To Study a Design of Current Transformer and Propose Improvement for Metering and release Power Up

Major Project Report

Submitted in Partial Fulfillment of the Requirements for the degree of

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IN

ELECTRICAL ENGINEERING
(Electrical Power Systems)

By

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CERTIFICATE

This is to certify that the Major Project Report entitled **"To study a design of current transformer and propose improvement for metering and release power up"** submitted by **Ms. Tapasya Kalariya (16MEEE09)**, 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 her 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

Air Circuit Breaker is a switching device. Capable of making and carrying current under normal circuit conditions and breaking currents under specified abnormal system conditions such as short circuit faults, ground faults etc.

Current Transformer (CT) is an integral part of an air circuit breaker. It is uses for measurement and protection purpose. The CT construction consists of two type of coils: Iron CT and Rogowski coil. Iron CT is used for generating the required power for Electronic release and Rogowski is used for measurement of the current flowing through the breaker.CT senses the current and continuously gives the input to Electronic release. During normal operations, current flowing through the breaker will be displayed on the Electronic release. Under abnormal conditions, the trip command is given by the electronic release, when it gets the signal from the CT.

There is a market requirement of 1 percent accuracy in metering characteristics of Rogowski coil for which existing design needs to be upgraded. Also, release powerup at 20 percent of single phase and 10 percent of three phase is required which will be achieved through design modification of iron CT. The main problem associated with the CT is the accuracy for the lower rating of Rogowski.And the size reduction in the Iron core. The CTs have the ratings of 400/630/800A, 1000/1250/1600A and 2000/2500A. The Breaker of 1000A having 1000/1250/1600A CT cannot set protection setting at current lower than 1000A. So a need is felt to develop a new CT with rating 1000/800/630A. This will help the customer to set protection setting at lower current for 1000A breaker (800 or 630A). Similarly, a new CT design for 2000/1600/1250A needs to be developed on the same line.

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Abbreviations

IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IS	Indian Standard
DC	Direct Current
I_n	Rated Current
kV	Kilo Volt
mV	Milli Volt
VA	Voltage Ampere
LL	Lower Layer
UL	Upper Layer
CT	Current Transformer
TT	Total Turns
EL	Effective Turns
FR	Frame
CAT no	Catalogue Number

Contents

Chapter 1

Introduction

1.1 Introduction

Transformers are normally used for the transfer electric energy by electromagnetic induction. Transformers are normally used for the transmission, distribution and utilization. Power is transferred through the magnetic fields, no physical connection between them. It obeys the Faraday's law of induction. 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.

Instrument transformer is classified in the following categories:

1. Potential Transformer (PT)

2. Current Transformer (CT)

Instrument transformers used to operate the instruments safely and secure the circuitry from high voltages or high currents. Current transformers are designed to provide the current in secondary winding proportional to the primary winding current or step down the current value. CTs are widely used in electrical power industries for the metering and protective relays. The flowing current through the line is very high. The CTs are used to extend the range of metering and protection.

Figure 1.1 shows the basic construction of CT. From the figure, it is clear that the CTs are constructed by passing the single primary turn through the well-insulated core wrapped to many turns of wires. This typically shows the current ratio of the primary current to secondary current as per below equation (1).

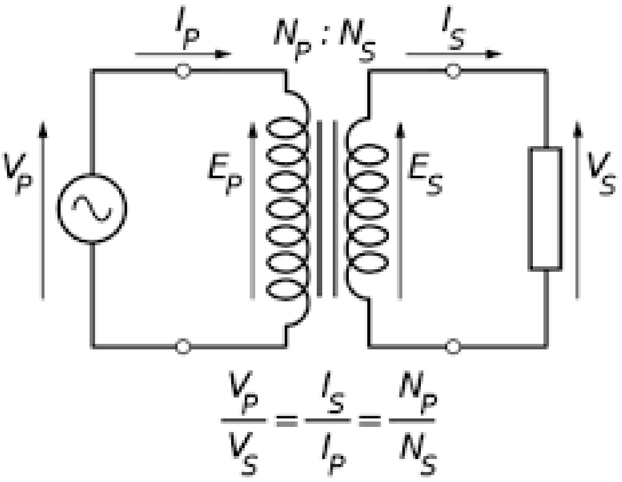

Figure 1.1: Basic construction of CT

$$T.R. = n = \frac{Number\ of\ turns\ in\ primary\ winding}{Number\ of\ turns\ in\ secondary\ winding} = \frac{Secondary\ current}{Primary\ current}$$

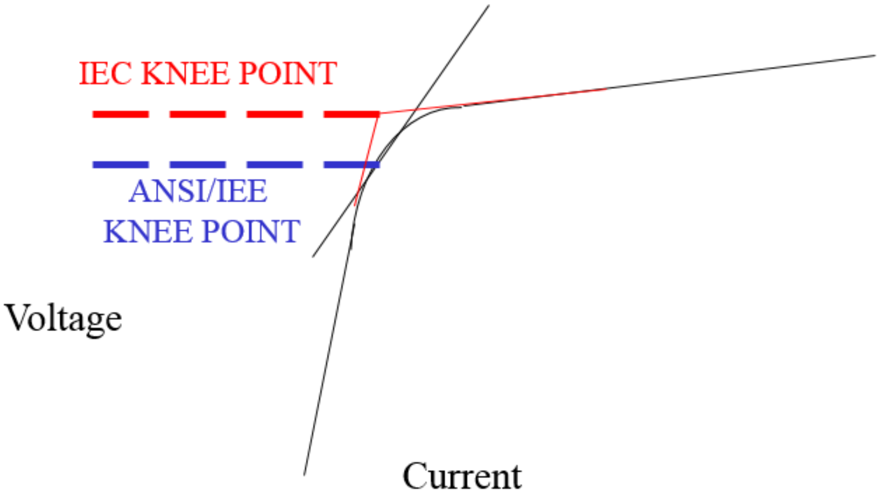

Figure 1.2: Graph of Knee Point

1.2 Literature Survey

The signals from the current transformers are delivered to the protective devices of power network. CTs deliver the least distorted wave to the protective relays. Current protection relays are able to protect to tolerate some level of deformation in the secondary current, so the voltage levels supported by magnetization branch would be lower, allowing a certain level of the saturation and thus decreasing the potential cost of the equipment.[1]. CT consists some amount of error in the measuring. So the main parameter is to determine the range of accuracy and error. The definitions of the accuracy classes are different according to the different standards. The other parameters which are related to the accuracy class of CT: The knee point voltage and burden[2]. When the high fault current passing through the core, the core get saturated. So the magnetization curve of the core at the saturated condition. The characteristic considerations of the CT is in the linear region. In normal fault conditions, the characteristics ends at the non-linear curve known as the saturation region. The point at the non-linearity starts is called the knee point [1, 2]. The theoretical relations of the parameters shown in the below equation[2]:

$$I_s = I_p/N, V_s = 4.44F.N.B.S. * 10^{-8}\ volts$$

Where,
I_p: Primary current (A)
I_s: Secondary current (A)
V_s: Secondary voltage (V)
F: System frequency (Hz)
N: Number of turns
B: Flux density (Wb/mm^2)
S: Cross section area (mm^2)

The current value measured from the current transformer is normally the fault current, because the max value of the current is considered which shows the CT is capable to withstand the worst condition. This current is 10 times to the rated current, so the current measured from the protective devices is based on the transient waveform of fault current. CT should be designed as per the maximum fault current and the worst case of DC offset. OKAN OZGONENED has given the FRHLICH Hysteresis Technique for estimate the corrected secondary current value[3]. LOUIE J. POWELL has discussed the saturation of the core, it contains flux prior to the start of the primary current wave is called the premagnetization or remanence. This remanence effect increase the time required to arrive at rms operating characteristics[4].

A.T.SINKS have discussed the calculation method for the accuracy of the current transformer. The calculation method obtained the experimental data without any making and testing the models of the current transformer. This method is very useful for the designer for proposed design[5]. MEHDI YAHYAVI, FARSHID VAHEDIAN BROJENI, MOHHAMD VAZIRI have discussed the calculation of burden with respect to the current and voltage[6].

IEEE standards define the different basic topologies of current transformer[7]. IS/IEC 60947-1-2 have the limits of the different parameters, the propposed design parameters should be in that limits[8, 9].For new design proposal of CT, it is necessary to compare the product to match market requirement. For that the catalogue of the ABB and Schneider must be referred[10, 11, 12].

Rogowski coils operate on the same principle of conventional iron-core CT. It consists the air core in the place of the iron core. Because of the air core, rogowski coils have high measurement accuracy and the wide operating range[13]. Normally CT produce the secondary current proportional to the primary current, but the rogowski coils produce the output voltage, which is scaled time derivative di/dt of primary current[14]. ALIREZA BAGHERI, MAHDI ALLAHBAKHSHI, DONYA BEHI, MOHSEN TAJDINIAN have discussed the hybrid scheme in the place of only iron CT, the RC used along with the conventional iron CT. This function is useful to prevent the mal operation[15]. Schneider Patent[16] also describes the hybrid type of mixed current sensor.

C D M OATES, A J BUR, C JAMES have discussed that the rogowski coil is now a days being popular due to their small size[17]. M. KOGA, M. TSUKUDA, K. NAKASHIMA, I. OMURA have developed PCB for improvement in power moduces and packages[18]. IEEE guide gives the basic definitions of rogowski coil and describe it with details as per the standards[19, 20] The saturation effect blockS or unblock the operation of the certain functions. So this operation reduce the sensitivity. Some compensation methods as per follows:

1. Utilized Digital Filter
2. Proposed Saturation Detection Algorithm
3. Proposed Reconstruction Algorithm

1.3 Problem Identification

The iron CT is used for power up the release. Rogowski coil is the sensor of the circuit. The main reason of using the rogowski coil as the sensor, it is not get saturated like the iron core CT.

The power up of the release is done by the three phase supply. It also be done by using the single phase only. The rogowski coil have the rating of 400/630/800A, 1000/1250/1600A, 2000/2500/3200A. But the 400/630/800A CT cannot work on the 1000A, its get burned the higher rating and 1000/1250/1600A CT cannot work on the 800A. The new CT of 630/800/1000A is required.

1.4 Objective of Work

The objective of this project to power up the release at the single phase only with the use of iron core CT. Achieve the lower rating in the rogowki coil. Get the lower rating at output of rogowski coil using the no of turns variation.

1.5 Outline of Thesis

The work done to achieve the objective of the project consists of designing and experimental validation of CT. The thesis is organized as per follows:

In chapter 1, the introductory part of the whole report and project. The background of the CT, literature survey, problem identification, objective of the work and scope of the work are introduced.

In chapter 2, the introduction of the ACB, the constructional detail, the ratings of the breakers and the information about the parts of the ACB are discussed.

In chapter 3, the existing iron CT design, the problem with that design, the new design, the experimental analysis, the comparison of the designs, the testing results of the new CT samples are analysed. From the analysis, the new iron CT which is power up at the single phase is developed.

In chapter 4, the existing design of rogowski coil, the calculation of the existing CT, the calculation of new CT, the testing results of the new designed samples are discussed. From the calculation and testing the new CT designed for the lower ratings.

In chapter 5, the conclusion of thesis work future scope of thesis work also discussed.

Chapter 2

Introduction of ACB

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. ACB is a circuit breaker with compressed air as arc quenching medium to exterminate the arc produced when the contacts are separated. The air circuit breaker is used for the voltages less than 3 kV.

2.1 Construction of ACB

The air circuit breaker consists of three types of contacts in a compressed air chamber. The three contacts are

- The main contacts which carries the load current
- The arching current which carries arching current
- The arching horns.

Main contacts of Air Circuit breaker

The main contacts are made from a good conducting material, usually made up of silver, copper. These offers low resistance to the load current flowing through the circuit. This also avoids over heating of the contacts while in service.

Arching contacts of air circuit breaker

The arching contacts are made of harder material with high resistance for example tungsten. Because the aching contacts should with stand very high arching current. Once the main contacts opens the arching current flows through the arching contacts with high resistance path.

Arching horns and chutes

The arching horns are also made up of hard material (tungsten or copper) to carry the arching current. The arc is transferred from arching contacts to moving contacts at last before extinction. The arc chutes made up of the fire proof insulating material because they are the last contacts of arc. The metal plates further stretches the arc and helps in reducing the heating of contacts.

The above parts are fitted in circuit breaker chamber with compressed air which acts as dielectric material for the arching current to flow.

2.2 Breaker Terminology and Study

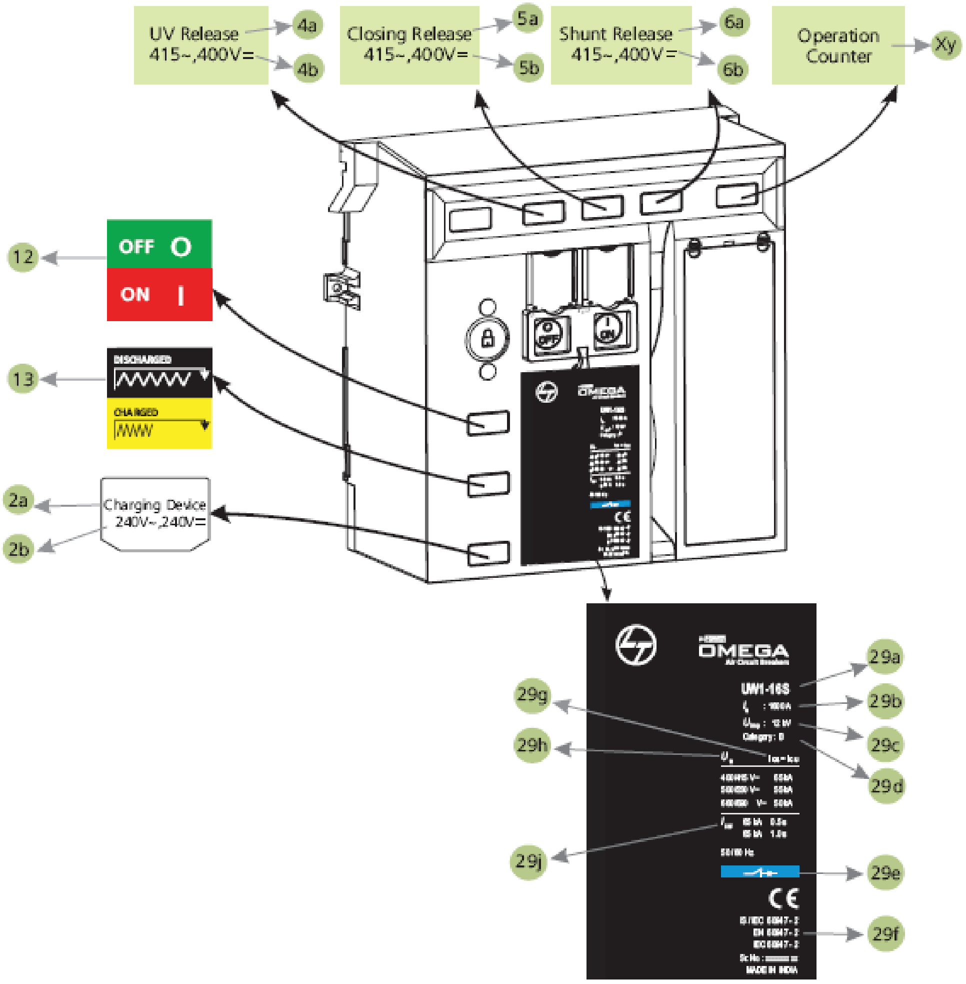

Figure 2.1: ACB Basic Diagram

Table 2.1: ACB caption 1

Caption	**Name**
2a	Type designation for Electrical Charging Device (ECD)
2b	Operating Voltage for ECD
4a	Type designation for Under voltage release
4b	Operating Voltage for Under voltage release
5a	Type designation for Closing release
5b	Operating Voltage for Closing release
6a	Type designation for Shunt release
6b	Operating Voltage for Shunt release
12	ON-OFF indication
13	Spring Status Indication
Xy	Operational Counter
29b	Rated Uninterrupted Current
29c	Rated Impuse Rated Voltage
29d	Utilization Category
29e	Suitability for isolation
29f	Standards compliance
29g	Rated Service Breaking Capacity
29h	Rated Operational Voltage
29j	Rated short time withstand current

Table 2.2: ACB caption 2

29a-UW1-16S					
1		**16** **Rated Uninterrupted Current (In)**		**S** **Version for Breaking Capacity**	
1	Frame 1	4	400A	N	50kA
2	Frame 2	6	630A	S	65kA
3	Frame 3	8	800A	H	80kA
		10	1000A	V	100kA
		12	1250A		
		16	1600A		
		20	2000A		
		25	2500A		
		32	3200A		
		40	4000A		
		50	5000A		
		63	6300A		

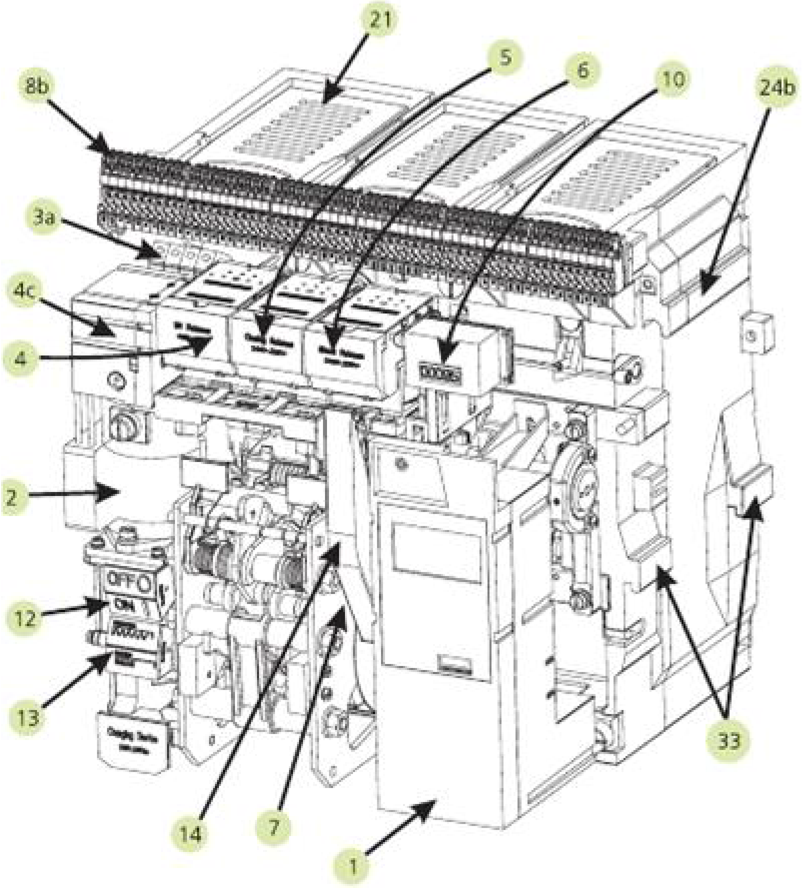

Figure 2.2: Breaker Details

Table 2.3: Breaker caption

Caption	Name
2	Electrical Charging Device
3a	Auxiliary Contacts
4	Under voltage release
4c	Under voltage release controller
5	Closing Release
6	Shunt Release
7	Ready to Close
8b	Secondary Isolating Contacts on Breaker
10	Operation Counter
12	ON-OFF Indication
13	Spring Status Indication
14	Charging Handle
21	Arc-Chute
24b	Lifting Location on Breaker
33	Protection for resting Breaker on Cradle

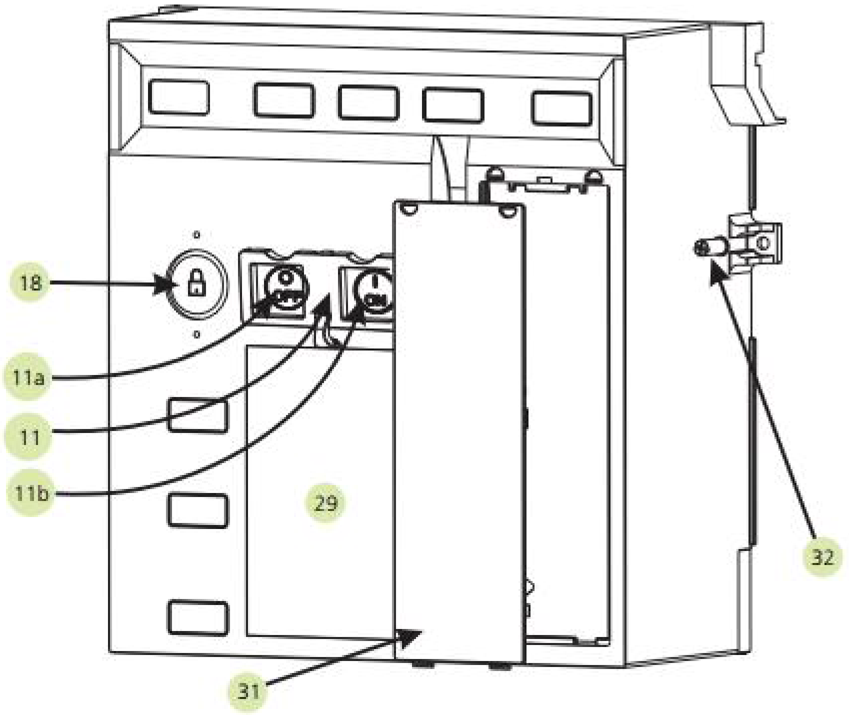

Figure 2.3: Facia

Table 2.4: Facia caption

Caption	Name
11	ON-OFF Buttons
11a	OFF Button
11b	ON Button
18	OFF Button locking
29	Facia Stricker
31	Cover for Protection Control Unit (UW-MTX Releses)
32	Facia Fixing screw

The above figure shows the positions of the contacts and releases in the breaker. The detail information about the parts of the breaker is given as follws:

AUXILARY CONTACT BLOCK:

Auxiliary Contact Block contains the changeover switch contacts in combination of 4 units of 1NO+1NC each. Auxiliary contact block reflects the breaker ON/OFF state in control circuit.

SHUNT RELEASE:

Shunt Release when energized opens the breaker instantaneously. Omega ACB's offer general purpose Shunt Release which can reliably trip the Circuit Breaker through external trip command.

CLOSING RELEASE:

Closing Release remotely closes the Circuit Breaker if the spring mechanism is already charged. Closing Releases in Omega Air-circuit breakers come with inbuilt Electrical anti-pumping feature. Inbuilt electrical anti-pumping feature prevents auto-reclosing of Circuit Breaker on faults. Anti-pumping relay cancels the persistent closing signal after successful completion of the closing operation.

UNDER VOLTAGE RELEASE WITH DELAY MODULE:

The Under voltage (UV) Release causes the Circuit Breaker to open if the operational voltage falls to a value between 35% and 70% of its rated voltage. UV Release mechanically lock the closing of breaker it makes impossible to close the Circuit breaker, either manually or electrically. The Circuit breaker can be closed with operation voltage of 85-110% of its rated value. UV Release can be used for monitoring the voltage in the primary (power circuit) or secondary (control circuits) circuits or can be used for electrical interlocking scheme (for DG synchronization, paralleling of transformers etc). In order to avoid the mal operation of the circuit breaker during short voltage dips, UV release comes with the UV-delay module. Operation of UVR can be delayed between 0 to 5 secs. In steps of 0-1-3-5 sec

ELECTRICAL CHARGING DEVICE:

Electrical Charging Device automatically charges the closing springs of the circuit breaker operating mechanism. After Circuit Breaker closing operation, the geared motor immediately recharges the closing spring. Thus instantaneous re-closing of the circuit breaker is possible opening operation. The closing springs can also be charged manually (using the spring-mechanism charging handle) in the event of an auxiliary power supply failure or during maintenance work.

OPERATION COUNTER:

The Operation Counter indicates the number of operating cycles the Circuit breaker has been subjected to and it is visible on the Circuit breaker front-facia. It is compatible with manual and electrical control functions. Counter readings serve as a guide for maintenance & inspection.

ARC CHUTE:

Arc chute in ACB is use to increase length of arc, make it weak and then extinguish the same.

MICRO SWITCHES FOR ELECTRICAL PROTECTION:

1. Common Fault Indication (CFI): CFI provides the electrical indication of circuit breaker tripping due to operation of protection & control unit.

2. Under-Voltage Release Trip Indication: Under voltage Release Trip Indication micro-switch provides electrical indication of circuit breaker tripping with the operation of under-voltage release.

3. Shunt Release Trip Indication: Shunt Release Trip Indication micro-switch provides electrical indication of circuit breaker tripping with operation of shunt release.

4. Spring Charging Indication: Spring Charging Indication micro-switch provides the electrical indication whether main mechanism spring is charged or not.

5. Ready-To-Close Indication (RTC): RTC takes into account all the safety parameters that are part of the control & monitoring system of electrical installation. OMEGA RTC allows the circuit breaker to close only if following conditions are met: Main spring is charged, All Arc-chutes are properly placed, Circuit Breaker is OFF, Mechanical trip indication lever on release is reset, Shunt release is de-energized, Under-Voltage release is energized, racking shutter is closed.

2.3 Cradle Terminology and Study

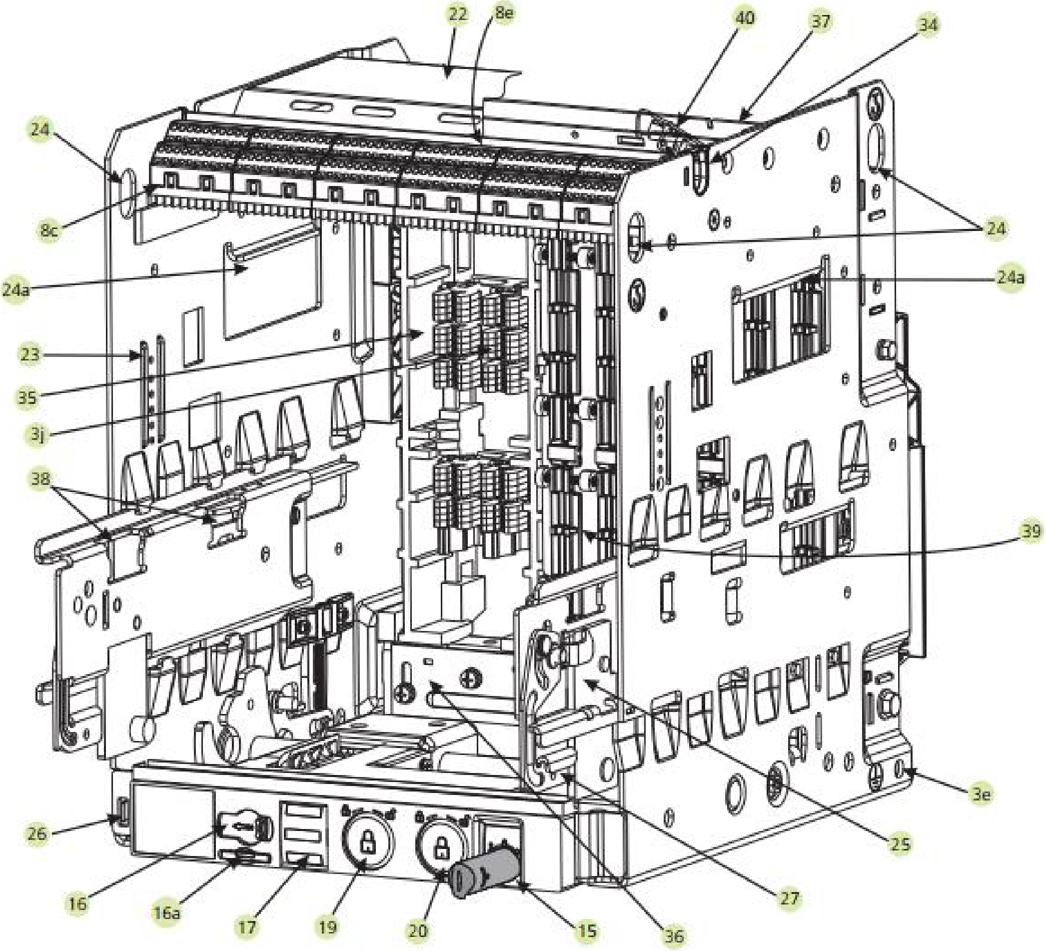

Figure 2.4: Cradle Diagram

Table 2.5: Cradle Captions 1

Caption	Name
3e	Hole for Earthing Connection
3j	Jaw Contacts
8c	Secondary Isolating Contacts on Cradle
8e	Electrical Position Indication
15	Racking Handle
16	Smart Racking Shutter
16a	Pad lock for Racking Shutter

Table 2.6: Cradle Captions 2

Caption	**Name**
17	Position Indicator
19	Position Lock-1
20	Position Lock-2
22	Arc-Shield
23	Rating Error Preventer
24	Lifting Locations
24a	Additional Lifting Locations
25	Withdrawal Rails
26	Door Locking Interlock
27	Breaker Pull Out Handle
34	Guide for routing Control
35	Terminal Supports
36	Cradle Bottom cross component
37	Cradle Top cross component
38	Slot for placing breaker on Cradle
39	Safety Shutter
40	Door Interlock

As shown in the figure, the different parts of the cradle and their operations in breaker is mentioned below:

ELECTRICAL POSITION INDICATOR (EPI):

Secondary Isolating Contact (SIC) blocks on ACB cradle assembly facilitates the electrical indication for the exact position of the breaker within the cradle. 3 SIC contacts electrically indicates the Connected / Test /Disconnected positions of breaker.

DOOR INTERLOCK:

Door-interlock inhibits the opening of door if ACB is in Test or Service position. Door-interlock can be mounted on either side of the cradle (LHS or RHS).

RACKING SHUTTER INTERLOCK:

Racking Shutter Pad-lock inhibits the access to the racking mechanism such that racking handle cannot be inserted to rack-in/rack-out the breaker. Racking Shutter Pad-lock is an inbuilt feature with U-POWER Omega ACBs. It can be pad-locked with lock handle of 6mm diameter.

DOOR RACKING INTERLOCK:

Door-racking interlock prevents the racking-in operation of the breaker if panel door is open.

LOCKING IN DISCONNECTED POSITION:

Locking in Isolated/Disconnected position inhibits the undesirable racking-in operation of the breaker from the isolated position. Locking in isolated position can be implemented using Castell/Ronis/Kirk/Profalux type of locks. Locking of the breaker in disconnected position ensures safety of the maintenance person working on downstream equipment. The locks are designed in such a way that the keys cannot be removed out till the breaker is locked, at the same time the breaker cannot be locked in "Service/Connected" or "Test" positions. Locking in Disconnected position can be used to design the interlocking schemes with other devices in the system.

LOCKING IN ALL POSITIONS:

Locking in all positions facilitates the locking of breaker in Connected/Test or isolated positions. Locking in all positions can be implemented using Castell/Ronis/Kirk/Profalux type of locks.

SAFETY SHUTTER:

The fixed part (cradle) of withdrawable Circuit Breaker contains safety shutters for preventing inadvertent access to live terminals of Circuit Breaker when breaker is withdrawn from the cradle. Safety shutters can be locked in closed position using pad-lock devices.

ARC SHIELD:

Arc-shield helps in reducing the vertical clearance between two ACBs in vertical tier panels from 300mm to mere 45mm. Arc-shield facilitates in compact design of switchboards it comes as an inbuilt feature with Omega ACBs. Rating Error-Preventer: Rating Error-Preventer ensures that the breaker of proper rating goes with the cradle of corresponding rating. It is made up of two sub-assemblies one on the cradle and other one on the breaker. Rating Error-Preventer offers distinct combination for a particular breaking capacity version within a particular rating of the breaker. Rating Error-Preventer comes as an inbuilt feature with Omega ACBs.

COVER:

Using Cover, panel door can be covered during maintenance at site to prevent the entry of dust or foreign material in the panel enclosure and cradle. The same can be fitted on the bezel without any tool and is common for fix and draw-out version of OMEGAACB.

2.4 Classification of U-Power Air Circuit Breakers

U-Power 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.

On basis of mounting arrangement

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

- Fixed Breakers:

  In fixed breakers, the breaker terminals are connected directly to the terminal adapters. For maintenance power supply must be cut off from terminal adapters. This is Major disadvantage of fixed breaker. Lower cost is advantage of fixed breaker

- Draw Out Breakers:

  The breaker is mounted on rail so breaker is rack in or out as per requirements. In normal operating condition breaker is racked in cradle.

Figure 2.5: Fixed Breakers

Figure 2.6: Draw Out Breakers

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

ACBs are also differentiated on basis of its Frame.

- Frame 1: 400 - 2500 A
- Frame 2: 400 - 2500 A
- Frame 3: 400 - 6300 A

Chapter 3

Proposed design of Iron CT

3.1 Existing design of Iron cored CT

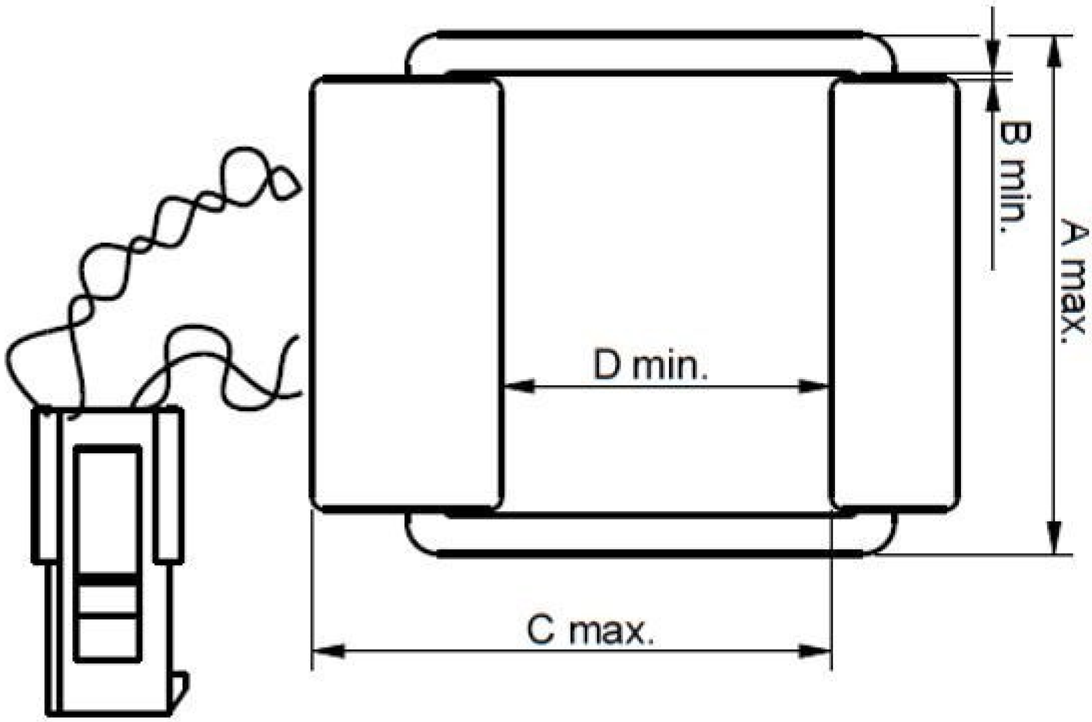

Figure 3.1: Iron cored CT

Table 3.1: CT dimensions

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
1	CL00015	88	2	79	50	15	70	65	8.5	600	1200	1800	600
1	CL00016	88	2	79	50	11	70	65	8.5	850	1420	2270	570
1	CL00017	88	2	79	50	8	70	65	6	600	1600	2200	1000
2	CL00018	122	4	79	50	17	104	65	8	500	1200	1700	700
2	CL00019	122	4	79	50	13	105	65	7	900	1700	2600	800
2	CL00020	122	4	79	50	12	105	65	4.5	850	1750	2600	900
3	CL00021	88	2	79	50	13	70	65	8	600	1100	1700	500
3	CL00022	88	2	79	50	11	70	65	8.5	850	1550	2400	700
3	CL00023	88	2	79	50	9	70	65	4	500	2300	2800	1800
3	CL00024	88	2	79	50	8	70	65	3	500	2300	2800	1800

Design of Iron CT

- Iron is used as the core material.
- CT secondary winding must be in layers of enameled copper wire.
- The upper limb of core shall be wound with the upper limb (UL) turns and also the lower limb (LL) of 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 the 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 the termination in the connector.

C.T. Saturation:

- CT saturation is the term, which is used to describe the state wherein a CT is no longer able to reproduce the output current which is 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.

Application of iron CT in ACB:

- Power up the release as per the standards

Figure 3.2: Release power up

Criteria for Release:

- For I_n (1600A) secondary output current should be less than 1 A.
- For $2I_n$ (3200A) secondary output current should be less than 1.6 A.

3.2 Standard definition for the Iron CT:

In the case of indirect releases operated by current transformers, the marking may refer either to the primary current of the current transformer through which they are supplied, or to the current setting of the overload release. In either case, the ratio of the current transformer shall be stated.

Following terms are described in IEEE standard. The ratings shall be as per the standards.

- Basic impulse insulation level in terms of full-wave test voltage (as per the frame of the breaker)
- Nominal system voltage or maximum system voltage
- Frequency 50Hz
- Rated primary and secondary currents (as per the frame of the breaker)
- Accuracy classes at standard burdens +/- 10%
- Continuous thermal current rating factor based on 30 C average ambient air temperature, unless otherwise stated
- Short-time mechanical current rating and short-time thermal current rating (as per the frame of the breaker)

3.3 Procedure

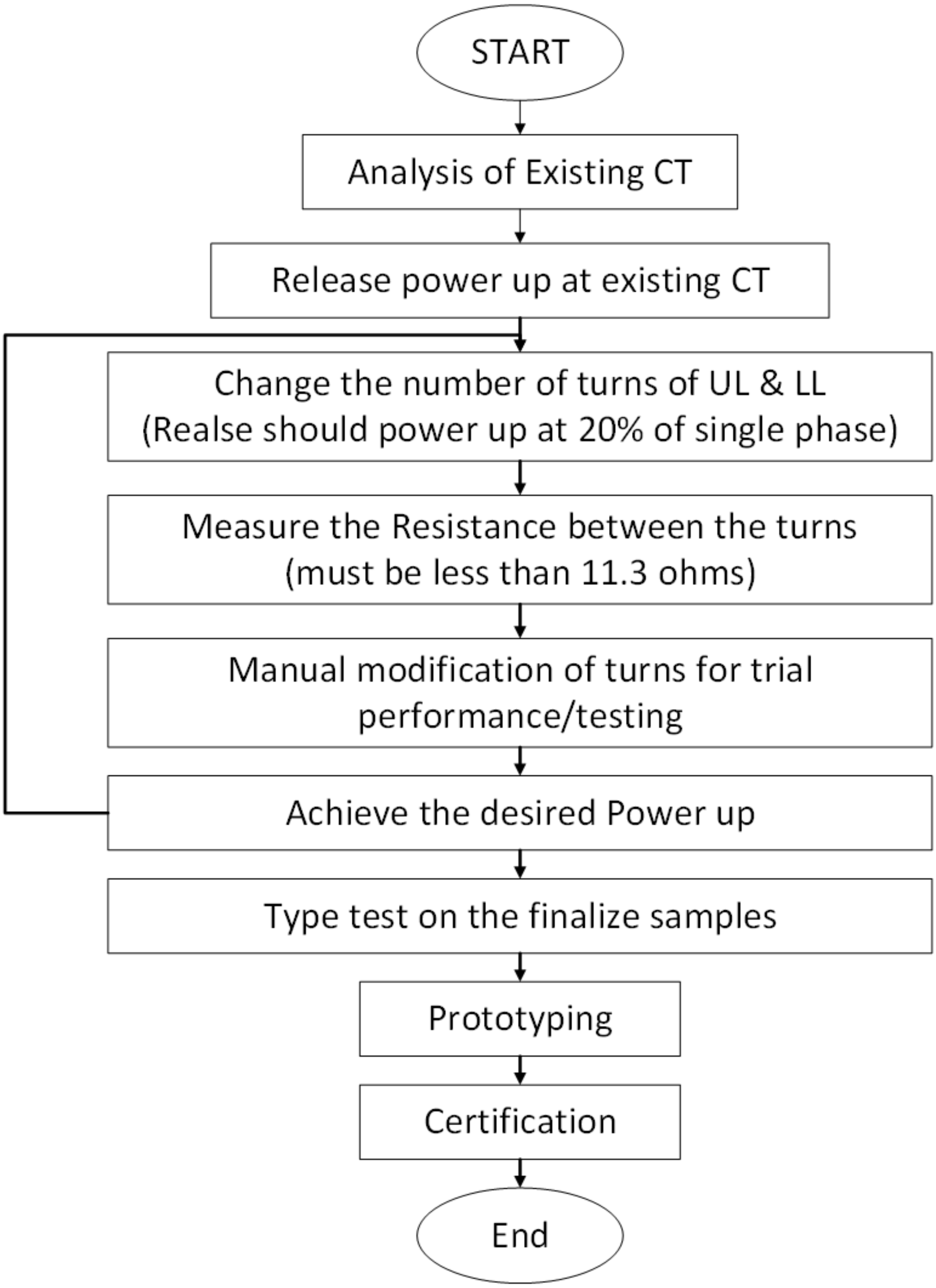

Figure 3.3: Procedure

Table 3.2: Existing Samples Test Data

CL00016-1		Cl00016-2	
Ip A	Is A	Ip A	Is A
203	0.125	205	0.112
412	0.283	413	0.277
613	0.388	613	0.364
802	0.463	800	0.443
1000	0.523	1000	0.514
1245	0.596	1250	0.573
1403	0.623	1403	0.604
1602	0.674	1610	0.656
2012	0.755	1803	0.683
3214	0.935	3195	0.917
3923	1.022	4453	1.056
4451	1.082	5412	1.136

Table 3.3: Modified Samples Test Results

Design	**LL**	**UL**	**TT**	**ET**	**Core Depth**		**R (ohm)**	**Release Power Up (A)**
					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	23.7	19.2	7.9	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 3.4: Sample 4 Test Results

Sample 4 (LL: 1100 Turns, UL: 600 Turns)(R=7.9Ohm)	
Ip A	**Is A**
100	0.103
156	0.146
206	0.235
400	0.462
795	0.652
1572	0.945
2035	1.075

Table 3.5: Sample 10 Results

Sample 10(LL: 1100 Turns, UL: 600 Turns)(R=7.2Ohm)	
Ip A	**Is A**
105	0.098
153	0.112
207	0.139
415	0.367
813	0.662
1650	0.990
2016	1.120

Table 3.6: Sample 11 Test Results

Sample 11(LL: 900 Turns, UL: 500 Turns)(R=5.9Ohm)	
Ip A	**Is A**
99	0.130
155	0.127
404	0.402
800	0.675
1610	0.925
2015	0.895

Measuring the resistance of the winding across the two ends shows that the CT is not open circuited. After performing test on 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 and 5 does not satisfy the required criteria of I_n and $2I_n$.

2. Sample 6 output current is not sufficient to power up the release at the required current.

3. Sample 1 is not suitable for the Release 3.5EC power up.

The sample 11 design is preferred over all the developed samples. Sample 11 is satisfying the criteria of I_n and $2I_n$ 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 follows:

Table 3.7: Sample 3 Test Results

U=9mm, UL: 500 LL: 1000 TT: 1500 ET :500								
Sample 3 (1) D: 22.2mm					**Sample 3 (2) D: 23.2 mm**			
Ip A	**Is A**	**Release**			**Ip A**	**Is A**	**Release**	
		3.5EC	**1.5G**				**3.5EC**	**1.5 G**
101	0.184	250	56		105	0.181	240	80
161	0.285				152	0.265		
206	0.344				204	0.354		
400	0.512				402	0.485		
805	0.722				801	0.691		
1615	0.977				1600	0.98		

Table 3.8: Sample 4 Test Results

U=11mm, UL: 500 LL: 900 TT: 1400 ET:400								
Sample 4 (1) D: 22.2mm					**Sample 4 (2) D: 23.2 mm**			
Ip A	**Is A**	**Release**			**Ip A**	**Is A**	**Release**	
		3.5EC	**1.5G**				**3.5EC**	**1.5 G**
101	0.228	195	74		106	0.255	195	80
156	0.336				155	0.338		
201	0.39				194	0.396		
412	0.584				411	0.615		
802	0.793				800	0.826		
1596	1.133				1605	1.206		

Table 3.9: Sample 5 Test Results

U=10mm, UL: 500 LL: 900 TT: 1400 ET:400								
Sample 5 (1) D: 20.5mm					**Sample 5 (2) D: 20.2 mm**			
Ip A	**Is A**	**Release**			**Ip A**	**Is A**	**Release**	
		3.5EC	**1.5G**				**3.5EC**	**1.5 G**
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 3.10: Sample 6 Test Results

U=9mm, UL: 500 LL: 900 TT: 1400 ET:400								
Sample 6 (1) D: 19.7mm					**Sample 6 (2) D: 19.6 mm**			
Ip A	**Is A**	**Release**			**Ip A**	**Is A**	**Release**	
		3.5EC	**1.5G**				**3.5EC**	**1.5 G**
103	0.068	750	110		102	0.064	534	110
150	0.069				154	0.122		
202	0.162				203	0.25		
411	0.387				405	0.43		
796	0.560				813	0.685		
1599	0.81				1594	0.943		

3.4 Type Tests of Samples

Validation of samples for following approval tests:

1. $6I_n$ test

2. VA characteristics.

3. Earth fault tripping at minimum setting
4. Temperature rise test

3.4.1 $6I_n$ test

Table 3.11: Sample 1 & 2 $6I_n$

Sample 1		**Sample 2**	
Ip	**Is**	**Ip**	**Is**
206	0.128	208	0.129
413	0.287	407	0.28
612	0.386	604	0.367
803	0.469	801	0.445
1004	0.528	998	0.515
1244	0.591	1239	0.572
1401	0.626	1390	0.607
1600	0.67	1598	0.65
2011	0.754	2025	0.681
3211	0.934	3119	0.913
3922	1.021	4002	1.052
4770	1.084	4820	1.134
6425	1.123	6412	1.15
7980	1.19	8020	1.173
9550	1.23	9523	1.254

3.4.2 VA characteristics

Table 3.12: 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
821	0.673	6.174	4.16
1623	0.959	6.123	5.87
2011	1.07	5.978	6.4
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

3.4.3 Earth fault tripping at minimum setting

CL00016 (1000,1250,1600A). Test conducted on MTX 1.5G release with in setting 1000A, Earth fault setting: pick up $0.2I_n$, Delay 0.1 (12T ON)

Table 3.13: Earth Fault I^2t

		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

Table 3.14: My caption

		Resistance (Ohm)	Test parameters						
Sample No.	**Discription**	**Iron Core**	**Rogowski**	**Release**	**Current (A)**	**Iron core output (mA)**	**Metering (A)**	**Trip time (sec)**	**%error**
1	Existing CL00016	12.24	313.3	1.5G	198	306	203	0.136	36
					197	306	201	0.248	24
				3.5EC	195	243	203	0.188	88
2	Tape-wound CL00701	12.11	504.7	1.5G	200	225	166	No trip	
					247	309	196	0.14	40
				3.5EC	248	294	206	0.144	44
					218	256	180	No trip	
3	New CT CL00016 Sample No. 4	6.97	293	1.5G	201	330	201	0.14	40
					202	330	203	0.25	25
				3.5EC	202	145	No navigation	0.204	104
					229	195	235	0.19	90
4	New CT CL00016 Sample No. 6	7.02	297.7	1.5G	211	345	204	0.14	40
					210	345	204	0.24	20
				3.5EC	221	150	No navigation	0.15	80
					249	176	258	0.18	80
5	New CT CL00016 Sample No. 2	7.02	293	1.5G	205	350	204	0.14	40
					223	354	221	0.14	40
					220	361	219	0.24	20
				3.5EC	351	355	349	0.18	80
					220	165	230	0.19	90

3.4.4 Temperature rise

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

Table 3.15: Temperature Rise Tes

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 4

PROPOSED DESIGN OF ROGOWSKI COIL

4.1 Introduction of Rogowski Coil

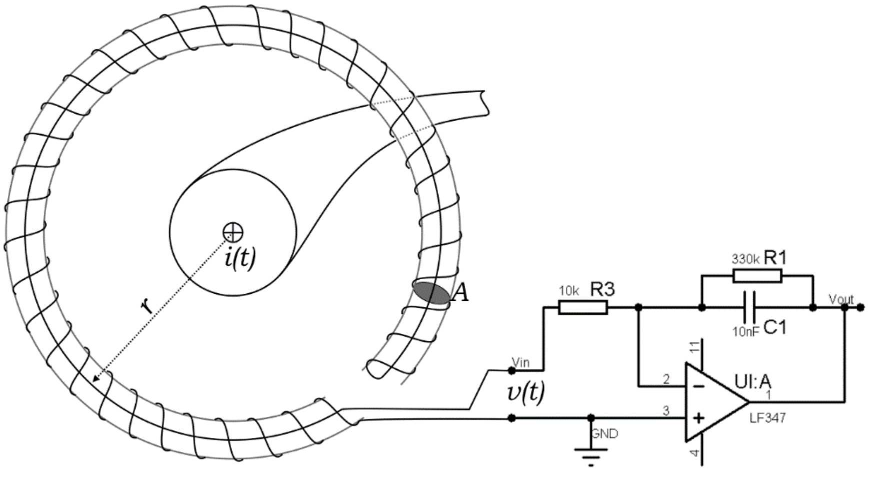

Figure 4.1: Rogowski Coil

Rogowski coil is mainly used for the measuring AC or high speed current pulses. It consists of the helical coil of wire with the lead from one end returning through centre of the coil to the other end, so that both terminals are at the same end of the coil. Whole assembly is then wrapped around straight conductor whose current is to be measured. There is no metal (iron) core. The voltage that is induced in coil is proportional to the rate of change (derivative) of current in straight conductor, the output of the rogowski coil is usually connected to an electrical (or electronic) integrator circuit to provide an output signal that is proportional to the current. The single-chip signal processors with built-in analog to digital converters are often used for this purpose.

The RC time constant reflects the relationship between resistance and capacitance with respect to time with the amount of time, given in seconds, being directly proportional to the resistance, R and the capacitance, C.

Thus the rate of charging or discharging depends on RC time constant, T = RC.

The main disadvantage of the rogowski coil is, the output of the coil must be passed through an integrator circuit to obtain the current waveform. The integrator circuit requires power, typically 3 to 24Vdc, and many commercial sensors obtain this from batteries. But this is given by the iron CT in case of ACB.

Voltage produced in rogowski coil,

$$E = \frac{-AN\mu_0}{l}\frac{dI}{dt}$$

Where,

A: Area of cross section of coil (35mm)

I: Current (800A)

N: Number of turns in coil (1920*6=11520)

μ_0 : $12.56 * 10^{-7}$

l: Length of winding

4.2 Comparison of rogowski coil with the conventional Iron CT

Rogowski Coils operate on same principles as the conventional iron-core current transformers (CTs). The main difference between the rogowski coils and CTs is that the rogowski coil windings are wound over an (non-magnetic) air core, instead of over an iron core. As a result, the rogowski coils are linear since the air core cannot saturate. Coils is much smaller than in CTs. Therefore, the rogowski coil output power is small, so low-resistance burden like CTs are able to drive.

In general, the rogowski coil current sensors have performance characteristics that are favourable when the 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. 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. resulting in negligible current flowing through the secondary circuit. Rogowski Coil has much smaller power loss. Rogowski Coils can replace conventional CTs for protection, metering, and control.

4.3 Application of Rogowski in ACB

Used for metering purpose of the rated current which is flowing through the breaker.

4.4 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 within the limit of 10% or better for a fault current 20 times the CT rated current and up to the standard burden. CTs are mainly designed to meet this requirement.

4.5 Existing rogowski coil

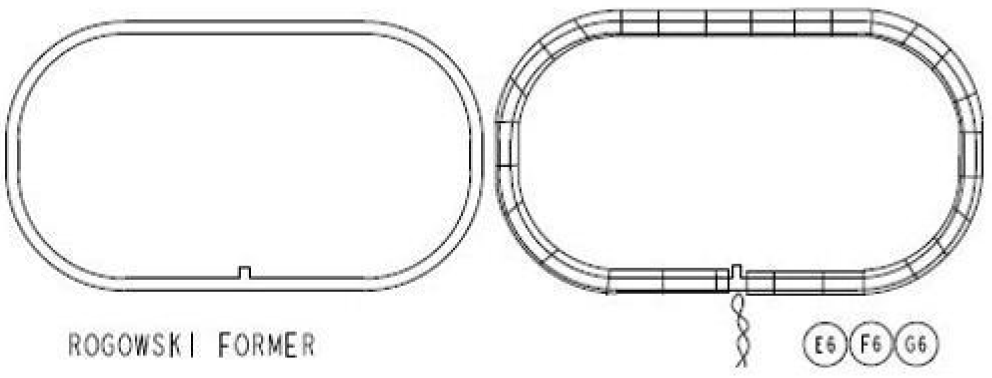

Figure 4.2: Rogowski coil design

Table 4.1: Existing rogowski coil dimensions

FRAME	**CT CAT NO.**	**MEAN LENGTH OF WINDING L (mm)**	**FORMER**	**SWG**	**LAYERS**	**TURNS PER LAYER**	**PITCH**	**OUTPUT (VOLT)**
1	CL00015	262	CL50058	42	6	1920	0.143	.500±-.025
	CL00016				5	1130	0.231	.500±.025
	CL00017				2	1480	0.177	.500±.025
2	CL00018	326	CL50059	42	6	2340	0.138	.500±.025
	CL00019				5	1410	0.228	.500±.025
	CL00020				2	1480	0.215	.500±.025
3	CL00021	262	CL50058	42	6	1950	0.14	.25±0.013
	CL00022				4	1470	0.186	.25±0.013
	CL00023				2	1190	0.22	.25±0.013
	CL00024				2	752	0.348	.25±0.013

The Rogowski having the ratings of 400/630/800A, 1000/1250/1600A, 2000/2500 A. But the Rogowski of 1000/1250/1600A cannot work on the 630A and 800A. Thus, the new having the ratings of 630/800/1000A. Which can be achieved by the changing the no of turns.

Rogowski Criteria of ACB

- 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 10 mV.

Calculation of rogowski coil:

Existing rogowski coil

$$E = \frac{-AN\mu_0}{l}\frac{dI}{dt}$$

Where,

A: Area of cross section of coil (35mm)

I: Current (800A)

N: Number of turns in coil (1920*6=11520)

μ_0 : $12.56 * 10^{-7}$

l: Length of winding (262mm)

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

$$EMF = 0.4855V$$

$A = (17.5 * 2)\, 35 * 10^{-6} mm^2$

$I = 800A$

$N = 1920 * 6 = 11520\ turns$

$\mu_0 = 12.56 * 10^{-7}$

$l = 262 * 10^{-3} mm$

For new current rating CT CL00015:

$$0.5 = \frac{35 * 10^{-6} * N * 12.56 * 10^{-7} * 6.28 * 50 * 1000}{262 * 10^{-3}}$$

So, N= 9490 turns

Thus, the new CT design as per the 9490 turns. On average number of turns are considered as per the 9000 turns, which consists 1500 turns with 6 layers.

For new current rating CT CL00016:

$$0.5 = \frac{35 * 10^{-6} * N * 12.56 * 10^{-7} * 6.28 * 50 * 2000}{262 * 10^{-3}}$$

So, N= 4745 turns

Thus, the new CT design as per the 5000 turns. On average number of turns are considered as per the 5640 turns, which consists 1410 turns with 4 layers.

FR 1 1000/800/630, At 1000A current, output required of rogowski 0.5V, No. of turns: 1500, 6 layers, Iron CT to be used of CL00015, 2mm shield to be used.

Table 4.2: The readings of CL00015 new design of Rogowski coil-1 Sample-1

Sample 1 POWER UP 81 A		
PRIMARY CURRENT	**METERING**	**mV**
125	124	62.7
161	160	80.9
203	202	101.6
630	620	310.5
796	779	391.2
1004	979	492.4

Table 4.3: The readings of CL00015 new design of Rogowski coil-1 Sample-2

Sample 2 POWER UP 80 A		
PRIMARY CURRENT	**METERING**	**mV**
125	122	61.8
160	156	78.7
200	195	98.4
628	602	303.4
802	768	387.2
995	949	489.6

Table 4.4: The readings of CL00015 new design of Rogowski coil-1 Sample-3

Sample 3 POWER UP 87 A		
PRIMARY CURRENT	**METERING**	**mV**
127	124	62.1
164	159	80.4
199	193	97.4
627	602	302.1
804	772	389.7
1001	958	482.3

Table 4.5: The readings of CL00015 new design of Rogowski coil-1 Sample-4

Sample 4 POWER UP 81 A		
PRIMARY CURRENT	**METERING**	**mV**
125	124	63.1
162	161	81.5
203	202	101.6
630	619	311.2
801	784	394.4
1009	984	495.2

FR 1 2000/1600/1250, At 2000A current, output required of rogowski 0.5V, No. of turns: 1410, 4 layers, Iron CT to be used of CL00016, 2mm shield to be used.

Table 4.6: The readings of CL00016 new design of Rogowski coil-1 Sample-1

Sample 1 POWER UP 248 A		
PRIMARY CURRENT	**METERING**	**mV**
254	258	65.7
313	316	81.9
406	408	103.4
1252	1236	311.1
1600	1536	395.5
1997	1940	491.7

Table 4.7: The readings of CL00016 new design of Rogowski coil-1 Sample-2

Sample 2 POWER UP 190 A		
PRIMARY CURRENT	**METERING**	**mV**
254	252	63.9
324	320	81.1
402	396	100.3
1248	1210	302.8
1590	1538	384.9
1996	1920	484.2

Table 4.8: The readings of CL00016 new design of Rogowski coil-1 Sample-3

Sample 3 POWER UP 285 A		
PRIMARY CURRENT	**METERING**	**mV**
247	250	63.7
316	320	80.9
398	402	101.4
1256	1242	310.6
1599	1572	394.4
1997	1962	491.8

Table 4.9: The readings of CL00016 new design of Rogowski coil-1 Sample-4

Sample 4 POWER UP 165 A		
PRIMARY CURRENT	**METERING**	**mV**
254	254	64.8
316	316	80.2
395	394	99.7
1258	1238	309.4
1605	1576	394.2
2006	1958	492.1

Chapter 5

Conclusion and Future Scope

Conclusion:

This project report consists the experimental results of iron core current transformer and rogowski coil. The improvement in the CT designs is useful for the better operation and cost reduction.

The existing iron core CT is used in the three phase of ACB for the power up the release. But as per new design of iron core CT, the release should power up at 20% of the single phase. The new design is implemented in the ACB. The certification work is going on the new design. The new design is heplful in the cost reduction of ACB.

By changing the number of turns as per the calculation, the rogowski coil is able to run for the lower ratings of 1000/800/630A.

Future Scope:

For the implementation of the new CT design, all the tests on CT must be carried out. The CT design can be modify as per the requirement of the customer. New hybrid CT design as per the standard requirements.

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