PSCAD Cookbook

AC Faults

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Contents

1. AC Fault Studies

1.1 Transmission Line Fault Study

Motivation

Faults are common occurrences in power transmission systems. They can cause immense transient currents, which are capable of damaging transformers, generators, and other equipment along the fault current path. Faults can also cause costly service interruptions and if not cleared within a specific time interval, may lead to power system instability.

Background

Consider the simplified power system network, as shown in Figure 1.
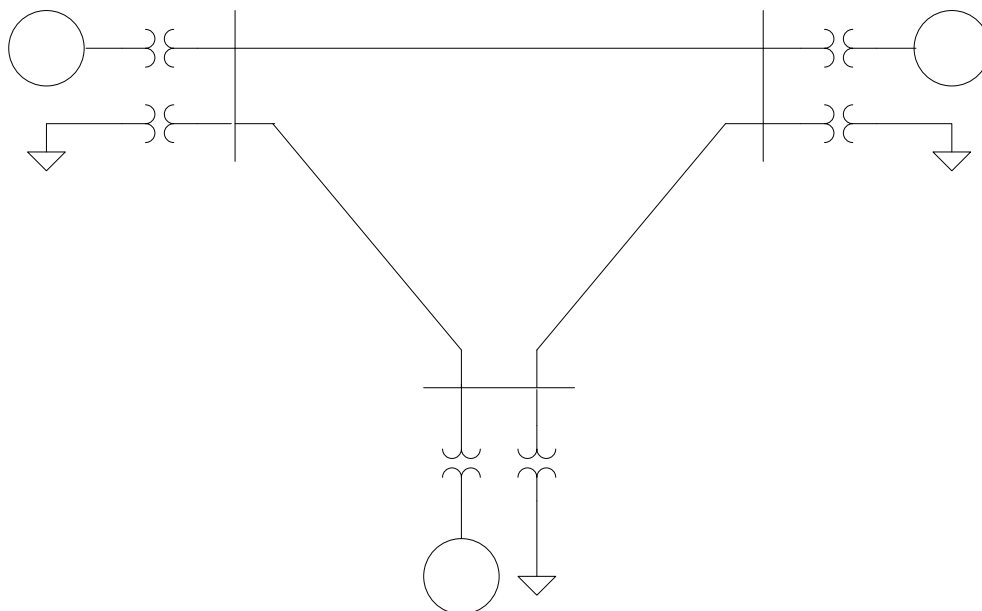

Figure 1: Simplified Power System Network

In Figure 1, generators and loads are connected to high-voltage buses through transformers. The buses are interconnected via long-distance transmission lines.

Faults generally occur when one or more transmission line conductors make contact with either each other or with ground. Some common causes are:

- Lightning strikes on towers or conductors, which cause voltage build-up and may result in a 'flash-over';
- Tree branches contacting conductors;
- Line sag, which if droops enough can lead to contact with tall objects on the ground; and
- Poles or pylons knocked down by storms, etc.

It is the role of the protection system relays to detect faults and issue the necessary signals to circuit breakers to isolate the fault. The magnitude and nature of the fault current depend on several factors, including:

- The type of fault;
- The location of the fault;
- The impedance of the fault;
- The point-on-wave of the fault inception; and
- The state of the power system immediately prior to the fault (i.e. initial or load flow conditions).

A PSCAD-based simulation may be used to study the impact of faults on the system and/or to assess the acceptable performance of the relays. The factors listed above must be included in the simulation setup.

System Overview

The PSCAD case project circuit is shown in Figure 2.
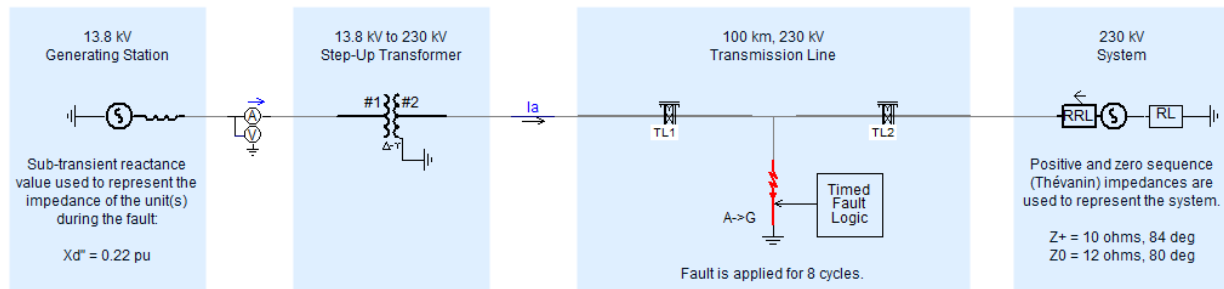

Figure 2: PSCAD Case Project Circuit

This is a simplified model of a generator connected to a larger system through a transmission line. The generator supplies active power *P* and reactive power *Q* to the network. The equations governing the *P* and *Q* absorbed by the network are given by:

$$P = \frac{|V_G||V_N|}{X}\sin(\delta_1 - \delta_2) \qquad\qquad 1\text{-}1$$

$$Q = \frac{|V_G||V_N|}{X}\cos(\delta_1 - \delta_2) - \frac{|V_N|^2}{X} \qquad\qquad 1\text{-}2$$

Where:

- V_G is the voltage seen at the HV side of the transformer;
- V_N is the Thévanin voltage of the network;
- X is the total reactance seen between the generator and network;
- δ_1 is the phase angle of the voltage at the HV side of the transformer; and
- δ_2 is the phase angle of the network's Thévanin voltage.

In this case, the synchronous generator is represented by a simple voltage source model with the subtransient reactance (i.e. X_d'') used as its internal impedance. This is typical[1] in many fault studies.

The voltage source parameters (i.e. magnitude and phase angle) are calculated from a load flow type study to ensure that the PSCAD case is initialized to the actual system operating condition.

The system parameters are listed in Table 1.

Parameter	Value
Generator Voltage (AC RMS, L-L)	14.0 kV
Network Voltage (AC RMS, L-L)	230 kV
Transformer Voltages (AC RMS, L-L)	13.8 to 230 kV (step-up)
Transformer Rating	300 MVA
Desired Active Power Flow, P	≈ 225 MW
Desired Reactive Power Flow, Q	≈ 15 MVAr
Generator Phase Angle, δ_1	-1.8°
Network Phase Angle, δ_2	0.0°

Table 1: System Parameters

Notes
1. The generator voltage is slightly above 13.8 kV (i.e. reactive power flowing from generator to network).

2. The generator phase angle is shifted back 30° due to the presence of the delta-wye transformer.

Fault Setup

In this case, we simulate a fault between phase A and ground (i.e. A-G). The fault occurs at 0.5 s into the simulation run (i.e. once the simulation has reached steady-state).

The fault is then cleared in approximately eight cycles hence.

The PSCAD fault component is used to simulate the fault. The transmission line is modeled as two segments in order to facilitate the fault at an arbitrary distance along it. This is illustrated in Figure 3: PSCAD Fault Component with 'Timed Fault Logic'.

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[1] For a more accurate representation of the fault current waveform, a complete generator model must be used.
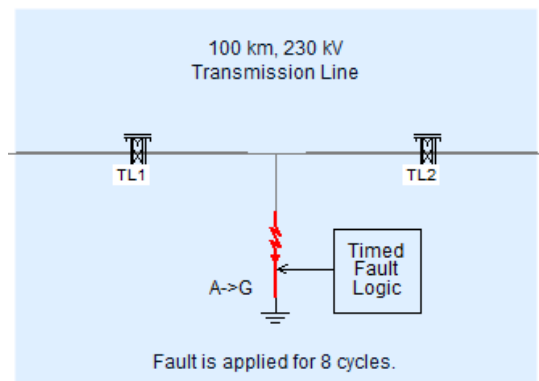
Figure 3: PSCAD Fault Component with 'Timed Fault Logic'

The fault component has two important parameters: Fault activation and type. In this case, the fault is activated by the 'Timed Fault Logic'[2] component, which generates a logical signal to control the fault component (see Figure 4).
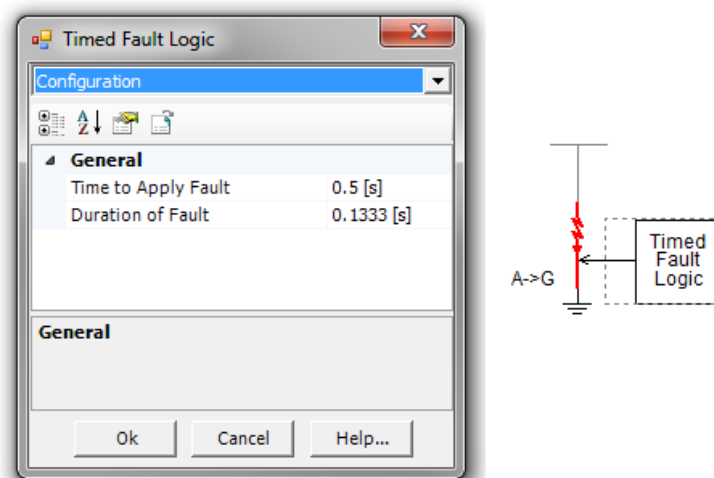

Figure 4: Timed Fault Logic Component and Parameters

The fault type signal may be controlled either internally or externally. For the internal mode, the fault type is set in the 'Fault Type' parameter field (see Figure 5).

[2] Faults can be activated by any PSCAD component that produces a logical output signal, such as the CSMF functions. An integer signal controls the fault activation (0 – no fault, 1 – fault).
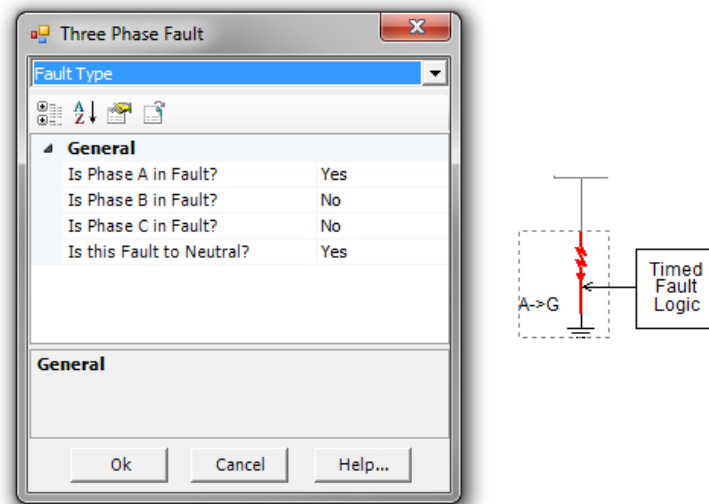
Figure 5: Internal Control of Fault Type

External control of the fault type is discussed in Section 1.3.

Simulation Results

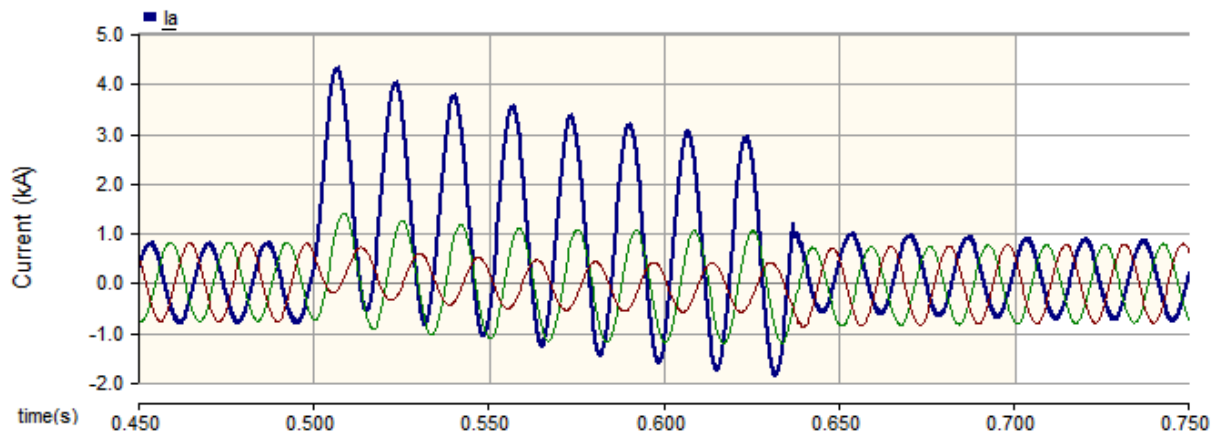The transmission line current resulting from the fault is shown in Figure 6.

Figure 6: Transmission Line Fault Current

Notice that the current in the fault phase (illustrated in blue) consists of a large sinusoidal component superimposed atop a decaying DC offset. The magnitude of this DC offset is determined by the 'point-on-wave' at which the fault occurs.

Discussion

Determining basic circuit parameters for simulating a generator and a simplified power network are discussed. The three-phase fault component in PSCAD is described, including internal control of the fault type. The results of a phase-to-ground fault are simulated and discussed. The need to initialize the simulation to a specific load flow result and the DC component in the fault current are highlighted.

PSCAD

Refer to PSCAD case: AC_Fault_study_01.pscx

1.2   Study Using Multiple-Run

Motivation

In this section, we investigate the use of the 'Multiple-Run' feature and component in PSCAD in order to determine the highest instantaneous current magnitude present during a fault.

System Overview

The PSCAD case project circuit is shown in Figure 7. This is the same circuit, along with the same parameters, that is used in Section 1.1.
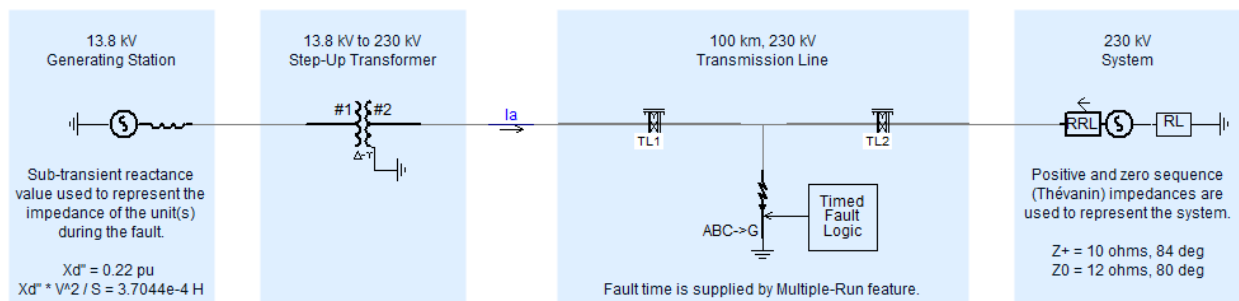

Figure 7: PSCAD Case Project Circuit

A fault between all three phases and ground (i.e. ABC-G) is explored. The multiple-run component is used to activate the fault at different points on the voltage waveform.

We wait a minimum of 0.5 s in order to ensure the simulation has reached steady-state, and then simulate the fault occurrence at 20, evenly spaced points during a single cycle of system voltage. The multiple-run component requires three parameters:

- A start of range of 0.5 s;
- An increment of 833.3 µs, corresponding to 18° of separation at 60 Hz; and
- An end of range of 0.515827 s (i.e. 0.5 s + 833.3*19 µs, to avoid repeating the 0° point-on-wave).

The output variable of interest is the maximum (i.e. peak) fault current in any phase. We use CSMF components to track the largest absolute current in all phases (see Figure 8).
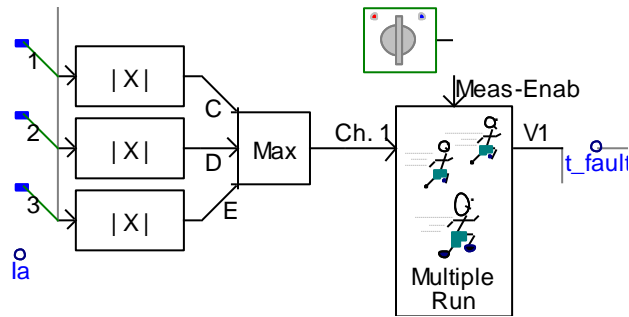
Figure 8: Multiple-Run Component

The simulation runs 20 times. The signal 't_fault' is incremented for each run, as shown in Figure 9.
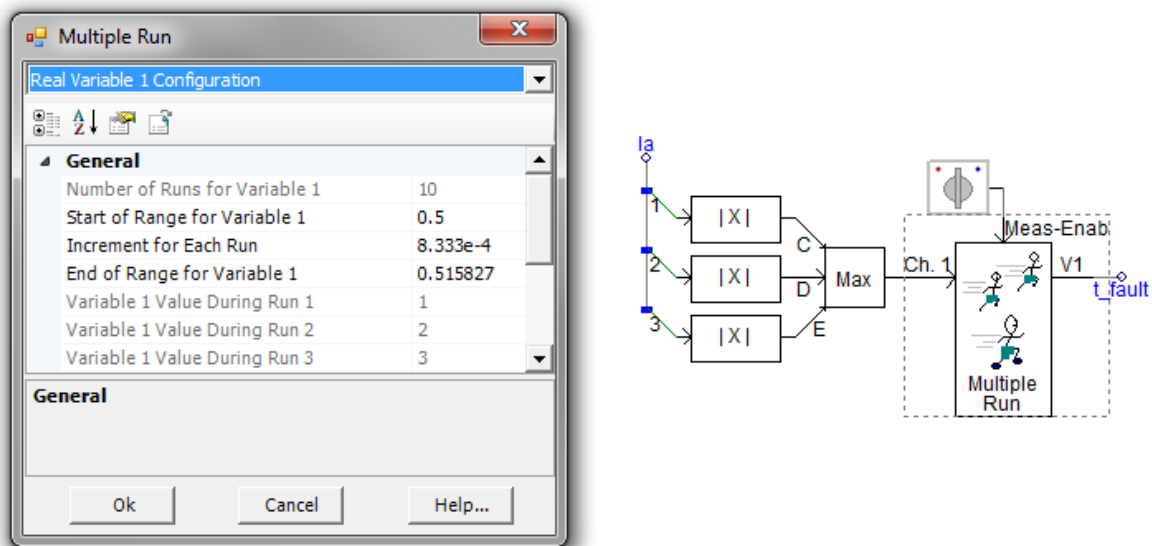

Figure 9: Multiple-Run Setup: Output (Fault Time) Configuration

To determine the highest magnitude of instantaneous current present during a fault, the multiple-run component is configured to record the maximum fault current for each run, as shown in Figure 10.
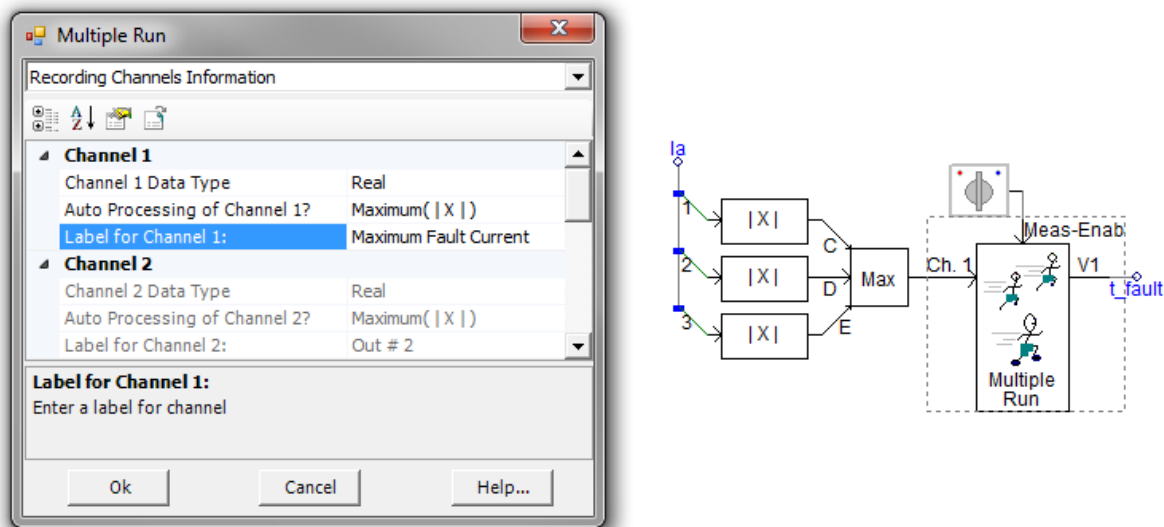
Figure 10: Multiple-Run Setup: Recording (Fault Current) Configuration

Once the multiple-run component is set up, we configure the Timed Fault Logic component to use the multiple-run output as the fault application time. The output signal of the multiple-run component controls the fault inception time, as is shown in Figure 11.
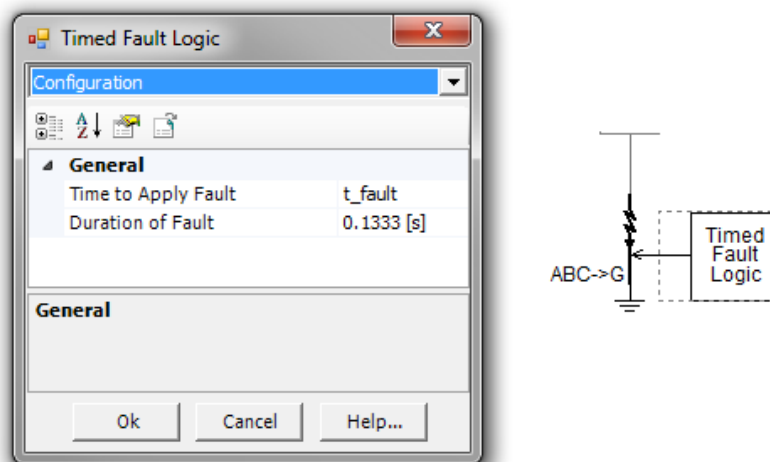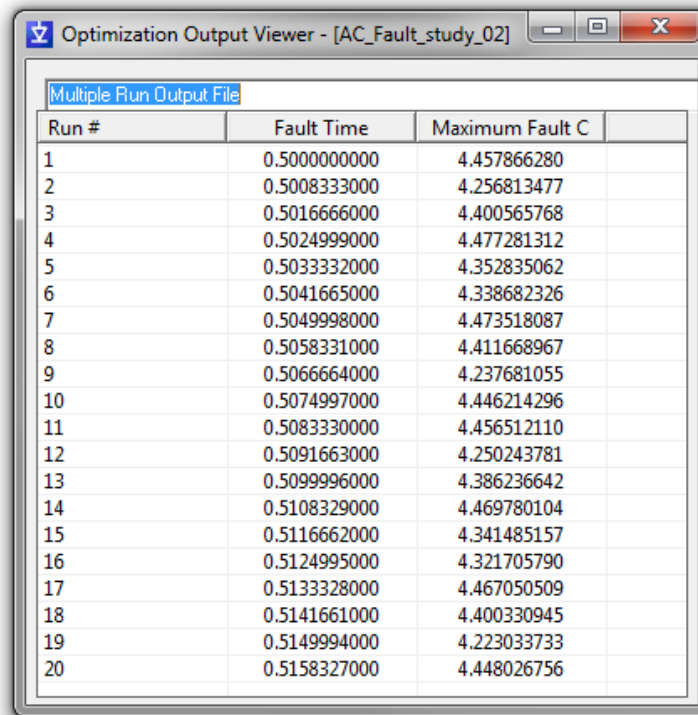

Figure 11: Timed Fault Logic Setup

Simulation Results

PSCAD runs 20 different simulations, one for each fault time. It then re-runs the simulation that yielded the absolute maximum fault current, which is defined by the user as the 'optimum' run. Data is saved in a text file, which can be referenced from within the simulation window or opened for processing by an external program (e.g. Microsoft Excel or ZSystems LiveWire) (see Figure 12).

Figure 12: Simulation Results

In addition to controlling the simulation and recording data, we can identify the 'worst case' current and determine the statistical and cumulative probability distributions of the fault currents.

Discussion

Setup of the multiple-run feature and component is discussed. As well, simulation results are interpreted.

PSCAD

Refer to PSCAD case: AC_Fault_study_02.pscx

1.3   External Fault Control Study

Motivation

In this section, we combine the external control option in the fault component with the multiple-run component to determine the largest magnitude of current present during a fault. Fault inception time (i.e. point-on-wave) and the fault type are both variables, controlled by the multiple-run component.

System Overview

The PSCAD case project circuit is similar to those used in the previous sections, and is shown in Figure 13.
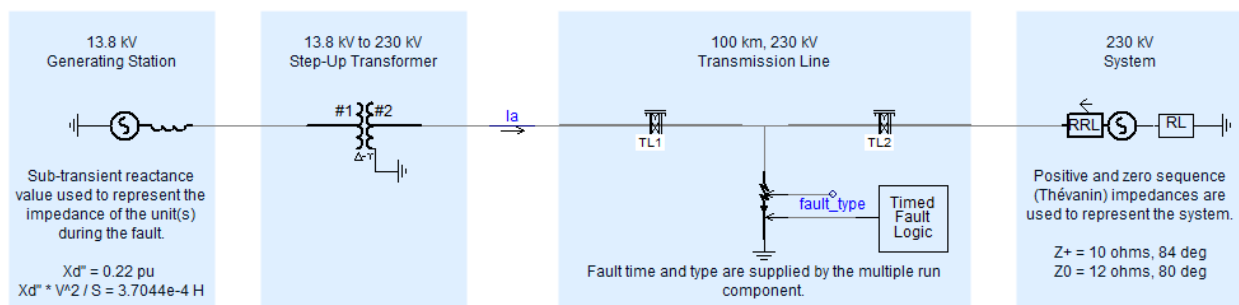

Figure 13: PSCAD Case Project Circuit

Note that the fault component has an additional input for fault type (i.e. when 'External' fault control is selected), where the `fault_type` signal is controlled by the multiple-run component.

Fault Setup

The current present during a fault is, among other things, a function of the 'point on wave' at which the fault occurs, as well as the type of fault. The multiple-run component is used to activate different fault types at different points on the voltage waveform.

Note that when 'External Control' is selected in the fault component, we can set the fault type external to the component. The fault type is set using an integer value from 0 to 11 (see Table 2).

Value	Fault Type
0	No Fault
1	Phase A to Ground
2	Phase B to Ground
3	Phase C to Ground
4	Phases AB to Ground
5	Phases AC to Ground
6	Phases BC to Ground
7	Phases ABC to Ground
8	Phases AB
9	Phases AC
10	Phases BC
11	Phases ABC

Table 2: Fault Types and their Respective Integer Codes

The external fault control feature must be enabled in the 'Configuration' parameter category page, as shown in Figure 14.
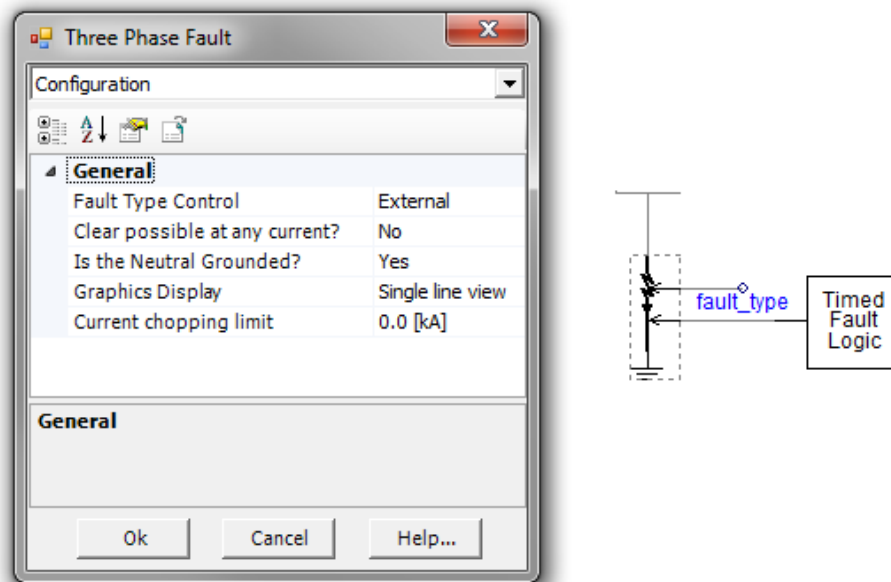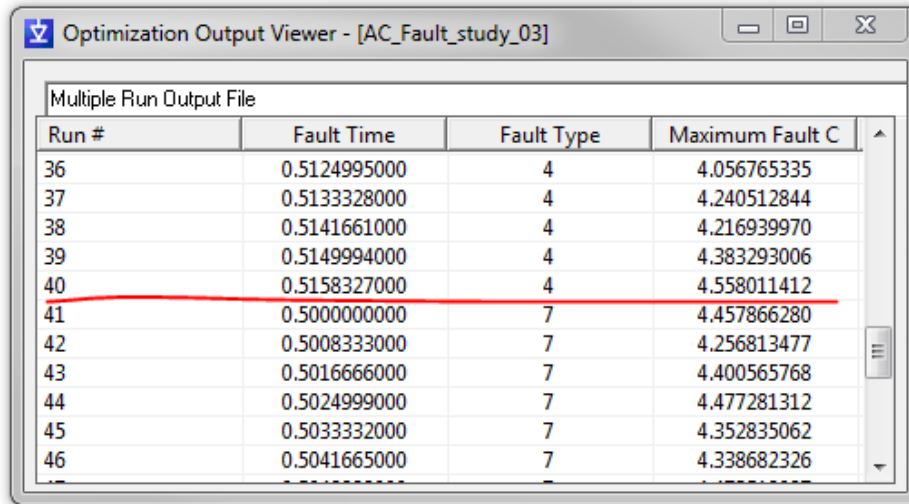

Figure 14: Enabling External Fault Control

The multiple-run component has been reconfigured to give two outputs: the fault time and the fault type. A list of integers is passed to the multiple-run component. In this case, we are simulating faults between phases A-G, AB-G, and ABC-G.

Simulation Results

We have 20 points-on-wave to simulate for each fault type, the same as in Section 2.2. We will therefore have 60 different iterations of the simulation, 20 runs for each of the three fault types.

The simulation indicates the greatest fault current occurs on the 40th run (see Figure 15).

Figure 15: Simulation Results

This window indicates the fault type was 4 (AB-G), at 0.5158327s, and resulted in a peak fault current of 4.558 kA (run the corresponding PSCAD case for a better understanding).

Discussion:

Setup of the external fault control setting is discussed. Interpreting the simulation results is also discussed.

PSCAD

Refer to PSCAD case: AC_Fault_study_03.pscx

1.4   Fault Location, Type, Point-on-Wave and Resistance Study

Motivation

This section shows how to use the multiple-run component, along with other logical components, to perform a fault study in which a number of parameters are varied.

The variables of interest in this case are the fault location, resistance, inception time, and the fault type. We record the fault current for each permutation of variables to determine the largest possible fault current (i.e. peak value).

System Overview

This PSCAD case project circuit, illustrated in Figure 16, is similar to that used in Sections 1.1 to 1.3, except that the transmission line has been partitioned into three separate 20 km sections. This enables us to place faults at 20, 40, and 60 km down the line. Using simple logic, we can choose one fault location per simulation.
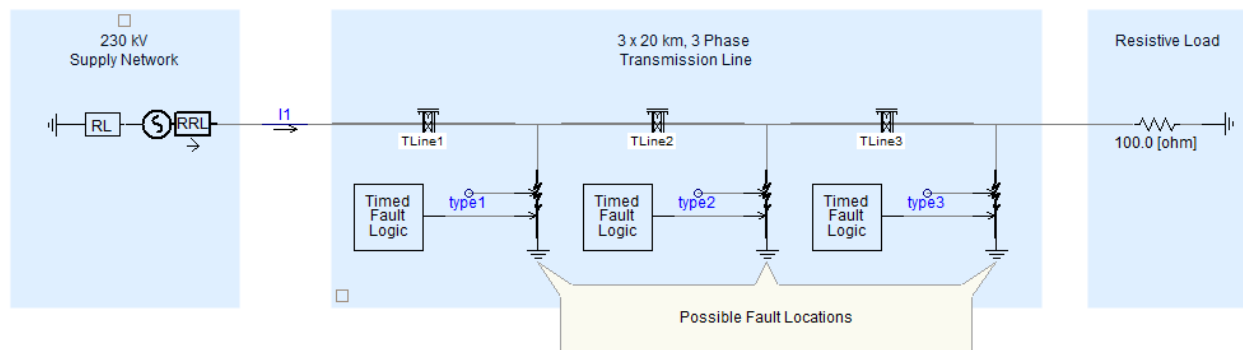

Figure 16: PSCAD Case Project Circuit

Fault Setup

The variables of interest for this example are described in Table 3.

Variable	Possible Values
Time (point on wave of fault inception)	20 runs between 0.10 and 0.12 s
Fault Type	A-G, AB-G, ABC-G
Fault Location	20, 40, 60 km
Fault Resistance	1, 10 Ω

Table 3: Simulation Results

The multiple-run component is used to simulate every possible combination of variables.

To ensure that only one fault is active at any given time, we use the Channel Decoder component from the master library (CSMF page).
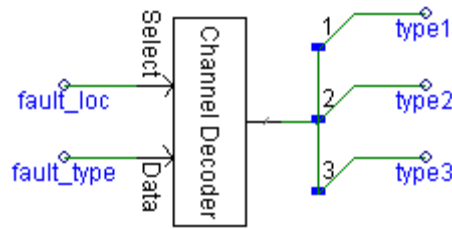
Figure 17: Location Logic Using the Channel Decoder

The multiple-run component outputs 1, 2, or 3 for the 'fault_loc' signal, and 1, 4, or 7 for the 'fault_type' signal. See the following references for more information:

- Section 1.2
- The PSCAD On-Line Help System (right-click on the multiple-run component and select 'Help')

The decoder outputs an array signal of dimension 16. The first, second and third elements of the array are extracted using Array Tap components.

The 'fault_type' signal (Data input) is output to the channel selected by the 'fault_loc' signal (Select input). Zero is output on all other channels (no fault). For example, if 'fault_loc' is 2 and 'fault_type' is 7, 'type1' and 'type3' will be 0, and 'type2' will be 7.

> **Note**
> See the accompanying PSCAD case (*AC_Fault_study_04.pscx*) to better understand the settings.

Simulation Results

In total, 360 simulations are run. The parameters of the largest fault current are listed in Table 4.

Variable	Value
Current	3.64 kA
Time	0.117 s
Type	ABC-G
Location	20 km
Resistance	1 Ω

Table 4: Largest Fault Current Parameters (as Recorded by 'Multiple Run')

Discussion

Calculating the fault type, resistance, location, and point-on-wave that produces maximum fault current is discussed. Using the Channel Decoder module to choose the fault location was also discussed.

The fault waveforms can be recorded in COMTRADE format for 'real time' relay testing purposes. See Section 1.5 for details.

PSCAD

Refer to PSCAD case: AC_Fault_study_04.pscx

1.5 Recording Transient Waveforms in COMTRADE Format for 'Real Time' Playback Study

Motivation

This section demonstrates the use of the COMTRADE recorder. The case is identical to that described in Section 1.4. The voltage and current waveforms as well as some digital signals are recorded in COMTRADE format.

System Overview

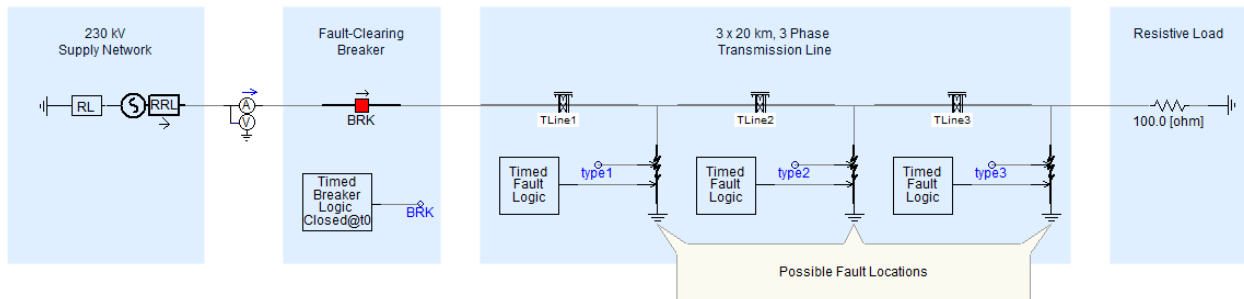The PSCAD case project circuit is similar to the one used in Section 1.4 (see Figure 18).

Figure 18: Case Circuit

The transmission line is driven by a 230 kV, 100 MVA voltage source representing a generator. The difference between this circuit and the circuit in Section 1.4 is the addition of a breaker between the generator and the transmission line. The breaker begins to open approximately 10 cycles after a fault condition occurs, extinguishing the fault current.

COMTRADE

PSCAD simulations are widely used in relay testing applications because they can generate waveforms that closely represent real-world scenarios.

The waveforms are recorded in the COMTRADE format. These waveforms can then be 'played back' in 'real time' synchronism into the relay using test sets and amplifiers.

Analog as well as digital signals (e.g. breaker contact status, etc.) can be recorded.

Setup

The variables of interest are the same as in the case in Section 1.4. The COMTRADE module is configured to record the currents and voltages of each phase (A1 to A6, which are the analog inputs). It is also configured to record the breaker signal and the state of each breaker phase (D1 to D4, which are the digital inputs).
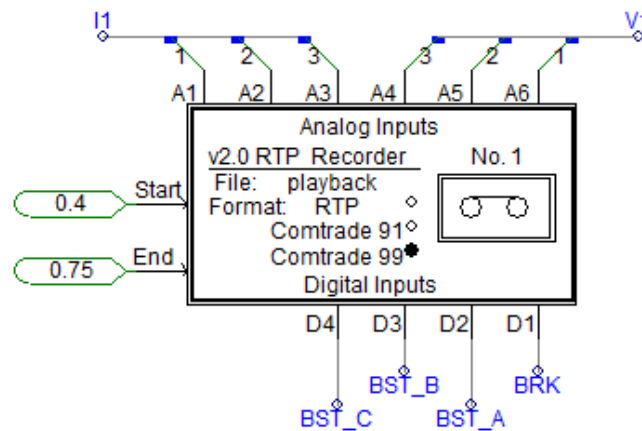
Figure 19: COMTRADE Module

Note

It is important to record enough pre-fault cycles to ensure that the relay is in a properly conditioned initial state when the fault occurs.

The digital signals recorded in this case are the breaker contact status and the breaker trip signal.

Discussion

Using the COMTRADE module to record fault waveforms for playback is discussed.

PSCAD

Refer to PSCAD case: AC_Fault_study_05.pscx

DOCUMENT TRACKING

Rev.	Description	Date
0	Initial	01/Jun/2013
1	Update to new brand guidelines	08/Aug/2018
2	Minor corrections	15/Aug/2018