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Different Techniques for Mitigation and Reduction Of Power Transformer Inrush Current

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Abstract

Transformer is a vital and major component in any electrical power system. When transformer is energized high peaky current is observed. This current called inrush current. This current has undesirable effect on transformer including reduction of the life time of transformer, Protective relay miss-operation and melting of fuse elements. In this paper different techniques for the mitigation and reduction of the transformer inrush current are investigated. It is found that, the sequential phase energization is the most effective one.

Keywords: **Power Transformer, Inrush current, mitigation techniques: switching angle, controlled switching, Transformer energization, Source resistance.**

1. Introduction

Transformers are vital, costlier and important component as heart in electrical transmission and distribution system. There are different purposes to use transformers they are inbuilt in nearly in all electric power system around us. They are used in transmission and distribution systems.

For transmission system, they are used to step up voltage to transmit power at high voltage level, to reduce the transmission line losses and improve the efficiency of the transmission. For distribution, they step down voltage to get the voltage at distribution level [1].

So, stability and security of transformers are necessary and important to the system operation. When the transformer is energized high peaky current will be appeared by transformer. This current called "inrush current".

This current will affect the transformer efficiency and performance as follows [2].

1.2. Effects of magnetizing inrush current in transformer [3] *:*

1) The efficiency of a transformer is reduced due to the increase of iron losses with the increased inrush current.
2) The increase of the temperature of the iron core, which become dangerous to the laminations insulations.
3) Transformer inrush current causes interference with the operation of other circuits.
4) Misoperation of the Protective relays and melting of fuse elements.
5) Circuit breakers and fuses over sizing due to inrush current.

1.3. Categories and types of transformer inrush current:

There are many types and categories of the transformer inrush current, which include [4]:

a) Energization inrush current:
It is occurred during energization of a transformer, when the value of residual magnetic flux is zero or any magnitude. The polarity depends on de-energizing time.

b) Recovery inrush current:
It is occurred when the voltage is recovered after a small dip or disturbance is restored.

c) Sympathetic inrush current:
When multiple transformers connected in the same line, Inrush current occurred at the transformer, which already energized due to the energization of new transformer.

2. Methods and Techniques to reduce inrush current

There are many methods and techniques for mitigation and reduction of inrush current in transformers, which are applied, studied and investigated [2, 5-10].

These methods and techniques are including:

- Point on wave switching method.
- Virtual air gap method.
- Optimal closing method.
- Asymmetrical winding.

- Bridge type inrush current limiter.
- Prefluxing method.
- Sequential phases energization technique.

2.1. The Factors affecting on the value of inrush current:

There are many factors affect the inrush current value. Each one of these factors had been studied in one of different previous works, while in the present work more than one factor will be investigated and compared, they are:

1. Series resistance

Line resistance, between the transformer and the source, affects on inrush current. If The line resistance between transformer and source is high, it will be reduced inrush current and increase the decay rate, so, transformer located near generator have high inrush current because the line resistance between transformer and generator is minimum [11].

2. Switching angle

Different studies showed that, when the switching angle of the applied voltage is zero, the inrush current is maximum, while, when the switching angle of the applied voltage is 90^0 the inrush current is minimum [12].

3. Source impedance

Source impedance, is defined by source impedance of the source power system. The inrush current is maximum, when the impedance of source is greater than or equal to the impedance of primary winding. Voltage sag is caused due to inrush current because of the impedance between transformer and source [12].

4. Size of transformer

The higher rated transformers (>1000 kVA) result low inrush current and long duration for seconds. The smaller transformers (< 1000 KVA) result in higher inrush current for small duration (100 ms) [12].

5. Inrush current under load

When a transformer is energized,with connecting a load on its secondary, inrush current effects on the value of load power factor.

If the value of power factor of the transformer is a unit and under heavy load, the maximum value of inrush current is low. When power factor is reduced, the value of inrush current will increase [12].

6. Residual flux density

Ferromagnetic is the material which the transformer is made from. Because of hysteresis effect, residual flux will present in it. Residual fluxes are the main cause of inrush current and depend on core material characteristics [12].

3. Techniques and cases of studies:

In this work, three different methods and techniques, for the reduction and mitigation, of inrush current in the power transformers are applied and investigated, which are:

1) ***Point on wave switching.***
2) ***Effect of source resistance and***
3) ***A sequential phase energization technique***

The following sections show the different systems and cases of the study, for, the mitigation of inrush current, and the results obtained in each case.

3.1 Point on wave switching method.

To investigate the ***Point on wave switching method,*** a system model shown in figure 1, is simulated using matlab-Simulink, for mitigation of inrush current in a three phase power transformer. Using ***point on wave switching***, this is a main factor, which affects inrush current. Inrush current in the three phase power transformer is studied and calculated. The transformer considered in this study having a rating of 500 MVA, 400kV/220kV grounded Y/D transformer. A three phase 400KV source is connected with the transformer. The transformer is considered with specify initial fluxes and saturated core.

In the simulation, the effect of the variation of switching angle, on inrush current characteristic is investigated and studied. The time and angle of switching is changed and taken as, 0^0, 45^0, 60^0, and 90^0. The obtained results are analyzed and observed, for a time of one second (1000 msec), which is the time duration for 50 cycles, so, the time for one cycle is 20 m secs.

3.1.1. Initial condition without mitigation method.

First the system is considered without any mitigation means, switching angle is zero. The circuit breaker closes its contacts when, the wave form of voltage passes through zero value. At this point the core flux reaches its maximum value. The core of transformer is operating at knee point. So, in this condition high current is required to drive the core material into saturation condition, because of non-liner characteristic of core material. The results obtained in this case of the study, the value of inrush current is 1341 A, Figure.2 shows the current wave form of this case.

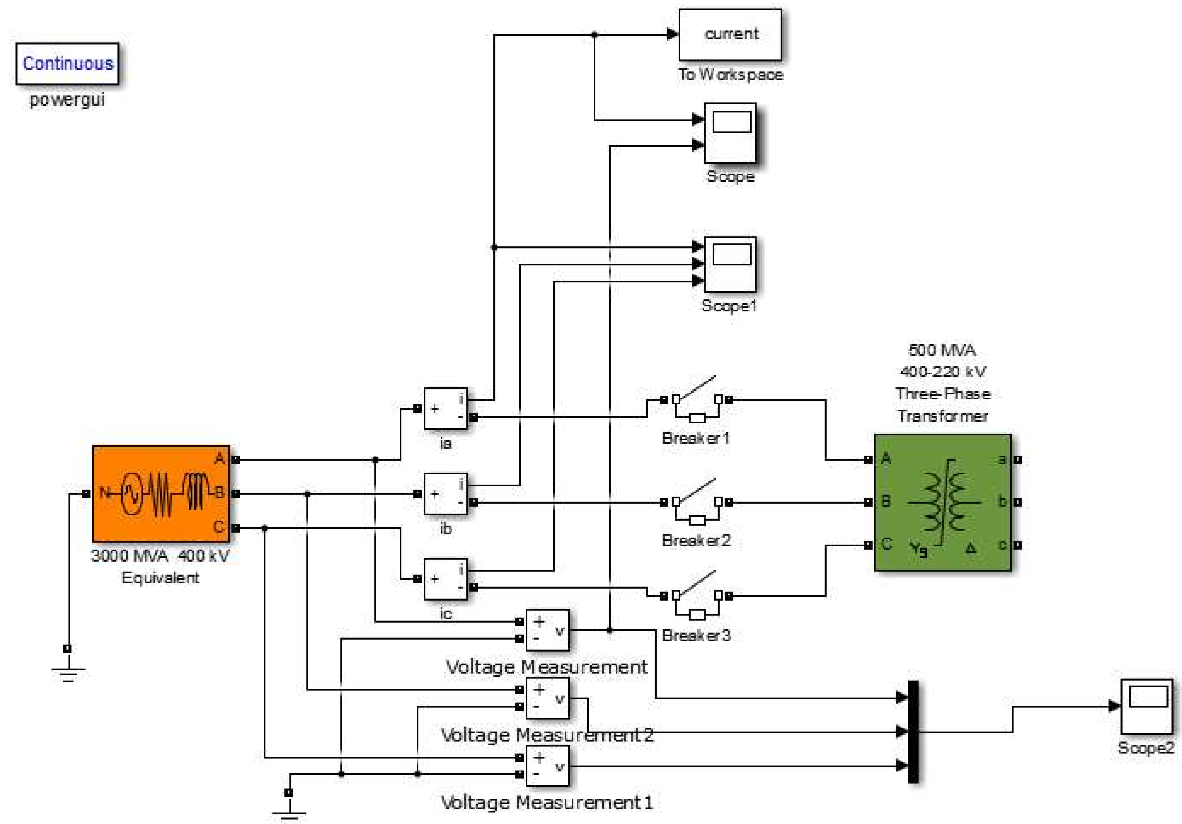

Fig.1: Mat lab Simulink model for a 500 MVA transformer system under study.

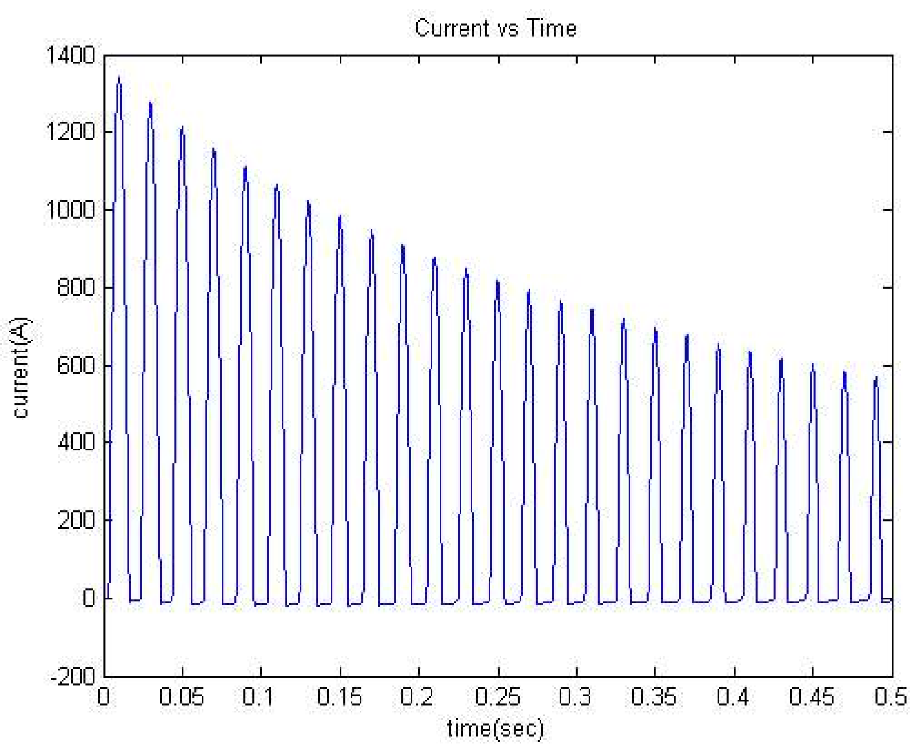

Fig.2: Current waveform for phase A without using any mitigation technique.

The effect of different switching angles are considered, taking the values of 0^0, 45^0, 60^0, 90^0. Table 1 shows the maximum inrush current for the different switching angle values.

Table.1 The effect of switching angle on inrush current

Switching angle (0^o)	The switching time of circuit breaker for phase A	The switching time of circuit breaker for phase B	The switching time of circuit breaker for phase C	Maximum current (A)
0^0	0	0	0	1341 A
45^0	.0025	.009166	.015833	1318 A
60^0	.00333	.01	.01666	1096 A
90^0	0.005	0.018333	.011666	552 A

It is noticed that, by increasing the value of the switching angle, the inrush current value is decreased.

Figure 3 shows the current wave form for the case of switching angle 90^0,

The switching time, for the condition of switching at 90^0 for phase A, B and C, are as:

1- Switching time for Phase A at 90°is 0.005sec.
2- Switching time for Phase B at 90+120= (210°) is 0.011666 sec.
3- Switching time for Phase C at 90 +240= (330°) is 0.018333 sec.

This means a switch is closed when the waveform of transformer pass through its peak value and maximum core flux is high and this value is considered normal value and also the current is normal. As shown below in figure.3 the value of current is 552 A. So, to mitigate inrush current, it is much better, that, the switch is to be closed at switching angle 90^0.

The peak magnetizing current is very high compared to normal magnetizing current. As seen from the results obtained from the different cases of simulation, *as the switching angle increases, the value of inrush current decreases.* Table.1 shows the effect of switching angle on inrush current. It is found that by increasing switching angle the value of inrush current decreases.

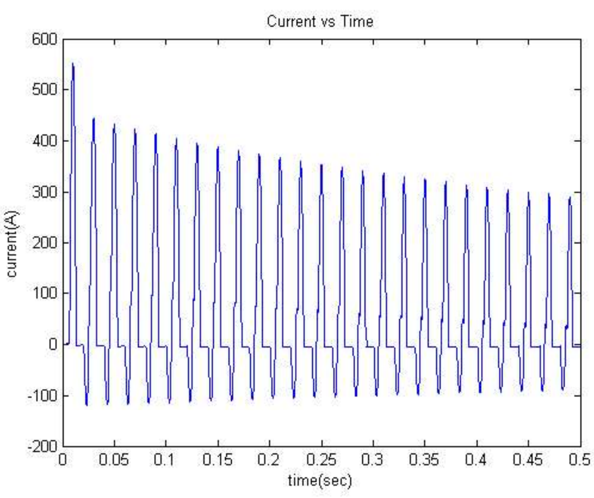

Fig.3 Current waveform for switching at 90° for phase (A).

3.2. Effects of source resistance (R_s)

The effects of source resistance R_s, in the value of inrush current have studied. By increasing the value of source resistance, from 6 Ω up to 30 Ω, with a step of 2 Ω, as shown in figure 4. With considering the switching angle is 0^0 and taking different values for the source resistance. It is found that, as the source resistance increases the inrush current decreases. It is found that, by increasing the value of source resistance up, the inrush current is reduced from the value of 1338 A (figure 5) to the value of 1121 A (figure 6).

For the value of Rs =30 Ω

As shown in figure.6, the value of inrush current reaches 1221 A. it noticed that a faster decay in the amplitude of inrush current as the value of the source resistance is increased.

From the results obtained, it can be noticed that, as the value of source resistance increases, the inrush current is decreased. Also, leads to faster decay in the amplitude of inrush current. It can be seen that inrush current is damped quickly because of source resistance. So, the transformers located near the generating plants have higher inrush current values than the transformers which, far way from generating plants.

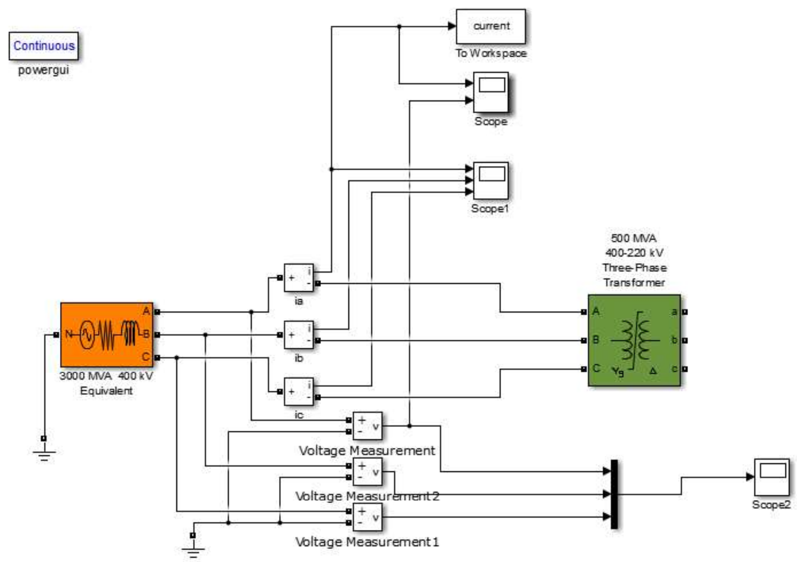

Fig.4 the system used for Mitigation of Inrush Current Using source resistance R_s

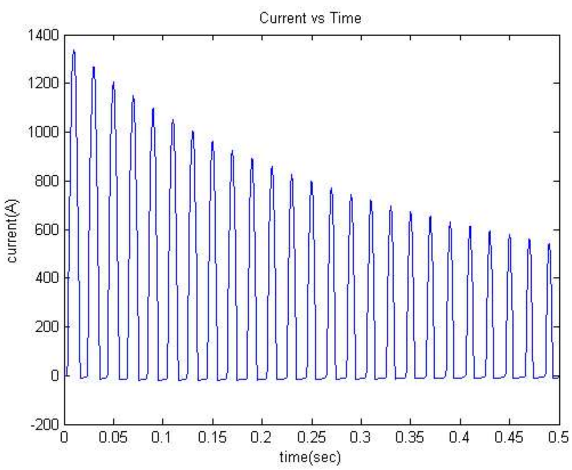

Fig.5: inrush current wave form with source resistance =6 Ω

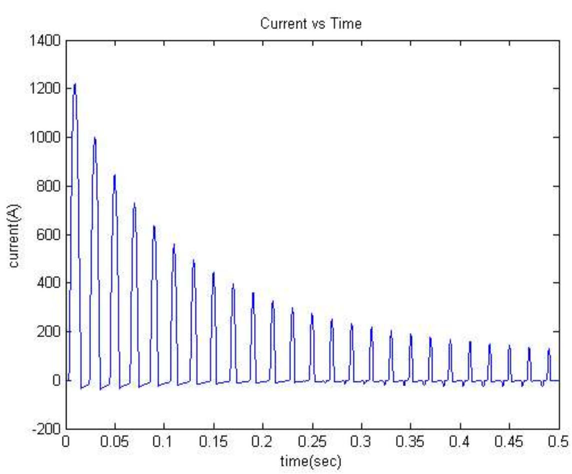

Fig.6: inrush current wave form with source resistance =30 Ω

3.3. A sequential phase energization technique

By applying ***the sequential phase energization technique*** [13, 14], when the primary side of the transformer, which is Y grounded is energized. If a resistor is inserted between the ground and neutral point, it will reduce the inrush current. It acts as a series inserted resistor. The scheme shown in fig.7, is illustrating the basic idea of the technique.

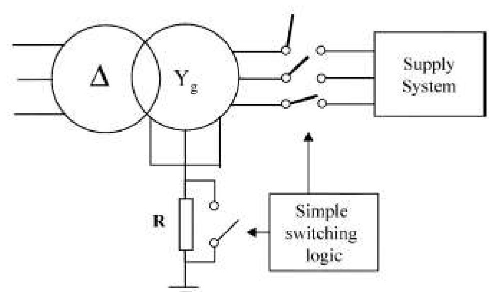

Fig.7 A Sequential phase energization inrush mitigation technique.

At normal condition the neutral current is close to zero so the bypass breaker has low rating so it may not be needed. Sufficient reduction not produces simultaneous closing of all three phase breaker. By energizing each phase of transformer in sequence so the inserted resistor could behave as a series resistor and the result would be improve.

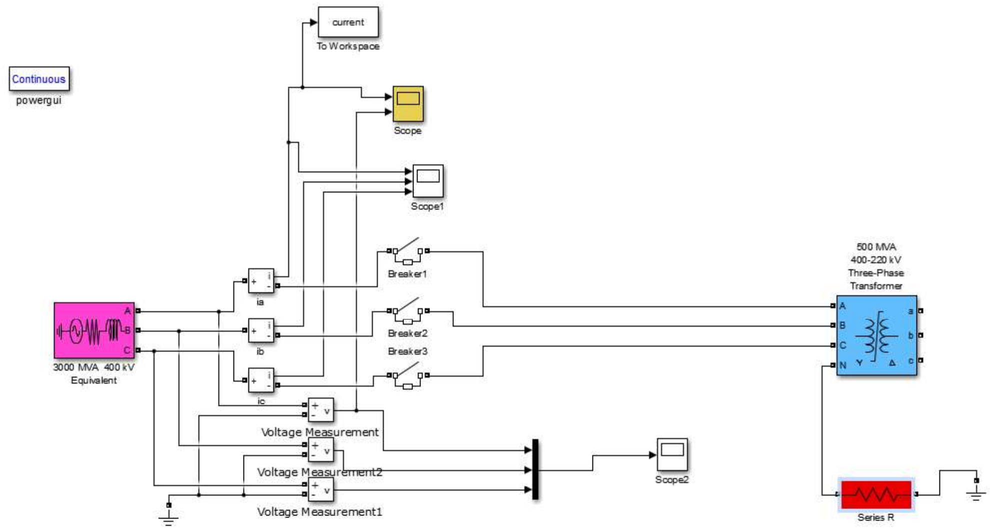

Fig.8 Sequential phase energization using Matlab Simulink model with changing the value of neutral resistance R_n.

This method has the advantages, which are: less expensive because at steady state it carries a small neutral current, there is only one resistor, very effective, simple method, contribute the damping of transient, reduce the voltage imposed on the transformer core. The idea of this method is using a resistor inserted between the ground and neutral point; it will reduce the inrush current. It acts as a series inserted resistor. Simulation of the system, using MATLAB SIMULINK as shown in figure 8, is used.

Fig 9 show the wave form of inrush current with no mitigation method is used, the inrush current reach the value of 1341 A.

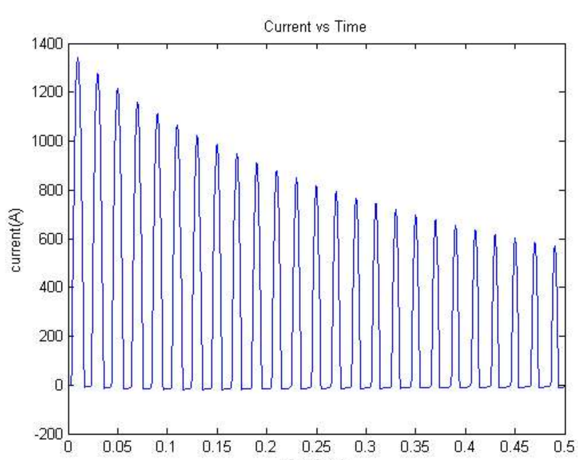

Fig 9: wave form of inrush current without any techniques is used

Using, sequential phase energization technique and taking the size of the neutral resistance for 30%, inrush current reduction ratio [10].

***Inrush current reduction ratio = i peak,** $_{Rn\ calculated}$ **/ I peak,** $_{Rn=0}$*

With taken a delay time between the three phases (phase A, B, and C) as 0.005 sec, .011666 sec. and 0.018333 sec respectively and with taken the value for neutral resistance $R_N = 159\Omega$.

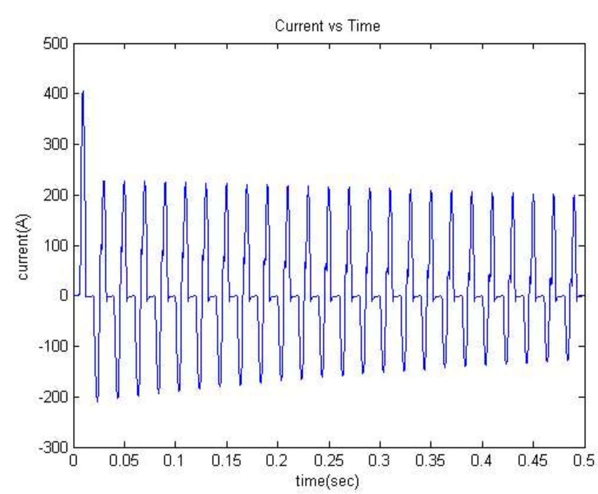

Fig 10: wave form of inrush current for phase A at neutral resistance 159Ω

From the results obtained, as seen from figure 10, the inrush current reaches the value of 404 A. With selection of $R_N = 159\Omega$, the peak value of the inrush current in phase A decreases to 30% of its value.

Conclusion

In this work, three different techniques, for the control and mitigation of the inrush current phenomena in power transformers, are studied and investigated. From the results obtained:

- Applying the technique ‘point on wave switching’, shows that, as switching angle increases inrush current decreased, with no control method, the value of inrush current is 1341 A and with switching angle 90^0 the value of inrush current is 552 A.

- Applying the ‘source resistance’ technique shows that, as the source resistance is increased, the value of inrush current is decreased so the value of inrush current at source resistance 30Ω is 1221 A.

- While for the ‘a sequential phase energization‘ technique and for R_N is taken = 159Ω, the value of inrush current is reduced to 404 A. so the technique of a sequential phase energization is effective.

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