Setting the TESLA Digital Fault Recorder Application Example

Introduction

Figure 1 shows a simplified single line diagram of a 345:138kV substation. Based on this power system data, we have generated a simple but effective sample set of trigger settings. In order to simplify the settings procedure, part 1 covers setting of triggers only for the analog signals, while part two covers triggers for the digital signals. It is assumed that users are familiar with how to create elements, analog and digital channels (as outlined in the “Configuring the Recorder” section of the TESLA manual). This application example concentrates on trigger levels, specifically for the 138kV portion (identical steps can be followed to create settings for the 345kV side).

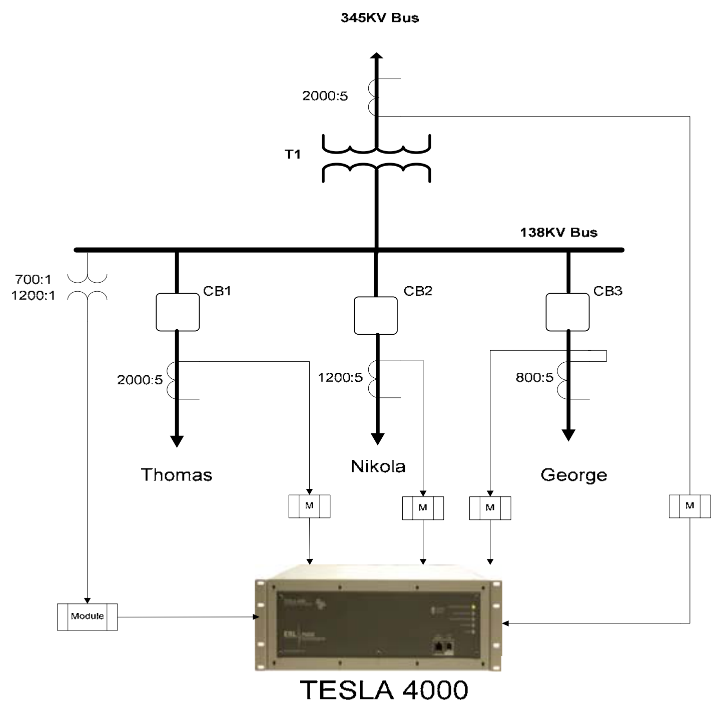

Figure 1. 345-138kV Substation

Part 1. Setting of Analog Channels

Power System Data

Table 1 shows the power system data used for this example. Substitute your own system parameters, using this application note as a guide.

Parameter	Value
Thomas CB1 CTR	2000:5
Nikola CB2 CTR	1200:5
George CB3 CTR	800:5
Transformer T1 CTR	2000:5
Potential Transformer PTR	700:1 L-N = 80.5kV:115V 1200:1 L-N = 80.4kV:67V

Table 1. System Data for 345:138kV Substation

As seen in Figure 1, the PT has a 1200:1 and a 700:1 ratio which will result in 67V and 115V secondary respectively. In order to measure the secondary voltages from the PTs, a voltage module must be used. The voltage modules are rated at 69Vrms for a line to neutral with a maximum continuous voltage of 138Vrms. According to the voltage module ratings and the available secondary PT voltage options, the module will be able to handle both sets of voltages. However, it is recommended that the user chooses the 1200:1 ratio since at voltages greater than 138Vrms, the module will clip the voltage and actual voltage values might be interpreted incorrectly. For this application, we will use the recommended PT ratio of 1200:1 with a secondary value of 67V.

Setting Voltages and Current Triggers

Create the analog settings for voltages and currents, as shown in Figure 2, and referring to each field's explanation notes below. Observe that the neutral voltage and current channels have not been configured. We will create the neutral channels by using summation elements (see "Setting Triggers for Current and Voltage Summation Channels" section in this document).

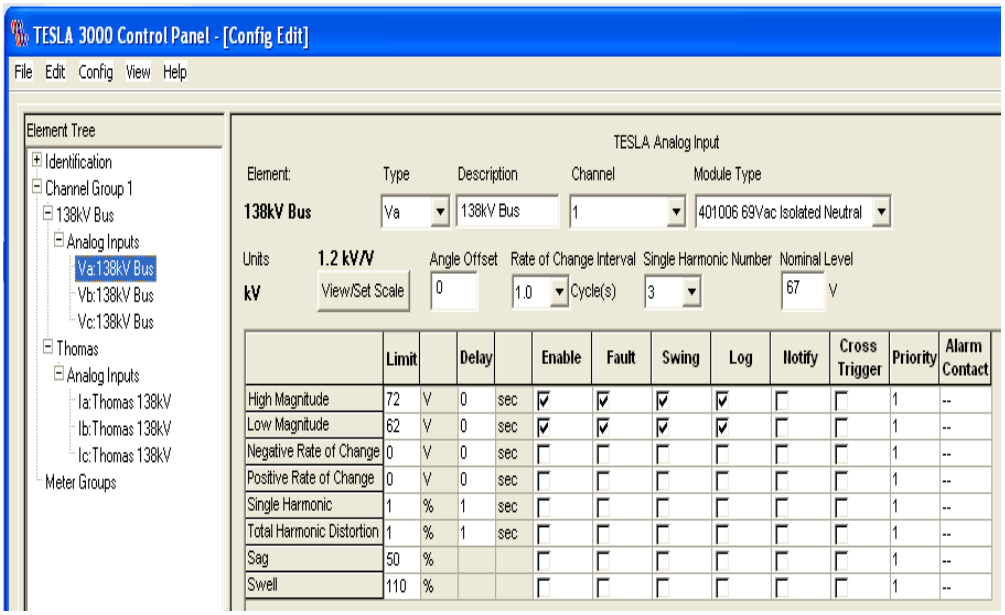

Figure 2. Analog Inputs Screen for Va

Setting Voltage Triggers: This section will show the user how to configure typical settings for analog voltage Va. Similar steps can be followed for Vb and Vc phases. Therefore, the settings for Vb and Vc will not be covered in this application example.

Type: Va Choosing the correct phase type is important for proper identification of the channel in the recording, as well as phase-dependent functions like sequence channels and fault location (fault location is not demonstrated in the example).

Description: It is important to label the channels with relevant and descriptive information that will allow the event analyst to easily interpret the location and type of signal being monitored in the recording. In this case we have chosen to describe the Va voltage for the 138kV bus as “138kV Bus.”

Channel: Choose the channel which matches the analog input that the signal is wired to. In this example we chose Va as Channel 1 in the configuration since Va of the PT is wired to the TESLA analog input 1. As in our example, it is best if the recorder panel is designed to have channels configured in a logical sequential order, (such as Va to analog input 1, Vb to analog input 2, etc.). This is beneficial for keeping the configuration organized and it streamlines the configuration creation process. Continue this process until you have configured all connected signals, up to 36 analog channels.

Module Type: For this application, we are using a voltage module that provides isolation and an interface between the PT and the recorder. There are different versions and types of modules so it is important that the correct module type is selected. If the incorrect module is chosen, then incorrect reading can be expected. For this application we are using module number 401006, 69Vac Isolated Neutral, as shown in Figure 3.

Note: The voltage input on the voltage module has a full scale continuous rating of 138kV rms.

Figure 3. AC Voltage Module

View and Set Scale: Enter the information from the potential transformer nameplate, as shown in Figure 4. For this example, the PT ratio for the phase to neutral voltage being used is 1200:1 which is equal to 80.4kV:67V. Therefore, enter “80.4” with units in kV and “67” for the nominal secondary voltage value. In this example, a PT ratio of 1200 results in a secondary voltage of 67V which is the recommended secondary voltage mentioned earlier.

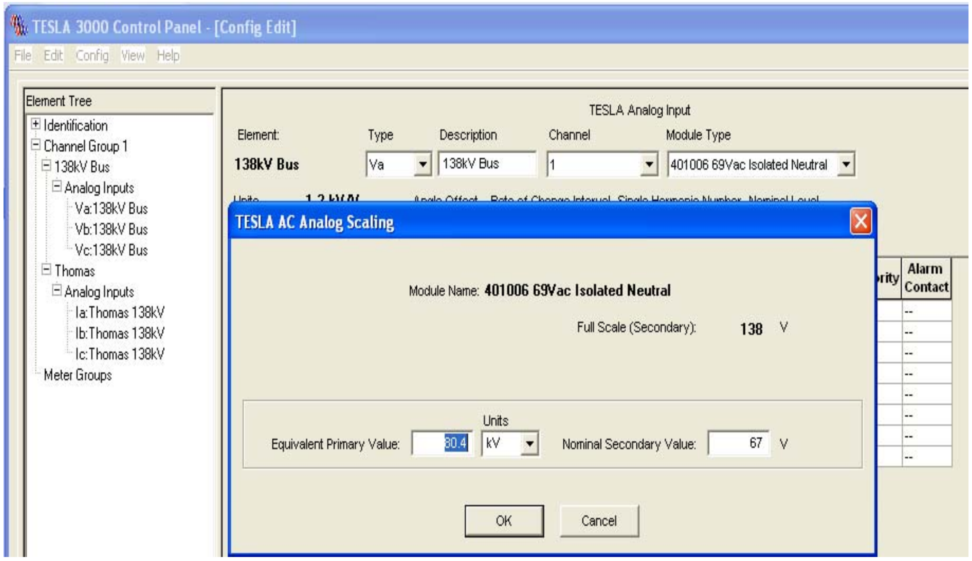

Figure 4. View/Set Scale Settings

Angle Offset: Not used for this application. Since we want the real response of the analog signal, an angle offset is not desired.

Rate of Change Interval ROC: Not used for this application since the ROC triggers will not be used.

Single Harmonic Number: Not used for this application. The user can use this setting to trigger records on any harmonic from the 1st up to the 100th (if the maximum recording sample rate of 384 samples per cycle has been chosen). By default, the recorder sample rate setting is 96 samples per cycle which allows up to 25th harmonic trigger. By default, the 3rd harmonic is selected, but the user still needs to choose a trigger level in order to create records.

Nominal Level: Set to 67V. This setting, which is available only on voltage channels, provides a nominal level for the sag and swell detectors. Even if sag and swell detectors are not used, it is best to enter the system nominal Line to Neutral voltage in this cell in order to provide the user with quick visual reference of the actual system voltage. For example, another person viewing the configuration can quickly compare your High and Low magnitude settings to your entered system “Nominal Level” to easily determine the percent deviation (or per unit) settings that you chose.

High Magnitude Trigger: For this application, we chose a trigger value of 72 V secondary, which is about 7% above the nominal value of 67. The trigger value should be higher than 5% since the system is able to operate at + and – 5%. For swing conditions, 7% is typically an adequate value. However, if normal operating levels are too close to your setting, then nuisance triggers may occur. Therefore, it is good commissioning practice to check the trigger settings against the actual operating level to ensure there is sufficient margin.

For other conditions, such as a deteriorated CCVT, the voltage values can be as high as 10% above and below the nominal. Such values will call for immediate attention since catastrophic failure of the CCVT may be possible. Consult the CCVT manufacturer for more information.

Low Magnitude Trigger: A 7% undervoltage trigger of 62 V has been selected. This trigger level should be adequate to detect voltage depressions caused by system faults and power swing conditions. Recordings created from undervoltages can be useful for evaluating system-wide affects caused by the disturbance, can trigger the TESLA's fault location function to give distance to fault, and may also pinpoint certain protection coordination problems, such as a false operation of a weak infeed relay scheme.

For the high and low magnitude triggers, the Enable, Fault, Swing and Log boxes will need to be checked. This will assure that the trigger will be enabled to create fault and swing records. It will also assure that the trigger will be logged in the sequence of events.

<u>Note 1:</u> Notify, cross triggering, priority and alarm settings are not demonstrated in this application.

<u>Note 2:</u> The negative and positive rate of change, single harmonic, total harmonic distortion, sag and swell settings are not demonstrated in this application.

Please follow similar steps to set the Vb and Vc analog values.

Setting Current Triggers: This section will show the user how to set the current analog channel for Ia (similar steps can be followed for Ib and Ic phases). Create the current channels as shown in Figure 5.

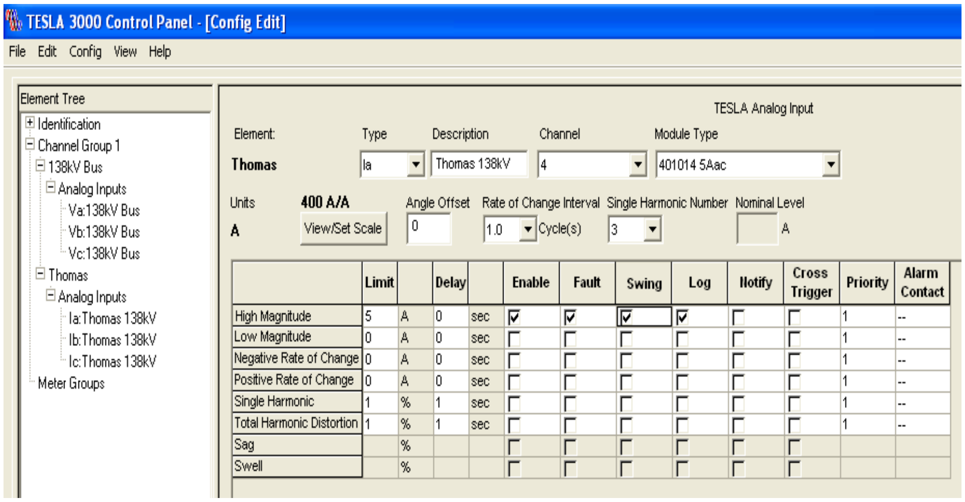

Figure 5. Analog Input Screen for Ia

<u>Type:</u> Ia Choosing the correct phase type is important for proper identification of the channel within the recording, as well as phase dependent functions like sequence channels and fault location.

<u>Description:</u> It is important to label the channels with relevant and descriptive information that will allow the event analyst to easily interpret the location and type of signal being monitored in the recording. In this case we have chosen to describe the Ia current for the Thomas line as "Thomas 138kV."

<u>Channel:</u> In this example, the current Ia has been connected to TESLA analog input 4, so we chose Channel 4 in our configuration. As in our example, it is best if the recorder panel is designed to have Ia, Ib, Ic of a particular element, (line, transformer, capacitor bank, etc.), connected sequentially to the recorder. Therefore, our Ib will be on Channel 5 and Ic on Channel 6. Continue this process until you have configured all connected signals, up to 36 analog channels.

<u>Module Type:</u> For this application, we are using the current module that provides isolation and an interface between the CTs and the recorder. There are different versions and types of modules so it is important that the

correct module type is selected. If the incorrect module is chosen, incorrect readings can be expected. For retrofit applications, it is recommended that the split core CTs be used, since their installation does not require an equipment outage. For this application we are using model 401014, 5A ac current module, as shown in Figure 6.

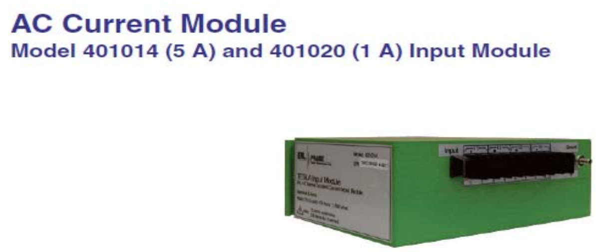

Figure 6. Current Module

<u>View and Set Scale</u>: Enter the information from the current transformer nameplate, as shown in Figure 7. For this example, the CT is a 2000:5 ratio (according to the single line diagram).

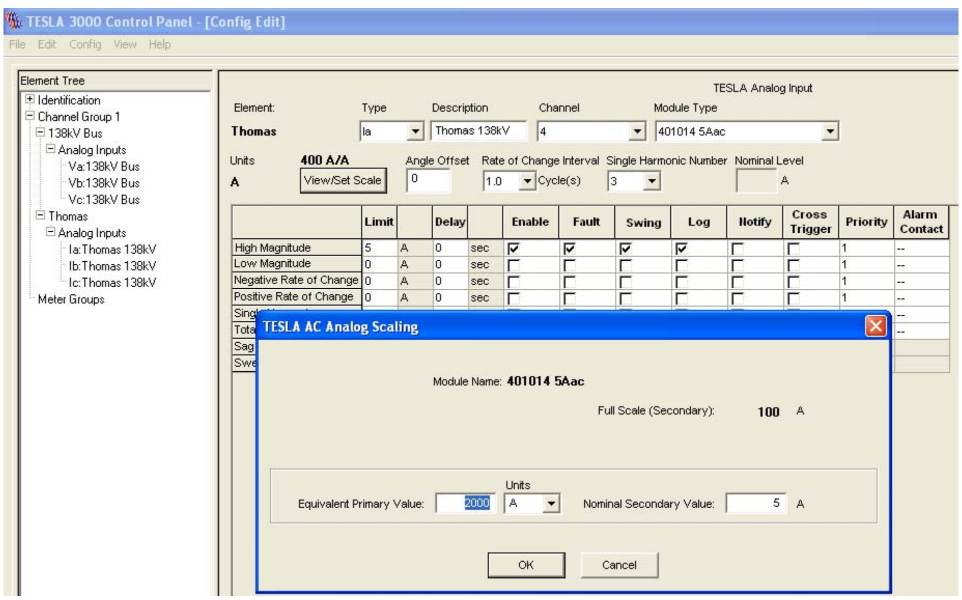

Figure 7. View/Set Scale Settings

<u>Angle Offset:</u> Not used for this application. Since we want the real response of the analog signal, an angle offset is not desired.

<u>Rate of Change Interval ROC:</u> Not used for this application, since the ROC triggers will not be used.

<u>Single Harmonic Number:</u> Not used for this application. The user can use to trigger records on excess of any harmonic from 1-100 (depending on the recording sample rate setting). By default, the 3rd harmonic is selected, but user still need to choose its trigger level in order to create records.

<u>High Magnitude Trigger:</u> The phase current trigger may be used to record extreme overloads and faults, but set it carefully to not trigger on predictable load excursions which may cause excessive record triggering. For this

example, we have chosen a trigger value of 5A. This is a good value in our example application where we have a line with a rating of 240MVA and the full load secondary current will be about 2.5A. If the recorder triggers at 5A, then the line will be running at close to 200% of its capability which would be an indication of a fault or overload. Most lines will not operate above 100% of their MVA capability unless during contingency conditions that might cause the lines to be overloaded.

<u>Low Magnitude Trigger:</u> Not used in this application example since low level triggers will not be used.

For the high and low magnitude triggers, the Enable, Fault, Swing and Log boxes will need to be checked. This will ensure that the trigger will be enabled to create fault and swing records and ensure that the trigger will be logged in the sequence of events.

<u>Note 1:</u> Notify, cross triggering, priority and alarm settings are not being used for this application example.

<u>Note 2:</u> The negative and positive rate of change, single harmonic, total harmonic distortion, sag and swell settings are not being used for this application example.

Please follow similar steps to set the Ib and Ic analog values.

Setting Triggers for Current and Voltage Summation Channels In and Vn

Please refer to application note “TESLA Capturing Residual Current,” to see how to create summation channels for neutral currents. The TESLA fault recorder gives the user the ability to create virtual channels that calculate the residual voltage or current from the 3 phase inputs. This is accomplished using Summation channels, and is a practical and economical benefit since a separate neutral input to measure residual is not required.

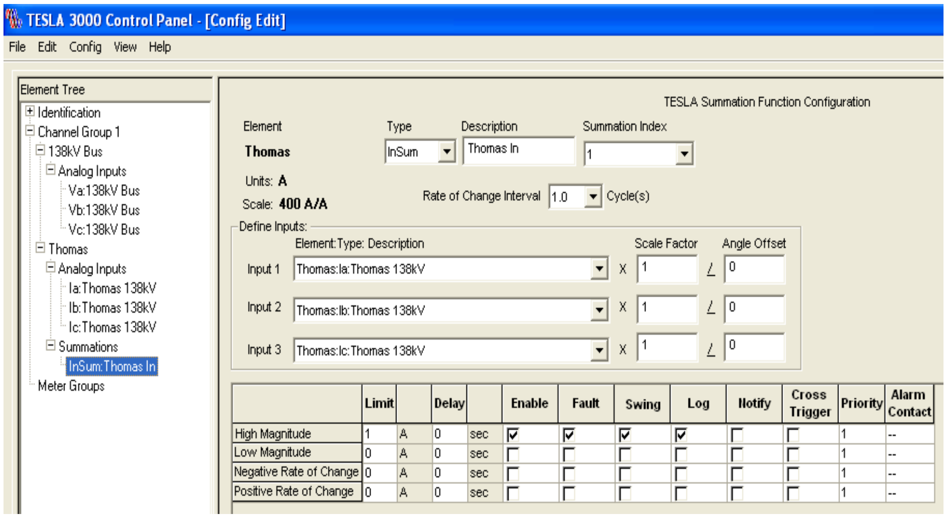

Figure 8. Neutral Current Summation

According to Figure 8, we are calculating the neutral (or 3IO residual) current by In = Ia + Ib + Ic. The In has been created by selecting the current inputs 1 through 3 from the Thomas line.

<u>High Magnitude Trigger:</u> A 1A neutral current value trigger has been chosen for this application. This value is adequate to detect most unbalanced faults that produce zero sequence currents. In a solidly grounded system,

all unbalanced faults that include ground will have some zero sequence current and this will be reliably detected by the neutral current trigger, which is typically set to be much more sensitive than a phase trigger.

The low magnitude trigger and rate of change triggers are not being used for this application example. Follow similar steps to configure the neutral voltage Vn by creating a New AC Voltage Summation.

Setting Sequence Function Triggers

The TESLA recorder offers the ability to create voltage (Vseq) and current (Iseq) sequence functions. The Vseq and Iseq functions can be used to trigger the recorder in case of unbalanced system conditions. For example, triggering on negative sequence quantities to detect generator or motor winding over-heating can be essential. For this application, we will use the Iseq function to detect unbalanced conditions in the Thomas line. The Vseq and Iseq functions will also be used in a later step to create 3 phase Watt and Var functions.

Create the Vseq and Iseq function as shown in Figures 9 and 10. The Vseq and Iseq functions are created by using the Bus voltages and Thomas currents. For this application, we will not trigger on the voltage sequence function and therefore the settings are unchecked. However, we will use the overall Vseq function to create a 3 phase watts and vars function. Notice that the Vseq function has been created under the 138kV Bus element.

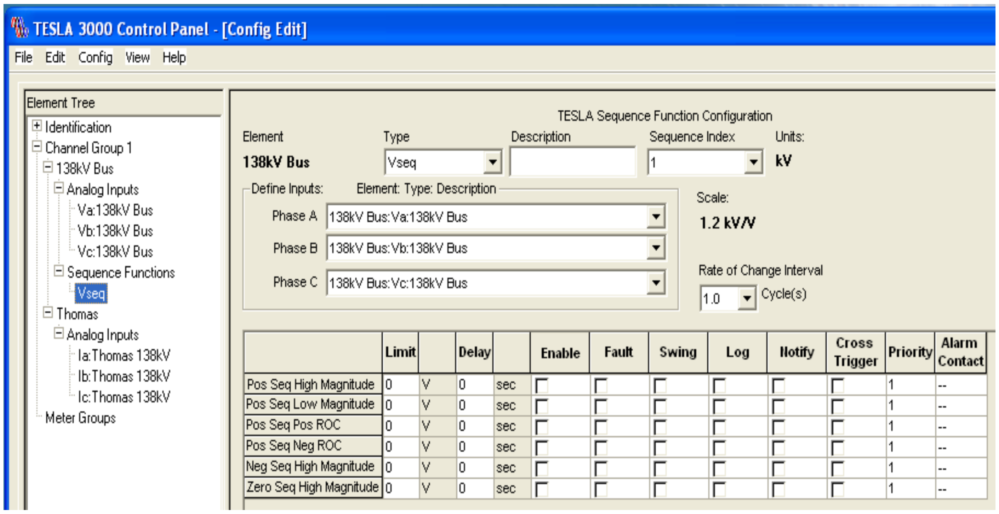

Figure 9. Voltage Sequence Function

We will use the negative sequence current trigger as shown in Figure 10 to detect unbalanced faults, such as Line to Line faults that are not detected by the In trigger. Set the Negative Sequence High Magnitude trigger to 1A, which is an adequate setting value in most applications. Check the Enable, Fault, Swing and Log boxes to enable the function and to create a fault and swing record and log an event in the sequence of events. We use the swing trigger not for just power swings; we also use it to capture pre and post trigger system abnormalities over a much longer duration than a fault record. Notice that the Iseq function is created under the Thomas line element since the sequence quantities are derived from the line currents.

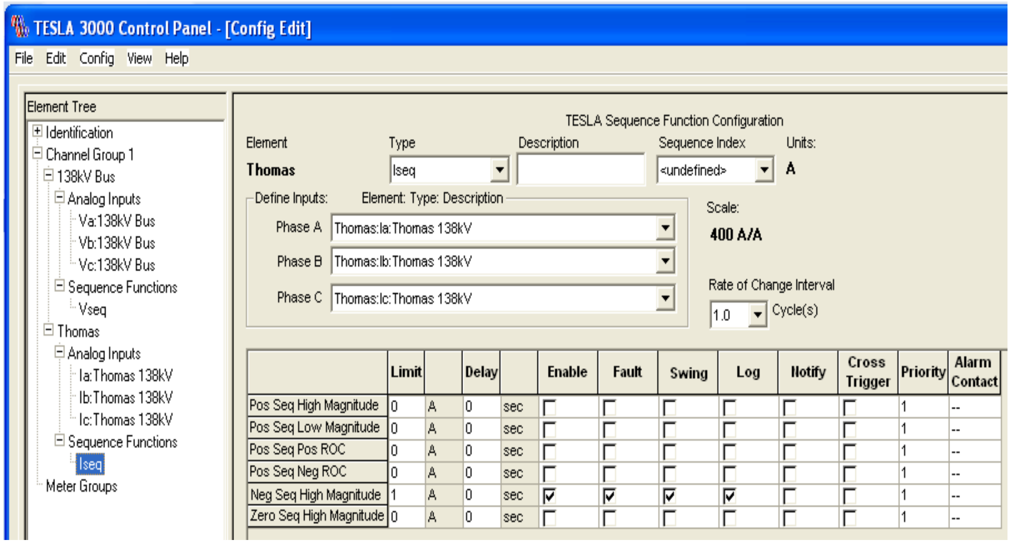

Figure 10. Current Sequence Function

Creating Watts and Var Functions

In this example, the Watt/Vars function will be strictly used for metering purposes; therefore trigger settings will be ignored. The Watt/Vars element will generally use one Vseq and one Iseq channel input to perform its 3 phase power calculations. As shown in Figure 11, we have created a new Watt/Vars function for Thomas 138kV line using the Bus Vseq and Thomas Iseq quantities as inputs. The trigger settings will not be enabled since in this example, the W/V values will be used only for metering. Later in this document we will describe how to create metering screens.

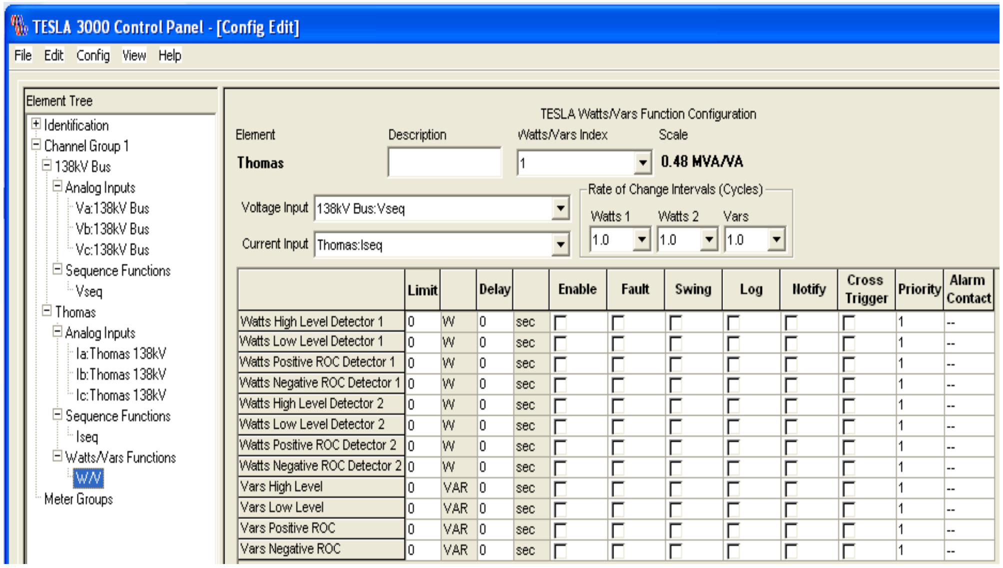

Figure 11. Watt and Var Function

Setting Frequency Triggers

Regional reliability organizations such as ERCOT and WECC have requirements for under-frequency load shedding schemes. For example, ERCOT requires that at 59.3Hz or 5% of the ERCOT total load be relieved by these relays. An under-frequency trigger element in the TESLA can be set to the same frequency level or higher to detect possible causes and duration of frequency excursions. Under-frequency problems can arise due to the shortage of generation and can cause the system to lose synchronism.

In this example, as shown in Figure 12, high and low frequency levels are set to 60.7 and 59.3Hz, respectively, which is ±0.7Hz from of the base 60Hz system frequency. Notice that a delay of 0.0333s (i.e. 2 cycles) is added to avoid nuisance's triggers. The frequency is derived from the Bus 138kV Va voltage. The Enable, Fault, Swing and Log boxes should also be checked. The rate of change triggers, cross trigger, priority, and alarm settings are not used for this example.

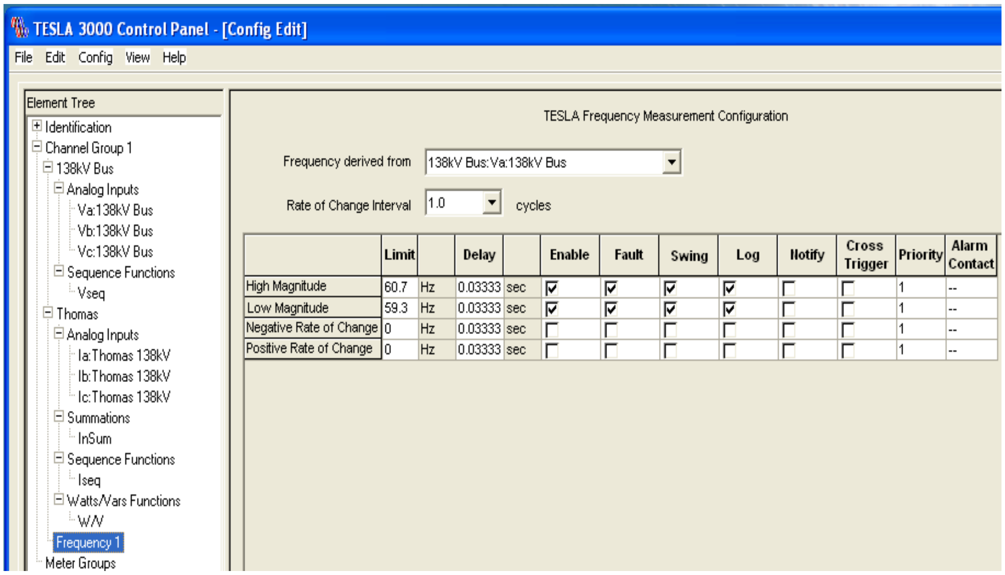

Figure 12. Frequency Settings

Setting a Meter Group

A group of settings should always have a meter group (see Figure 13). In order to create a meter group, follow the steps in the Meter Groups section of the TESLA manual. The meter group should have the voltage and current magnitudes and their respective angles, as well as any the digital signals. The user can also show the watts and vars, along with a frequency channel. Once the settings have been loaded to the recorder, the meter group is helpful to verify the signals and detect abnormalities in the analog and digital values. This can be done locally at the recorder or from a remote location that has a network connection to the TESLA.

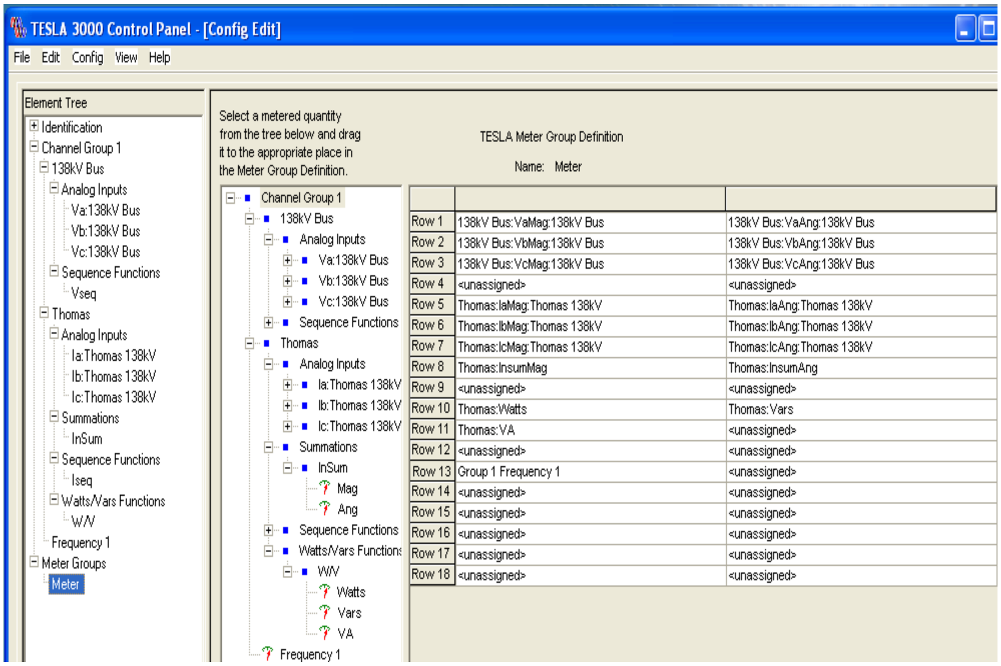

Figure 13. Meter Group

Part 2. Setting of Digital Channels

The TESLA Fault Recorder has the ability to monitor 64 digital signals that allow for verification of system protection performance. The relay engineer can decide to integrate a complete relay monitoring system by monitoring relay trip signals, trip coils, and breaker status.

Monitoring Trip Coils
Monitoring trip coils is a great way to determine when the breaker receives a tripping signal from a relay. Figure 14 shows a simplified DC schematic of two of several ways to monitor trip coils. During normal operation, the trip coil will only energize when a tripping signal is received from a protective relay or controls. Therefore, when a trip signal is received, the trip coil and the TESLA digital input will simultaneously be energized.

Another way to record a tripping signal is by using high speed surge detectors (74-1) in series with the trip coil. These current operated relays usually operate in 1ms and a dropout time of greater than 50ms might be an indication of a breaker problem. The auxiliary contacts from the surge detector are wetted and connected to the TESLA for proper recording.

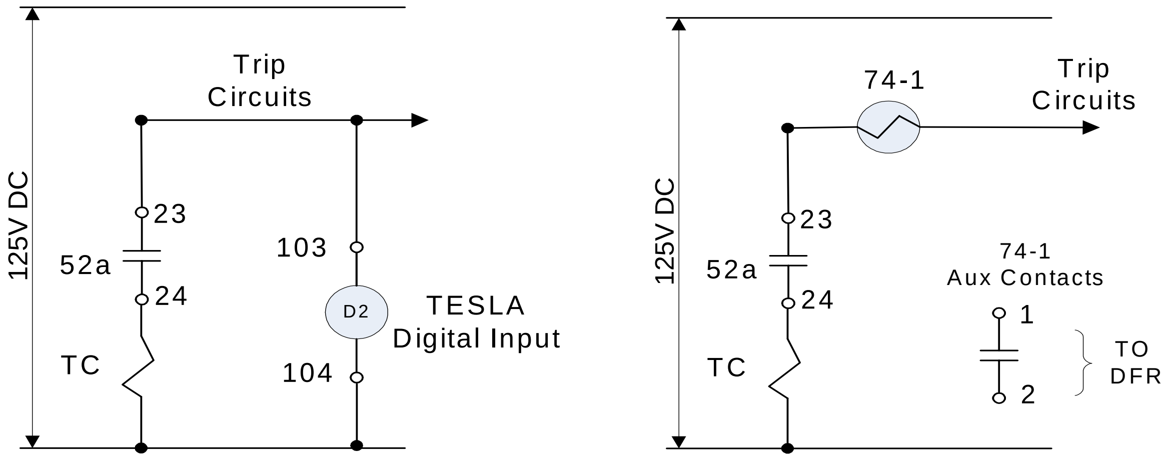

Figure 14. Trip Coil Monitoring

Settings:
In the event of a trip initiation by one of the relays, the digital input will become high. The user can then set the recorder to create a record or just log the information in the sequence of events. If the recorder has been set to trigger a record for overcurrent, undervoltage, or sequence component, then the user may decide to log the trip coil input and not create a record. If a record has been created by some other trigger, any changes in the digital signal status will still be captured in the oscillography along with all other digital signals, voltages and currents. In our example, we are logging state changes to the sequence of events only as shown in Figure 15.

The user can also consider creating a record to capture breaker operations caused by inadvertent relay operations, defective relays, operations due to technician errors that won't necessarily be triggered by the current and voltage triggers. However such triggers may create a number of records during maintenance operations that might not necessarily need attention. The user can create special logic to avoid nuisance triggers during maintenance tests.

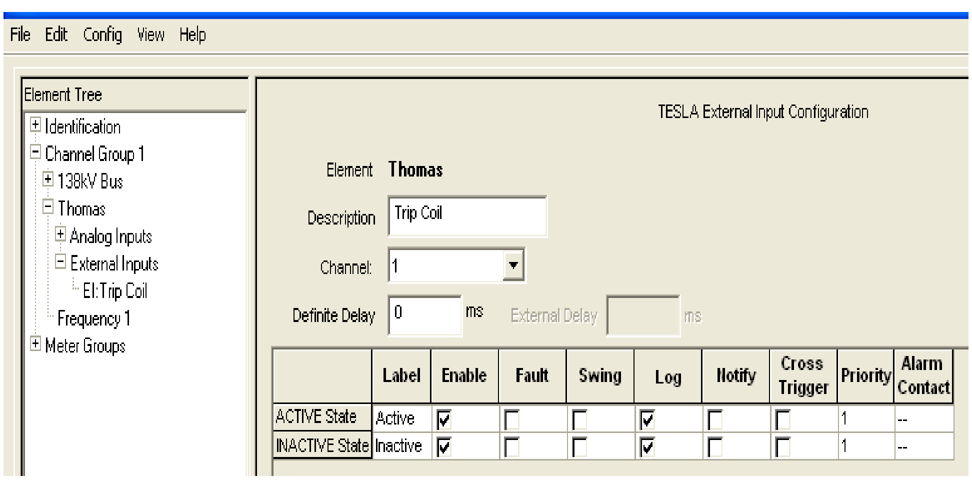

Figure 15. Trip Coil Settings

Monitoring Lock out Relays

Breaker failure 86BF, transformer 86T and bus 86B Lock Out Relays (LOR) can also be monitored by the TESLA 4000. The ability to see the reset and operate state of all LOR relays is of tremendous help when analyzing power system faults. Figure 16 is a simplified DC circuit indicating how the digital input of the TESLA is connected to one of the auxiliary contacts of the 86T LOR. The same method can be used to monitor other LORs. In the case of a transformer failure, the LOR relay will be activated and close its normally open contacts, thus, energizing all TESLA digital inputs that are connected to a LOR auxiliary contact.

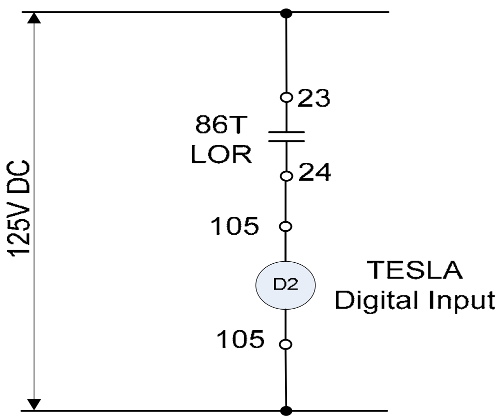

Figure 16. LOR monitoring

Settings:

As stated before, we normally don't want to create a record of such an event because one will already be created as a result of the current and voltage triggers. However, we want to enable and log the active and inactive events in the sequence of events as shown Figure 17.

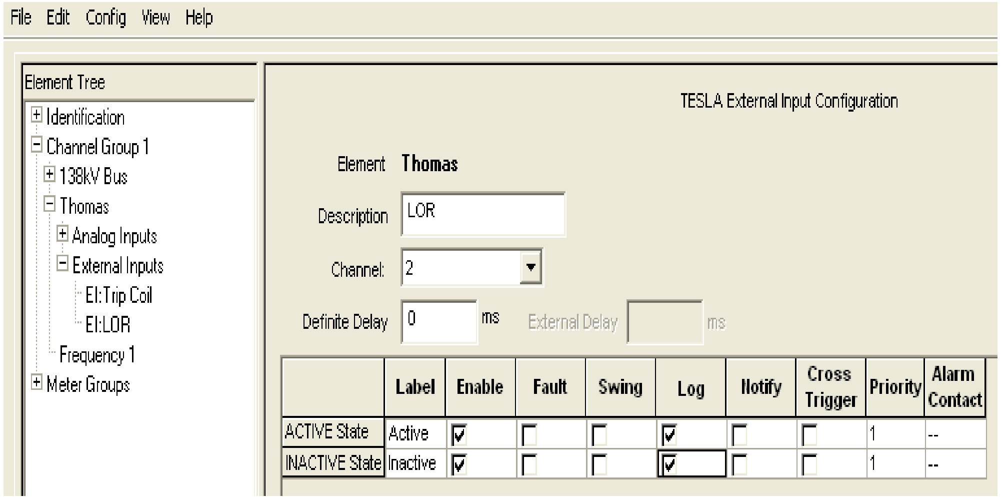

Figure 17. LOR Digital Signal Settings