VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES

Ronny Mustajärvi

# INSTRUMENT TRANSFORMER DIMENSIONING FOR SUBSTATIONS

School of Technology
2016

VAASAN AMMATTIKORKEAKOULU
Sähkötekniikan koulutusohjelma

# TIIVISTELMÄ

| | |
|---|---|
| Tekijä | Ronny Mustajärvi |
| Opinnäytetyön nimi | Instrument Transformer Dimensioning for Substations |
| Vuosi | 2016 |
| Kieli | englanti |
| Sivumäärä | 41 + 1 liite |
| Ohjaaja | Vesa Verkkonen |

Tämä opinnäytetyö tehtiin ABB Oy:n Power Grids yksikölle. Jotkut asiakkaat vaativat virta- ja jännitemuuntaja laskelmia joissa todetaan että mittamuuntajat pystyvät toistamaan mitatut signaalit kyllästymättä. Tässä työssä tutustuttiin mittamuuntajien teoriaan ja luotiin laskentapohja virta- ja jännitemuuntajille.

Virtamuuntajan, siihen liittyvän kaapeloinnin ja käytetyn suojausfunktion tietojen avulla voidaan laskemalla todeta että virtamuuntaja ei kyllästy vikatilanteissa, joka mahdollistaa luotettavan ja virheettömän releen laukaisun.

Aikaansaadulla laskentapohjalla pystytään laskemalla toteamaan virtamuuntajien virheetön toiminta vikatilanteissa IEC 61869 standardin mukaisesti sekä luomaan dokumentit tehdyistä laskelmista.

Avainsanat mittamuuntaja, sähköasema, relesuojaus, virtamuuntaja

VAASAN AMMATTIKORKEAKOULU
UNIVERSITY OF APPLIED SCIENCES
Sähkötekniikan koulutusohjelma

## ABSTRACT

| | |
|---|---|
| Author | Ronny Mustajärvi |
| Title | Instrument Transformer Dimensioning for Substations |
| Year | 2016 |
| Language | English |
| Pages | 41 + 1 Appendix |
| Name of Supervisor | Vesa Verkkonen |

This thesis was made for ABB Oy, Power Grids unit. Some customers demand instrument transformer calculations, which state that the current transformers can accurately reproduce the occurring fault currents without saturation. The aim of the thesis was to get familiar with relevant instrument transformer theory and to create a calculation template.

With the data of the current transformer, secondary cables and the used protection function it is possible to calculate that the current transformer will not saturate during fault situations which enables the protective relay to function properly.

The operation of the current transformers in fault situations can be verified with the created calculation template according to the instrument transformer standard IEC 61869 and the documents of the calculations can be made.

| | |
|---|---|
| Keywords | Instrument transformer, substation, relay protection, current transformer |

# CONTENTS

## LIST OF FIGURES AND TABLES

## LIST OF APPENDICES

LIST OF ABBREVATIONS

| | |
|---|---|
| ABB | Asea Brown Boveri |
| ALF | Accuracy Limit Factor |
| CT | Current transformer |
| e.m.f. | Electromotive force |
| FOCS | Fiber Optic Current Sensor |
| FS | Instrument Security Factor |
| IEC | International Electrotechnical Commission |
| IED | Intelligent Electric Device |
| PDF | Portable Document Format |
| PT | Potential Transformer |
| VT | Voltage Transformer |

# 1 INTRODUCTION

## 1.1 The Objective of the Thesis

This thesis was made for ABB Oy, Power Grids divisions Power Integration unit with Magnus Udd from ABB and Vesa Verkkonen from Vaasa University of Applied Sciences as the supervisors.

The purpose of this thesis was to get to know the theory behind instrument transformers and to create a calculation template in Microsoft Excel which would simplify the current transformer calculation process. The way of implementing different calculations to be print ready to customers was to make several sheets for different protection functions.

The basic instrument transformer theory is covered in the first segment followed by basic relay protection functions. In the dimensioning segment the used standards for instrument transformer from IEC are presented along with different types of current transformers that are specified in the IEC 61869 instrument transformer standard. The theory behind the current transformer calculations is looked at and the created calculation template is explained. In the conclusions segment the future of the accomplished calculation template is assessed

## 1.2 ABB

ABB Asea Brown Boveri is the result of a merger between ASEA AB of Sweden and BBC Brown Boveri Ltd. of Switzerland.

ABB is the leading power and automation technology group. ABB employs approximately 150000 people and operates in 100 countries. 5200 employees work in Finland. ABB has four different divisions which are: Electrification Products, Discrete Automation and Motion, Process Automation and Power Grids

Power Grids divisions Grid Integration delivers turnkey substation solutions and is the subdivision for which the thesis was made.

# 2 INSTRUMENT TRANSFORMERS

Instrument transformers are transformers which are specially made for accurate measurement of current or voltage.

## 2.1 Current Transformers

Current transformers or CT's are instrument transformers that convert a generally high primary current Ip to a lower secondary current Is that can be connected to standard measuring or protection devices.

The most important property of the current transformer is the ratio between primary and secondary turns. Other important properties are rated primary current, rated secondary current, accuracy class, accuracy limit factor or instrument security factor (magnetization characteristic), secondary resistance and rated burden.

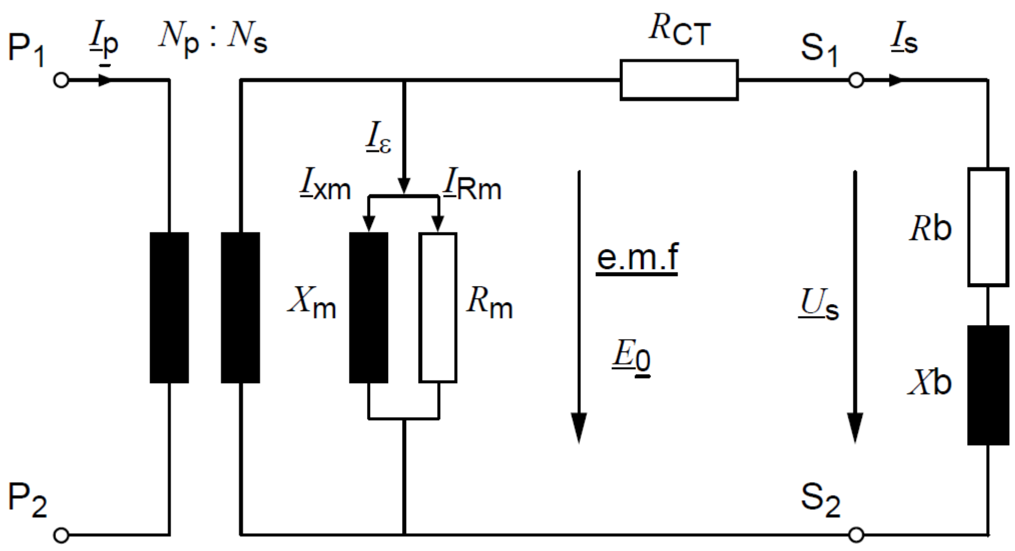


**Figure 1.** Simplified Equivalent Circuit of a Current Transformer

In Figure 1, Ip is the primary current, Is is the secondary current, Xm is the magnetizing reactance, Rm is the magnetic losses of the core, Rct is the current transformers secondary resistance, Rb and Xb are the resistance and reactance of the burden respectively and e.m.f is the electromotive force.

$P_1$ and $P_2$ are the primary coil taps and $S_1$ and $S_2$ are the secondary coil taps of the current transformer. One current transformer can have multiple cores for measurement and protection purposes.

$$f_i = \frac{I_2 - I'_1}{I'_1} * 100\% \quad (1)$$

Where $f_i$ is the error percentage, $I_2$ is the secondary current and $I'_1$ is the primary current reduced to the secondary.

A current transformer does not accurately reproduce the primary current because magnetizing current causes current error $f_i$ as seen in Equation 1. The current error is usually expressed in a percentage form.

$$\delta_i = arg\bar{I}_2 - arg\bar{I}'_1 \quad (2)$$

Where $\delta_i$ is the phase error, $\bar{I}_2$ is the vector of the secondary current and $\bar{I}'_1$ is the vector of the primary current.

The phase error is the phase difference between currents $\bar{I}_2$ and $\bar{I}_1$ as seen in Equation 2. The phase error is positive when the secondary current is ahead of the primary current. The phase error is normally expressed in minutes. /1/

It is dangerous to open the secondary circuit while the current transformer is in use because then the whole primary current would magnetize the iron core which would saturate quickly and cause extremely high voltages in the secondary terminals and possibly damage or destroy the current transformer. /1/

### 2.1.1 Protection Current Transformers

The protection core of a current transformer is designed so that the iron core of the current transformer does not saturate at high fault currents. This is achieved in a traditional current transformer by a physically bigger iron core.

Without the saturation of the iron core, the secondary current is accurate enough for protection purposes even during fault transient currents. This is important for correct functioning of the relays protection functions.

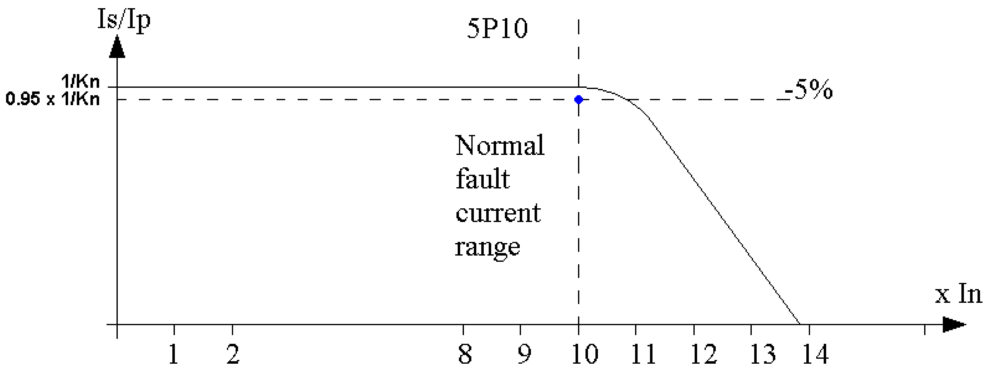


**Figure 2.** Accuracy Limit Factor

One important factor that determines the saturation point is the accuracy limit factor or ALF. ALF times the rated primary current is the saturation point where the iron core begins to saturate as seen in Figure 2. The physical size of the iron core greatly depends on the accuracy limit factor. The knee point voltage of current transformer is when 10 % increase in the secondary voltage causes a 50 % increase in the exciting current. /1/

A current transformer needs to produce the necessary flux to feed the fault current to the secondary which has two components: the DC offset asymmetrical component and the AC component (symmetrical). The resultant voltage must be higher than that necessary to feed the load connected in the secondary side of CT's without distortions caused by saturation.

| Accuracy class | Current error (%) | Angle error at In in: | | total error at accuracy limit (%) |
|---|---|---|---|---|
| | | minutes | centiradians | |
| 5P | 1% | 60 | 1,8 | 5% |
| 10P | 3% | | | 10% |

**Figure 3.** Protection Core Classes

For example a 5P10 rated current transformer core has the accuracy class of 5P and the accuracy limit factor of 10, which means 1% maximum error at rated current and 5% maximum error at 10 times the rated primary current as seen in Figure 3.

### 2.1.2 Measurement Current Transformers

The measurement core of a current transformer accurately measures the current within normal operating range. The measurement core saturates at a much lower point than the protection core. This limits the secondary current through the meter and protects the measurement devices from overloading or breaking. Measurement cores cannot be used for high current protection purposes because high fault transients would not be accurate at the secondary measuring circuit because of saturation.

| Accuracy class | % Current error @ % of In | | | | | | % Angle error @ % of In | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Minutes | | | | | Centiradians | | | | |
| | 1 | 5 | 20 | 50 | 100 | 120 | 1 | 5 | 20 | 100 | 120 | 1 | 5 | 20 | 100 | 120 |
| 0,1 | | 0,4 | 0,2 | | 0,1 | 0,1 | | 15 | 8 | 5 | 5 | | 0,45 | 0,24 | 0,15 | 0,15 |
| 0,2 | | 0,75 | 0,35 | | 0,2 | 0,2 | | 30 | 15 | 10 | 10 | | 0,9 | 0,45 | 0,3 | 0,3 |
| 0,2S | 0,75 | 0,35 | 0,2 | | 0,2 | 0,2 | 30 | 15 | 10 | 10 | 10 | 0,9 | 0,45 | 0,3 | 0,3 | 0,3 |
| 0,5 | | 1,5 | 0,75 | | 0,5 | 0,5 | | 90 | 45 | 30 | 30 | | 2,7 | 1,35 | 0,9 | 0,9 |
| 0,5S | 1,5 | 0,75 | 0,5 | | 0,5 | 0,5 | 90 | 45 | 30 | 30 | 30 | 2,7 | 1,35 | 0,9 | 0,9 | 0,9 |
| 1 | | 3 | 1,5 | | 1 | 1 | | 180 | 90 | 60 | 60 | | 5,4 | 2,7 | 1,8 | 1,8 |
| 3 | | | | 3 | | 3 | | | | | | | | | | |
| 5 | | | | 5 | | 5 | | | | | | | | | | |

**Figure 4.** Measurement Core Classes

IEC defines the standard accuracy classes as seen in Figure 4. Class 0,2S and 0,5S are meant to be more accurate at lower currents. They have one accuracy measurement point more at one percent of rated current and angle error as seen in Figure 4.

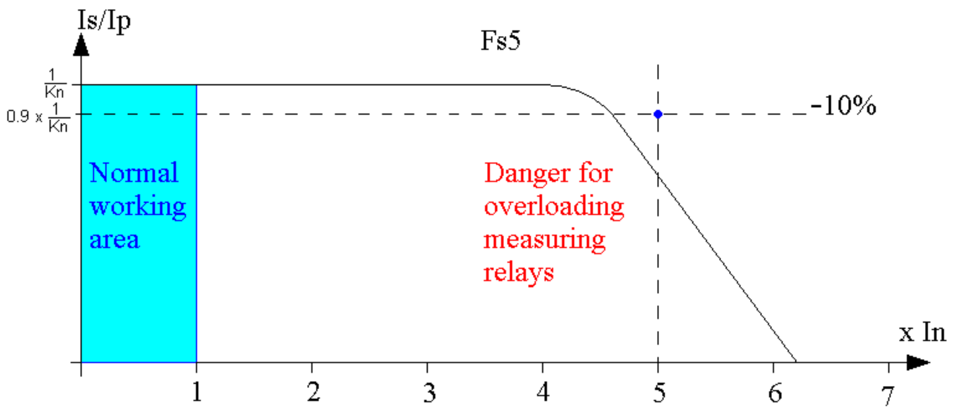


**Figure 5.** Instrument Security Factor

The ratio of rated instrument limit primary current to the rated primary current is known as the instrument security factor or FS. FS 5 rated measurement core will begin to saturate before the security limit and the error is 10 % at the rated burden at the security limit of five times the rated current as seen in Figure 5.

The ALF of the protection core and the FS of the measurement core both represent the ratio of rated accuracy limit primary current to the rated primary current

### 2.1.3 Rogowski Coil

The Rogowski coil consists of a wire wound in a helical shape around the primary conductor so that both ends of the conductor are at one end. The coil will not saturate because there is no iron core. The Rogowski coil also has a low inductance and thus is faster and better suited for measuring high frequency currents than a traditional current transformer.

The induced voltage to the coil is proportional to the derivative of the primary current. To get practical measurement data from the coil, the output must be connected to an integrator circuit. One of the downsides to the Rogowski coil is the low signal strength in the output, which makes it vulnerable for interference of nearby high electric and magnetic fields. /10/

### 2.1.4 Fiber Optic Current Sensor

The fiber optic current sensor uses the Faraday effect to measure current. The Faraday effect rotates the plane of polarization of light which is proportional to the magnetic field produced by the current flowing through the sensor. The result is converted to an optical IEC 61850 Ethernet output.

The sensor has notable advantages over conventional current transformers. The fiber optic current sensor is free of magnetic saturation which allows the measurement of high fault currents and fast transients. The sensor has redundancy available and it simplifies engineering.

FOCS can be integrated in circuit breakers thus saving space and reduces substation footprint /3/

## 2.2 Voltage Transformers

Voltage transformers or VT's also called potential transformers are instrument transformers that convert a generally high primary voltage to a lower secondary voltage that can be connected to standard measuring or protection devices. There are two primary types of voltage transformers which are inductive voltage transformer and capacitive voltage transformer or capacitor voltage transformer.

It is important that the voltage transformer, for thermal and protection reasons, can withstand and reproduce the continuous fault over voltages that can occur in the grid. The over voltage factor is abbreviated as $F_V$. IEC specifies a voltage factor of 1.9 for systems not being solidly earthed and 1.5 for systems with solidly earthed neutral. /9/

| Class | Voltage (ratio) error $\varepsilon_u$ ±% | Phase displacement $\Delta\varphi$ | |
|---|---|---|---|
| | | ±Minutes | ±Centiradians |
| 3P<br>6P | 3,0<br>6,0 | 120<br>240 | 3,5<br>7,0 |

**Figure 6.** IEC Protective Voltage Transformer Accuracy Classes

| Class | Voltage (ratio) error $\varepsilon_u$ ±% | Phase displacement $\Delta\varphi$ | |
|---|---|---|---|
| | | ±Minutes | ±Centiradians |
| 0,1 | 0,1 | 5 | 0,15 |
| 0,2 | 0,2 | 10 | 0,3 |
| 0,5 | 0,5 | 20 | 0,6 |
| 1,0 | 1,0 | 40 | 1,2 |
| 3,0 | 3,0 | Not specified | Not specified |

**Figure 7.** IEC Measuring Voltage Transformer Accuracy Classes

The accuracy for measuring windings of different classes as seen in figures 6 and 7 is fulfilled between 0.8 and 1.2 times the rated voltage and up to the voltage factor (1.5 or 1.9 x rated voltage) for protection windings. IEC specifies that the accuracy class shall be fulfilled from 0.25 to 1.0 of the rated burden of the measuring voltage transformer. /9/

### 2.2.1 Inductive Voltage Transformer

The inductive voltage transformer is like a traditional transformer where the primary voltage is transformed to the secondary via induction. In the case of an inductive voltage transformer a high primary voltage is converted to a lower secondary voltage which can be connected to protection relays inputs. Inductive voltage transformer is usually more cost-effective than a capacitive voltage transformer at voltages below 123 kV. /1/

### 2.2.2 Capacitive Voltage Transformer

Capacitive voltage transformers use capacitors to divide the primary voltage to a lower value. The lowered voltage is then stepped down with a transformer to the secondary. The circuit is tuned to line frequency with an inductive coil.

During transients a capacitive voltage transformer behaves differently than the inductive voltage transformer. Even if short-circuit happened near the capacitive voltage transformer, the secondary voltage would not immediately drop to nearly zero, because the energy in the capacitors upkeeps the voltage. This effect slows down line distance protection, because the protective relay measures a higher voltage and the fault being further away. /1/

## 2.3 Combined Instrument Transformers

Combined instrument transformers have a current transformer and a voltage transformer in one housing which lowers the total cost substantially. Capacitive voltage tapping is possible in current transformers. It is inexpensive and supports only low burdens for example a voltage meter. Capacitive voltage tapping is used for example synchro-check and voltage-check purposes. /1/

# 3 RELAY PROTECTION

Instrument transformers are a key part of relay protection. The measured signals from current and voltage transformer secondary coils are used in the relay to detect fault situations and quickly isolate the fault from the network.

## 3.1 Protection Functions

Different protection functions are used to protect different parts of the electrical grid. Different protection functions set different requirements for the protective current transformer.

### 3.1.1 Line Distance Protection

Line distance protection is one of the most used and important functions of high voltage transmission line protection. The impedance of a transmission line is proportional to its length. If the measured impedance of the transmission line is smaller than the calculated impedance of the transmission line then the distance protection function will trip. Distance protection is also called impedance protection.

Distance protection has multiple zones which can be configured freely. Usually at least two zones are in use: zone 1 which is set to reach point which is 80-90 % of line impedance and zone 2 which is 120 % or more of line impedance. This way zone 2 acts also as a backup for the next transmission line.

Transmission lines vary in length and distance protection is not ideal for protecting short transmission lines.

### 3.1.2 Line Differential Protection

Differential protection compares the current amplitude and/or –phase angle of both ends of the transmission line. If the measured value exceeds a set value; circuit breakers will trip at both ends of the transmission line and isolating the faulty section of the network. Line differential is usually a better option than distance protection for short transmission lines.

Differential protection is also commonly used in transformer and generator protection.

### 3.1.3 Bus Bar Protection

Faults that occur in the substation are bus faults if they are on the bus side of the current transformers. Faults that occur on the feeder side of the current transformers are feeder faults. The position of the current transformers affect which faults are bus- or feeder faults.

Using differential protection based on the Kirchhoff's first law the currents are measured at each feeder connected to the substation which is the nodal point. If the sum of these currents does not equal to nearly zero; there is a fault current flowing somewhere on the bus side of the current transformers and all circuit breakers connected to the bus will trip and the bus will remain dead. /1/

The protection core of current transformers in each feeder provides the measurement by which the protective relay choose to trip the circuit breakers. For an optimal result all of the protection cores would be identical.

Bus bar protection can also be engineered with overcurrent relays which is commonly the case in medium voltage switchgear where it is cost efficient to use an overcurrent relay in the supply cubicle to protect the bus bar. /1/

### 3.1.4 Overcurrent Protection

Overcurrent protection functions operate when the current exceeds the set value for set time. Different time-current characteristics are used, which are: instantaneous, definite time and inverse time delayed overcurrent protection. The instantaneous mode operates instantaneously when the set current is exceeded. The definite time operates when the set current is exceeded for a set time. Inverse time delayed mode operates like the definite time but as the current gets higher the time needed to operate also drops.

### 3.1.5 Earth Fault Protection

For earth fault protection the protective relays measure residual overcurrent or residual voltage. The trip will happen when residual current or voltage exceeds the set limit for set time. Residual current is measured with a core balance current transformer or calculated from the three individual current transformers. Residual voltage can be measured with an open delta winding or calculated from the sum of each phase voltage transformer.

Earth fault currents are typically small and usually below the rated current of the current transformer. Measurement class current transformers are better suited for measuring low currents than protection class current transformers. /1/

### 3.1.6 Restricted earth fault protection

Restricted earth fault protection is commonly used in transformer protection. Current is measured in all three phases and the grounded neutral. For solidly grounded systems a restricted earth fault protection is often provided as a complement to the normal transformer differential function. The advantage with the restricted ground fault functions is the high sensitivity for internal earth faults in the transformer winding. Sensitivities of 2-8% can be achieved whereas the normal differential function will have sensitivities of 20-40%. It is connected across each directly or low impedance grounded transformer winding. /5/

# 4 DIMENSIONING

Instrument transformers are dimensioned with cost effectiveness and functionality in mind. They need to withstand large fault currents and accurately enough reproduce the current to the secondary and to the protection devices. Environmental stress and reliability are also important factors to consider.

Current transformers are much harder to dimension optimally compared to voltage transformers. That is because the fault current can be multiple times the rated current while the voltage changes only slightly and operates mostly at the rated range.

The performance of protection functions of a protection relay will depend on the quality of the measured signal. The saturation of the current transformer will cause distortion of the current signal and can result in a failure to operate or cause unwanted operations of some protection functions.

Current transformers must be able to correctly reproduce the current for a minimum time before the current transformer will begin to saturate. To fulfil the requirement on a specified time to saturation the current transformers must fulfil the requirements of a minimum secondary e.m.f. /2/

The dimensioning of current transformers at medium voltages is not as critical as high voltages because of higher operating times of protection functions and smaller time constants in middle voltage grid. /1/

Different protection functions set different requirements for CT's. For example non-directional overcurrent protection does not need a high accuracy limit factor but it is still recommended to choose an ALF of at least 20. /4/

### 4.1 Standards

IEC 61869 is the instrument transformer standard which consists of the following parts:

- IEC 61869-1 Instrument transformers – Part 1: General requirements
- IEC 61869-2 Instrument transformers – Part 2: Additional requirements for current transformers
- IEC 61869-3 Instrument transformers – Part 3: Additional requirements for inductive voltage transformers

The standard has more parts for capacitive voltage transformers, current transformers for transient performance, electronic voltage and current transformers and low-power stand-alone current sensors but only the first three parts are relevant for this thesis.

From different standards and available data for relaying applications it is possible to approximately calculate the secondary e.m.f. of the CT comparable with Eal. By comparing this with the required secondary e.m.f. Ealreq it is possible to judge if the CT meets the requirements.

A CT according to IEC 61869-2 is specified by the secondary limiting e.m.f. $E_{2max}$. The value of the $E_{2max}$ is approximately equal to the corresponding $E_{al}$ according to IEC 61869-2. Therefore, the CTs according to class P and PR must have a secondary limiting e.m.f. $E_{2max}$ that meets the following: /2/

$$E_{2max} > maximum\ of\ E_{alreg} \qquad (3)$$

Current transformers according to IEC 61869-2, class PX, PXR CTs classes are specified approximately in the same way by a rated knee point e.m.f. Eknee (Ek for class PX and PXR). The value of the $E_{knee}$ is lower than the corresponding $E_{al}$ according to IEC 61869-2. It is not possible to give a general relation between the $E_{knee}$ and the $E_{al}$ but normally the $E_{knee}$ is approximately 80 % of the $E_{al}$. /2/

Therefore, the CTs according to class PX, PXR, X and TPS must have a rated knee point e.m.f. $E_{knee}$ that meets the following: /2/

$$E_{knee} \approx E_k > 0{,}8 \times (maximum\ of\ E_{alreg}) \quad (4)$$

## 4.2 Current Transformer Types

Many different standards exist regarding current transformers and their types. The IEC 61869 standard defines different types as follows:

- Class P is a protective current transformer without remanent flux limit for which the saturation behaviour is specified /8/
- Class PR is a protective current transformer with remanent flux limit for which the saturation behaviour is specified /8/
- Class PX is a protective current transformer of low leakage reactance without remanent flux limit for which knowledge of the excitation characteristic and of the secondary winding resistance, secondary burden resistance and turns ratio, is sufficient to assess its performance in relation to the protective relay system with which it is to be used /8/
- Class PXR is a protective current transformer with remanent flux limit for which knowledge of the excitation characteristic and of the secondary winding resistance, secondary burden resistance and turns ratio, is sufficient to assess its performance in relation to the protective relay system with which it is to be used /8/
- Class TPX is a protective current transformer without remanent flux limit, for which the saturation behaviour in case of a transient short-circuit current is specified by the peak value of the instantaneous error /8/
- Class TPY is a protective current transformer with remanent flux limit, for which the saturation behaviour in case of a transient short-circuit current is specified by the peak value of the instantaneous error /8/
- Class TPZ is a protective current transformer with a specified secondary time-constant, for which the saturation behaviour in case of a transient short-circuit current is specified by the peak value of the alternating error component /8/

### 4.2.1 High Remanence Type

The high remanence type has no specified limit for the remanent flux and remanence can be up to 80 % of the saturation flux. Classes P, PX, TPS and TPX are high remanence type current transformers according to IEC. /8/

### 4.2.2 Low Remanence Type

The low remanence type specifies a limit for the remanent flux. Remanent flux cannot exceed 10 % of the saturation flux. This is achieved by an air gap in the iron core. Classes PR and TPY are low remanence type current transformers according to IEC. /8/

### 4.2.3 Non Remanence Type

The non-remanence type has practically zero remanent flux. This is achieved using large air gaps in the iron core. This reduces the influence of the DC-component from the primary fault current but measuring accuracy is decreased in the non-saturated region of the operation. According to IEC class TPZ is an example of this type. /8/

## 4.3 Calculations

The current transformer requirements are based on the maximum fault current which can be a three-phase fault or a single-phase-to-earth fault in different positions. The operating current of a function is used instead of maximum fault current in some calculations.

$$E_{al} \geq E_{alreq} = \frac{I_{kmax} \cdot I_{sn}}{I_{pn}} \cdot \left(R_{CT} + R_L + \frac{S_R}{I_r^2}\right) \tag{5}$$

Where $I_{kmax}$ is the maximum fault current, $I_{sn}$ is the secondary current, $I_{pn}$ is the primary current, $R_{CT}$ is the current transformers internal resistance, $R_L$ is the secondary lead resistance, $S_R$ is the relay input burden and $I_r$ is the rated secondary current.

Equation 5 is an example of an equation which calculates the $E_{alreg}$ for a current transformer which can then be compared to the $E_{al}$ value of the current transformer. $E_{alreg}$ is the minimum voltage required to reproduce the maximum secondary fault current without any saturation. The current transformers must have a rated equivalent secondary e.m.f. $E_{al}$ that is larger than the required maximum secondary e.m.f. $E_{alreg}$. The rated equivalent limiting secondary e.m.f. $E_{al}$ is used to specify the current transformer requirements for ABB relays.

The old instrument transformer standard IEC 60044 was replaced by IEC 61869. Using this standard the requirements are also specified according to other standards. /2/

An oversizing factor may be added to Equation 5 in different protection functions. For example in line distance protection, an oversizing factor is added to equation 5 to make sure that the current transformer does not saturate even with the DC component in the transient current. Equations are different for each protective function.

### 4.3.1 Actual Accuracy Limit Factor

Current transformers have a rated accuracy limit factor $F_n$ for protection cores or instrument security factor $F_s$ for measurement cores.

$$F_a \approx F_n = \frac{S_{in}+S_n}{S_{in}+S_a} \qquad (6)$$

Where $F_a$ is actual accuracy limit factor, $F_n$ is rated accuracy limit factor $S_{in}$ is internal burden, $S_n$ is rated burden and $S_a$ is actual burden.

The accuracy limit factor describes the saturation point of the current transformer at rated burden. However the actual accuracy limit factor is proportional to the ratio of the rated burden and the actual burden as seen in equation 6. The same equation can be used for calculating actual instrument security factor.

The actual instrument security factor is calculated for the measurement cores to make sure that the secondary measurement circuit is not overloaded during a fault. /6/

## 4.4 Practical Viewpoints

### 4.4.1 Current Transformer Analyzer

Current transformers are measured on site with a CT analyzer to make sure that they meet all of the requirements.


**Figure 8.** 110 kV Current Transformer

The current transformer seen in figure 8 has been tested on site with a CT analyzer. The CT analyzer measures many values, but the most important one is the magnetization curve from which the knee point can be seen. Protection cores are class 10P50 and measured knee point in core 3S was at 1147 V and 864 mA.

$$E_{2max} = I_{sn} \cdot n \cdot \left( R_{CT} + \frac{S_n}{I_{sn}^2} \right) \quad (7)$$

Where $I_{sn}$ is the secondary current of the CT, n is the accuracy limit factor, $R_{ct}$ is the internal resistance of the CT, Sn is the rated burden of the CT and the $I_{sn}$ is the rated secondary current of the CT.

Using Equation 7 the $E_{2max}$ or the secondary limiting e.m.f can be calculated approximately. The secondary limiting e.m.f should be close to the calculated knee point. In the case of current transformer in Figure 6 the calculated $E_{2max}$ is 1200 V, which approximately matches with the measured value of 1147 V.

### 4.4.2 Medium Voltage Current Transformer

Medium Voltage Current Transformers usually have a standard sized housing which contains all of the used measurement and protection cores.

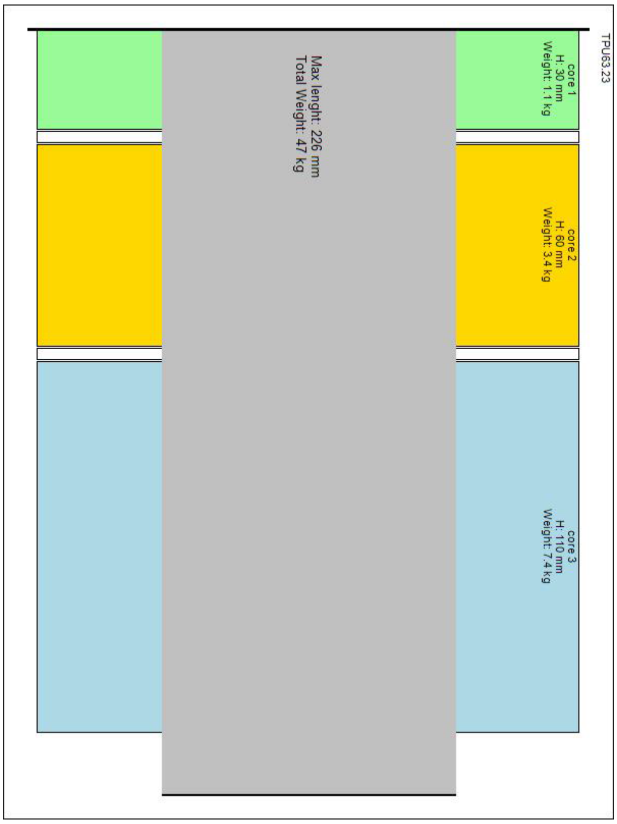


**Figure 9.** Three Core Medium Voltage Current Transformer

Calculations can be made to make sure if all of the cores fit inside one standard medium voltage current transformer housing. The smallest core (green) is the measurement core, the orange core is one of the protection cores and the largest core (blue) is the second protection core as seen in figure 9. The size of a core greatly depends on the accuracy limit factor of the core.

Physical space is limited in some medium voltage switchgear assemblies. It is important to dimension the used measurement and protection cores with care because unnecessarily large iron cores require more space and situations may arise where all of the needed cores do not fit inside the standard current transformer housing.

# 5 CALCULATION TEMPLATE

The aim of this thesis was to create a calculation template with Microsoft Excel which would simplify the current transformer calculation process. Excel is ideal for this calculation, because it is easy to use, the sheets are easy to modify and Excel is the industry standard in spreadsheets.

The template has an input sheet where the user enters all of the needed values of the current transformer and other relevant data. The calculations are made in separate sheets for each protection function which are designed to be print ready. Once the data is entered at the input sheet; all of the necessary calculations are ready to be printed out in a format which can be sent to customers.

## 5.1 Input Sheet

The user inputs the relevant current transformer, cable and project data in the input sheet. These values are then used in the calculation sheets.

| | |
|---|---|
| **Project name** | Substation 110/20 kV |
| **Customer Name** | Client Ltd. |
| **Document name** | AE12 Bay |
| **Document number** | 12 |
| **Issued by departmen** | Power Grids |
| **Status of document** | - |
| **Document type** | - |
| **Creator Name** | R. Mustajärvi |
| **Revision** | - |
| **Revision date** | - |

**Figure 10.** Project Data

The entered project data as seen in Figure 10 is used in the title page of the document. An example title page can be seen in Appendix 1.

| DISTANCE PROTECTION | | | |
|---|---|---|---|
| Max three phase fault current | Ikmax | 25000 | A |
| Max three phase fault current at zone 1 reach | Ikzone1 | 10000 | A |
| Max single phase fault current | Ikmaxe | 10000 | A |
| Max single phase fault current at zone 1 reach | Ikzone1e | 8000 | A |
| Time constant co-efficient for three phase | a | 2 | |
| Time constant co-efficient for one phase | a | 2 | |
| Time constant co-efficient for three phase | k | 4 | |
| Time constant co-efficient foe one phase | k | 4 | |
| | | | |
| **CT VALUES** | | **PROTECTION CORE** | |
| CT designation | | T11-13 | |
| CT core | | Core 1 | |
| Rated primary current of the CT | Ipn | 1200 | A |
| Rated output of the CT | Sn | 15 | VA |
| CT internal resistance | Rct | 8,9 | Ω |
| Rated secondary current of the CT | Isn | 1 | A |
| Rated current of the protection IED | Ir | 1 | A |
| Accuracy class | | 10 | |
| Accuracy limiting factor | Fn | 50 | |
| Total burden of devices | Sb | 0,02 | VA |

**Figure 11.** Relevant Distance Protection Input Values

Each protection function has its own separate input box. For example distance protections input box is seen in Figure 11. The relevant data needed for the calculations is entered in the blue cells. The maximum fault current in different situations, time constant co-efficient and current transformer data is needed for distance protection function.

Most of the CT values are found in the rating plate of the current transformer. The burden of the input channel of the relay can be found in the relay manual. The rated secondary current greatly influences the burden of the input channel.

These values are then used in the distance protection functions calculation sheet. There is a separate sheet for each protection function because the used equations are different for each protective function.

| DIFFERENTIAL PROTECTION | | | |
|---|---|---|---|
| Maximum 3-phase current for close in faults | Ikmax | 31500 | A |
| Maximum 3-phase current for external through faults | Itmax | 25000 | A |
| Maximum 1-phase current for close in faults | Ikmaxe | 20000 | A |
| Maximum 1-phase current for external through faults | Itmaxe | 20000 | A |
| | | | |
| **CT VALUES** | | **PROTECTION CORE** | |
| CT designation | | T11-13 | |
| CT core | | Core 1 | |
| Rated primary current of the CT | Ipn | 800 | A |
| Rated output of the CT | Sn | 15 | VA |
| CT internal resistance | Rct | 9 | Ω |
| Rated secondary current of the CT | Isn | 1 | A |
| Rated current of the protection IED | Ir | 1 | A |
| Accuracy class | | 5 | |
| Accuracy limiting factor | Fn | 50 | |
| Total burden of devices | Sb | 0,02 | VA |

**Figure 12.** Differential Protection Input Values

The differential protection input box in Figure 12 only needs the maximum fault current values in addition to the current transformer values.

| BUSBAR PROTECTION | | | | |
|---|---|---|---|---|
| Max three phase fault current | If3max | 25000 | | A |
| Max one phase fault current | If1max | 16000 | | A |
| Current transformer type | | No/Low Remanence | | |
| Breaker failure protection used | | NO | | |
| Primary operate value (breaker failure protection) | Iop | 5500 | | A |
| | | | | |
| **CT VALUES** | | **PROTECTION CORE** | | |
| CT designation | | | T11-13 | |
| CT core | | | Core 4 | |
| Rated primary current of the CT | | Ipn | 1200 | A |
| Rated output of the CT | | Sn | 15 | VA |
| CT internal resistance | | Rct | 9,1 | Ω |
| Rated secondary current of the CT | | Isn | 1 | A |
| Rated current of the protection IED | | Ir | 1 | A |
| Accuracy class | | | 5 | |
| Accuracy limiting factor | | Fn | 50 | |
| Total burden of devices | | Sb | 0,02 | VA |

**Figure 13.** Busbar Protection Input Values

The busbar protection input box in Figure 13 has a choice for low remanence of high remanence current transformer type.

| GENERATOR PROTECTION | | | |
|---|---|---|---|
| **Generator differential function** | | | |
| Rated primary current of the generator | Ing | 3250 | A |
| Maximum primary fault current that passes two main CTs for external faults | Itf | 13000 | A |
| | | | |
| **CT VALUES** | | **PROTECTION CORE** | |
| CT designation | | T11-13 | |
| CT core | | Core 1 | |
| Rated primary current of the CT | Ipn | 4000 | A |
| Rated output of the CT | Sn | 15 | VA |
| CT internal resistance | Rct | 5 | Ω |
| Rated secondary current of the CT | Isn | 1 | A |
| Rated current of the protection IED | Ir | 1 | A |
| Accuracy class | | 5 | |
| Accuracy limiting factor | Fn | 10 | |
| Total burden of devices | Sb | 0,02 | VA |

**Figure 14.** Generator Protection Input Values

The generator differential protection box in Figure 14 needs only the rated primary current of the generator and the maximum fault current values in addition to the current transformer values.

| TRANSFORMER PROTECTION | | | |
|---|---|---|---|
| **Transformer differential function** | | | |
| Rated primary current of the power transformer | Int | 210 | A |
| Maximum primary fundamental frequency current that passes two main CTs and the power transformer | Itf | 15000 | A |
| Breaker-and-a-half or duplex (double-breaker, double-busbar) arragment used | | YES | |
| Maximum primary fundamental frequency phase-to-earth fault current that passes two main CTs WITHOUT passing the power transformer | If | 60000 | A |
| | | | |
| **Restricted earth fault protection** | | | |
| Maximum primary fundamental frequency phase-to-earth fault current that passes the CTs and the power transformer neutral | Ietf | 10000 | A |
| Maximum primary fundamental frequency phase-to-earth fault current that passes the CTs WITHOUT passing the power transformer neutral | Ief | 688 | A |
| | | | |
| **CT VALUES** | PROTECTION CORE | | |
| CT designation | | T11-13 | |
| CT core | | Core 1 | |
| Rated primary current of the CT | Ipn | 800 | A |
| Rated output of the CT | Sn | 15 | VA |
| CT internal resistance | Rct | 9 | Ω |
| Rated secondary current of the CT | Isn | 1 | A |
| Rated current of the protection IED | Ir | 1 | A |
| Accuracy class | | 5 | |
| Accuracy limiting factor | Fn | 50 | |
| Total burden of devices | Sb | 0,02 | VA |

**Figure 15.** Transformer Protection Input Values

In Figure 15 there are input cells for transformer differential function and an option for restricted earth fault protection. Restricted earth fault protection calculations are done in a separate sheet from the differential function.

| OVERCURRENT PROTECTION | | | |
|---|---|---|---|
| Maximum close-in fault current | Ikmax | 40000 | A |
| Primary operate value | Iop | 20000 | A |
| Directional OC used | | YES | |
| Non-directional OC used | | YES | |
| Non-directional inverse time OC used | | YES | |
| Breaker failure protection | | NO | |
| **CT VALUES** | | **PROTECTION CORE** | |
| CT designation | | T11-13 | |
| CT core | | Core 1 | |
| Rated primary current of the CT | Ipn | 800 | A |
| Rated output of the CT | Sn | 15 | VA |
| CT internal resistance | Rct | 9 | Ω |
| Rated secondary current of the CT | Isn | 1 | A |
| Rated current of the protection IED | Ir | 5 | A |
| Accuracy class | | 5 | |
| Accuracy limiting factor | Fn | 50 | |
| Total burden of devices | Sb | 0,02 | VA |

**Figure 16.** Overcurrent Protection Input Data

Used overcurrent function types must be stated in the overcurrent input box, because different options use a different set of equations, as seen in Figure 16. For example, if the non-directional inverse time overcurrent function is the only one used, the requirements are much higher than with a definite time overcurrent function. Yes or no choice in the cells affect the calculation sheet so that the correct $E_{alreg}$ values are compared to the calculated $E_{al}$ value.

Other input boxes also have yes or no choice inputs for example in busbar protection the user must state if the used current transformer is a low remanence or a high remanence type current transformer because low and high remanence CT's are calculated with different equations in the case of busbar protection.

| CABLE VALUES | | | |
|---|---|---|---|
| Maximum length of the cable | l | 100 | m |
| Cross-section of the cable | A | 4 | mm2 |
| Resistivity of the conductor (Copper 75°C) | ρ | 0,0216 | μΩm |
| Calculated lead resistance (Phase-to-phase fault) | RL | 0,540 | Ω |
| Calculated loop resistance (Phase-to-earth fault) | Rle | 1,080 | Ω |

**Figure 17.** Cable values

Cable burden is a part of the total burden of the CT. The calculated resistance values can be seen in the grey areas in Figure 17. Length, cross-section, conductor material and temperature affect the calculated resistance. The resistance values are calculated for copper at 75°C.

| METERING | | | |
|---|---|---|---|
| CT designation | | T11-13 | |
| CT core | | Core 1 | |
| Rated primary current of the CT | Ipn | 1200 | A |
| Rated output of the CT | Sn | 5 | VA |
| CT internal resistance | Rct | 3,3 | Ω |
| Rated secondary current of the CT | Isn | 1 | A |
| Rated current of the measurement device | Ir | 1 | A |
| Accuracy class | | 0,2S | |
| Instrument security factor | Fs | 5 | |
| Burden of the devices | Sb | 1 | VA |
| Minimum burden | %/Sn | 25 | |
| Minimum required instrument security factor of devices | Fsmin | 10 | |
| Additional resistor | R | 0 | Ω |
| Extended current measurement rating | | 1 | |
| Used connection | 4 wire connection | | |
| Calculated lead resistance 4W connection | RL | 0,648 | Ω |
| Calculated lead resistance 6W connection | RL | 1,080 | Ω |

**Figure 18.** Measurement core values

Measurement core values are mostly the same as protection core values but with added minimum burden, minimum required instrument security factor and additional resistor values as seen in Figure 18.

## 5.2 Calculation Sheets

Calculation sheets show the relevant data needed to calculate the secondary limiting e.m.f $E_{alreg}$ for each protection function. The calculated secondary limiting e.m.f $E_{alreg}$ is then compared to the $E_{2max}$ e.m.f value of the current transformer.

As seen in appendix 1, a calculation sheet was made for the following functions:

- Line distance protection
- Line differential protection
- Overcurrent protection
- Busbar protection
- Transformer protection
- Transformer low impedance restricted earth fault protection
- Generator protection

### 5.2.1 Example Calculation Sheet

The distance protection sheet is one of the calculation sheets which are meant to be printed out and are designed to be easy to read and the relevant calculations as well as the used equations are all shown. The difference between the different calculation sheets is the used equations and function related data.

| | | | | |
|---|---|---|---|---|
| **ADEQUACY CHECK FOR DISTANCE PROTECTION FUNCTION** | | | | |
| **REL670 AND REL650** | | | | |
| **T11-13** | **Core 1** | | | |
| CT ratio: | | **1200** | / **1** | A |
| CT rated burden: | Sn = | **15** | VA | |
| CT resistance: | $R_{ct}$< | **8,9** | Ω | |
| Accuracy class | | **10** | | |
| Accuracy limiting factor | | **50** | | |

| | | | | |
|---|---|---|---|---|
| Maximum current for 3-phase close in faults | $I_{k3max}$ | = | **25000** | A |
| Maximum current for 3-phase faults at zone 1 reach | $I_{k3zone1}$ | = | **10000** | A |
| Maximum current for 1-phase close in faults | $I_{k1max}$ | = | **10000** | A |
| Maximum current for 1-phase faults at zone 1 reach | $I_{k1zone1}$ | = | **8000** | A |
| CT rated primary current | $I_{pn}$ | = | 1200 | A |
| CT rated secondary current | $I_{sn}$ | = | 1 | A |
| The protection terminal rated current | $I_r$ | = | 1 | A |
| CT secondary winding resistance | $R_{CT}$ | = | 8,9 | Ω |
| The resistance of the secondary cable and additional load for 3-phase faults | $R_{L3}$ | = | 0,54 | Ω |
| The resistance of the secondary cable and additional load for 1-phase faults | $R_{L1}$ | = | 1,08 | Ω |
| Total burden of devices | $S_R$ | = | 0,02 | VA |
| This factor is a function of the primary time constant for the dc component in the fault current | a | = | 2 | |
| A factor of the primary time constant for the dc component in the fault current for a three-phase fault at the set reach of zone 1 | k | = | 4 | |

**CT adequacy check for distance protection function**

Current transformer used must have rated secondary limiting e.m.f that is greater than or equal to required secondary e.m.f that fulfills the following conditions:

For close-in faults:

$$E_{al} \geq E_{alreq} = \frac{I_{kmax} \cdot I_{sn}}{I_{pn}} \cdot a \cdot \left(R_{CT} + R_L + \frac{S_R}{I_r^2}\right) \quad (1)$$

For external through faults:

$$E_{al} \geq E_{alreq} = \frac{I_{kzone1} \cdot I_{sn}}{I_{pn}} \cdot k \cdot \left(R_{CT} + R_L + \frac{S_R}{I_r^2}\right) \quad (2)$$

**Figure 19.** Distance Protection Calculation 1

Current transformer values from the input sheet are shown at the top of the calculation sheet. All the relevant data needed to calculate the secondary limiting e.m.f $E_{alreg}$ is listed below the CT data. The used equations for the calculations are shown at bottom of the page as seen in Figure 19. Equation 1 is used for close-in faults and Equation 2 for external through faults. External through faults are calculated at the end of zone 1 reach.

**CT calculations**

**Phase-to-phase fault**

Faults near the CB

$$E_{alreq1} = \frac{25000 \times 1}{1200} \times 2 \times \left( 8{,}9 + 0{,}54 + \frac{0{,}02}{1^2} \right) = \mathbf{394{,}2}\ \text{V} \quad (1)$$

Faults at the end of zone 1

$$E_{alreq2} = \frac{10000 \times 1}{1200} \times 4 \times \left( 8{,}9 + 0{,}54 + \frac{0{,}02}{1^2} \right) = \mathbf{315{,}3}\ \text{V} \quad (2)$$

**Phase-to-earth fault**

Faults near the CB

$$E_{alreq3} = \frac{10000 \times 1}{1200} \times 2 \times \left( 8{,}9 + 0{,}54 + \frac{0{,}02}{1^2} \right) = \mathbf{166{,}7}\ \text{V} \quad (1)$$

Faults at the end of zone 1

$$E_{alreq4} = \frac{8000 \times 1}{1200} \times 4 \times \left( 8{,}9 + 0{,}54 + \frac{0{,}02}{1^2} \right) = \mathbf{266{,}7}\ \text{V} \quad (2)$$

**Verification of CT data according to IEC 61869**

The CT according to class P/PR must have a secondary limiting e.m.f $E_{2max}$ higher than the maximum value of $E_{alreq}$

$$E_{2max} = I_{sn} \cdot n \cdot \left( R_{CT} + \frac{S_n}{I_{sn}^2} \right) \quad (3)$$

| | | | | |
|---|---|---|---|---|
| CT rated secondary current | $I_{sn}$ | = | 1 | A |
| CT secondary winding resistance | $R_{CT}$ | = | 8,9 | Ω |
| CT rated output | $S_n$ | = | 15 | VA |
| Rated accuracy limit factor (ALF) | n | = | 50 | |

CT secondary limiting e.m.f:

$$E_{2max} = 1 \times 50 \times \left( 8{,}9 + \frac{15}{1^2} \right) = \mathbf{1195{,}0}\ \text{V} \quad (3)$$

**Conclusion**

| | | | |
|---|---|---|---|
| Highest secondary limiting e.m.f | $max(E_{alreq1} \ldots E_{alreq4})$ = | 394,2 | V |
| CT secondary limiting e.m.f | $E_{2max}$ = | 1195,0 | V |

Secondary limiting e.m.f > Existing e.m.f

1195,0 > 394,2

CT is: **Suitably dimensioned**

**Figure 20.** Distance Protection Calculation 2

The calculations are clearly represented on the second page and the largest value of $E_{alreg}$ is then compared to the calculated $E_{2max}$ value of the current transformer in Figure 20. From this comparison a conclusion can be made if the calculated CT is adequate or not. $E_{2max}$ must be larger than the maximum of the calculated $E_{alreg}$ for correct functioning of the protection.

## 5.3 Metering Sheet

The metering sheet is used to calculate the actual instrument security factor and if the calculated burden is within acceptable limits.

| ADEQUACY CHECK FOR METERING | | | | | |
|---|---|---|---|---|---|
| **T11-13** | **Core 1** | | | | |
| CT ratio: | | **1200** | / | **1** | A |
| CT rated burden: | Sn = | **5** | VA | | |
| CT resistance: | $R_{ct}$< | **3,3** | Ω | | |
| Accuracy class | | **0,2S** | | | |
| Instrument security factor | | **5** | | | |
| Minimum required safety factor of connected devices | | $F_{Smin}$ | = | 10 | |
| CT rated safety factor | | $F_S$ | = | 5 | |
| CT rated burden | | $S_n$ | = | 5 | VA |
| CT minimum secondary burden | | $S_{min\%}$ | = | 25 | % of $S_n$ |
| CT rated secondary current | | $I_{sn}$ | = | 1 | A |
| CT secondary winding resistance | | $R_{CT}$ | = | 3,300 | Ω |
| The resistance of the secondary cable | | $R_L$ | = | 0,648 | Ω |
| The resistance of the attached resistor | | Rres | = | 0 | Ω |
| Total burden of devices | | $S_R$ | = | 1 | VA |
| Extended current measurement rating | | | | 100 | % |

**Figure 21.** Metering Sheet Relevant Values

All of the relevant entered data for the calculations are clearly shown at the top of the page as seen in Figure 21. The current transformer must be correctly burdened to make sure that the effective safety factor is within acceptable limits and the measuring accuracy is sufficient.

**CT adequacy check for metering function**

Current transformer used must have rated burden higher than total connected burden. At the same time to ensure metering accuracy the connected burden must be higher than minimum required burden. In addition, effective safety factor must be lower than minimum required safety factor for connected

Burden of the secondary cable:

$$S_a = I_{sn}^2 \cdot R_L \cdot E_{xt} \quad (1)$$

Total connected burden:

$$S = S_a + S_R + I_{sn}^2 \cdot R_{res} \quad (2)$$

Internal burden of the current transformer:

$$S_{in} = R_{CT} \cdot I_{sn}^2 \quad (3)$$

Minimum required burden:

$$S_{min} = S_{min\%} \cdot S_n \quad (4)$$

Effective safety factor of the CT:

$$F_{sa} = F_s \cdot \frac{S_{in} + S_n}{S_{in} + S} \quad (5)$$

Resistance of the cable for 4 wire connection:

$$R_l = 1{,}2 \times \frac{\rho \times l}{A} \quad (6)$$

Resistance of the cable for 6 wire connection:

$$R_l = 2 \times \frac{\rho \times l}{A} \quad (7)$$

**Figure 22.** Metering Equations

The burden of the secondary cable, total connected burden, internal burden of the current transformer, minimum required burden, effective safety factor and cable resistance equations are shown below the relevant current transformer data in Figure 22.

**Burden of the secondary cable**

$$Sa = (0{,}65 \times 1^2) = \mathbf{0{,}65}\ \text{VA} \quad (1)$$

**Total connected burden**

$$S = 0{,}65 + 1 + 1^2 \times 0 = \mathbf{1{,}65}\ \text{VA} \quad (2)$$

**Internal burden of the current transformer**

$$Sin = 3{,}3 \times 1^2 = \mathbf{3{,}3}\ \text{VA} \quad (3)$$

**Minimum required burden**

$$Smin = 5{,}00 \times 0{,}25 = \mathbf{1{,}25}\ \text{VA} \quad (4)$$

**Effective safety factor of the CT**

$$Fsa = 5 \times \left( \frac{3{,}3 + 5}{3{,}3 + 1{,}65} \right) = \mathbf{8{,}39} \quad (5)$$

**Conclusion**

**Condition 1**

| Rated burden, Sn | > | Total connected burden, S | > | Minimum required burden, Smin |
|---|---|---|---|---|
| **5** VA | > | **1,65** VA | > | **1,25** VA |

**Condition 2**

| Minimum Safety Factor of connected devices | > | Effective safety factor of CT |
|---|---|---|
| **10** | > | **8,39** |

The current transformer is correctly dimensioned if condition 1 and condition 2 are within acceptable limit

| | |
|---|---|
| Condition 1 | OK |
| Condition 2 | OK |

The CT is suitably dimensioned

**Figure 23.** Metering Sheet Calculations

Two conditions are checked in Figure 23:

- Total connected burden is between the rated burden and minimum required burden
- Effective safety factor of the current transformer is smaller than minimum required safety factor of the connected devices.

The measurement core is correctly dimensioned if both of these conditions are met.

### 5.4 Creating Documents

Once the user has entered all of the necessary data in the input sheet; the title page and the calculation sheets can then be printed, for example in the pdf format and a document for each feeder can be created.

# 6 CONCLUSIONS

The aim of this thesis was to create a calculation template in Microsoft Excel which would simplify the current transformer calculation process and would enable calculation documents to be created.

The workflow of this thesis was first getting to know relevant instrument transformer and relay protection theory then creating the calculation template. Thanks to Meelis Melder from ABB for providing a good base template to work and improve on.

The accomplished calculation template in Microsoft Excel can be used to calculate most of the different instrument transformer protection and metering situations. Easily readable pdf documents which state that the instrument transformers are correctly dimensioned for each protection function can easily be created from this template. Possible future changes are easy to make to the Excel template and new protection functions or equations can be added to the template.

## REFERENCES


/1/ Mörsky, J. 1992. Relesuojaustekniikka. Hämeenlinna. Otatieto.

/2/ ABB Instrument Transformers Application Guide. 2015. http://library.e.abb.com/public/94c2ba5a2f381077c1257df000504e0c/1HSM%209543%2040-00en%20IT%20Application%20Guide%20Ed4.pdf

/3/ ABB Fiber Optics Current Sensor – Free Standing (FOCS-FS) Manual http://library.e.abb.com/public/5720cab59ebf14d8c1257dcb0031121e/Fiber%20Optics%20Current%20Sensor%20(FOCS-FS)%20Presentation.pdf

/4/ ABB Current Transformer Requirements for Non-Directional Overcurrent Protection. 2004. http://library.e.abb.com/public/eb71e99b34df40fac2256f230034b639/applicationCTreqENa.pdf

/5/ Line differential protection RED670 Application Manual. 2010. http://library.e.abb.com/public/9922d42ef60039dec12578570041dd47/1MRK505186-UEN_D_en_Application_manual__Line_Differential_Protection_IED_RED_670_1.1.pdf

/6/ ABB Calculation of the Current Transformer Accuracy Limit Factor. 2004. http://library.e.abb.com/public/194811e319ce2bb7c2256f9e00324a2f/applicationCT_accuracylimitfactorENa.pdf

/7/ IEC 61869-1 Instrument transformers – Part 1: General requirements. 2007.

/8/ IEC 61869-2 Instrument transformers – Part 2: Additional requirements for current transformers. 2012.

/9/ IEC 61869-3 Instrument transformers – Part 3: Additional requirements for inductive voltage transformers. 2011.

/10/ An Overview of Rogowski Coil Current Sensing Technology
http://www.dynamp.net/ldadocum.nsf/c2270fbdd892ac3e86256e75000ad88a/e710af6d3e0f6255862565d7004b19db/$FILE/Report.pdf