



The Source Concept Considerations in a Protective Relay



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Abstract—This paper presents a concept of "sources" in protective relaying. A source is a novel configuration mechanism for protective relays allowing a user to logically associate protection and control functions of a multi-function protective relay with physically connected AC input signals. The concept of sources simplifies protection schemes, as well as reduces both wiring and relay hardware. Through the concept of sources, the AC input signal to which a given protection or control element responds becomes a setting. In conjunction with multiple setting groups, the mechanism of sources allows the user to dynamically reconfigure a relay not only in terms of numerical settings, but also in terms of connections of the input AC. This brings a completely new level of adaptivity into the field of protective relaying. The concept of sources is introduced first. Actual application examples such as breaker-and-a-half applications, multi-winding transformer protection, and restricted earth fault protection for autotransformers follow.

Keywords: protective relaying, microprocessor-based relay, multi-function relay, relay wiring, relay input signals, signal sources.

I. INTRODUCTION

Protective relays evolved from single-function electro-mechanical devices, through single-function or integrated static devices into a multi-function integrated microprocessor-based Intelligent Electronic Devices (IEDs). This evolution has not been limited to the change in technology, i.e. the way the input signals are processed into protection and control actions. Other aspects include performance, cost, savings in space, savings in wiring, benefits resulting from the technology such as lower CT/VT burden, self-monitoring, etc. Another often overlooked difference is the way a user would select and apply his/hers the protection system.

An electromechanical relay has very limited flexibility. Its behavior is determined by its construction. The user settings are limited to a very few parameters. Quite often these parameters needed to be re-calculated from physical settings because the "user interface" of the relay is driven by its de-

sign. All the flavors of a given type of relay are selectable through different models (example: different curves of a Time OverCurrent, TOC, relay). This segmentation of the relay setting process between the ordering, installation (mounting and wiring), and set-point adjustment stages is a disadvantage of older type of equipment.

The added flexibility of modern microprocessor-based relays results in the combination of all the previously separated stages into one elaborate phase. Protection elements within a multi-function relay have been granted multiple operating modes (type of a curve could be selected anytime after ordering a relay), DC wiring has been replaced by programmable logic, input and output contacts could be replaced by communications, the new set-points could be loaded down depending on system configuration, etc.

Up to now however, even modern microprocessor-based relays used to keep their AC input connections logically fixed: protection and control elements made available for configuration used to be logically connected to specified input terminals. The user used to deal with one universal wiring diagram without an opportunity to connect available protection functions to various AC input signals as per given application.

This paper presents a concept of sources – a new relay configuration tool – that makes logical connections between protection, control and metering functions and physically connected AC signals, a user setting.

First, a brief discussion of other modern user configuration tools is presented (Section II). Next, the concept of sources is presented (Section III). Several practical application examples follow (Section IV).

The concept of sources has been implemented on a commercially available family of relays. The presented examples are practical and use actual relay configuration screens.

II. RELAY CONFIGURATION TOOLS

Typical modern microprocessor-based relays provide the user with significant flexibility.

Configuration mechanisms available to a user include:

A. Numerical Settings

This is a basic configuration level available in any generation of numerical protective relays. Compared to previous technologies, many more numerical parameters of a

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given protection or control element of a numerical relay are offered as user settings. Also, the settings could be entered in physical or convenient p.u. units. The ranges of settings are wider.

B. User Programmable Curves

Numerous protection functions such as time overcurrent, under- and over-voltage, and volts-per-hertz use inverse time characteristics. Typically, several standard curves are provided, so user may select the desired characteristic. Additionally, a few curves that permit a user to specify the characteristic on the point-by-point basis for better coordination are also available on modern microprocessor-based relays.

C. Multiple Operating Modes

Often, several modes of operation of a given protection or control element are available to a user. For example, an out-of-step tripping element may generate a trip command in an “Early mode”, i.e. instantaneously, or slowly in a “Delayed mode” when the current levels drop, in order to avoid the circuit breakers over-stressing. A neutral directional overcurrent element may be polarized from the zero sequence voltage, ground current, or both. A time overcurrent element may respond to the true RMS value (appropriate for thermal protection) or to phasor magnitude (appropriate for overcurrent protection), etc.

This level of flexibility demonstrates itself as a multi-choice selection and was rarely available in previous technologies.

D. Programmable Logic

Programmable logic has become a standard feature for microprocessor-based relays. It permits a user to perform some basic control functions and to build an application from elements available in a relay by combining the outputs from the protection elements into auxiliary signals to be used within the relay and to be interfaced with output contacts or sent to other equipment over communications channels.

A typical set of functions consists of gates, latches, timers, edge detectors, and counters. Some relays allow a user to attach a “digital element” to any of internal signals within the programmable logic scheme in order to name (label) the signal, generate display message or sequence of events logs when the state of the signal changes.

Advancements in relay communications, such as the UCA protocol [1] and GOOSE messaging allowing the exchange of state information on the peer-to-peer basis between several relays opens a whole new areas for distributed logic schemes.

E. Configurable Output Contacts

Configurable output contacts providing the convenience to drive the contact from any variable within the programmable logic has become standard as well.

F. Configurable Display Messages, Target LEDs and Event Logs

Modern relays allow the user to specify for each protection and control element whether upon pickup, dropout or operation of the element a target LED should be fired and/or an event log should be created. This allows for customizing of the relay and avoiding overflowing Sequence Of Events (SOE) records with non-critical information.

In addition, user-programmable LEDs and display messages have become an option. This capability is used to customize and enhance the relay from the point of view of a local display.

G. Programmable Oscillography

Modern relays allow programming the oscillography recording. The user choices often include sampling rate, file content, triggering signal, position of a trigger (split between the pre-trigger and post-trigger data), number of records versus record length, ways to treat old records (overwrite or not), etc.

H. Multiple Setting Groups

Multiple (switchable) setting “groups” (or “banks”) have become standard. A modern relay allows a user to enter several values of the same setting, typically organizing the entries into groups, and provides a programmable mechanism to switch the groups based on various conditions such as state of protection and control elements, input contacts, keypad commands, communications ports, self-monitoring alarms, etc.

It is expected that the use of multiple setting groups to perform “adaptive” protection functions will increase in use in the near future.

The described flexibility levels are available to various extent on modern microprocessor-based relays. The new level – sources – shifts logical connections between relay protection, control and metering features and physically wired AC input signals into the area of relay settings.

III. THE CONCEPT OF SOURCES

A “source” is a point of interest in a three-phase power system. Consider for example a breaker-and-a-half arrangement for transmission line protection shown in Fig.1:

?? From the point of view of transmission line protection, voltage signals supplied from VT-1 and current signals supplied from CT-3 are required. Traditionally, for protection and metering of the transmission line, VT-1 and CT-3 signals (or practically a sum of CT-1 and CT-2) shall be wired into the Line Protection Relay. If the relay uses a current from a neutral point of a transformer in the substation for polarization of, say, neutral directional overcurrent function, then the said current shall be connected as well. Thus, a collection of VT-1 voltages, CT-3

currents, and the ground current becomes a point of interest for the Line Protection Relay.

- ?? From the point of view of the Breaker Fail function for the 52-1 breaker, the current signals supplied from CT-1 are required. Thus, the CT-1 currents become a point of interest for the Breaker Failure Relay.
- ?? If power metering or protection directional function is required for the 52-1 leg, then a collection of VT-1 voltages and CT-1 currents becomes a point of interest.
- ?? Etc.

Note, however, that all the protection, control and metering functions can be accomplished based on VT-1 voltages, CT-1 currents and CT-2 currents. These signals could be wired to a relay and a user can select appropriate logical connections to accommodate the needs of line protection, breaker fail, metering and other functions that use the AC input signals.

A source is a combination of 1, 2, 3, 4, 5, 6, 7 or 8 signals as shown in Table 1.

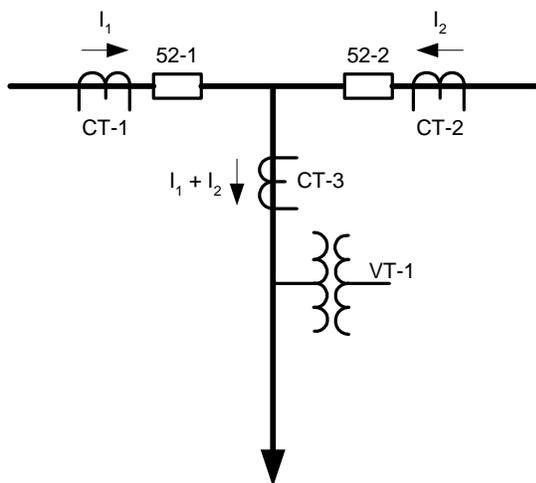


Fig.1. Breaker-and-a-half example.

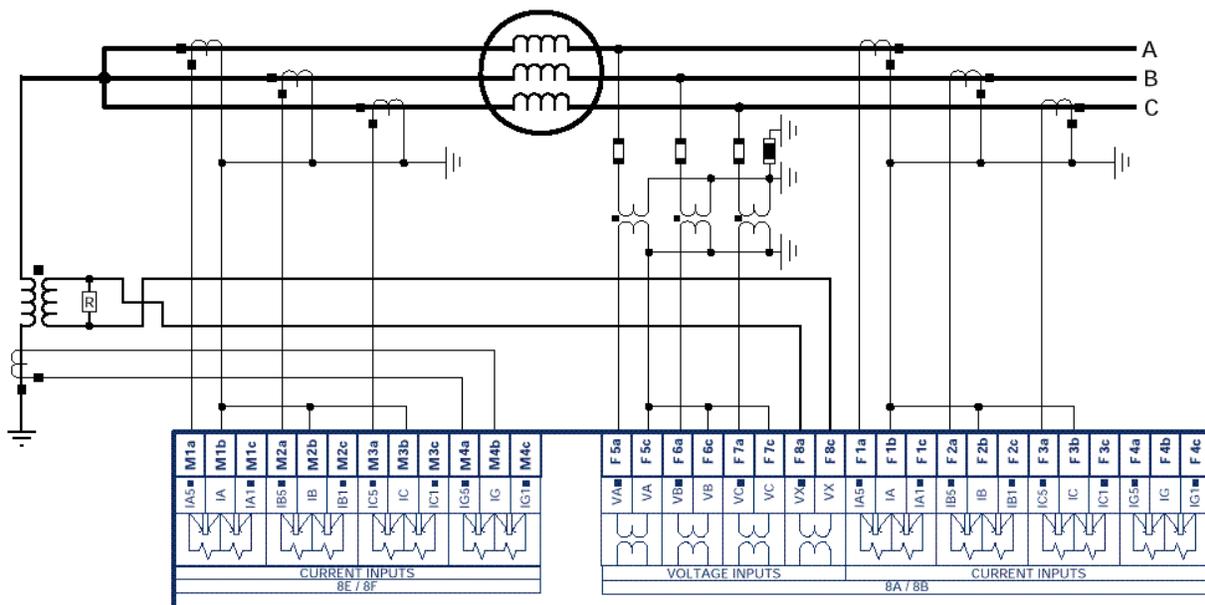


Fig.2. Example of connecting AC signals to VT and CT banks.

TABLE 1. STRUCTURE OF A SOURCE

	Meaning of the AC Signals	Actual Signal
Voltage	Three-phase Voltage Bank	VA or VAB
		VB or ABC
		VC or VCA
	Auxiliary Voltage	VX
Current	Three-phase Current Bank	IA
		IB
		IC
	Ground Current	IG

The actual AC signals are connected to Voltage or Current Banks as illustrated in Fig.2. The banks are individually labeled (F1 for inputs F1..F4; F5 for inputs F5..F8, M1 for inputs M1..M5, for example) and equipped with their own configuration mechanisms that allow to specify CT and VT ratios, nominal secondary values, connection of the VTs (wye or delta), meaning of the auxiliary voltage (3V0, VA, VAB, etc.).

In Fig.2, the generator relay is equipped with 2 three-phase CT inputs (F1..F3 and M1..M3), 2 ground current inputs (F4 and M4), 1 three-phase VT input (F5..F7) and 1 auxiliary voltage input (F8).

Sources for this sample application are configured as shown in Fig.3 by composing the available AC signals and labeling (naming for user convenience) the entire signal “bundle”.

The first source in Fig.3 has been named “NEUTRL” and consists of three-phase currents measured at the neutral of a machine, ground current measured in the neutral connection of the machine, three-phase voltages measured at the terminals of the machine and an auxiliary voltage measured at the neutral point of the machine. All the protection, control and metering functions configured to respond to the source “NEUTRL” will use the above signals to perform their functions.

PARAMETER	SOURCE 1	SOURCE 2	SOURCE 3	SOURCE 4
Name	NEUTRL	TERM	SUM	SRC x
Phase CT	M1	F1	F1+M1	None
Ground CT	M1	None	F1+M1	None
Phase VT	F5	F5	None	None
Aux VT	F5	F5	None	None

Fig.3. Sample source configuration.

The second source in Fig.3 is named “TERM” and consists of three-phase currents measured at the terminal side of the machine, three-phase voltages measured at the terminals of the machine and an auxiliary voltage measured at the neutral point of the machine. All the relay features configured to respond to the “TERM” source will use the above combination of signals.

For example, phase distance protection element could be configured using the “NEUTRL” or “TERM” source giving a user the freedom to follow his/hers own relaying philosophy.

One great feature of Sources is the ability to perform summations of any combination of available phase and ground currents. As an example, the third source in Fig.3 has been configured to be a vectorial sum of the phase currents of the banks F1 and M1. This means that the current in phase A of the “SUM” source is a sum of the currents wired to F1 and M1, in phase B – a sum of currents wired to F2 and M2, etc.

Prior to summation, the currents are ratio-matched and scaled to the CT having a maximum primary current. Consequently, the summed currents may be supplied from 1A or 5A CTs of different ratios and primary currents. The source mechanism uses the CT bank configuration data to perform appropriate ratio matching.

Summation of currents enables several applications as demonstrated in the following section.

Another useful consequence of making logical connection between the physically connected AC signals and protection / control elements user settings, is an ability to dynamically re-configure (in relay software) the AC wiring.

To illustrate this Fig.4 shows a configuration window for the first Time Over-Current element (TOC) of our sample generator relay under the setting group 1. The element responds to the true RMS value of the “NEUTRL” source current. If, however, the setting group no. 2 is in effect – as programmed by user under the setting group control – the same element responds to the “TERM” source current as shown in Fig.5.

This is a very powerful user configuration mechanism.

First, it enables the relay to respond to different AC signals upon certain system conditions. For example, if a given relay has two full sets of voltage signals connected for synchrocheck purposes, and one of the VT suffers a VT fuse fail conditions while the breaker is closed, elements of the relay that use the affected voltage could be transferred to the

PARAMETER	PHASE TOC1	PHASE TOC2	PHASE TOC3
Function	Enabled	Disabled	Disabled
Signal Source	NEUTRL (SRC 1)	NEUTRL (SRC 1)	NEUTRL (SRC 1)
Input	RMS	RMS	Phasor
Pickup	1.000 pu	1.000 pu	1.000 pu
Curve	IEEE Mod Inv	IEEE Mod Inv	IEEE Mod Inv
TD Multiplier	1.00	1.00	1.00
Reset	Instantaneous	Instantaneous	Instantaneous
Voltage Restraint	Disabled	Disabled	Disabled
Block A	OFF	OFF	OFF
Block B	OFF	OFF	OFF
Block C	OFF	OFF	OFF
Target	Self-reset	Self-reset	Self-reset
Events	Disabled	Disabled	Disabled

Fig.4. TOC1 configured to respond to NEUTRL source under setting group No.1

PARAMETER	PHASE TOC1	PHASE TOC2	PHASE TOC3
Function	Enabled	Disabled	Disabled
Signal Source	TERM (SRC 2)	NEUTRL (SRC 1)	NEUTRL (SRC 1)
Input	RMS	RMS	Phasor
Pickup	1.000 pu	1.000 pu	1.000 pu
Curve	IEEE Mod Inv	IEEE Mod Inv	IEEE Mod Inv
TD Multiplier	1.00	1.00	1.00
Reset	Instantaneous	Instantaneous	Instantaneous
Voltage Restraint	Disabled	Disabled	Disabled
Block A	OFF	OFF	OFF
Block B	OFF	OFF	OFF
Block C	OFF	OFF	OFF
Target	Self-reset	Self-reset	Self-reset
Events	Disabled	Disabled	Disabled

Fig.5. TOC1 configured to respond to TERM source under setting group No.2

that use the affected voltage could be transferred to the other VTs.

Second, the user can maximize the usage of provided protection and control functions by using the same element (TOC, for example) for various purposes under various system conditions. For example, the same TOC element could be used in conjunction with terminal-side CTs on a generator for transformer backup protection if the breaker is closed, and in conjunction with neutral-side CTs for generator backup if the breaker is opened.

IV. APPLICATION OF SOURCES

A. Breaker-and-a-half

Breaker-and-a-half application is probably the most typical application of sources. Refer to Fig.1 and assume CT-1 wired to the F1 bank, CT-2 wired to M1 bank and VT-1 wired to F5 bank. Three sources are configured: “BRK 1”, “BRK 2” and “LINE” as shown in Fig.6. The first Breaker Fail (BF) element of the relay is configured to respond to the “BRK 1” source, the second BF element is configured to respond to the “BRK 2” source. The line protection is configured to respond to the “LINE” source.

B. Transformer and feeder protection

Consider configuration of a very simple substation as in Fig.7. As the radial feeders cannot feedback any fault current

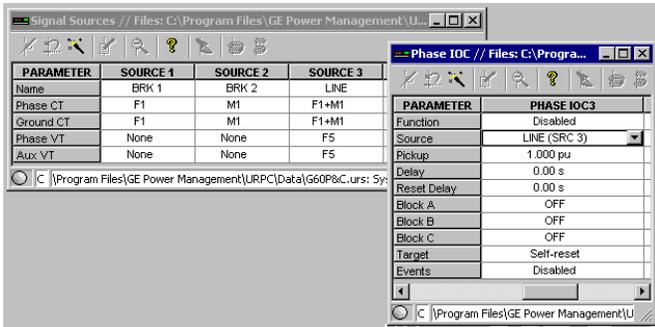


Fig.6. Breaker-and-a-half example.

their currents can be summed and used for transformer differential protection. In this way transformer differential protection remains a percentage (restraint) protection and the busbar gets included into the zone. Additionally, overcurrent protection can be provided for the feeders as their currents are individually measured by the relay.

It is assumed that the transformer relay uses F1, F5, M1

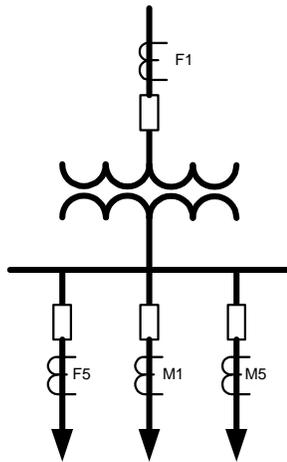


Fig.7. Transformer and feeder protection example.

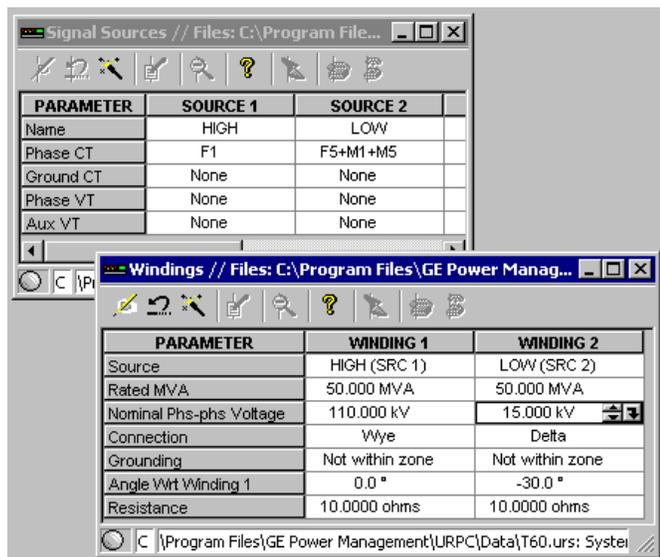


Fig.8. Source and protection configuration for the application of Fig.7.

and M5 CT banks, and the sources are configured as in Fig.8. The source mechanism will match the CT ratios on the feeders, sum the currents and store them as the “LOW” source. The transformer differential element shall be configured to respond to the “HIGH” and “LOW” sources.

C. Restricted earth fault protection for Autotransformers

Consider an Autotransformer shown in Fig.9. The restricted earth fault protection can be achieved by comparing the neutral current in the sum of the H and X windings with the ground current measured at the neutral of the transformer.

It is assumed that the transformer relay uses F1, F5, and M1 CT banks, the sources are configured as in Fig.10. The transformer differential protection shall be configured as in Fig.10; the restricted earth fault protection shall be configured as in Fig.11.

V. CONCLUSIONS

The paper presents “sources” – a new concept in protective relaying allowing a user to create logical associations be-

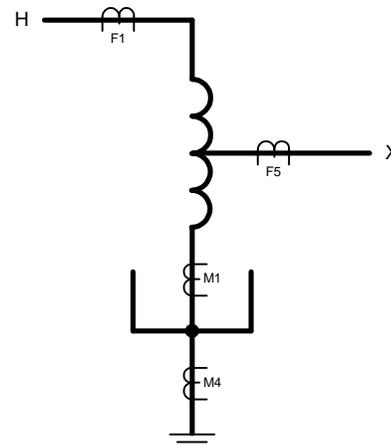


Fig.9. Autotransformer protection example.

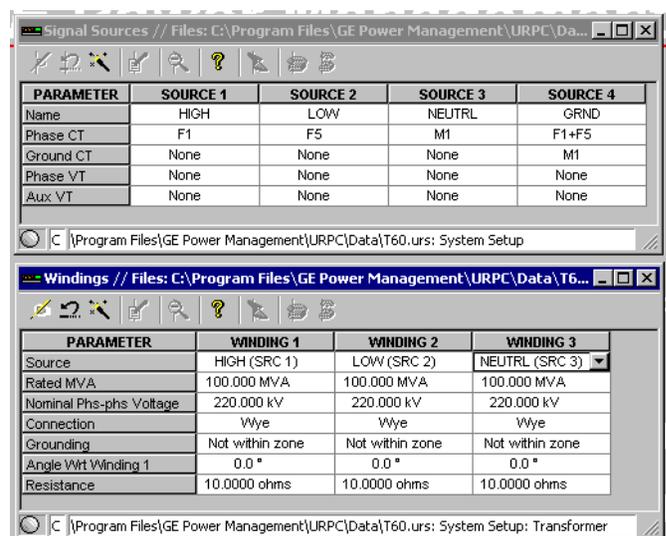


Fig.10. Source and protection configuration for the application of Fig.9.

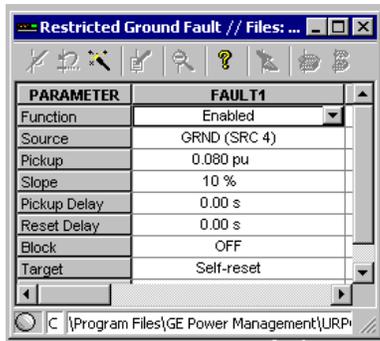


Fig.11. Earth fault protection configuration for the application of Fig.9.

tween physically wired AC signals and protection, control and metering elements of a multi-function protective relay.

The application of sources brings the advantages of reduced wiring, greater flexibility, and advanced adaptivity of the protection system.

The mechanism of sources has been implemented on a Universal Relay (UR) platform [2].

VI. REFERENCES

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BIOGRAPHIES

Bogdan Kasztenny (M'95, SM'98) received his M.Sc. and Ph.D. degrees from the Wroclaw University of Technology (WUT), Poland. He joined the Department of Electrical Engineering of WUT after his graduation. Later he was with the Southern Illinois and Texas A&M Universities. Currently, Dr. Kasztenny works for GE Power Management as a Chief Application Engineer. Bogdan is a Senior Member of IEEE and has published more than 100 papers on protection and control.

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