To Study the Design of Current Transformer and make the Improvement in Existing CT used in Air Circuit Breaker

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the Degree of

MASTER OF TECHNOLOGY
IN
ELECTRICAL ENGINEERING
(Electrical Power Systems)

By

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Certificate

This is to certify that the Major Project Report entitled **To Study the Design of Current Transformer and make the Improvement in Existing CT used in Air Circuit Breaker** submitted by **Mr. Uday Barad (15MEEE02)** towards the partial fulfillment of the requirements for the award of degree in Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.
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Abstract

Circuit Breaker is a switching device, capable of making, carrying and breaking current under normal circuit conditions, carrying fault current for a specified time and breaking currents under specified abnormal system conditions such as short circuit faults, ground faults etc. In Air Circuit Breaker, arc-quenching medium is air at atmospheric pressure.

Current Transformer (CT) is an integral part of air circuit breaker. It is use for measurement and protection purpose in Air Circuit Breakers. The output of the CT will be the input for Electronic Release. Electronic release is the heart of protection circuit. Based on the signal received from CT, Electronic release will give signal to Flux Shifting Device to Trip the breaker under faulty conditions. Under routine operation, the Electronic release displays the Current, Voltage, Power and other parameters of the system based on the inputs from CTs.

Present competitive market requires robust and accurate current monitoring and related functions. To cater this market requirement, the Current Transformer design needs to be reliable and satisfying the required customer demands. A need was felt for improvement in reliability and robustness of existing design of Current Transformer for Market requirement.

The existing CT design needs to be studied, analyzed and based on the requirement, new CT design needs to be developed. Prototype CT samples of new design to be tested validated for required performance. Post satisfactory validation of the new design of CT, it will be replacing the existing design.

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Chapter 1

INTRODUCTION TO LARSEN & TOUBRO LTD.

We make things that make INDIA proud

Larsen & Toubro's record of outstanding achievements coupled with its European name lead many to believe that it is an Indian arm of a foreign corporation. The truth is that the genesis is very much of an Indian soil in fact, in a tiny room in south Mumbai just a few hundred meters from where the corporate headquarters now stands. Two engineers set it from distant Denmark, Henning Holck Larsen and Soren Kirsten Toubro, men with the infallible prescience of visionaries and the daring of entrepreneurs. They also shared an abiding infatuation with the country that has become an adopted homeland India.

During the IInd World war, they bought a damaged Italian ship **"M.V.HILDA"**

& set up their floating workshop on the ship itself.

On 1st May 1938, they set up a partnership firm named Larsen & Toubro to repair market Danish dairy equipment. A legend was born. Gradually their enterprise progressed in 1941, they started manufacturing simple products of dairy plant and machinery. In 1944, the company went into construction business and started Engineering Construction Company (E.C.C). Later the company became Pvt. Ltd. In Feb. 1946. In early 1950s, L&T became a Public Ltd. Company.

The motto of L&T is **"In service lies success"**, which is the embodiment of true culture pervading in today's cutthroat competition. L&T's distinction service outreach underlines its strong customer orientation. The network extends to virtually every district in the country. The company's products are doing record business and maintain their leading position in spite of stiff competition. The company has become Indias most diversified and multi product engineering organization that absorbs technology from collaboration worldwide.

L&T's strength lies in its widely diversified range of products services. With dynamic management heading it and positive attitude of its employees, L&T enjoys for five decades, leadership in design, manufacturing and installation of food, chemicals, petro-chemicals, fertilizers, steel and thermal power generation. L&T now have 23 manufacturing units spread all over the country. It has a network of 4 regional offices 10 resident representatives.

1.1 TODAY:

Over the years, the Company has grown up by leaps and bounds and has diversified into a range of products. The companys products are doing record business and maintain their leading position in spite of stiff competition. L&T Employees about 25000 personnel, which includes 8000 about Executive and Supervisory staff. L&T have 19 manufacturing units, spread in 7 states in the country. It has a network of 4 regional Offices, 05 Branch Offices and 12 Resident Representatives. L&T- Group of Companies includes 3 Subsidiary and 2 Associate Companies.

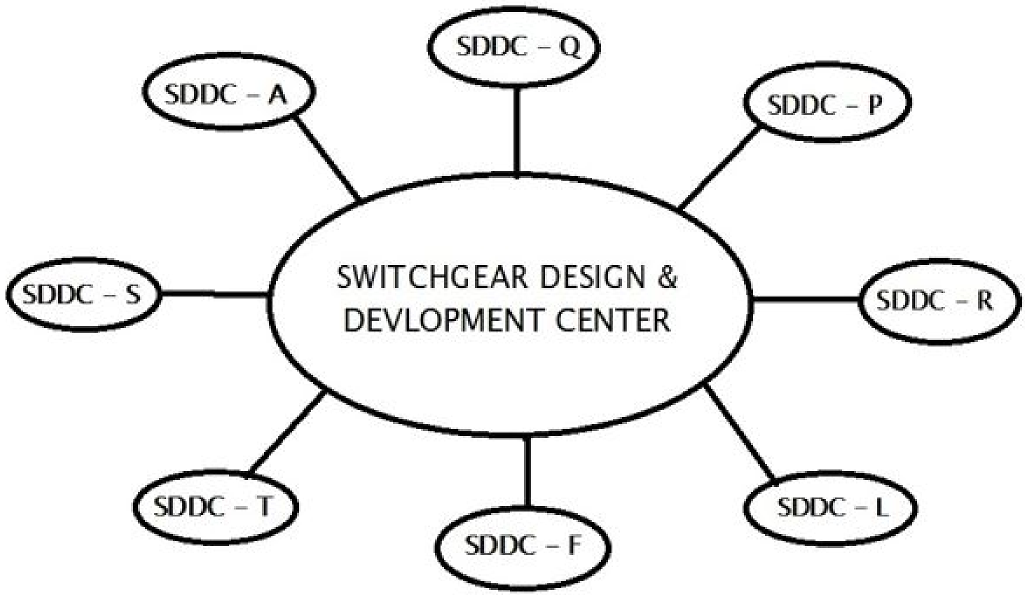
L&T VADODARA has a total built up area of 27,000 sq. meters. Over the years, the Company has established itself as one of the largest industries and Engineering Institutions of India. Currently it ranks among the top ten private sector companies in terms of sales & assets having an annual turnover about Seven Billion Dollars.

1.2 INTRODUCTION TO SWITCHGEAR DESIGN & DEVELOPMENT CENTRE (SDDC):

The Product Development of L&T's R&D is the nerve center of new product design and development. During the last two decades, this department has brought out several switchgear products through indigenous design as well as through absorption and adaptation of imported technology. Products developed through indigenous design effort alone account for a major share in the annual turnover of the company.

1.3 CLASSIFICATION OF SDDC:

Figure 1.1: Classification of SDDC



1.3.1 SDDC - A: Analysis

This department deals with high breaking capacity products like ACB, MCCB and FUSES. New products as well as existing products are developed and modified.

1.3.2 SDDC - S: Starter

Starter group comprises of relays and starter. This works in idea of design and development of relays, DOL and Star - delta starters.

1.3.3 SDDC - T: Switchboard

Switchboard group works on optimum design of switchboards as per requirements of customers e.g. different effective way of mounting bus bars.

1.3.4 SDDC - L: Electronics

This department gives technical support and design electronic item

1.3.5 SDDC - R: Basic Research

Basic research group has been established for basic research. As the name suggests it is not directly related to any of the product range, but it can be used for any product research.

1.3.6 SDDC - Q: Query: Life Cycle Management

This department is specially meant for solving the customer queries and difficulties. The department does the product approval. The department also works for the certification of the products.

1.3.7 SDDC - F: Switch Fuse

This group works on design and development of switches, fuse switches and switch fuse.

Chapter 2

INTRODUCTION TO AIR CIRCUIT BREAKER

2.1 What is Circuit Breaker?

Mechanical switching device, capable of making, carrying and breaking current under normal circuit condition, and making, carrying, breaking current under abnormal circuit condition such as short-circuit. A circuit breaker is a device, which can,

1. Make or Break a circuit manually or by remote control under normal conditions.
2. Break a Circuit automatically under fault conditions (like over current, Short circuit, etc.).
3. Make a circuit manually or by remote control under fault conditions.

A circuit breaker is used for switching mechanism and protection of the system. Other associated devices and components are also used for this purpose associated with circuit breakers like fuses, relays, switches etc. Circuit breakers are widely used in industries as well as in Power system for controlling and protection of different parts of the circuit like Transformers, Motors, Generators/Alternator etc., which leads the system to be stable and reliable.

There are different types of Circuit Breakers available in the market.

2.2 Features of Air Circuit Breaker:

- High making and breaking capacity.
- High fault withstanding capacity.
- Robust design.
- Mechanical and Electrical life.
- Resistance to electrodynamics forces of short circuit
- Electronic device ”Release” with wide range of setting. The Release for overload and short circuit protection, volt metric releases are the under voltage and shunt release.
- Easy maintenance.
- Capability of accepting a wide range of accessories for signaling, interlocking and automatic control.

2.3 Applications of Air Circuit Breaker:

- Power stations
- Process plants like steel, cements etc.
- Almost invariably by all industries where there is a demand for high current.
- Some machines such as blowers, large motors, conveyors and cooling plants themselves require a separate Air Circuit Breaker.

Chapter 3

INTRODUCTION TO U-POWER OMEGA AIR CIRCUIT BREAKER

U-Power OMEGA employ state-of-the-art technology to offer a comprehensive system solutioN from intelligent protection to complete controL from installation to operating convenience from user safety to system security, all this in the most modular design of optimized dimensions just like a beehive.

3.1 Classification of U-Power OMEGA Air Circuit Breakers

U-Power OMEGA Air Circuit Breakers are classified on basis of its mounting arrangement, its current carrying capacity and the number of poles present. This classification is detailed as follows.

3.1.1 On basis of mounting arrangement

On basis of the mounting arrangement, U-Power OMEGA ACBs are classified as:

- **Fixed Breakers:**
  In fixed breakers, the breaker terminals are connected directly to the terminal adapters. The advantage of fixed breakers is their low cost. But for maintenance, the power supply of the system must be cut off and the breaker must be disconnected from the terminal adapters. This is a major disadvantage of a fixed breaker.

- **Draw Out Breakers:**
  The breaker is mounted on telescopic rails that can translate on the cradle side

plates guided by the protrusions present in the plate due to lancing operations. In order to create an electrical contact between the spring loaded jaws mounted on the cradle and the terminals present on the beaker, the breaker needs to be racked in the cradle.

Advantages of a Draw out Breaker compared to a Fixed Breaker:

- During maintenance, the power supply need not be cut off, as the breaker can be racked out and locked in the ISOLATED position.
- If the breaker is being repaired, it can be replaced with a spare breaker of a similar rating.
- It is possible to check the operation of the control unit without switching ON the main power supply, by racking the breaker in the TEST position.
- For routine inspection, it can be totally racked out to the MAINTENANCE position.

3.1.2 On basis of its Current Carrying Capacity (Rating) and the Number of pole

Air Circuit Breakers are also differentiated on basis of its Frame i.e. its current carrying capacity and the number of poles.

- Frame 1: 400 - 3200 A
- Frame 2: 400 - 4000 A
- Frame 3: 3200 - 6300 A

Chapter 4

CURRENT TRANSFORMER

4.1 Introduction:

The transformer used for measurement of current is called a Current Transformer or C.T. The extension of instrument range, so that current, voltage, power and energy can be measured with instruments or meters of moderate size is of very great importance in commercial metering. In power systems, currents and voltage handled are very large and, therefore, direct measurements are not possible as these currents and voltages are far too large for any meter of reasonable size and cost. Current Transformers have basically extensive use in measuring of the currents in electrical circuits either for Metering or for Protection applications.

The Current Transformer is used with its primary winding connected in series with line carrying the current to be measured and, therefore, the primary current is dependent upon the load connected to the system and is not determined by the load(burden) connected on the secondary winding of the current transformer.

The primary winding consisting of very turns and, therefore, there is no appreciable voltage drop across it. The secondary winding of the current transformer has larger number of turns. Thus a current transformer operates its secondary winding nearly short circuit condition. Like any instrument, a CT involves certain values of error in measuring of the current. The two other main parameters of the CT: knee point voltage and the burden.

CT performance during normal fault conditions can be simply analyzed considering the linear region of the CT characteristic. However, this linear region ultimately ends up to a non-linear region known as saturation region on the CT curve discriminated by the knee point. A common method to ensure that the CT does not get in saturation is to calculate the secondary voltage for the maximum fault currents considering all the connected burden to the CT, and determine the knee point voltage so that to be above this operating voltage.

Figure 4.1: Current Transformer

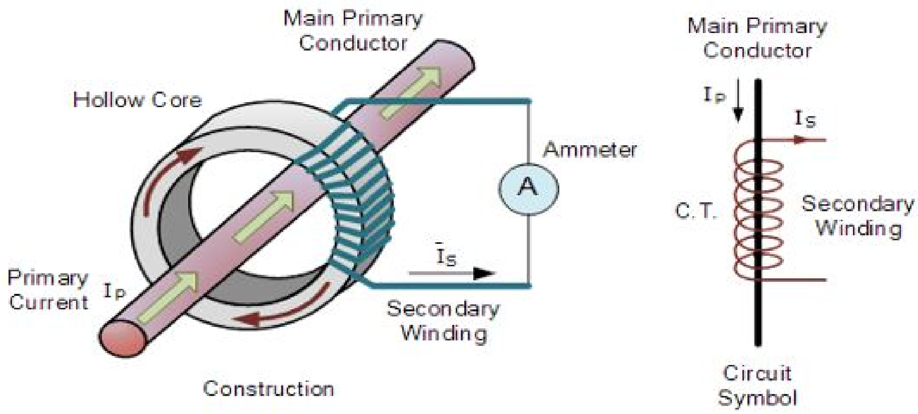


Figure 4.2: Basic Transformer Equation

$$T.R. = n = \frac{N_P}{N_S} = \frac{I_S}{I_P}$$

Chapter 5

CURRENT TRANSFORMER IN U-POWER OMEGA ACB

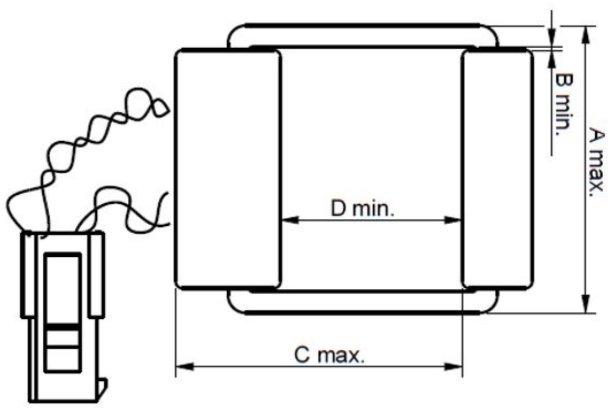
5.1 Classification based on Current Rating:

Frame Size	Current Rating
1	400-3200 A
2	400-4000 A
3	400-6300 A

5.2 Iron Cored Current Transformer:

5.2.1 Construction:

Figure 5.1: Iron Cored C.T.



5.2.2 Design:

- In this CT, Iron is used as Core Material.
- CT secondary winding shall be in layers of enameled copper wire.
- The Upper limb of the core shall be wound with the upper limb(UL) turns and also the lower limb(LL) of the core shall be wound with the lower limb turns specified in design.
- Connect the finish terminal of UL turns to the finish terminal of the LL turns insulate the joint properly.
- Final Terminations shall be from start terminals of both the UL LL windings and will be taken on the lower limb.
- Ends Of the winding shall be properly soldered insulated prior to termination in the connector.

5.2.3 C.T. Saturation:

- CT saturation is a term used to describe the state wherein a CT is no longer able to reproduce an output current in proportional to its primary current or as per its Ratio. The basic reason for CT saturation is due to the property of the core which goes to magnetic saturation due to number of reasons like large primary current or high burden at the secondary or an open circuit in the secondary.
- Characteristic will be Non Linear and as a result it cannot be used for metering purpose.

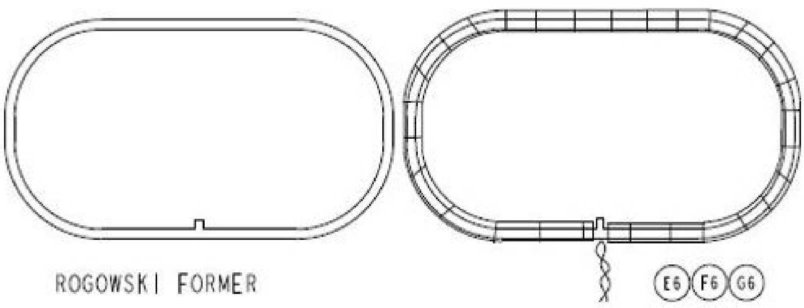
5.2.4 Application of Iron C.T. in U-Power Omega ACB:

- Used to power up the release as per designed condition.

5.3 Rogowski Coil:

5.3.1 Construction:

Figure 5.2: Rogowski Coil



5.3.2 Introduction:

Rogowski Coils operate on the same principles as conventional iron-core current transformers (CTs). The main difference between Rogowski Coils and CTs is that Rogowski Coil windings are wound over an (non-magnetic) air core, instead of over an iron core. As a result, Rogowski Coils are linear since the air core cannot saturate. However, the mutual coupling between the primary conductor and the secondary winding in Rogowski Coils is much smaller than in CTs. Therefore, Rogowski Coil output power is small, so it cannot drive current through low-resistance burden like CTs are able to drive. Rogowski Coils can provide input signals for microprocessor-based devices that have a high input resistance; therefore, these devices measure voltage across the Rogowski Coil secondary output terminals.

In general, Rogowski Coil current sensors have performance characteristics that are favorable when compared to conventional CTs. These characteristics include high measurement accuracy and a wide operating current range allowing the use of the same device for both metering and protection. This can result in reduced inventory costs since fewer sensors are needed for all applications.

In addition, Rogowski Coils make protection schemes possible that were not achievable by conventional CTs because of saturation, size, weight, and/or difficulty encountered when attempting to install current transformers around conductors that cannot be opened.

An additional advantage of Rogowski Coil current sensors is significantly lower power consumption during operation. Rogowski Coils are connected to devices that have high input resistance, resulting in negligible current flowing through the secondary circuit.

Conventional CTs contain a ferromagnetic core that also consumes energy/power due to hysteresis losses. Rogowski Coils have no core losses. In fact, an operating Rogowski Coil has much smaller power loss than conventional CTs which leads to significant savings of energy and ultimately reduced lifecycle costs. Rogowski Coils can replace conventional CTs for protection, metering, and control. Rogowski Coils have been applied at all voltage levels (low, medium, and high voltage).

5.3.3 Application of Rogowski in U-Power Omega ACB:

- Used for Metering purpose of the rated current flowing through the breaker.

5.4 Standards:

ANSI/IEEE Standard C57.13-2008 specifies CT accuracy class for steady state and symmetrical fault conditions. Accuracy class of the CT ratio error is specified to be ±10% or better for a fault current 20 times the CT rated current and up to the standard burden. CTs are designed to meet this requirement.

Chapter 6

New Design of Iron CT

Aim: To reduce the depth of CT (Rating: 1000/1250/1600 A) from 41mm to 31mm.

6.1 Introduction:

This CT is used in frame-1 breaker(400-3200A) and its rating is from 1000-1600 A.

CT is a combination of Iron Core and Rogowski Coil. As a result, both will contribute to the total depth of CT.

The Rogowski Coil deals with the metering purpose and occupies the space of 10mm while Iron CT used to power up the release having width (core + winding) of 28mm. After the complete potting the total width of the CT is 41mm.

Due to reliability and accuracy issues, Rogowski Coil modification is a constraint. Due to such constraint, modification of Iron Core needs to be done.

Before the new design development existing behavior of the CT is to be analyzed and required criteria for the performance of the electronic device working from the input of the CT is to be studied and maintained.

6.1.1 Factors to be consider for Iron CT Modification:

- Effective numbers of turns which will results into the total flux production the cause behind the secondary current of CT.
- Core width will behave as a medium for flux linkage between primary and secondary.

6.2 Existing Design:

Figure 6.1: Iron CT

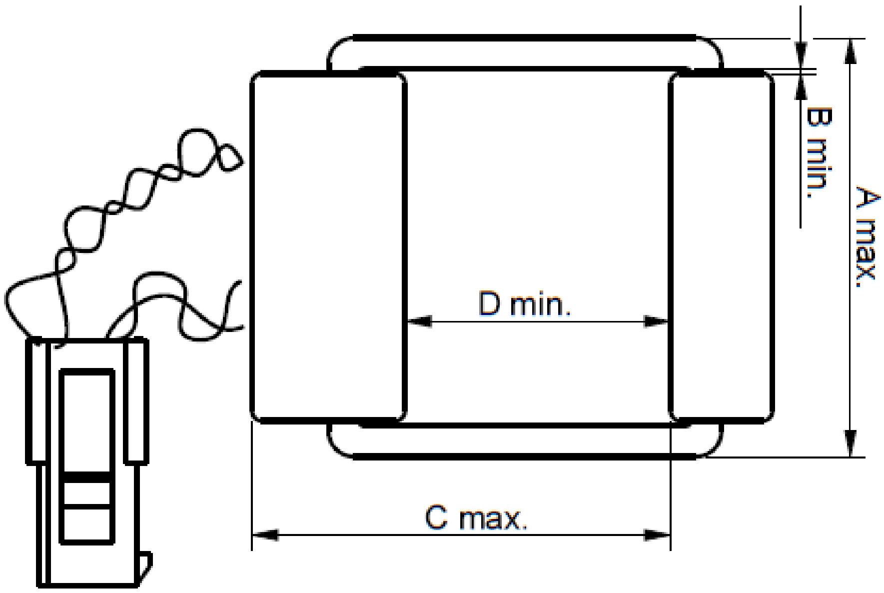


Figure 6.2: Core Dimension

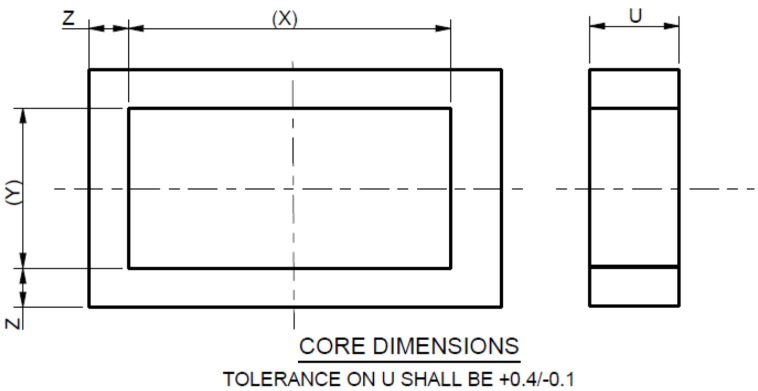


Figure 6.3: Existing CT Design Dimension

Frame Size	CT CAT NO.	A max.	B min.	C max.	D min.	U	X min.	Y min.	Z min.	UL Turns	LL Turns	Total Turns	Effective Turns	SWG
I	CL00016	88	2	79	50	**11**	70	65	8.5	**850**	**1420**	**2270**	**570**	25

6.3 Procedure:

- **Step 1**: At the initial stage, Test Report of the existing CT is studied and analyzed. As discussed the secondary current of Iron CT is responsible for the power up of the release.

  The Iron CT characteristic are defined from core width, numbers of turns on LL UL, resistance of winding, VA output. These parameters set the secondary current of the CT which is the input to electronic release. These parameters need to be consider for modification to achieve the desired task.

  Resistance Value= 11.3 to 13.3 ohm.

  Criteria for Release:

  1. For In (Rated Current=1600) secondary output current should be less than 1A.

  2. For 2In (3200A) secondary output current should be less than 1.6A.

Table I: Existing Samples Test Data

CL00016-1		**Cl00016-2**	
Ip	**Is**	**Ip**	**Is**
206	0.128	208	0.116
413	0.287	418	0.279
612	0.386	617	0.367
803	0.469	802	0.445
1004	0.528	1006	0.515
1244	0.591	1247	0.572
1401	0.626	1402	0.607
1600	**0.67**	**1604**	**0.65**
2011	0.754	1805	0.681
3211	**0.934**	**3192**	**0.913**
3922	1.021	4451	1.052
4450	1.084	5416	1.134

3. **Step 2**: From the analysis of existing CT design sheet, Lower Limb is having comparatively more turns (1420) than upper limb, LL turns acquires higher space.

   Initial modification is carried out from the turns as it contributes more towards the depth of CT and manual modification of the turns is possible for the trail performance/testing. For Core width modification, vendor need to be consult as manual removal of core is not possible. Existing core is 11 mm in depth.

   Existing Design Parameters: U=11mm, UL: 850 LL: 1420 TT: 2270 ET: 570

4. **Step 3**: By observing, the number of turns in one layer of the LLUL, its contribution in the width of the CT can be measured.

   Based on the requirement for the experiment, removal of turns is carried out and the testing is performed to check the behavior of the CT under different modified turns and results are recorded for the analysis and for the new design purpose.

   In achieving the desired task, the release constraint also needs to be follow to avoid improper functioning or damage to any electronic device.

Table II: Modified Samples Test Results

Design	**LL**	**UL**	**TT**	**ET**	**Core Depth**		**R**	**Release PowerUp**
					UL	**LL**		
Sample 1	1400	600	2000	800	27.2	19.2	11.2	80
Sample 2	1300	600	1900	700	26.11	19.2	9.8	90
Sample 3	1200	600	1800	600	25.1	19.2	8.7	85
Sample 4	**1100**	**600**	**1700**	**500**	**23.75**	**19.2**	**7.95**	**90**
Sample 5	1100	480	1580	620	23.75	18	7.5	85
Sample 6	1000	480	1480	520	22.8	18	6.7	92
Sample 7	1000	430	1380	520	22.8	18	6.4	90
Sample 8	950	430	1330	470	22.8	18	6	95
Sample 9	900	430	1330	470	21.5	18	5.7	95
Sample 10	**1000**	**600**	**1600**	**400**	**22.8**	**19.2**	**7**	**95**
Sample 11	**900**	**500**	**1400**	**400**	**21.5**	**18**	**5.7**	**100**

Table III: Sample 4 Test Results

Sample 4 (LL: 1100 Turns, UL: 600 Turns)(R=7.95)	
Ip	**Is**
99	0.109
160	0.142
208	0.238
400	0.466
795	0.656
1577	**0.943**
2038	1.07

Table IV: Sample 10 Test Results

Sample 10(LL: 1100 Turns, UL: 600 Turns)(R=7)	
Ip	**Is**
107	0.092
151	0.115
206	0.137
417	0.365
815	0.664
1648	**0.989**
2014	1.112

Table V: Sample 11 Test Results

Sample 11(LL: 900 Turns, UL: 500 Turns)(R=5.7)	
Ip	**Is**
98	0.129
153	0.126
405	0.403
802	0.67
1618	**0.927**
2018	0.896

In the tests performed the Core width is **11mm** constant for all the samples only modification is carried out in turns of winding of the CT.

From the different combination of UL & LL turns, test results are obtained and based on the results best samples are selected which followed the required criteria.

5. **Step 4**: From the analysis of the result obtained in the above tests, New design samples are developed at the vendor side by selecting the best combination of UL & LL turns alomg with the Core width modification.

Finalised Design samples are shown below:

Figure 6.4: Proposed Design Dimension

Sr. no	CT CAT NO.	A max.	B min.	C max.	D min.	U	X min.	Y min.	Z min.	UL Turns	LL Turns	Total Turns	Effective Turns	SWG	Complete Depth		Iron CT Depth	
															1	2	1	2
*	CL00016	88	2	79	50	11	70	65	8.5	850	1420	2270	570	25				
1	Sample 1	88	2	79	50	10	70	65	8.5	600	1000	1600	400	25	28.8	31.2	21.3	21.7
2	Sample 2	88	2	79	50	10	70	65	8.5	500	1000	1500	500	25	30.1	27.6	22.2	23.2
3	**Sample 3**	**88**	**2**	**79**	**50**	**9**	**70**	**65**	**8.5**	**500**	**1000**	**1500**	**500**	**25**	**28.4**	**27.3**	**20.5**	**20.8**
4	Sample 4	88	2	79	50	11	70	65	8.5	500	900	1400	400	25	30.5	30.3	22.8	23
5	Sample 5	88	2	79	50	10	70	65	8.5	500	900	1400	400	25	27.5	26.55	20.5	20.2
6	Sample 6	88	2	79	50	9	70	65	8.5	500	900	1400	400	25	23.78	28.4	19.7	19.6

Table VI: Sample 1 Test Results

<table>
<tr><th colspan="9">U=10mm, UL: 600LL: 1000 TT: 1600 ET:400</th></tr>
<tr><th colspan="4">Sample 1 (1) D: 21.3mm</th><th rowspan="9"></th><th colspan="4">Sample 1 (2) D: 21.7mm</th></tr>
<tr><th rowspan="2">Ip</th><th rowspan="2">Is</th><th colspan="2">Release</th><th rowspan="2">Ip</th><th rowspan="2">Is</th><th colspan="2">Release</th></tr>
<tr><th>3.5EC</th><th>1.5G</th><th>3.5EC</th><th>1.5G</th></tr>
<tr><td>95</td><td>0.142</td><td rowspan="6">325</td><td rowspan="6">75</td><td>99</td><td>0.171</td><td rowspan="6">315</td><td rowspan="6">77</td></tr>
<tr><td>153</td><td>0.27</td><td>155</td><td>0.272</td></tr>
<tr><td>197</td><td>0.312</td><td>212</td><td>0.362</td></tr>
<tr><td>409</td><td>0.482</td><td>394</td><td>.464</td></tr>
<tr><td>811</td><td>0.656</td><td>801</td><td>0.663</td></tr>
<tr><td>1595</td><td>0.945</td><td></td><td>1592</td><td>0.951</td></tr>
</table>

Table VII: Sample 2 Test Results

<table>
<tr><th colspan="9">U=10mm, UL: 500LL: 1000 TT: 1500 ET:500</th></tr>
<tr><th colspan="4">Sample 2 (1) D: 22.2mm</th><th rowspan="9"></th><th colspan="4">Sample 2 (2) D: 23.2mm</th></tr>
<tr><th rowspan="2">Ip</th><th rowspan="2">Is</th><th colspan="2">Release</th><th rowspan="2">Ip</th><th rowspan="2">Is</th><th colspan="2">Release</th></tr>
<tr><th>3.5EC</th><th>1.5G</th><th>3.5EC</th><th>1.5G</th></tr>
<tr><td>109</td><td>0.058</td><td rowspan="6">340</td><td rowspan="6">97</td><td>98</td><td>0.183</td><td rowspan="6">165</td><td rowspan="6">65</td></tr>
<tr><td>156</td><td>0.198</td><td>151</td><td>0.274</td></tr>
<tr><td>198</td><td>0.238</td><td>196</td><td>0.342</td></tr>
<tr><td>411</td><td>0.497</td><td>402</td><td>0.52</td></tr>
<tr><td>794</td><td>0.637</td><td>794</td><td>0.704</td></tr>
<tr><td>1617</td><td>0.951</td><td></td><td>1594</td><td>1.054</td></tr>
</table>

After performing the test on the developed samples and from the analysis of the results obtained the design samples which satisfy the required criteria is to be finalized.

From the test result following conclusion is obtained:

1. Samples 1,4,5 doesnt satisfy the required criteria of In and 2In.
2. Sample 6 output current is not sufficient to power up the release at the required current (approx. 80-85A).
3. Sample 1 is not suitable for the Release 3.5EC power up.

The sample 3 design is preferred over all the developed samples.
Sample 3 is satisfying the criteria of In and 2In and the release power up is occurring at lower current value compared to other samples and existing samples too.

Presently Release 1.5G is consider for the for the prototype testing.
Finalized Design from the developed samples are as follow.

Table VIII: Sample 3 Test Results

U=9mm, UL: 500 LL: 1000 TT: 1500ET:500								
Sample 3 (1) D: 22.2mm					**Sample 3 (2) D: 23.2mm**			
Ip	**Is**	**Release**			**Ip**	**Is**	**Release**	
		3.5EC	**1.5G**				**3.5EC**	**1.5G**
100	0.182	250	56		108	0.182	240	80
160	0.287				150	0.262		
207	0.348				206	0.351		
403	0.51				400	0.484		
806	0.7				804	0.692		
1600	**0.978**				**1600**	**0.984**		

Table IX: Sample 4 Test Results

U=11mm, UL: 500 LL: 900 TT: 1400 ET:400								
Sample 4 (1) D: 22.2mm					**Sample 4 (2) D: 23.2mm**			
Ip	**Is**	**Release**			**Ip**	**Is**	**Release**	
		3.5EC	**1.5G**				**3.5EC**	**1.5G**
100	0.229	195	74		107	0.253	195	80
157	0.337				154	0.338		
200	0.39				195	0.397		
411	0.584				412	0.616		
803	0.793				803	0.825		
1595	**1.133**				**1607**	**1.205**		

Table X: Sample 5 Test Results

U=10mm, UL: 500 LL: 900 TT: 1400 ET:400								
Sample 5 (1) D: 20.5mm					**Sample 5 (2) D: 20.2mm**			
Ip	**Is**	**Release**			**Ip**	**Is**	**Release**	
		3.5EC	**1.5G**				**3.5EC**	**1.5G**
95	0.108	340	76		95	0.089	350	76
155	0.295				152	0.263		
195	0.334				194	0.329		
405	0.522				397	0.516		
803	0.693				796	0.73		
1609	**1.012**				**1611**	**1.021**		

Table XI: Sample 6 Test Results

<table>
<tr><th colspan="9">U=9mm, UL: 500 LL: 900 TT: 1400 ET:400</th></tr>
<tr><th colspan="4">Sample 6 (1) D: 19.7mm</th><th rowspan="9"></th><th colspan="4">Sample 6 (2) D: 19.6mm</th></tr>
<tr><th rowspan="2">Ip</th><th rowspan="2">Is</th><th colspan="2">Release</th><th rowspan="2">Ip</th><th rowspan="2">Is</th><th colspan="2">Release</th></tr>
<tr><th>3.5EC</th><th>1.5G</th><th>3.5EC</th><th>1.5G</th></tr>
<tr><td>104</td><td>0.067</td><td rowspan="6">750</td><td rowspan="6">110</td><td>104</td><td>0.069</td><td rowspan="6">535</td><td rowspan="6">110</td></tr>
<tr><td>149</td><td>0.068</td><td>155</td><td>0.123</td></tr>
<tr><td>202</td><td>0.160</td><td>200</td><td>0.252</td></tr>
<tr><td>410</td><td>0.388</td><td>406</td><td>0.45</td></tr>
<tr><td>795</td><td>0.567</td><td>812</td><td>0.684</td></tr>
<tr><td>1598</td><td>0.81</td><td>1593</td><td>0.942</td></tr>
</table>

Figure 6.5: Finalised Proposed Design

Frame Size	CT CAT NO.	A max.	B min.	C max.	D min.	U	X min.	Y min.	Z min.	UL Turns	LL Turns	Total Turns	Effective Turns	SWG
I	CL00016 new	88	2	79	50	**9**	70	65	8.5	**500**	**1000**	**1500**	**500**	25

6.4 Testing For Validation Of Samples

Validation of samples for following approval tests:
1. Iron CT characteristics till 6In
2. VA characteristics
3. Earth fault tripping at minimum setting
4. Temperature rise test

Table XII: Sample 1 Test Results

Sample 1	
Resistance	6.5 ohm
Thickness	21mm
Primary Current	Secondary Current
105	0.2
150	0.261
206	0.344
403	0.461
800	0.644
1592	0.922

Table XIII: Sample 2 Test Results

Sample 2	
Resistance	6.4 ohm
Thickness	21mm
Primary Current	Secondary Current
102	0.175
148	0.254
201	0.32
401	0.453
797	0.617
1605	0.902

Table XIV: Sample 3 Test Results

Sample 3	
Resistance	6.5 ohm
Thickness	20.9mm
Primary Current	Secondary Current
101	0.184
151	0.265
207	0.352
398	0.459
798	0.653
1602	0.932

Figure 6.6: Sample 2 Test Results

Sample 2			
Primary Current	Secondary Current	Secondary Voltage	VA
100	0.181	12.15	2.20
156	0.271	10.15	2.75
205	0.321	9.46	3.04
406	0.479	7.88	3.77
807	0.482	7.71	3.72
1596	0.965	5.74	5.54
2007	1.101	5.53	6.09
2503	1.242	5.5	6.83
3064	1.327	6.07	8.05
3556	1.412	5.26	7.43
4449	1.526	5.24	8.00
5311	1.631	4.49	7.32
6200	1.7	5.43	9.23
6820	1.76	4.85	8.54
7137	1.79	4.76	8.52
7850	1.84	4.74	8.72
8850	1.92	4.74	9.10

6.4.1 Temperature rise test

Temperature raise test was carried out by passing rated current in primary (2800A) for 4 hrs. Through link, till the temperature of the CT body had reached steady state condition. CT mounted in breaker. The temperature raise observed as below against specified limit of 105C mentioned in CD sheet.

6. Metering test
3 samples to be submitted to Quality for independent validation the new design.

Figure 6.7: Sample 3 Test Results

Sample 3			
Primary Current	Secondary Current	Secondary Voltage	VA
101	0.185	12.026	2.22
149	0.27	10.2	2.75
200	0.322	9.358	3.01
401	0.478	7.968	3.81
812	0.673	6.174	4.16
1623	0.959	6.123	5.87
2011	1.07	5.978	6.40
2508	1.196	5.876	7.03
4660	1.41	5.845	8.24
5100	1.564	5.43	8.49
5634	1.633	5.05	8.25
6300	1.676	5.03	8.43
7010	1.719	5.29	9.09
7990	1.792	5	8.96
8775	1.855	4.72	8.76

Figure 6.8: Earth Fault I^2t

CL00016 (1000,1250,1600A)

Test conducted on MTX 1.5G release Rev-03 919651000112140008 with In setting-1000A, Earth fault setting : Pickup-0.2In, Delay 0.1(I2T ON)

		Resistance(Ohm)		Test parameters			
Sample No.	Discription	Iron Core	Rogowski	Current (A)	Iron core output(mA)	Metering(A)	Trip time(sec)
1	Existing CL00016	12.24	313.3	204	320	208	1.38
				220	321	225	1.22
				275	303	290	0.75
				346	382	365	0.52
2	Tape-wound CL00701	12.11	504.7	210	230	171	0.28
				221	275	169	-
3	New CT CL00016 Sample No. 4	6.97	293	208	328	197	1.76 to 1.84
				220	241	215	1.26
4	New CT CL00016 Sample No. 6	7.02	297.7	222	341	210	1.43
5	New CT CL00016 Sample No. 2	7.02	293	203	335	174	-
				220	358	213	1.26

Figure 6.9: Earth Fault I^2t

		Resistance(Ohm)		Test parameters						
Sample No.	Discription	Iron Core	Rogowski	Release	Setting	Current (A)	Iron core output(mA)	Metering(A)	Trip time(sec)	% error
1	Existing CL00016	12.24	313.3	1.5G	0.2In, I2T OFF, delay 0.1sec	198	306	203	0.136	36
					0.2In, I2T OFF, delay 0.2sec	197	306	201	0.248	24
				3.5EC	0.2In, I2T OFF, delay 0.1sec	195	243	203	0.188	88
2	Tape-wound CL00701	12.11	504.7	1.5G	0.2In, I2T OFF, delay 0.1sec	200	225	166	No trip	
						247	309	196	0.14	40
				3.5EC	0.2In, I2T OFF, delay 0.1sec	248	294	206	0.144	44
						218	256	180	No trip	
3	New CT CL00016 Sample No. 4	6.97	293	1.5G	0.2In, I2T OFF, delay 0.1sec	201	330	201	0.14	40
					0.2In, I2T OFF, delay 0.2sec	202	330	203	0.25	25
				3.5EC	0.2In, I2T OFF, delay 0.1sec	202	145	No navigation	0.204	104
						229	195	239	0.19	90
4	New CT CL00016 Sample No. 6	7.02	297.7	1.5G	0.2In, I2T OFF, delay 0.1sec	211	343	204	0.14	40
					0.2In, I2T OFF, delay 0.2sec	210	343	204	0.24	20
				3.5EC	0.2In, I2T OFF, delay 0.1sec	221	150	No navigation	0.18	80
						249	176	258	0.18	80
5	New CT CL00016 Sample No. 2	7.02	293	1.5G	0.2In, I2T OFF, delay 0.1sec	205	350	204	0.14	40
						223	364	221	0.14	40
					0.2In, I2T OFF, delay 0.2sec	220	361	219	0.24	20
				3.5EC	0.2In, I2T OFF, delay 0.1sec	351	355	349	0.18	80
						220	165	230	0.19	90

Figure 6.10: Temperature Rise Test

Before start of test measured parameter		After 4 hr. measured parameters	
Rogowski Temperature	21.7 'C	Rogowski Temperature	50.87 'C
Rogowski Resistance	302.56 Ohm	Rogowski Resistance	362.65 Ohm
Iron CT Temperature	21.7 'C	Iron CT Temperature	38.68 'C
Iron CT Resistance	11.99 Ohm	Iron CT Resistance	13.8 Ohm

Chapter 7

Conclusion:

By modification of the total numbers of turns and core width, the characteristics of CT has changed. Behavior of new developed CT has been analyzed with the electronic devices. Final Test Report will conclude the task.

Chapter 8

New Design Of Rogowski For Neutral CT

Aim: Elimination of Iron CT from Neutral CT.

8.1 Introduction:

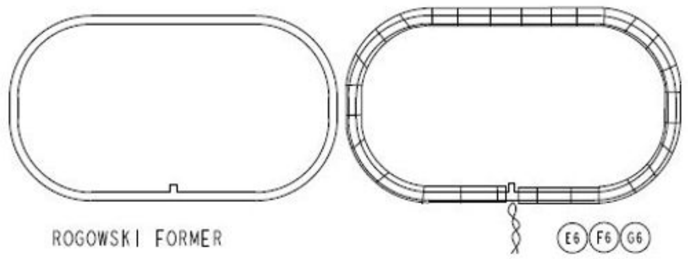
Presently in neutral pole, Neutral CT comes in a combination of Rogowski Coil and Iron Cored CT. The Purpose of Rogowski Coil is metering while of Iron Cored CT is to power Up the release.

Under the faulty condition individual neutral fault will never occur, it always comes along with any of the one phases. Due to such condition Power up current required for the release will be provided by the Iron CT of that phase which is with the neutral pole in the faulty condition. Therefore, Iron CT of the neutral pole will remain unused.

In order to overcome such condition new neutral CT to be developed which consists only Rogowski Coil for metering purpose. This implementation will save the cost of manufacturing and falls under the category of Value Engineering (VE).

8.2 CT Theoritical Design:

Figure 8.1: Core Design



Expression for induced emf in rogowski coil

$$E = \frac{-A * N * \mu_0}{l} * \frac{\mathrm{d}I}{\mathrm{d}t}$$

Where,
A: Area of cross section of coil (17.5x 2= 35mm^2)
$N : Numberofturnsincoil$
$\mu_o : 12.56X10^{-7}$
l: length of winding (Differ as per the CAT no. Of CT)

EMF Induced Calculation (CL00015):

Expression for induced emf in rogowski coil.

$$E = \frac{-A * N * \mu_0}{l} * \frac{\mathrm{d}I}{\mathrm{d}t}$$

Where,
A: Area of cross section of coil (35mm)I: Current (800A)
N: Number of turns in coil (1920*6=11520)
$\mu_0 : 12.56X10^{-7}$
l: Length of winding 262mm as specified in Drawing

$$EMF = \frac{35 * 10^{-6} * 11520 * 12.56 * 10^{-7} * 6.28 * 50 * 800}{262 * 10^{-3}}$$

$$EMF = 0.4855V$$

Rogowski Criteria:

- Initially mV band defined for the Rogowski Coil is **530 mV**.
- Modified mV band selected for the Rogowski is from **505-525 mV**.
- At defined mV rated current will be displayed on the release and due to the linear characteristics of the Rogowski Coil at the any value of the current flowing in the breaker mV output will be generated with respect to that current.
- From the value of mV obtained in the above equation the number of turns can be found out.
- With respect to the 0.4855mV output **0.4755** mV to be considered as band needs to be decreased by 10mV.

For CL00015:

$$E = \frac{-A * N * \mu_0}{l} * \frac{\mathrm{d}I}{\mathrm{d}t}$$

N=11281.69
For 6 layers
Number of turns/Layers=1880
Initial Turns N/Layers= 1920 for 6 layers.

8.3 Procedure:

For other CAT No. CT turns are calculated in the similar manner and new developed turns design is shown below.

Design.PNG

CAT No.	Turns	Layers	Total Turns	Rated Current	EMF	Actual EMF	New Turns	Per Layer	Ordered
CL00015	1920	6	11520	800	0.487	0.477	11283	1881	1880
CL00016	1130	5	5650	1600	0.478	0.468	5532	1106	1110
CL00017	1480	2	2960	3200	0.501	0.491	2901	1450	
CL00018	2340	6	14040	800	0.594	0.584	13803	2301	
CL00019	1410	5	7050	1600	0.596	0.586	6932	1386	
CL00020	1480	2	2960	4000	0.626	0.616	2913	1456	1450
CL00021	1950	6	11700	800	0.495	0.485	11463	1911	
CL00022	1470	4	5880	1600	0.497	0.487	5762	1440	
CL00023	1190	2	2380	4000	0.503	0.493	2333	1166	
CL00024	752	2	1504	6300	0.501	0.491	1474	737	

CAT No.	Rated Current	Existing Design			New Design 1			New Design 2		
		Turns	Layers	Total Turns	Turns	Layers	Total Turns	Turns	Layers	Total Turns
CL00015	800	1920	6	11520	1850	6	11100	1800	6	10800
CL00016	1600	1130	5	5650	1110	5	5550	1110	5	5550
CL00017	3200	1480	2	2960	1450	2	2900	1450	2	2900
CL00018	800	2340	6	14040	2300	6	13800	2200	6	13200
CL00019	1600	1410	5	7050	1380	5	6900	1410	5	7050
CL00020	4000	1480	2	2960	1450	2	2900	1450	2	2900
CL00021	800	1950	6	11700	1910	6	11460	1800	6	10800
CL00022	1600	1470	4	5880	1440	4	5760	1440	4	5760
CL00023	4000	1190	2	2380	1165	2	2330	1165	2	2330
CL00024	6300	752	2	1504	735	2	1470	735	2	1470

8.4 Future Work:

1. Quality Approval.
2. Required Tests on test bench at the breaker.

CL00015(400/630/800) (1850*6=11100)																			
Sample 1							Sample 2							Sample 3					
Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Errror	%Error In Metering
408		291.1	255	14.16%			409	457	275.8	255.6	7.89%	12%		405	441	266.7	253.1	5.36%	9%
625		446.7	390.625	14.36%			633	705	427.4	395.6	8.03%	11%		630	681	412	393.8	4.63%	8%
797		568.1	498.125	14.05%			800	888	540	500	8.00%	11%		795	858	519	496.9	4.45%	8%

CL00016(1000/1250/1600) (1110*5=5550)																			
Sample 1							Sample 2							Sample 3					
Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering
200	203	62	62.5	-0.80%	2%		1000	1032	311	312.5	-0.48%	3%		198	207	61.6	61.88	-0.44%	5%
409	424	127	127.813	-0.64%	4%		1261	1289	390	394.1	-1.03%	2%		395	413	123	123.4	-0.35%	5%
815	836	251	254.688	-1.45%	3%		1613	1640	499	504.1	-1.00%	2%		804	832	250	251.3	-0.50%	3%
1018	1025	313	318.125	-1.61%	1%									1004	1032	310	313.8	-1.20%	3%
1246	1273	383	389.375	-1.64%	2%									1262	1298	391	394.4	-0.86%	3%
1605	1624	492	501.563	-1.91%	1%									1604	1650	497	501.3	-0.85%	3%

CL00019(1000/1250/1600) (1380*5=6900)																			
Sample 1							Sample 2							Sample 3					
Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering
197	194	57.6	61.5625	-6.44%	-2%		196	193	57.6	61.25	-5.96%	-2%		197	194	57.5	61.56	-6.60%	-2%
405	398	118	126.563	-6.77%	-2%		404	396	118	126.3	-6.53%	-2%		403	395	117.6	125.9	-6.62%	-2%
807	789	235	252.188	-6.82%	-2%		817	801	238	255.3	-6.78%	-2%		808	787	234.8	252.5	-7.01%	-3%
1010	985	293	315.625	-7.17%	-2%		1017	982	297	317.8	-6.55%	-3%		1019	989	295.4	318.4	-7.23%	-3%
1240	1200	360	387.5	-7.10%	-3%		1251	1200	365	390.9	-6.63%	-4%		1240	1184	359	387.5	-7.35%	-5%
1600	1550	465	500	-7.00%	-3%		1610	1535	462	503.1	-8.17%	-5%		1610	1584	468	503.1	-6.98%	-2%

CL00020(2000/2500/3200/4000) (1450*2=2900)																			
Sample 1							Sample 2							Sample 3					
Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering
1610	1668	200	201.25	-0.62%	4%		1600	1626	195	200	-2.50%	2%		1604	1660	198	200.5	-1.25%	3%
2000	2080	251	250	0.40%	4%		2010	2040	245	251.3	-2.49%	1%		2000	2040	251	250	0.40%	2%
2480	2558	310	310	0.00%	3%		2510	2550	307	313.8	-2.15%	2%		2520	2580	310	315	-1.59%	2%
3180	3254	391	397.5	-1.64%	2%		3220	3276	394	402.5	-2.11%	2%		3200	3294	397	400	-0.75%	3%

CL00021(400/630/800) (1910*6=11460)																			
Sample 1							Sample 2							Sample 3					
Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering
197	232	138	123.125	12.08%	18%		195	260	137	121.9	12.41%	33%		196	228	136	122.5	11.02%	16%
402	470	280	251.25	11.44%	17%		404	500	282	252.5	11.68%	24%		404	470	280	252.5	10.89%	16%
668	740	445	417.5	6.59%	11%		640	743	446	400	11.50%	16%		639	738	443	399.4	10.92%	15%
804	927	560	502.5	11.44%	15%		807	933	562	504.4	11.43%	16%		810	932	560	506.3	10.62%	15%

CL00022(1000/1250/1600) (1440*4=5760)																			
Sample 1							Sample 2							Sample 3					
Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering
810	870	263	253.125	3.90%	7%		805	873	261	251.6	3.75%	8%		811	873	260	253.4	2.59%	8%
1017	1099	238	317.813	-25.11%	8%		1013	1195	327	316.6	3.30%	18%		1005	1065	322	314.1	2.53%	6%
1250	1316	401	390.625	2.66%	5%		1254	1355	405	391.9	3.35%	8%		1257	1350	403	392.8	2.59%	7%
1610	1729	518	503.125	2.96%	7%		1608	1721	519	502.5	3.28%	7%		1610	1719	517	503.1	2.76%	7%

CL00023(2000/2500/3200/4000) (1165*2=2330)																			
Sample 1							**Sample 2**							**Sample 3**					
Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering
1018	1048	124.6	127.25	-2.08%	3%		1609	1644	245	201.1	21.81%	2%		2050	2140	257	256.3	0.29%	4%
1257	1292	153	157.125	-2.63%	3%		2510	2562	310	313.8	-1.20%	2%		2530	2620	314	316.3	-0.71%	4%
1598	1632	195	199.75	-2.38%	2%		3200	3284	395	400	-1.25%	3%		3189	3288	396	398.6	-0.66%	3%
2006	2052	245	250.75	-2.29%	2%		4010	4112	496	501.3	-1.05%	3%		3980	4120	496	497.5	-0.30%	4%
2490	2550	307	311.25	-1.37%	2%														
3200	3250	390	400	-2.50%	2%														
4040	4072	490	505	-2.97%	1%														

CL00024(5000/6300) (735*2=1470)																			
Sample 1							**Sample 2**							**Sample 3**					
Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering		Current	Release Current	mV Output	Actual mV	%Error	%Error In Metering
2020	2050	156	160.32	-2.69%	1%		2020	2150	164	#####	2.30%	6%		1995	2045	154	158.33	-2.74%	3%
2460	2490	189	195.24	-3.20%	1%		2523	2700	205	#####	2.38%	7%		2500	2580	195	198.41	-1.72%	3%
3250	3280	249	257.94	-3.46%	1%		3260	3500	267	#####	3.20%	7%		3220	3300	257	255.56	0.57%	2%
3990	4025	307	316.67	-3.05%	1%		5040	5280	402	#####	0.50%	5%		4040	4130	317	320.63	-1.13%	2%
5000	5025	387	396.83	-2.48%	1%									5040	5140	393	400.00	-1.75%	2%

Chapter 9

Literature Survey

[Ljubomir A. KOJOVIC, Martin T. BISHOP], **Comparative Characteristics of Iron-Core Current Transformers and Rogowski Coils for Applications for Protective Relaying Purposes., IEEE.**

(1) Comparison between Rogowski and Iron C.T.

(2) Formulae.

(3) Characteristic of C.T.

(4) Saturation Phenomenon.

(5) Advantages and Application.

[Mehdi Yahyavi, Farshid Brojeni, Mohammad Vaziri],**Basic Theory and Practical Considerations in a Current Transformer, IEEE.**

(1) Fundamentals of Current Transformer.

(2) Working Principles.

(3) Design Criteria.

[C D M Oates, A J Burnett, C James],**THE DESIGN OF HIGH PERFORMANCE ROGOWSKI COILS**, ALSTOM Research Technology Centre, UK.

(1) Basics Rogowski Coils design.

(2) Industrial Implementation.

(3) Standard for Low Voltage Air Circuit Breaker.

(4) L T U-Power Omega ACB catalogue.

(5) IEC-60947 Part-I II.

Chapter 10

FUTURE WORK AND CONCLUSION

10.1 Future Work:

Implementation and Observation of the Design samples to be done and if any necessary modification is required according to the need/demand or for some special feature in the Release then design to be change accordingly.

10.2 Conclusion:

Basics of Current Transformer used in Air Circuit Breaker (U-Power OMEGA) and its Applications are studied. From the literature survey, theoretical knowledge of Current Transformers is obtained. Problem Identification is done and accordingly the prototype is developed in order to make the effective improvement on existing design to overcome the errors faced in the existing Current Transformer.

From the various samples developed, the samples which match the desired characteristic are selected. On the selected samples, validation testing is carried such as VA characteristics, 6In characteristics, Temperature Rise Test, Metering, Earth Fault Testing. etc for the successful implementation of the design samples in the breaker.

Chapter 11

References

1.[Mehdi Yahyavi, Farshid Brojeni, Mohammad Vaziri],**Basic Theory and Practical Considerations in a Current Transformer, IEEE.**

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4.IEC 60947 Low-voltage switchgear and control gear, Part 1: General rules,2006

5.IEC 60947 Low-voltage switchgear and control gear, Part 2: Circuit breakers,2006

6. L& T ACB U-Power OMEGA catalogue.