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ImprovedProtectionon162MVA, 330/132kV Power Transformer in Afam IV Transmission Station

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ABSTRACT:

This work is based on improved protection on 162 MVA, 330 kV/132 kV power transformer in Afam IV transmission station. This is achieved by using Differential Protectionin determining the overcurrent, Restricted Earth Fault (REF).Electrical Transient Analyzer Program (ETAP) is used for the simulation. The result shows that the three (3) phase fault outside the differential relay protection zone on the primary side of the 162MVA power transformer did not penetrate inside the primary side of the transformer and so, the relay did not operate. The three (3) phase fault within the differential relay protection zone on the primary side of the 162MVA power transformer shows that the fault penetrates inside the primary side of the transformer and so, the relay operates.The three (3) phase fault within the differential relay protection zone on the secondary side of the 162MVA power transformer shows that the fault penetrates inside the secondary side of the transformer and thus, the relay operates. The three (3) phase fault outside the differential relay protection zone on the secondary side of the 162MVA power transformer indicates that the fault did not penetrate inside the secondary side of the transformer therefore, the relay did not operate. Differential relay has the inherent ability to differentiate between through-fault and internal fault current, the protection operational time (0.03s) and the coordination inside the differential relay protection zone. The simulated network of Afam IV transmission station network worked optimally without fault when the differential relay protection of the 162MVA power transformer is established through the application of the differential current as the difference between the primary side current and the secondary side current of the 162MVA power transformer.

Key Words: Improved, protection, 162MVA, 330/132kV, transformer, Afam IV, transmission station.

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I. INTRODUCTION

Power transformers are one of the most important equipment in power systems that are subjected to faultssimilar to any other component of the power system, thus transformer protection is of critical importance since they are indispensable element of power system. According to [1], power transformer which is also called backbone of the power transmission systems, high reliability of the transformer is therefore essential to avoid disturbances in transmission of power. Transformer has an important role to play in the power system where it may be used to level up the voltage for transmission, distributing the energy to consumers, it has to live long and operate stably [2].The transformers in high voltage networks are always protected by one main protection device and at least one back-up protection device[3]. The major concern in power transformer protection is to avoid mal-operation of protective relays due to transient phenomena including magnetic inrush current, simultaneous inrush with internal fault and external faults with current transformer (CT) saturation.

The main problem in the degradation of life of transformer is the degradation of insulation in the transformer, it happens in the transformer because of several factors, some of them are included in electrical stresses and thermal stresses. These are voltage level, harmonics, use of power electronic devices, evolution of gasses, heating, water content etc. The insulation used for the transformer may be inorganic and organic, dry or oil insulation, or solids insulation which include concrete blocks, spacers etc. Life of the transformer depends upon the condition of insulating material [4]. About 10% of the faults take place inside the transformers and 70% of these faults are caused by short circuits in the windings [5]. According to [6],when a fault occurs in a transformer, the damage is proportional to the fault time. The transformer should therefore be disconnected from the network as soon as possible. In the view of [7], the impact of a transformer fault is often more serious than a transmission line outage. [8] say that to prevent faults and to minimize the damage in case of a fault, transformers are equipped with both protective relays and monitors. According to [9], the choice of protective equipment varies depending on the criticality of the load, relative size of the transformer compared to the total system load and potential safety concerns.

Percentage differential protection is the most widely used scheme for the protection of transformers rated 10 MVA and above [10]. However, in the perspective of[11], percentage differential relay converts the primary current and secondary currents in a common base and comparing them can mal-operate due to various phenomena related to the non-linearities in the transformer core. The main challenge in differential protection is to discriminate between an internal fault and other operating conditions such as magnetizing inrush current, over excitation [12].

According to [13], Main Intelligent Electronic Device (IED) uses all the protection functions, and the back-up IED has at least an (overcurrent) OC low stage with Inverse Definite Minimum Time (IDMT) curves, an OC high stage and an Earth Fault (EF) protection. In the view of [11], harmonic restraint is one of the simplest and most widely used approaches that has limitations with new low-loss amorphous core materials in modern transformers, these materials produce low harmonic content during magnetizing inrush current. Also, internal faults might contain sufficient amount of second and fifth harmonics like inrush current. So, it is hard to distinguish between internal fault and energization. According to [12] and [10], other approaches have been developed to overcome the above limitations, these approaches include voltage and flux restraints. The inductance-based methods have high dependence on transformer parameters [14]. Digital signal processing technique avoids mal-operation of transformer differential protection[15]. Among these approaches are pattern recognition based on neural networks and fuzzy logic, their main drawbacks include the need for more training, complex computation, large memory and complex setup of experimental work[16].

1.1 Statement of the Problem

The problems relating to 162MVA, 330/132KV power transformer in Afam IV Transmission Station are as follows :

i. Primary winding Phase-Phase fault
ii. Primary winding Phase-Earth fault
iii. Secondary winding Phase-Phase fault
iv. Secondary winding Phase-Earth fault
v. Delayed operation of differential protection

1.2 Objectives of the Study

The objectives of this work are :

i. To collect of fault data of162MVA, 330/132KV Power Transformer in Afam IV Transmission Station
ii. Tomodel the switchgear of the circuit
iii. To apply Differential Protection in determining the overcurrent and Restricted Earth Fault (REF)
iv. To Validate the numerical differential protection relay over electromechanical differential protection relay.
v. To use Electrical Transient analyzer program (ETAP) for the simulation.

II. LITERATURE REVIEW

The electrical equipment and circuits in a substation must be protected in order to limit the damages due to abnormal currents and over voltages. All equipment installed in a power electrical system have standardized ratings for short-time withstand current and short duration power frequency voltage. The role of the protection is to ensure that these withstand limits can never be exceeded, therefore clearing the faults as fast as possible. When a fault occurs in a transformer, the damage is proportional to the dissipated fault energy which relates to the fault time. The transformer should therefore be disconnected from the network as soon as possible. Fast reliable protective relays are therefore used for detection of faults. Monitors can also detect faults and sense abnormal conditions which may develop into a fault. The size of the transformer and the voltage level has an influence on the extent and choice of protective equipment. Monitors prevent faults and protective relays limit the damage in case of a fault [3].

[17] says thatelectricalprotectionoftheTransformercomprisesofthefollowing:

i. TransformerOverCurrentProtection
ii. DifferentialCurrentProtection
iii. FusedProtection
iv. OverExcitationProtection
v. OverVoltageProtection

2.1 Transformer over Current Protection

Overcurrentprotectioniscommonlyusedforprotectionfromphaseandgroundfaults. It isusedasprimaryprotectionwheredifferentialprotectionisnotused, theprotectionzoneofovercurrentdevicesisnormallymorethanthetransformer[18].Hence,theyarepartofthesystemprotectionandneedtobecoordinatedwiththeothersystemprotectiondevices. Fuses may adequately protect small transformers, but larger ones require overcurrent protection using a relay and circuit breaker, as fuses do not have the required fault breaking capacity [19].

According to [20],typicallyfusesareusedasprimaryprotectionfortransformersbelow10MVA.Above10MVAovercurrentrelaysareusedasbackupalongwithdifferentialrelaysasprimaryprotectionfortransformers.Instantaneousovercurrentrelaysarealsousedforbackupwheredifferentialrelayshavebeenused.Typically,theyaresetto150%to200%ofthemaximumof Magnetizingcurrentinrush(Ifharmonicrestraintisnotused), Shorttimeload (ColdPickup) and Maximum3phaseshortcircuitcurrent [21].

2.2 TransformerthroughFaultWithstandStandards

Thephilosophyoftransformerovercurrentprotectionistolimitthefaultcurrentbelowthetransformerthroughfaultwithstandcapability.Thefaultwithstandcapabilityinturnisbasedonthe possibilityofmechanicalofthewindingsduetothefaultcurrent,ratherthanonthermalcharacteristicsofthetransformer[22].[23] says that the proceduretodecideonovercurrentprotectionrating,asperthetransformerfaultwithstandratingsare asfollows:

i. Determinethetransformercategoryfromtheabovetable
ii. IfincategoryIIorIIIdetermineifitwillbesubjecttofaultsfrequentlyorinfrequently.Usefigure3–Guidetofaultfrequency
iii. Baseduponthe abovedeterminethecurveapplicable
iv. Replotthecurvedeterminedinstep3specificallyforthetransformerunderconsiderationusingthesecondaryortheprimaryamperesastheabscissa,secondaryamperesarepreferredforcoordinationwithdownstreamprotectivedevices.
v. Selecttheproperfusesorrelays:tap,timedialsettingetc.suchthatcoordinationismaintainedandwithinthetransformerwithstandcurvedeterminedabove.

2.3 Transformer Differential Current Protection

The transformer is one of the major equipment in power system. It is a static device, totally enclosed and usually oil immersed, and therefore the fault occurs on them are usually rare. But the effect of even a rare fault may be very serious for a power transformer [19]. Hence the protection of power transformer against possible fault is very important.

The fault that occurs on the transformer is mainly divided into two type external faults and internal fault, the external fault is cleared by the relay system outside the transformer within the shortest possible time in order to avoid any danger to the transformer due to these faults, while the protection for internal fault in such type of transformer is to be provided by using differential protection system [24]. Differential protection schemes are mainly used for protection against phase-to-phase fault and phase to earth faults[25]. In the perspective of [26], the differential protection used for power transformers is based on Merz-Prize circulating current principle, such types of protection are generally used for transformers of rating exceeding 2MVA.

2.4. Working of Differential Protection System

Normally, the operating coil carries no current as the current are balanced on both the side of the power transformers, when the internal fault occurs in the power transformer windings the balanced is disturbed and the operating coils of the differential relay carry current corresponding to the difference of the current among the two sides of the transformers[27]. Thus, the relay trip the main circuit breakers on both sides of the power transformers.

2.5 Power Transformer Protection Methods and Relay Schemes

The considerations for a transformer protection vary with the application and importance of the power transformer. It is normal for a modern relay to provide all of the required protection functions in a single package, in contrast to electromechanical types that would require several relays complete with interconnections and higher overall CT burdens [28]. Table 2.1 shows the different Transformer fault types and its protection methods.

Table 2.1:Transformer Fault Types and its Protection Methods

S/No.	Fault Type	Protection used
1	Primary winding Phase-Phase fault	Differential; Overcurrent
2	Primary winding Phase-Earth fault	Differential; Overcurrent
3	Secondary winding Phase-Phase fault	Differential
4	Secondary winding Phase-Earth fault	Differential; Restricted Earth Fault (REF)
5	Interturn Fault	Differential; Buchholz
6	Core Fault	Differential; Buchholz
7	Oil tank Fault	Differential; Buchholz; Tank Earth
8	Over fluxing	Over fluxing
9	Overheating	Thermal

Source:[2]

III. MATERIALS AND METHOD

3.1 Materials

The major data source for this research are gotten from Transmission company of Nigeria, (TCN), Afam Transmission Station. In the course of the investigation, the single line diagram, the power transformers, Busbars, disconnectors, breakers and the 162MVA transformer fault data are gotten from Afam IV Transmission Station.

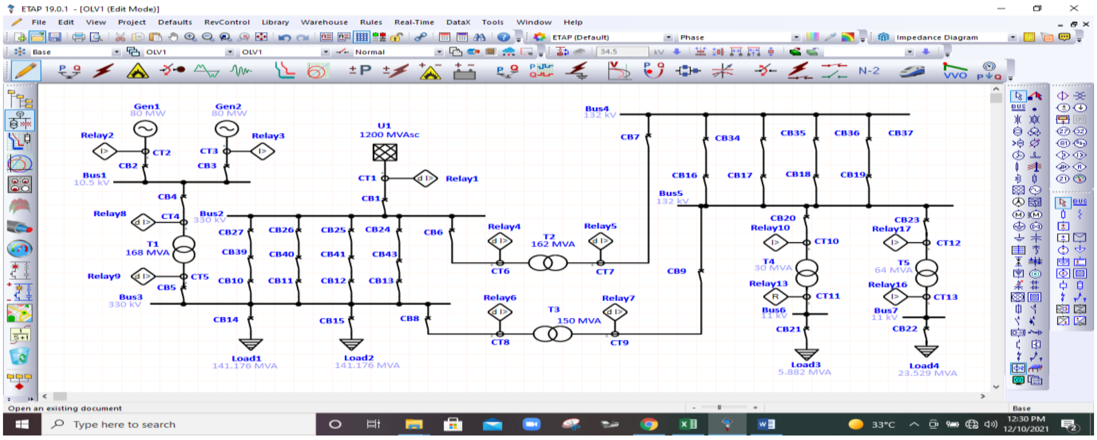

Figure 3.1: Single line diagram of Afam Transmission Station showing 162MVA 330/132kV Power Transformer.

3.2 Method of Analysis

This is achieved by using Differential Protection in determining the overcurrent and Restricted Earth Fault (REF); and power triangle is employed for the analysis. Electrical Transient Analyzer Program (ETAP) is used for the simulation.

3.2.1 Determination of the Afam IV Transformers Input/Output Power (MVA) on each Transformer on the Network.

Transformer loading MVA = $\sqrt{3}IV_L$ (3.1)

Power (P) in MVA = $\sqrt{3}IV_L$

Hence, $I = \frac{P(MVA)}{\sqrt{3}V_L}$ (3.2)

$I = \frac{P(MVA)}{\sqrt{3}V_L} \times SafetyFactor$ (3.3)

Equation (3.2) is used in determining the primary and secondary Current of the 168 MVA, 162 MVA and 150 MVA transformers.

The values of the transformers current in (3.2) is inputted into (3.1) to determine the transformer-loading (MVA) of both the primary and the secondary side of each transformer on the network.

3.2.2 Determination of the Afam IV Transformers Input/Output Active Power (MW) Determination on each Transformer on the Network

Inputting the transformer-loading values in (3.1) into (3.4) to determine the active power on each transformer on the network.

Active power in watts or kW = $\sqrt{3}IVcos\theta$ (3.4)

3.2.3 Determination of the Afam IV Transformers Input/Output Reactive Power (VAR or MVAR) on each Transformer on the Network.

The transformer-loading value in (3.1) is inputted into (3.5) to determine the value of reactive power on each transformer on the network.

Reactive power in VAR or MVAR = $\sqrt{3}VIsin$ (3.5)

3.2.4 The Determination of the Afam IV Transformers Input/OutputApparent power in VA or MVA on each Transformer on the Network

Inputting the values of the transformers active power (MW) and thetransformers reactive power (VAR or MVAR) in (3.4) and (3.5) into (3.6), to determine the value of apparent power on each transformer in the network, we have

Apparent power in VA or MVA = $\sqrt{MW^2 + MVAR^2}$ (3.6)

3.2.5 The Determination of the Afam IV Transformers Input/Output Complex Power (S) on each Transformer on the Network

Inputting the active and reactive power values in (3.4) and (3.5) into (3.7) to determine the value of complex power on each transformer on the network, we have

Complex power, S = P + JQ (3.7)

3.2.6 The Determination of the Afam IV Transformers Input/OutputPower Factor on each Transformer on the Network

Dividing the values of the active power in (3.4) by the values of the apparent power in (3.6) into (3.8) in determining for the value of Power factor ($cos\theta$), we have

Power factor, $cos\theta = \frac{Activepower}{Apparentpower} = \frac{MW}{MVA}$ (3.8)

3.2.7 Determination of the Afam IV Phase Voltage

Equation (3.9) shows the phase voltage on transformer winding connected in star, as follows

$Phasevoltage = \frac{linevoltage}{\sqrt{3}}$ (3.9)

3.2.8 Determination of BusBar Current on the Afam IV Network

Busbar are normally made of copper or aluminum, the busbar continuous current carrying capacity is the maximum current that the bus bar can carry before exceeding the maximum defined temperature normally 70^{o}C. Equation (3.2) is used in determining the Busbar current on each Bus on the Afam IV network.

3.2.9 Determination of Conductor Size on the Network

Conductor sizing choosing should be considered based on the conductor type such as underground and overhead conductor, an important factor for choosing the transformer conductor is the load on the primary and secondary side of the transformer. The rating of the conductor should be 150% of the full load current.

Equation (3.10) is used in determining the conductor size on the network, the transformer current values in table 3.1 is divide by the multiplying factor of the conductor.

Conductor Size capacity$C_S = \frac{T_C}{C_{mf}}$ (3.10)

Where, C_S represent the conductor size, T_C represent the transformer current capacity and C_{mf} represent multiplying factor

3.3 The Determination of the Circuit Breaker Size for the Primary and the Secondary Side of the Transformers

Equation (3.3) is used in the determining the circuit breaker size for the primary and the secondary side of the transformers, the transformers current values in (3.2) are multiplied by safety factor of the circuit breaker of (1.25).

3.4 The 162MVA Transformer Fault Data

Fault currents through bus are independent of fault distances and fault resistances.

Table 3.1: The 162MVA Transformer Fault Data

Name of Feeder	Total times of SLG Fault	Total times of LL Fault	Total times of DLG	Total times of 3-phase fault	Total times of Miscellaneous	Total Time of Fault	Monthly Total Time of Fault
June, 2021	9	3				13	**12**
July, 2020	7	6	1	1	1	15	**15**
August, 2020	8	3		1		8	**12**
September, 2020	6	5	2	2	1	10	**15**
October, 2020	7	5			2	8	**12**
November, 2020	8	4	1	2	1	10	**15**
Total	**45**	**26**	**4**	**6**	**5**	**64**	**81**

3.5. Transformer Differential Protection

Differential Protection is normally applied to Transformers 10MVA and above or depending upon its criticality. The following factors affect the differential current in transformers and should be considered while applying differential Protection. These factors can result in a differential current even under balanced power in and out conditions :

i. Magnetizing inrush current: The normal magnetizing current drawn is 2 – 5% of the rated current. However, during magnetizing inrush, the current can be as high as 8 – 30 times the rated current for typically 10 cycles, depending upon the transformer and system resistance.

ii. Over excitation: Transformers are typically designed to operate just below the flux saturation level, any further increase from the max permissible voltage level (or Voltage / Frequency ratio), could lead to saturation of the core, in turn leading to substantial increase in the excitation current drawn by the transformer.

iii. CT Saturation: External fault currents can lead to CT saturation; this can cause relay operating current to flow due to distortion of the saturated CT current. Alternatively, the harmonic current present in the saturated CT can cause a delay in the operation of the differential relay during internal faults. Proper selection of CT ratios is essential to minimize problems due to the saturation.

iv. The different in primary and secondary voltage levels, that is the primary and secondary CTs are of different types and ratios.

v. Phase displacement in Delta-Wye transformers.

vi. Transformer voltage control taps.

IV. RESULTS AND DISCUSSION

4.1 The Result of the Occurrence of Fault on the 162MVA Power Transformers

The fundamental protections of power transformers are differential current protection, this protection works on the principle of Kirchhoff law, by comparing the current that enters the transformer (current on the primary side of the transformer) and the current that comes out of the transformer (current on the secondary winding). Obviously, in normal operating conditions the primary and secondary current are different, therefore it is necessary to perform correction of a transformer's current ratio and the current phase rotation.

4.1.1 Fault on the Primary side of 162 MVA Power Transformer within its Differential zone of protection in Afam Transmission Station Network.

The result in Figure 4.1 indicates that the three (3) phase fault within the differential relay protection zone on the primary side of the 162MVA power transformerpenetrates inside the primary side of the 162MVA power transformer and causes current imbalance between the two CTs and current flows in the operating coil of the differential relay, since the differential relay has the inherent ability to differentiate between through-fault and internal fault current, the protection operational time (0.03 second) and the coordination inside the differential relay protection zone, the relay operates.

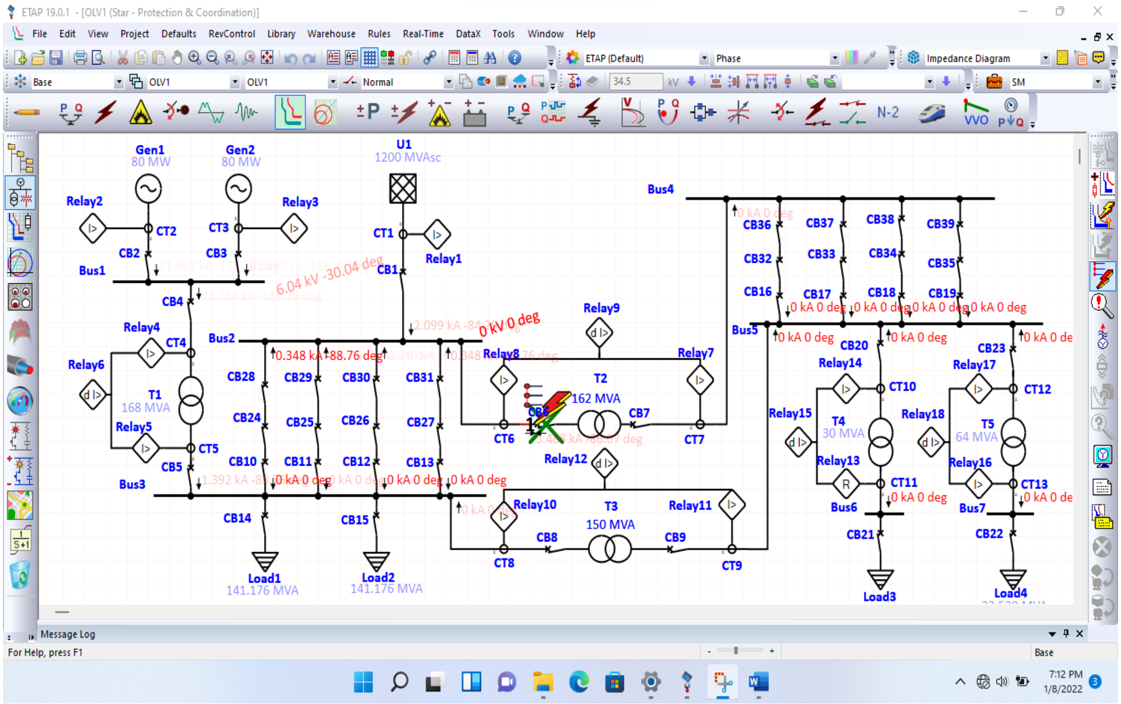

Figure 4.1: Fault on the Primary side of 162 MVA Power Transformer within its Differential zone of protection in Afam Transmission Station Network.

4.1.2 Fault on the Primary Side of 162MVA 330/132kV Power Transformer outside its differential zone of protection in Afam IV Transmission Station Network.

The result in Figure 4.2 shows that the three (3) phase fault outside the differential relay protection zone on the primary side of the 162MVA power transformer did not penetrate inside the primary side of the 162MVA power transformer, therefore there will be no current imbalance between the two CTs which by extension zero current flows in the operating coil of the differential protection relay and the relay did not operate.

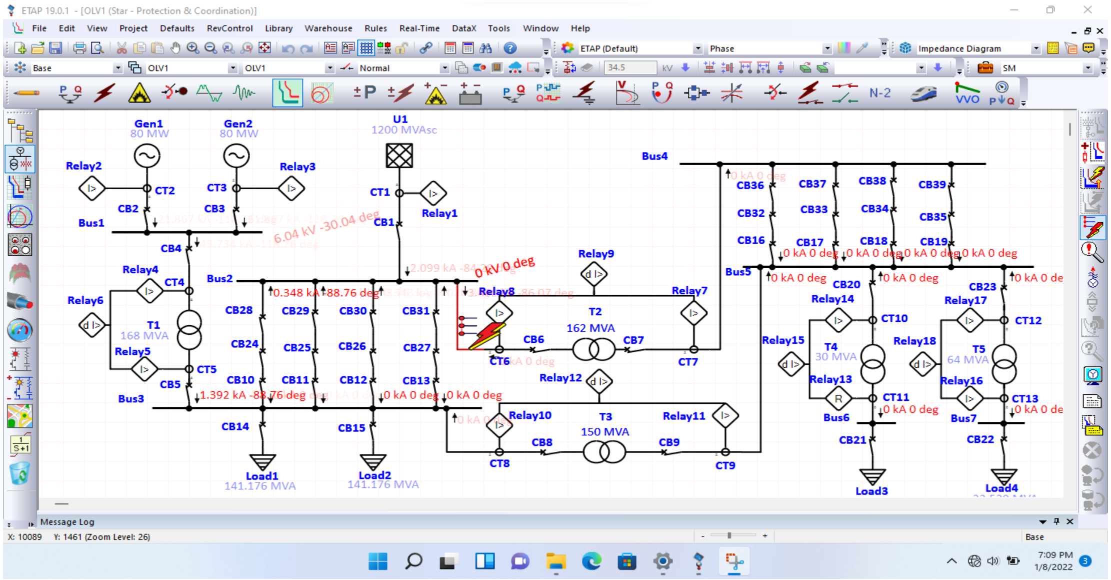

Figure 4.2 : Fault on the Primary Side of 162MVA 330/132kV Power Transformer outside its differential zone of protection in Afam Transmission Station Network.

4.1.3. Fault on the Secondary side of 162 MVA Power Transformer within its Differential zone of protection in Afam Transmission Station Network.

The result in Figure 4.3 indicates that the three (3) phase fault within the differential relay protection zone on the secondary side of the 162MVA power transformer penetrates inside the secondary side of the 162MVA power transformer and causes current imbalance between the two CTs and current flows in the operating coil of the differential relay, since the differential relay has the inherent ability to differentiate between through-fault and internal fault current, the protection operational time (0.03 second), and the coordination inside the differential relay. The difference between both primary and secondary sides current indicates an abnormal operation or internal fault, and therefore the relay operates.

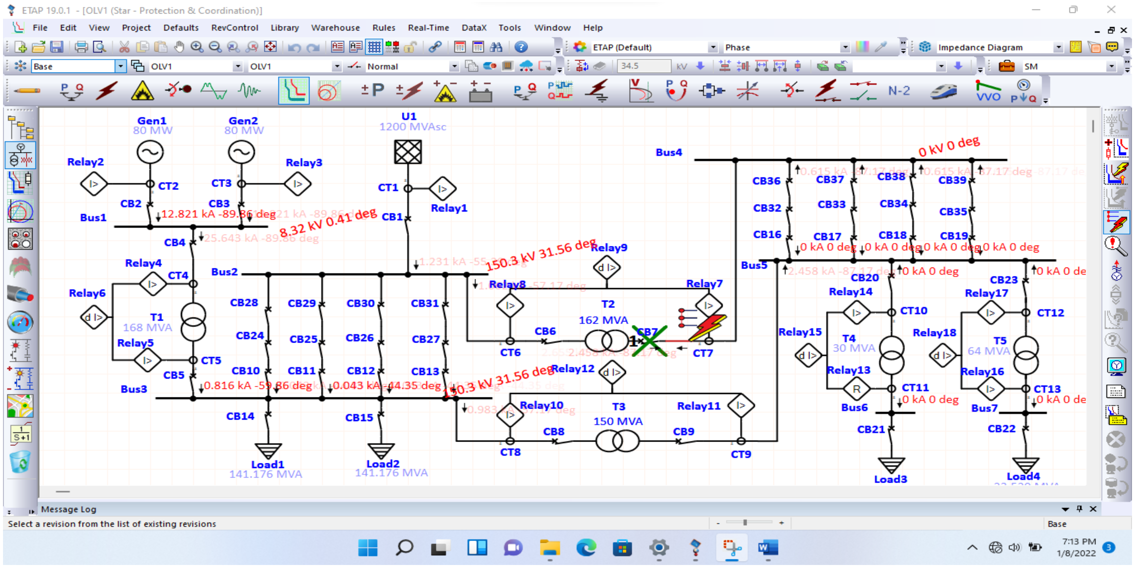

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Figure 4.3: Fault on the Secondary side of 162 MVA Power Transformer within its Differential zone of protection in Afam Transmission Station Network.

4.1.4. Fault on the Secondary Side of 162MVA 330/132kV Power Transformer outside its differential zone of protection in Afam Transmission Station Network.

The result in Figure 4.4 shows that the three (3) phase fault outside the differential relay protection zone on the secondary side of the 162MVA power transformer did not penetrate inside the secondary side of the 162MVA power transformer, no current imbalance between the two CTs and no current flowing into the operating coil of the differential relaythus, the relay did not operate.

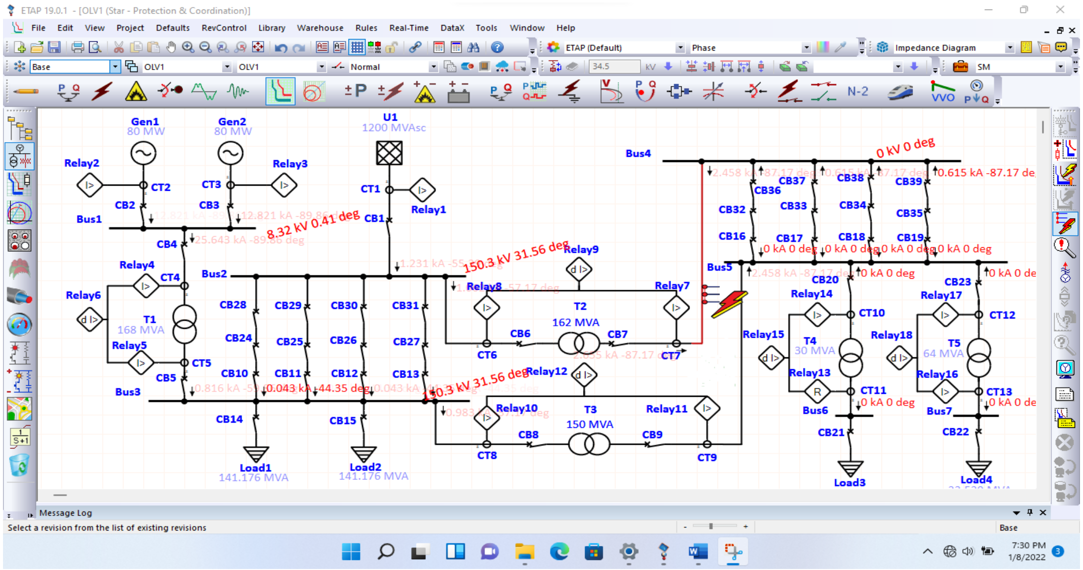

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Figure 4.4: Fault on the Secondary Side of 162MVA 330/132kV Power Transformer outside its differential zone of protection in Afam Transmission Station Network.

4.2. Differential operating characteristics of old electromechanical differential relay

From the graph in Figure 4.5 below, the old differential relay is not operating correctly, as faults in both the operate region (in zone) and the non-operate region (the out of zone) cannot be measured.

The relay tests are conducted using CMC 356 OMICRON software.

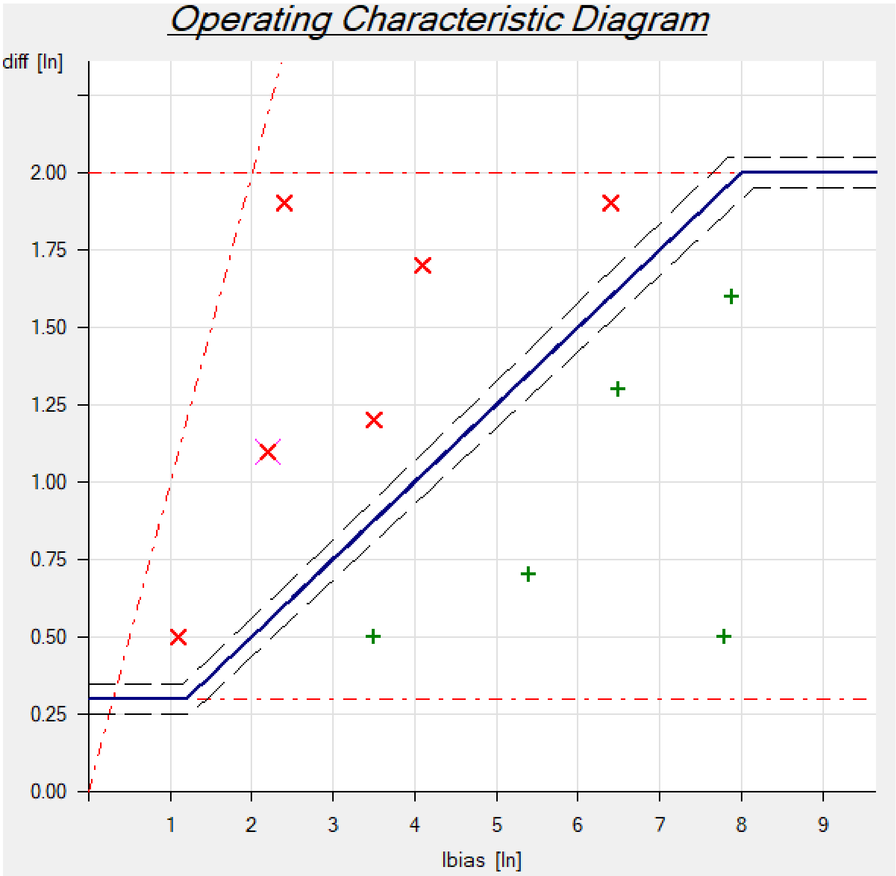

Figure 4.5: Differential operating characteristics of old electromechanical differential relay

4.3 : Differential operating characteristics of Numerical differential relay

From figure 4.6, the new differential relay is operating correctly, as faults in the operate region (in zone) are measured with time of 0.03s while the relay is not operating for faults in the non-operate region (the out of zone).

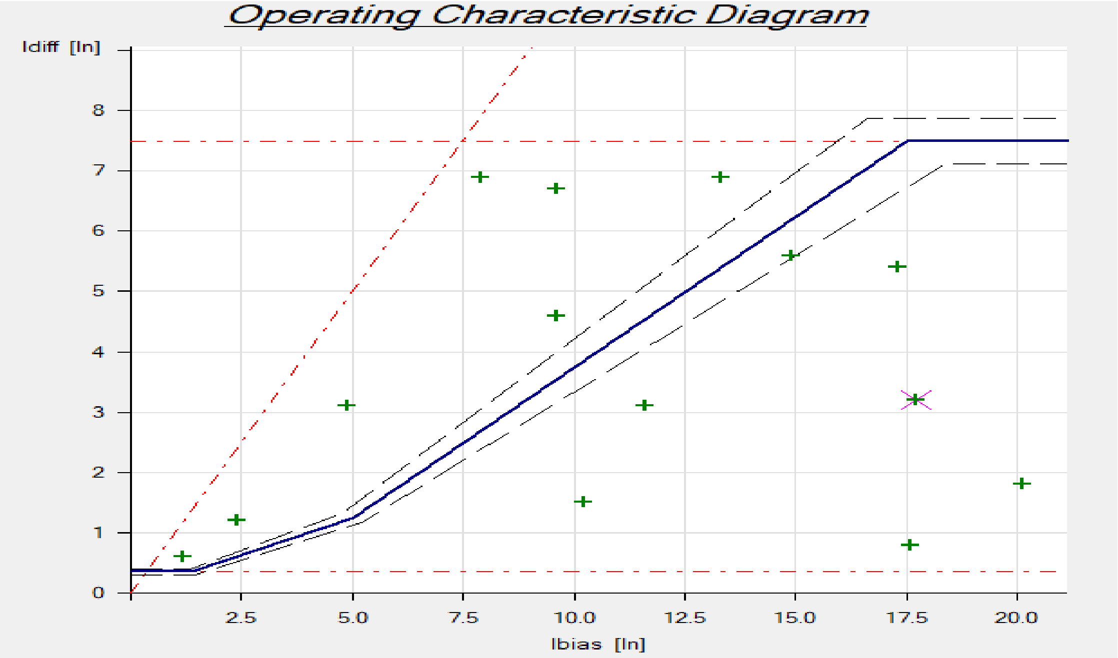

Figure 4.6: Differential operating characteristics graph of Numerical differential relay

4.4: The 162MVA Power Transformer Simulation Result of the AfamIV Transmission Station Network without Fault

The result in Figure 4.7, shows that the simulated network of Afam transmission station network worked optimally without fault when the differential relay protection of the 162MVA power transformer is established through the application of the differential current as the difference between the primary side current and the secondary side current of the 162MVA power transformer.
It is observed that the introduction of a new Intelligent Electronic Device (IED) differential protection relay into the Afam IV transmission network did not alter with the flow of power as shown in fig. 4.6, the system is stable.

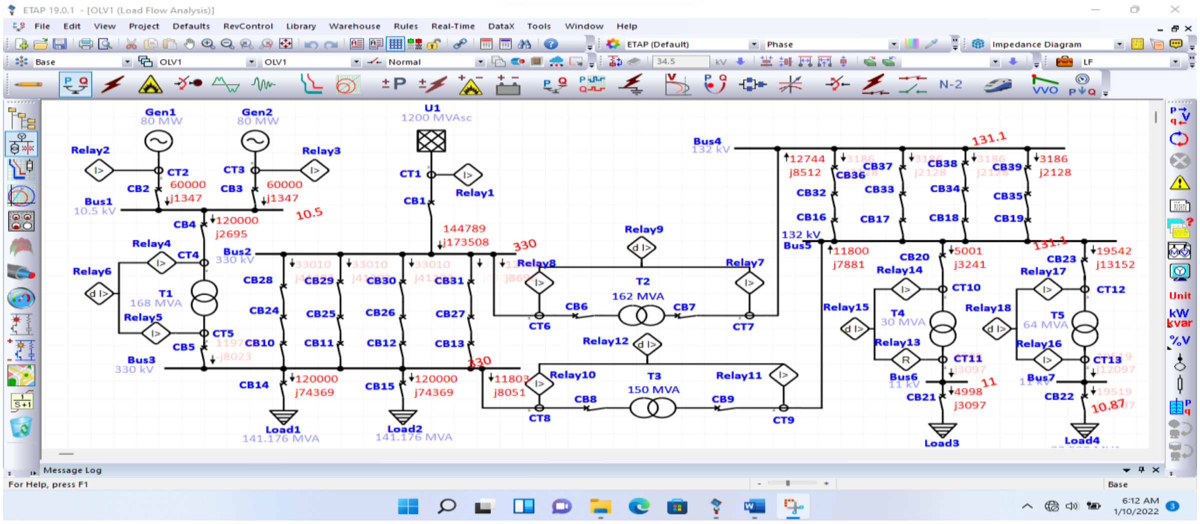

Figure 4.7: The 162MVA Power Transformer Simulation Result of the Afam Transmission Station Network without Fault

4.4:The Timing Characteristics of the Two Differential Protection relays

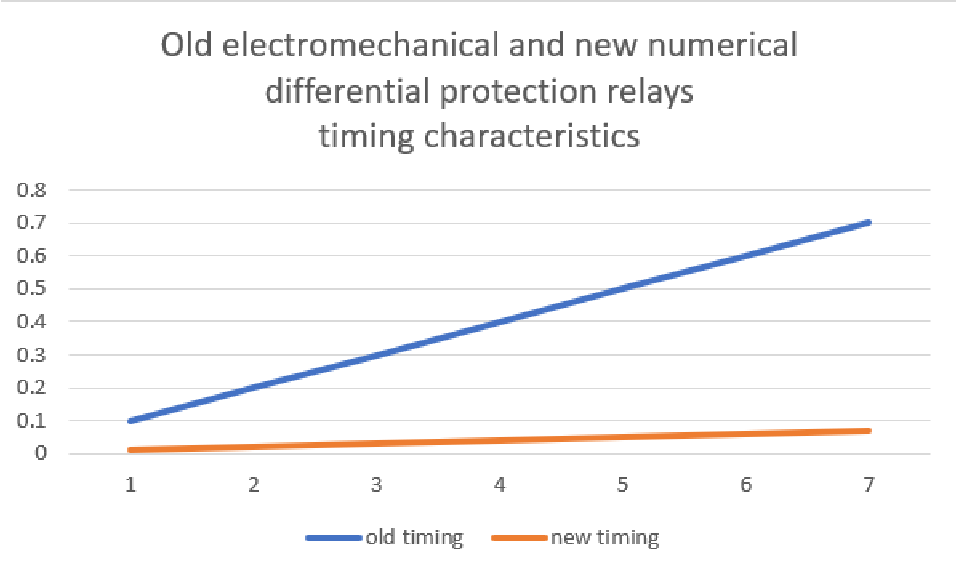

Figure 4.8: The Timing Characteristics of the Two Differential Protection relays

Figure 4.8 shows the comparison between the timing of the old electromechanical differential relay and the new numerical relay. The numerical relay operates faster as compared to the electromechanical relay which is sluggish due to its burden and operating disk movement.

V. CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

The protection on 162MVA, 330/132kV power transformer in Adam IV transmission station has been improved by the application of numerical differential relay protection. The simulation of fault current inside and outside zones of protection of the differential relay shows the stability of the relay under normal and abnormal conditions.

5.2. Recommendations

Based on the analysis carried out, the following recommendations are essential :

I. Further research on this work should employ the use of numerical differential relay protection for power transformer in Nigeria power stations.

II. Electromechanical differential protection relays should be phased out, this is because they are slow and require additional current transformers thereby incurring more cost during installation and troubleshooting.

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