Condition Monitoring Techniques and Simulation of Transformer Differential Protection Scheme using Matlab

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Abstract— Differential Protection is expected to play a key role in the protection system of power transformer. Two of the most typical weaknesses of the power transformer differential protection are long delays or even a failure to operate in case of heavy internal faults with current transformer saturation, and unwanted operations for external faults. These disadvantages can be avoided if the position of the fault is quickly and correctly determined. The differential protection relay is used for power transformer differential protection and is capable of protection transformers of any vector group. This paper deals with steps of modeling the differential relay with the Matlab Simulink model and the application of the modeled relay in testing a protection system. In this case, simulating the differential current transformer that includes vector group compensation. Simulation done with main part are , setting of the relay, zero sequence elimination of the ground connected transformer current transformer, vector compensation of the secondary winding current transformer output and final decision to trip the breakers in an event of a fault.

Key words: Condition Monitoring, Differential Protection, Power Transformers

I. INTRODUCTION

There is an increasing need for power utilities to use assets to their fullest while maintaining system reliability. Transformers, which have exceeded their design life or are approaching the end of their operating life, require all the more attention as compared to new transformers. Due to increasing failure of large power transformers, the maintenance engineers are seriously reviewing their O&M procedure in order to prevent forced outages, incur less maintenance cost, and to have longer life of equipment. To assess the extent of deterioration within the transformer, it is necessary to employ the appropriate diagnostic tool.

Tan delta and insulation resistance measurement of winding/bushing, monitoring of oil/winding temperature, checking BDV of oil and fault gas analysis are formed the part of condition monitoring strategy. Fast clearance of faults in the transformer is important for stability of the system and therefore adequate protections should be provided. Requirement of trhough fault withstand is also important and should be considered. The relay model provides a valuable insight into the internal behavior of a relay in a wide range of field events and applications.

A. Basic Aspects of Protection System:

Transformers are a critical and expensive component of the power system. Due to the long lead time for repair of and replacement of transformers, a major goal of transformer protection is limiting the damage to a faulted transformer. Some protection functions, such as over excitation protection and temperature based protection may aid this goal by identifying operating conditions that may cause transformer failure. The comprehensive transformer protection provided by multiple function protective relays is appropriate for critical transformers of all applications.

B. Transformer Protection Overview

The type of protection for the transformers varies depending on the application and the importance of the transformer. Transformers are protected primarily against faults and overloads. The type of protection used should minimize the time of disconnection for faults within the transformer and to reduce the risk of catastrophic failure to simplify eventual repair. Any extended operation of the transformer under abnormal condition such as faults or overloads compromises the life of the transformer, which means adequate protection should be provided for quicker isolation of the transformer under such conditions.

C. Transformer Failures

Failures in transformers can be classified into:

- Winding failures due to short circuits
- Core faults
- Terminal failures
- On-load tap changer failures
- Abnormal operating conditions
- External faults.

II. TRANSFORMER FAULTS AND DETECTION

A. Methods of Detection of Transformer Faults

Within the transformer, there are many types of way to detect the internal faults are by evaluating the quantities of hydrocarbon gases, hydrogen and oxides of carbon present in the transformer. Different gases can serve as markers for different types of faults. For Instance.

- Large quantities of hydrogen and acetylene can indicate heavy current arcing.
- The presence of hydrogen & lower order hydrocarbons can be a sign of partial discharge.
- Significant amounts of methane and ethane may mean localized heating or hot spots.
- CO and CO2 may evolve if the paper insulation overheats; which can be a result of prolonged overloading or impaired heat transfer.

III. CONDITION MONITORING AND DISSOLVED GAS ANALYSIS OF POWER TRANSFORMER

A. Condition Monitoring of Transformers:

Power transformer is one of the costliest and vital equipment therefore the loss of a transformer can have an enormous impact on continuity, reliability of supply and results into considerable loss of revenue. Now a days emphasis is given to need based remedial action that should be carried out based on periodical condition monitoring of various components of equipment. It enables utilities to take appropriate, timely action and avoid premature failure.

B. Benefits of Condition Monitoring:

- Timely filled measurements
- Confirmation, on the spot, of the presence of the fault gases in the event of alarms.
- On time proactive decision making reducing unplanned outages
- More predictable and reliable maintenance schedules
- Prevention of catastrophic failure and destruction of peripheral equipment
- Reduced maintenance costs
- The case study results provide a quality control feature, limiting the probability of destructive failures

This leads to improvements in operator safety and quality of supply, limiting the severity of any damage incurred elimination of consequential repair activities and identifying the root causes of failures.

C. Dissolved Gas Analysis (DGA):

The DGA analysis is performed in three steps

- Extraction of all the gases in the oil sample.
- Measurement of the quantity of each gas in the extracted gas.
- Calculation of the concentration of each gas in the oil sample.

DGA is powerful diagnostic and it has capability to detect faults in the incipient stage before they develop into major faults and cause serious damage to transformer. The conventional Bucholz Relay is universally used in transformer, to protect againts severe damages. However, the limitations of this is that enough gas must be generated first to saturate the oil fully & then to come out and collect the relay. The DGA technique detect gas in parts per million (ppm) dissolved oil by the use of gas extraction unit and a gas chromatograph. It checks whether a transformer under service is being subjected to a normal aging and healthy or whether there are incipient defects such as hot spots, arcing, overheating or patial discharge.

If any one of the gases exceeds a given level as shown in table below the transformer is classified accordingly.

Gas	Condition 1	Condition 2	Condition 3	Condition 4
H_2	<101	100-700	701-1800	>1800
CH_4	<120	121-400	401-1000	>1000
C_2H_2	<35	36-50	51-80	>80
C_2H_4	<50	51-100	101-200	>200
C_2H_6	<65	66-100	101-150	>150
CO	<350	351-570	571-1400	>1400
CO_2	<2500	2500-4000	4001-10000	>10000

Table 1: Individual Gas Limits

D. Gas Content in Oil Due to Fault:

Sr. No.	Type of fault	Decomposable Gases In Transformer Oil
01	Arcing in oil	CH_4 , C_2H_4
02	Over heating of solid insulating Materials	CO , CO_2
03	Over heating of oil and paper Combination	CH_4, C_2H_2, CO, CO_2 and H_2
04	Arcing of oil and paper Combination	H_2, C_2H_2, CO, CO_2

Table 2: Gas content in oil due to fault

E. Continuous Monitoring of Key Fault Gases

Key Gas method becomes applicable to transformer with developed faults where absolute values of key gases are considered. The key gases are acetylene, hydrogen, ethylene and carbon monoxide. Following table illustrates the nature of faults, when key gas is abnormally high.

KEY GAS	NATURE OF FAULT
Acetylene C_2H_2	Electrical arc in oil
Hydrogen H_2	Corona , partial discharge
Ethylene C_2H_4	Thermal degradation of oil
Carbon Monoxide	Thermal ageing of oil

Table 3: Key gases

F. Various types of Faults Depending on Gas Composition

GAS CONTENTS		NATURE OF FAULT
MAJOR	MINOR	
Ethylene	Ethane	Thermal Decomposition
Methane	Hydrogen	(Hot Spots)
Hydrogen Methane	Acetylene Ethylene Ethane	Electrical Discharge (Except Corona)
Hydrogen	Methane Ethane	Internal Corona
Carbon Monoxide Carbon Dioxide	-	Cellulosic insulation decomposition

Table 4: types of fault depending on gas

IV. MODELING OF DIFFERENTIAL PROTECTION RELAY

A. Need of Modeling of Differential Protection Relay:

Vector group D11 will be shown and the fault currents discussed. Graphs showing the phase voltages and currents will be inspected. In this work is to simulate a differential delay, which ensures security for external fault, inrush, and over excitation conditions and provides dependability for internal faults, to protect a single phase power transformer. This work combines harmonic restraint and blocking methods with a wave shape recognition technique. The differential relay is modeled in MATLAB. Two approaches are used to simulate the power transformer zone fault and out of zone fault modeling to evaluate the differential relay performance for different operation conditions. The first approach has modeled the power transformer differential relay protection in MATLAB functions to simulate the different fault at zone and out of zone fault at different vector group, the sampler model which is simulated in the environment of SIMULINK.

B. Basic Concept of Differential Protection Relay:

Differential protection relies on the Kirchoff principle that states that the sum of currents entering a node equals the sum of currents leaving a node. Applied to differential protection, it means that the sum of currents entering a bus equals the sum of those leaving. If the sum of these currents is not zero, then it must be due to short circuit caused either by an earth fault or phase-to-phase fault.

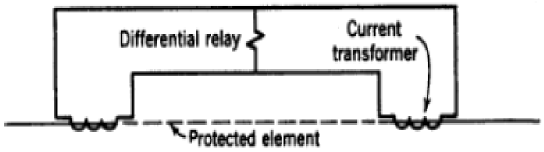


Fig. 4.1: A simple differential relay application

Figure 4.1 illustrates the implementation of a simple differential protection application. The dashed portion of the line indicates the protected Zone. CTs are installed at either end of the segment and secondary windings of the CTs are interconnected with a differential relay in parallel.

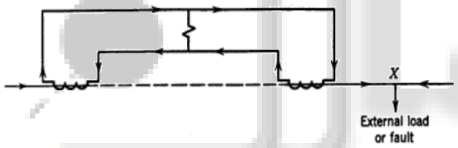


Fig. 4.2: Condition of external fault

If there is current flow through the line to a load or external fault at X the differential protection should not trip. Provided that the 2 CTs are of the same ratio and properly connected, the secondary currents of the CTs should only circulate as shown by arrows in fig 4.2 Hence, no current should flow through differential relay.

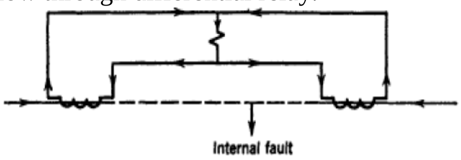


Fig. 4.3: Condition of internal fault

Figure 4.3 illustrates the occurrence of an internal fault. In this case, the sum of currents entering the protected segment does not equal the currents leaving. This results in current flowing through the differential relay, which then initiates a trip.

V. SIMULATION USING MATLAB & SIMULINK

A. Simulation of Differential Relay:

MATLAB and Simulink presently do not have a toolbox which helps us in simulating power system protection equipment. Therefore, MATLAB scripts must be written in order to model the relays. In our case we are simulating the differential current transformer that includes vector group compensation. There are four main parts in simulating the differential relay. They include

- The setting of the relay by the user
- The zero sequence elimination of the ground connected transformer current transformer
- The vector compensation of the secondary winding current transformer output
- The decision to trip the breakers in an event of a fault.

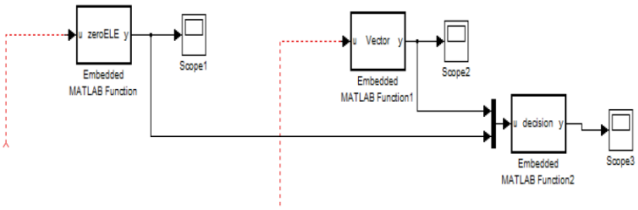


Fig 5.1: Relay block diagram

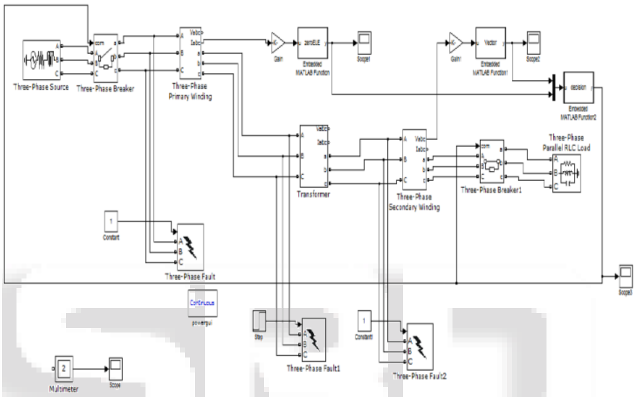


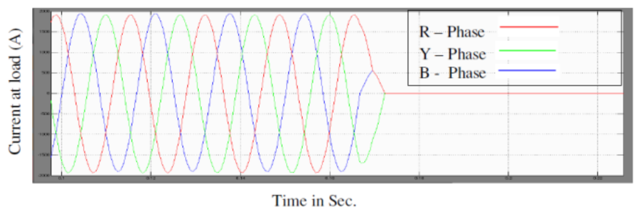
Fig 5.2: Matlab Simulink model

Fig 5.1 shows Relay block diagram and 5.2 shows matlab Simulink model. The block output will be an input to the breakers connected to the transformer. An output of 1 from this block will tell the breaker to keep closed and an output of 0 will tell the breaker to open. Therefore this block will need to use the previous condition or state to make the present decision. If the past output is 1 then the block will see if there is a fault. If not then the block will have to output a 0. This condition is called lock out. This is important because the output of this block will be used to operate the relay where the breaker will close if the input is 1 and open if the input is 0. If lock out does not exist, then the relay will not detect a fault when the relay is open and close the breaker again. Without lock out a condition where the relay will open and close rapidly the instant we have a fault will exist.

VI. SIMULATION RESULTS

A. Example Fault Trappings for D11 Vector Group:

1) Single Phase to Ground Fault:



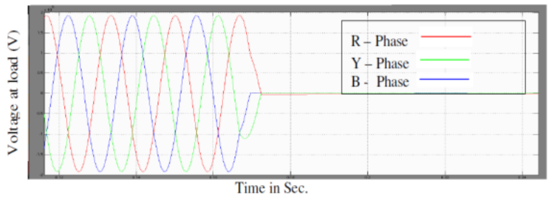


Fig. 6.1: single phase to ground fault

2) *Double Phase to Ground Fault:*

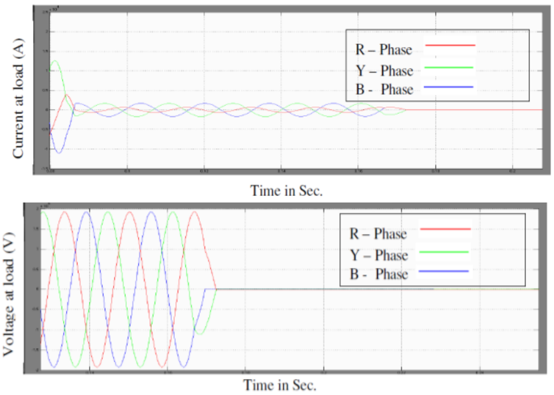


Fig 6.2- Double phase to ground fault

3) *Double Phase to Phase Fault:*

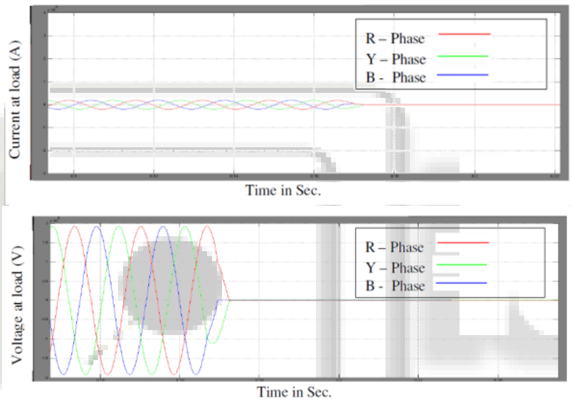


Fig 6.3: Double phase to phase fault

4) *Triple Phase- to- phase Fault:*

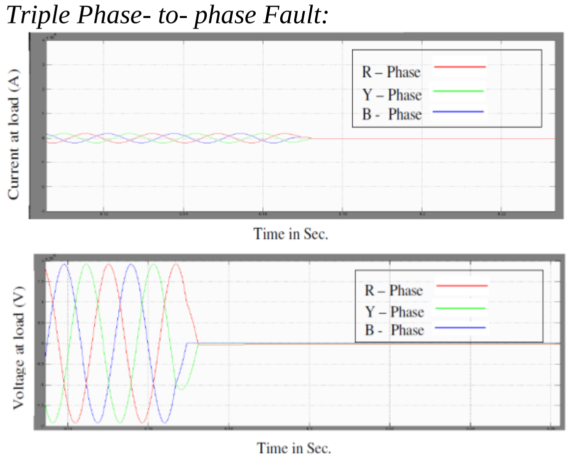
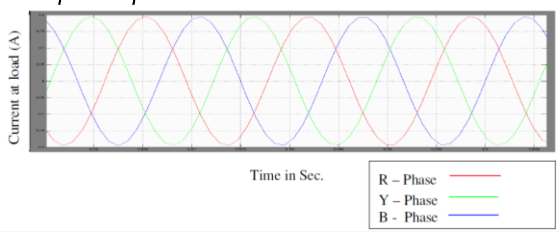


Fig 6.4: Triple phase to phase fault

5) *Out of Zone fault:*



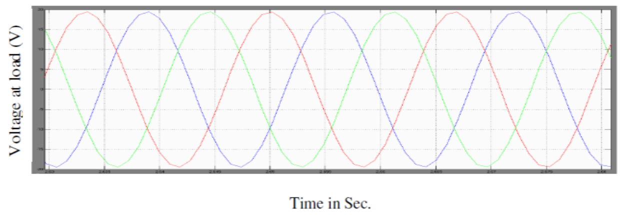


Fig. 6.5: Out of Zone fault

VII. CONCLUSION

The power transformers have a large thermal heat sink and can withstand overloads for certain limited time. Selective protection and monitoring and load management is necessary. The tripping of the transformer should be the last action. Fast clearance of faults in the transformer is important for stability of the system and therefore adequate protections should be provided. Requirement of through fault withstand is also important and should be considered. The relay model provides a valuable insight into the internal behavior of a relay in a wide range of field events and application. When we create different fault as describe in above result in Matlab Simulink model with Three-phase fault for DY11 vector group, the differential relay will operate with its set current and give command to C.B. to open for internal fault condition for transformer we can see the result by waveform of load current and voltage which is discontinuous when it clear fault at set current, and relay will not operate for external fault condition and give continuous phase current and voltage as shown by the wave form of out of zone fault condition.

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