Department of Electrical and Electronics Engineering

Reduction of Three-Phase Transformer Inrush Currents using Controlled Switching

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CONTENTS

INTRODUCTION

- Power transformers play a very important role in power transmission and their operating characteristics have significant impacts on lifetime of power system apparatus.
- Uncontrolled energization of transformer can create large flux asymmetries and saturation of the winding core of the transformer which results in Inrush currents.
- Magnetic inrush currents are extremely detrimental to the normal operation of transformer and other power system apparatus.
- Developing methods or tools to mitigate or reduce inrush currents will therefore increase the lifetime of transformers and other equipments.

OBJECTIVES

- To familiarize controlled switching of transformer
- To determine optimal closing instants of energization of a three-phase three legged stacked core power transformer
- Verify the proposed strategy by conducting simulations and laboratory experiments

EFFECTS OF INRUSH CURRENT

- Inrush currents causes damage to the transformer due to both high currents and the resulting mechanical stresses.
- Malfunction of transformer differential protection as well as other protective relays and fuses.
- Power quality issues due to high harmonic content of inrush currents.
- Voltage sags or dips in power system network.

CAUSES OF INRUSH CURRENT

- Random Closing Angle of Transformer
  - Doubling Effect
  - Transformer Core Saturation
- Residual Flux in core

DOUBLING EFFECT

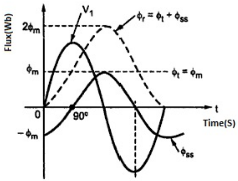

Figure: 1. Doubling effect

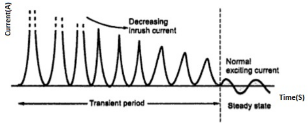

Figure: 2. Waveform of inrush current

DOUBLING EFFECT cont.

- The Emf equation at the primary winding of a single-phase Transformer without load can be expressed as:-

$$N\frac{d\phi}{dt} + iR = U_m \sin(\omega t + \alpha) \qquad (1)$$

On solving eqn (1), we get

$$\phi = \frac{-LU_m \cos(\omega t + \alpha)}{\sqrt{R^2 + (\omega L)^2}} + \left(\phi_r + \frac{LU_m \cos\alpha}{\sqrt{R^2 + (\omega L)^2}}\right) e^{-\frac{R}{L}t}$$

FACTORS AFFECTING FLUX

- Resistance of the primary winding
- Inductance of the primary winding
- Residual Flux
- Epoch angle

CONTROLLED SWITCHING

Single-phase Transformer

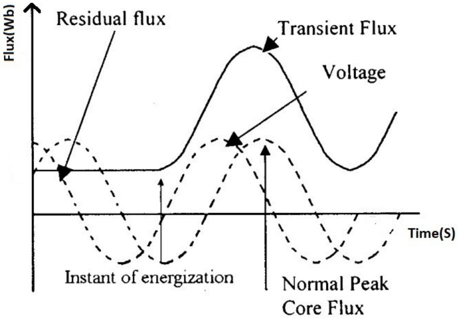

Figure: 3. Worst energization case for a single-phase transformer with residual flux

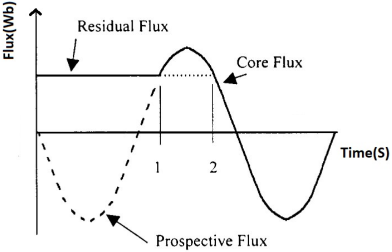

Figure: 4. Optimal energization points of a single-phase transformer with residual flux.

CONTROLLED SWITCHING

Three-phase Transformer(Triplex Transformer)

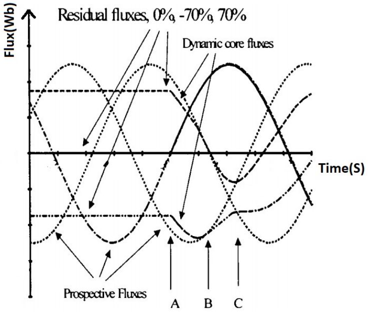

Figure: 5. Optimal energization points of Triplex Transformer

- First phase with zero residual flux is closed at A
- Depending upon the polarities of the residual flux in the three legs, the dynamic core flux and prospective flux will be equal either at points B or C.

PROPOSED CONTROL STRATEGY

Three-phase three legged stacked core transformer

- Simulate the prospective waveforms of the three phases.
- Set Ta as the instant when voltage A peaks. Simulate the dynamic flux waveforms, switching phase A at Ta.
- Compare phase B waveforms to determine Tb, the earliest instant when the phase B dynamic flux becomes equal to prospective flux. Simulate the dynamic flux waveforms again switching phase A at Ta and phase B at Tb.
- Compare phase C waveforms to determine Tc, the earliest instant when the phase C dynamic flux becomes equal to phase C prospective flux.

EQUIVALENT ELECTRICAL CIRCUIT

Three-phase three legged stacked core transformer

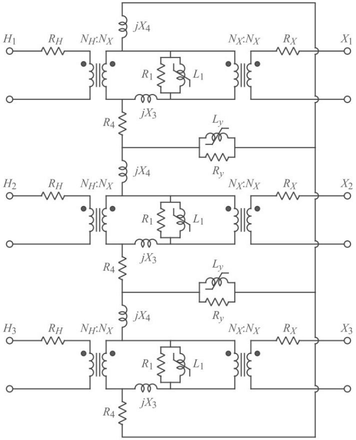

Figure: 6. Equivalent electrical circuit of a three-phase three legged stacked core transformer

SIMULATION MODEL

Three-phase three legged stacked core transformer

- Dry type transformer unit rated at 15KVA
- Y-Δ Connection with voltage ratios of 208/240 V

TABLE I
MEASURED TRANSFORMER PARAMETERS

Phase	R_H	R_4	X_4	X_3	R_1	R_X	R_y
A	0.1754	0.2112	0.3703	0.0267	412.88	0.0393	312.74
B	0.1786	0.2112	0.3703	0.0273	412.88	0.0389	312.74
C	0.1771	0.2112	0.3703	0.0277	412.88	0.0389	312.74

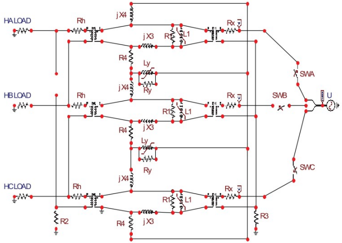

Figure: 7. Equivalent circuit of a three-phase three legged stacked core transformer in ATP

SIMULATION RESULTS AND DISCUSSIONS

CASE: 1

- In this case, all the three phases are energized simultaneously at t=0 s with zero residual fluxes

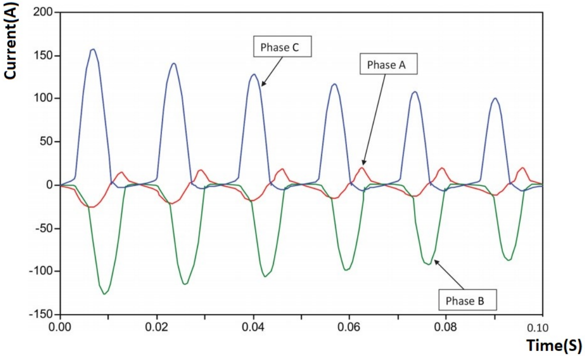

Figure: 8. Current Waveform for Case 1

- In this case, phases A,B,C are energized at instants t=0 s, 0.0967 s, 0.0967 s instants seperately

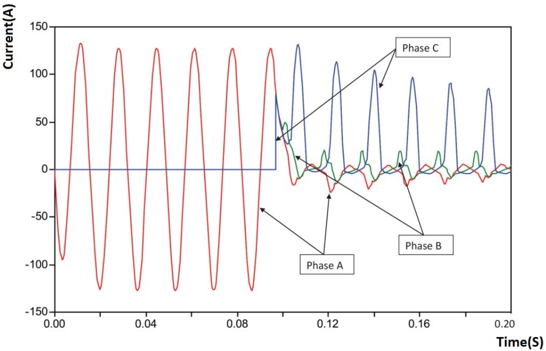

Figure: 9. Current Waveform for Case 2

- In this case, phases A,B,C are energized at instants t=0 s, 30.65 ms, 42.3 ms instants seperately using the proposed strategy

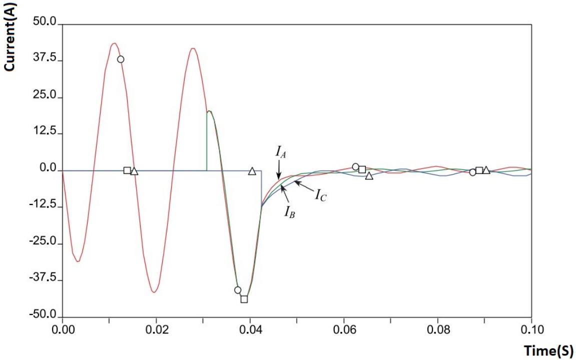

Figure: 10. Current Waveform for Case 3

EXPERIMENTAL VALIDATION

Approach experimentally validated using given Transformer

- The low-voltage side of the transformer is supplied using a programmable power supply (Pacific Power Source UPC-3)
- Phases A,B,C are energized at instants t=0 s, 30.65 ms, 42.3 ms seperately

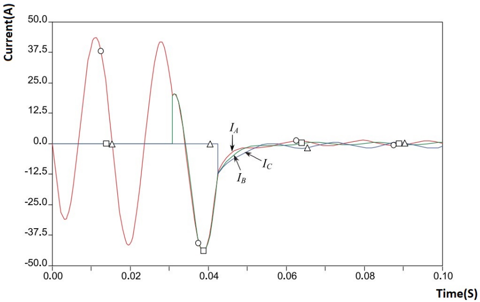

Figure: 11. Actual Waveform, with phase A,B,C are energized at t=0 s, 30.65 ms, 42.3 ms

CONCLUSION

- A controlled switching scheme for reducing inrush currents in three-phase three legged stacked core transformer was introduced.
- The proposed scheme was tested on a real power transformer by means of simulations, and the results were validated through laboratory experiments.
- The results show that the inrush currents are reduced significantly when the proposed scheme is used.
- Reducing inrush currents will reduce the complexity of transformer design and cost.

REFERENCES

- Joydeep Mitra, Xufeng Xu, and Mohammed Benidris, "Reduction of Three-Phase Transformer Inrush Currents Using Controlled Switching" IEEE Transactions on Industry Application, vol. 56, no. 1, January/February 2020
- J. H. Brunke and K. J. Frohlich, "Elimination of transformer inrush currents by controlled switching - Part I: Theoretical considerations," IEEE Trans. Power Del., vol. 16, no. 2, p. 276-280, Apr. 2001.
- J. H. Brunke and K. J. Frohlich, “Elimination of transformer inrush currents by controlled switching—Part II: Application and performance considerations,” IEEE Trans. Power Del., vol. 16, no. 2, pp. 281–285, Apr. 2001.

Thank You!