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A Novel Transient Current Limiter Based on Three-Phase Thyristor Bridge for Y-yg Transformers

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ABSTRACT

The transformer in flux current may be a transient current that happens in electrical devices has been charged. This current depends on completely different parameters probably the voltage magnitude, the switching on angle the permanent flux, the core physical phemeon characteristics, the primary circuit resistance, etc. To beat the issues arising owing to transients, these are required to be suppressed.In this paper, an easy and economical techniquie is conferred to limit the transient current of the Y-yg transformers. One amongst the most benefit of this technique is it doesn't would like any negative feedback circuit or activity unit. The tactic relies on a three-phase thyristors bridge single RL reactor with the individual phases of electrical device. Since the amount of thyristors is reduced, the voltage ripple, electrical losses and therefore the malfunction likelihood due to device failure is reduced significantly. The projected technique has been simulated by MATLAB simulation. It's shown that the projected method is a lot of economical for the transient current limitation of Y-yg transformers.

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1. INTRODUCTION

At the point when a transformer is charged, a transient present, known as charging Inrush Current, by and large streams for a little period of time until typical flux condition are secured. Amid most handy framework conditions, this present transient is of a high values, may be the ten times the full load current of the transformer. This transient which is rich in all harmonics has been found to bring about wide boiling over disturbing influences in influence framework and influence supplies [1]-[2]. Lately a few arrangements have been prescribed to beat the issue like diode bridge with DC reactor and voltage source PWM converter are utilized [3], putting the resistance in arrangement or at the impartial point to the twisting of transformers [4]. These strategies have some disadvantage like voltage drop or need detour resistance, extra control circuits and exchanging gadgets. However a few analysts proposed different techniques in view of flux estimations [5]. Be that as it may, measuring this parameter is not helpful as alternate parameters.

The plan of this paper to talk about the system of computing transient current and strategy for lessening transient present or alleviating its endeavors in three stage transformers with an extensive variety of attractive and electrical design.

2. STRUCTURE OF TRANSFORMER CORE

Three-stage transformers contrast one from the other both in their attractive and winding association. The attractive circuit of 3-stage transformers can take any of the structures indicated in Figures 1(a), 1(b) and 1(c). Just the instance of the transformer banks demonstrated in Figure 1(a) agrees to the confinements forced on the magnetic circuit to permit it to be enunciated to by a solitary stage model. The three-limb and five-limb magnetic cores demonstrated in Figures 1(a) and 1(c) is more perplexing because of the coupling between the different limbs.

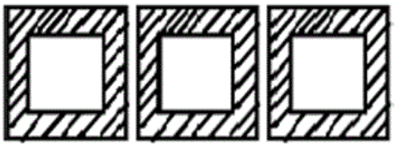

Figure 1(a). Magnetic core of three phase transformer bank

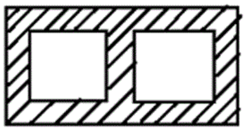

Figure 1(b). Three-limb Magnetic Core

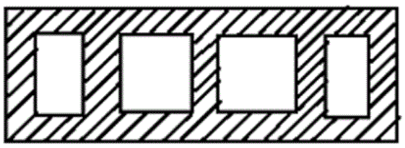

Figure 1(c). Five-limb magnetic core

In this work, the attractive circuits of the individual stages are considered totally free, which entirely applies just to transformer banks. Nonetheless, as this work focuses essentially on the determination of the transient current under saturated conditions, the magnetic circuits demonstrated in Figures 1(b) and 1(c) can be approximated to three different magnetic circuits.

3. ANALYSIS OF TRANSIENT CURRENT

Transient current in transformer results from any sudden change in the charging voltage. The transient current waveform contains a substantial and durable DC segment and harmonics [5]. It may accomplish expansive crest qualities toward the starting rots significantly after a couple of second, yet its full rot happens when a few seconds. A waveform of regular transient current is demonstrated in Figure 2. It shows even harmonic without a doubt and RL balance of shifted extents regularly comprising of high estimation of second harmonic.

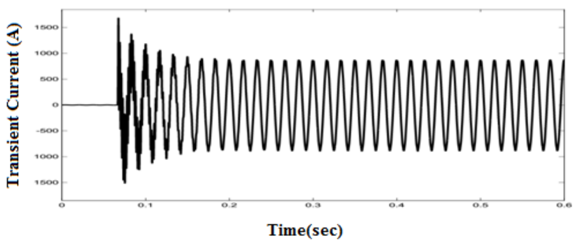

Figure 2. Transient current of transformer at 100% nominal voltage

4. THREE SINGLE -PHASE TRANSFORMER CONNECTED WITH TCL IN SERIES

The TCL, indicated in Figure 3, has a low resistance curl with a specific end goal to increase better results. The arrangement TCL is straightforward and works in two modes. The principal mode is the charging mode and the second one is the releasing mode. At the point when the transformer is empowered, one sets of Thyristor (e.g. T1 and T4 or T2 and T3) is on, so the RL current reactor drives in arrangement with source and transformer.

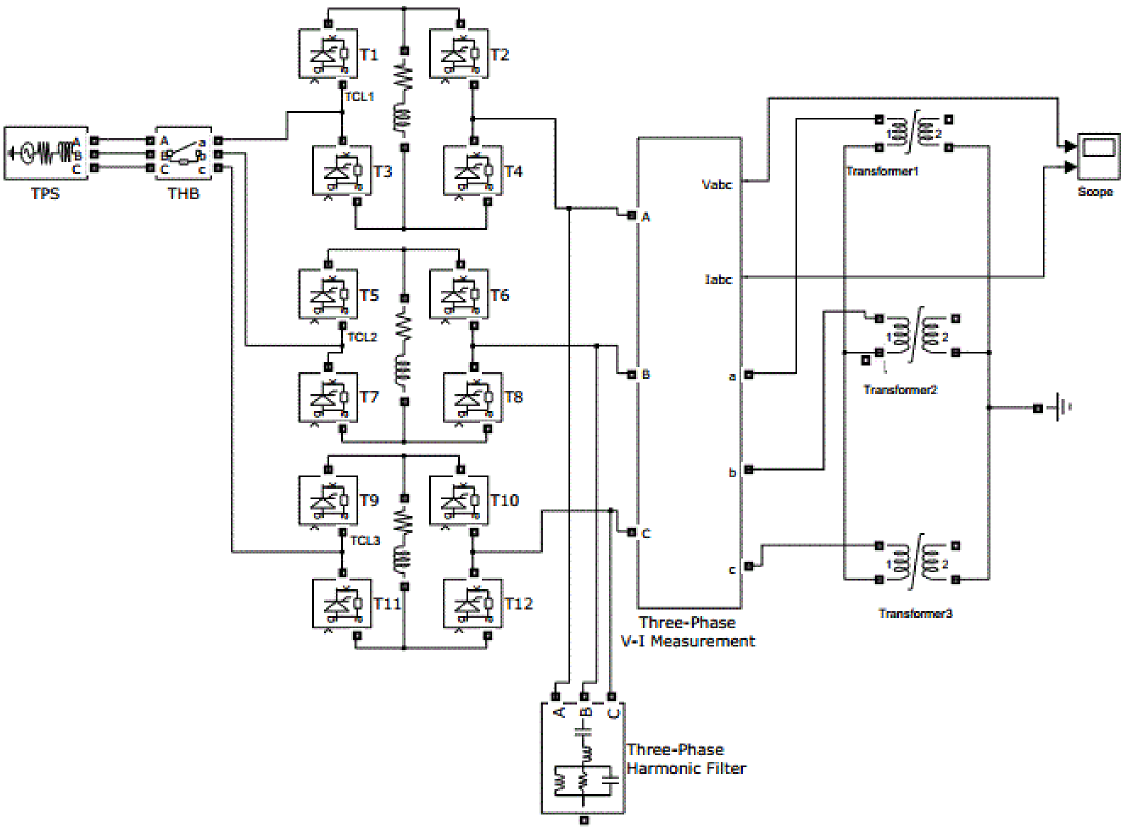

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Figure 3. Equivalent circuit of three, single-phase TCLs

Under this condition, on account of the constant change in the line current, the voltage drop (L_{TCL} (di_1 /dt)) will create a blocking impact in the circuit, so the plentifulness of the transient current lessens significantly. The present mathematical statement in charging mode is composed, as takes after [5].

$$i(t) = e^{-(R/L)t}\left(\frac{-Vp}{\sqrt{(R^2)+(wL^{2)}}}\sin(wt_1-\delta)+\frac{2V_{TF}}{R}\right)+\frac{Vp}{\sqrt{(R^2)+(wL^2)}}\sin(wt_2-\delta)-\frac{V_{TF}}{R} \tag{1}$$

where $R = R_P + R_{TCL}$ (R_p is the resistance in the essential side of the transformer and R_{TCL} is the RL reactor resistance), $L = L_p + L_{TCL} + L_m$ (L_p is the leakage spillage inductance in the essential side of the transformer and L_{TCL} is the RL reactor inductance and Lm is the charging inductance of the transformer), V_{TF} is the forward thyristor voltage drop and is the crest plentifulness of the utility voltage. L_{TCL} is the RL reactor inductance and L_m is the magnetizing inductance of the transformer), V_{TF} is the forward thyristor voltage drop and V_p is the peak amplitude of the utility voltage.

$$i(t) = i_{TCL}$$

$$\delta = \arctan\left(\frac{Lw}{R}\right)$$

It ought to be noticed that the polarizing inductance of the transformer is not consistent and can be partitioned into two sections: One is the soaked inductance and the second one is not-immersed inductance. In this paper, the transformer is considered in immersion mode [6]. The charging mode proceeds until the TCL current achieves its first crest. At that point, the releasing mode will begin and can proceed for a few cycles. In this condition, all thyristors are on as demonstrated in Figure 3. Therefore the circle mathematical statement can be composed as takes after

$$L_{TCL}\frac{di_{TCL}}{dt} + R_{TCL}i_{TCL} + 2V_{TF} = 0. \tag{2}$$

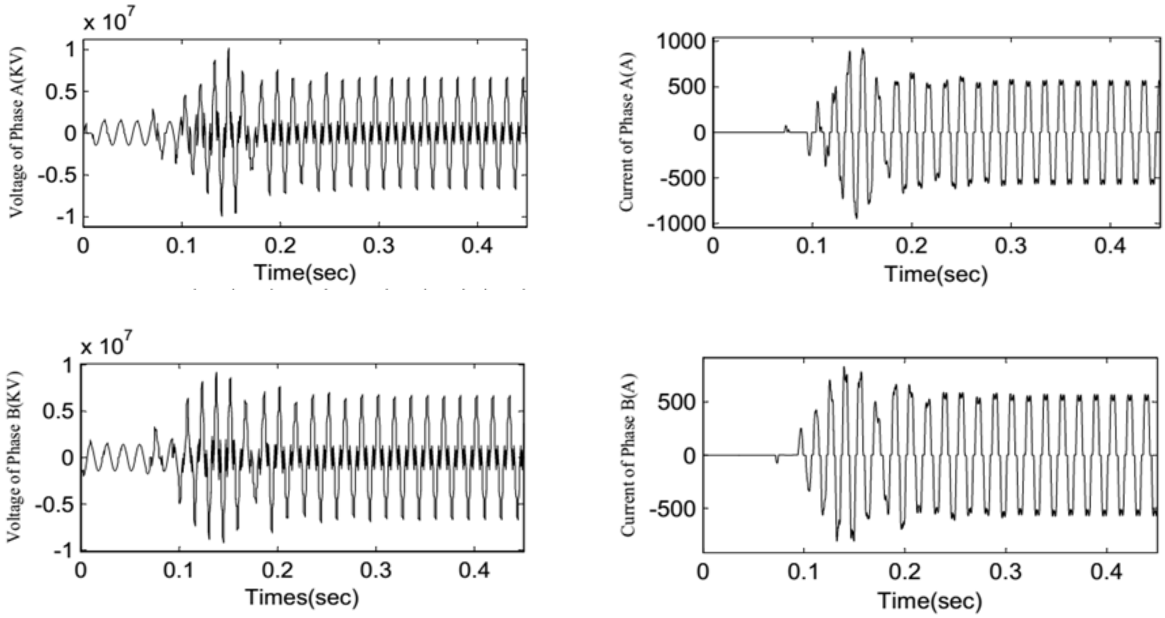
In the releasing mode, the TCL current is written as follows

$$i_{TCL} = e^{-(R_{TCL}/L_{TCL})t}\left(i_{\max} + \frac{2V_{TF}}{R_{TCL}}\right) - \frac{2V_{TF}}{R_{TCL}} \tag{3}$$

After a few cycles, the abundancy of the RL reactor current in the AC structure ((di_{TCL}/dt) = 0) diminishes to achieve the ordinary circuit current. Thus, the TCL does not have any impressive impact on the typical mode operation of the framework. The estimation of inductance in the TCL is critical. By expanding L_{TCL}, the transient current adequacy will diminish a great deal [7], so the transient current and its results can be disposed of. There are a few restrictions to build the inductance, as indicated in (4), i.e;

$$L_{TCL} = \frac{\left(R_p + R_{TCL}\right)T}{4\ln\left(\left(V_{TS} - 2V_{TF}\right)/\left(V_{TS} - 2V_{TF} - Ri_{\max}\right)\right)} - L_p - L_m \tag{4}$$

Where R_p is the resistance in the primary side of the transformer, R_{TCL} is the resistance of the RL reactor, L_p is the spillage inductance in the primary side of the transformer and L_m is the charging inductance of the transformer, V_{TF} is the Thyristor forward voltage drop and V_{TS} is the normal of the redressed source voltage. Figure 3 demonstrates the TCL for a three-stage transformer. As indicated in Figure 4, the primary winding voltage and current of three-phase transformers, though Figure 5 displays how it can be restricted by the TCL.



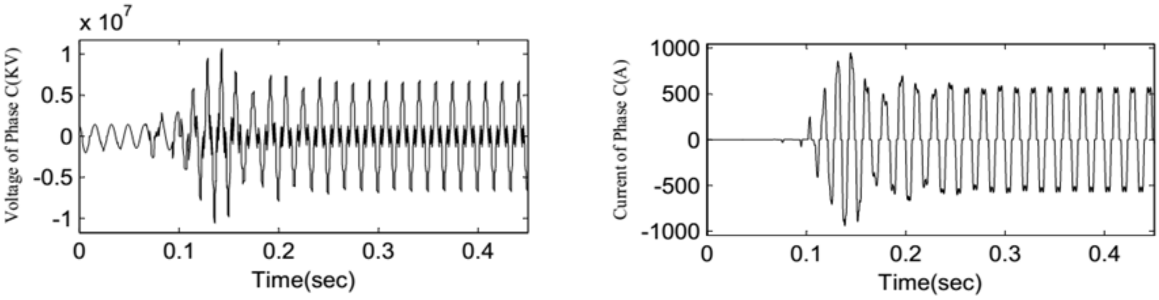


Figure 4. Voltage and Current of Phase A, B, & C without TCL

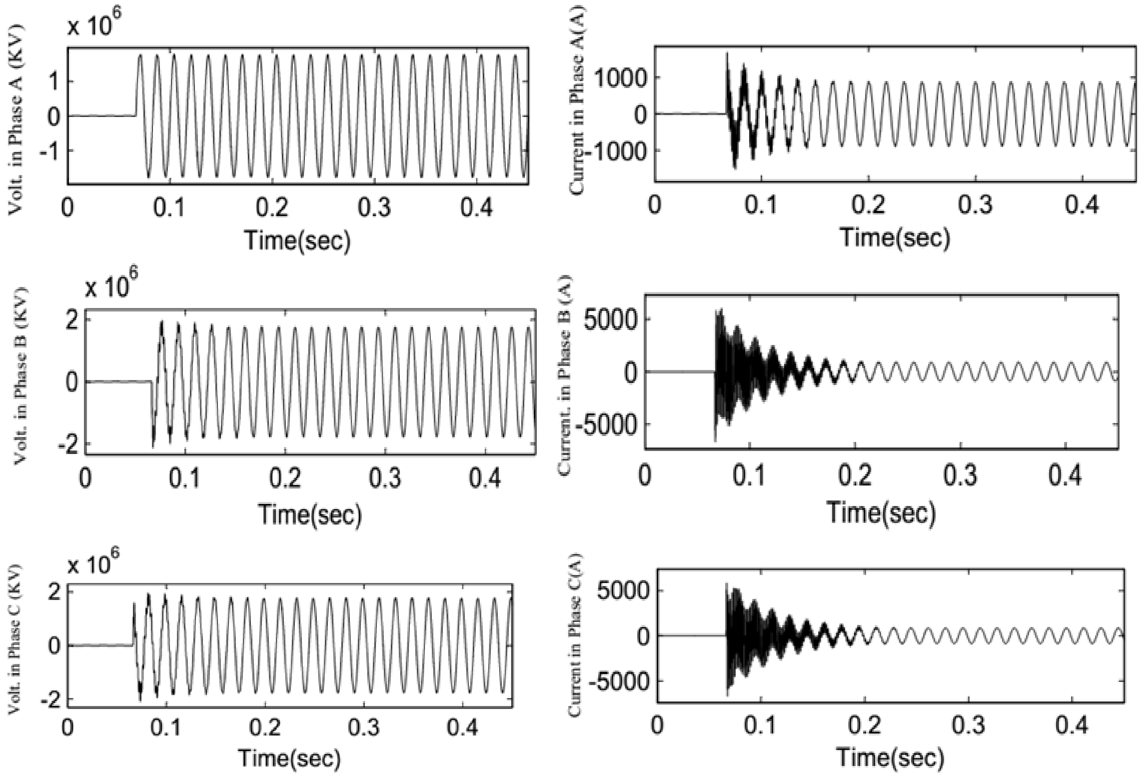


Figure 5 Voltage and Current of Phase A, B, & C with TCL

5. PROPOSED TCL

As demonstrated in Figure3, the transient current of the three-stage transformer can be controlled by utilizing twelve thyristor of the arrangement TCL. Through these thyristor, extensive current of the stacked transformers streams. Consequently they are expensive and due to getting old, the voltage drop or current swell may be expanded amid the typical operation mode. The new arrangement, which is indicated in Figure 5, just uses six thyristors as a TCL in Y-yg transformers.

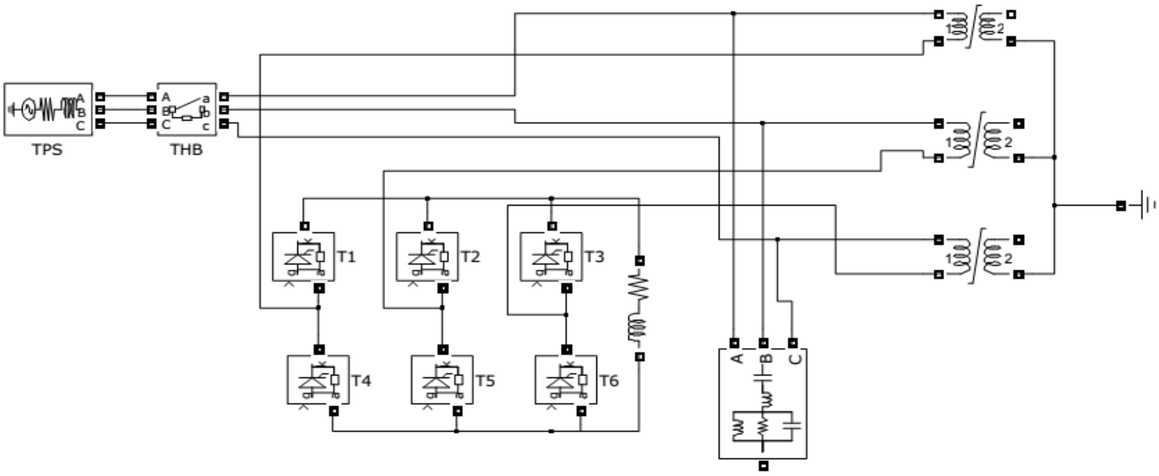


Figure 5. Proposed TCL connected to Y-yg transformer

The operation of the new TCL can be separated into two operation modes; charging and releasing modes. At initial, one of the three thyristors of T1, T2 and T3 and one of the three thyristors of T4, T5 and T6 are in the ON state. At that point, the circle, which is demonstrated in Figure 6, is framed and the present can be acquired. In this paper, the recompense current is disregarded. To identify the phenomenon, the most ideal way is measuring the three stage voltages between the TCL and the ground [8]-[13]. This condition will proceed until the TCL current achieves the first crest. At that point, the releasing mode will begin and can proceed for a few cycles. For this situation, all the thyristors are in on state so the RL reactors current will be released in circles.

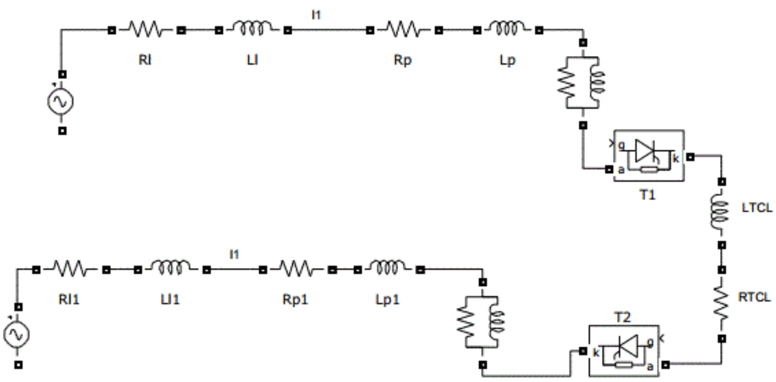


Figure 6. Coil charging mode

5.1. CHARGING MODE

According to Figure 6, the circle comparison with disregarding R1 and L1 is communicated as,
Charging method of conducting coil

$$V_{LL}\sin(wt-30) = 2R_p i_1 + 2L_p\frac{di_1}{dt} + 2V_{TF} + L_{TCL}\frac{di_1}{dt} + R_{TCL} i_1 + 2\frac{d\varphi}{dt} \tag{5}$$

Differentiating (5) leads to the following equation

$$wV_{LL}\cos(wt-30) = 2R_p\frac{di_1}{dt} + 2L_p\frac{d^2 i_1}{dt^2} + L_{TCL}\frac{d^2 i_1}{dt^2} + R_{TCL}\frac{di_1}{dt} + 2\frac{d^2\varphi}{dt^2} \tag{6}$$

It is clear that

$$i_1(t) = i_m(t) + i_c(t) \tag{7}$$

$$\frac{d\phi}{dt} = R_c i_c \tag{8}$$

And

$$\frac{d\ \phi}{dt} = \frac{d\phi}{di_m} * \frac{di_m}{dt} = L_m \frac{di_m}{dt} \tag{9}$$

Utilizing (7), (8) and (9), the accompanying comparison is communicated as

$$i(t) = i_{m1}e^{Ft} + i_{m2}e^{Gt} + i_{m3}\sin(wt + \phi) + i_{m4}$$

$$\frac{d^2\phi}{dt^2} = R_c \frac{di_1}{dt} - \frac{R_c}{L_m}\frac{d\phi}{dt} \tag{10}$$

Supplanting (10) in (6), prompts (11).

$$wV_{LL}\cos(wt - 30) = 2R_p \frac{di_1}{dt} + 2L_p \frac{d^2 i_1}{dt^2} + L_{TCL}\frac{d^2 i_1}{dt^2} + R_{TCL}\frac{di_1}{dt} + 2(R_c \frac{di_1}{dt} - \frac{R_c}{L_m}\frac{d\varphi}{dt}) \tag{11}$$

Comparison (5) can be revised in the accompanying structure

$$A\frac{d^2 i_1}{dt^2} + B\frac{di_1}{dt} + Ci_1 = D\sin(wt + \alpha) + E \tag{12}$$

Where

$$A = L_m \frac{2L_p + L_{TCL}}{R_C}$$

$$B = L_m(\frac{2R_p + R_{TCL}}{R_c}) + 2L_p + L_{TCL} + 2L_m$$

$$C = 2R_p + R_{TCL}, D = V_{LL}\sqrt{\frac{R_c^2 + L_m^2 w^2}{(R_c)^2}}, E = -2V_{TF}, \alpha = \varphi - 30, \cos\varphi = \frac{V_{LL}}{D}$$

Using Laplace transform, (12) can be rewritten, as follows

$$A(s^2 I(s) - sI(0) - I^{'}(0)) + B(sI(s) - I(0)) + CI(s) = D\frac{s\sin(\alpha) + w\cos(\alpha)}{s^2 + w^2} + \frac{E}{S} \tag{13}$$

Consequently

$$I(s) = D\frac{s\sin(\alpha)}{(s^2 + \omega^2)(As^2 + Bs + C)} + D\frac{\omega\cos(\alpha)}{(s^2 + \omega^2)(As^2 + Bs + C)} + \frac{E}{s(As^2 + Bs + C)} \tag{14}$$

Utilizing the inverse Laplace transform, the transient current somewhere around 0 and T/4 can be dictated by the accompanying mathematical

$$i(t) = i_{m1}e^{Ft} + i_{m2}e^{Gt} + i_{m3}\sin(wt + \varphi) + i_{m4} \tag{15}$$

where

$$i_{m1} = \left(\frac{E}{F(F-G)} + \frac{DFSin(\alpha)}{(F-G)(F^2+w^2)} + \frac{Dw\cos(\alpha)}{(F-G)(F^2+w^2} \right)$$

$$i_{m2} = \left(\frac{E}{G(G-F)} + \frac{DG\sin(\alpha)}{(G-F)(G^2+w^2)} + \frac{Dw\cos(\alpha)}{(G-F)(G^2+w^2)} \right)$$

$$i_{m3} = \left(\frac{2wD}{\sqrt{4w^4(F+G)^2(2wFG-2w^3)^2}} \right)$$

$$i_{m4} = \frac{E}{GF}$$

$$F = \frac{-B+\sqrt{B^2-4AC}}{2A} \ , \ G = \frac{-B-\sqrt{B^2-4AC}}{2A}$$

$$\cos(\gamma) = \frac{(2wFG-2w^3)\cos(\alpha)-(2w^2(F+G))\sin(\alpha)}{\sqrt{4w^4(F+G)^2+(2wFG-2w^3)^2}}$$

As given in (15), the principle a piece of the present in charging mode somewhere around 0 and T/4 comprises of two exponential and one sinusoidal segment. Since F and G are negative, these two exponential parts will rot.

5.2. RELEASING MODE

The second method of the TCL is the releasing mode, so the circle comparison can be composed by the accompanying mathematical statement

$$2V_{TF} + L_{TCL}\frac{di_{TCL}}{dt} + R_{TCL}\frac{di_{TCL}}{dt} = 0 \tag{16}$$

Explaining the mathematical statement for i(t) we have

$$i_{TCL} = e^{-(R_{TCL}/L_{TCL})(t-(T/4))}\left(i_{\max} + \frac{2V_{TF}}{R} \right) - \frac{2V_{TF}}{R_{TCL}} \tag{17}$$

Where the most extreme current i_{max} is in charging mode as an introductory condition for (16). As is given in (17), the first part of the mathematical statement is exponential with a negative example, so it will decay after a few cycles.

5.3. PREFERRED VALUE FOR L_{TCL}

Since the computation of L_{TCL} from the quadratic mathematical statement is lengthy, by expecting R_c huge, the levels of (5) will lessening to one. By explaining the lessened request mathematical statement, i(t) can be communicated by the accompanying comparison

$$i(t) = e^{-(R/L)t}\left(\frac{-V_{LL}}{\sqrt{(R^2)+(wL^{2)}}}\sin(wt_1-30-\delta) + \frac{2V_{TF}}{R} \right) + \frac{V_{LL}}{\sqrt{(R^2)+(wL)^2}}\sin(wt_2-30-\delta) - \frac{V_{TF}}{R} \tag{18}$$

where $\delta = \arctan\left(\frac{Lw}{R}\right)$ and t_1 is the beginning moment. In this circumstance, substituting the i_{max} in i (t), (18) is communicated as [10]

$$i_{\max} = \frac{V_{TS} - 2V_{TF}}{R}(1 - e^{-(RT/4L)}) \quad (19)$$

Where T is the period of the power frequency and $V_{TS} = (2\sqrt{2}/\Pi)V$ is the average of the rectified source voltage.

$$\frac{R}{L}\frac{T}{4} = \ln\left(\frac{V_{TS} - 2V_{TF}}{V_{TS} - 2V_{TF} - Ri_{\max}}\right) \quad (20)$$

By, the preferred value for L_{TCL} in three-phase Y-yg power transformers is communicated as

$$L_{TCL} = \frac{RT}{4\ln((V_{TS} - 2V_{T})/(V_{TS} - 2V_{TF} - Ri_{\max}))} - 2L_p - 2L_m \quad (21)$$

6. RESULTS AND DISCUSSIONS

The simulation results are completed in a MATLAB situation. The simulation parameters are given in Table 1. Figure 7(a) and 7(b) demonstrates the transformer transient voltage and current of phase A, B and C. Under this condition, the new TCL limits the no-load current to 800, 50 and 30 A in phases A, B and C, separately. As indicated in Figure 4(a) and 4(b), the transient voltage and current without utilizing the TCL can surpass past 5000A or it can achieve 100A utilizing the ordinary TCL (indicated in Figure 3). Figure 8(a) and 8(b) demonstrates the simulation result of three phase voltage and current without utilizing of transient current limiter (TCL) and double tuned harmonic filter.

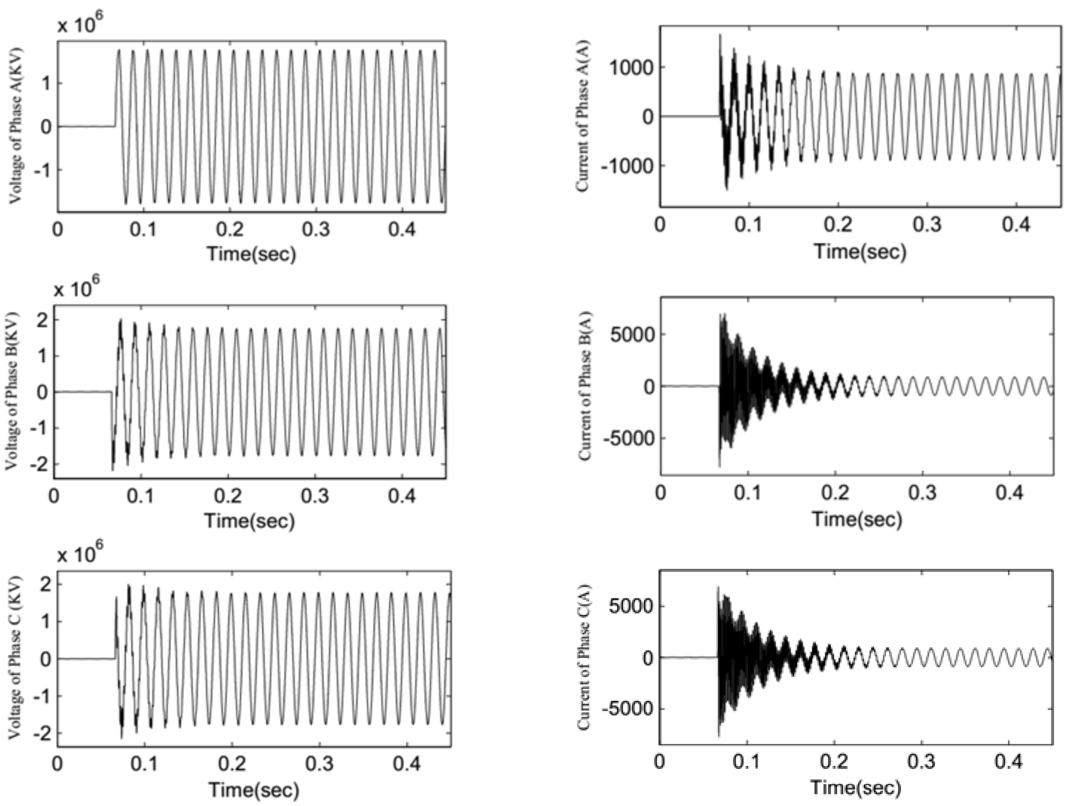


Figure 7 Voltages and Currents of Phase A, B, & C with TCL

Table 1. Simulation parameters

Parameter	Value	Parameter	Value
R_p	0.65Ω	L_{TCL}	0.8H
R_1	0.05Ω	R_{TCL}	0.03Ω
L_p	0.0025H	V_{TF}	10V
L_1	0.001H	ω	314.15
L_m	0.9H	S	20 MVA
R_c	2000Ω	V_{LL}	2000(V_{rms})

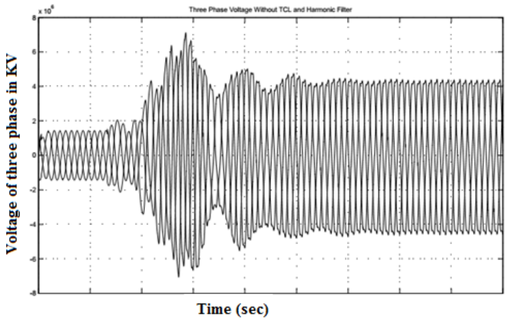


Figure 8(a). Simulation outcome of three phase - voltage without TCL and harmonic filter.

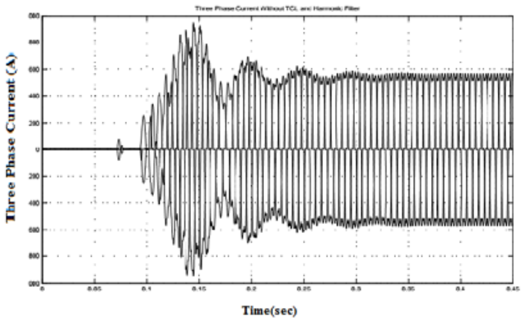


Figure 8(b). Simulation outcome of three phase - current without TCL and harmonic filter.

Figure 9(a), 9(b) and 10(a), 10(b) delineate the harmonic investigation for the transformer voltage and current in three phases, with utilizing TCL. An examination of these figures demonstrates that utilizing the proposed TCL comes about as a part of the lessening of the abundancy of the transient voltage and current by weakening the RL segment.

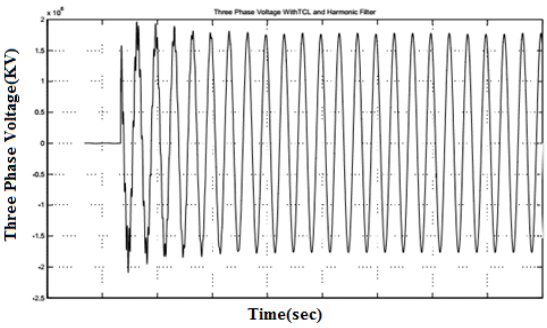


Figure 9(a). Simulation outcome of three phase - voltage with TCL and harmonic filter.

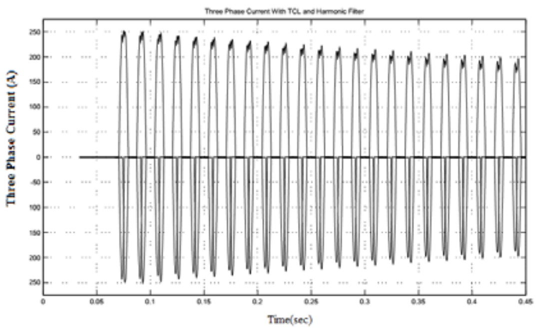


Figure 9(b). Simulation outcome of three phase - current with TCL and harmonic filter.

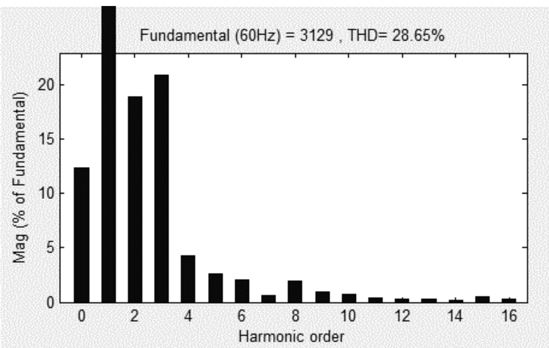


Figure 10(a) Total Harmonic Distortion without TCL

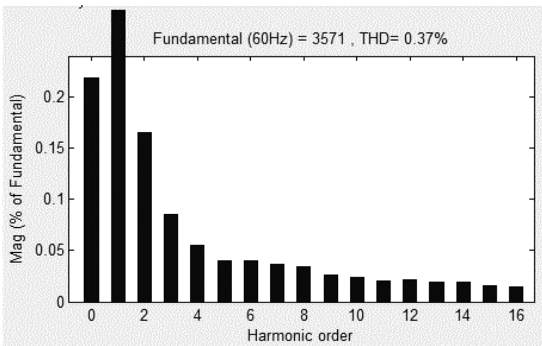


Figure 10(b) Total Harmonic Distortion with TCL

7. CONCLUSION

In this paper, a novel TCL, taking into account a three-stage thyristor bridge for the alleviation of Y-yg transformers transient voltage and current has been proposed. The proposed TCL has a basic topology, does not require any controlling circuit and uses less thyristors than different TCLs. What's more, it prompts lower swell and voltage drop and lower burden voltage mutilation for transformers. The exploratory and recreation results demonstrate the viability of the proposed TCL. What's more, it ought to be noticed that the authors have concentrated on the essential winding of this transformer. The secondary side is open circuit. So it can be said that the outcomes can be the same for Y-yg transformers which are regular in the dispersion system.

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