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Generic Overcurrent Relay Model for the Western Electricity Coordinating Council

Prepared by: Relay Subgroup of the

WECC Modeling SPS and Relays Ad-Hoc Task Force (MSRATF)

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1 Introduction

In May of 2012, the Federal Energy Regulatory Commission (FERC) and North American Electric Reliability Corporation (NERC) issued a joint report on the September 8, 2011 Southwest Blackout Event calling, among other things, for improved planning. It recommended that entities throughout WECC identify and plan for external contingencies that could impact their systems and internal contingencies that could impact their neighbors' systems, and expand entities' external visibility in their models through, for example, more complete data sharing.

To achieve WECC wide visibility of contingencies in planning and operating the Modeling SPS and Relays Ad-Hoc Task Force (MSRATF) was created by TSS to develop and/or implement models for Remedial Action Scheme (RAS), relays and contingency definitions in WECC base cases, in BCCS, and in cases that are consistent with the West-Wide System Model (WSM). This task force will also coordinate with the RAS and Protective Systems Modeling Oversight Task Force (RPSOTF).

In response to the Sep 8th, 2011 outage, the following relay actions took place (among others). They highlight the need to be able to model relays in operations and planning studies, particularly overcurrent relays. At the time of the outage none of these relay functions were explicitly modeled in the WECC base cases.

		Major Sept 8 Transmission Operations	
1	15:28:16	Coachella Transformer #2, 230/92 kV	Overcurrent
2	15:28:17	Coachella Transformer #1 230/92 kV	Overcurrent
3	15:32:10	Ramon Transformer, 230/92 kV	Overcurrent
4	15:32:14	F Line, Niland – Blythe 161 kV	Overcurrent
5	15:32:15	N Line, Niland – Coachella 161 kV	Zone 3
6	15:35:40	Gila Transformers #1 & #2, 161/69 kV	Overcurrent
7	15:36:40	AX Line, Pilot Knob – Yucca	Overcurrent
8	15:37:55	A Line, El Centro - Pilot Knob Hydro	Zone 3
9	15:37:56	Julian Hinds-Mirage, Blythe Energy Center	RAS
10	15:38:02	S Line, Imperial Valley – El Centro 230 kV	RAS
11	15:38:21	SCE SONGS Separation Scheme	OC Separation

It is envisioned that transmission planning engineers will begin to more completely model automatic actions in their simulations. This will include an emphasis on modeling relays and remedial action schemes within the modeling software environment.

2 Purpose and Scope of Specifications

This document is intended to serve as a specification for two types of generic dynamic models of time inverse overcurrent relays to be used by WECC. One is curve based and the other is equation based. Both are to be implemented by software developers and approved by the WECC MVWG for use in dynamic simulations in accordance with various NERC standards. Additionally, these requirements describe how these models should be interpreted and implemented in the power flow simulation environment.

This document discusses existing technology that is presently available in at least one of the software tools used by WECC Planners (circa spring 2013). The intended purpose of this document is to provide adequate background information for these models to be approved by MVWG for use in WECC wide simulations (both power flow and transient stability).

Future requirements for improved overcurrent relay models are outside the scope of this document and shall be addressed via the formal MVWG modeling development process. Presumably many of the future requirements will be developed by the MSRATF membership, such as the ability to monitor multiple elements and to include directional control.

3 Purpose and Scope of Model

Existing models available in the GE, PTI, and PowerWorld software's adequately model the traditional user specified curve associated with overcurrent relays (**LOCTI**, **TIOCR1**). These existing relay models require that a piece-wise linear curve based on user specified set points be developed to specify how quickly the relay will operate. This is further discussed in this document.

This document also describes a new Time Inverse Overcurrent Relay Standard (**TIOCRS**) model that largely mimics the functionality of the **LOCTI** and **TIOCR1.** However, instead of specifying the piecewise linear curve, standard equations will be used that replicate what is implemented in actual modern relays. Relay engineers refer to time inverse overcurrent relays as "Very Inverse", "Moderately Inverse", "Extremely Inverse", etc. with the coefficients of specific curves determined by these names. Using the equation-based curves with the same terminology as is used by the relay engineering community will improve interactions of planning and relay engineers and minimize problems when converting relay settings from the relay engineering data sets.

The models described in this document are existing models in at least one of the various planning software used by WECC. This document describes the basic features and functions of these models.

3.1 Model Function and Software Requirements

It is well known that system faults cause notable changes in various electrical quantities that are calculated in both the power flow and transient stability tools. One of the most common fault indicators is a sudden, and generally significant, increase in the current; subsequently, overcurrent protection (i.e. relays) may be widely used.

Accordingly, the WECC MSRATF has developed a series of functional requirements for use within the various study software used by WECC members. These requirements are listed below (in no particular order):

- Requirement: That overcurrent relays can be applied to branches…i.e. lines, transformers, or series capacitors. Although over-current protection is often applied to other devices specifying the requirement to those devices is beyond the scope of this document and should be addressed in a future requirements document.

- Requirement: That overcurrent relays may command other branches to function regardless if that device is monitored by the relay.
    - For example: A relay may monitor line A, but command Line B and C to open (i.e. different lines than is monitored by the specific relay).

- Requirement: That overcurrent relays have the option to be in monitor only mode. When only monitoring, the relay will create reporting to indicate that branch would have tripped, but the relay will not actually trip any lines.

- Requirement: That overcurrent behavior should be imported from the transient stability environment and enabled in a meaningful way within the power flow environment.
    - Overcurrent relays may not operate during stressed system conditions until after a many-second time delay. Thus modeling the relays in power flow based contingency analysis is important. Typical transient stability practice in WECC has simulation times that seldom exceed 30 seconds for a faulted condition. A run time of up to 60 seconds appears to be the maximum simulation time modeled and is only used to determine case adequacy for a “no-bump” or “flat-line” simulation.

3.2 Modeling of Relays in Steady State Contingency Analysis

The existing models and the new model will be active in both the transient stability software environment as well as the power flow environment. We expect that the dynamics data can be parsed by the power flow software and the appropriate <If/Then> detection of the overcurrent relay and subsequent action be modeled in the power flow contingency tool. It is important to note that this represents a paradigm shift of the merging of power flow data and transient stability data. Presumably the future trend will be that, someday, there exists a single unifying electric system model that stores both power flow data and transient stability data in a single data structure or file.

4 Specification of Time Inverse Overcurrent Relay – Curve Based

The existing GE LOCTI model and the PTI TIOCR1 model are curve based overcurrent relays for line protection. The detailed operation of these relay models is generally the same as the TIOCRS relay which is described in the next section. The primary difference is how the *TimeToClose* is specified. These differences are described in the next section.

Generally these models perform adequately. Though, the following specific, near term improvements would make the existing models more useful:

- **LOCTI -** allow the model to be assigned to any branch (including both a transformer and transmission line). Presently the **LOCTI** model can be assigned only to a transmission line.
- **TIOCR1** - specify a Time Dial Multiplier (*Tdm*) in a manner similar to **LOCTI** and **TIOCRS**.

5 Specification of Time Inverse Overcurrent Relay Standard (TIOCRS) – Equation Based

New relay model will be named **TIOCRS**, which is short for "Time-Inverse Overcurrent Relay Standard".

5.1 Prerequisite

TIOCRS will be assigned to a branch. Requirement is that this can be any type of branch (i.e. a line, transformer, or series capacitor). Also, the relay must be assigned to a particular end of the branch (*From* or *To* End) with the current measured at that particular end of the branch.

5.2 Relay Operation and Resetting

A *TimeToClose* function is specified which varies as a function of the multiple above the threshold current that the relay is presently experiencing. The various relay models specify this *TimeToClose* functions in different ways, but the time at which the relay will close is determined by integrating the following function of the *TimeToClose*. When the function reaches 1.0 then the relay operates.

$$\theta = \int \left[\frac{1}{TimeToClose}\right] dt$$

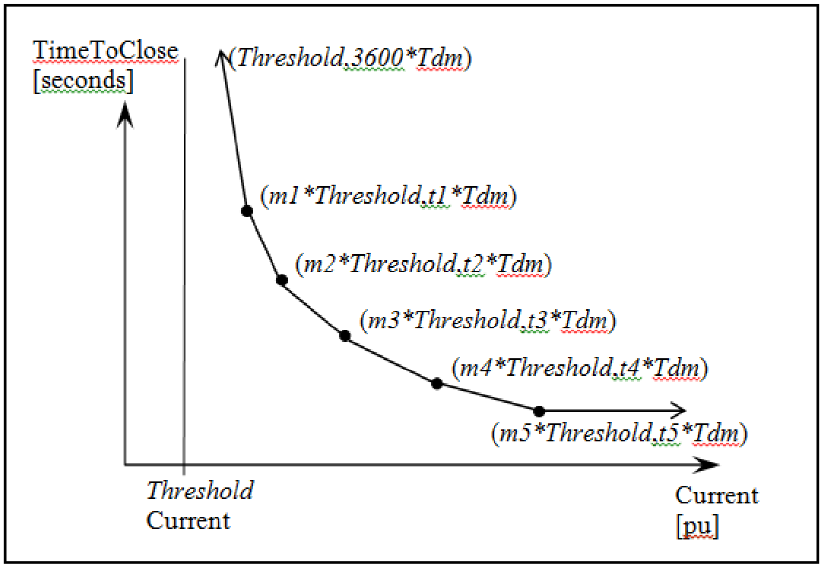
If a relay exceeds its *Threshold* current, then the function above will be integrating upward. If however the current drops below the *Threshold* before the state variable θ reaches a value of 1.0, then the relay resets according to the parameter *TReset* (multiplied by *Tdm*). If *TReset* is zero (or *Tdm*), then the relay resets to θ=0 instantaneously. Otherwise a timed reset occurs by integrating the following function.

$$\theta = \int \left[1 - \left(\frac{ICurrent}{Threshold}\right)^2\right] \left[\frac{-1}{TReset * Tdm}\right] dt$$

This function means that at zero current, it completely resets in *TReset***Tdm* seconds. The use of the reset time is identical for all these relay models and is the same as used in **TIOCR1** and **LOCTI**.

5.2.1 Specification of *TimeToClose*

For the **LOCTI** and **TIOCR1** relay models, *TimeToClose* is specified as a piecewise linear function of per unit current generally as shown below.



For the equation-based relay models, instead of using a piece-wise linear curve, an equation as described in IEEE, IEC , SEL or other standards is used. The task forces' discussions with many relay engineers from within member utilities indicates that some relay engineers are most accustomed to specifying overcurrent relays using these types of equations.

To specify which standard to use, a parameter CurveType will be set to either 1, 2, or 3 which translates to the following standards.

1. IEEE C37.112-1996 standard (see Reference [1])
2. IEC 255-4 or British BS142 (see Reference [2])
3. IAC Curves from GE (see Reference [3])

The *TimeToClose* functions are specified by the parameters *Tdm*, *p*, *A*, *B*, *C*, *D*, and *E* depending on the Curve Type. The three standards are shown below.

<u>IEEE C37.112-1996 Standard (CurveType = 1)</u>
Using the parameters Threshold, Tdm, p, A, and B, the TimeToClose as a function of per unit current is calculated using the following equations

$$TimeToClose = T_{dm}\left(B + \frac{A}{\left(\frac{Icurrent}{Threshold}\right)^{p} - 1}\right)$$

<u>IEC 255-4 or British BS142 Standard (CurveType = 2)</u>
Using the parameters Threshold, Tdm, p, and A the TimeToClose as a function of per unit current is calculated using the following equations

$$TimeToClose = T_{dm}\left(\frac{A}{\left(\frac{Icurrent}{Threshold}\right)^{p} - 1}\right)$$

<u>IAC GE Curves (CurveType = 3)</u>
Using the parameters Threshold, Tdm, A, B, C, D, and E the TimeToClose as a function of per unit current is calculated using the fllowing equations

$$TimeToClose = T_{dm}\left(A + \frac{B}{\left(\frac{Icurrent}{Threshold} - C\right)} + \frac{D}{\left(\frac{Icurrent}{Threshold} - C\right)^{2}} + \frac{E}{\left(\frac{Icurrent}{Threshold} - C\right)^{3}}\right)$$

In practice, each relay manufacturer will specify particular settings (such as "Very Inverse") for which the manufacture's manual will list appropriate *p*, *A*, *B*, *C*, *D*, and *E* parameters. For instance SEL publishes 5 sets of coefficents they name as follows

- US U1 (Moderately Inverse)
- US U2 (Inverse)
- US U3 (Very Inverse)
- US U4 (Extremely Inverse)
- US U5 (Short-Time Inverse)

They refer to these as IEEE "standard" relay models and they are very similar to the set of coefficients found the in IEEE C37.112 overcurrent relay standard, but are slightly different. Regardless, this WECC specification recommends that the actual coefficients for the equations be specified with each model.

Also note, these curves describe the shape of the *TimeToClose* function. In practice the relay engineer then uses the "Time Dial Multiplier" (*Tdm*) to make the relay operate slower or faster to coordinate with other protection functions.

5.3 Monitoring Only Features

The software implementation should include a flag with each particular relay which puts that relay in a "monitor only" mode. When only monitoring, the relay will create reporting to indicate that lines would have tripped, but the relay will not actually trip any lines. If tripping is enabled, then the relay will send a trip signal to the branch when $\theta \geq 1$, the branch will trip after the Breaker Time seconds have elapsed, and report the action.

5.4 Modeling of an Instantaneous Trip

It should be noted that the model parameter "Time Dial Multiplier" (*Tdm*) is a value that pre-multiplies all times associated with this model. Thus if an engineer wants to model a relay that instantaneously trips above the *Threshold*, then specifying *Tdm* = 0 achieves this.

5.5 Operation of Multiple Line Trips

A mechanism is desired to permit the specification of multiple branches to trip when the relay meets the conditions for sending a trip signal. This can be used to model transfer trip features.

5.6 Input Parameters

The basic functionality for specifying when the relay will cause devices to trip should be based on the input parameters shown in the following table. Remember that some mechanism should also be made to permit additional branches be specified to allow multiple line trips to simulate transfer trip. The mechanism to specify other devices that trip will be left to the software vendors and may be done by specifying additional integers or by referring to the objects directly.

Parameter	Type	Description
Monitor	Integer	0 (alarm); 1 (trip)
Curve Type	Integer	Determines equation used to calculated the TimeToClose. Value interpreted as 1. IEEE C37.112-1996 standard 2. IEC 255-4 or British BS142 3. IAC Curves from GE
Threshold aka Pickup	Float	Current at which relay operates. Value should be specified in Amps. (this value also specifies the current that separates the trip and reset characteristics)
Tcb	Float	Breaker Time in Seconds. After the relay integration reaches a value 1.0 then a relay trip signal is sent to the devices with a delay based on this breaker time.
Tdm	Float	Time Dial Multiplier. This parameter is specified with typical relay data and represents a single value for the relay engineer to tweak until desired relay response is achieved.
Treset	Float	Describes shape of Reset Characteristic Curve for values below Threshold. Reset time in Seconds
p	Float	Describes shape of Trip Characteristic Curve for values above Threshold. Only used for Curve Type = 1 and 2 (IEEE and IEC Curves)
A	Float	Describes shape of Trip Characteristic Curve for values above Threshold. Used for all Curve Types.
B	Float	Describes shape of Trip Characteristic Curve for values above Threshold. Only used for Curve Type = 1 and 3 (IEEE and IAC Curves)
C	Float	Describes shape of Trip Characteristic Curve for values above Threshold. Only used for Curve Type = 3 (IAC Curves)

D	Float	Describes shape of Trip Characteristic Curve for values above Threshold. Only used for Curve Type = 3 (IAC Curves)
E	Float	Describes shape of Trip Characteristic Curve for values above Threshold. Only used for Curve Type = 3 (IAC Curves)

6 Dynamic Data Conversion to Steady State Contingency Analysis

Overcurrent relay models may not operate when performing typical dynamic simulations due to expected trip times often in excess of standard transient stability simulation times (i.e. usually no more than 30 seconds). A number of OC relays tripped during the September 8, 2011 event in about 35 seconds to- 3½ minutes.

It is important to determine whether the modeled current would exceed the relay threshold (pickup) value, which indicates an eventual trip. In such a case there is an issue requiring further investigation. This motivates the requirement that we include the modeling of overcurrent relays in the power flow based contingency analysis processing.

Steady State Contingency Analysis tools should interpret the dynamic model data for use in the contingency analysis processing. The steady state contingency analysis processor should trip the line for any current above the Threshold current and would report that the threshold current has been exceeded based on the load flow (not fault current). In a situation where multiple relays exceed their threshold in the steady state simultaneously, then the contingency processor should choose only those relays that would trip first based on their respective *Time To Close* calculation. If multiple relays have the same *time to close*, then they should trip together. This list of "first to trip" relays should cause devices to trip, after which the steady state power flow should be resolved and remaining relays should be re-evaluated to see if they may also trip. The contingency processor should continue re-evaluating relays iteratively until no new relays operate.

7 Summary

This model is to represent the behavior of the overcurrent relay, but not to model the relay in detail. This is to simulate for the purposes of operations/planning studies, which is not the same as a protection system level model of a relay. These relay "models" mostly REPLACE switch "decks" and other non-syntax based files/scripts/code.

8 References

[1] IEEE C37.112-1996 curves are described in the IEEE standard found at http://standards.ieee.org/findstds/standard/C37.112-1996.html

[2] IEC 255-4 or British BS142 curves are described on page 5-101 of the GE D60 Line Distance Relay Manual at http://www.gedigitalenergy.com/products/manuals/d60/d60man-f5.pdf

[3] GE IAC curves are described on page 5-102 of the GE D60 Line Distance Relay Manual at http://www.gedigitalenergy.com/products/manuals/d60/d60man-f5.pdf