

7SG13 Delta

Protection and Control Relays

Document Release History

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Pre release

2010/02	Document reformat due to rebrand
2006/09	“3Vo Input” setting added
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Software Revision History

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Section 1: Introduction

1.1 Introduction

This document covers the voltage-based protection elements and their applications found in the Modular II range of relays, as listed below. A Diagrams and Parameters document which covers each individual model is available, which lists explicitly the functions that are provided and the manner in which they are connected.

- 27, Phase undervoltage
- 27, Voltage blocking
- 47, Phase sequence voltage
- 59, Phase overvoltage
- 81, Frequency

Notes

1. The following notational and formatting conventions are used within the remainder of this document:

- Setting: Elem Setting name
- Setting value: **value**
- Alternatives: [1st] [2nd] [3rd]

2. The purpose of this document is to describe the capabilities and functionality of Overcurrent Protection elements. Separate User Manual documents describe how to set up and operate the equipment: apply configuration, settings and passwords, view instruments and set default instruments, and retrieve fault data.

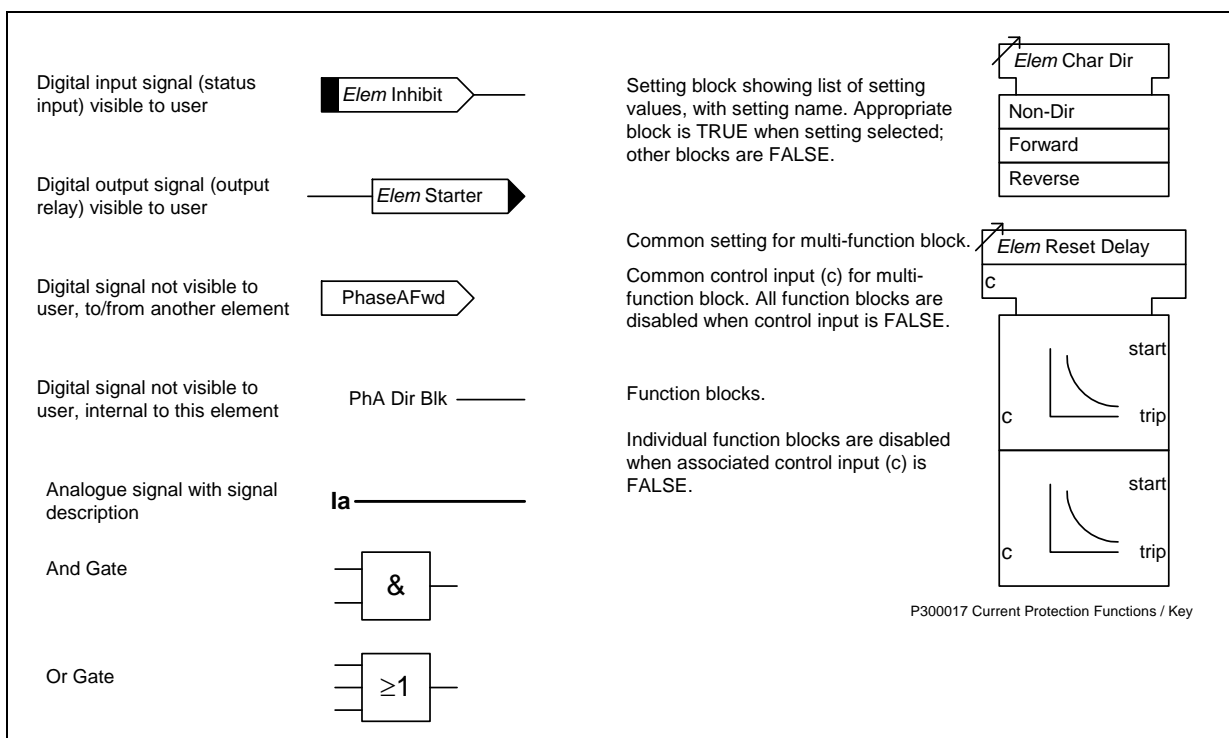


Figure 1-1 Key to Functional Block Diagrams

Section 2: Element Definitions

2.1 Voltage Protection

2.1.1 Phase Undervoltage and Overvoltage Elements (ANSI 27 and 59)

2.1.1.1 Description

Phase overvoltage and undervoltage elements use the same functionality, as shown in Figure 2-1. In some implementations, the sense of the element (undervoltage or overvoltage) can be set by the ***Elem Operation*** setting, while in others it will be pre-defined as undervoltage or overvoltage. If a voltage blocking element is provided, it will inhibit voltage elements.

The elements can be selected to operate either when any of the phase elements are picked-up, or alternatively when all of the phase elements are picked-up. As can be seen in Figure 2-1 this affects the starter and operate outputs.

In some implementations an ***Elem Hysteresis*** setting is provided, which allows the user to vary the pick-up drop-off ratio for the element.

Table 2-1 Typical Settings Phase Voltage Element

<u>Setting name</u>	<u>Range (bold = default)</u>	<u>Units</u>	<u>Notes</u>
Volt Input Mode	Ph-N, Ph-Ph		
Elem Operation	Off, U/V, O/V		
Elem Setting	5.0, 5.5... 55.0 ...200.0	V	
Elem Hysteresis	1, 2...90	%	<i>This setting is not always provided.</i>
Elem Delay	0.0 , 0.1...10.0, 10.5...100, 101...1000, 1010...10000, 10100...100000, 101000...864000	s	<i>The actual setting range may differ from that shown here.</i>
Elem O/P Phases	Any, All		<i>This setting is not always provided.</i>
<u>Sub-menu: Output Relays</u>			
Elem Starter	_, 1 for each output contact		
Elem Trip			
<u>Sub-menu: Status Inputs</u>			
Elem Inhibit	_, 1 for each status input		<i>The inhibit input is not always provided</i>

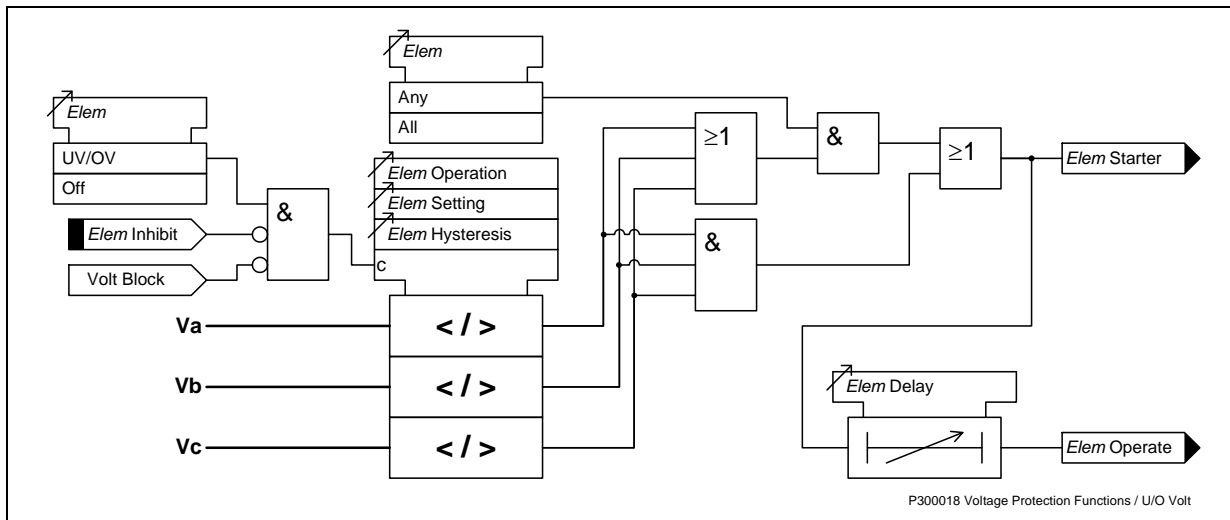


Figure 2-1 Functional Diagram for Phase Voltage Element

2.1.1.2 Specification

Element Parameters

The element will take the following parameters, unless otherwise specified in the appropriate Diagrams and Parameters document.

	Parameter	Value
t_{cycle}	Element cycle time	10 ms
f_{nom}	Nominal frequency	50 Hz

Reference

	Parameter	Value
V_n	Nominal voltage	63.5, 110 V
V_s	Absolute settings	55.0 V
$hyst$	Hysteresis	2 %
t_d	Delay setting	0.0...600.0 s
	Frequency	f_{nom}
	Ambient temperature	20 °C

Operate and Reset Level

	Attribute	Value
V_{op}	Operate level	100 % V_s , ± 1 % V_n
	Reset level	overvoltage $\geq (100 \% - hyst) \times V_{op} \pm 1 \%$
		undervoltage $\leq (100 \% + hyst) \times V_{op} \pm 1 \%$
	Repeatability	± 1 %
	Variation	-10 °C to +55 °C ≤ 5 %
		$f_{nom} - 3$ Hz to $f_{nom} + 2$ Hz ≤ 5 %

Operate and Reset Time

	Attribute	Value
t_{basic}	Element basic operate time	overvoltage 0.9 to 1.1 x V_s : 45 ms, $\pm t_{cycle}$
		undervoltage 0.9 to 2.0 x V_s : 35 ms, $\pm t_{cycle}$
		undervoltage 1.1 to 0.5 x V_s : 60 ms, $\pm t_{cycle}$

	Attribute	Value
t_{op}	Operate time following delay	$t_{basic} + t_d, \pm 1 \% \text{ or } \pm t_{cycle}$
	Repeatability	$\pm 1 \% \text{ or } \pm t_{cycle}$
	Disengaging time	< 100 ms
	Variation	$f_{nom} - 3 \text{ Hz}$ to $f_{nom} + 2 \text{ Hz}$ $\leq 5 \%$

2.1.2 Voltage Blocking Element (ANSI 27)

2.1.2.1 Description

The voltage blocking element acts as a block to the phase and negative sequence voltage elements and frequency elements. If all phase voltages fall below the threshold level then the blocking output will operate.

This element is required mainly for undervoltage operation conditions. Under normal circumstances, if all phase voltages fall below the undervoltage setting, a trip output would be the expected response. However, in some applications e.g. auto-reclose schemes, having an undervoltage relay trip when the line is de-energised during the auto-reclose sequence is not desirable. Blocking the undervoltage operation in this situation can be achieved by using the voltage blocking threshold, which should generally be set above the level of expected induced voltages on the line.

Table 2-2 Typical Settings Voltage Blocking Element

Setting name	Range (bold = default)	Units	Notes
Sub-menu: System Config			
Volt Block Level	OFF, 1, 2... 5 ...100	V	

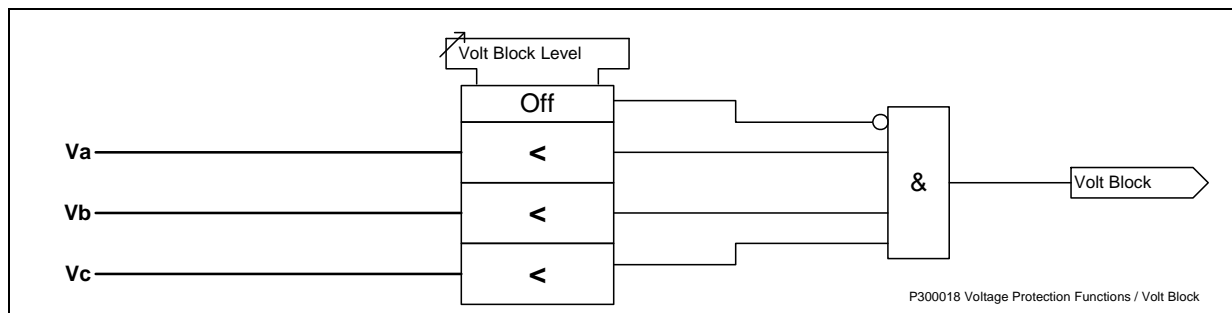


Figure 2-2 Functional Diagram for Voltage Blocking Element

2.1.2.2 Specification

Element Parameters

The element will take the following parameters, unless otherwise specified in the appropriate Diagrams and Parameters document.

	Parameter	Value
t_{cycle}	Element cycle time	5 ms
f_{nom}	Nominal frequency	50 Hz

Reference

	Parameter	Value
Vs	Setting	2.0 V
	Frequency	f_{nom}
	Ambient temperature	20 °C

Operate and Reset Level

	Attribute	Value
V_{blk}	Operate level	100 % V_s , $\pm 1\%$ V_n
	Reset level	$\leq 105\%$ V_{blk}
	Repeatability	$\pm 1\%$
	Variation	-10 °C to +55 °C
		$f_{nom} - 3$ Hz to $f_{nom} + 2$ Hz

2.1.3 Neutral Voltage Displacement Element (ANSI 59N)

2.1.3.1 Description

Neutral Voltage Displacement provides two stages of Earth Fault protection using residual earth voltage. This allows for an alarm to be issued, followed by a trip if the fault is not located and cleared. The two stages can be configured to be either definite time lag (DTL) or inverse definite minimum time (IDMT).

Elem Setting provides the 3V0 level for the starter. A DTL or alternatively an IDMT characteristic of

$t_{op} = \left[\frac{M}{\left[\frac{3V_0}{V_s} \right] - 1} \right]$ can be selected using **Elem Character**, the multiplier M on the IDMT characteristic is set using

the **Elem Multiplier** setting; when DTL is selected this is ignored and the **Elem Delay** setting is used instead. An instantaneous or definite time delayed reset can be applied using **Elem Reset Delay** to cater for flashing faults.

If directional elements are present, additional logic is provided for directional control. **Elem Dir** will set the direction in which the element is applied.

It should be noted that neutral voltage displacement can only be achieved for VT arrangements that allow zero sequence flux to flow in the core. i.e. a 5-limb VT or 3 single phase VTs should be used. Another requirement is for the VT primary winding neutral to be earthed to allow earth zero sequence exciting current to flow.

For relay models that do not provide Check Synchronising, the fourth VT input is available for Residual Voltage (3Vo) measurement. If this input is used, the **3Vo Input** setting should be set to Measured. Otherwise it should be left as Calculated; even if the Residual Voltage is measured as one of the other 3 VT inputs.

Table 2-3 Typical Settings Neutral Voltage Displacement Element

Setting name	Range (bold = default)	Unit	Notes
3Vo Input	Calculated , Measured		
Elem Character	Off , DTL, IDMTL		
Elem Dir	Non-Dir , Forward, Reverse		<i>Requires appropriate directional element to be present</i>
Elem Setting	1, 1.5... 5.00 ...100	V	
Elem Delay (DTL)	0.00 , 0.01...2.00, 2.1...20.00,21...600	s	
Elem Multiplier	0.1, 0.2... 0.5 ...10,10.5...140		
Elem Reset Delay	INST , 1, 2...60	s	
Sub-menu: Output Relays			
Elem Starter	_, 1 for each output contact		<i>The starter output is not always provided</i>
Elem Trip	_, 1 for each output contact		
Sub-menu: Status Inputs			
Elem Inhibit	_, 1 for each status input		<i>The inhibit input is not always provided</i>

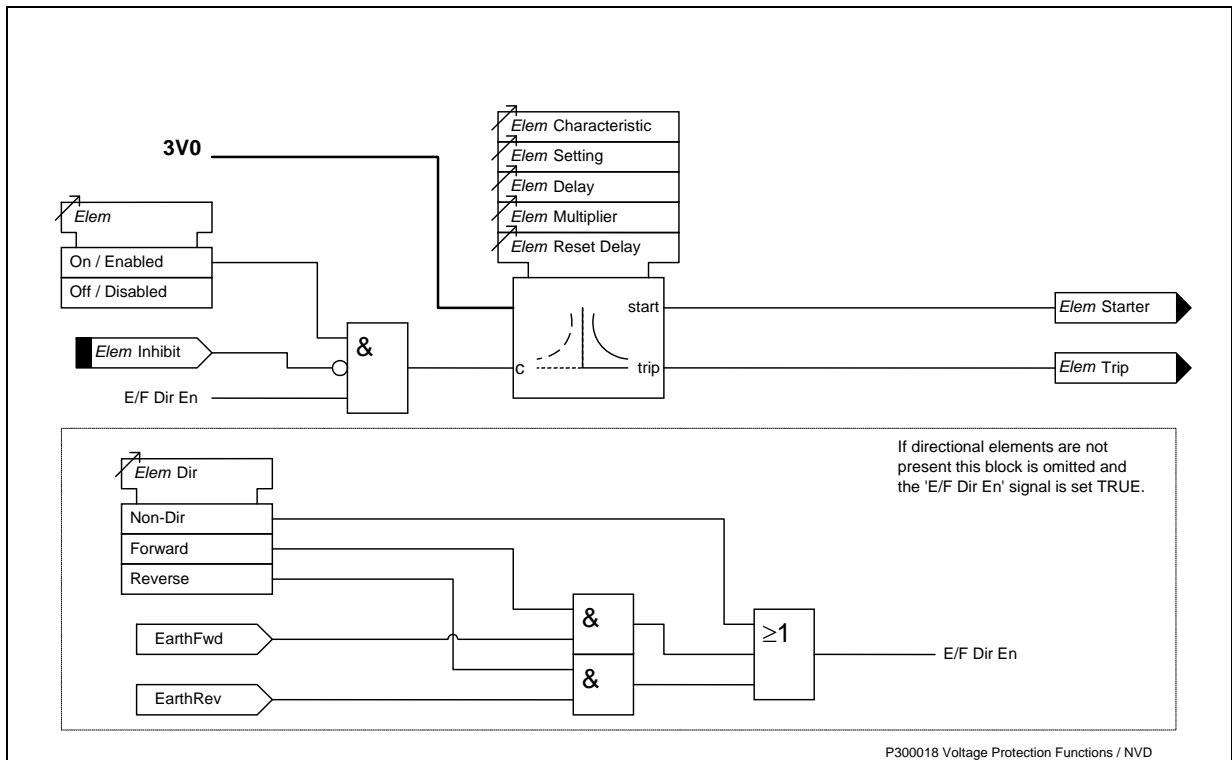


Figure 2-3 Functional Diagram for Neutral Voltage Displacement Element

2.1.3.2 Specification

Element Parameters

The element will take the following parameters, unless otherwise specified in the appropriate Diagrams and Parameters document.

	Parameter	Value
t_{cycle}	Element cycle time	10 ms
f_{nom}	Nominal frequency	50 Hz

Reference

	Parameter	Value
V_n	Nominal voltage	63.5, 110 V
V_s	Setting	5V
M	Multiplier	40
t_d	Delay setting	0.00...600.00 s
t_{res}	Reset setting	INST, 1, 2...60 s
$3V0$	Applied voltage (for operate time)	IDMTL 2 to 20 xVs
		DTL 10 xVs
f_{nom}	Frequency	f_{nom}
	Ambient temperature	20 °C

Operate and Reset Level

	Attribute	Value
V_{op}	Operate level	IDMT 105 % Vs, ± 2 % or ± 0.5 V
		DTL 100 % Vs, ± 2 % or ± 0.5 V

Attribute		Value
Reset level		$\geq 95 \% V_{op}^1$
Repeatability		$\pm 1 \%$
Variation	-10 °C to +55 °C	$\leq 5 \%$
	$f_{nom} - 3 \text{ Hz}$ to $f_{nom} + 2 \text{ Hz}$	$\leq 5 \%$

¹ For NVD settings below 7.5V the reset level can be up to 80% of operate value.

Operate and Reset Time

Attribute		Value
t_{basic}	Element basic operate time	0V to 1.5 x Vs 0V to 10 x Vs
		$\leq 43 \text{ ms}$ $\leq 38 \text{ ms}$
t_{op}	Operate time	$t_{op} = \frac{M}{\left[\frac{3V_0}{V_s}\right] - 1}$, $\pm 5 \%$ or $\pm 40 \text{ ms}$,
	char = DTL	$t_{basic} + t_d$, $\pm 1 \%$ or $\pm t_{cycle}$
t_{res}	Reset time	$t_{basic} + t_{res}$, $\pm 1 \%$ or $\pm t_{cycle}$
Repeatability		$\pm 1 \%$ or $\pm 10 \text{ ms}$
Overshoot time		$< 40 \text{ ms}$
Disengaging time		$< 50 \text{ ms}$
Variation	$f_{nom} - 3 \text{ Hz}$ to $f_{nom} + 2 \text{ Hz}$	$\leq 5 \%$

2.1.4 Negative Phase Sequence Overvoltage Element (ANSI 47N)

2.1.4.1 Description

The negative sequence component is derived from the three phase voltages. It is a measure of the quantity of unbalanced voltage in the system.

The protection comprises two independent instantaneous elements, each with a follower time delay. These delays can be used to provide time grading margins, sequence co-ordination grading or scheme logic.

Elem Setting provides the voltage level for the element and a follower time delay **Elem Delay** is then applied.

Table 2-4 Typical Settings NPS Voltage Element

Setting name	Range (bold = default)	Units	Notes
V2-1	Off, On		
V2-1 Setting	1.0, 1.5... 20.0 ...90	V	
V2-1 Delay	0, 0.01...2.0, 2.1... 5.0 ...20, 21...600	s	
V2-2	Off, On		
V2-2 Setting	1.0, 1.5... 20.0 ...90	V	
V2-2 Delay	0, 0.01...2.0, 2.1... 5.0 ...20, 21...600	s	
Sub-menu: Status Inputs			
V2-1 Inhibit	_, 1 for each status input		
V2-2 Inhibit			

Setting name	Range (bold = default)	Units	Notes
Sub-menu: Output Relays			
V2 Starter	_, 1 for each output contact		Alarm output
V2-1 Operate			Trip output if enabled
V2-2 Operate			Trip output if enabled

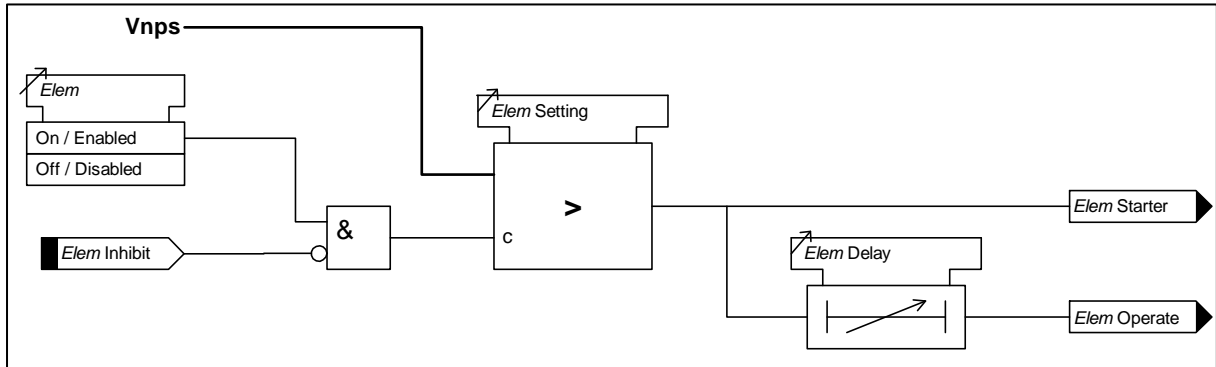


Figure 2-4 Functional Diagram for NPS Voltage Element

2.1.4.2 Specification

Element Parameters

The element will take the following parameters, unless otherwise specified in the appropriate Diagrams and Parameters document.

	Parameter	Value
t_{cycle}	Element cycle time	10 ms
f_{nom}	Nominal frequency	50 Hz

Reference

	Parameter	Value
V_n	Nominal voltage	63.5, 110 V
V_s	Absolute settings	55.0 V
$hyst$	Hysteresis	2 %
t_d	Delay setting	0.0...600.0 s
	Frequency	f_{nom}
	Ambient temperature	20 °C

Operate and Reset Level

	Attribute	Value
V_{op}	Operate level	100 % V_s , ± 1 % V_n
	Reset level	overvoltage $\geq (100 \% - hyst) \times V_{op} \pm 1 \%$
	Repeatability	± 1 %
	Variation	-10 °C to +55 °C ≤ 5 %
		$f_{nom} - 3$ Hz to $f_{nom} + 2$ Hz ≤ 5 %

Operate and Reset Time

	Attribute	Value
t_{basic}	Element basic operate time	overvoltage 0.9 to 1.1 x V_s : 45 ms, $\pm t_{cycle}$
		0.9 to 2.0 x V_s : 35 ms, $\pm t_{cycle}$

	Attribute	Value
t_{op}	Operate time following delay	$t_{basic} + t_d, \pm 1 \% \text{ or } \pm t_{cycle}$
	Repeatability	$\pm 1 \% \text{ or } \pm t_{cycle}$
	Disengaging time	< 100 ms
	Variation	$f_{nom} - 3 \text{ Hz}$ to $f_{nom} + 2 \text{ Hz}$ $\leq 5 \%$

2.2 Frequency Protection

2.2.1 Underfrequency and Overfrequency Elements (ANSI 81)

2.2.1.1 Description

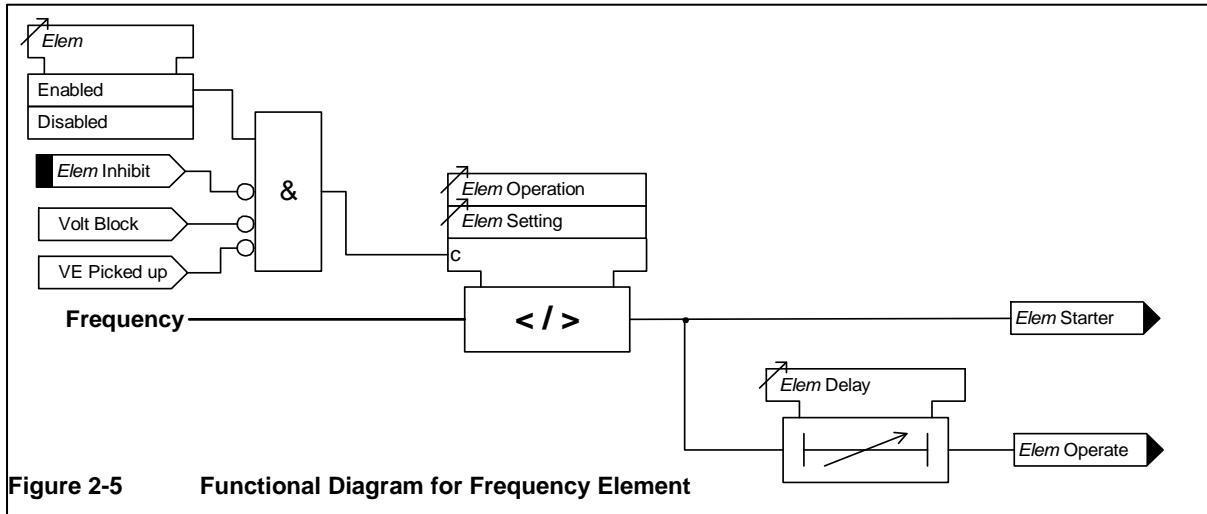
Overfrequency and underfrequency elements use the same functionality, as shown in Figure 2-1. The sense of the element (underfrequency or overfrequency) can be set by the **Elem Operation** setting. Each element can be inhibited in four different ways;

- If all phase voltages fall below the voltage blocking threshold level.
- Via a status input inhibit signal.
- Via any combination of voltage elements starting.
- If all of the phase voltages fall below an absolute level of 29V. This is independent of the voltage blocking threshold and is required to ensure that the frequency accuracy claims are within $\pm 10\text{mHz}$.

The frequency calculation is performed on data from one input phase only. If all phase voltages are above an internal threshold of 29V, then the frequency calculation will be derived from the phase A input. If however, phase A falls below 29V, then the calculation will automatically switch to phase B data. During the switchover process the last frequency value measured is held until phase B returns a valid frequency answer. This will take approximately 180ms. The switchover precedence is A-B-C and as each phase recovers its voltage then the frequency calculation is switched back to this phase. This method ensures that the frequency calculation is performed on a solid system voltage and not on low levels of input voltage where noise could cause incorrect calculation.

Table 2-5 Typical Settings Frequency Element

Setting name	Range (bold = default)	Units	Notes
Elem Operation	Off, U/F, O/F		
Elem Setting	47.00, 47.01 ... 50.00 ... 52.00	Hz	
Elem Delay	0.0 , 0.01...2.0, 2.1...20, 21...600	s	
Elem Inhibit	_, 1 for each voltage element		
Sub-menu: <u>Output Relays</u>			
Elem Starter	_, 1 for each output contact		
Elem Trip			
Sub-menu: <u>Status Inputs</u>			
Elem Inhibit	_, 1 for each status input		



2.2.1.2 Specification

Element Parameters

The element will take the following parameters, unless otherwise specified in the appropriate Diagrams and Parameters document.

	Parameter	Value
t_{cycle}	Element cycle time	10 ms

Reference

	Parameter	Value
V_n	Nominal voltage	63.5, 110 V
$hyst$	Hysteresis	2 %
	Ambient temperature	20 °C

Operate and Reset Level

	Attribute	Value
F_{op}	Operate level	100 % F_s , $\pm 10\text{mHz}$
	Reset level	overfrequency $\geq (100 \% - hyst) \times F_{op} - 25\text{mHz}$
		underfrequency $\leq (100 \% + hyst) \times F_{op} + 25\text{mHz}$
	Repeatability	$\pm 1 \%$
	Variation	-10 °C to +55 °C $\leq 5 \%$

Operate and Reset Time

	Attribute	Value	
t_{basic}	Element basic operate time	overfrequency	Typically < 110ms Maximum < 150ms
		underfrequency	Typically < 110ms
			Maximum < 150ms
		t_{op}	Operate time following delay
	Repeatability	$\pm 1 \%$ or $\pm t_{cycle}$	
	Disengaging time	< 100 ms	

Section 3: Application Notes

3.1 Voltage Blocking Element

The voltage blocking element acts as a block to the phase voltage elements. If all phase voltages fall below the threshold level then the blocking operation will operate.

The voltage blocking element performs a number of functions:

- If the relay has been set up with undervoltage elements enabled and is switched on with no volts applied to its inputs then, an undervoltage starter would pickup and the relay may issue a trip. The relay would then stay locked in this trip condition until volts are applied and the element is reset. To prevent this from happening the voltage blocking threshold has to see volts above its set level otherwise the phase voltage elements are fully blocked and no starter or trip operation will follow.
- In auto-reclose schemes, the voltage blocking threshold can be used to prevent unnecessary operations of the undervoltage elements during the time when the line is de-energised. For this type of blocking operation the threshold is typically set to 20% of rated volts, though it should always be set to a value above the expected level of induced voltages on the line.

3.2 Voltage Protection

3.2.1 Voltage Element Hysteresis

The voltage element hysteresis setting (if available) allows the user to alter the pick-up / drop-off ratio of the element.

When using the variable hysteresis, care has to be taken to ensure that with undervoltage elements, the reset level of the element is not set to a value higher than that at which the system rated voltage is expected to operate. The system rated voltage will typically have a tolerance of $\pm 10\%$, so the upper level of the hysteresis must be below the lower limit of the tolerance, otherwise the element may not reset. Conversely, the level of hysteresis set for an overvoltage element should not be set below that at which the system rated voltage is expected to run.

Typical values for hysteresis applied to a voltage element are $< 5\%$. When setting the hysteresis level the user has to be aware that if the amount of hysteresis is set too low e.g. 1%, then for large frequency excursions and low values of voltage element setting, the element might become unstable and 'chatter'. This will produce nuisance alarms / tripping and generate large numbers of stored event records. A minimum recommended level is 2% for this reason.

3.2.2 Undervoltage Protection

Undervoltages are reasonably frequent events on power systems and can occur for a number of different reasons. Faults on the system can cause the phase voltages to be depressed, the actual voltage drop being dependent upon a number of factors including the fault type and system earthing etc. During system earth fault conditions, the undervoltage protection is not generally required to operate and thus connecting the relay in the phase-phase configuration will make it less susceptible to single-phase voltage depressions.

Another cause of undervoltage is an increase in system loading, which should be corrected by system regulating equipment such as tap-changers and AVR's. However, if this equipment is defective then an undesirable situation will occur which will require an undervoltage relay to trip non-essential loads to correct for this voltage excursion and to bring it back to its nominal level. This tripping should happen after an appropriate time delay has expired. Generally, wherever voltage relays are employed, timing elements should be used to prevent operation during transient disturbances.

If the system is supplying 3-phase induction motors or variable frequency thyristor drives, undervoltages can have the following effect. Voltage depressions down to approximately 80 % of rated voltage cause the load current to increase, possibly resulting in a larger voltage depression due to the supply source impedance. Below 80 % the current drawn is proportional to the voltage and an induction motor is likely to stall. The current drawn is then dependent on the drive design e.g. thyristor drives include current limitation. An undervoltage element can be set to trip out a motor circuit when the voltage falls below a preset value, selected based on the motor drive and system design parameters, and after a preset time delay. The time delay is required to ensure voltage dips due to remote system faults do not result in an unnecessary trip.

If the system supply to a group of motors is lost, undervoltage protection can be applied to ensure that each of the motor circuit breakers or contactors are tripped so that on restoration of the main supply, it is not overloaded by

the simultaneous starting of all the motors. A 3-phase undervoltage relay may be used for this task of tripping a feeder for the detection of a complete loss of voltage. Also, where a supply to induction motors is lost, the undervoltage relay can be used to detect the loss of supply or to monitor any busbar residual voltage e.g. resulting from back e.m.f. generated by the induction motors as they run down. The relay can act as a guard prior to re-connecting a supply from an alternative source.

Where undervoltage relays are used on a system, the voltage elements should be set to a value below that where a normal system voltage excursion can be expected. (See also section 2.5). Typically the set values may be 65 % to 80 % of nominal for protection of the system or plant. For confirmation that a monitored supply is 'dead' or that any residual voltage has reduced to a safe level, typical set values should be 10 % to 30 % of nominal voltage.

3.2.3 Overvoltage Protection

Overvoltages may be caused for a number of different reasons. On generator sets for example, it may be caused by defective operation of the voltage regulator, or, if there is a sudden loss of load due to line tripping. Under this load rejection situation the generator set may overspeed causing a dangerous voltage rise. This should be corrected by system regulating equipment such as tap changers and AVR's, but if this equipment mal-functions then, voltage levels may rise. High levels of overvoltages on a system cannot be sustained for long periods because they can cause damage to the system insulation and severely affect the life of the insulation. An overvoltage element with an appropriate DTL time delay setting to allow the normal system regulating equipment to operate can be used to protect against this type of condition.

If a number of overvoltage elements are available, a variety of different applications can be covered. If the overvoltage condition is small, a relatively long DTL time delay can be set on an element to clear the fault. If the overvoltage is more severe then another element, set at a higher pickup level and with a faster DTL time, can be used to clear the fault more quickly. Alternatively, elements can be set to provide alarm and tripping stages, with the alarm levels set lower than the tripping stages.

The use of instantaneous and wide ranging DTL settings allows a simple and secure grading system to be applied to co-ordinate the network design, the regulating plant design and system plant insulation withstand. The use of IDMTL protection is not recommended because of the difficulty of choosing settings to ensure correct co-ordination and security of supply.

Generally, wherever voltage relays are employed, timing elements should be used to prevent operation during transient disturbances. In addition, overvoltage relays must be co-ordinated with other overvoltage relays elsewhere on the system.

3.2.4 Neutral Voltage Displacement

Neutral Voltage Displacement (Residual Overvoltage) protection is used to detect an earth fault where there is little or no earth current present.

This would occur, for example, where a feeder has been tripped at its HV side for an earth fault, but current is still being supplied to the fault from the LV side via an unearthed transformer. This current might be provided through interconnection or a secondary supply source. Insufficient earth current would be present to cause a trip, but residual voltage would increase significantly; reaching up to 3-times the normal Vphase level.

The same situation could also be allowed for by utilising inter-tripping from the HV side of the feeder to its LV side.

If NVD protection is used, it must be suitably time graded with other protections in order to prevent unwanted tripping for external feeder faults. Although operating characteristics are provided by the relay for NVD, this grading would typically be achieved using a DTL.

Calculations are performed on the voltage fundamental component. This gives the feature excellent 3rd Harmonic rejection.

3.2.5 Negative Phase Sequence Overvoltage

Negative Phase Sequence (NPS) protection detects phase unbalances and is widely used in protecting rotating plant such as motors and generators. However such protection is almost universally based on detecting NPS Current rather than Voltage. This is because the NPS impedance of motors etc. is much less than the Positive Phase Sequence (PPS) impedance and therefore the ratio of NPS to PPS Current is much higher than the equivalent ratio of NPS to PPS Voltage.

NPS Voltage is instead used for monitoring busbar supply quality rather than detecting system faults. The presence of NPS Voltage is due to unbalanced load on a system. Any system voltage abnormality is important since it will affect every motor connected to the source of supply and can result in mass failures in an industrial plant.

The two NPS Voltage DTL elements should therefore be used as Alarms to indicate that the level of NPS has reached abnormal levels. Remedial action can then be taken, such as introducing a Balancer network of capacitors and inductors. Very high levels of NPS Voltage indicate incorrect phase sequence due to an incorrect connection.

The Relay uses NPS Voltage as an integral part of other protection algorithms, such as VT Supervision. NPS polarising is also utilised when reliable Zero Phase Sequence (ZPS) quantities are not available, for example due to the VT connection configuration.

3.3 Frequency Protection

3.3.1 Underfrequency and Overfrequency Protection

When a power system is in stable operation at normal frequency, the total mechanical power input from the prime movers to the generators is equal to the sum of all the connected loads, plus all real power losses in the system. Any frequency variation is an indication of generator-load imbalance in the system. If an interconnected system splits, for example, there might be a situation where the load in one of the subsystems is in excess of the generator capacity in that subsystem. In this instance the generator speed will begin to decrease causing a proportional frequency drop. An underfrequency condition at nominal voltage can lead to over-fluxing of plant such as generators and transformers. If the governors and other regulating equipment cannot respond quickly enough, a sustained underfrequency condition may lead to a system collapse. Conversely, if there is an excess of generation in the subsystem then the generator speed will increase causing a proportional frequency rise. This may be unacceptable to industrial loads, for example, where the running speeds of synchronous motors will be affected.

In the situation where the system frequency is collapsing rapidly it is common practise to disconnect non-essential loads for short periods of time, until the generation-load requirements and network configuration can be corrected. This is designed to preserve system integrity and minimise outages. Normally utilities will avoid intentionally interrupting service, but in this case non-critical loads can be interrupted for short periods. This type of scheme is known as an underfrequency load shedding scheme. Usually, automatic load shedding, based on underfrequency, is necessary since sudden, moderate-to-severe frequency shifts can throw a system into a dangerous state much faster than an operator can react. Underfrequency relays are usually installed at distribution substations, or industrial plant, where selected loads can be disconnected and where similar priority loads are often grouped together.

The object of load shedding is to re-establish the generator-load equation. At the instant of a disturbance a measure of the amount of overload is not readily available and thus load is shed in stages until the frequency stabilises and returns to within the nominal band. An example scheme would have the first load shedding stage set just below the nominal frequency, e.g. between 49.0 - 49.5Hz. A time delay element would be associated with this and this would be set to allow for transient dips in frequency, as well as to provide a time for the system regulating equipment to respond. The first load shedding stage would be set to shed a significant percentage of the system load. If this drop is sufficient, the frequency will stabilise and perhaps increase and return to nominal. If, however, this is not sufficient then a second load shedding stage, set at a lower frequency, will now shed a smaller percentage of load until the overload is relieved. This process will continue until all stages have operated. In the event of the load shedding being unsuccessful, a final stage of underfrequency protection should be provided to totally isolate all loads before plant is damaged, e.g. due to overfluxing.

An alternative type of load shedding scheme would be to set all underfrequency stages to about the same frequency setting but to have different length time delays set on each stage. If after the first stage is shed the frequency doesn't recover then subsequent stages will shed after longer time delays have elapsed.

As has been mentioned earlier, where there is an excess of generation in a subsystem the frequency will rise. This is most commonly due to loss of load situations, which cause the generators to speed up. Normally the generator control equipment will respond to regain the normal running speed, but if this equipment fails then the overfrequency protection can be used as a backup. The settings for the overfrequency elements should be set to allow for transient frequency excursions following a loss of load condition and allow time for the generator control systems to recover the situation.

The relay has four frequency elements, each of which can be set for underfrequency operation. These, coupled with independent voltage elements and a large number of output contacts available, enable economic application for complex load shedding schemes. The accuracy and security of operation built into the numeric algorithms makes them ideally suited for this type of application. All frequency elements can be blocked in a number of different ways. It is important to note that where there is other load shedding equipment on a system, the relay should be set to co-ordinate with it.