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UHV TRANSFORMERS DIFFERENTIAL PROTECTION BASED ON THE SECOND HARMONIC SUPPRESSION

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Abstract- Ultra-high voltage (UHV) transmission results enormous economic benefits and technical superiorities. It is essential that UHV transformers should be protected against many kind of faults. An important fault which could be cause of maloperation of differential protection in UHV transformers, is internal fault. It happens when parts of the UHV transformer windings get short circuited. Also energizing an UHV transformer could lead to maloperation of differential protection. Suppression of the second harmonic during energization and internal faults is a method for preventing of maloperation in differential protection of UHV transformers. So we need to study on them which could be done by a computer software PSCAD EMTDC. By studying on the harmonics we can specify the percent of the second harmonic that should be blocked. Other studies on different kind of high voltage transformers are not enough and new study and simulation is essential. For simulating this problem, a three winding autotransformer model is firstly built according to the existing Unified Magnetic Equivalent Circuit transformer model provided by EMTDC software and then harmonics during internal faults and energization have been studied.

Keywords: UHV, Transformer, Second Harmonic, Simulation.

I. INTRODUCTION

Distinguishing between magnetic inrush and the fault current for differential protection of power transformer is a problem, and this challenge when it is about UHV transformers, gets more serious. By using a UMEC model of a transformer we can model a single phase transformer and because, an autotransformer doesn't exist in this software, we use a common transformer. In this method we can have several windings in high voltage end, instead of one winding which provides our problem requirements. Autotransformer is the main type of UHV transformer, but the model of autotransformer provided by most simulation software is absent.

PSCAD/EMTDC is typical simulation software applied in various fields of power systems. In particular, it is suitable for electromagnetic transient simulations. In this paper, according to the equivalent circuit of three-winding autotransformer, we set up the UHV autotransformer model and its internal faults model by means of a unified magnetic equivalent circuit (UMEC) transformer model provided by EMTDC software. This new model takes into accounted both the particularity of UHV transformer and the nonlinearity of the transformer core [8].

Based on described model we simulate 30% phase to phase fault, 60% fault and phase to ground fault and energization. Remnant fluxes are considered to be zero.

II. THE UHV TRANSFORMER INTERNAL FAULTS AND ENERGIZATION MODELING AND SIMULATING

A. Equations and Fault Modeling

For simulating different kinds of faults, we should do short circuit the different point of primary windings which could be done by breakers. By placing breakers in appropriate points we could have different types of faults. For having more different percent of short circuited windings we can have Equations (1, 2) [8]:

$$X_2 + X_3 = X_C \tag{1}$$

$$\frac{X_2}{X_3} = \left(\frac{N_2}{N_3}\right)^2 \tag{2}$$

where, X_C is the leakage reactance of series windings, X_2 and X_3 are the leakage reactance of number two and number three windings, and N_2 and N_3 are the turn quantities of number two winding and number three winding, respectively.

Figures 1 and 2 illustrate basic models for simulating required faults. In Figure 2, the model for simulating interturn fault with short circuit turn ratio lower than 50% and turn to ground fault with short circuit ratio bigger than 50% is been illustrated. By changing the position of number four winding with number two and number three winding, we simulate other percent of faults, so it does not need to replace the breakers. In this case, one end of number four winding is connected to the terminal of HV side and the other one is connected to one end of number two winding. Internal faults of UHV transformer should be investigated by virtue of this arrangement.

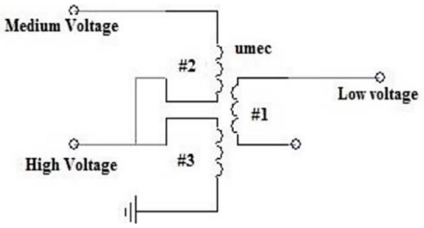

Figure 1. Basic configuration of the UHV transformer

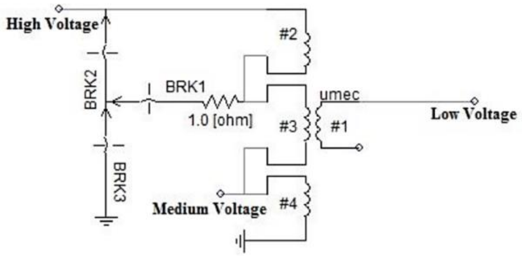

Figure 2. Modeling of internal faults of the transformers

In order to cut out a part of primary windings off the circuit, we have several options that depend on demanded fault. For example, by closing BRK1 and BRK3, short circuit to ground happens. Other faults happen when different modes of closing of the breakers occur.

B. Simulation 30% Internal Fault

Breakers which are involved in this problem are BRK1 and BRK2, so we can study on harmonics that occur after 30% fault. In this case, number two winding gets short circuited. This model is shown in Figures 3, and the results of the harmonics on the output current and voltage have been illustrated in Figures 4 and 5. It is evidence that, after fault, output have some changes.

As illustrated in Figure 4, the second harmonic (green one), has a much bigger amount rather than other harmonics which is really important in differential protection.

In Figure 5, it is shown that there is no significant change in output voltage but as we considered before in Figure 4, there are harmonics that can be harmful for the UHV transformers.

C. 60% Internal Fault Simulating

In Figure 6, the model of 60% internal fault. By closing BRK1 and BRK3, 60% of the primary windings gets off the primary windings of the transformer. In this case two primary windings of three primary windings short circuit and we will have corresponding harmonics that we can view in Figure 7. The Figure 8 shows the output voltage of transformer in the case of 60% internal fault.

In Figure 7, there are harmonics after fault happens and still the second harmonic has a bigger percent rather than other harmonics. This case versus the 30% fault has a bigger the second harmonic that could be caused by more short circuit windings. On the other hand, output voltage reduced after fault. Red line shows the reduction in output voltage and its affect after fault happens.

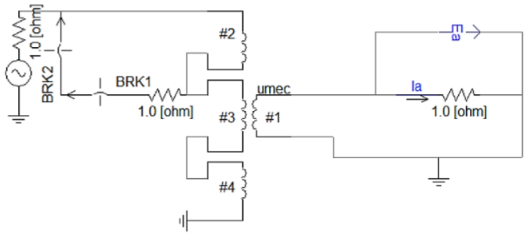

Figure 3. 30% internal fault modeling

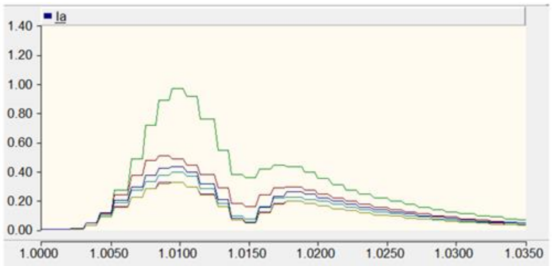

Figure 4. Harmonics in the case of 30% internal fault

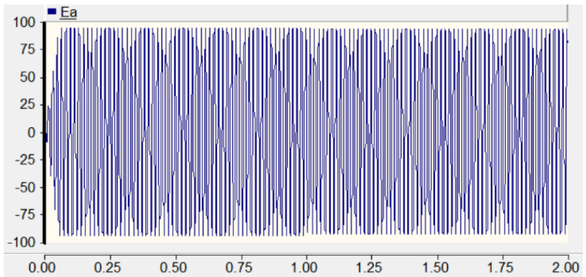

Figure 5. Output voltage in the case of 30% internal fault

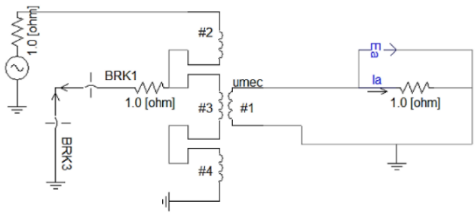

Figure 6. The 60% internal fault modeling

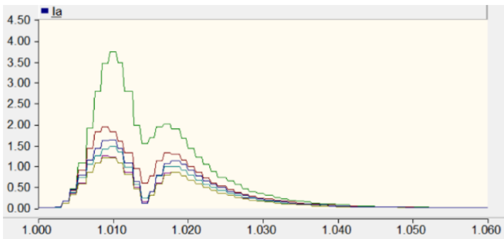

Figure 7. Harmonics in the case of 60% internal fault

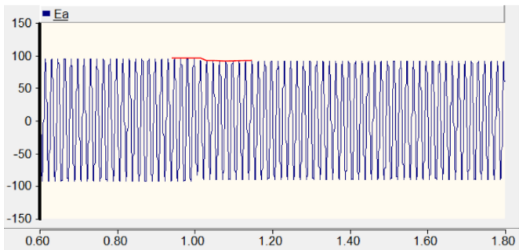

Figure 8. Output voltage in the case of 60% internal fault

D. Short Circuit to Ground Fault

For modeling this fault, another closing combination of the breakers is required. So breakers BRK2 and BRK3 act at the same time and considered fault happens and the whole of transformer primary windings are short circuited to ground. Figure 9 illustrates which breakers play the roll in this fault simulating. Figure 10 shows harmonics in the case of short circuit to ground fault and output voltage in shown in Figure 11.

As it is clear in Figure 10, the second harmonic, farther more of other harmonic rises and reaches to a higher point than the other cases we've analyzed, that could be due to increment of windings which are involve in short circuit matter. Against last cases, we have a rise of seventh harmonic rise here quickly. But it's not a problem because of the filters that would be considered in a real grid system.

Figure 11 shows that after short circuit to ground fault occurred, output voltage almost reaches to zero that means we don't have any output voltage.

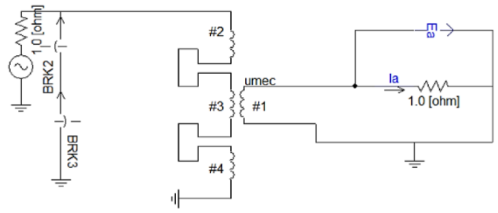

Figure 9. The short circuit to ground fault modeling of Figure 6

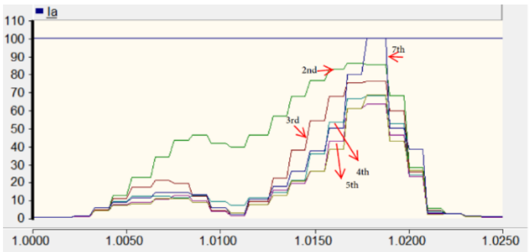

Figure 10. Harmonics in the case of short circuit to ground fault

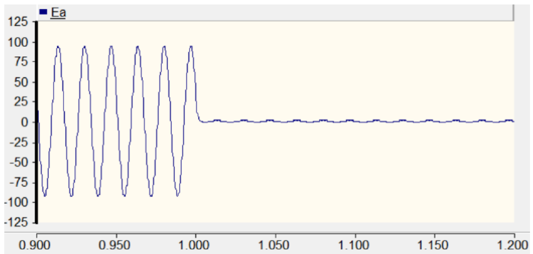

Figure 11. Output voltage in the case of short circuit to ground fault

E. Energization Simulation

It has been discussed that for using the second harmonic restraint in protection relay applications, we should analyze the harmonics and especially the second harmonic in different faults and since there are harmonics during energization, we need to consider its simulation in our analyzes.

For instance Figure 12 illustrates harmonics during energization that effect on output current in a three phase UHV transformer [8]. As seen in Figure 12, the harmonics of the inrush is more abundant than the transformer's in EHV and lower level systems, leading to the more abnormal waveforms. Figure 13 illustrates the harmonics during energization. As we can realize, the higher order harmonics, especially the odd harmonic of the inrushes of UHV transformer are very abundant.

In compare with the second harmonic, seventh harmonic has a bigger amount at the first place but as time goes by, the second harmonic grows. We have a bigger amount of the second harmonic and faster rise in all harmonics in compare with the other foregoing cases.

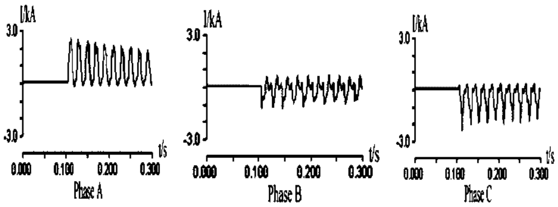

Figure 12. Magnetic inrush currents in the condition of typical energization; initial angle of phase A is 0; permeant flux densities of the three phase are all 0 [8]

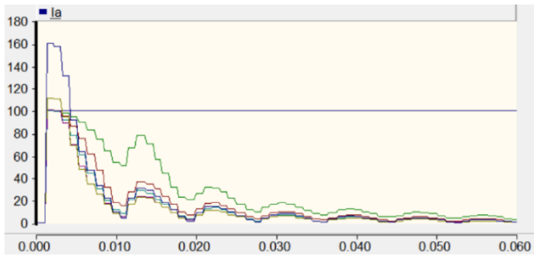

Figure 13. Harmonic change in the case of energization

III. ANALYZING EFFECT OF LONG DISTANCE TRANSMISSION LINE ON THE SECOND HARMONIC

Based on former studies [3] [8] which has been done on energization and internal faults cases in three winding UHV transformer, prove that long line is not a key factor to influence the second harmonic content of inrushes. The studied system illustrated in Figure 14 and results of energization illustrated in Figure 15.

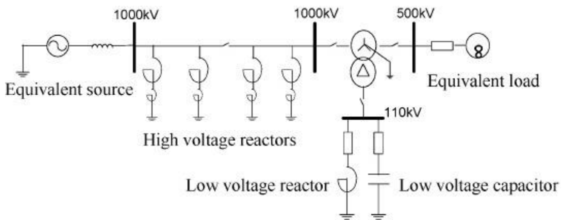

Figure 14. System model [3]

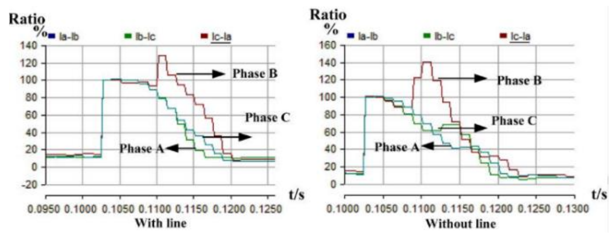

Figure 15. Comparison of the second harmonic characteristic in the case of energization with line and without long [8]

In this case, the simulation is done, once by a long transmission line and once more without a transmission line. As you can analyze in Figure 15, there is no significant difference between these two results. So we can conclude that long line won't have basic influence on our system either.

IV. DISCUSSIONS

By simulating different internal fault we found out that by increasing internal fault, the amount of output current grows which could have an impropriate effect on system. Other references [8] pointed out the growing of output current during other more percent of fault is shown in Figure 16.

As seen, no matter for interturn short-circuited faults or for phase to ground faults, the more turns are short-circuited, the higher the primary current is. The second harmonic in other percent of faults have been reported in many references [8]. Therefore by simulating all kind of internal faults and energization we have to offer the percent of the second harmonic suppression for applying in differential protection. In the case which simulated in reference [8], this amount offered to be 10% which could be different in other cases. Investigations shows that with a long line and without it, results are almost the same.

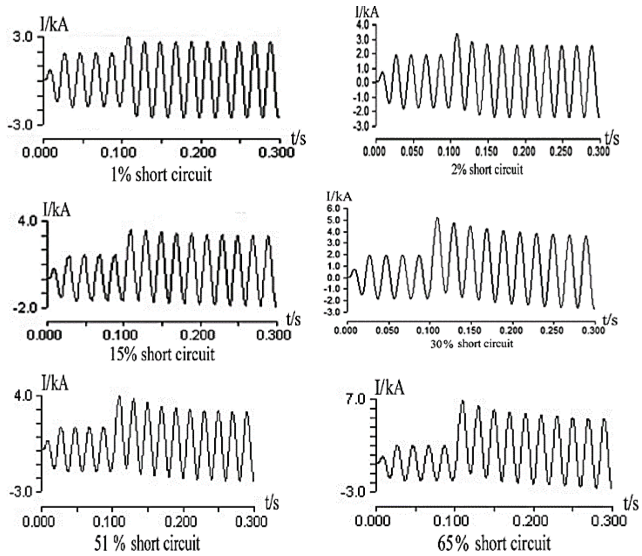

Figure 16. Phase Currents in the case of internal faults [8]

V. CONCLUSIONS

Based on the benchmark model of transformer provided by EMTDC, the energization and internal fault models of UHV transformer are established in this paper in terms of autotransformer model. We accomplish the corresponding electromagnetic transient simulations in UHV environment, and offer the reasonable precondition for investigating the protection operation of the UHV transformer, especially for proving its applicability to the UHV test. The emphasis is on evaluating amount of 2nd harmonic blocking to improve operation reliability of the differential protection.

As seen, no matter for interturn short-circuited faults or phase to ground faults which the most of turns are short-circuited and the highest current is the primary one. These models could useful and applicable for UHV transformers protection test. According this paper, the operational level of the differential protection of UHV transformer can be improved further which improves the security of grids. According to the simulation results, the second harmonic based blocking scheme can distinguish between inrush and fault current on the whole. A great deal of beneficial works for identifying the inrush from fault current have been reported [15-24].

However, in some scenarios of internal faults it may lead to some time delay for the response of the differential protection. In this sense, the discrimination between the inrush and the fault current of UHV transformer is still a valuable work. Furthermore, we investigate the harmonic change trends. As seen, the higher order harmonic content and the change trends are similar to the second harmonic. Also magnitude of the second harmonic is not dependent on long transmission line and it is not a key factor to influence the second harmonic.

NOMENCLATURES

X_2 : Leakage reactance of number two windings
X_3 : Leakage reactance of number three windings
X_C : Leakage reactance of the series winding
N_2 : turn quantities of number two winding
N_3 : turn quantities of number three winding

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BIOGRAPHIES

Naser Mahdavi Tabatabaei was born in Tehran, Iran, 1967. He received the B.Sc. and the M.Sc. degrees from University of Tabriz (Tabriz, Iran) and the Ph.D. degree from Iran University of Science and Technology (Tehran, Iran), all in Power Electrical Engineering, in 1989, 1992, and 1997, respectively. Currently, he is a Professor in International Organization of IOTPE. He is also an academic member of Power Electrical Engineering at Seraj Higher Education Institute (Tabriz, Iran) and teaches power system analysis, power system operation, and reactive power control. He is the General Chair of International Conference of ICTPE, Editor-in-Chief of International Journal of IJTPE and Chairman of International Enterprise of IETPE all supported by IOTPE. He has authored and co-authored of six books and book chapters in Electrical Engineering area in international publishers and more than 135 papers in international journals and conference proceedings. His research interests are in the area of power quality, energy management systems, and power networks smart grid. He is a member of the Iranian Association of Electrical and Electronic Engineers (IAEEE).

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