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Oak Ridge National Laboratory Current Magnitude and Frequency Response of SIPROTEC Relays

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June 2020

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Electrical and Electronics Systems Research Division

OAK RIDGE NATIONAL LABORATORY
CURRENT MAGNITUDE AND FREQUENCY RESPONSE OF SIPROTEC RELAYS

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June 2020

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CONTENTS

LIST OF FIGURES v
LIST OF TABLES v
ACRONYMS vii
ABSTRACT 1
1. INTRODUCTION 1
2. EXPERIMENTS AND TESTBEDS 2
2.1 RELAY EXPERIMENTS 2
2.2 TESTBED WITH RELAY TEST EQUIPMENT 3
2.3 TESTBED WITH RELAY TEST EQUIPMENT AND HIGH-FREQUENCY POWER SOURCE/AMPLIFIER 3
3. SIPROTEC RELAYS 4
3.1 RELAY SAMPLE RATES 4
3.2 RELAY SETTINGS 5
4. RESULTS AND CONCLUSIONS 7
5. REFERENCES 9
APPENDIX A. CURRENT FREQUENCY ANALYSIS UP TO 1 kHZ A-1
APPENDIX B. CURRENT FREQUENCY ANALYSIS UP TO 20.16 kHZ B-1
APPENDIX C. CURRENT MAGNITUDE ANALYSIS UP TO 1 kHZ C-1
APPENDIX D. CURRENT MAGNITUDE ANALYSIS UP TO 20.16 kHZ D-1
APPENDIX E. CURRENT MAGNITUDE INTENSITY FROM 1 TO 20.16 kHZ E-1

LIST OF FIGURES

Figure 1. Software steps for 7SJ61 and 7SJ62 SIPROTEC relays. 2
Figure 2. Testbed with Relay Test Equipment. 3
Figure 3. Testbed with Relay Test Equipment and High-Frequency Power Source/ Amplifier. 4
Figure 4. Record events and sample rates for 7SJ61 (A) and 7SJ62 (B) SIPROTEC relays. 5
Figure 5. Definite-time overcurrent setting curve (A) and relays' displays (B). 6
Figure A.1. Measured frequency of 7SJ61 SIPROTEC relay. A-1
Figure A.2. Measured frequency of 7SJ62 SIPROTEC relay. A-1
Figure A.3. Measured frequency versus alias frequency of 7SJ61 SIPROTEC relay. A-1
Figure A.4. Measured frequency versus alias frequency of 7SJ62 SIPROTEC relay. A-2
Figure A.5. Percentage error of frequency response of 7SJ61 SIPROTEC relay. A-2
Figure A.6. Percentage error of frequency response of 7SJ62 SIPROTEC relay. A-2
Figure B.1. Measured frequency versus real (source) frequency of 7SJ61 SIPROTEC relay....B-1
Figure B.2. Measured frequency versus real (source) frequency of 7SJ62 SIPROTEC relay....B-1
Figure B.3. Measured frequency versus alias frequency of 7SJ61 SIPROTEC relay. B-1
Figure B.4. Measured frequency versus alias frequency of 7SJ62 SIPROTEC relay. B-2
Figure C.1. Measured current magnitude at 0.5 (A) and 0.1 (B) Arms of 7SJ61 SIPROTEC relay. C-1
Figure C.2. Measured current magnitude at 0.5 (A) and 0.1 (B) Arms of 7SJ62 SIPROTEC relay. C-1
Figure C.3. Percentage error of current magnitude of 7SJ61 (A) and 7SJ62 (B) SIPROTEC relays. C-2
Figure D.1. Measured current magnitude at 0.5 (A) and 0.1 (B) Arms of 7SJ61 SIPROTEC relay. D-1
Figure D.2. Measured current magnitude at 0.5 (A) and 0.1 (B) Arms of 7SJ62 SIPROTEC relay. D-1
Figure E.1. Current magnitude intensity response of 7SJ61 (A) and 7SJ62 (B) SIPROTEC relays. E-1

LIST OF TABLES

Table 1. Testing setup for 7SJ61 and 7SJ62 SIPORTEC relays. 2
Table 2. Sample rates of 7SJ61/ 7SJ62 SIPROTEC relays. 5
Table 3. Settings for 7SJ61 and 7SJ62 SIPROTEC relays. 6
Table 4. Zones for 7SJ61 and 7SJ62 SIPROTEC relays up to 20.16 kHz. 9

ACRONYMS

AC	Alternate Current
CT	Current Transformer
DC	Direct Current
HFPS/A	High Frequency Power Source/ Amplifier
HV	High Voltage
NE	Number of Events
NT	Number of Tests
RMS	Root Mean Square
RTE	Relay Test Equipment
SR	Sample Rate

ABSTRACT

This project examined the current magnitude and frequency response of 7SJ61 and 7SJ62 SIPROTEC relays. The measured sample frequencies for the 7SJ61 and 7SJS62 relays were 800 and 960 Hz, respectively. The relays were tested at frequencies of up to 1 and 20.16 kHz. Two experiments were run in a lab environment. The first experiment was run at frequencies of up to 1 kHz every 10 Hz. The second one was run at frequencies of up to 20.16 kHz every 200 and 240 Hz (common factors of sample rate frequency) for the 7SJ61 and 7SJ62 SIPROTEC relays, respectively. Both experiments were set at a current magnitude of 0.1 and 0.5 Arms.

A testbed with a Relay Test Equipment (RTE) was set to run the experiment at frequencies of up to 1 kHz, while a testbed with a RTE and High Frequency Power Source/ Amplifier (HFPS/A) was set to run at frequencies of up to 20.16 kHz. Currents of 0.1 and 0.5 Arms at different frequencies were connected at Phase A of the relays, and a current of 1 Arms (60 Hz) was connected at Phase B of relays. The 1 Arms current allowed the relays to trip and saved their record events by setting both relays at a definite-time overcurrent protection function. The record events were collected after the 7SJ61 and 7SJ62 relays tripped, and the current magnitude and frequency were plotted. The record events from the relays were collected using the DIGSI® 4 software. The SYNCHROWAVE® Event and MATLAB® software were then used to plot the current magnitude and frequency, respectively, from the relay record events. The current magnitude and frequency were plotted at time and frequency domain, respectively.

The 7SJ61 and 7SJ62 relays measured source frequencies of up to 400 and 480 Hz, respectively. The percentage error of frequency for the relays increased after 400 and 480 Hz, respectively. The 7SJ62 relay with 0.1 and 0.5 Arms measured the alias frequency up to 1440 Hz. The 7SJ61 relay with 0.1 and 0.5 Arms measured the alias frequency up to 1000 and 1200 Hz, respectively. At frequencies higher than the alias frequency, the relays measured a DC amplitude current instead of an AC amplitude current. In the DC amplitude current zone, non-desired frequencies were measured by both relays. The current magnitude intensity (dB) for the 7SJ61 and 7SJ62 relays from 1 to 20.16 kHz were plotted. The current magnitude intensity for the 7SJ61 relay decreased up to 2600 and 1200 Hz for 0.5 and 0.1 Arms tests, respectively. However, the current magnitude intensity for the 7SJ62 relay decreased up to 4800 and 2640 Hz for 0.5 and 0.1 Arms tests, respectively. The current magnitude and frequency response study for the 7SJ61 and 7SJ62 relays was performed satisfactorily, observing the source, alias, and non-desired measured frequency zones for both relays.

1. INTRODUCTION

In this project, the current magnitude and frequency response of the 7S61 and 7SJ62 relays were tested to observe the behavior of different frequency signals. The test framework was based on generating 0.1 and 0.5 Arms sinusoidal currents at frequencies of up to 20.16 kHz. The current magnitude and frequency response from these relays were collected and plotted. The states for the analog signals (current magnitude and frequency) were generated with a RTE and HFPS/A. Protection Suite® and DIGSI® 4 software were used to set the test states and relays, respectively. After running the tests, the record events from the relays were collected using DIGSI 4 software. The SYNCHROWAVE Event and MATLAB software were then used to plot the current magnitude and frequency from the relay record events, respectively. Figure 1 shows the software steps for the 7SJ61 and 7SJ62 relays.

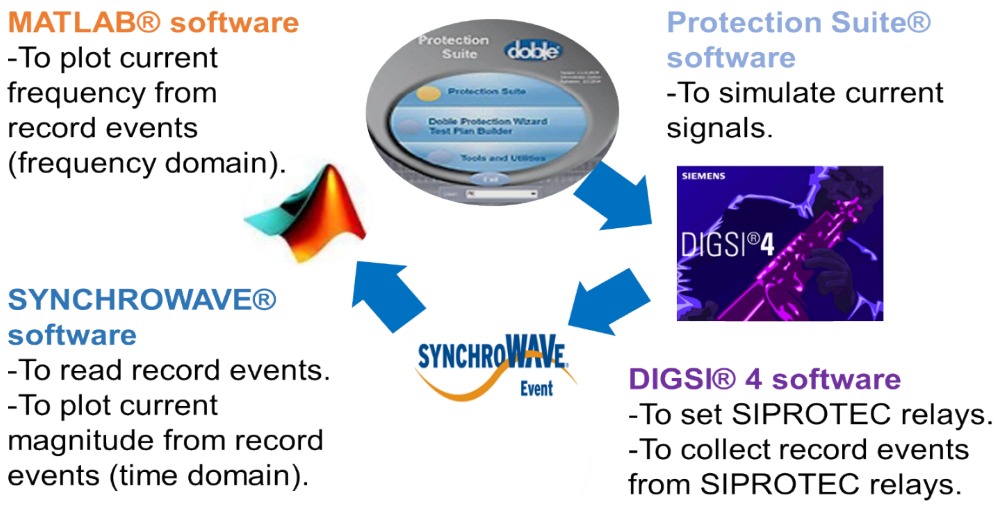


Figure 1. Software steps for 7SJ61 and 7SJ62 SIPROTEC relays.

2. EXPERIMENTS AND TESTBEDS

2.1 RELAY EXPERIMENTS

The technical approach to testing the relays was based on collecting the current frequency and magnitude at up to 1 and 20.16 kHz for the 7SJ61 and 7SJ62 relays. The relays were tested for sinusoidal currents at different frequency signals using two testbeds. Table 1 shows the experimental setup for the 7SJ61 and 7SJ62 relays.

Table 1. Testing setup for 7SJ61 and 7SJ62 SIPORTEC relays.

Experiments			**Up to 1 kHz (From 1 to 1000 Hz)**		**Up to 20.16 kHz (From 0.96 to 20.16 kHz)**	
Testbeds			**with RTE[a]**		**with RTE[a] and HFPS/A[b]**	
Analog Signals	**Phase A**	**Frequency**	Tests every 10 Hz		Tests performed every 200[c] and 240[c] Hz for 7SJ61 and 7SJ62 relay, respectively.	
		RMS Current	0.1 / 0.5 Arms	0.1 / 0.5 Arms	0.1 / 0.5 Arms	0.1 / 0.5 Arms
	Phase B	**Frequency**	60 Hz	60 Hz	60 Hz	60 Hz
		RMS Current	1 Arms	1 Arms	1 Arms	1 Arms
Relays		**SIPROTEC Model**	7SJ61	7SJ62	7SJ61	7SJ62
Tests		**N° of Events (NE)**	202 events	202 events	192 events	162 events
		N° of tests (NT = ∑ NE)	404 tests		354 tests	

[a] Relay Test Equipment (RTE)
[b] High Frequency Power Source/ Amplifier (HFPS/A)
[c] Common factors of relay sample rate frequency (800 and 960 samples/sec for 7SJ61 and 7SJ62 SIPROTEC relays, respectively)

The first testbed was run with a RTE that performed simulations up to 1 kHz. The second testbed added a HFPS/A that performed current simulations of up to 20.16 kHz. In the RTE testbed, a sinusoidal current of 0.5 and 0.1 Arms was simulated at 1, 10, 20, 30, up to 1000 Hz. However, the testbed with the RTE and HFPS/A simulated a sinusoidal current of 0.5 and 0.1 Arms up to 20.16 kHz. The measured sample frequencies for the 7SJ61 and 7SJS62 relays were 800 and 960 Hz, respectively. Therefore, tests up to 20.16 kHz were performed at 200 and 240 Hz (common factors of sample rate frequency) for the 7SJ61 and 7SJ62 relays, respectively. Currents of 0.1 and 0.5 Arms were set at phase A of the relays, and a current of 1 Arms (60 Hz) was set at phase B of the relays. The current of 1 Arms (60 Hz) allowed the relays to trip and saved their record events. The experiment up to 1 kHz had 404 tests. However, the experiment up to 20.16 kHz had 354 tests.

2.2 TESTBED WITH RELAY TEST EQUIPMENT

The testbed with the RTE performed the experiment up to 1 kHz. The Doble® F6150 was used as RTE, and it simulated the currents from 1 to 1000 Hz. The 7S61 and 7SJ62 relays were tested at 0.1 and 0.5 Arms. The testbed with the RTE is shown in Figure 2. The Relay laptop was used to set the relays and collect the record events after the tests were run using the DIGSI 4 software. The Relay laptop was connected to a relay with a SEL C662 serial cable.

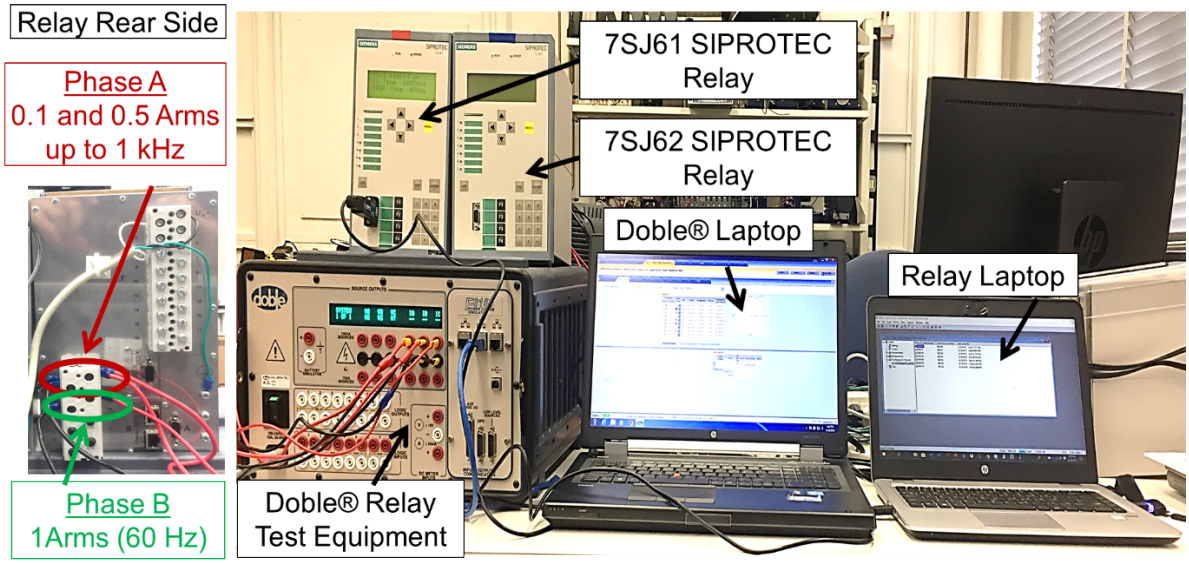


Figure 2. Testbed with Relay Test Equipment.

The Doble laptop, shown in Figure 2, was used to set the current magnitude and frequency for every test and to run the simulation. The tests were run at currents of 0.1 and 0.5 Arms at phase A of the relays. In addition, a current of 1 Arms (60 Hz) was set at phase B of the relays, to allow the relay to trip. The relay's record events were saved. The tests were run in groups of seven and eight tests for the 7SJ61 and 7SJ62 relays, respectively (maximum number of saved record events for these relays). Once the test group was run for every relay, the record events were collected to prevent loss of stored data.

2.3 TESTBED WITH RELAY TEST EQUIPMENT AND HIGH-FREQUENCY POWER SOURCE/AMPLIFIER

The testbed with the RTE (Doble F6150), high-frequency voltage source (Agilent® 33522A), and voltage-current power amplifier (KEPCO®) performed the experiment up to 20.16 kHz. Figure 3 shows the Testbed with RTE and HFPS/A. The Relay laptop was used to set the relays and collect the records

events after the test were run using the DIGSI 4 software. The Relay laptop was connected to a relay with a SEL C662 serial cable. The Doble laptop set the current magnitude and frequency for the tests and the simulations. In this testbed, the RTE generated a current of 1 Arms (60 Hz) to trip the relays. On the other hand, the HFPS/A generated currents of 0.1 and 0.5 Arms up to 20.16 kHz.

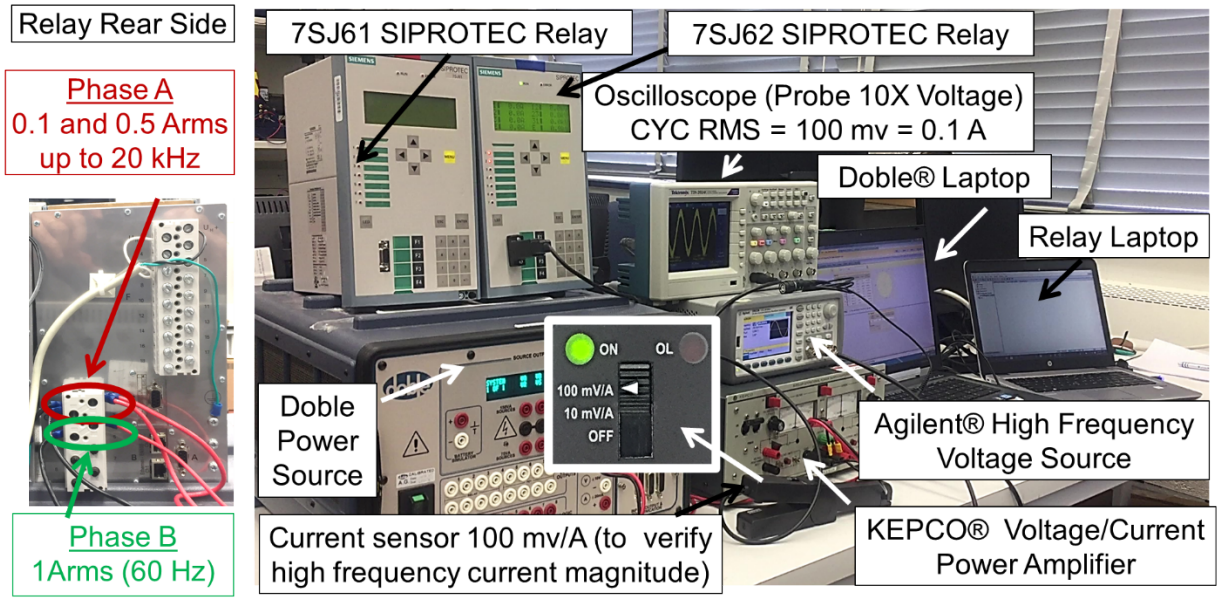


Figure 3. Testbed with Relay Test Equipment and High-Frequency Power Source/ Amplifier.

In Figure 3, the high-frequency voltage source was connected to the voltage/current power amplifier. Then, the high-frequency currents were generated by setting a sinusoidal voltage (up to 20.16 kHz). The sinusoidal voltage was converted into a sinusoidal current by the voltage/current power amplifier that was connected to the relay (Phase A). To verify currents of 0.1 or 0.5 Arms for the relay tests, a clamp current sensor scaled at 100 mv/A was connected to an oscilloscope with a Probe 10x Voltage, measuring 100 and 500 mV (RMS cycle voltages on the oscilloscope) for the 0.1 and 0.5 Arms current tests, respectively.

3. SIPROTEC RELAYS

3.1 RELAY SAMPLE RATES

The sample rate (SR) is defined as the speed at which samples are taken by the data acquisition units of measurement devices. The SR is measured in "samples per second," and it is usually expressed in Hertz (Hz), which means a collection of one data point per second. In relays, the data acquisition unit is the basic building block that collects the data points with a stamped time. In these devices, the data acquisition unit computes the voltage and current phasors from analog voltage and current waveforms. Based on a publication [1], the SR for the 7SJ61 and 7SJ62 SIPROTEC relays should be 800 Hz. However, the 7SJ62 SIPROTEC relay instruction manual [2] reported a SR of 960 Hz. To validate the SR for the 7SJ61 and 7SJ62 relays, a sinusoidal current (60 Hz) with the RTE (Doble F6150) was generated and injected to the relays. Then, the record events were collected and plotted to find the measured sample rate for both relays. Figure 4.A-B shows the record event and sample rate for the 7SJ61 and 7SJ62 relays, respectively. The record events validated a sample rate of 800 and 960 Hz for the 7SJ61 and 7SJ62 relays, respectively. Table 2 shows the sample rates for the relays.

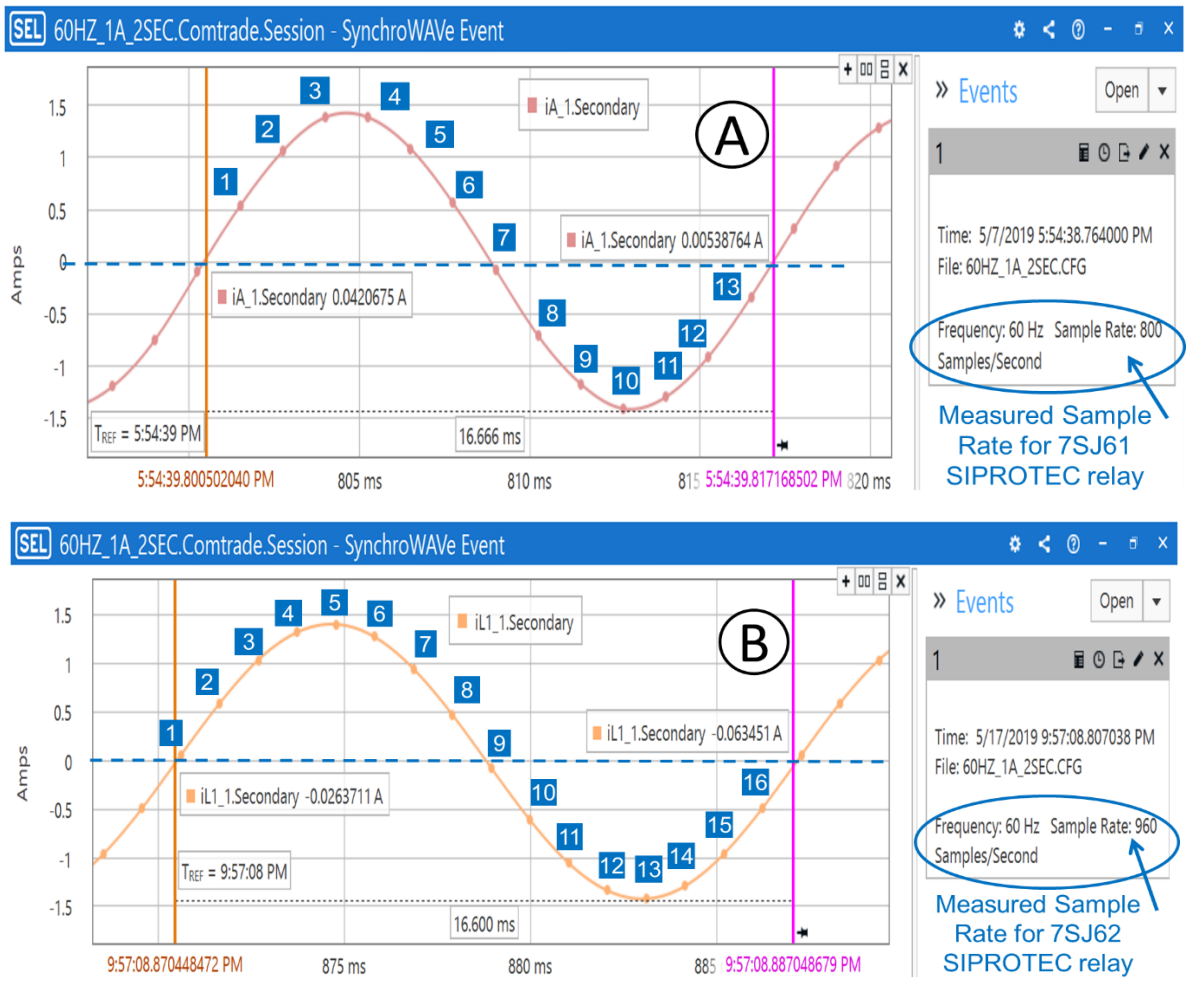


Figure 4. Record events and sample rates for 7SJ61 (A) and 7SJ62 (B) SIPROTEC relays.

Table 2. Sample rates of 7SJ61/ 7SJ62 SIPROTEC relays.

Relay Model	Sample rate from literature review [Hz]		Measured sample rate from record events [Hz]
			SYNCHROWAVE Event software
7SJ61	800 [a]	- [b]	800
7SJ62	800 [a]	960 [b]	960

[a] HV Power Measurements & Protection Ltd.
[b] SIPROTEC® Multi-Functional Protective Relay with Local Control 7SJ62/63/64 (V4.6) manual.

3.2 RELAY SETTINGS

The 7SJ61 and 7SJ62 relay settings are shown in Table 3. In the "Power System Data 1" function, the rated frequency and current transformer (CT) rated primary/secondary currents were set on the relays. However, the time delay and pickup for the 50-1 and 50-2 elements were set in the "Setting Group A," and the record event was set at the set "Oscillographic Fault Records."

Table 3. Settings for 7SJ61 and 7SJ62 SIPROTEC relays.

Functions	Settings	Descriptions	Values of SIPROTEC Relays	
			7SJ61	7SJ62
Power System Data 1	Power Systems	Rated Frequency	60 Hz	60 Hz
	CTs	CT Rated Primary Current	10 A	100 A
		CT Rated Secondary Current	5 A	1 A
Setting Group A	50/51 Phase/Ground Overcurrent Protection	50-1 Time Delay	0.50 sec	0.50 sec
		50-1 Pickup	0.50 A	0.50 A
		50-2 Time Delay	0.00 sec	0.00 sec
		50-2 Pickup	5.00 A	5.00 A
		50-3 Time Delay	0.00 sec	0.00 sec
		50-3 Pickup	oo A	oo A
Oscillographic Fault Records	Osc. Fault Rec.	Waveform Capture	Save with Pickup	Save with Pickup
		Scope of Waveform Data	Fault event	Fault event
		Max. length of a Waveform Capture Record	2.00 sec	2.00 sec
		Captured Waveform Prior to Triger	0.25 sec	0.25 sec
		Captured Waveform after Event	0.10 sec	0.10 sec
		Capture Time via Binary Input	0.50 sec	0.50 sec

The 7SJ61 and 7SJ62 relays were set with a time overcurrent protection. This function is based on the phase-selective measurement of the phase current to trip the relay in an overcurrent fault situation. The relays were set with two definite-time overcurrent protection elements for the phase currents. The current threshold and the delay time were set within a range that allowed the relays to trip during the tests and their record events to be stored. The relays were set with a 50-1 and 50-2 time delay of 0.50 and 0.00 seconds, respectively, and a 50-1 and 50-2 pickup of 0.5 and 5.00 Arms, respectively. Based on these time delay and pickup settings, the definite-time overcurrent setting curve for the relays was plotted, as shown in Figure 5-A. At the current test of 1.0 Arms, the relays tripped at 0.5 seconds (500 milliseconds). The displays for the 7SJ61 and 7SJ62 relays are shown in Figure 5-B.

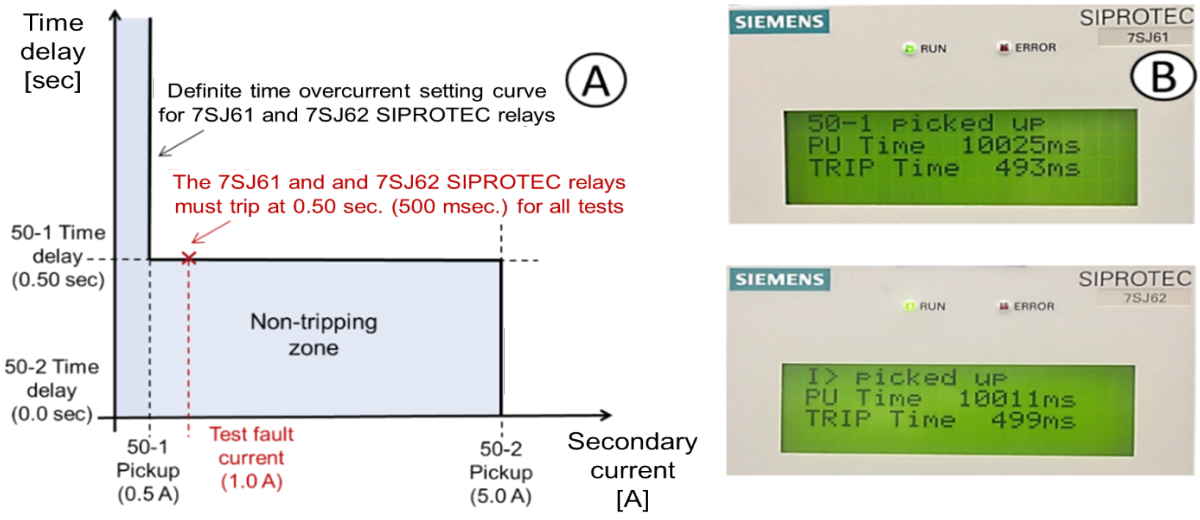


Figure 5. Definite-time overcurrent setting curve (A) and relays' displays (B).

4. RESULTS AND CONCLUSIONS

The test results for 7SJ61 and 7SJ62 SIPROTEC relays were based on current magnitude and a frequency response of up to 1 and 20.16 kHz. For the first experiment, tests of up to 1 kHz were run every 10 Hz for both relays. For the second experiment, tests of up to 20.16 kHz were run every 200 and 240 Hz (common factors of sample rate frequency) for the 7SJ61 and 7SJ62 relays, respectively. Analyses of the frequency and current magnitude were performed in frequency and time domain, respectively. The frequency analysis was performed by plotting the phase A current from the record events. The time and frequency response of phase A current was plotted using MATLAB software. All the frequencies were then collected from the MATLAB plots, and the relay and source current frequencies were plotted and compared. On the other hand, the current magnitude analysis was performed by plotting the phase A current from the record events using SEL SYNCHROWAVE Event software. The maximum and minimum current magnitudes for all the tests were then collected, and the midpoint current magnitude was calculated, to plot and compare the measured relay current with the source current magnitude.

The frequency analysis for 7SJ61 and 7SJ62 relays up to 1 kHz showed the following conclusions.

- The 7SJ61 and 7SJ62 relays measured the source frequency up to 400 Hz (Figure A.1) and 480 Hz (Figure A.2), respectively.
- The 7SJ61 and 7SJ62 relays generated the alias frequencies after 400 Hz (Figure A.3) and 480 Hz (Figure A.4), respectively (up to 1000 Hz).
- The tests for 0.1 and 0.5 Arms showed identical frequency responses (Figure A.1–2).
- The percentage error of frequency for the 7SJ61 and 7SJ62 relays increased after 400 and 480 Hz, respectively (Figure A.5–6). The percentage error of frequency was calculated by Equation (1).

$$E_{\%} = \frac{f_r - f}{f} \times 100\,, \tag{1}$$

  where $E_{\%}$ is the percentage error of frequency, f_r is the measured relay frequency in Hz, and f is the source (real) frequency in Hz.

- The alias frequency Equation (2), collected from a weblink [3], was validated by the relay measured frequency (Figure A.3–4).

$$f_a = \left| f - \frac{(k+1) \times f_s}{2} \right|, \tag{2}$$

where f_a is the alias frequency in Hz, f is the source (real) frequency in Hz, k is equal to 1, and f_s is the sampling frequency of 800 and 960 Hz for the 7SJ61 and 7SJ62 relays, respectively.

The frequency analysis for the 7SJ61 and 7SJ62 relays up to 20.16 kHz led to the following conclusions.

- The 7SJ61 and 7SJ62 relays did not measure the source frequency at ≥ 1 kHz (Figure B.1-2).
- The 7SJ61 relay with 0.1 Arms did not measure the alias frequency at ≥ 1 kHz (Figure B.3).
- The 7SJ61 relay with 0.5 Arms measured the alias frequency up to 1.2 kHz (Figure B.3).
- The 7SJ62 relay with 0.1 and 0.5 Arms measured the alias frequency up to 1.44 kHz (Figure B.4).

The current magnitude analysis for the 7SJ61 and 7SJ62 relays up to 1 kHz led to the following conclusions.

- The measured current magnitude for 7SJ61 and 7SJ62 relays oscillated between a maximum and minimum value, current magnitude band (Figure C.1–2). Then the measured midpoint current magnitude of relay was calculated by Equation (3).

$$I_{mp} = I_{min} + \frac{I_{max} - I_{min}}{2}, \tag{3}$$

where I_{mp} is the midpoint current magnitude of relay in Arms, I_{min} is the minimum current magnitude of relay in Arms, and I_{max} is the maximum current magnitude of relay in Arms.

- The higher the source frequency, the smaller the measured relay current magnitude for both relays (Figure C.1–2).

- The 0.5 and 0.1 Arms tests for the 7SJ61 relay showed a similar shape for the current magnitude band up to 490 Hz (Figure C.1).

- The 0.5 and 0.1 Arms tests for the 7SJ62 relay showed a similar shape for the current magnitude band up to 1000 Hz (Figure C.2).

- The percentage error of the current magnitude for 7SJ61 and 7SJ62 relays was smaller around the fundamental frequency (Figure C.3). The percentage error of current magnitude was calculated by Equation (4).

$$E_{M\%} = \frac{I_{mp} - I_s}{I_s} \times 100, \tag{4}$$

where $E_{M\%}$ is the percentage error of current magnitude, I_{mp} is the midpoint current magnitude of relay in Arms, and I_s is the source (real) current magnitude in Arms.

The current magnitude analysis for the 7SJ61 and 7SJ62 relays up to 20.16 kHz led to the following conclusions.

- The 7SJ61 relay with a source current of 0.5 and 0.1 Arms measured 0.042 and 0.018 Arms (1 kHz), respectively, decreasing to zero from 1 to 20 kHz (Figure D.1).

- The 7SJ62 relay with a source current of 0.5 and 0.1 Arms measured 0.049 and 0.008 Arms (0.96 kHz), respectively, decreasing to zero from 0.96 to 20.16 kHz (Figure D.2).

The current magnitude intensity (dB) for 7SJ61 and 7SJ62 relays from 1 to 20.16 kHz led to the following conclusions.

- The measured current magnitude intensity (*dB*) for 7SJ61 and 7SJ62 relay was plotted by Equation (5).

$$I(dB) = 10\ Log_{10}\left[\frac{I_{mp}}{I_s}\right], \tag{5}$$

where I (*dB*) is the current magnitude intensity in decibels, I_{mp} is the midpoint current magnitude of the relay in Arms, and I_s is the source (real) current magnitude in Arms.

- The current magnitude intensity in dB for the 7SJ61 relay decreased up to 2600 and 1200 Hz for 0.5 and 0.1 Arms tests, respectively (Figure E.1-A).

- The current magnitude intensity in dB for the 7SJ62 relay decreased up to 4800 and 2640 Hz for 0.5 and 0.1 Arms tests, respectively (Figure E.1-B).

In conclusion, the test results for 7SJ61 and 7SJ62 SIPROTEC relays revealed an AC and DC amplitude time domain zone. Within the AC amplitude time domain zone, the relays measured the source and alias frequency. The 7SJ61 and 7SJ62 relays measured the source frequency up to 400 and 480 Hz, respectively. Then, the 7SJ61 and 7SJ62 SIPROTEC relays measured the alias frequency up to 1200 and 1440 Hz, respectively. However, within the DC amplitude time domain zone, the relays measured a non-desired frequency up to the current magnitude decreased to zero. Table 4 shows the time and frequency domain zones for 7SJ61 and 7SJ62 SIPROTEC relays up to 20.16 kHz.

Table 4. Zones for 7SJ61 and 7SJ62 SIPROTEC relays up to 20.16 kHz.

Zones	Time Domain	Relay Measurements		Source Frequency Range [R]			
		Frequency Domain	Midpoint of Current Range	7SJ61 Relay Tests[a, b] (Sample rate = 800 Hz)		7SJ62 Relay Tests[a, c] (Sample rate = 960 Hz)	
				0.1 Arms	0.5 Arms	0.1 Arms	0.5 Arms
1	AC Amplitude	= source frequency	≤ source current magnitude	$R \leq 400$ Hz	$R \leq 400$ Hz	$R \leq 480$ Hz	$R \leq 480$ Hz
2		= alias frequency	<< source current magnitude	400 Hz < R ≤ 1000 Hz	400 Hz < R ≤ 1200 Hz	480 Hz < R ≤ 1440 Hz	480 Hz < R ≤ 1440 Hz
3	DC Amplitude	Non-desired frequency	<<< source current magnitude, decreasing to zero	1000 Hz < R ≤ 20000 Hz	1200 Hz < R ≤ 20000 Hz	1440 Hz < R ≤ 20000 Hz	1,440 Hz < R ≤ 20000 Hz

[a] Tests for 7SJ61 and 7SJ62 SIPROTEC relays up to 1,000 Hz were performed every 10 Hz.
[b] Tests for 7SJ61 SIPROTEC relays higher than 1,000 Hz were performed every 200 Hz.
[c] Tests for 7SJ62 SIPROTEC relays higher than 960 Hz were performed every 240 Hz.

5. REFERENCES

1. Event and Fault records in SIPROTEC® COMPACT and SIPROTEC® 4 relays. HV Power Measurements & Protection Ltd., Auckland, New Zealand, P O Box 26-074. Available on 6/10/20 at http://www.hvpower.co.nz/TechnicalLibrary/Siprotec/Event_and_Fault_Records_in_SIPROTEC_COMPACT_and_SIPROTEC_4_Relays.pdf
2. SIPROTEC® Multi-Functional Protective Relay with Local Control 7SJ62/63/64 (V4.6) manual. Available on 6/10/20 at http://www.automation-berlin.com/downloads/siemens/energy_ptd/7SJ62-64_Manual_A9_V046300_us.pdf
3. Alias Frequency Scaling Factor. Available on 6/10/20 at https://i.redd.it/3hh4sucp0ir01.png

APPENDIX A. CURRENT FREQUENCY ANALYSIS UP TO 1 kHZ

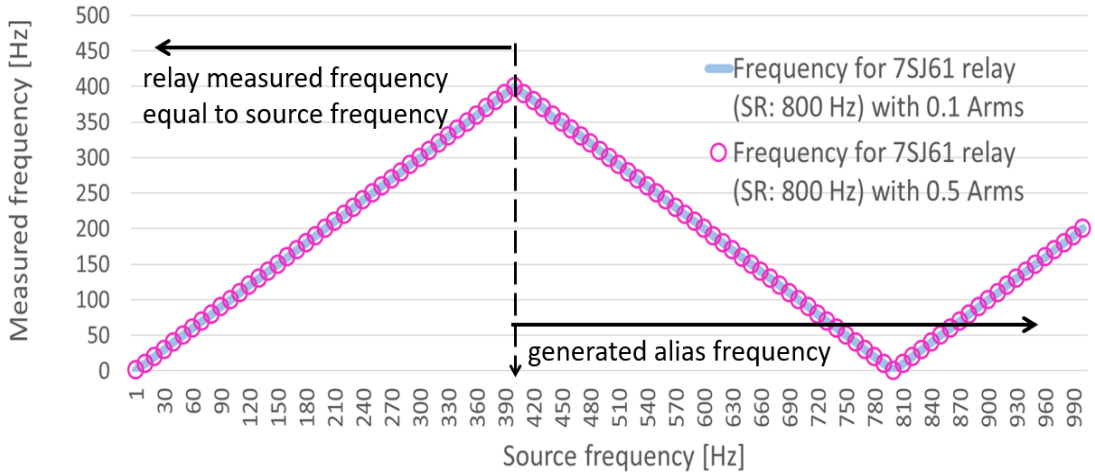


Figure A.1. Measured frequency of 7SJ61 SIPROTEC relay.

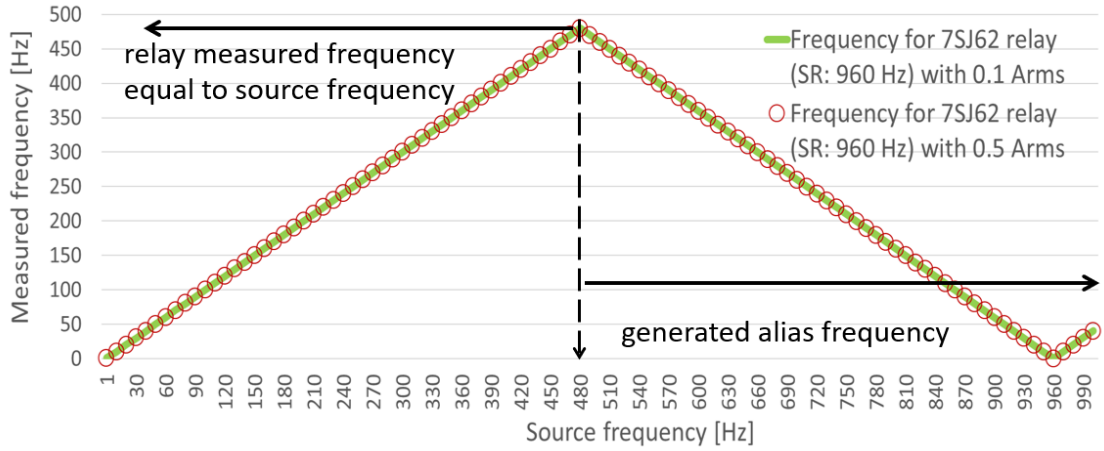
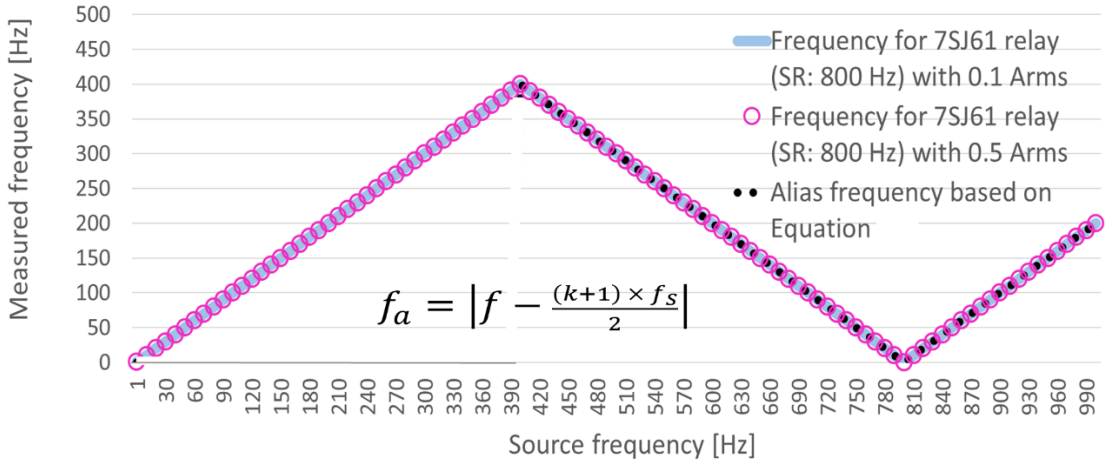
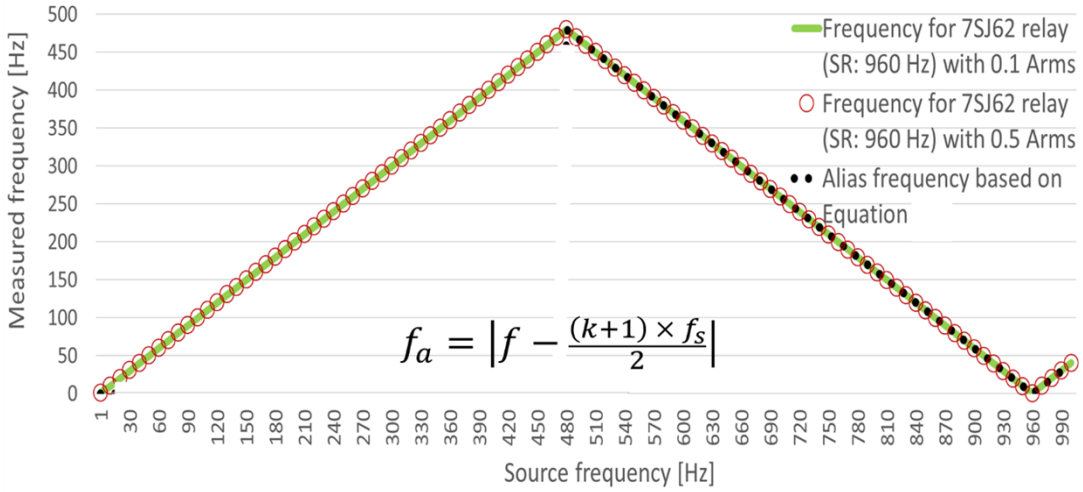


Figure A.2. Measured frequency of 7SJ62 SIPROTEC relay.



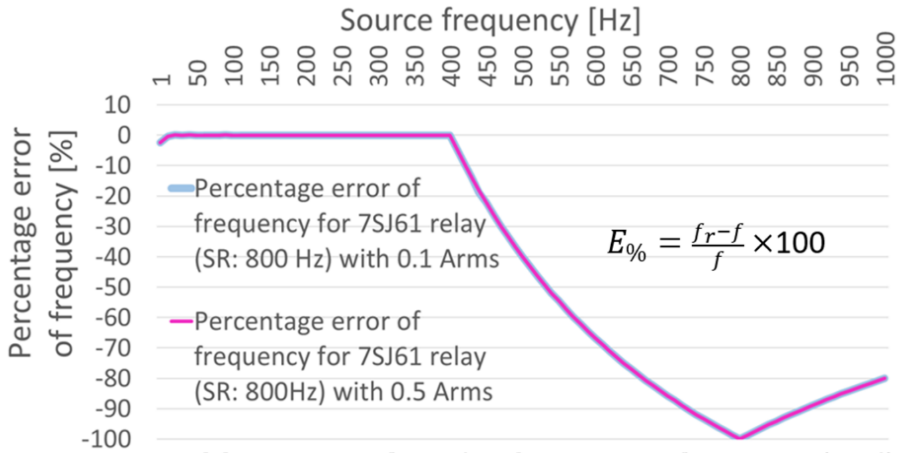
f_a = alias frequency, f = source (real) frequency, f_s = sampling frequency (800 Hz), k = 1

Figure A.3. Measured frequency versus alias frequency of 7SJ61 SIPROTEC relay.



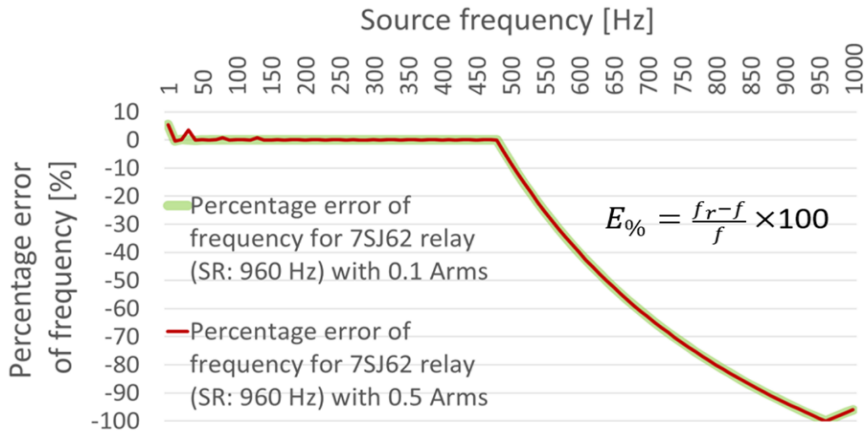
f_a = alias frequency, f = source (real) frequency, f_s = sampling frequency (960 Hz), k = 1

Figure A.4. Measured frequency versus alias frequency of 7SJ62 SIPROTEC relay.



$E_{\%}$= percentage error of frequency, f_r = relay frequency, f = source (real) frequency

Figure A.5. Percentage error of frequency response of 7SJ61 SIPROTEC relay.



$E_{\%}$= percentage error of frequency, f_r = relay frequency, f = source (real) frequency

Figure A.6. Percentage error of frequency response of 7SJ62 SIPROTEC relay.

APPENDIX B. CURRENT FREQUENCY ANALYSIS UP TO 20.16 kHZ

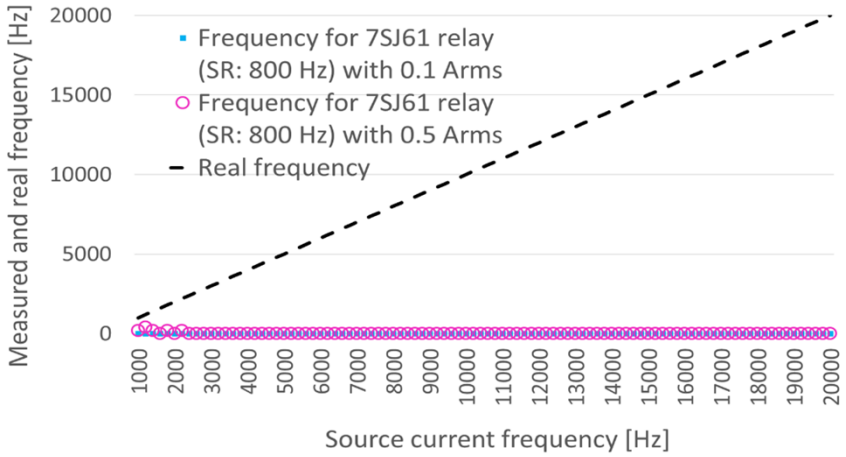


Figure B.1. Measured frequency versus real (source) frequency of 7SJ61 SIPROTEC relay.

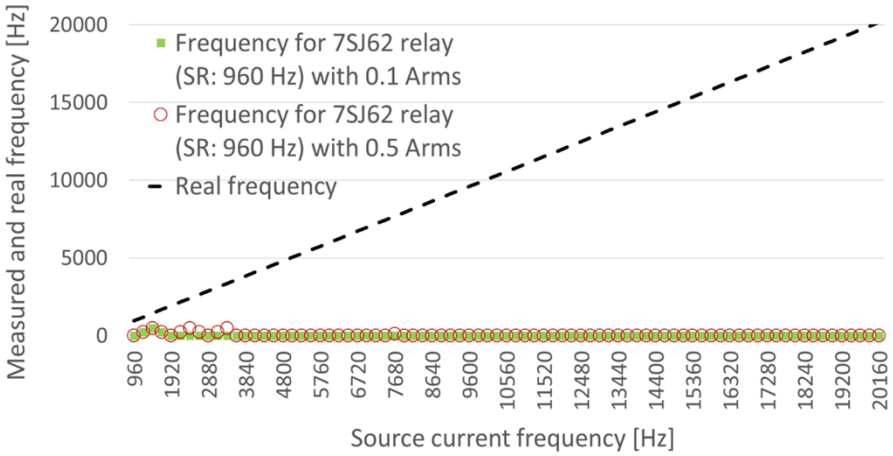


Figure B.2. Measured frequency versus real (source) frequency of 7SJ62 SIPROTEC relay.

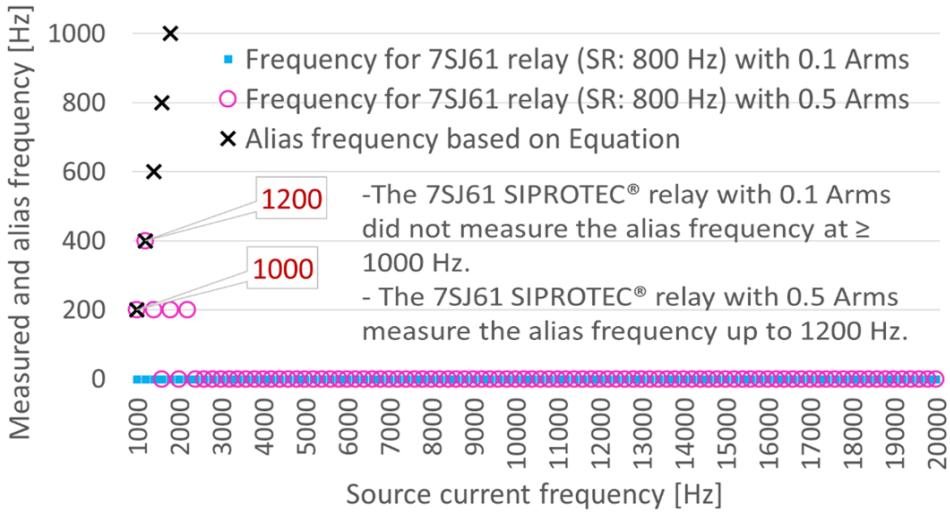


Figure B.3. Measured frequency versus alias frequency of 7SJ61 SIPROTEC relay.

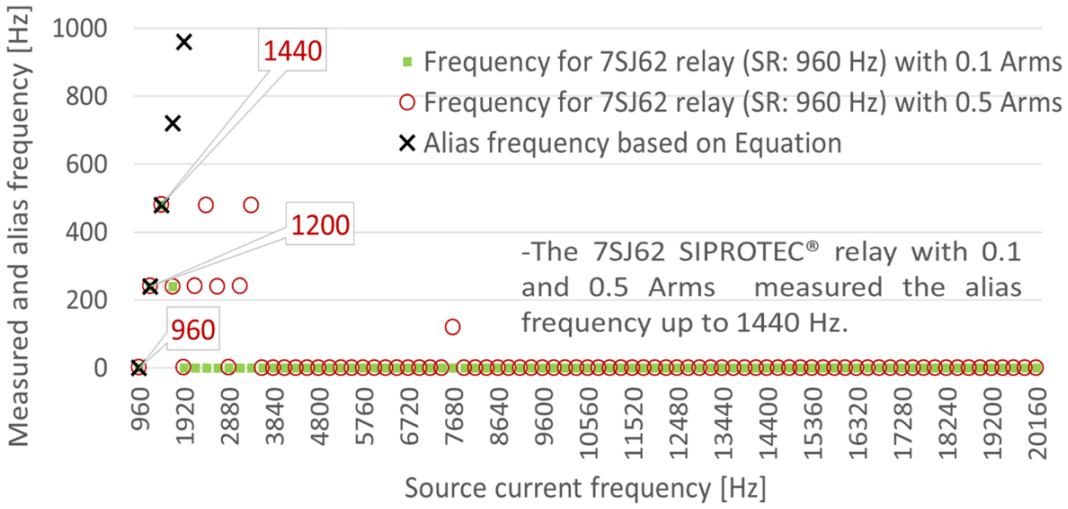


Figure B.4. Measured frequency versus alias frequency of 7SJ62 SIPROTEC relay.

APPENDIX C. CURRENT MAGNITUDE ANALYSIS UP TO 1 kHZ

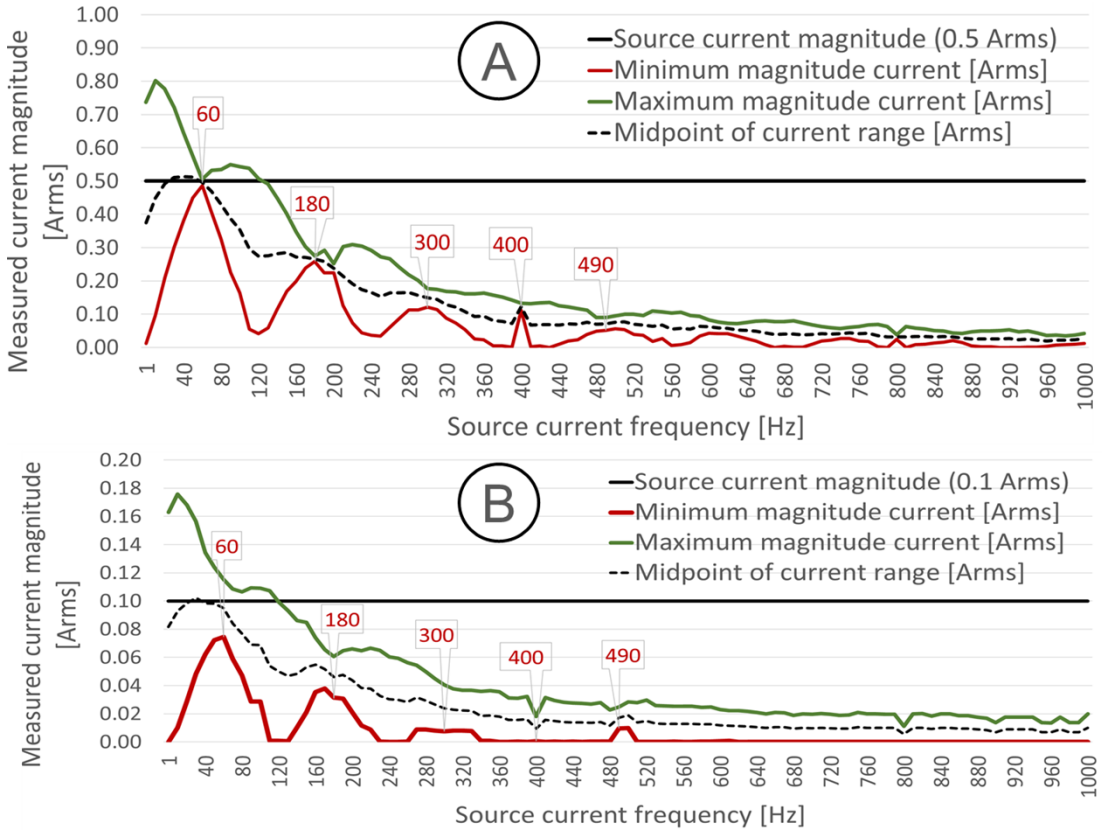


Figure C.1. Measured current magnitude at 0.5 (A) and 0.1 (B) Arms of 7SJ61 SIPROTEC relay.

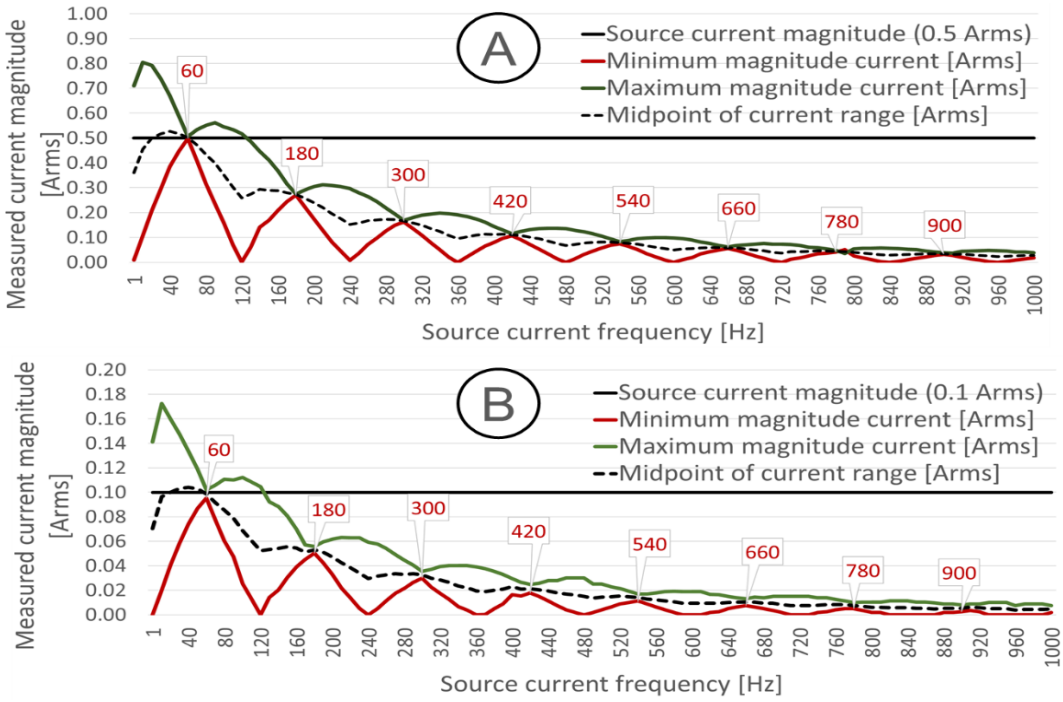
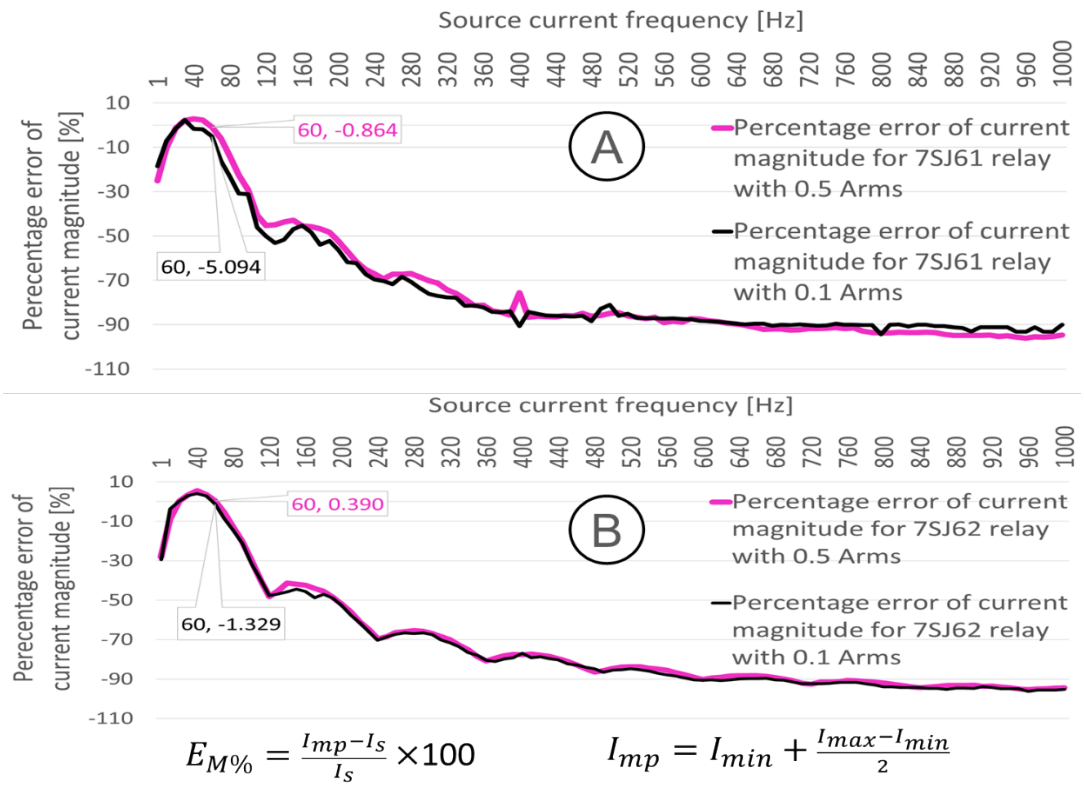


Figure C.2. Measured current magnitude at 0.5 (A) and 0.1 (B) Arms of 7SJ62 SIPROTEC relay.



$$E_{M\%} = \frac{I_{mp} - I_s}{I_s} \times 100 \qquad I_{mp} = I_{min} + \frac{I_{max} - I_{min}}{2}$$

$E_{M\%}$= percentage error of current magnitude of relay, I_{mp} = measured mid-point current of relay, I_s = source (real) current magnitude, I_{min}= measured minimum current magnitude of relay, I_{max} = measured maximum current magnitude of relay

Figure C.3. Percentage error of current magnitude of 7SJ61 (A) and 7SJ62 (B) SIPROTEC relays.

APPENDIX D. CURRENT MAGNITUDE ANALYSIS UP TO 20.16 kHZ

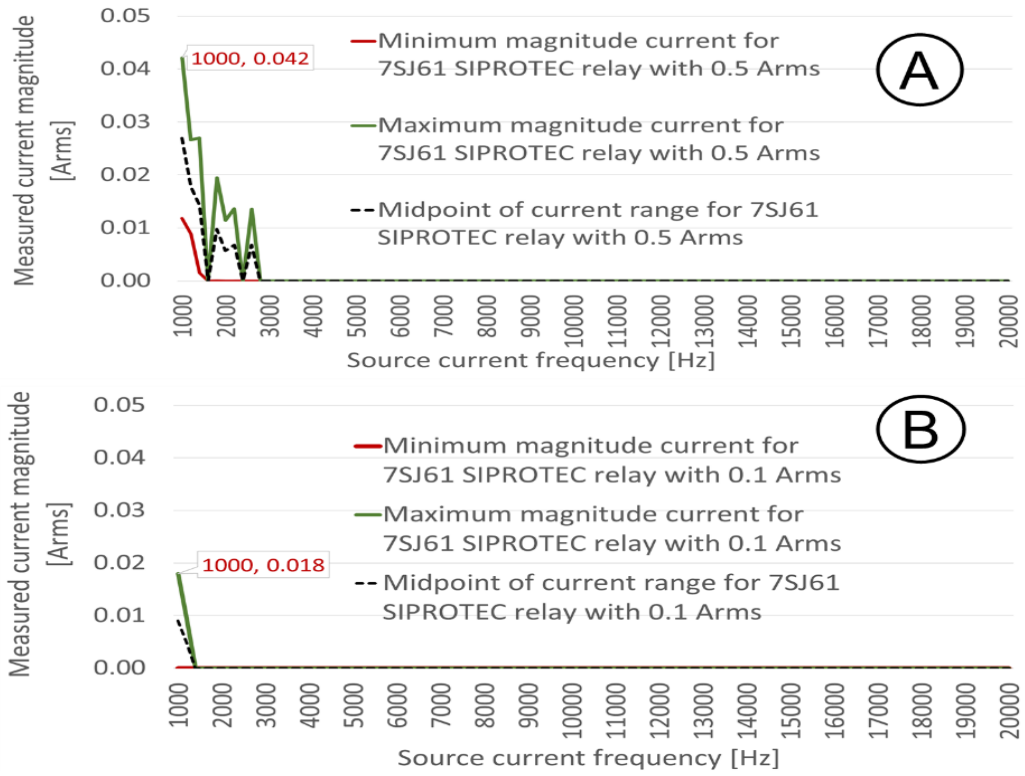


Figure D.1. Measured current magnitude at 0.5 (A) and 0.1 (B) Arms of 7SJ61 SIPROTEC relay.

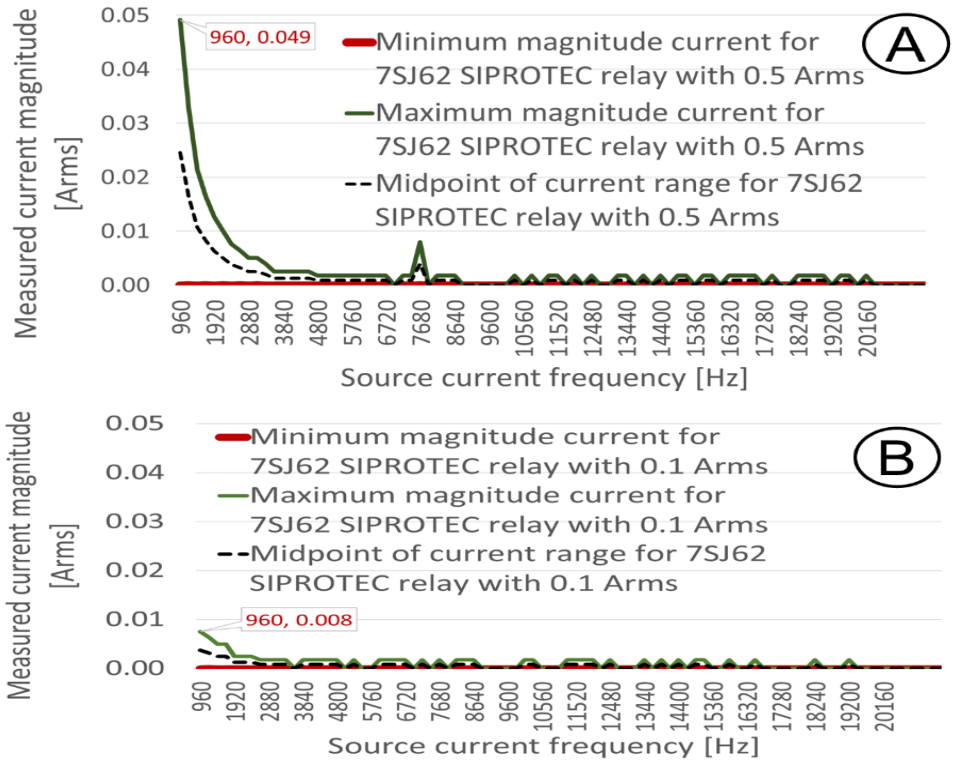
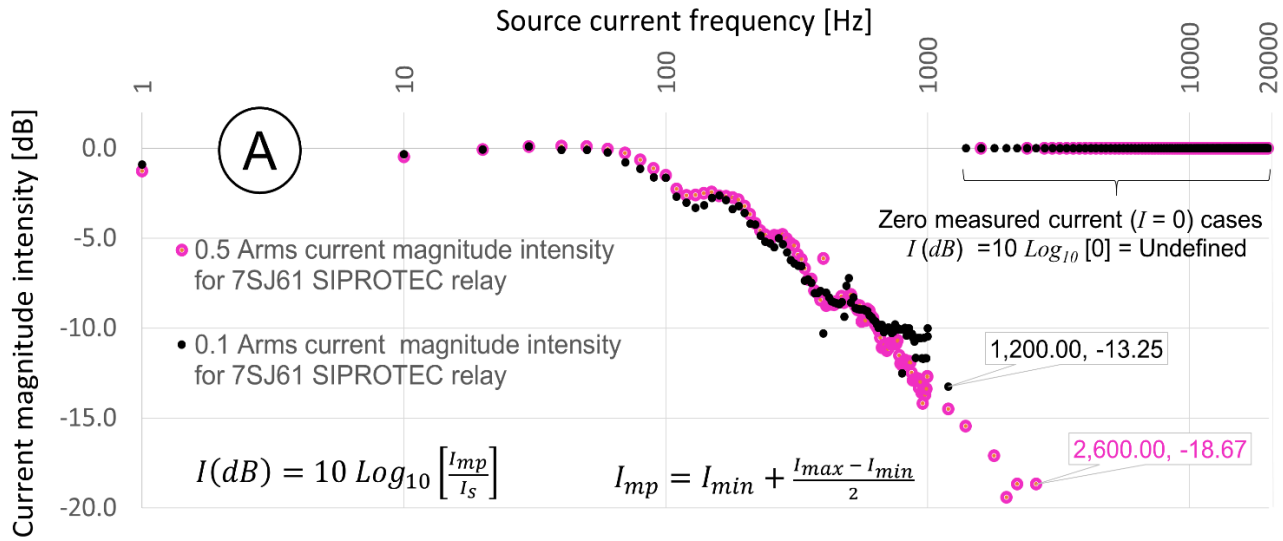
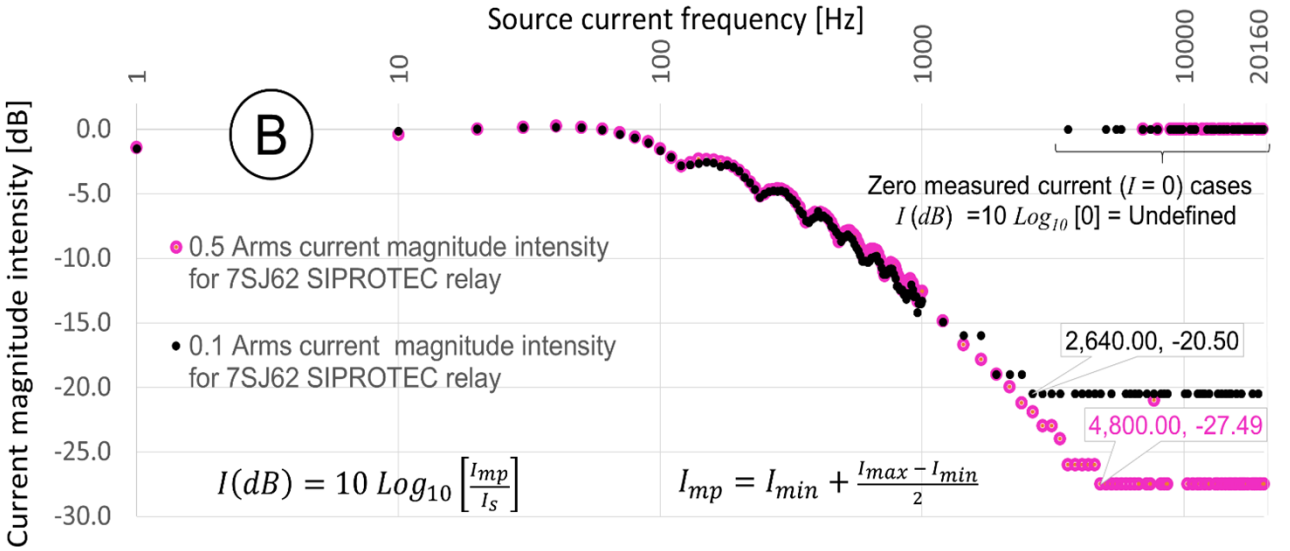


Figure D.2. Measured current magnitude at 0.5 (A) and 0.1 (B) Arms of 7SJ62 SIPROTEC relay.

APPENDIX E. CURRENT MAGNITUDE INTENSITY FROM 1 TO 20.16 kHZ



$I\,(dB)$ = current magnitude intensity in decibels, I_{mp} = measured midpoint current magnitude of relay in Arms, I_s = source (real) current magnitude in Arms, I_{min} = measured minimum current magnitude in Arms, I_{max} = measured maximum current magnitude in Arms



$I\,(dB)$ = current magnitude intensity in decibels, I_{mp} = measured midpoint current magnitude of relay in Arms, I_s = source (real) current magnitude in Arms, I_{min} = measured minimum current magnitude in Arms, I_{max} = measured maximum current magnitude in Arms

Figure E.1. Current magnitude intensity response of 7SJ61 (A) and 7SJ62 (B) SIPROTEC relays.