Novel Model of Circuit Breaker for 275kV Substation

Hamid Radmanesh and Amir Heidary

***Abstract*—In this paper, at first non-conventional ferroresonance phenomenon is introduced, then various types of ferroresonance in a potential transformer is simulated. So, effect of circuit breaker shunt resistance on controlling chaotic ferroresonance in a potential transformer has been studied, it is shows that for some parameter value this resistance cannot clamp the ferroresonance overvoltages in potential transformers. Finally effect of neutral earth resistance on the controlling these oscillations has been investigated. The proposed approach was implemented using MATLAB, and results are presented. It is concluded that this resistance generally can cause ferroresonance decreasing. For confirmation this aspect simulation has been done on a one phase potential transformer rated 100VA, 275kV. The simulation results show that considering the neutral earth resistance on the system configuration, shows a great controlling effect on ferroresonance nonlinear overvoltages.**

***Index Terms*—Ferroresonance oscillation, stabilizing, chaos control, potential transformer, circuit breaker shunt resistance.**

I. Introduction

Ferroresonance is initiated by improper switching operation, routine switching, or load shedding involving a high voltage transmission line. It can result in Unpredictable overvoltage and high currents. The prerequisite for ferroresonance is a circuit containing iron core inductance and a capacitance. Kieny first suggested applying chaos to the study of ferroresonance in electric power circuits [1]. He studied the possibility of ferroresonance in power system, particularly in the presence of long capacitive lines as highlighted by occurrences in France in 1982, and produced a bifurcation diagram indicating stable and unstable areas of operation. A special ferroresonance phenomenon on 3-phase66kV VT-generation of 20 Hz zero sequence continuous voltage is given in [2]. Typical cases of ferroresonance are reported in [3], [4], in these papers power transformer and VTs has been investigated due to ferroresonance overvoltage. Digital simulation of transient in power system has been done in [5]. Application of nonlinear dynamics and chaos to ferroresonance in the distribution systems can be found in [6]. The susceptibility of a ferroresonance circuit to a quasi-periodic and frequency locked oscillations has been presented in [7]. In this case, investigation of ferroresonance is done upon the new branch of chaos theory which is quasiperiodic oscillation in the power system and finally ferroresonance appears by this route. Modeling iron core nonlinearities has been illustrated in [8]. Mozaffari is investigated the ferroresonance in power transformer and effect of initial condition on this phenomenon. He analyzed condition of occurring chaos in the transformer and suggested the reduced equivalent circuit for power system including power switch and trans [9], [10]. The mitigating effect of transformer connected in parallel to a MOSA has been illustrated in [11]. Analysis of ferroresonance in voltage transformer has been investigated by zahawi in [12], [13]. Analysis of ferroresonance phenomena in the power transformers including neutral resistance effect has been reported in [14]. Ferroresonance conditions associated with a 13 kV voltage regulator during back-feed conditions are given in [15]. Performance of various magnetic core models in comparison with the laboratory test results of a ferroresonance test on a 33 kV voltage transformer investigated in [16]. Mitigating ferroresonance in voltage transformers in ungrounded MV networks has been reported in [17]. An approach for determining the subsystem experiencing and producing a bifurcation in a power system dynamic model has been reported in [18]. Then controlling ferroresonance oscillation has been investigated in [19], [20]. It is shown controlling ferroresonance in voltage transformer including nonlinear core losses by considering circuit breaker shunt resistance effect, and clearly shows the effect of core losses nonlinearity on the system behavior and margin of occurring ferroresonance. In [21], electromagnetic voltage transformer has been studied in the case of nonlinear core losses by applying metal oxide surge arrester in parallel with it and simulations have shown that a change in the value of the equivalent line to ground capacitance, may originate different types of ferroresonance overvoltage. In current paper, a novel model of circuit breaker for decreasing of high amplitude ferroresonance oscillation is used. Using of this method results improving voltage waveform which leads to protection from insulation, fuses and switchgears.

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II. System Modeling without Neutral Resistance

Fig. 1 shows the circuit diagram of system components at the 275 kV substations. Ferroresonance occur in circuit involving a linear capacitance and nonlinear inductance. In high voltage systems capacitance is due to reserve busbars that are near of main busbars and nonlinear inductance is due to voltage transformer. Single line diagram of circuit is shown in Fig. 1.

When voltage is induced in reserve busbar and disconnectors in both side of circuit breaker are opened and ferroresonance is produced. Grading capacitors and capacitors between main busbar and reserve busbar are caused that value of this induced voltage can be nominal voltage nearly. When disconnectors are closed capacitors are connected to under voltage busbar (main busbar) and also reserve busbar. Because of low thermal capacity of voltage transformers ferroresonance can damage to its insulation severely. Thevinen equivalent circuit of Fig. 1 is shown in Fig. 2. In Fig. 2 grading capacitors are series in thevenin model. Capacitors between main and reserve busbars and between busbars and earth are modeled as a shunt capacitor with voltage transformer. Fig.2 shows the basic ferroresonance equivalent circuit used in this analysis. The resistor R represents transformer core losses. In [22] accurate model for magnetization curve of core considering hysteresis, was introduced but in current paper the nonlinear transformer magnetization curve was modeled by a single valued seventh order polynomial obtained from the transformer magnetization curve[23].

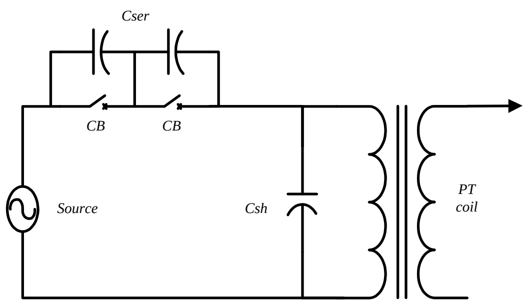

Fig. 1. System one line diagram arrangement resulting to PT ferroresonance

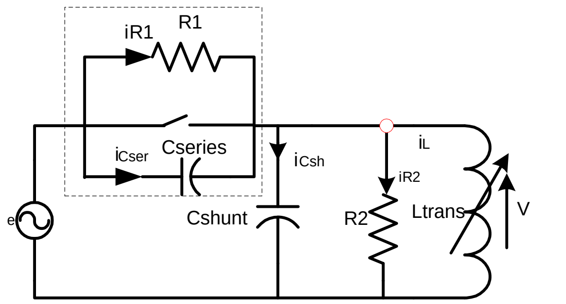

Fig. 2. Basic reduced equivalent ferroresonance circuit including shunt resistance effect [19]

In Fig. 2, E is the RMS supply phase voltage, C_{series} is the circuit breaker grading capacitance, and C_{shunt} is the total phase-to-earth capacitance of the arrangement. The resistor R represents a potential transformer core losses, R_1 is the circuit breaker air gape effect. In the peak current range flux-current linkage can be approximated by a highly nonlinear equation, here the $\lambda - i$ characteristic of the potential transformer is modeled as in [24] by the polynomial

$$i = a\lambda + b\lambda^7 \tag{1}$$

where $a = 3.14,\ b = 0.41$

III. System Dynamic And Equation

Mathematical analysis of equivalent circuit by applying KVL and KCL has been done and equations of system can be presented as below:

$$e = \sqrt{2}E\sin(\omega t) \tag{2}$$

$$\begin{aligned}
&\frac{C_{series}}{(C_{series}+C_{shunt})}\left(\sqrt{2}E\,\omega\cos\omega t\right)+ \\
&\left(\frac{1}{R_1(C_{series}+C_{shunt})}\right)\sqrt{2}E\sin\omega t = \frac{d^2\lambda}{dt^2} \\
&+\left(\frac{R_1+R_2}{R_1R_2(C_{series}+C_{shunt})}\right)\frac{d\lambda}{dt} \\
&+\frac{1}{C_{series}+C_{shunt}}(a\lambda+b\lambda^7)
\end{aligned} \tag{3}$$

where ω is supply frequency, and E is the rms supply phase voltage and in equation (1) a=3.4 and b=0.41 are the seven order polynomial sufficient [25]. The time behavior of the basic ferroresonance circuit is described by (3). Table I shows base values used in the analysis and parameters different states are given in Table II.

TABLE I: Base Values of the System Used for Simulation

Base value of input voltage	158 kV
Base value of volt-amperes	100 VA
Base angular Frequency	2π60 rad/sec

TABLE II: Parameters Used for Various States Simulation

System Parameters	C_{series} (nf)	C_{shunt} (nf)	R_{core} (MΩ)	R_n (MΩ)	ω (rad/sec)	E (KV)
value	3	0.1	1900	25	314	275

IV. System Descriptions Connecting Neutral Earth Resistance

Neutral Grounding Resistors are used for resistance grounding of industrial power system. They are generally connected between ground and neutral of transformers, and grounding transformers. Neutral grounding resistors are used in order to limit maximum fault current to a value which will not damage the equipment in the power system, yet allow sufficient flow of fault current to operate protective relays to clear the fault. Although it is possible to limit fault currents with high resistance neutral grounding resistors, earth short circuit currents can be extremely reduced. As a result of this fact, protection devices may not sense the fault. Therefore, it is the most common application to limit single phase fault currents with low resistance neutral grounding resistors to approximately rated current of transformer. This resistors are designed to absorb a large amount of energy without exceeding temperaturea limitations cuased by ferroresonance phenomenon. Suggested neutral grounding resistors can be used for indoor and outdoor..In this case, the system which was considered for simulation is shown in Fig.3 while neutral grounding resistor has been connected to the transformer.

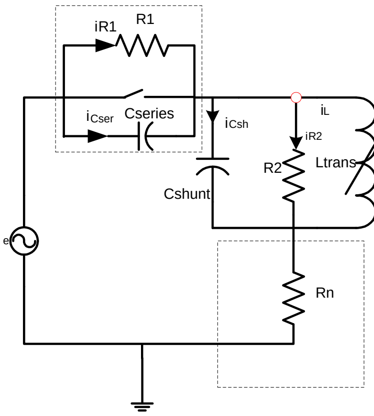

Fig. 3. Basic reduced equivalent ferroresonance circuit with considering neutral earth resistance including shunt resistance

Typical values for various system parameters has been considered for simulation were kept the same by the case 1, while neutral resistance has been added to the system and its value is given below:

$$R_{neutral} = 25M\Omega$$

The differential equation for the circuit in Fig.3 can be presented as follows:

$$\begin{aligned}
&C_{ser}\sqrt{2}E\omega\cos\omega t - C_{ser}\frac{d^2\lambda}{dt^2} - C_{ser}C_{sh}R_n\frac{d^2 v_L}{dt^2} \\
&-C_{ser}\frac{R_n}{R_2}\frac{dv_L}{dt} - C_{ser}R_n a\frac{d\lambda}{dt} - C_{ser}R_n bq\lambda^6\frac{d\lambda}{dt} \\
&+\frac{1}{R_1}\sqrt{2}E\sin\omega t - \frac{v_L}{R_1} = \frac{R_n}{R_1}C_{sh}\frac{d^2\lambda}{dt^2} + \frac{R_n}{R_2R_1}v_L \\
&+\frac{R_n}{R_1}a\lambda + \frac{R_n}{R_1}b\lambda^7 + C_{sh}\frac{d^2\lambda}{dt^2} \\
&+\frac{v_L}{R_2} + \left(a\lambda + b\lambda^7\right)
\end{aligned} \tag{4}$$

V. Simulation Results

In this section of simulation, system has been considered without neutral earth resistance and time-domain simulations were performed using the MATLAB programs. One state of ferroresonance has been studied in two cases, without considering neutral earth resistance and with considering neutral earth resistance.

A. Subharmonic Response

Phase space and waveform of voltage for subharmonic response were shown in Figs. (4.a) and (4.b). The phase plane diagram clearly shows the closed trajectory characteristic of a subharmonic response waveform. Due to the abnormal condition such as switching action or other cases that may cause transient phenomena, When input voltage of power system goes up to 4p.u, in the case of without considering shunt resistance effect, ferroresonance over voltage on voltage transformer reach up to 5p.u, this state has been shown by phase plan diagram in Fig. 4.

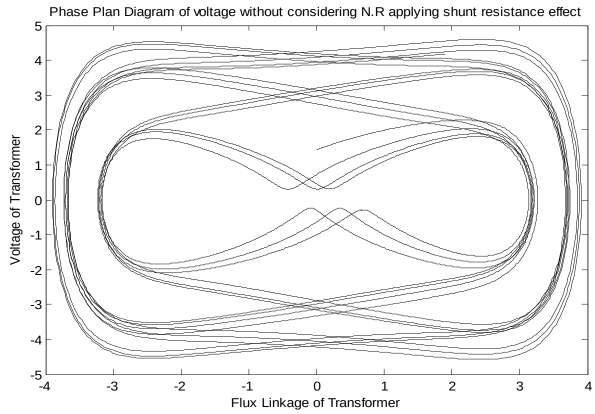

Fig. (4.a). Phase plan diagram for subharmonic ferroresonance motion without neutral earth resistance effect

By applying shunt resistance effect to the system while the input voltage is 4p.u, it is shown in Fig. (4.b) that ferroresonance overvoltages has been clamped.

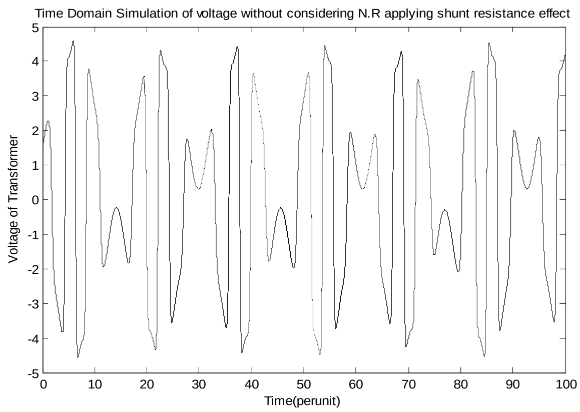

Fig. (4.b). Time domain simulation for subharmonic ferroresonance motion without neutral earth resistance effect

B. Normal Sinusoidal Response

Phase space and waveform of voltage for normal sinusoidal response were shown in Figs. (5.a) and (5.b). The phase plane diagram clearly shows the closed trajectory characteristic of a normal waveform, and amplitude of the previous case has been decreased to 1p.u as shown in Figs. (5.a), (5.b), also subharmonic ferroresonance has been changed to the sinusoidal response.

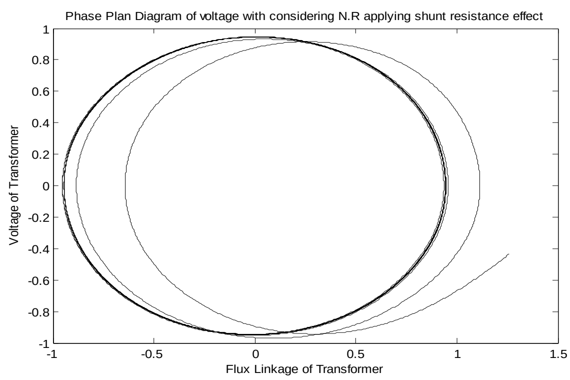

Fig. (5.a). Phase plan diagram for normal sinusoidal resonance motion with neutral earth resistance effect

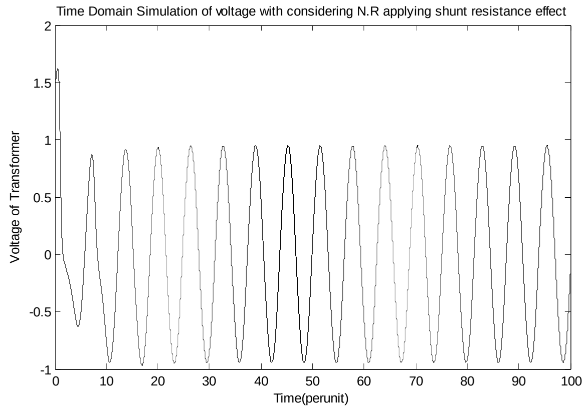

Fig. (5.b). Time domain simulation for normal sinusoidal resonance motion with neutral earth resistance effect

VI. Bifurcation Diagram Analysis

Bifurcation diagram has shown the effect of variation in the voltage of the system on the ferroresonance overvoltage in the PT, and finally effect of applying neutral earth resistance on this overvoltage by bifurcation diagrams. By using the bifurcation diagrams, Fig. 6 clearly shows the ferroresonance overvoltage in PT when voltage of system increase up to 5p.u. In this plot, there are many resonances on the system behavior and amplitude of the ferroresonance overvoltages reaches to 4.5p.u. System parameters of this case was chosen from table (2) and it is shows by these parameters, chaotic overvoltages occurs with the big amplitude and strongly can cause PT failure.

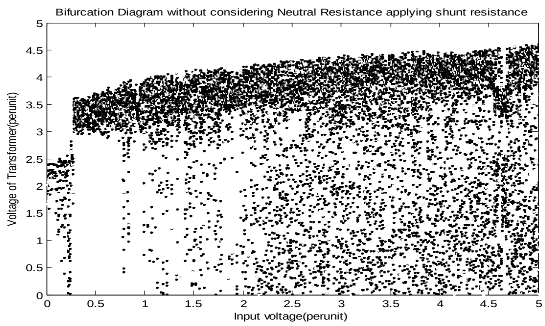

Fig. (6.a). Bifurcation diagram for voltage of transformer versus voltage of system, without considering neutral earth resistance effect

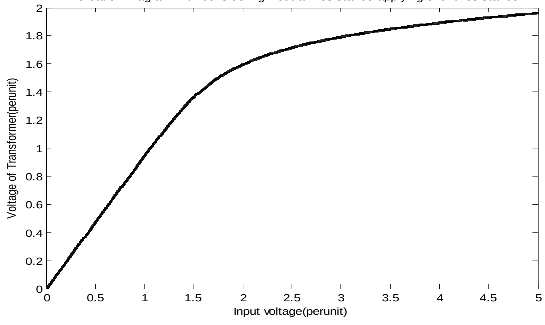

Fig. (6.b). Bifurcation diagram for voltage of transformer versus voltage of system, with considering neutral earth resistance effect

By connecting neutral earth resistance, ferroresonance overvoltage is ignored and even if unwanted phenomena are appeared, power transformer can works in the safe operation region and there is no dangerous condition in the power system.

VII. Conclusion

In this work it has been shown that system has been affected by neutral earth resistance. By considering air gap resistance of circuit breaker as a shunt resistance of it, it is shows that ferroresonance can be controlled for some value of system parameters, but for some of them it cannot controlled the nonlinear oscillations, presence of the neutral earth resistance results in controlling the ferroresonance overvoltages in studied system for all conditions of occurring ferroresonance, in this case, overvoltages reach up to 1 per unit and system works under normal condition. The neutral resistance successfully, controls the chaotic overvoltages of proposed model. Finally, system shows less sensitivity to initial conditions in the case of connecting neutral earth resistance to the system grounding.

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