Time-Current Curves Using Excel 2013

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Abstract

This document serves a guide for the creation of time-current curves using Excel[1] 2013. The user is expected to have at least an intermediate level of knowledge in the usage of aforementioned software else it will be difficult to understand the procedures presented herein. Calculating fault currents is likewise beyond the scope of this document.

Index Terms

time-current curve, fault current, protection relay

I. Introduction

In 2008, I have created some articles on the creation of time-current curves using Excel 2003.
1) Creating Coordination Curves with Excel (Pangonilo, 2008) [1];
2) Time-current Curves with Excel Part II (Pangonilo, 2008) [2];
3) Time-current Curves with Excel Part III (Pangonilo, 2008) [3];
4) Time-current Curves with Excel Part IV (Pangonilo, 2008) [4].

The steps mentioned in above tutorials may not be applicable anymore with the newer versions of Excel particularly if you are a beginner. This tutorial is an update of those tutorials combined into single article complete with a downloadable pdf. While the 2008 tutorials referred to the IEC[2] 60255-3:1989, this tutorial was updated to IEC 60255-151:2009 which is the current revision of the standard and supersedes IEC 60255-3:1989.

II. Skills Requirement

To be able to follow through process of this tutorial, familiarity with the use of Excel 2013 is necessary particularly with the creation of graphs. Without this knowledge, it will be very difficult to understand the steps provided herein.

The minimum requirements of this tutorial are the following
- You have MS Excel - at least MS Excel 2013 or higher versions;
- You know how to use MS Excel;
- You know how to create graphs.

If you do not have the skills listed, Excel online tutorials are available online. Try this link "https://bit.ly/2koZQ9P".

III. Objectives

Performing protective devices coordination is always a part of our tasks as Electrical Engineers. You may use ETAP[3], SKM Power Tools[4] or any Power System Analysis software to do the job, if your company has the money to buy the software. What matters most however is the technical know-how in using the sophisticated power system analysis software.

The objective of this tutorial is to guide the Electrical Engineer to create coordination curves for any particular application. This tutorial also aims to provide tips during the process.

Calculating fault–currents are beyond the scope of this tutorial.

Figure 1 is a sample of coordination curve plot that we will produce by the end of this tutorial. If you are able to plot the desired graph, then you have successfully learned how to create T-C curve using Excel 2013.

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[1] Microsoft® Excel

[2] International Electrotechnical Commission

[3] https://etap.com

[4] https://skm.com

Figure 1: Completed T-C Curve
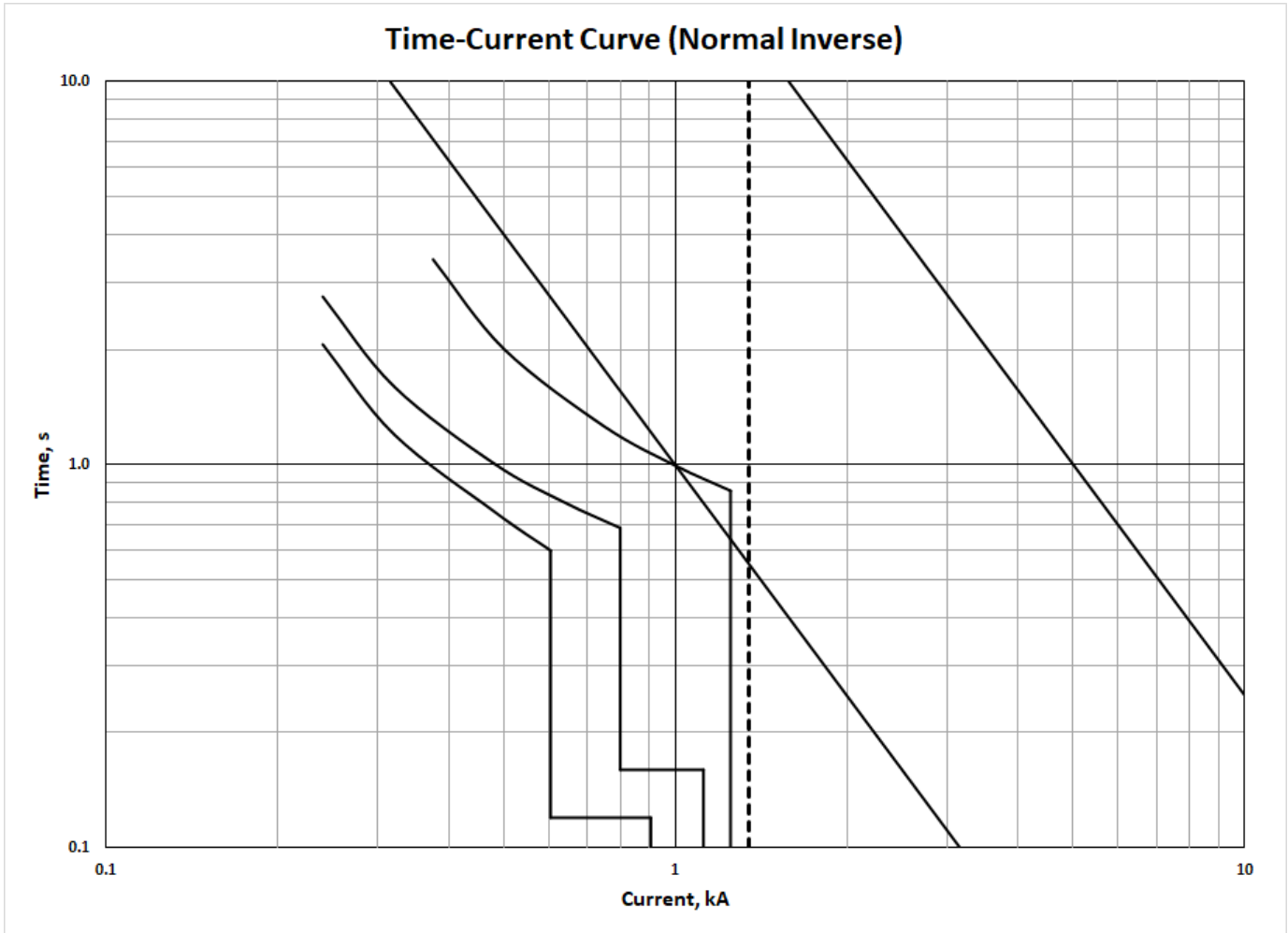
Table I: Normal Inverse Curve - 400A Setting

I (A)	t (s)
600	2.75
800	1.60
1200	1.01
1600	0.80
1600	0.80
1600	0.14
4800	0.14
4800	0.10

IV. PLOTTING THE T-C CURVE

In this part of the tutorial, we shall be able to produce a **Normal Inverse Time-Current** curve. Given the values Table I, we plot the values on an XY Scatter graph with data points connected without markers.

Table II: Data Series 1

I (A)	t (s)
600	2.75
800	1.60
1200	1.01
1600	0.80

Table III: Data Series 2

I (A)	t (s)
1600	0.80
1600	0.14

A. Preliminary T-C Curve

Try to plot the values and I presume that you will be getting a graph similar to Figure 2. We know that we are not getting the correct plot profile that we wanted. We will find a way to produce the plot we desire.

Figure 2: Normal Inverse Curve 400A Setting (Wrong Plot)
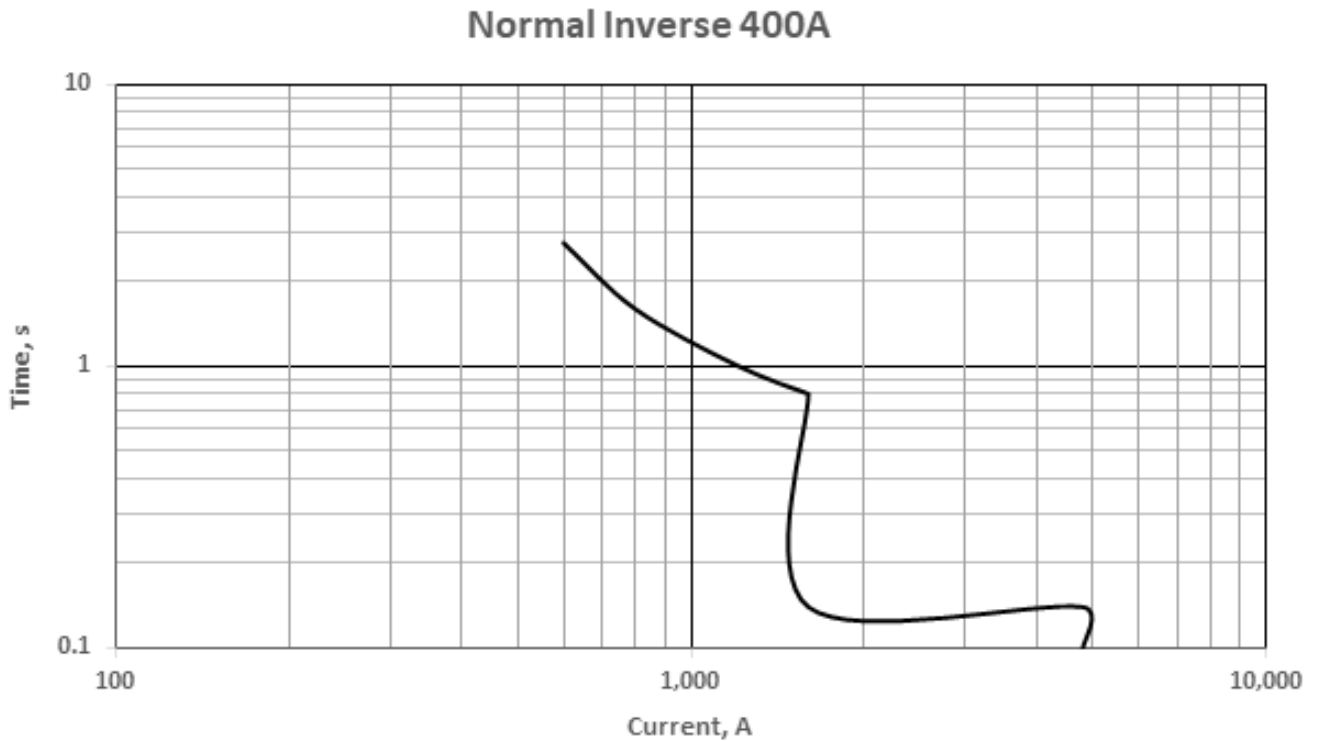
To plot a graph similar to Figure 3, the technique is to chunk the data into separate data series (refer to Tables II, III, IV and V). Plot each data series as individual curves on the graph.

Figure 3: Normal Inverse Curve 400A Setting (Correct Plot)
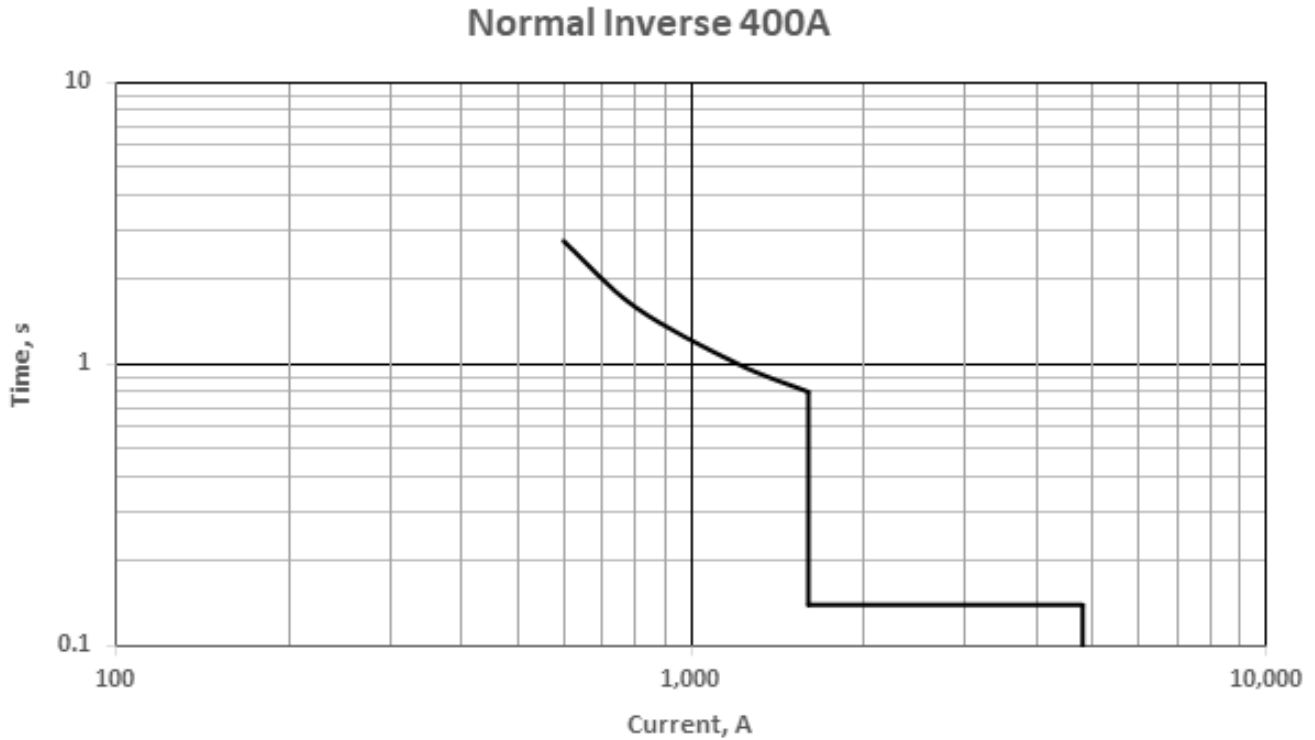

Normal Inverse 400A

Table IV: Data Series 3

I (A)	t (s)
1600	0.14
4800	0.14

B. T-C Curve Creation

As mention in Section II of this tutorial, it is presumed that you know how to use Excel 2013 or newer.

In this part, we shall learn how to calculate curves for normal inverse, very inverse, extreme inverse and longtime inverse.

We shall also be able to create Normal Inverse curves from the formula given in (1). This formula has been used in so many coordination studies worldwide. You can actually use it to coordinate your protection settings with your power supplier. Normally the time setting for the network protection will be provided by the power supplier. We shall discuss this on the succeeding sections of the tutorial.

Table V: Data Series 4

I (A)	t (s)
4800	0.14
4800	0.10

$$t(G) = TMS \left[\frac{k}{\left(\frac{G}{G_S}\right)^\alpha - 1} + c \right] \qquad (1)$$

where:

t(G) is the theoretical operate time with constant value of *G* in seconds;

k, c, a are the constants characterizing the selected curve;

G is the measured value of the characteristic quantity;

G_S is the setting value;

TMS is the time multiplier setting.

The constants *k* and *c*, have a unit of seconds, *a* has no dimension.

Below table list the values required in the equation (1).

Table A.1 – Constants for dependent time operating and reset characteristics

Curve type	Operating time $t(G) = TMS \left[\frac{k}{\left(\frac{G}{G_S}\right)^\alpha - 1} + c \right]$			Reset time $t_r(G) = TMS \left(\frac{t_r}{1 - \left(\frac{G}{G_S}\right)^\alpha} \right)$		Commonly used name
	k	**c**	**α**	**t_r**	**α**	
	s	**s**		**s**		
A	0,14	0	0,02	[a]	[a]	Inverse
B	13,5	0	1	[a]	[a]	Very inverse
C	80	0	2	[a]	[a]	Extremely inverse
D	0,0515	0,1140	0,02	4,85	2	IEEE Moderately inverse
E	19,61	0,491	2	21,6	2	IEEE Very inverse
F	28,2	0,1217	2	29,1	2	IEEE Extremely inverse

[a] For curves A, B and C, the manufacturer shall declare if dependent time reset characteristic is implemented and provide the appropriate information.

Source IEC 60255-151:2009 Table A-1

Using (1), the resulting values will be the Table VI. You could copy the whole table and paste it into your worksheet or create the values yourself following the sample in (2).

Remember that this curve is for Normal Inverse curve. To provide an example calculation with values taken from Table VI - (*TMS=0.05*, $\frac{G}{G_S}$ = 1.5, *k=0.14, c=0, α=0.02*)

$$t(G) = 0.05 \left[\frac{0.14}{(1.5)^{0.02} - 1} + 0 \right] \qquad (2)$$

$$t(G) = 0.86 \qquad (3)$$

Table VI: Normal Inverse Curve - 500A CT Rating

$\frac{G}{G_S}$	G (A)	Time (t), s											
		0.05	0.10	0.20	0.25	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
1.5	750	0.86	1.72	3.44	4.30	5.16	6.88	8.60	10.32	12.04	13.76	15.47	17.19
2.0	1000	0.50	1.00	2.01	2.51	3.01	4.01	5.01	6.02	7.02	8.02	9.03	10.03
3.0	1500	0.32	0.63	1.26	1.58	1.89	2.52	3.15	3.78	4.41	5.04	5.67	6.30
4.0	2000	0.25	0.50	1.00	1.24	1.49	1.99	2.49	2.99	3.49	3.98	4.48	4.98
5.0	2500	0.21	0.43	0.86	1.07	1.28	1.71	2.14	2.57	3.00	3.42	3.85	4.28
6.0	3000	0.19	0.38	0.77	0.96	1.15	1.53	1.92	2.30	2.69	3.07	3.45	3.84
7.0	3500	0.18	0.35	0.71	0.88	1.06	1.41	1.76	2.12	2.47	2.82	3.17	3.53
8.0	4000	0.16	0.33	0.66	0.82	0.99	1.32	1.65	1.98	2.31	2.64	2.97	3.30
9.0	4500	0.16	0.31	0.62	0.78	0.93	1.25	1.56	1.87	2.18	2.49	2.80	3.12
10	5000	0.15	0.30	0.59	0.74	0.89	1.19	1.49	1.78	2.08	2.38	2.67	2.97
20	10000	0.11	0.23	0.45	0.57	0.68	0.91	1.13	1.36	1.59	1.81	2.04	2.27

By following the above sample calculation, Table VI could now be completed. It would be very easy to use Excel formula to fill up the table.

Using Table VI , we shall be able to plot a T-C curve using the 2013 version of Excel. Please note that, I have not tested this method in any other Excel version, I could not tell if the steps or methodology will still be the same and workable.

1) Excel Table Selection: Select the range of cells as shown in Figure 4. Do not include the $\frac{G}{G_S}$, else you will be getting a different graph profile.

Figure 4: Select The Range

I/IO	I (A)	Time, s											
		0.05	0.1	0.2	0.25	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
1.5	750	0.86	1.72	3.44	4.3	5.16	6.88	8.6	10.32	12.04	13.76	15.47	17.19
2	1000	0.5	1	2.01	2.51	3.01	4.01	5.01	6.02	7.02	8.02	9.03	10.03
3	1500	0.32	0.63	1.26	1.58	1.89	2.52	3.15	3.78	4.41	5.04	5.67	6.3
4	2000	0.25	0.5	1	1.24	1.49	1.99	2.49	2.99	3.49	3.98	4.48	4.98
5	2500	0.21	0.43	0.86	1.07	1.28	1.71	2.14	2.57	3	3.42	3.85	4.28
6	3000	0.19	0.38	0.77	0.96	1.15	1.53	1.92	2.3	2.69	3.07	3.45	3.84
7	3500	0.18	0.35	0.71	0.88	1.06	1.41	1.76	2.12	2.47	2.82	3.17	3.53
8	4000	0.16	0.33	0.66	0.82	0.99	1.32	1.65	1.98	2.31	2.64	2.97	3.3
9	4500	0.16	0.31	0.62	0.78	0.93	1.25	1.56	1.87	2.18	2.49	2.8	3.12
10	5000	0.15	0.3	0.59	0.74	0.89	1.19	1.49	1.78	2.08	2.38	2.67	2.97
20	10000	0.11	0.23	0.45	0.57	0.68	0.91	1.13	1.36	1.59	1.81	2.04	2.27

500 A CT Rating (Normal Inverse)

2) Select Type of Graph: Start chart wizard and select XY (Scatter) with data points connected by smoothed lines without marker, see Figure 5.

Unfortunately, in MS Excel 2013 however, Figure 6 will produce a graph which looks like Figure 6. This is not the graph we wanted to produce.

3) Alternative Method: To ensure that we will be able to plot the correct graph, let us reduce the number of columns in our selection. Select only up to column 0.8 as shown in Figure 7

Using the method in Figure 7, will produce the graph we wanted as shown in Figure 8. You may ask how about the last two (2) columns? We can add them manually using the following steps.
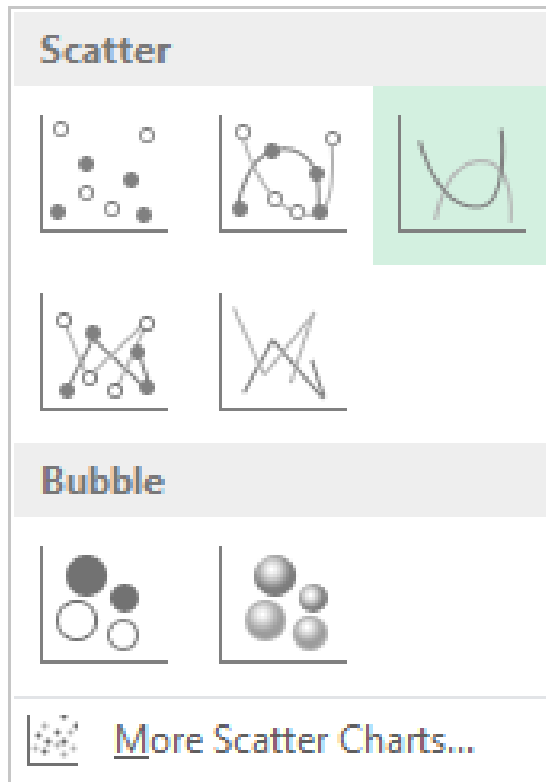
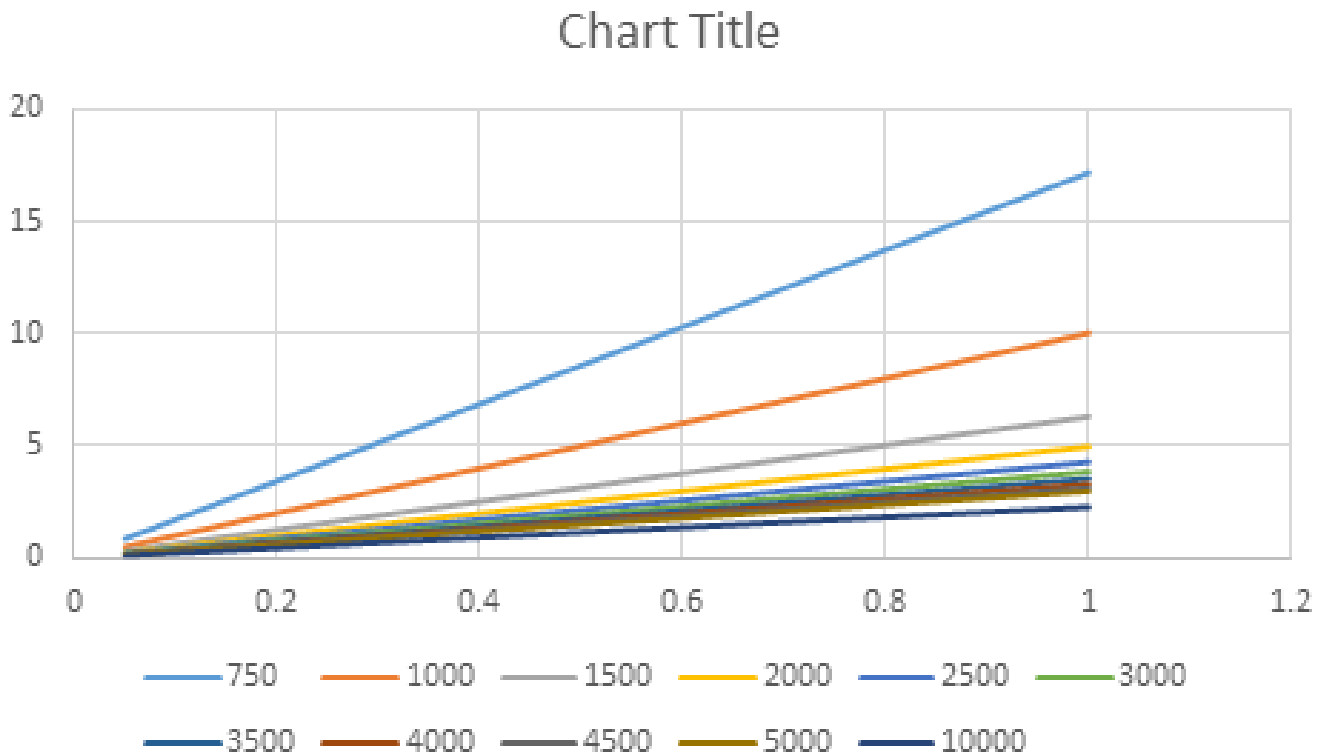Figure 5: Select Type of Graph

Figure 6: Incorrect Graph

Chart Title

Legend: 750, 1000, 1500, 2000, 2500, 3000, 3500, 4000, 4500, 5000, 10000

Figure 7: Alternative Selection Method

I/IO	I (A)	Time, s											
		0.05	**0.1**	**0.2**	**0.25**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1**
1.5	750	0.86	1.72	3.44	4.3	5.16	6.88	8.6	10.32	12.04	13.76	15.47	17.19
2	1000	0.5	1	2.01	2.51	3.01	4.01	5.01	6.02	7.02	8.02	9.03	10.03
3	1500	0.32	0.63	1.26	1.58	1.89	2.52	3.15	3.78	4.41	5.04	5.67	6.3
4	2000	0.25	0.5	1	1.24	1.49	1.99	2.49	2.99	3.49	3.98	4.48	4.98
5	2500	0.21	0.43	0.86	1.07	1.28	1.71	2.14	2.57	3	3.42	3.85	4.28
6	3000	0.19	0.38	0.77	0.96	1.15	1.53	1.92	2.3	2.69	3.07	3.45	3.84
7	3500	0.18	0.35	0.71	0.88	1.06	1.41	1.76	2.12	2.47	2.82	3.17	3.53
8	4000	0.16	0.33	0.66	0.82	0.99	1.32	1.65	1.98	2.31	2.64	2.97	3.3
9	4500	0.16	0.31	0.62	0.78	0.93	1.25	1.56	1.87	2.18	2.49	2.8	3.12
10	5000	0.15	0.3	0.59	0.74	0.89	1.19	1.49	1.78	2.08	2.38	2.67	2.97
20	10000	0.11	0.23	0.45	0.57	0.68	0.91	1.13	1.36	1.59	1.81	2.04	2.27

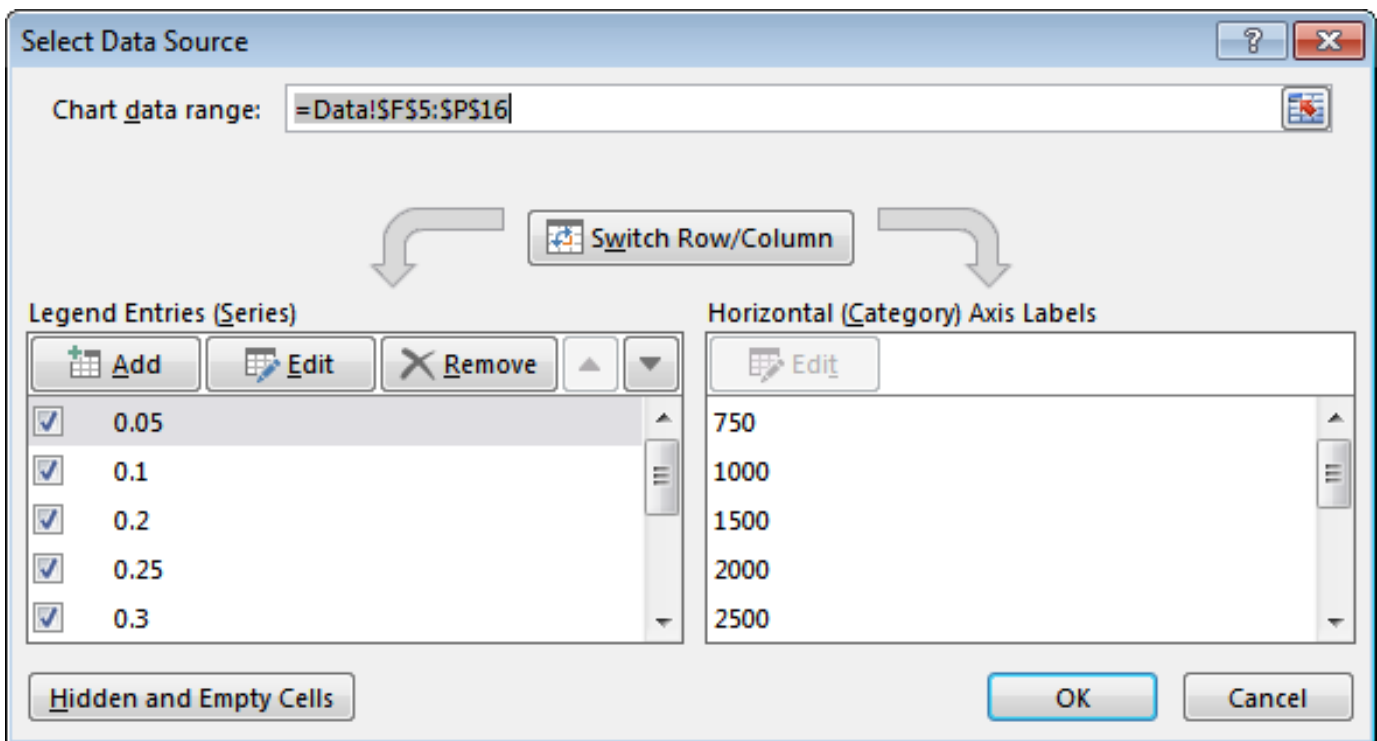**500 A CT Rating (Normal Inverse)**

Figure 8: Correct Graph Plotting
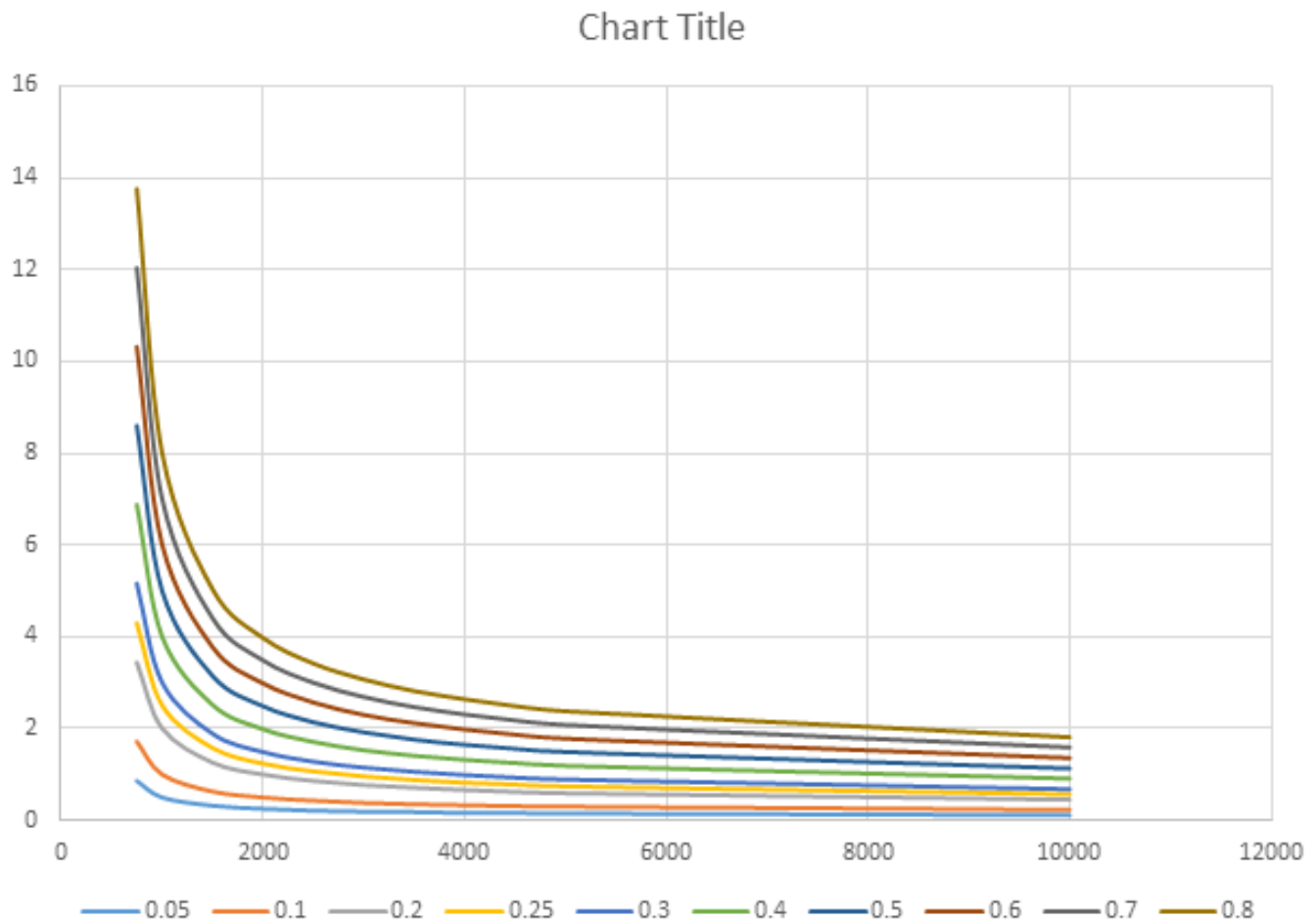
4) Adding Last Two(2) Columns: Right-click on the plot area. A context menu will appear ad shown in Figure 9.

Figure 9: Graph Context Menu
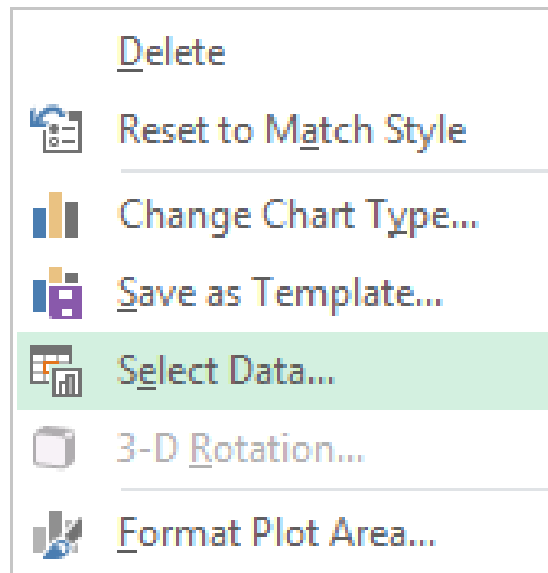
A Select Data Source form will appear as shown in Figure 10.

Figure 10: Select Data Source

Notice that in Figure 10, the columns names appear on the left. If you scroll the left column down, you will only see up to column 0.8. Now click the Add button. A new dialog box will appear as shown in Figure 11.

For column **0.9**, fill-in the form using the values similar to Figure 12. For column **1**, fill-in the form using the values similar to Figure 13.
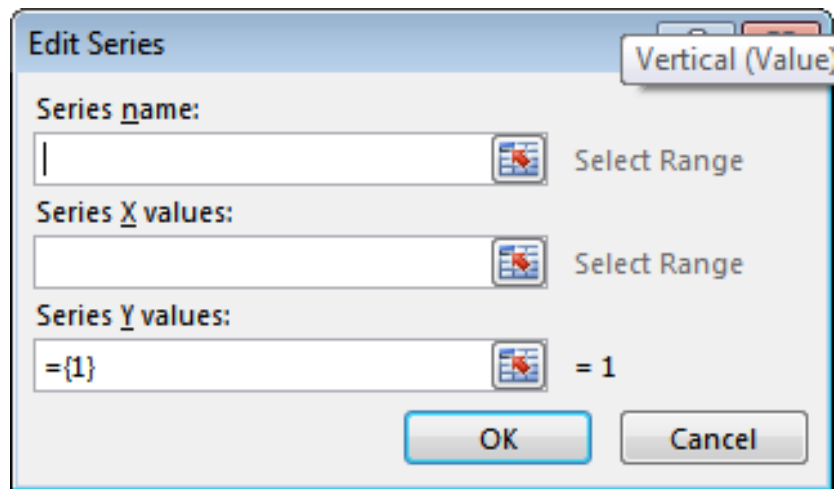
Figure 11: Edit Series 1
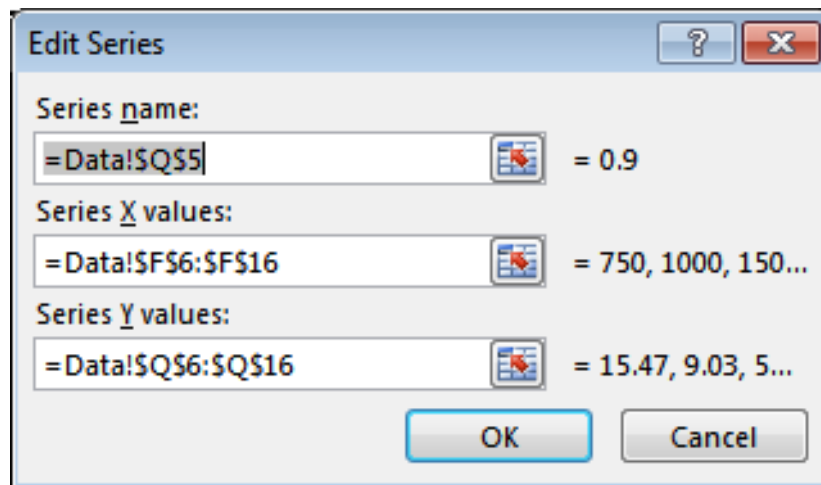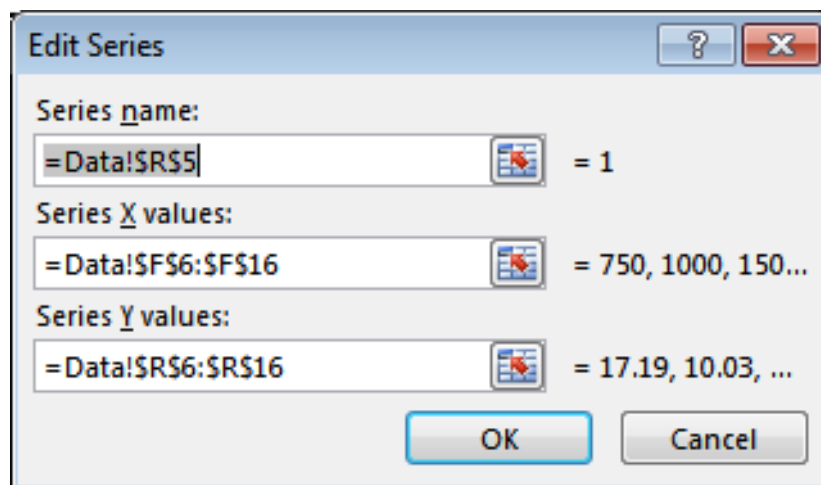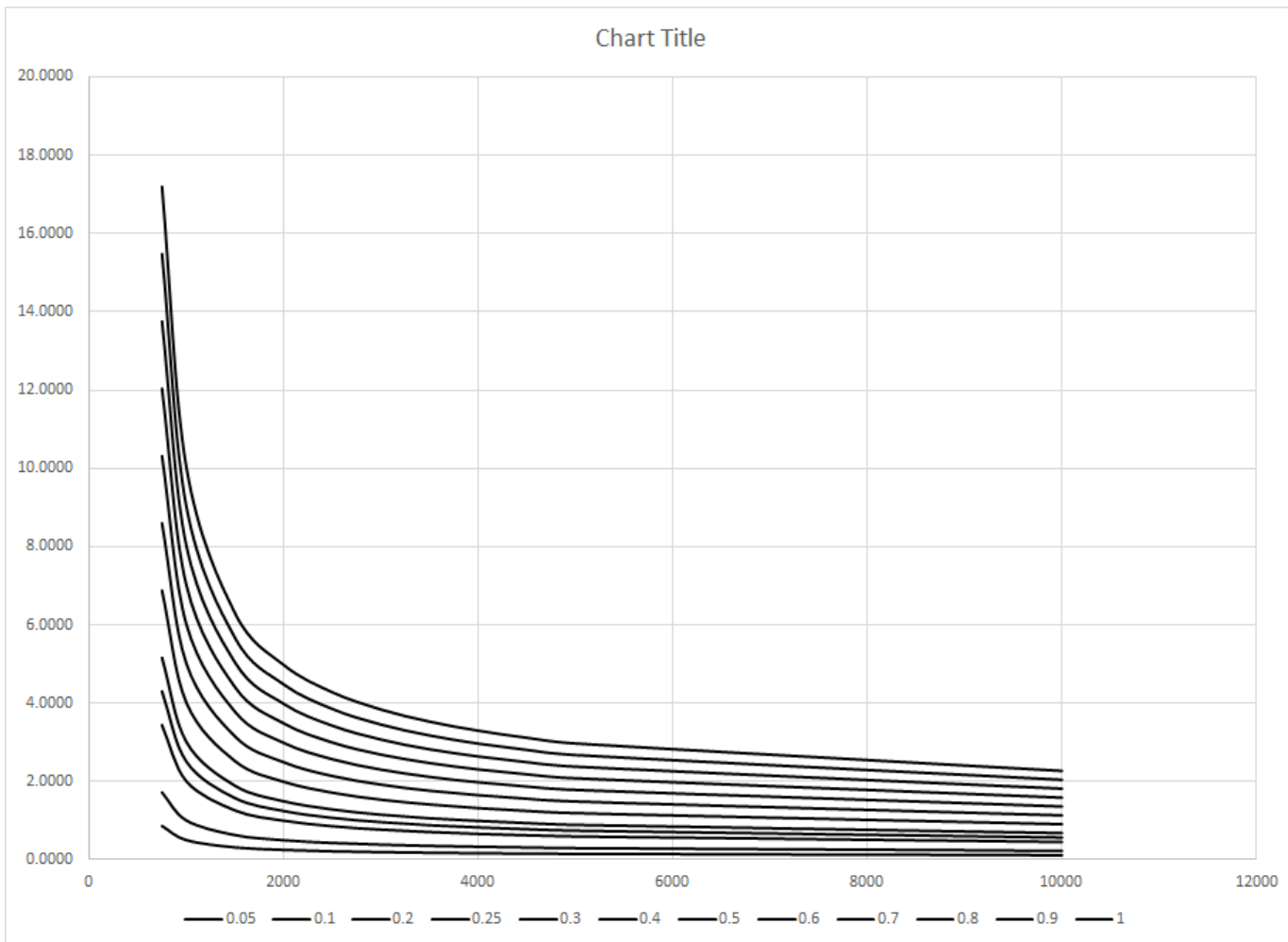

Figure 12: Edit Series - Coloumn **0.9**

Figure 13: Edit Series - Column **1**

If you have created your own worksheet, the cell locations will be different. Do not get upset, the final result in Figure 14 will still be the same. I have made all the series of the graph *black* for more visibility.

Figure 14: Plotted Graph With Complete Columns

Now that the correct graph has been create, it is now time to modify the graph into a log-log plot. T-C curves all are plotted in a log-log graph.

The T-C curve in Figure 14 when plotted into a log-log graph will become similar to Figure 15. Adjust the axes maximum and minimum values to suit your requirement.

V. PLOTTING ACTUAL COORDINATION CURVES

This is the final part of the tutorial this tutorial. We will apply the skills we have learned from the previous sections. We shall be able to attain a complete relay coordination similar to Figure 1.

To understand better the coordination curve, here are the parameters. Please note that all values are referred to the primary which is 11kV.
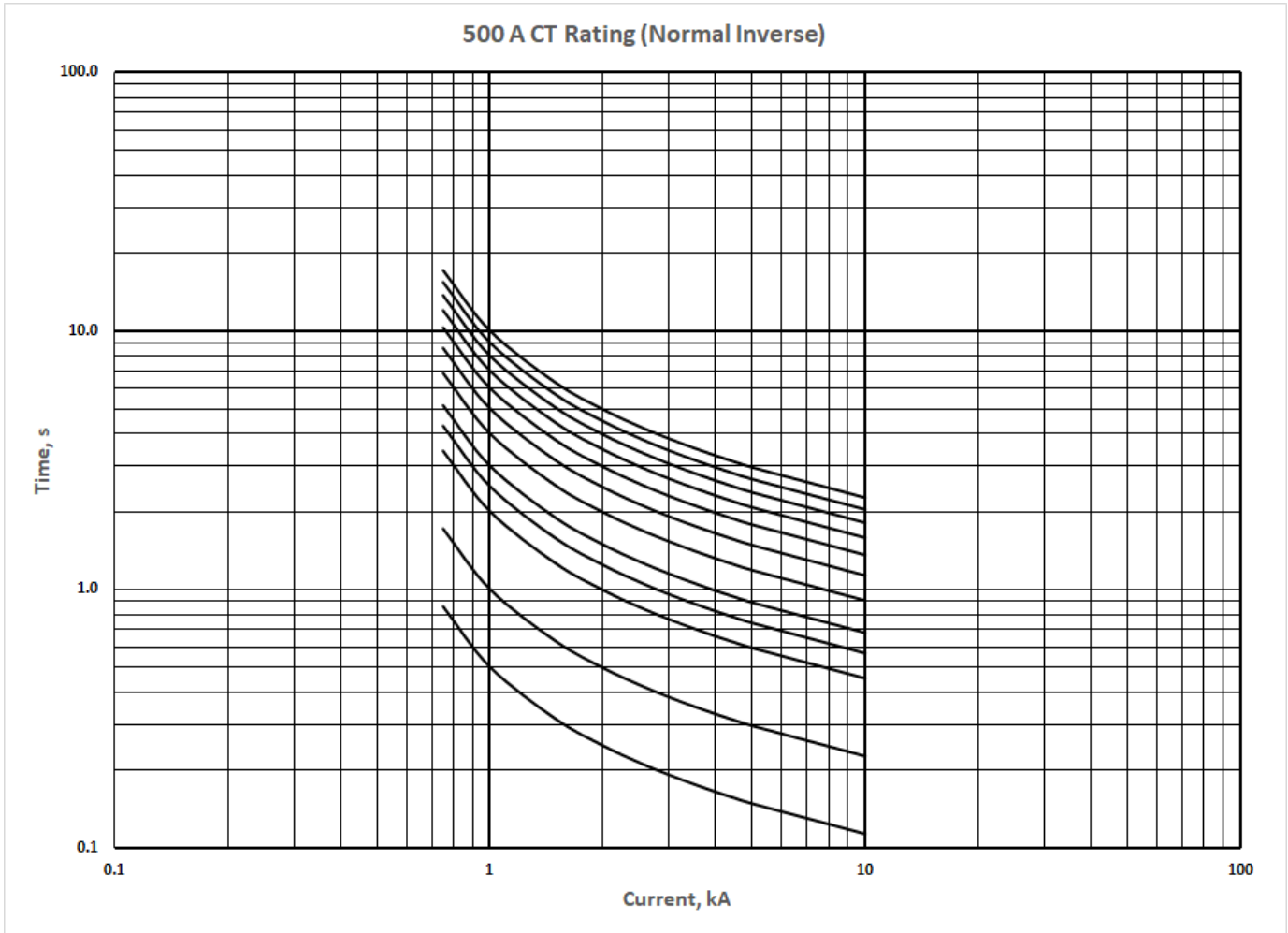
Utility Supply 11kV
    TMS : 0.2
    Short Circuit Capacity : 75MVA
    Protection Setting (I_N): 250A set @ $5I_N$
Supply Cable
    Size : 35 mm2 PVC/PVC

Figure 15: T-C Curves on Log-Log Graph

Primary Circuit Breaker
  TMS : 0.16
  Rating (I_N): 160A
  Setting 1 : 800A @ $5I_N$
  Setting 2 : 1120A @ $7I_N$
Power Transformer
  Rating: 2500 kVA
  Voltage: 11/0.415kV
  Impedance: 6.25%
Secondary Circuit Breaker
  TMS = 0.12
  Rating (I_N): 4000A *(150A - referred to Primary)*
  Setting 1 : 604A @ $4I_N$
  Setting 2 : 905A @ $6I_N$
Motor Cable
  Size : 185 mm^2 PVC/PVC
Motor Circuit Breaker
  TMS = 0.1
  Rating (I_N): 800A *(30A - referred to Primary)*
 Setting 1 : 483A @ $16I_N$

Setting 2 : 604A @ 20I$_N$

The utility time multiplier (TMS) is normally provided by the power provider. Then, we need to work below it else, our protection is not time coordinated with the utility.

For the motor circuit breaker, we need to select a setting wherein the value protection will not trip during motor starting which is ideally 6 times the full load motor current and it should still be tripping below the secondary circuit breaker setting.

The damaged curve of the cables of the cables has been included to show that these are correctly selected as their curves are way above the protection setting of the utility.

Figure 16: Time-Current Coordination Curve
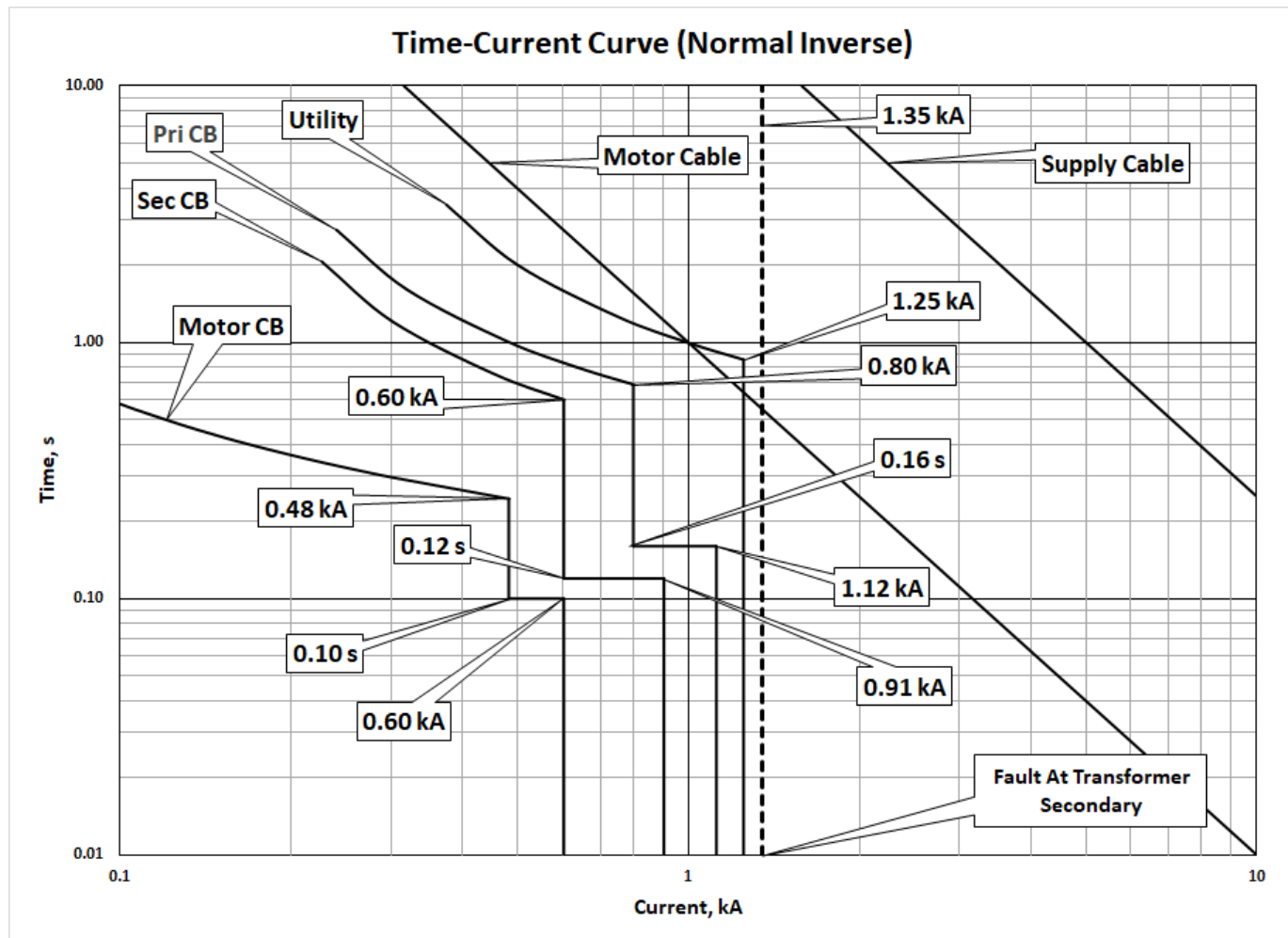
It is evident in Figure 16 that there are no overlapping of the time-current curves from the utility down to the motor circuit. From which we could conclude that the circuit breakers are properly coordinated.

As a final note, I have included an accompanying worksheet which contains all the values used in this tutorial. All data used in the creation of the final time-current curve was based on Sheet "Data". The final plot can be seen on Sheet "Final".

REFERENCES

[1] Silverio M. Pangonilo, Creating Coordination Curves with Excel, Available at https://eeame.com/portal/tutorials/110-creating-coordination-curves-with-excel.html, 2008.
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ABOUT THE AUTHOR

Silverio M. Pangonilo is a **Professional Electrical Engineer (First Placer – April 1991)** and **Registered Professional Engineer of Queensland (RPEQ)Australia** with 35+ years of experience in design, management, engineering, construction, maintenance and manufacturing including 25+ years in Engineering, Procurement and Construction (EPC) and Engineering, Procurement, Construction and Management (EPCM) projects.