

Limiting the Transform Inrush Current by Switching at the Optimal Phase of the Supply Voltage Waveform

Mohamed Ali¹, Tariq Fulayfil², Abdulmanam Abdulwhab³

¹College of science and Technology, Surman, Libya.

²Higher Institute of Marine Science Technology, Sabratha, Libya

³Higher Institute of Marine Science Technology, Sabratha, Libya

Abstract— the article deals with the cause of the inrush current in single-phase power transformers and provides a detailed analysis of one method for eliminating the inrush current – connecting the transformer to the network at the optimal phase of the supply voltage. Attention is given to the theoretical foundations utilized by the method. Possibilities for practical implementation are indicated, with a warning about potential pitfalls in the accuracy of the measured quantity and the speed of the actuator.

Keywords— Inrush current, phase transformer, speed of the actuator, Optimal phase.

I. INTRODUCTION

Inrush current occurs when a transformer is connected to the power network because of the saturation of its magnetic circuit. The magnitude of this overcurrent depends on the design of the transformer, the characteristics of the power network at the point of connection, and the conditions now the transformer is connected to the network. In some cases, the inrush current can exceed fifty times the rated current of the transformer. An overcurrent of this magnitude causes operational difficulties for the transformer. Securing such a device is particularly problematic. The interference produced by current impulses is also significant. There are many ways to deal with inrush current. By changing the transformer design, it is possible to only reduce the magnitude of the inrush current. If greater limitation of the overcurrent or its complete elimination is necessary, a suitable limiting circuit must be used

In the primary circuit of the transformer. In principle, three methods can be employed to limit inrush current: reducing the operating induction, reducing the residual induction, and connecting the transformer at an appropriate angle of the voltage in the network. The methods used are, for example, described in [1].

II. TRANSFORMER INRUSH CURRENT

The inrush current of a transformer arises because of a transient phenomenon, during which, after switching on the transformer, the initial remanent magnetic flux of the transformer core Φ_r gradually transitions into the alternating magnetic flux in the steady operating state of the transformer Φ_m . During this transient phenomenon, the magnetic flux density Φ_{max} can theoretically reach nearly three times the amplitude of the magnetic flux density under normal operating conditions. After core saturation, the transformer loses its impedance and draws a much higher magnetizing current from the network, known as inrush current. After core saturation, the leakage magnetic field of the transformer increases.

$$\Phi_{max} = 2\Phi_m + \Phi_r \quad (1)$$

The real properties of the transformer core material limit the maximum value of magnetic induction of the core. The magnitude of the inrush current depends on the initial remanent flux and the moment of connecting the transformer to the network relative to the voltage waveform. While the magnetic flux during the transient phenomenon upon switch-on can, when neglecting winding parameters, be expressed by the formula derived in the contribution.

$$\Phi(t) = \frac{\sqrt{2}U}{N_1 \omega} [\cos(\omega t + \gamma) - \cos(\gamma) + \Phi_r] \quad (2)$$

Where U is the effective value of the network voltage, N1 is the number of turns of the primary winding, ω is the angular frequency of the network, and ψ is the moment of switching the transformer to the network expressed as the switching angle. The magnitude of the inrush current is not easy to determine due to the nonlinearity caused by the hysteresis of the magnetic circuit. Simple methods for estimating the magnitude of the inrush current, as mentioned for example in [3], are not

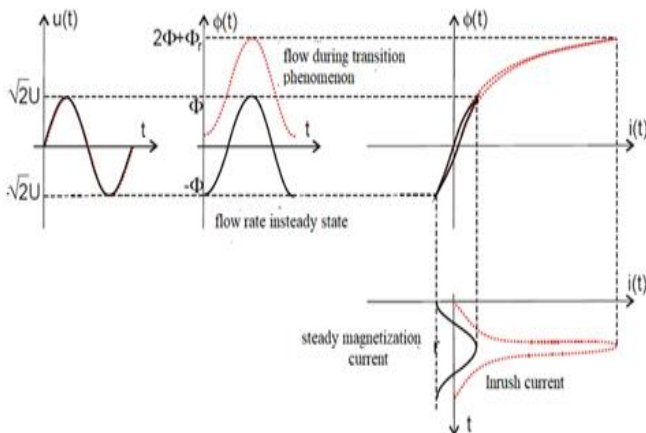


Figure 1: Illustration of the inrush current formation

sufficiently accurate. When calculating the inrush current, it is necessary to consider the nonlinearity of the magnetic circuit.

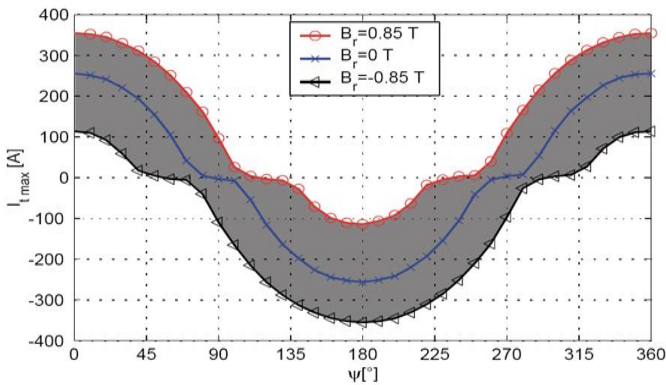


Fig. 2: Dependence of the peak switch-on current on the remanent flux density B_r and the network connection angle ψ , with the area of possible values for the transformer RJV 1.6 (230/230V; $I_n=7$ A; 1.6 kVA) indicated.

A typical dependence of the peak inrush current on the initial conditions when switching on a transformer is shown in Figure 2. The waveform was obtained from a mathematical model of the transformer with a description of the magnetic circuit hysteresis and the nonlinearities of the leakage flux. The accuracy of the waveform was confirmed by experimental measurements.

III. CONNECTING THE TRANSFORMER IN THE OPTIMAL PHASE OF THE SUPPLY VOLTAGE

According to [1], the inrush current can be eliminated by choosing an appropriate moment to connect the transformer ψ to the network.

$$\Phi_m \cos \gamma - \Phi_r = 0 \quad (3)$$

For clarity, it is appropriate to rewrite equation (3) in the form

$$\cos \gamma = \frac{B_r}{B} \quad (4)$$

Where B is the amplitude of the working induction of the transformer. For each initial remanent induction, it is possible to determine the moment of appropriate energizing so that the course of the magnetic flux after energizing corresponds to the flux in the steady operating state of the transformer.

The condition for optimal energizing (4) is met twice during one period, as illustrated in Figure 3.

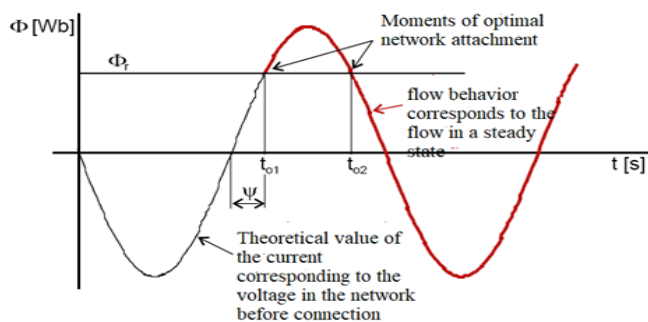


Fig. 3: Appropriate moments for energizing the transformer at a given remanent induction

Practically, the switching can be realized using a semiconductor-switching component, for example, a trial with

the appropriate control circuit. In the case of a mechanical switch, it is necessary for the control circuit to account for the delay in the closure of its contacts. The pull-in time of a contactor should be considered as a statistical quantity with a mean value and variance determined by external conditions such as temperature, mechanical vibrations, aging, etc. The switching defined by equation (4) will therefore be carried out with some error. It follows from Figure 2 that with a contactor switching error of up to 0.5 ms, the peak of the inrush current will not exceed the transformer's rated current.

To calculate the moment of optimal clamping, it is necessary to know the operating induction B and the initial remanent induction B_r . The operating induction is determined by the design of the transformer and the supply voltage. The remanent induction of the transformer core must be measured the initial remanent induction can be measured in several ways. The induction can be calculated from the circuit quantities of the primary and secondary windings. Evaluating the remanent induction is complicated by the unknown load connected to the transformer and by surrounding electromagnetic interference, and therefore cannot be recommended.

Direct measurement of induction, for example with a Hall probe, requires intervention in the magnetic circuit of the transformer. Modern magnetic field sensors are very small, so the disruption of the magnetic circuit's properties is negligible. The limiting factor is the technical complexity associated with interfering with the magnetic circuit. The required accuracy of measuring remanent induction does not need to be high. From the graph in Figure 4, it follows that the switching current of the examined RJV 1.6 transformer will be effectively suppressed even with a remanent induction measured with a relatively large error of 0.2 T.

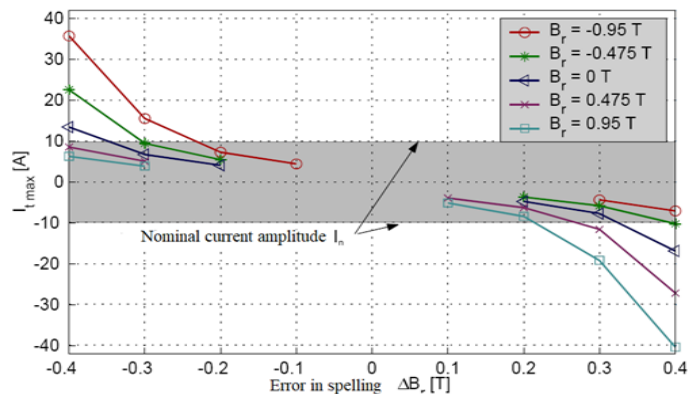


Fig. 4: Dependence of the peak inrush current on the error in measuring remanent flux when using the transformer switching method at the optimal phase angle of the supply voltage for the RJV 1.6 transformer.

IV. CONCLUSION

Eliminating the inrush current of a transformer by switching it on at the optimal phase of the supply voltage is among the promising methods of limiting inrush current. Compared to other methods, it allows for the complete elimination of inrush current. An undeniable advantage is the speed of

Connecting the transformer within one period of the supply voltage. The method is also suitable for transformers operating

in intermittent mode with frequent switching. The only active component of the circuit is the primary current switch.

The disadvantage of the method of switching at the optimal phase of the supply voltage is primarily the interference with the transformer's magnetic circuit and the relatively high cost caused by it. When using a semiconductor switching element, the increased short-circuit impedance caused by the switch's resistance can be considered a drawback. The advantages of the mentioned method of inrush current limitation outweigh the disadvantages as the transformer power increases, where core disruption by the sensor will be negligible due to the transformer cross-section.

REFERENCES

- [1] Novák M. Inrush phenomenon when connecting a transformer to the network. SYMEP 2002 Proceedings. Liberec: TUL, 2002. pp. 133–137. ISBN 80-7083-612-
- [2] Novák M. Soft-Start Control for Fast Transformer Switching to the Network. EPVE 2002 Proceedings. Brno: VUTB – UVEE, 2002. pp. 81–84. ISBN 80-214-2246-7.
- [3] Karzai K., Karunya D., Kiss L. Large Power Transformers. Revised English version. Budapest: Akademia Kiadó, 1987. 615 p. ISBN 963-05-4112-2.
- [4] Brunke J. H., Fröhlich K. J. Elimination of Transformer Inrush Currents by Controlled Switching. IEEE Transactions on Power Delivery. Vol. 16, No. 2, 2001, pp. 273–280. ISSN 0885-8977.
- [5] A., Kodak J., Żywic A.: Parametry elektromagnetyczne maszyny synchronicznej. Wykorzystanie metody elementów skończonych. Wydawnictwo Politechniki Śląskiej "MONOGRAFIA", z. 7, Gliwice, 1998.
- [6] Bubo A., Kudła J., Żywic A.: Determination of Spectral Transfer Functions of a Synchronous Machine by the Finite Element Method. International Workshop on Electrical Machines, 7-8 Sept. 1998, Prague, pp. 102-110.
- [7] Kudła J.: Obliczenia nieliniowych charakterystyk sprzężeń magnetycznych pola magnetycznego głównego w maszynie synchronicznej cylindrycznej. Zeszyty Naukowe Pol. Śl. „Elektryka” z. 149, Gliwice 1996, s. 99-110.
- [8] Kudła J. Model matematyczny generatora synchronicznego uwzględniający zjawisko nasycenia dla pola głównego i pola rozproszenia stojana. Politechnika Warszawska Prace Naukowe „Elektryka” z. 111, Warszawa 1999, s. 81-90.
- [9] Bobon A., Kudła J.: Badania symulacyjne stanów dynamicznych generatora synchronicznego przy wykorzystaniu parametrów wyznaczonych metoda elementów skończonych. Zeszyty Naukowe Politechniki Śląskiej "Elektryka" z.171, Wydawnictwo Politechniki Śląskiej, Gliwice 2000, ss.215-226.
- [10] Boboń A., Kudła J., Żywic A.: Modele generatorów synchronicznych w badaniach system elektroenergetycznego, VIII Międzynarodowa Konferencja Naukowa "Aktualne Problemy w Elektroenergetyce", Gdańsk -Jurata, czerwiec 1997., ss.133-140.
- [11] Kudła J.: Simulation investigations of induction motor start-up when using field-circuit model, Proceedings of X International Symposium on Electric Machinery "ISEM 2002" in Prague, pp. 96-104.
- [12] Kudła J.: Methodology of determining static characteristics of induction motors basing on quasistatic waveforms. Use of the machine field-circuit model, Proceedings of EPVE 2002
- [13] G. Eason, B. Noble, and I. N. Sneddon, "On certain integrals of Lipschitz-Hankel type involving products of Bessel functions," Phil.