RESEARCH ARTICLE OPEN ACCESS

Implementation of Transformer Protection by Intelligent Electronic Device for Different Faults

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ABSTRACT
Protection of power system equipments was traditionally done by using electromagnetic relay, static relays, and numerical relays. At present the microprocessor based relays are replacing the old Electromagnetic relays because of their high level accuracy and fast operation. RET670(Transformer protection relay), an IED (INTELLIGENT ELECTRONIC DEVICE) provides fast and selective protection, monitoring, and control of all types of transformer. The configured IED is tested under different fault conditions simulated by using mobile test kit to ensure IED's reliable operation on site. With preconfigured algorithms, the IED will automatically reconfigure the network in case of a fault, and a service restoration is carried out within milliseconds by giving trip signal to the corresponding Circuit breakers. On receiving the trip signal the circuit breaker operates providing quicker isolation of transformers under the fault condition. This enables to have a complete and an adequate protection to the specified power transformer.
Keywords – Transformer protection, IED, RET670

I. INTRODUCTION

An **Intelligent Electronic Device** (**IED**) is a term used in the electric power industry to describe **microprocessor-based controllers** of power system equipment, such as circuit breakers and transformers.

1. RET670 Introduction

RET670 provides fast and selective protection, monitoring and control for two- and three-winding transformers, autotransformers, generator-transformer units, phase shifting transformers, special railway transformers and shunt reactors. The transformer IED is designed to operate correctly over a wide frequency range in order to accommodate power system frequency variations during disturbances and generator start-up and shut-down as in Fig.1

A very fast differential protection function with settable CT ratio matching and vector group compensation makes this IED the ideal solution even for the most demanding applications. Since RET670 has very low requirements on the main CTs, no interposing CTs are required. It is suitable for differential applications with multi-breaker arrangements with up to six restraint CT inputs. The differential protection function is provided with 2nd harmonic and wave-block restraint features to avoid tripping for magnetizing inrush current, and 5^{th} harmonic restraint to avoid tripping for over excitation. The differential function offers a high sensitivity for low-level internal faults. The unique and innovative sensitive differential protection feature of the RET670 provides the best possible coverage for winding internal turn-to-turn faults, based on the theory of symmetrical components.

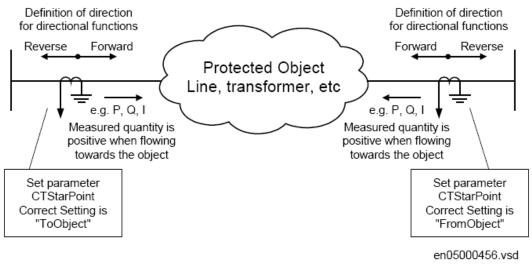


Fig.1: Internal Conventions of the directionality in the IED.

Tripping from pressure relief/Buchholz and temperature devices can be done through the transformer IED where pulsing, lock-out contact output and so on, is performed. The binary inputs are heavily stabilized against disturbance to prevent incorrect operations at for example dc system capacitive discharges or DC earth faults. The transformer IED can also be provided with a full control and interlocking functionality including Synchrocheck function to allow integration of the main and/or a local back-up control. Out of Step function is available to separate power system sections close to electrical centre at occurring out of step.

RET670 can be used in applications with the IEC 61850-9-2LE process bus with up to two Merging Units (MU) as in fig1.1. Each MU has eight analogue channels, normally four current and four voltages. Conventional and Merging Unit channels can be mixed freely in your application.

1.1RET 670 hardware

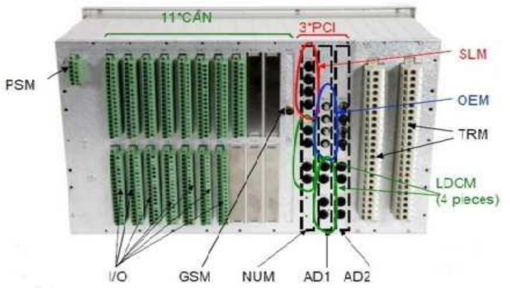


Fig.1.1 Rear side view of RET670

1.1.1 Available functions of RET670

Differential protection, Distance protection, Current protection, Voltage protection, Frequency protection, Multipurpose protection, Control, Logic, Metering, Monitoring, Station communication etc are the functions carried out by RET670.

II. Block diagram

The block diagram in fig.2 shows the implementation of **RET670** in transformer protection

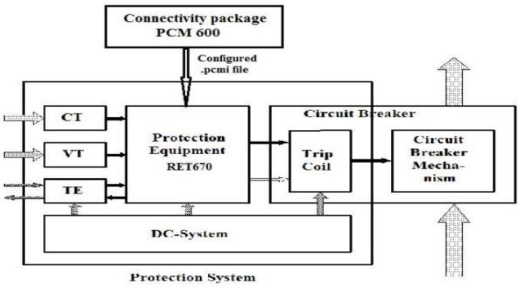


Fig.2. Block Diagram of Implementation of RET670 in transformer protection.

PCM600 is a connectivity package which provides the means for system products and tools to connect and interact with the IED in an efficient way as well as data to allow efficient engineering of system products. RET670 supports IEC 61850 standard. Configuration of RET670 is done by using signal matrix tool of PCM600, generating a **.pcmi** file. After establishing communication with **RET670** the **.pcmi** file is uploaded to RET670 and then the parameter setting is done as per the required transformer protection scheme.

The **CT's and VT's** will provide the necessary actuating signals to RET670 under the fault condition. Operation of RET670 gives the trip signal to the physical **trip coils**. When once the IED is configured for different protection schemes the fault voltage is applied by simulating the fault condition through Mobile test kit.)

2.1. Protection and Control Manager (PCM 600) with Connectivity Package for Relay.

PCM600 is used to do complete engineering and configuration activities needed for the IEDs. Product type and version specific engineering data needed by PCM600 for protection, control and communication engineering of a particular IED is given in an IED connectivity package. A PC with PCM600 can be connected to any 670 series IED within a station using the Ethernet connection. The connection allows to reading and writing all configuration data needed for proper operation from or to the IED. The IEDs have communication interfaces for protocols and media used for station communication. IED
IEC-61850 station communication files can export from PCM600 to station engineering tools for engineering of station communication between bay IEDs and station IEDs.

2.1.1 Tasks of PCM600 in IED engineering process

IED engineering management ,Communication engineering, Disturbance record management
Service management are the tasks of PCM600 in IED engineering process.

2.1.2 Available Protection

The following are the few among the various protections which is provided to the above mentioned transformer by an IED, RET670.

i. Two winding differential protection.
ii. High impedance differential protection (REF).
iii. Over current and Earth fault protection.
iv. Over excitation protection.
v. Transformer troubles.

III. TWO WINDING DIFFERENTIAL PROTECTION

The task of the power transformer differential protection is to determine whether a fault is within the protected zone, or outside the protected zone. The protected zone is delimited by the position of current transformers , and in principle can include more objects than just transformer. If the fault is found to be internal, the faulty power transformer must be quickly disconnected. Thus the IED will always internally measure the currents on all sides of the power transformer with the same reference direction towards the power transformer windings.

3.1 Configuration

The functions Transformer differential protection, two-winding (T2WPDIF) is provided with internal CT ratio matching and vector group compensation and when required zero sequence current elimination is also made internally in the software. T2WPDIF is the functional block of two winding differential protection.

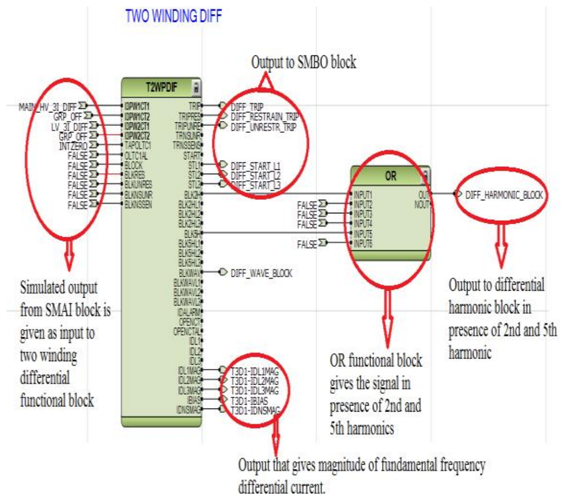


Fig 3.1 : Two winding differential protection functional block

The configuration of the particular functional block
is as shown in fig.3.1.

1 - T2WPDIF Analog inputs from SMAI.
2 - T2WPDIF output signals to SMBO.
3- Outputs which gives the magnitude of fundamental frequency differential currents.
4 - OR logic functional blocks which gives the indication for the presence of 2nd and/or 5^{th} harmonics.
5 - Output indicating the presence of harmonics.

Analog inputs from SMAI

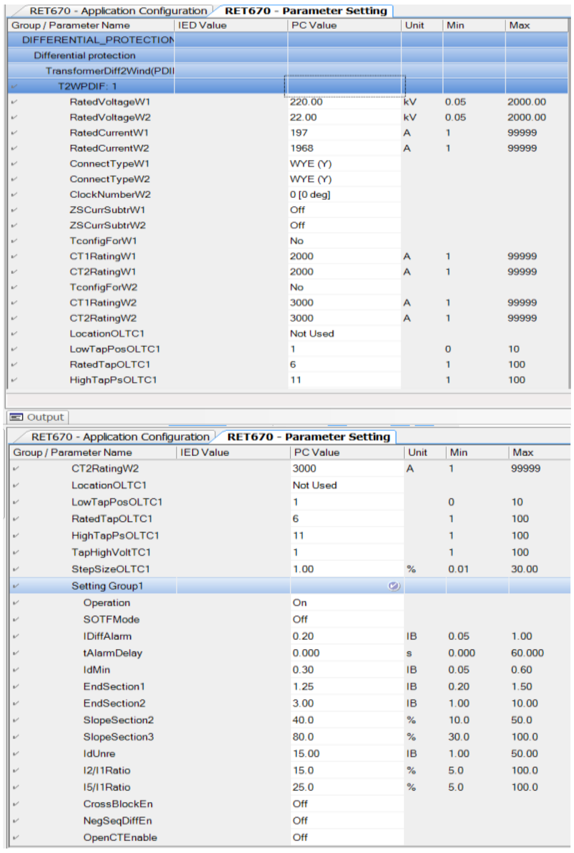
AI_HV_1MS = Current reading from the HV side CT obtained from SMAI.
AI_LV_1MS = Current reading from the LV side CT obtained from SMAI.

Output signals to SMBO

DIFF_TRIP _ General differential trip signal.
DIFF_RESTRAIN_TRIP = Trip signal under restrained condition.
DIFF_UNRESTRAIN_TRIP = Trip signal under unrestrained condition.
These trip signals are given to the trip logic and in-turn goes to SMBO block.

3.2 Parameter setting

This is done in PCM600 by using Parameter Setting Tool (PST) as in table 3.2The specified settings for the parameters of the physical IED for communication channels, CT and VT conversion values of the transformer modules, presentation parameters for local HMI, settings for protection and control functions, number of setting groups etc., are provided by using PST.



RET670 - Application Configuration / RET670 - Parameter Setting

Group / Parameter Name	IED Value	PC Value	Unit	Min	Max
DIFFERENTIAL_PROTECTION					
Differential protection					
TransformerDiff2Wind(PDI					
T2WPDIF: 1					
RatedVoltageW1		220.00	kV	0.05	2000.00
RatedVoltageW2		22.00	kV	0.05	2000.00
RatedCurrentW1		197	A	1	99999
RatedCurrentW2		1968	A	1	99999
ConnectTypeW1		WYE (Y)			
ConnectTypeW2		WYE (Y)			
ClockNumberW2		0 [0 deg]			
ZSCurrSubtrW1		Off			
ZSCurrSubtrW2		Off			
TconfigForW1		No			
CT1RatingW1		2000	A	1	99999
CT2RatingW1		2000	A	1	99999
TconfigForW2		No			
CT1RatingW2		3000	A	1	99999
CT2RatingW2		3000	A	1	99999
LocationOLTC1		Not Used			
LowTapPosOLTC1		1		0	10
RatedTapOLTC1		6		1	100
HighTapPsOLTC1		11		1	100

Output

RET670 - Application Configuration / RET670 - Parameter Setting

Group / Parameter Name	IED Value	PC Value	Unit	Min	Max
CT2RatingW2		3000	A	1	99999
LocationOLTC1		Not Used			
LowTapPosOLTC1		1		0	10
RatedTapOLTC1		6		1	100
HighTapPsOLTC1		11		1	100
TapHighVoltTC1		1		1	100
StepSizeOLTC1		1.00	%	0.01	30.00
Setting Group1					
Operation		On			
SOTFMode		Off			
IDiffAlarm		0.20	IB	0.05	1.00
tAlarmDelay		0.000	s	0.000	60.000
IdMin		0.30	IB	0.05	0.60
EndSection1		1.25	IB	0.20	1.50
EndSection2		3.00	IB	1.00	10.00
SlopeSection2		40.0	%	10.0	50.0
SlopeSection3		80.0	%	30.0	100.0
IdUnre		15.00	IB	1.00	50.00
I2/I1Ratio		15.0	%	5.0	100.0
I5/I1Ratio		25.0	%	5.0	100.0
CrossBlockEn		Off			
NegSeqDiffEn		Off			
OpenCTEnable		Off			

Table 3.2:Parameter Settings of Two winding differential protection

3.3 Transformer Differential Protection Details

Description	Setting
Trans.Rating	75MVA
Trans.Vector Group	YY0
HV side full load current (pri)	197A
HV side full load current (sec)	0.985A
LV side full load current (pri)	1972A
LV side full load current (sec)	0.986A
Diff. Pickup Id>(restraint)	30% of full load current
Diff. Pickup Id>(restraint)	30% of full load current
Diff. Pickup Id>(Unrestraint)	10 Times of full load current
Slope Section 2	40%
Slope Section 3	80%
2nd Harmonic Blocking	15%

3.4 Testing procedure

When once the complete configuration of an IED is done it is tested for its operation and reliability by using mobile test kit (Doable, Omicron).

Differential protection test is classified based on the parameters which are to be checked. They are,

i. Pick up test
ii. Stability test
iii. Slope test

3.4.1. PICK UP TEST

Pick up test is done to verify the pick-up value of the relay on both HV and LV side of the transformeras in fig 3.4.1 & 3.4.1.1.

For a 75MVA, 220kV/22kV power transformer,
HV tripping value = 0.985A
We have Idmin = 0.3
Therefore, HV pick up = 0.985 * 0.3 = 0.295A
Similarly,
LV tripping value = 0.984A
We have Idmin = 0.3
Therefore, LV pick up = 0.984 * 0.3 = 0.295A

This value of current is injected to the relay for each one of the phases and also for all the three phase by using Doble or omicron test kit and is checked for its reliability. Pick up value of current is been injected to the R phase of HV as in table3.4.1.2 & for LV side as in table 3.4.1.3. As soon as the injected current exceeds 295mA the relay gets tripped.

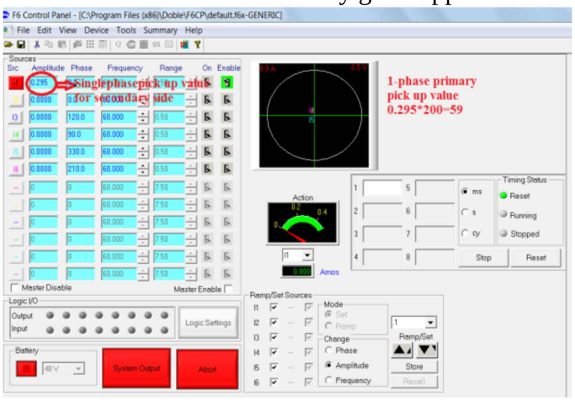


Table 3.4.1Testing procedure for 1- Phase

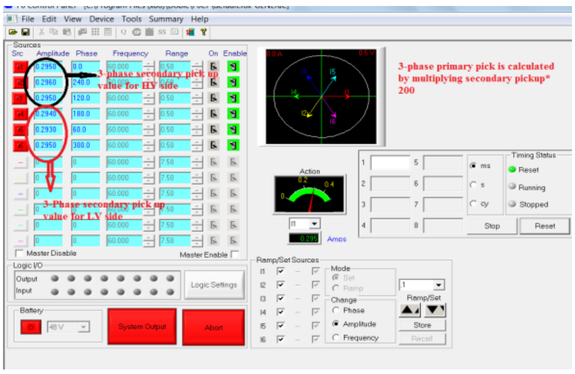


Table 3.4.1.1 Testing procedure for 3- Phase

3.4.1.2 PICK UP TEST MEASURED IN 1Φ INJECTION

Phase	INJECTED CURRENT(HV SIDE)	OPERATING TIME(MS)	DIFFERENTIAL CURRENT	BIAS CURRENT
R-PH	0.295	26.3	59	59.09
Y-PH	0.296	29.3	59	59.18
B-PH	0.295	27.2	59	59.99

TABLE 3.4.1.2 PICKUP TEST TABULATION ON HV SIDE

Phase	INJECTED CURRENT (LV SIDE)	OPERATING TIME(MS)	DIFFERENTIAL CURRENT	BIAS CURRENT
R-PH	0.294	26.1	59	59.29
Y-PH	0.293	29.8	59	59.37
B-PH	0.295	27.1	59	59.93

TABLE 3.4.1.3 PICKUP TEST TABULATION ON LV SIDE

3.4.2. STABILITY TEST

This test is done to check the stability of the relay. The transformer under consideration is a Y-Y connected transformer with 0 degree phase shift. An equal current of magnitude 1A is been injected to both HV and LV (when both HV and LV has CTs of same ratio) or current of magnitude equal to the pick-up value of HV and LV respectively is been injected. The phase angle of any one of the phases of either HV or LV is changed. When once the current goes out of phase the relay is tripped. This is indicated by indication LED as in the Figure 3.4.2. 75MVA, 220kV/22kV power transformer has different CT ratios of HV and LV is different. Hence, the actuating value of 0.295A is been injected for R phase of HV and LV. Since the phase angles are balanced the relay is under stable state.When once the phase angle of either HV or LV is changed the currents become out of phase issuing a trip.

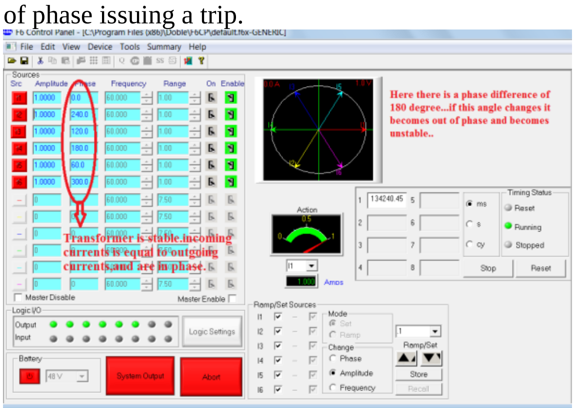


TABLE 3.4.2 TESTING PROCEDURE FOR STABILITY TEST

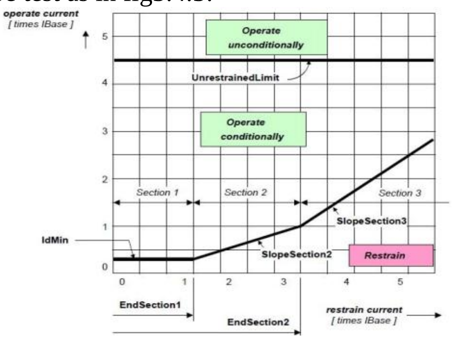
3.4.2.1 STABILITY TEST RESULTS

Phase	INJECTED CURRENT(HV SIDE)		INJECTED CURRENT(HV SIDE)		STABILITY
	CURRENT	PHASE (DEG)	CURRENT	PHASE (DEG)	
R-PH	1A	0^0	1A	180^0	OK
Y-PH	1A	240^0	1A	60^0	OK
B-PH	1A	120^0	1A	300^0	OK

Table 3.2.2.1 Stability Test Tabulation

3.4.3. SLOPE TEST

The operate restrain characteristic has three regions. One is non operating region in which the relay won't operate. Operating region in which the relay operates but conditionally. The unrestrained region in which the relay is operated unconditionally. This operation of the relay is verified by conducting slope test as in fig3.4.3.



3.4.3 Fault currents with DC offset during an external fault Slope = (ΔIoperate/ ΔIrestrain) *100

3.4.3.1 SLOPE TEST(HV&LV) RESULTS FOR SLOPE-1

Current injected as below**:**

PHASE	Injected Current (HV SIDE)		Injected Current (LV SIDE)		Differential Current(A)	Bias Current(A)	Tripping
	Current (A)	Phase (deg)	Current (A)	Phase (deg)			
R-PH	1.71A	0^0	1A	180^0	97.503A		Operated
Y-PH	1.71A	240^0	1A	60^0	97.503A	347.88	Operated
B-PH	1.71A	120^0	1A	300^0	97.503A		Operated

Current injected at HV side and LV side 2 times of full load current and LV side current is reduced.

PHASE	Injected Current (HV SIDE)		Injected Current (LV SIDE)		Differential Current(A)	Bias Current(A)	Tripping
	Current (A)	Phase (deg)	Current (A)	Phase (deg)			
R-PH	2.76A	0^0	2A	180^0	137.5A		Operated
Y-PH	2.76A	240^0	2A	60^0	137.5A	438.12	Operated
B-PH	2.76A	120^0	2A	300^0	137.5A		Operated

Table 3.4.3.1 Slope-1 Test Results

3.4.3.2 CALCULATION:

$$slope = \frac{IDL1 - IDL2}{IB1 - IB2} * 100$$

$$slope = \frac{137.5 - 97.503}{438.12 - 347.88} * 100$$

$$slope = 43.09\%$$

3.4.3.3 SLOPE TEST(HV&LV) RESULTS FOR SLOPE-2

Current injected as below**:**

PHASE	Injected Current (HV SIDE)		Injected Current (LV SIDE)		Differential Current(A)	Bias Current(A)	Tripping
	Current (A)	Phase (deg)	Current (A)	Phase (deg)			
R-PH	4.77A	0^0	3A	180^0	1230A		Operated
Y-PH	4.75A	240^0	3A	60^0	1230A	1882	Operated
B-PH	4.74A	120^0	3A	300^0	1230A		Operated

Current injected at HV side and LV side 2 times of full load current and LV side current is reduced.

PHASE	Injected Current (HV SIDE)		Injected Current (LV SIDE)		Differential Current(A)	Bias Current(A)	Tripping
	Current (A)	Phase (deg)	Current (A)	Phase (deg)			
R-PH	7.71A	0^0	4.7A	180^0	1425A		Operated
Y-PH	7.70A	240^0	4.7A	60^0	1425A	2127A	Operated
B-PH	7.71A	120^0	4.7A	300^0	1425A		Operated

Table 3.4.3.3 Slope-2 Test Results

3.4.3.4 CALCULATION:

$$slope = \frac{IDL1 - IDL2}{IB1 - IB2} * 100$$

$$slope = \frac{1425 - 1230}{2127 - 1882} * 100$$

$$slope = 79.59\%$$

IV. APPLICATIONS

The protection and control IEDs have many functions included. They included self supervision with internal event list function block provides good supervision of the IED. The fault signals make it easier to analyze and locate a fault.

Both hardware and software supervision is included and it is also possible to indicate possible faults through a hardware contact on the power supply module and/ or through the software communication. Internal events are generated by the built-in supervisory functions. The supervisory functions supervise the status of the various modules in the IED and, in case of failure, a corresponding event is generated. Similarly, when the failure is corrected, a corresponding event is generated.

V. CONCLUSION

The Protection Scheme with a particular rating of the transformer has been designed. For that rating of the transformer the CT ratio on primary and secondary sides are calculated and by using that ratio HV and LV tripping values are calculated. Now by using PCM600 Connectivity Package the configuration is done.

In PCM600 there are different functional blocks by using those functional blocks the configuration for different faults is done according to the scheme .The harmonic effect and stable operation regions are also taken into consideration. once the configuration is done it is tested using doble or omicron and parameter setting are done. The test involves pickup test, slope test, stability test etc..the protection for different faults have been done. Hence by doing this, the protection system has become more reliable and efficient. The transformer is protected against different faults by Intelligent electronic device.

References

[1] Å. Carlson, "*Power Transformer Design Fundamentals*", ABB Transformers, Ludvika 2000-08-25.

[2] A. R. van C. Warrington, *Protective Relays: Their Theory and Practice*, Volume One and Two, London: Chapman and Hall, 1962 & 1969.

[3] ABB Document 1MRK 504 086-UEN, "*Technical reference manual, Transformer Protection IED RET 670*", Product version: 1.1, ABB Power Technologies AB, Västerås, Sweden, Issued: March 2007

[4] J.A.B. Elston, *Methods and Apparatus for Differential Current Measurement in a three-phase power system*, U.S. Patent 6,507,184; 2003-01-14.

Journal Papers:

[1] A.G. Phadke, J.S. Thorp "*A New Computer-Based Flux-Restrained Current-Differential Relay for Power Transformer Protection*", IEEE Transactions on Power Apparatus and Systems Volume PAS-102, *Issue 11, pp. 3624-3629, Nov. 1983.*

[2] K. Tian, P. Liu "*Improved Operation of Differential Protection of Power Transformers for Internal Faults Based on Negative Sequence Power*", IEEE Proceedings of *EMPD'98 Conference, Vol. 2, pp. 422-425, March 1998.*

Books:

[1] ABB Book, "*Transformer Handbook*"1LAC 000 010 ABB Power Technologies Management Ltd. Transformers Switzerland.

[2] Transformer Book, Tampere University of Technology, (http://www.e-leeh.org/transformer/)