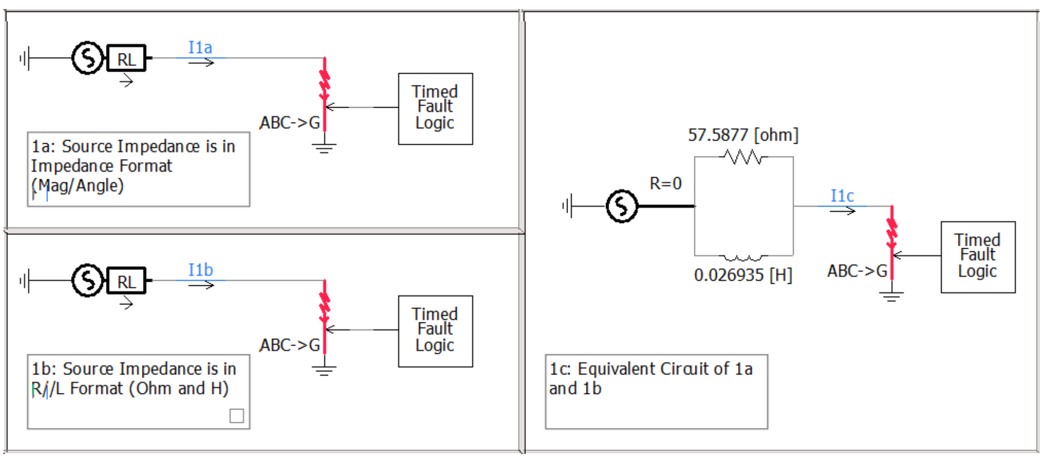

Figure 17: Example 1 Impedance Format Circuit

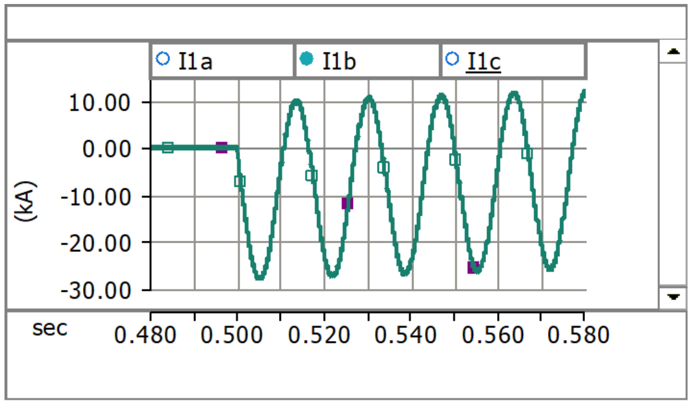

Figure 18: Fault Current of Source 1 with Different Impedance Format

2.1.2. Circuitry 2: Voltage Source in Fixed Control Mode

For fixed control mode, the source parameters can be directly entered as frequency (f), the voltage of the source behind the impedance (E) and the angle of the source behind the impedance (Circuit 2.1). The source parameters can also be specified by entering the terminal parameters (i.e. frequency (f), terminal voltage (V), terminal phase angle, active (P) and reactive (Q) power terminal output) (Circuit 2.2). The sources in circuit 2.1 have the source parameters directly entered (shown in Figure 19); the source parameters for circuit 2.2 are specified by the terminal condition of the sources (shown in Figure 20). The faults are applied at the receiving end at 1 second for the duration of 100 milliseconds with fault impedance of 0.1 ohm. The active, reactive power and the terminal voltages are measured at the source terminals. As shown in Figure 21, both circuits have the same power flow and fault transient response although the source parameters are specified in different ways.

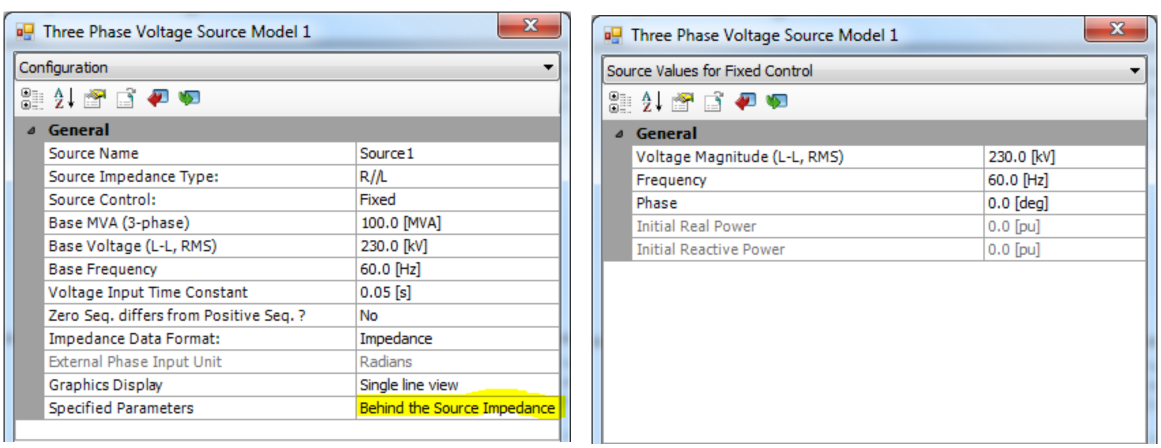

Figure 19: circuit 2.1 source parameters

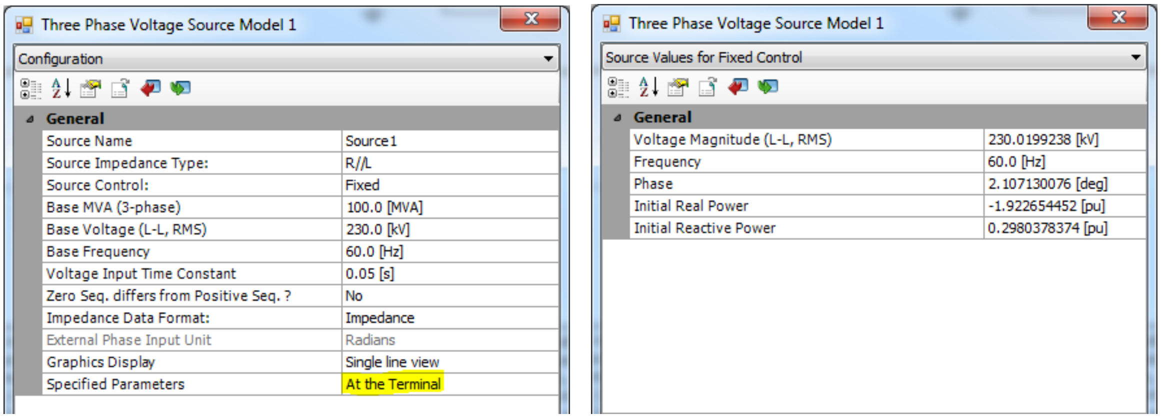

Figure 20: circuit 2.2 source parameters

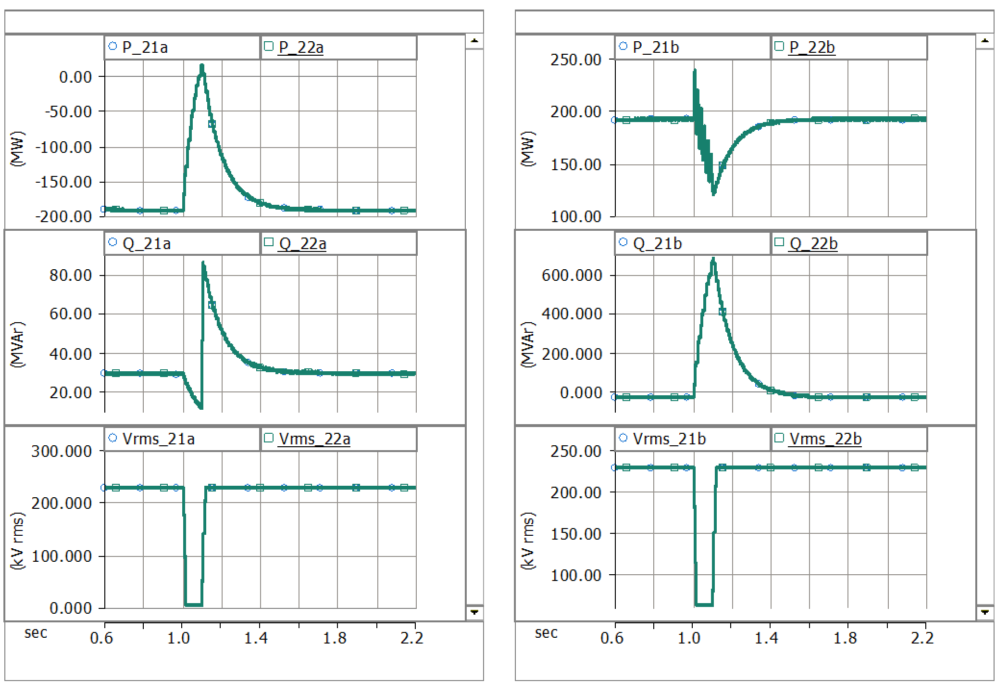

Figure 21: Receiving end and Sending end Power, Reactive Power, and Terminal Voltage Measurements of Circuit 2.1 and 2.2

2.2. Example 2:

The objective of this example is to demonstrate the functionality of the external control mode and automatic voltage and power control mode.

Source 1a in circuitry 1 is in automatic control mode as shown in Figure 23. The control parameters are shown in Figure 22. Source 1a is regulating the voltage at point of connection (POC, Bus1) based on the voltage and power set points (V_setPoint and P_setPoint).

Source 2a in circuitry 2 is in external control mode as shown in Figure 24. Circuitry 2 utilizes the control blocks available in PSCAD/EMTDC and the control block diagram discussed in section 1.2.3 to regulate the voltage at point of connection (POC, Bus2) and the terminal power output.

Source 1b and 2b are identical and fixed.

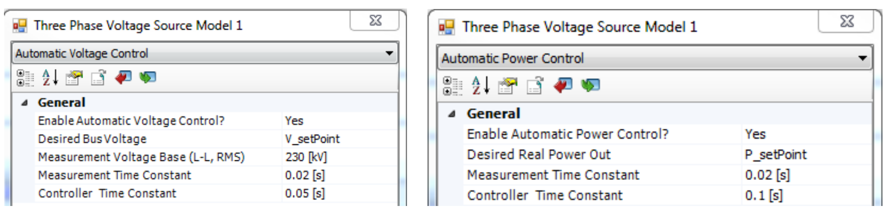

Figure 22: Automatic voltage and power control Parameters

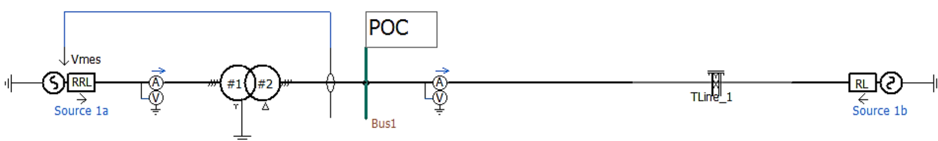

Figure 23: Example 2 Circuit 1

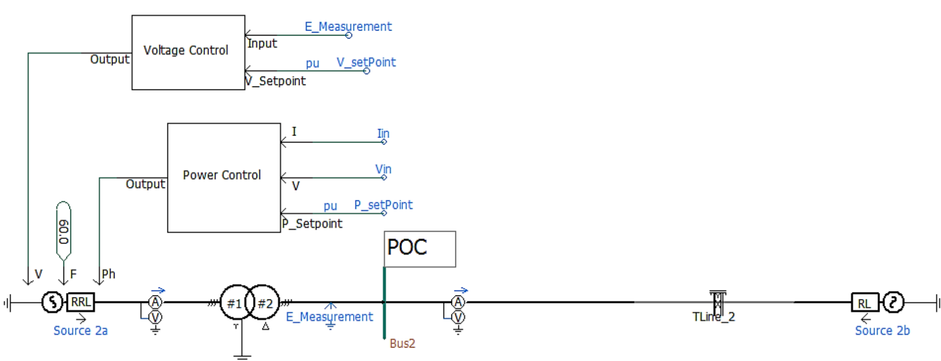

Figure 24: Example 2 Circuit 2

The following step changes were applied to compare the performance of both Source 1a and 2a,

- The voltage set point at POC (Bus1 and Bus 2) was increased by 5% at 3 seconds.
- The voltage set point at POC (Bus1 and Bus 2) was reduced by 5% at 6 seconds.
- The power set point was increased by 30% at 9 seconds.
- The power set point was reduced by 30% at 11 seconds.

The voltage at the POC and the power output of source 1a and 2a are identical despite the selected approach as illustrated in Figure 25 and Figure 26.

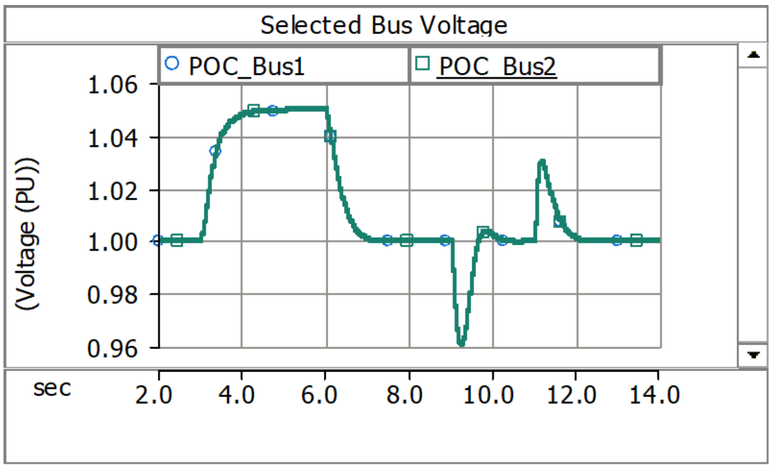

Figure 25: Voltage measurements at bus 1 in circuit 1 and bus 2 in circuit 2

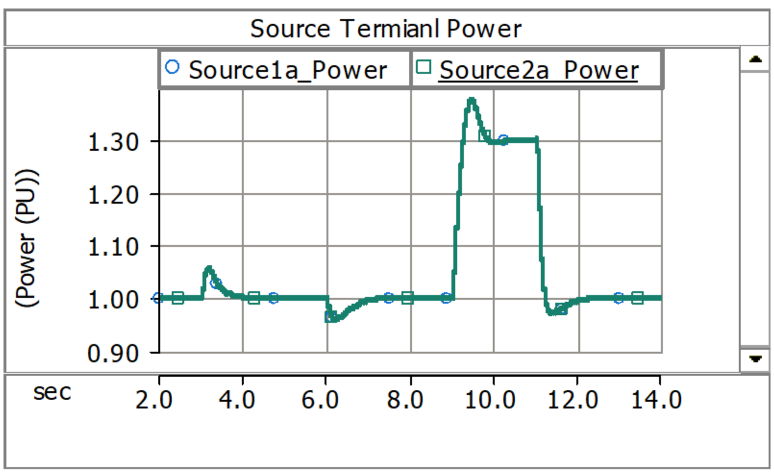

Figure 26: Power measurements at the terminals of source 1a and 2a

APPENDIX A

1. $Z\angle\theta = R_1 // L_1 = \frac{R_1 \cdot j\omega L_1}{R_1 + j\omega L_1}$

Multiply the numerator and denominator by the conjugate of the denominator:

$$Z\angle\theta = \frac{R_1 \cdot j\omega L_1}{R_1 + j\omega L_1} = \frac{1}{\frac{1}{R_1} + \frac{1}{j\omega L_1}} \tag{17}$$

The result can be further simplified as follow:

$$\frac{1}{Z\angle\theta} = \frac{1}{Z}\angle - \theta = \frac{1}{R_1} + \frac{1}{j\omega L_1} \tag{18}$$

$$1\angle\theta = \frac{Z}{R_1} + \frac{Z \cdot j}{\omega L_1} \tag{19}$$

$$\frac{Z}{R_1} = \cos(\theta) \tag{20}$$

$$\frac{Z}{\omega L_1} = \sin(\theta) \tag{21}$$

The L1 and R1 can be represented by

$$R_1 = \frac{Z}{\cos(\theta)} \tag{22}$$

$$L_1 = \frac{Z}{\sin(\theta)} \tag{23}$$

APPENDIX B

In PSCAD, the users can directly specify the voltage magnitude (E) and the angle (ϕ) of the source behind the impedance. The user can also specify the source by providing the terminal (i.e. frequency (f), terminal voltage magnitude (V), terminal phase angle (δ), terminal output active (P) and reactive (Q) power). The two methods of specify the source behind an impedance are related as shown in equation (15) and (16). The derivation of equation (15) and (16) is shown in (24) - (28).

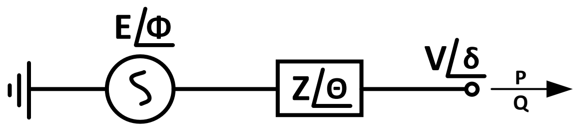

Figure 27: Equivalent Source and Impedance

$$Complex\ Power\ Output = P + jQ = V\angle\delta \cdot \left(\frac{E\angle\varphi - V\angle\delta}{Z\angle\theta}\right)^{*} \quad (24)$$

$$\frac{E\angle\varphi - V\angle\delta}{Z\angle\theta} = \frac{P - jQ}{V\angle-\delta} \quad (25)$$

$$E\angle\varphi = \frac{P - jQ}{\frac{V}{Z}\angle(-\delta-\theta)} + V\angle\delta = \frac{P - jQ + \frac{V^2}{Z}\angle-\theta}{\frac{V}{Z}\angle(-\delta-\theta)} \quad (26)$$

$$E = \left|\frac{P - jQ + \frac{V^2}{Z}\angle-\theta}{\frac{V}{Z}\angle(-\delta-\theta)}\right| = \frac{\sqrt{\left(P + \frac{V^2}{Z}\cdot\cos\theta\right)^2 + \left(Q + \frac{V^2}{Z}\cdot\sin\theta\right)^2}}{\frac{V}{Z}} \quad (27)$$

$$\varphi = \text{angle}\left(\frac{P - jQ + \frac{V^2}{Z}\angle-\theta}{\frac{V}{Z}\angle(-\delta-\theta)}\right) = \delta + \theta - \tan^{-1}\left(\frac{Q + \frac{V^2}{Z}\cdot\sin\theta}{P + \frac{V^2}{Z}\cdot\cos\theta}\right) \quad (28)$$

DOCUMENT TRACKING

Rev.	Description	Date
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