IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676, p-ISSN: 2320-3331, Volume 17, Issue 2 Ser. I (Mar. – Apr. 2022), PP 01-17
www.iosrjournals.org

Current Transformer Performance Optimization in Relation to its Burden for Power System Protection

OGUMBA, LEVI NNAMDI
Department of Electrical Electronic, University of Port Harcourt, Nigeria leviogumba@yahoo.co.uk

OGBOGU, NELSON O.
Department of Electrical Electronic, University of Port Harcourt, Nigeria nelsonogbogu@gmail.com

Abstract
In electrical power systems or networks, protection systems play a vital role in ensuring system safety and reliability, therefore, optimized performance of the protection system should be intensively evaluated to ensure that no failure is experienced. Evaluating the Burden of a current transformer (CT) is a valuable means of measuring the efficiency of the protection system since it is the principal point of communication amid the power system network and the protection system. Having compared the performance of rated C800 CT at different secondary burdens realized from changing the cable core sizes and varying the cable length, the behavior of the CT clearly informs if the CT is likely going to saturate or not when subjected to fault current condition, based on the IEEE guidelines for CT performance calculations. A program developed using Python programming language can show if the selected CT is adequate or not adequate based on the burden connected to its secondary terminal, maintaining other system parameters. This research work throws more light on the fact that increasing the cable length will increase the burden and increasing the cable size will reduce the rate of burden increase resulting from increased cable length. It is revealed that exceeding the burden that a selected CT can handle will lead to CT saturation which should be avoided in order to keep the electrical system intended to protect safe and reliable.

Key Words: ***System protection, Current transformer, Burden, Cable size and cable length.***

Date of Submission: 27-02-2022 Date of Acceptance: 09-03-2022

I. Introduction

The intention of a protection system in any power system/network is to monitor one or more parameters of the installation, such as current, voltage, frequency phase angle, etc. These mentioned parameters of the power system are continuously monitored by measuring and comparing its value per time with set points or thresholds values, beyond which the situation is considered abnormal and thereby could lead to an unacceptable result which could become dangerous to the system, personnel or environment. In event of fault occurrence, the protection device sends a predetermined command, such as signal, trip, lock, etc. to a circuit breaker for instance, with the intention to durably isolate the faulty part in the power system. It could as well prevent reclosing until the device has been fixed or replaced. It can also generate an alarm to inform operator/maintenance personnel which will enable them to take the necessary action.
Basically, the summaries of what a protection system does are listed below:

1. Ensuring continuity of power supply in healthy circuits having isolated the faulty part in the power system.
2. To minimize danger to human life because if the fault is not eliminated, it poses a danger to human life.
3. To reduce electrically initiated fires that might occur due to electrical faults.
4. To avoid damaging the entire power system assets, equipment/circuits.

Current transformers (commonly denoted as CTs), are integral components for electrical protective relaying in power system protection. CT and VT (Voltage Transformer) are both classified as instrument transformers. They replicate the big values of voltage and current in a system to a small and standardized value that is easy for instruments used for measuring and protective relays to handle. Again these instrument transformers separate the measurement or protection system components from the big amount of voltage and current from the main system – that is, keep them safe from high voltage and current. Focusing on the CT, the main need for current transformers in the power system network is to ensure safe and reliable operation of the electrical power system. The above could only be achieved when the CTs perform their stated functions normally starting from power generation systems, transmission networks and distribution systems. It will be right to say that all types of protection systems and measuring systems all need instrument transformers to function effectively. Once more, the type for protection function is referred to as Current Transformer (CT).

Current transformer as the name implies is the current-detecting component of the power system and is used at all levels of power system networks such as generating stations, transmission stations and distribution stations. CT is composed of primary winding, a core and then the secondary winging side. But we have to note that some CTs use an air core. (Forford and Linders, 2018). As stated by Sachin et al (2015), Current transformers as mentioned earlier are often used to scale high current value to a smaller standardized value. Without any compromise, Current transformers in any protection system must not saturate in the event of a fault occurrence as this will undermine the effectiveness of the protection system. All technical procedures, standards and good engineering design practices should be deployed in ensuring the safety and reliability of the electrical system and network installations while using current transformers as part of the protection system component.

Current transformers can become saturated due to many factors such as high AC fault current or DC current components, high burden, remanence etc. Clearly, the current values calculated or translated by the CT on the basis of the secondary saturated CT will fall very far from their correct values (Wu et al., 2016). In effect, incorrect calculation can lead to false decisions (for example, in the classification of over-current relays, loop impedance fault over-estimation in distance relays) and safety system disoperation. It can therefore be claimed that if adequate procedures for saturation detection or improvement are not implemented to remove the problem, the CT saturation occurrence can impair the reliability of the electrical system protection. However, for the optimal performance of a CT, the influence of the CT burden cannot be overstressed. Going by the IEEE C57-13 (2016), definition, the secondary burden of a current transformer is constituted by the secondary circuit properties of the connected load to the secondary winding of the current transformer. The CT burden is measured either as the total impedance in ohms, alongside the active components of resistance and reactance or as the total voltage and power factor of the secondary devices.

FACTORS AFFECTING CT PERFORMANCE

The optimum performance of current transformer hinges on some factors which include: Current magnitude, System X/R Ratio, Remanence, Burden, etc., which in this study, the focus is on the CT Burden. The CT Burden is the least understood of these factors and experience has shown, as reviewed, that this is the major cause of problems with current transformer application.

Among many other methods of analyzing CT performance, the CT Transient Performance Analysis method will be used to confirm the maximum burden allowed for a selected CT at a given fault current.

In Equation (1), the mathematical model for the above-mentioned methods as per IEEE definition has been stated.

$$\frac{I_{FAULT}}{I_{PRI}} = \frac{Z_B + R_S}{Z_{B\,STD} + R_S}\left(\frac{X}{R} + 1\right) \leq 20 \qquad (1)$$

Where,

I_{FAULT} equals the maximum primary winding fault current measured in amperes (A)

I_{PRI} equals the marked primary side current of the CT. For instance, a 1000/5 CT (Ratio Marking), I_{PRI} is 1,000 A).

Z_B equals the actual burden of the CT's secondary circuit. That is, the impedance of the connecting cable and that of the relay.

R_S equals the CT secondary winding internal resistance which is provided in the manufacturer datasheet.

$Z_{B\,STD}$ is the standard burden of the CT for instance, a C400 CT, the Z_B STD is 4 Ω).

X over R (X/R) ratio accounts for DC offset for asymmetrical fault.

Referencing IEEE C57-13 (2016), as regards to voltage rating of a Current Transformer, it defines the minimum secondary voltage that the Current Transformer has to reproduce to a standard burden at 20 times rated secondary current and would not go more than 10% tolerable ratio error. Once the fault current over a CT is higher than 20 times of the CT current rating, or the connected burden is higher than the maximum allowable burden, we are at risk of the CT going into saturation, that is, over 10 percent error.
ANSI/IEEE accuracy class designations, in many applications, are adequate to assure satisfactory relay operation. There are two standard classes: Class T and Class C. These designations are followed by a number that indicates the secondary terminal voltage that the transformer can deliver as stated above, for example C400. Class C CT accuracy class is constructed such that the leakage flux is negligible; hence the performance of the CT can be determined by calculation. The ten per cent ratio error won't be surpassed at any current from 1 to 20 times the rated secondary current at the standard burden or any lesser standard burden. For relays, standard Burden is represented by a later B followed by a number which corresponds to the voltage class. For instance, the voltage classes of 100, 200, 400 and 800 V, the corresponding standard burden are B-1, B-2,B-4 and B-8 respectively. These burdens are at 0.5 power factor. The burdens are measured in ohms which are derived by dividing the voltage rating by times 20 of the rated secondary current. For example, for a 400 V rating, the burden is equal to 400 V divided by 100 A which equals 4 ohms, assuming that the current rating of the secondary is 5 A. 400 / (20 * 5) = 4 ohms.

Table 1: IEEE C57.13 various relay accuracy classes and CT burden data.

Secondary terminal voltage (V)	Secondary burden designation	Resistance (Ω)	Inductance (mH)	Impedance (Ω)	Total power (VA at 5 A)
10	B-0.1	0.09	0.116	0.1	2.5
20	B-0.2	0.18	0.232	0.2	5.0
50	B-0.5	0.45	0.580	0.5	12.5
100	B-1.0	0.50	2.30	1.0	25.0
200	B-2.0	1.00	4.60	2.0	50.0
400	B-4.0	2.00	9.20	4.0	100.0
800	B-8.0	4.00	18.40	8.0	200

Again, the mathematical model stated in equation (1) has been written in Python programming language to analyze the impact of the cable length connected to the secondary terminal of the CT, cable size used and the resistance of the relay in relation to burden adequacy as the real burden connected to the secondary terminal of the CT is the sum of the impedance of the connected cable per meter and the impedance of the relay. Microsoft Visual Studio using C# programming language will be used also, such that selecting a CT suited for any given task can be very easy and simple for system protection engineers by inputting the necessary parameters in the application programs to determine if the chosen current transformer is adequate according to the burden connected to it, taking into consideration properly other system parameters.

The program will be developed in such a way that it can assess and evaluate the burden of the chosen current transformer with respect to the cable size and its length (distance from current transformer to relay) and the program will be very simple and user friendly.

ANALYSIS PERFORMED

Having written equation 1 using Python programming language, with the site data collected from one of the Nigerian LNG switchgear, such as the CT internal resistance, the CT standard burden and the Protection relay resistance, a C800 CT was run through the program, in which the CT was adequate in one scenario and not adequate in another scenario due to different burdens connected to its secondary terminal at different times. It was noted that the burden at the secondary terminal of the CT is a function of the selected cable size, type and the distance of the cable from the CT to the Relay and as well the relay resistance. All data inputted into the program can be seen in appendix A.

SCENARIOS 1. CABLE SIZE OF 1.5 MM^2 AT 10 METER DISTANCE.

The C800 CT was adequate as the burden connected to its secondary is suitable for the CT, which entails that the CT is not likely going to saturate at times 20 of the rated secondary current, maintaining a ten per cent (10%) ratio error. To achieve this suitable burden, cable size selected is 1.5 mm^2 and the distance of the cable from the CT to the relay is kept at 10 meters. See figure 1, below being graph of Threshold Value vs. Cable Lengths in meter:

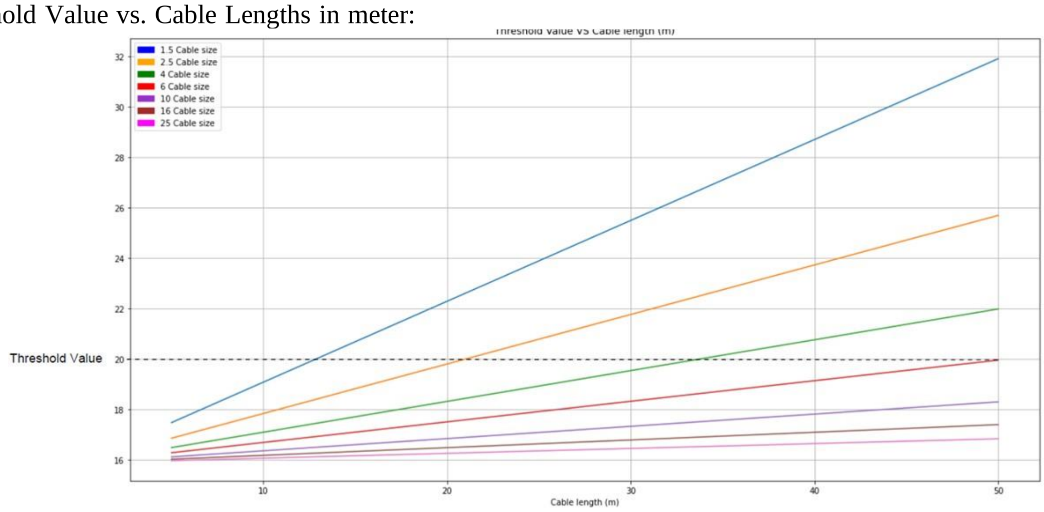


Figure 1: Graph of Threshold Value vs. Cable Lengths in meter

SCENARIOS 2. CABLE SIZE OF 1.5 MM^2 AT 20 METER DISTANCE.

From above figure 1, it is also seen that the C800 CT was not adequate as the burden connected to its secondary is not suitable for the CT, which shows that the CT may likely saturate at times 20 of the rated secondary current beyond a 10 percent ratio error. This burden was achieved by selecting a cable size of 1.5 mm^2 and the distance of the cable from the CT to the relay is kept at 20 meters. However, to reduce the burden in this scenario, increasing the cable size to 2.5 mm^2 would make the C800 CT become adequate.

Discussion of Finding

There are two main insights from this research:

1. the higher the cable length connected from the CT to the Relay the higher the burden to be carried at the secondary terminal of the CT.
2. the rate at which the burden increases as a result of increased cable length, are reduced by increasing the cable size.

The above two points can be clearly read and understood from figure 2 being the graph of calculated Burden (Ohms) vs. Cable Lengths (m).

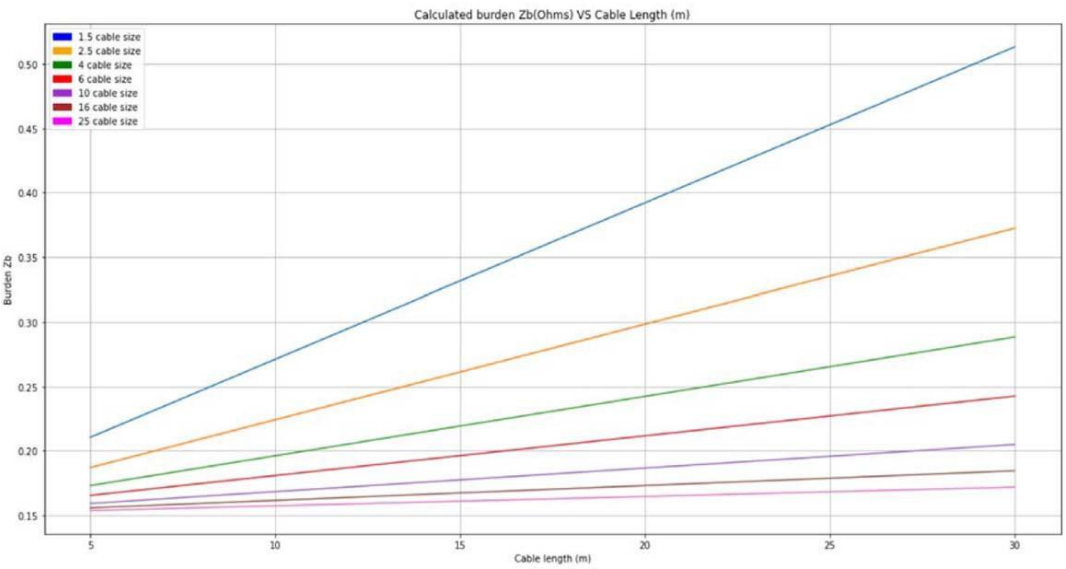


Figure 2: Graph of calculated Burden (Ohms) vs. Cable Lengths (m).

The plot shows the burdens for each cable size at lengths, 5,10,15,20,25 and 30 meters. From the graph, it can be seen that the longer the length, the higher the burden, but increasing the cable sizes reduces the effect of increased cable length as also demonstrated in figure 2.

BURDEN ADEQUACY STANDALONE APPLICATION FOR A SELECTED CT.

With intent to develop a standalone application with all possible flexibility to enable a protection engineer easily select the right CT with respect to the burden adequate for the selected CT based on his design requirement, a visual studio standalone application written in C# programming language have also been developed in which the necessary parameters can be keyed in. when the 'calculate' button is pressed, the application runs and displays either 'Suitable' or 'not Suitable' with respect to the value of burden entered in the application. That is to say, if 'Suitable' is displayed, the selected CT is not likely going to saturate maintaining other system parameters and when it displays 'not Suitable' the selected CT is likely going to saturate due to the high connected burden, For explanation, see figure 4 and figure 5 for the two events mentioned.

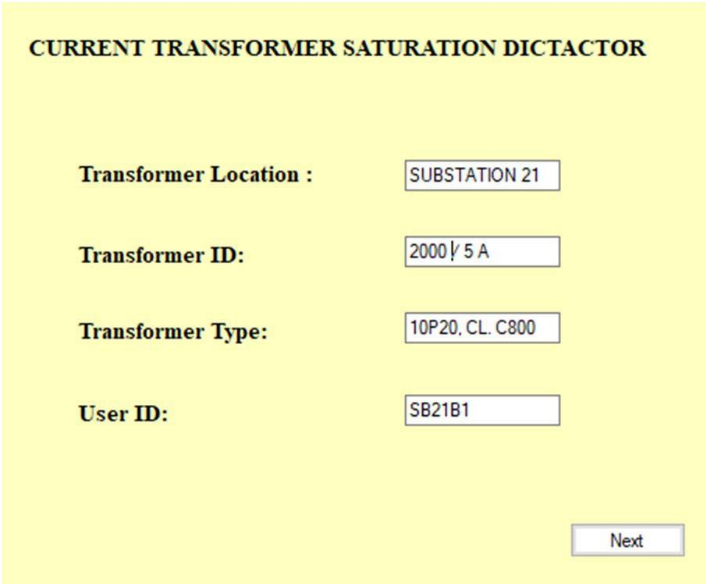


Figure 3: CT data.

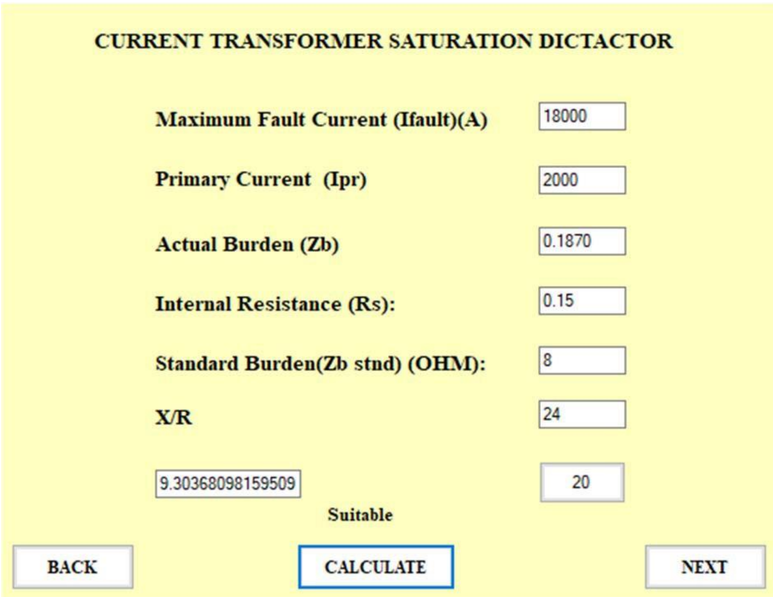


Figure 4: Inputted Fault current and CT data with 'Suitable' burden.

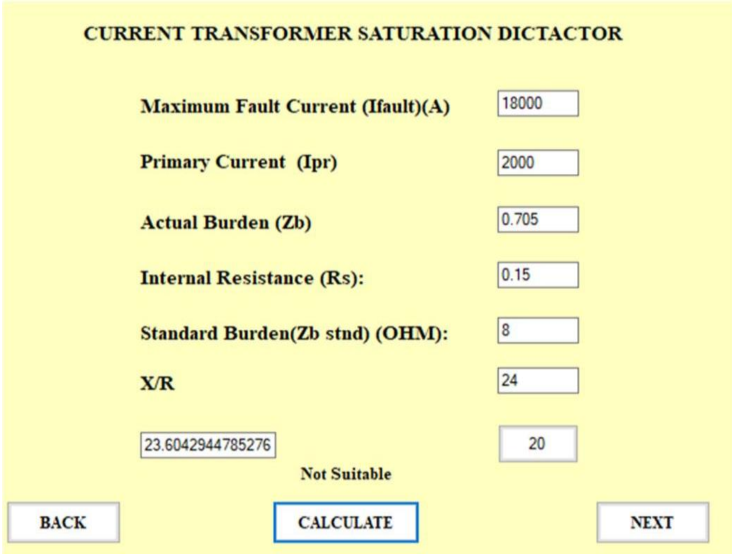


Figure 5: Inputted Fault current and CT data with ‘not suitable’ Burden.

Table 2: output of calculated burdens at different distances.

	1.5	2.5	4	6	10	16	25
0	0.2105	0.1870	0.1730	0.1654	0.1591	0.1557	0.1536
1	0.2710	0.2241	0.1961	0.1808	0.1683	0.1615	0.1573
2	0.3315	0.2611	0.2192	0.1962	0.1774	0.1673	0.1609
3	0.3920	0.2982	0.2422	0.2116	0.1866	0.1730	0.1645
4	0.4525	0.3352	0.2652	0.2270	0.1957	0.1787	0.1682
5	0.5130	0.3723	0.2883	0.2424	0.2049	0.1845	0.1718

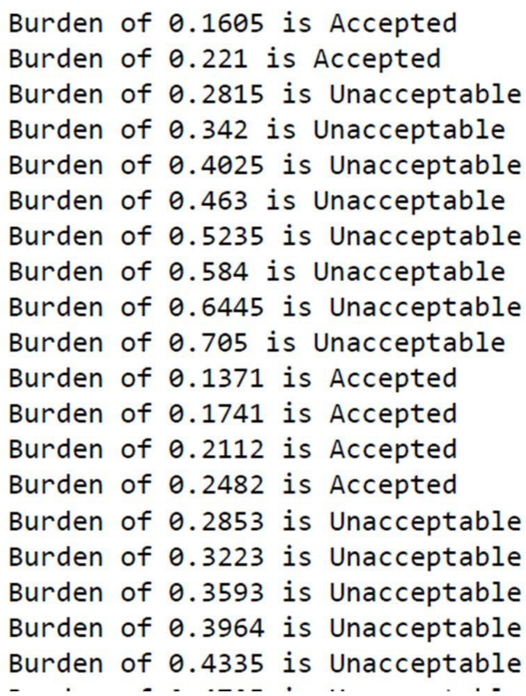


Figure 6 – Result of Acceptable and Unacceptable Scenarios.

Table 2 shows the different calculated Burden at distances of 5,10,15,20,25 and 30-meter interval based on the different resistance data of various copper cable sizes taken from Nexans manufacturer Catalogue. See appendix B. Refer to figure 1. Note that "acceptable and unacceptable" remarks are interchangeably used with "suitable and not suitable" outputs.

II. Conclusion

In order to avoid the danger that may occur due to failure of protection system put in place to protect an entire electrical system or network as a result of Current Transformer saturation during a fault condition, that is over 10 percent error, it is very important that the burden of the selected CT is critically looked into and confirmed quite adequate for the selected CT by considering the right cable size, type and distance from the secondary terminal of the CT to the Protection relay. Morden Relays have low internal resistance, hence this is of less concern, but in any case, should be considered as well while calculating the adequate burden of a selected CT as has been demonstrated in this work.

There are factors that affect CT performance which include Current magnitude, System X/R Ratio, Remanence and Burden. In this work, how to optimize the CT burden has been examined. However, to ensure total effectiveness, safety and reliability of any protection system, other factors as mentioned should at the same time be optimized alongside the CT burden. Some recommendations as listed below should be considered by a protection engineer to inform his decision in selecting adequate CT:

1. That study should always be conducted before confirming that a particular CT is adequate, meeting all design requirements.
2. That the result of the study should be strictly adhered to, by purchasing and installing the confirmed selected CT having considered the burden and other factors that affect CT performance.
3. Any action that might lead to a connection of high burden to a selected CT should be avoided such as changing the right cable size or increasing the cable length during installation without checking again if the selected CT is still capable to handle the burden that has resulted due to the changes made.
4. Higher cable sizes are selected to ensure secondary burn adequacy, especially when it is seen that the relay is far away from the point of relay installation.
5. Select relays that are microprocessor-based as they have lesser internal resistance which contributes to the entire CT secondary burden.

References

[1]. Ariana, H., Michael, J. T., and Brad, H. (2017). Beyond the Knee Point: A Practical Guide to CT Saturation. Schweitzer Engineering Laboratories, Inc.

[2]. Barner, K N. Klingerman, M. Thompson, R. Chowdhury, D. Finney, and S. Samineni, (2019). Out of Phase Synchronization: proceedings of the 73rd Annual Georgia Tech Protective Relaying Conference, Atlanta, GA.

[3]. Cowan, P., Neale, R. (2017): Holistic Substation Asset Management. Energize Power Journal of the South African Institute of Electrical Engineers, 42-25.

[4]. Forford, T. and Linders, J. R. (2018). A Half Cycle Bus Differential Relay and Its Application. IEEE Transactions on Power Apparatus and Systems, vol. 93, no. 4, pp. 1110-1120.

[5]. Linders, J. R., Barnett, C. W. and Chadwick, J. (2018). Relay Performance Considerations with Low-Ratio CTs and High-Fault Currents. IEEE Transactions on Industry Applications, Vol. 31, Issue 2.

[6]. Mariani, F. (2017). Inductive Instrument Transformers and Protective Applications.

[7]. Johannesburg, Crown Publications, 2(6), 632-646

[8]. Morshuis, P.H.F. (2016). Degradation of Solid Dielectrics due to Internal Partial Discharge.

[9]. IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 12 (5), 905-906.

[10]. Obi, P.I., Oputa, O., Okeke, C., Onwuka, I.K. and Apkan, A.E. (2018) Evaluating Protective System's Reliability Using Current Transformer Burden Rating. Nigerian Research Journal of Engineering and Environmental Sciences 3(1) 2018 pp. 148-153.

[11]. Sachin T. and Aditya P. (2015). Current Transformer Sizing & Saturation Calculation with Transient Performance Analysis of CT Using ATP Software. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 4, Issue 5, pp3853-3860

[12]. Wright, A. (2018). Current Transformers: Their Transient and Steady State Performance.

[13]. IEEE Transactions on Dielectrics and Electrical Insulation, Vol. 12 (5), 905-906.

[14]. Wu, T., Zhou Y. Q. and Gong W. (2016). Performance Analysis on Electronic Current Transformer Based on PCB Planar-type of Air Core Coil. Power System Technology, Vol. 34, No. 6, pp. 210-214.

[15]. Zocholl, S. E. (2004). Analyzing and Applying Current Transformers. Schweitzer Engineering Laboratories, Inc., Pullman, WA, 2004.

APPENDICES
Appendix A

Levi Ogumba - Original copy 08/03/2021, 19:40

```
In [1]: import pandas as pd
        import matplotlib.pyplot as plt
        import seaborn as sns
        import matplotlib.patches as mpatches

In [2]: #Initialise cable sizes
        cable_sizes = {'1.5':0.0121, '2.5':0.00741, '4': 0.00461, '6':0.003
        08, '10':0.00183,'16':0.00115,'25':0.000727}

In [3]: cable_sizes

Out[3]: {'1.5': 0.0121,
         '2.5': 0.00741,
         '4': 0.00461,
         '6': 0.00308,
         '10': 0.00183,
         '16': 0.00115,
         '25': 0.000727}

In [4]: #initialise cable lengths
        cable_lengths = [5,10,15,20,25,30]
        relay_impedance = 0.15

In [5]: #calculate burden for 2 by 6 for 20meters
        Burden_Zb = (cable_sizes['6'] * cable_lengths[3]) + 0.15
        Burden_Zb

Out[5]: 0.21159999999999998

In [6]: #Get the burdens for all the cable types at different cable lengths
        Burdens = {}
        for cable, resistance in cable_sizes.items():
            burds = []
            for length in cable_lengths:
                burds.append(round((resistance * length)+0.15,4))
            Burdens[cable] = burds
        Burdens

Out[6]: {'1.5': [0.2105, 0.271, 0.3315, 0.392, 0.4525, 0.513],
         '2.5': [0.187, 0.2241, 0.2611, 0.2982, 0.3352, 0.3723],
         '4': [0.173, 0.1961, 0.2192, 0.2422, 0.2652, 0.2883],
         '6': [0.1654, 0.1808, 0.1962, 0.2116, 0.227, 0.2424],
         '10': [0.1591, 0.1683, 0.1774, 0.1866, 0.1957, 0.2049],
         '16': [0.1557, 0.1615, 0.1673, 0.173, 0.1787, 0.1845],
         '25': [0.1536, 0.1573, 0.1609, 0.1645, 0.1682, 0.1718]}
```

Levi Ogumba - Original copy 08/03/2021, 19:40

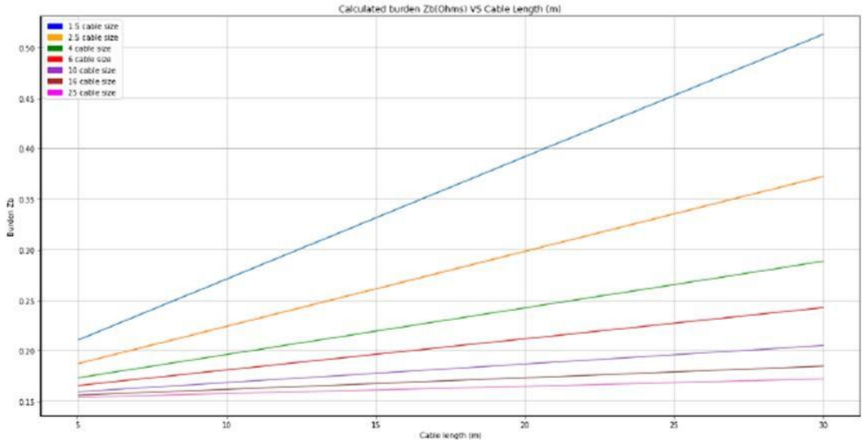
In [7]:
```
burdens_table = pd.DataFrame(Burdens)
burdens_table
```

Out[7]:

	1.5	2.5	4	6	10	16	25
0	0.2105	0.1870	0.1730	0.1654	0.1591	0.1557	0.1536
1	0.2710	0.2241	0.1961	0.1808	0.1683	0.1615	0.1573
2	0.3315	0.2611	0.2192	0.1962	0.1774	0.1673	0.1609
3	0.3920	0.2982	0.2422	0.2116	0.1866	0.1730	0.1645
4	0.4525	0.3352	0.2652	0.2270	0.1957	0.1787	0.1682
5	0.5130	0.3723	0.2883	0.2424	0.2049	0.1845	0.1718

In [8]:
```
plt.figure(figsize=(20,10))
plt.plot(cable_lengths, Burdens['1.5'])
plt.plot(cable_lengths, Burdens['2.5'])
plt.plot(cable_lengths, Burdens['4'])
plt.plot(cable_lengths, Burdens['6'])
plt.plot(cable_lengths, Burdens['10'])
plt.plot(cable_lengths, Burdens['16'])
plt.plot(cable_lengths, Burdens['25'])

plt.title('Calculated burden Zb(Ohms) VS Cable Length (m)')

plt.grid()

blue_patch = mpatches.Patch(color='blue', label='1.5 cable size')
orange_patch = mpatches.Patch(color='orange', label='2.5 cable size
')
green_patch =  mpatches.Patch(color='green', label='4 cable size')
red_patch = mpatches.Patch(color='red', label='6 cable size')
maroon_patch = mpatches.Patch(color='darkorchid', label='10 cable s
ize')
brown_patch = mpatches.Patch(color='brown', label='16 cable size')
pink_patch = mpatches.Patch(color='fuchsia', label='25 cable size')


plt.legend(handles=[blue_patch,orange_patch,green_patch,red_patch,m
aroon_patch,brown_patch,pink_patch])


plt.xlabel('Cable length (m)')
plt.ylabel('Burden Zb')

plt.show()
```

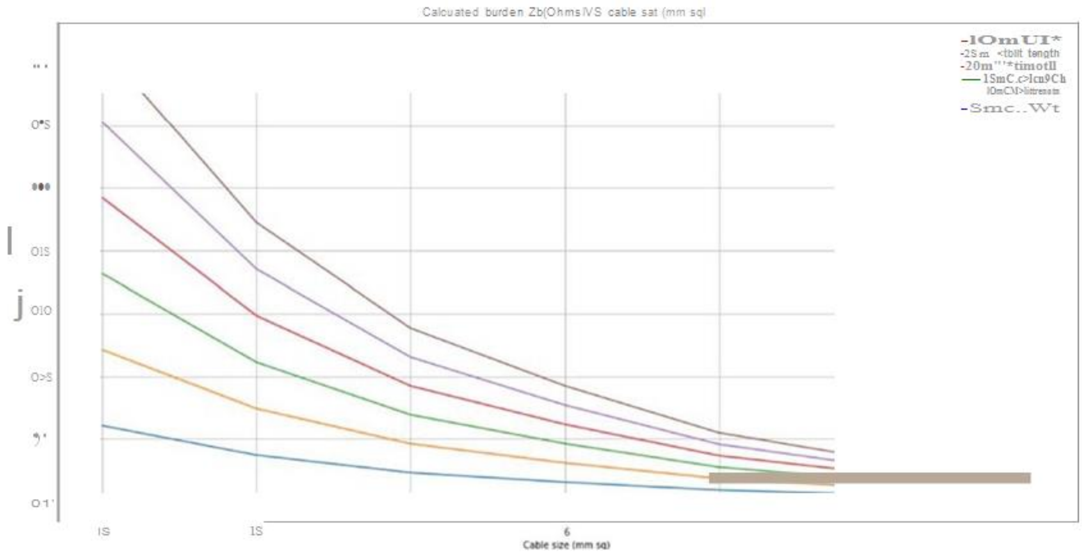
Levi Ogumba - Original copy 08/03/2021, 19:40



As can be seen on the graph, two points should be noted:

1. The higher the cable length, the higher the burden.
2. From the slope of the lines, the rate of change reduces as cable size increase even at a higher cable length.

In [9]:
```
plt.figure(figsize=(20,10))
plt.plot(Burdens.keys(), list(burdens_table.iloc[0]))
plt.plot(Burdens.keys(), list(burdens_table.iloc[1]))
plt.plot(Burdens.keys(), list(burdens_table.iloc[2]))
plt.plot(Burdens.keys(), list(burdens_table.iloc[3]))
plt.plot(Burdens.keys(), list(burdens_table.iloc[4]))
plt.plot(Burdens.keys(), list(burdens_table.iloc[5]))


plt.title('Calculated burden Zb(Ohms) VS Cable size (mm sq)')

plt.grid()

brown_patch = mpatches.Patch(color='brown', label='30m cable length
')
maroon_patch = mpatches.Patch(color='darkorchid', label='25m cable
length')
red_patch = mpatches.Patch(color='red', label='20m Cable length')
green_patch =  mpatches.Patch(color='green', label='15m Cable lengt
h')
orange_patch = mpatches.Patch(color='orange', label='10m Cable leng
th')
blue_patch = mpatches.Patch(color='blue', label='5m Cable length')

plt.legend(handles=[brown_patch,maroon_patch,red_patch,green_patch,
orange_patch,blue_patch])


plt.xlabel('Cable size (mm sq)')
plt.ylabel('Burden Zb (ohms)')

plt.show()
```



The plot shows the burdens for each cable size at lengths, 5, 10,15,20,25 and 30 meters. From the graph, it can be seen that the longer the length, the higher the burden, but increasing the cable sizes reduces the effect of increased cable length as also demostratred in figure 4.1.

In [10]:
```
#check adequacy of each burden with the formula
def check_adequacy(Zb):
    Zb = Zb
    Ifault = 18000
    Ipri = 2000
    Rs = 0.5
    X_R = 24
    Zbtsd = 8

    formula = (Ifault/Ipri) * (((Zb + Rs)/(Zbtsd + Rs)) * (X_R + 1)
)

    if formula <= 20:
        print('Burden of ' + str(Zb) + ' is Accepted')

    else:
        print('Burden of ' + str(Zb) + ' is Unacceptable')

    return formula
```

In [11]:
```
def calc_burden(cable_size, cable_length):

    #get the resistance
    res = cable_sizes[str(cable_size)]

    relay_impedance = 0.1

    #calculate burden for 2 by 6 for 20meters
    burden = round((res  * cable_length) + relay_impedance,4)

    return burden
```

In [12]:
```
check_adequacy(0.5130)
```

```
Burden of 0.513 is Unacceptable
```

Out[12]:
```
26.81470588235294
```

Levi Ogumba - Original copy   08/03/2021, 19:40

In [13]:
```
#inputs
#collect cable size

size = str(input('Enter cable size: '))
length = int(input('Enter length(m): '))

burden = calc_burden(size,length)

print(burden)

#check adequacy of burden
check_adequacy(burden)
```

```
Enter cable size: 2.5
Enter length(m): 10
0.1741
Burden of 0.1741 is Accepted
```

Out[13]: 17.843823529411768

In [14]:
```
calc_burden(2.5,5)
```

Out[14]: 0.1371

In [15]:
```
vals = {}
s = [1.5, 2.5,4,6,10,16,25]
for j in s:
    values = []
    for i in range(5,55,5):
        burden = calc_burden(j,i)
        values.append(check_adequacy(burden))
    vals[str(j)] = values
vals
```

```
Burden of 0.1605 is Accepted
Burden of 0.221 is Accepted
Burden of 0.2815 is Unacceptable
Burden of 0.342 is Unacceptable
Burden of 0.4025 is Unacceptable
Burden of 0.463 is Unacceptable
Burden of 0.5235 is Unacceptable
Burden of 0.584 is Unacceptable
Burden of 0.6445 is Unacceptable
Burden of 0.705 is Unacceptable
Burden of 0.1371 is Accepted
Burden of 0.1741 is Accepted
Burden of 0.2112 is Accepted
Burden of 0.2482 is Accepted
Burden of 0.2853 is Unacceptable
Burden of 0.3223 is Unacceptable
Burden of 0.3593 is Unacceptable
Burden of 0.3964 is Unacceptable
Burden of 0.4335 is Unacceptable
```

Levi Ogumba - Original copy 08/03/2021, 19:40

```
Burden of 0.4705 is Unacceptable
Burden of 0.1231 is Accepted
Burden of 0.1461 is Accepted
Burden of 0.1692 is Accepted
Burden of 0.1922 is Accepted
Burden of 0.2152 is Accepted
Burden of 0.2383 is Accepted
Burden of 0.2614 is Unacceptable
Burden of 0.2844 is Unacceptable
Burden of 0.3075 is Unacceptable
Burden of 0.3305 is Unacceptable
Burden of 0.1154 is Accepted
Burden of 0.1308 is Accepted
Burden of 0.1462 is Accepted
Burden of 0.1616 is Accepted
Burden of 0.177 is Accepted
Burden of 0.1924 is Accepted
Burden of 0.2078 is Accepted
Burden of 0.2232 is Accepted
Burden of 0.2386 is Accepted
Burden of 0.254 is Accepted
Burden of 0.1092 is Accepted
Burden of 0.1183 is Accepted
Burden of 0.1275 is Accepted
Burden of 0.1366 is Accepted
Burden of 0.1457 is Accepted
Burden of 0.1549 is Accepted
Burden of 0.1641 is Accepted
Burden of 0.1732 is Accepted
Burden of 0.1824 is Accepted
Burden of 0.1915 is Accepted
Burden of 0.1058 is Accepted
Burden of 0.1115 is Accepted
Burden of 0.1173 is Accepted
Burden of 0.123 is Accepted
Burden of 0.1288 is Accepted
Burden of 0.1345 is Accepted
Burden of 0.1403 is Accepted
Burden of 0.146 is Accepted
Burden of 0.1517 is Accepted
Burden of 0.1575 is Accepted
Burden of 0.1036 is Accepted
Burden of 0.1073 is Accepted
Burden of 0.1109 is Accepted
Burden of 0.1145 is Accepted
Burden of 0.1182 is Accepted
Burden of 0.1218 is Accepted
Burden of 0.1254 is Accepted
Burden of 0.1291 is Accepted
Burden of 0.1327 is Accepted
Burden of 0.1363 is Accepted
```

Levi Ogumba - Original copy 08/03/2021, 19:40


```
 20.68676470588235,
 22.288235294117648,
 23.889705882352946,
 25.491176470588236,
 27.092647058823523,
 28.694117647058825,
 30.295588235294115,
 31.897058823529413],
'2.5': [16.86441176470588,
 17.843823529411768,
 18.82588235294118,
 19.80529411764706,
 20.78735294117647,
 21.766764705882352,
 22.746176470588235,
 23.728235294117646,
 24.71029411764706,
 25.68970588235294],
'4': [16.493823529411767,
 17.1026470588235 3,
 17.714117647058824,
 18.32294117647059,
 18.931764705882358,
 19.543235294117647,
 20.154705882352943,
 20.763529411764708,
 21.375,
 21.983823529411765],
'6': [16.29,
 16.697647058823527,
 17.105294117647063,
 17.512941176470587,
 17.92058823529412,
 18.328235294117647,
 18.735882352941175,
 19.14352941176471,
 19.551176470588235,
 19.958823529411767],
'10': [16.125882352941176,
 16.366764705882353,
 16.610294117647058,
 16.851176470588236,
 17.09205882352941,
 17.335588235294118,
 17.579117647058826,
 17.82,
 18.063529411764705,
 18.304411764705883],
'16': [16.035882352941176,
 16.186764705882354,
 16.34029411764706,
 16.491176470588236,
 16.64470588235294,
```

```
 16.79558823529412,
 16.949117647058824,
 17.099999999999998,
 17.250882352941176,
 17.40441176470588],
'25': [15.97764705882353,
 16.075588235294116,
 16.170882352941174,
 16.266176470588235,
 16.364117647058823,
 16.459411764705884,
 16.554705882352938,
 16.65264705882353,
 16.747941176470587,
 16.843235294117644]}
```

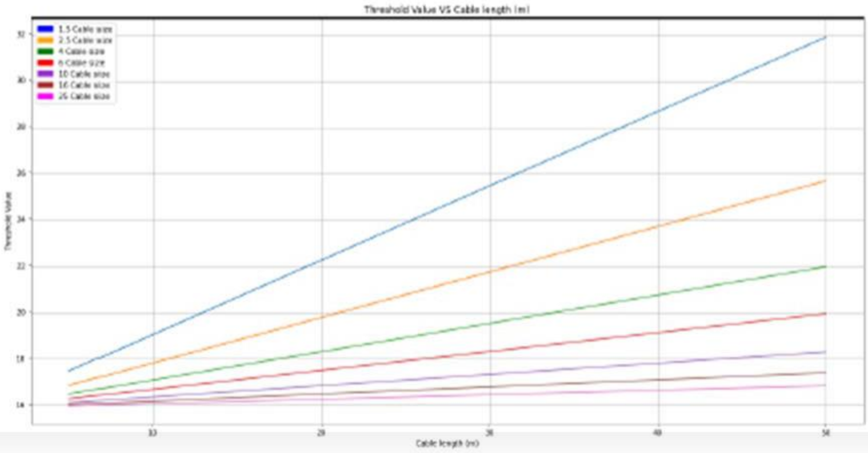
In [16]:
```
vals_data = pd.DataFrame(vals)
vals_data
```

Out[16]:

	1.5	2.5	4	6	10	16	25
0	17.483824	16.864412	16.493824	16.290000	16.125882	16.035882	15.977647
1	19.085294	17.843824	17.102647	16.697647	16.366765	16.186765	16.075588
2	20.686765	18.825882	17.714118	17.105294	16.610294	16.340294	16.170882
3	22.288235	19.805294	18.322941	17.512941	16.851176	16.491176	16.266176
4	23.889706	20.787353	18.931765	17.920588	17.092059	16.644706	16.364118
5	25.491176	21.766765	19.543235	18.328235	17.335588	16.795588	16.459412
6	27.092647	22.746176	20.154706	18.735882	17.579118	16.949118	16.554706
7	28.694118	23.728235	20.763529	19.143529	17.820000	17.100000	16.652647
8	30.295588	24.710294	21.375000	19.551176	18.063529	17.250882	16.747941
9	31.897059	25.689706	21.983824	19.958824	18.304412	17.404412	16.843235

Levi Ogumba - Original copy 08/03/2021, 19:40

In [17]:
```python
plt.figure(figsize=(20,10))
plt.plot(range(5,55,5), vals_data['1.5'])
plt.plot(range(5,55,5), vals_data['2.5'])
plt.plot(range(5,55,5), vals_data['4'])
plt.plot(range(5,55,5), vals_data['6'])
plt.plot(range(5,55,5), vals_data['10'])
plt.plot(range(5,55,5), vals_data['16'])
plt.plot(range(5,55,5), vals_data['25'])

plt.grid()

blue_patch = mpatches.Patch(color='blue', label='1.5 Cable size')
orange_patch = mpatches.Patch(color='orange', label='2.5 Cable size
')
green_patch =  mpatches.Patch(color='green', label='4 Cable size')
red_patch = mpatches.Patch(color='red', label='6 Cable size')
maroon_patch = mpatches.Patch(color='darkorchid', label='10 Cable s
ize')
brown_patch = mpatches.Patch(color='brown', label='16 Cable size')
pink_patch = mpatches.Patch(color='fuchsia', label='25 Cable size')


plt.legend(handles=[blue_patch,orange_patch,green_patch,red_patch,m
aroon_patch,brown_patch,pink_patch])

plt.title('Threshold Value VS Cable length (m)')

plt.ylabel('Threshold Value')
plt.xlabel('Cable length (m)')
plt.show()
```



Appendix B

CABLE STANDARD RESISTANCE (Extract from Nexans Cable Data)				
2 CORE CONDUCTOR 0.6/1 KV (COPPER STRANDED CONDUCTORS,				
XLPE INSULATED, PVC SHEATHED)				
Cross	AC			
Section	Resistance			
mm^2	at 20^oC			
	(ohm/m)			
2C+E x 1.5	0.0121000			
2C+E x 2.5	0.0074100			
2C+E x 4	0.0046100			
2C+E x 6	0.0030800			
2C+E x 10	0.0018300			
2C+E x 16	0.0011500			
2C+E x 25	0.0007270			
ACTUAL BURDEN (Zb) = SUM OF THE CABLE IMPEDANCE/METER				
PLUS THE IMPEDANCE OF THE RELAY.				
Cable Selected	Selected Cable Resistance (ohm/m)	Cable Length (m)	Relay Impedance (ohm)	Actual Burden Zb (ohm)
2C+E x 1.5	0.0121	20	0.8	1.042

Appendix B - Nexans Cable data.x

CTCHECKERS.msi

OGUMBA, LEVI NNAMDI, et. al. "Current Transformer Performance Optimisation In Relation To Its Burden for Power System Protection." *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*, 17(2), (2022): pp. 01-17.