Hindawi Publishing Corporation
Applied Computational Intelligence and Soft Computing
Volume 2012, Article ID 525494, 5 pages
doi:10.1155/2012/525494

Research Article

Analyzing Ferroresonance Phenomena in Power Transformers Including Zinc Oxide Arrester and Neutral Resistance Effect

Hamid Radmanesh[1,2] and Fathi Seyed Hamid[2]

[1] *Electrical Engineering Department, Islamic Azad University, Takestan Branch, Takestan, Ghazvin 1995755681, Iran*
[2] *Electrical Engineering Department, Amirkabir University of Technology, Tehran, Iran*

Correspondence should be addressed to Hamid Radmanesh, hamid.nsa@gmail.com

Received 19 April 2012; Accepted 25 June 2012

Academic Editor: F. Morabito

This paper studies the effect of zinc oxide arrester (ZnO) and neutral earth resistance on controlling nonconventional oscillations of the unloaded power transformer. At first, ferroresonance overvoltage in the power system including ZnO is investigated. It is shown this nonlinear resistance can limit the ferroresonance oscillations but it cannot successfully control these phenomena. Because of the temperature dissipation of ZnO, it can withstand against overvoltage in a short period and after that ferroresonance causes ZnO failure. By applying neutral earth resistance to the system configuration, mitigating ferroresonance has been increased and chaotic overvoltage has been changed to the smoother behavior such as fundamental resonance and periodic oscillation. The simulation results show that connecting the neutral resistance exhibits a great mitigating effect on nonlinear overvoltage.

1. Introduction

Ferroresonance is a complex electromagnetic phenomenon which may be neglected in power system studies which is carried out for routine designs, planning, and operations [1]. A stability domain calculation of period-1 ferroresonance in nonlinear resonant circuit power system elements is given in [2]. In this case, quasistatic analytical approaches can be used to give a quick indication of the locations of domains of different ferroresonant states as a function of a set of parameters. Fast ferroresonance suppression of coupling capacitor voltage transformers (CCVT) is studied in [3]. This paper describes a procedure for fast suppression of the phenomenon of ferroresonance in CCVT without major change in the design. The design of a hall effect current transformer and examination of the linearity with real time parameter estimation is given in [4]. The aim of "blind source separation" (BSS) is to recover mutually independent unknown source signals only from observations obtained through an unknown linear mixture system [5]. Sensitivity studies on power transformer ferroresonance of a 400 kV double circuit are given in [6]. Novel analytical solution to fundamental ferroresonance in [7] investigated a major problem with the traditional excitation characteristic of nonlinear inductors. Application of wavelet transform and MLP neural network for ferroresonance identification was done in [8]. Impacts of transformer core hysteresis formation on stability domain of ferroresonance modes were done in [9]. The principle of AC current transformers (CT) based on the magnetic coupling principle is given in [10]. Current paper studies the effect of neutral resistance on the global behavior of a ferroresonance circuit including ZnO in parallel to the transformer with linear core losses. Then, neutral earth resistance effect is discussed.

2. Power System Modeling Connecting ZnO

Transformer is connected to the power system while one of the three switches are open and only two phases of it are energized, which induced voltage in the open phase. This voltage back feeds the distribution line. Ferroresonance phenomenon is occurring if the distribution line is capacitive.

Base system model is adopted from [1] while ZnO is added to the initial ferroresonance circuit. Linear approximation of the peak current of the magnetization reactance can be presented by the following:

$$i_L = a\lambda, \quad (1)$$

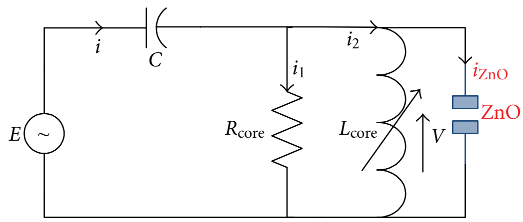


Figure 1: Final reduced model of power system for ferroresonance studies.

Table 1: Typical value of q and its coefficients.

q	(a)	(b)
11	0.0028	0.0072
7	3.14	0.41

Table 2: Power system parameters considered for simulation.

Parameters	Actual value	Per unit value
S_{base}	50 MVA,	—
V_{base}	635.1 kv	—
I_{base}	78.2 A	—
R_{base}	8121.4 Ω	—
C	4.9 μF	0.07955 pu
R_{core}	4.5 MΩ	554.09 pu
ω	377 (rad/sec)	1 pu
K	—	2.5101 pu
α	—	25

where λ is flux of the transformer coil and q is transformer nonlinear curve index. However, for very high currents λ-i characteristic of the transformer can be demonstrated by the polynomial in the following:

$$i_L = a\lambda + b\lambda^q. \quad (2)$$

The differential equation for the circuit in Figure 1 can be derived as follows. Polynomial coefficient of (2) is tabulated in Table 1:

$$v_l = \frac{d\lambda}{dt},$$

$$\frac{dv_l}{dt} = \frac{dE}{dt} - \frac{1}{RC}\frac{d\lambda}{dt} - \frac{1}{C}(a\lambda + b\lambda^q) - \frac{1}{C}\left(\frac{v_l}{k}\right)^{\alpha}, \quad (3)$$

$$\frac{dv_l}{dt} = \frac{d^2\lambda}{dt^2},$$

where $v_l = d\lambda/dt$, ω represents the power frequency and E is the peak value of the voltage source. Also, α and k are ZnO parameters as shown in Figure 1.

3. Simulation Results

Case 1 (Power System Behavior Connecting ZnO). In this section, effect of ZnO on mitigating ferroresonance phenomenon is investigated. Power system parameters values are tabulated in Table 2.

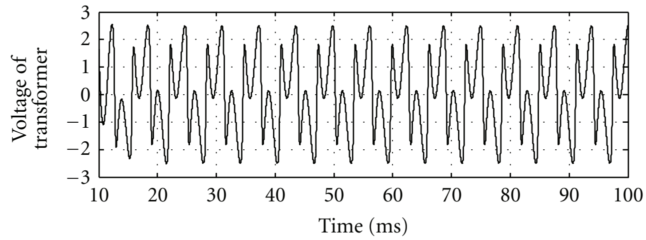


Figure 2: Time domain simulation for $q = 7$ (ZnO effect).

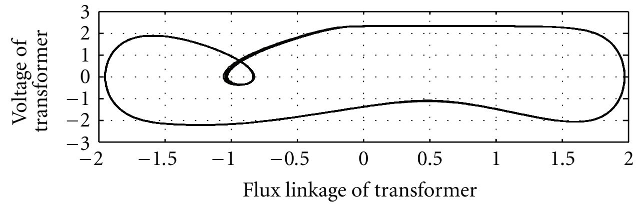


Figure 3: Phase plan diagram for $q = 7$ (ZnO effect).

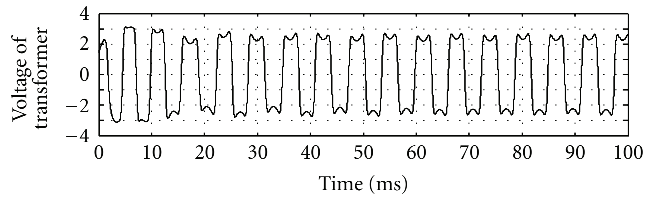


Figure 4: Time domain simulation for $q = 11$ (ZnO effect).

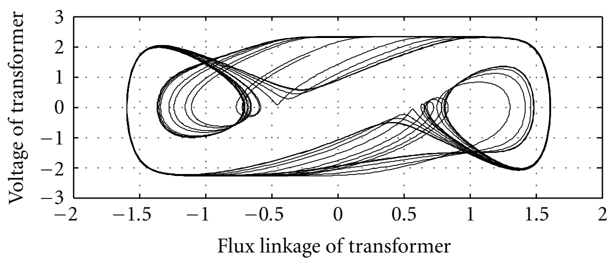


Figure 5: Phase plan diagram for $q = 11$ (ZnO effect).

It was shown that for proper representation of the saturation characteristics of a power transformer the values of q are 5, 7, and 11 [1].

Behavior of the system is analyzed by considering q degrees 7 and 11.

Figures 2 and 3 show time domain and phase plan simulation of the system behavior considering ZnO effect. By connecting ZnO chaotic ferroresonance is changed to fundamental resonance for $q = 7$ and subharmonic behavior for $q = 11$. ZnO clamps this overvoltage successfully. ZnO effect is shown in Figures 2 and 3 for $q = 7$ and in Figures 4 and 5 for $q = 11$.

Changing subharmonic resonance and ferroresonance overvoltage in the purpose power system by connecting ZnO

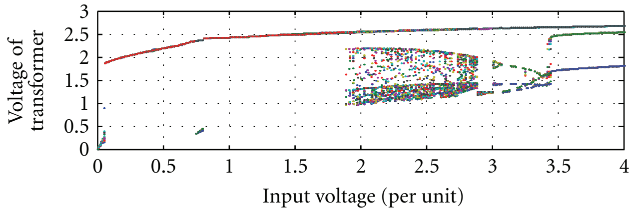


Figure 6: Bifurcation diagram with $q = 7$ (ZnO effect).

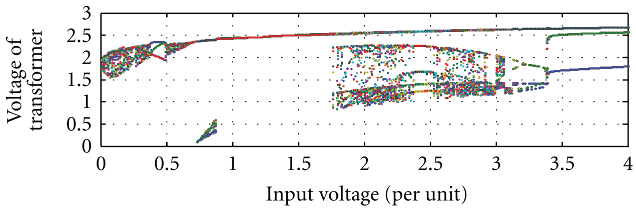


Figure 7: Bifurcation diagram with $q = 7$ (ZnO effect).

is clearly shows by using phase plan diagrams in Figures 4 and 5. Effect of ZnO surge arrester is clearly obvious, ZnO limit the ferroresonance overvoltage.

By increasing degree of q, amplitude of overvoltage remains in 2 p.u. Some sudden changes in nonlinear systems parameters may cause to the chaotic behavior. The noun "chaos" is used to describe the time behavior of a system when the behavior is nonperiodic and it never exactly repeats. In fact, most of the systems that will be studying are completely deterministic. In general we need these three factors to determine the behavior of the proposed power system. The time equations which are derived from ferroresonance equivalent circuit are given in (4) and (5). The value of parameters describing the system which all parameters values are tabulated in Table 2, then the initial conditions are most important factor for initiating ferroresonance and given in (6).

For studying the nonlinear dynamical systems as like power system, we need some tools such as time domain simulation, phase plan, and bifurcation diagrams. So, one of the most useful nonlinear dynamical tools is the bifurcation diagram [11]. To produce this diagram, we record the value of the peak voltage of the transformer as a function of control parameter being varied [11]. Here, control parameter is input voltage of the power system. In practice, a computer records the sampled values and then plotted as a function of the value of the control parameter. Two of these bifurcation diagrams are shown in Figures 6 and 7, where we have recorded sampled value of transformer voltage as a function of input voltage applied to the ferroresonance circuit with the frequency fixed.

According to the bifurcation diagram, it shows the ferroresonance overvoltage has been begun after 3 p.u. Tendency to chaos exhibited by the system voltage increases while q increases too.

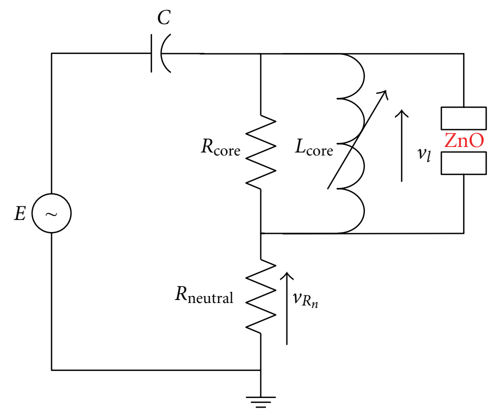


Figure 8: Equivalent circuit of the power system connecting ZnO and earth resistance.

4. Power System Modeling Considering Earth Resistance Effect

The main purpose of connecting resistance to the star point of a transformer is to limit ferroresonance. Low impedance is conventionally defined as impedance that limits the prospective ferroresonance to the no load of the transformer. The value of impedance required is easily calculated to a reasonable approximation by dividing the rated phase voltage by the rated phase current of the transformer. Neutral earthing resistance is achieved using resistors so as to limit the tendency for the ferroresonance to persist due to inductive energy storage. These resistors will limit heat when ferroresonance current flows and are usually only short term rated (typically 30 secs) so as to achieve an economic design.

So the typical values for various system parameters which have been considered for simulation were kept the same by Case 1, while earth resistance is added to the system and its value is given below and new system configuration is shown in Figure 8:

$$R_{\text{natural}} = 40\,\mathrm{k}\Omega. \tag{4}$$

The differential equation for the circuit in Figure 8 is given by the following:

$$\begin{aligned}\frac{dv_l}{dt} &= \frac{dE}{dt} - \frac{1}{RC}\frac{d\lambda}{dt} - \frac{1}{C}\left(a\lambda + b\lambda^q\right) - \frac{R_n}{R}\frac{d^2\lambda}{dt^2} \\ &\quad - R_n \cdot a\frac{d\lambda}{dt} - R_n q b \lambda^{q-1}\frac{d\lambda}{dt} - \alpha\left(\frac{1}{k}\right)^{\alpha}\left(\frac{d^2\lambda}{dt^2}\right)^{\alpha-1}.\end{aligned} \tag{5}$$

For the initial conditions, we have:

$$\lambda(0) = 0.0; \qquad v_l = \frac{d\lambda}{dt}(0) = \sqrt{2}, \tag{6}$$

where R_n is the neutral earth resistance.

5. Simulation Results

Case 2 (Power System Behavior Considering Neutral Earth Resistance Effect). Figures 9 and 10 show the corresponding

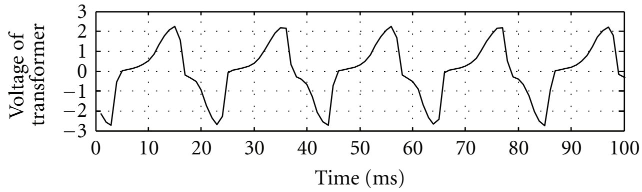


FIGURE 9: Time domain simulation for $q = 7$ (neutral resistance effect).

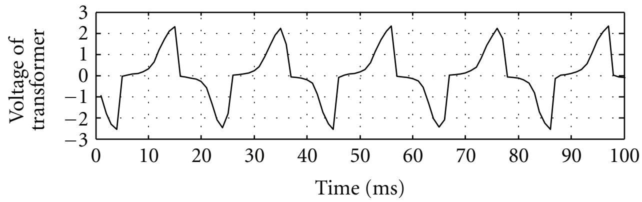


FIGURE 10: Time domain simulation for $q = 11$ (neutral resistance effect).

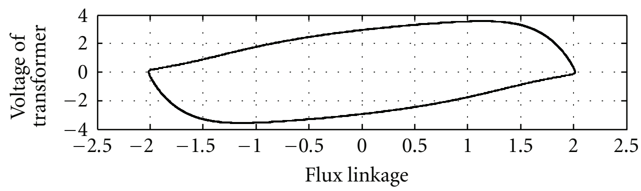


FIGURE 11: Phase plan diagram with $q = 7$ (neutral resistance effect).

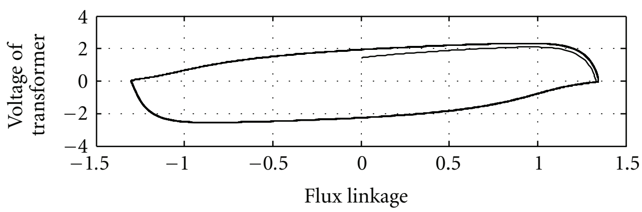


FIGURE 12: Phase plan diagram with $q = 11$ (neutral resistance effect).

time domain simulation which shows the effect of earth resistance. Also Figures 11 and 12 show the phase plan diagrams for corresponding system including earth resistance effect. It is shown that subharmonic regions mitigates by applying earth resistance. It is shown that tendency to chaos reduce in this case. In the big degree of q, system has been simulated when neutral resistance is considered. It shows the ferroresonance carried out and there are no abnormal phenomena and chaotic region mitigates by applying neutral resistance.

By increasing in the degree of q, there is no more change in the system behavior. By comparing this case of bifurcation diagram with the previous case, it is clearly obvious that neutral resistance successfully clamps the ferroresonance overvoltage. This effect is shown in Figures 13 and 14.

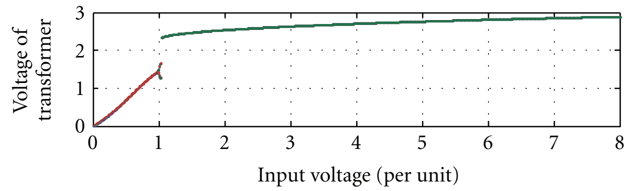


FIGURE 13: Bifurcation diagram with $q = 7$ (neutral resistance effect).

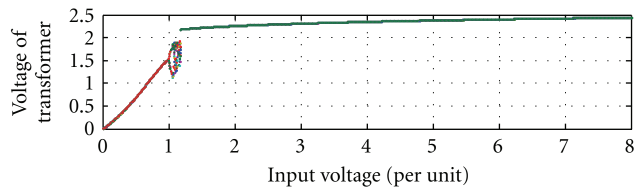


FIGURE 14: Bifurcation diagram with $q = 11$ (neutral resistance effect).

6. Conclusions

The nonlinear behavior of ferroresonance falls into two main categories. In the first, the response is a distorted periodic waveform, containing the fundamental harmonics of the fundamental frequency. The second type is a chaotic response. In both cases response's phase plan diagram contains fundamental and odd harmonic frequency components. In the chaotic response, there is also distributed subharmonics frequency. The simulation results confirm that system goes to chaos and bifurcation occurs in the proposed power system. The presence of the neutral resistance causes to clamp the ferroresonance overvoltage. The neutral resistance successfully, reduces the chaotic region for higher exponents of q. Simulation of system consists of two cases, at first, system modeling of power transformer including ZnO arrester and second, system contains ZnO and neutral earth resistance. Finally we compare the result of these two cases.

References

[1] S. Mozaffari, S. Henchel, and A. C. Soudack, "Chaotic ferroresonance in power transformers," *IEE Proceedings—Generation, Transmission and Distribution*, vol. 142, no. 3, pp. 247–250, 1995.

[2] D. A. N. Jacobson, P. W. Lehn, and R. W. Menzies, "Stability domain calculations of period-1 ferroresonance in a nonlinear resonant circuit," *IEEE Transactions on Power Delivery*, vol. 17, no. 3, pp. 865–871, 2002.

[3] M. Graovac, R. Iravani, X. Wang, and R. D. McTaggart, "Fast ferroresonance suppression of coupling capacitor voltage transformers," *IEEE Transactions on Power Delivery*, vol. 18, no. 1, pp. 158–163, 2003.

[4] G. Gokmen and K. Tuncalp, "The Design of a hall effect current transformer and examination of the linearity with real time parameter estimation," *Electronics and Electrical Engineering*, no. 5(101), pp. 3–8, 2010.

[5] K. Pukėnas, "Blind separation of noisy pseudo periodic chaotic signals," *Electronics and Electrical Engineering*, no. 3(91), pp. 31–34, 2009.

[6] C. Charalambous, Z. D. Wang, M. Osborne, and P. Jarman, "Sensitivity studies on power transformer ferroresonance of a 400 kV double circuit," *IET Generation, Transmission & Distribution*, vol. 2, no. 2, pp. 159–166, 2008.

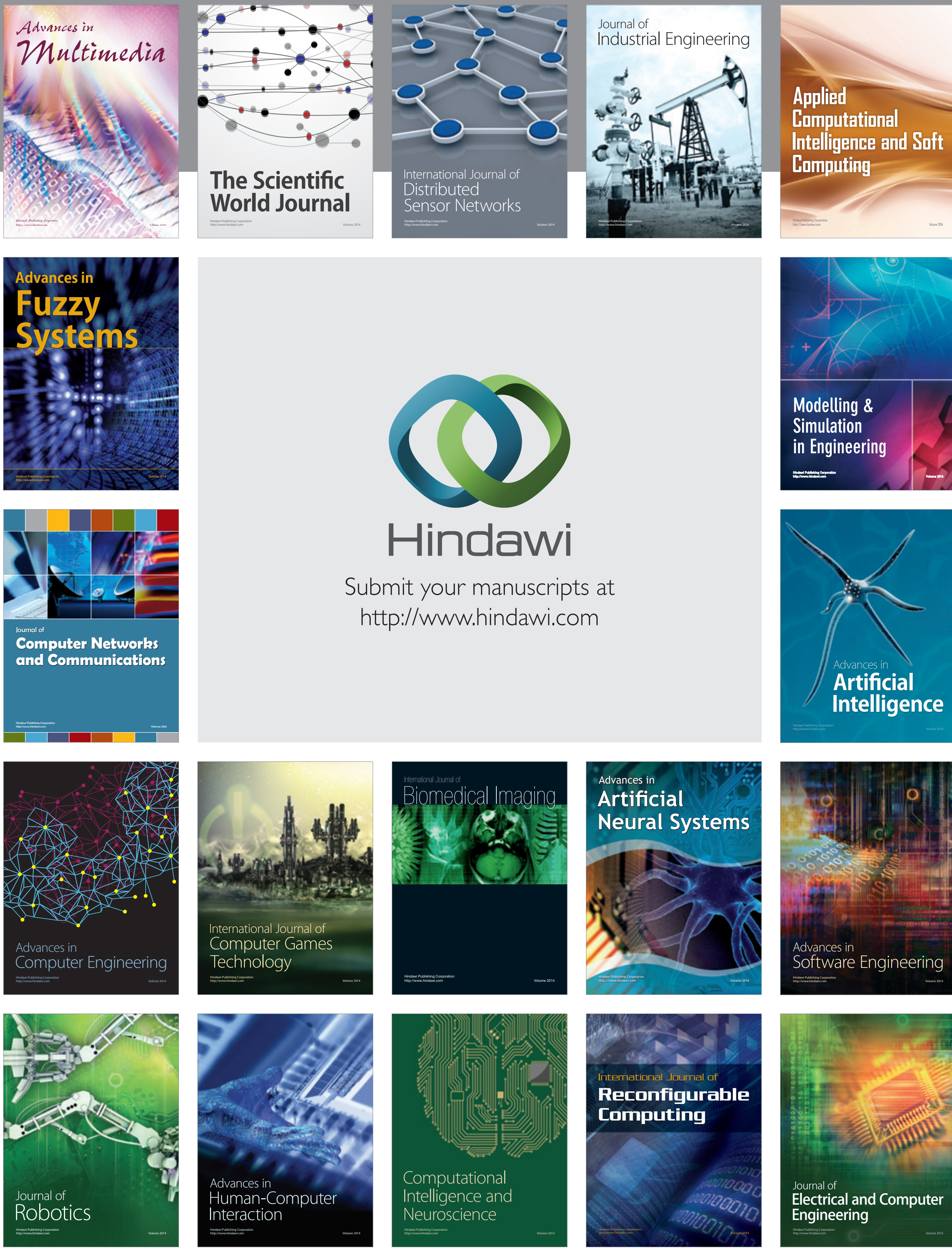
[7] Y. Li, W. Shi, and F. Li, "Novel analytical solution to fundamental ferroresonance—Part I: power frequency excitation characteristic," *IEEE Transactions on Power Delivery*, vol. 21, no. 2, pp. 788–793, 2006.

[8] G. Mokryani and M.-R. Haghifam, "Application of wavelet transform and MLP neural network for Ferroresonance identification," in *Proceedings of IEEE Power and Energy Society General Meeting—Conversion and Delivery of Electrical Energy in the 21st Century*, vol. 3, no. 4, pp. 1–6, Pittsburgh, Pa, USA, July 2008.

[9] A. Rezaei-Zare, R. Iravani, and M. Sanaye-Pasand, "Impacts of transformer core hysteresis formation on stability domain of ferroresonance modes," *IEEE Transactions on Power Delivery*, vol. 24, no. 1, pp. 177–186, 2009.

[10] P. Rafajdus, P. Braciník, and V. Hrabovcová, "The current transformer parameters investigation and simulations," *Electronics and Electrical Engineering*, no. 4(100), pp. 29–32, 2010.

[11] H. Radmanesh, G. B. Gharehpetian, and H. Fathi, "Ferroresonance of power transformers considering non-linear core losses and metal oxide surge arrester effects," *Electric Power Components and Systems*, vol. 40, no. 5, pp. 463–479, 2012.



Advances in Multimedia
The Scientific World Journal
International Journal of Distributed Sensor Networks
Journal of Industrial Engineering
Applied Computational Intelligence and Soft Computing
Advances in Fuzzy Systems
Modelling & Simulation in Engineering
Hindawi
Submit your manuscripts at
http://www.hindawi.com
Journal of Computer Networks and Communications
Advances in Artificial Intelligence
Advances in Computer Engineering
International Journal of Computer Games Technology
International Journal of Biomedical Imaging
Advances in Artificial Neural Systems
Advances in Software Engineering
Journal of Robotics
Advances in Human-Computer Interaction
Computational Intelligence and Neuroscience
International Journal of Reconfigurable Computing
Journal of Electrical and Computer Engineering