International Review of Electrical Engineering (I.R.E.E.), Vol. 6, N. 1
January-February 2011

Modeling of Polarization in Oil-Paper Insulation Using Recovery Voltage Measurements

Božidar Filipović-Grčić[1], Dalibor Filipović-Grčić[2], Ivo Uglešić[1]

Abstract – *The state of the oil-paper insulation is a key factor for assuring a reliable operation of power transformers. Recovery voltage measurement is one of the methods utilized to estimate the polarization spectrum. Analysis of the polarization spectrum is used to evaluate the condition of the insulation with respect to moisture content and aging. In this paper, the elements which represent a polarization process are determined from recovery voltage measurement test results by using a new method based on genetic algorithm. The method was successfully tested on a simple circuit and then applied to two power transformers located in hydropower plants.*

***Keywords**: Genetic Algorithm, Oil-Paper Insulation, Polarization, Power Transformer, Recovery Voltage Measurement*

Nomenclature

U_c	DC charging voltage
t_c	Charging time
t_d	Discharging time, $t_d=t_c/2$
U_{max}	Maximum of the recovery voltage
t_{peak}	Peak time at which U_{max} occurs
S_r	Initial slope of the recovery voltage
R_i	Insulation resistance
C_g	Geometrical capacitance of the insulation
R_nC_n	Elements that represent polarization processes
R_p	Polarization resistance
C_p	Polarization capacitance
τ_p	Polarization time constant, $\tau_p=R_p\cdot C_p$
R	Resistance of the connecting wires
ε	Fitness function
ε_{best}	The best fitness value

I. Introduction

The condition of the insulation system is of critical importance for a continued functioning of a power transformer [1]-[3]. With time, the insulation undergoes an aging process which is depended on the operating conditions of a transformer. The aging process becomes faster at higher operating temperatures, especially when moisture is present. Several dielectric diagnosis methods have been developed in order to evaluate the condition of the insulation: polarization and depolarization current measurements (PDC) [4], frequency domain spectroscopy (FDS) [5], [6] and recovery voltage measurement (RVM) [7]-[12].

The RVM method is based upon the analysis of the curve of the maximum recovery voltage versus charging time, the so-called polarization spectrum.

In this paper, the elements of the circuit that represent the polarization process were deduced from the RVM test results using genetic algorithm (GA). The calculation method was tested on a simple measuring circuit and applied in order to calculate the polarization parameters of the power transformer insulation.

II. Recovery Voltage Measurement

RVM is an insulation diagnostic technique used to detect the moisture content being present in an oil-paper insulation system. It can be applied as an indicator of insulation quality and future insulation ageing problem based on the analysis of polarization spectrum.

Each RVM cycle consists of 4 phases: (1) charging, (2) discharging, (3) measurement and (4) relaxation (Fig. 1). In phase 1, the insulation sample is charged with a voltage U_c, water molecules contained in the insulation are polarized, and they align in the direction of the electric field.

In phase 2, the sample is short-circuited for a predetermined period of time t_d, causing the molecules to be partially depolarized. When the short circuit is opened in phase 3, a voltage will build up between the terminals of the insulation sample due to the remaining charge. The charging and discharging procedure is repeated using a sequence of increasing charging times ranging from tens of milliseconds up to thousands of seconds.

Afterward, the curve of the maximum recovery voltage versus charging time is plotted. This curve is known as the polarization spectrum [13].

The basic quantities which are measured during an RVM cycle are: U_c, t_{peak}, U_{max} and S_r.

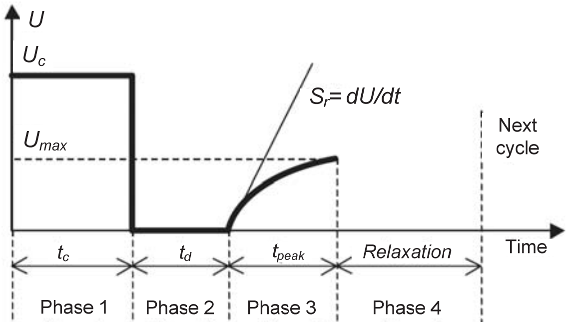

Fig. 1. Test phases in an RVM cycle

Recovery voltage spectrum [14] is dependent on the moisture level present in the insulation system (Fig. 2). The behavior of the polarization spectrum (especially, the displacement of the curve peak towards lower time constants) closely follows the change of the insulation state (i.e. a different moisture level and a degradation of the dielectric). Recovery voltage versus different ageing periods is shown in Fig. 3 [15].

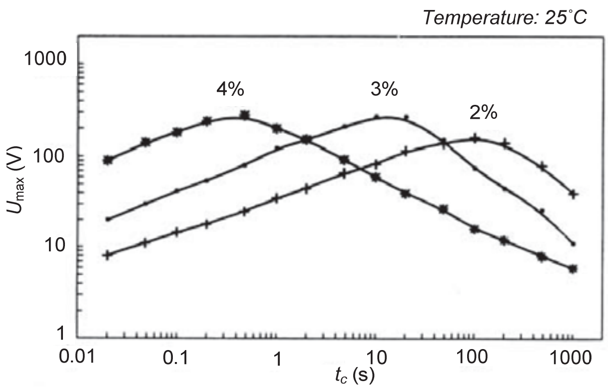

Fig. 2. Polarization spectrum of oil-paper insulation models with various moisture content

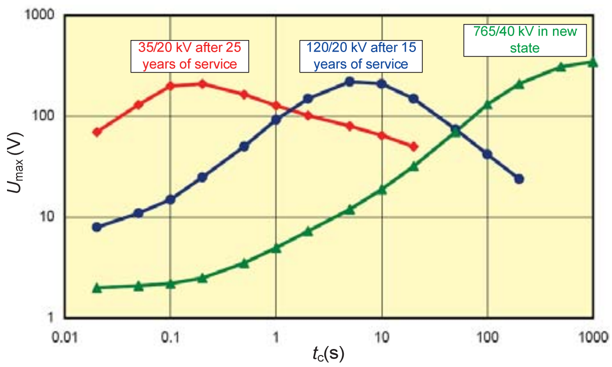

Fig. 3. Polarization spectrum of three transformers of different age

In the past few years, several researchers [16]-[19] have proposed a number of equivalent circuits for modeling the transformer oil-paper insulation system in order to better understand the dielectric response. An insulation system can be represented using insulation resistance (resistance between HV and ground), geometrical capacitance (the capacitance as imposed by the spatial relations in the insulation system), plus several *RC* branches which represent various polarization processes that are present in the insulation [20].

A simplified equivalent circuit that can be used to describe the polarization behavior of an insulation system is shown in Fig. 4. This model is also known as the extended Debye (ED) circuit and it can be used to mathematically describe the behavior of the polarization processes in an insulation material.

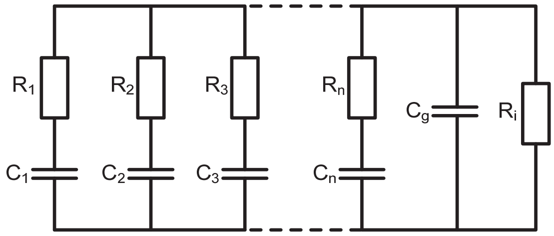

Fig. 4. Simplified equivalent circuit used to describe the polarization behavior of an insulation system

During the service time of an insulation system, the values of elements that represent polarization process may change, thereby changing the time constant of an insulation. In this paper the polarization process was modeled using a single *RC* branch with variable elements.

III. Calculation of Recovery Voltage using Laplace Transform

The Laplace transform was used to calculate the recovery voltage. This method converts a set of differential equations, describing a circuit in its transient behavior in the time domain, to the set of linear algebraic equations in the complex frequency domain. The set of linear algebraic equations is solved and variables of interest are calculated. The measuring circuit shown in Fig. 5 was used for testing of the calculation method.

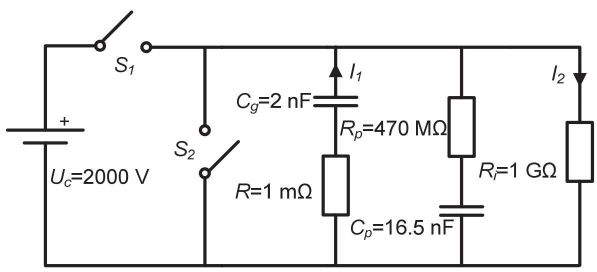

Fig. 5. Measuring circuit used for testing of the calculation method (marked current directions are valid only for phase 3)

Calculations were conducted for the following phases of each RVM cycle: charging (S_1 closed, S_2 opened), discharging (S_1 opened, S_2 closed) and measurement (S_1 opened, S_2 opened). All calculations were performed using the Matlab software.

In phase 1 (charging), voltages on capacitors C_g and C_p are calculated in the frequency domain by using the expressions (1) and (2):

$$U_{C_g,1}(s)=\frac{U_c}{s}\cdot\left(1-\frac{sRC_g}{sRC_g+1}\right) \tag{1}$$

$$U_{C_p,1}(s)=\frac{U_c}{s}\cdot\left(1-\frac{sR_pC_p}{sR_pC_p+1}\right) \tag{2}$$

In phase 2 (discharging), voltages on capacitors C_g and C_p, which were calculated in phase 1, are used in the expressions (3) and (4):

$$U_{C_g,2}(s)=U_{C_g,1}(s)\cdot\frac{sRC_g}{sRC_g+1} \tag{3}$$

$$U_{C_p,2}(s)=U_{C_p,1}(s)\cdot\frac{sR_pC_p}{sR_pC_p+1} \tag{4}$$

In phase 3 (measurement), voltages on capacitors C_g and C_p, which were calculated in phase 2, are used in the expression (5):

$$\begin{bmatrix} I_1(s) \\ I_2(s) \end{bmatrix} = \\ = \begin{bmatrix} R+\dfrac{1}{sC_g} & R_i \\ -\left(R_p+\dfrac{1}{sC_p}\right) & R_i+R_p+\dfrac{1}{sC_p} \end{bmatrix}^{-1} \cdot \begin{bmatrix} U_{C_g,2}(s) \\ U_{C_p,2}(s) \end{bmatrix} \tag{5}$$

The recovery voltage is calculated using the following expression:

$$U(s)=I_2(s)\cdot R_i \tag{6}$$

Recovery voltage is expressed as a function of time using the inverse Laplace transform:

$$U(t)=L^{-1}\left(U(s)\right) \tag{7}$$

t_{peak} is obtained by solving the following equation:

$$\frac{dU(t)}{dt}=0 \tag{8}$$

U_{max} can now be determined from (7).

Measurements were performed on the circuit shown in Fig. 5 and compared to the calculation results (Figs. 6 - 8). The calculated and measured maximum values of the recovery voltage, the time to peak and the initial slope of recovery voltage show a good agreement (Figs. 6, 7 and 8).

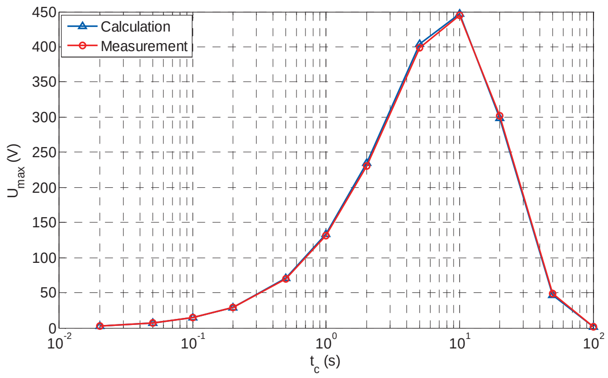

Fig. 6. Comparison of measured and calculated U_{max}

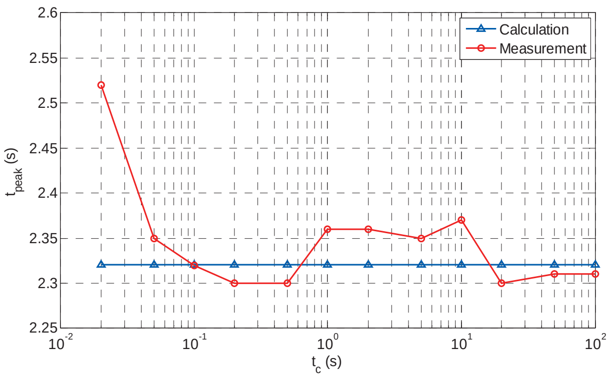

Fig. 7. Comparison of measured and calculated t_{peak}

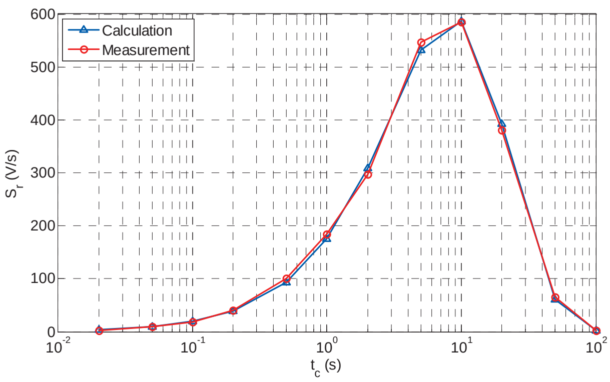

Fig. 8. Comparison of measured and calculated S_r

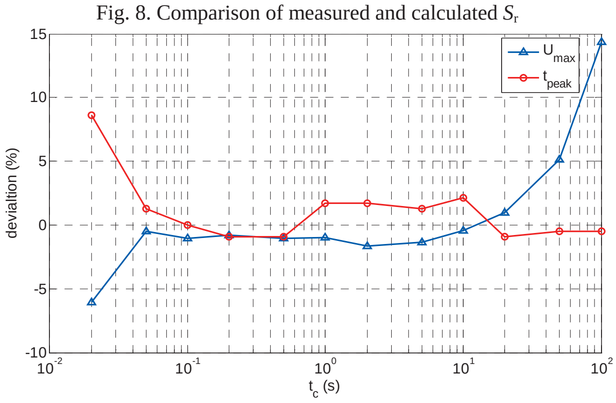

Fig. 9. Deviation of measured U_{max} and t_{peak} regarding calculation results

The percentage error (deviation) for each measured value regarding each corresponding calculation result is obtained using (9), and the results are shown in Fig. 9:

$$deviation = \frac{measured - calculated}{calculated} \cdot 100 \ (\%) \qquad (9)$$

IV. A Method for Calculation of Insulation Polarization Parameters

GA is a method for solving both constrained and unconstrained optimization problems based on the natural selection, a process that drives the biological evolution [21], [22]. It repeatedly modifies a population of individual solutions. In each step, the individuals are randomly selected from the current population to be parents and to produce the children for the next generation. Over successive generations, the population "evolves" towards an optimal solution [23], [24]. The GA uses three main types of rules in each step in order to create the next generation from the current population:

1) The selection rules pick out the individuals, called parents, which will contribute to the population of the next generation.
2) The crossover rules combine two parents which will form children for the next generation.
3) The mutation rules apply random changes in individual parents which create children.

The fitness function is the objective function minimized by the GA, which in this case takes into account the percentage error for each calculated U_{max} and t_{peak} regarding known values. The fitness function is calculated by using the following expression:

$$\varepsilon = max\left(\frac{U_{max,GA} - U_{max,measured}}{U_{max,measured}}, \ \frac{t_{peak,GA} - t_{peak,measured}}{t_{peak,measured}} \right) \cdot 100 \ (\%) \qquad (10)$$

The flowchart of the algorithm for calculating the insulation polarization parameters is shown in Fig. 10.

The GA is used to determine the R_pC_p polarization elements that represent a polarization process from the RVM results. Polarization elements are calculated for each charging time. The following measured parameters represent the inputs for the GA: U_{max}, t_{peak}, t_c, R_i and C_g.

At first, the GA generates a population of polarization elements. Population size specifies how many individuals there are in each generation (in this case 1000 R_pC_p elements per generation). Initial population is created randomly with a uniform distribution from a predefined range.

After the creation of the initial population, U_{max}, t_{peak} and ε are calculated for each polarization element in the initial population. Each polarization element is then rated according to the value of the fitness function.

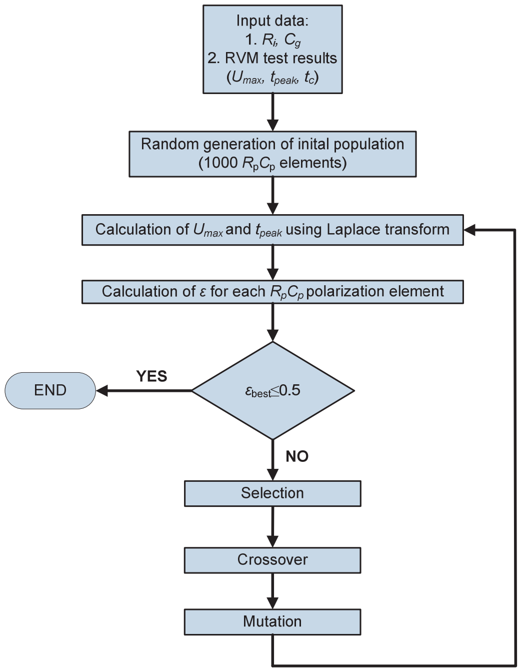

Fig. 10. Flowchart of the algorithm for determination of insulation polarization parameters

The selection function chooses the parents for the next generation based on fitness results [24].

The elite count specifies the number of individuals that are guaranteed to survive to the next generation (in this case 10). Crossover fraction specifies the fraction of the next generation, other than elite individuals, that are produced by crossover (80 %). The remaining individuals are produced by mutation.

The scattered crossover function creates a random binary vector. It then selects the genes for which the vector value is a 1 from the first parent, and the genes for which the vector value is a 0 from the second parent, and combines the genes to form the child.

Mutation functions create small random changes in individuals from a population, and they provide genetic diversity and enable the GA to search a broader space. Mutation function based on the Gaussian distribution with a mean value of 0 adds a random number to each vector entry of an individual. The stopping criteria determine what causes the algorithm to terminate. If the best fitness value ε_{best} is less than or equal to the value of the fitness limit, the algorithm stops. In this case, the fitness limit was set to 0.5 %.

The GA was used to fit the results of measurement and calculation for the measuring circuit (Fig. 5). When the GA was used for fitting of the measurement results (Fig. 11), the deviations were under 10 % for majority of measuring points, except for t_c=0.02 s and t_c=5 s. When the GA was used for fitting of the calculation results, all deviations were under 3 % (Fig. 12).

Numerous GA simulations indicated that the polarization resistance and the capacitance are uniquely determined for known parameters R_i, C_g, U_{max}, t_{peak} and t_c.

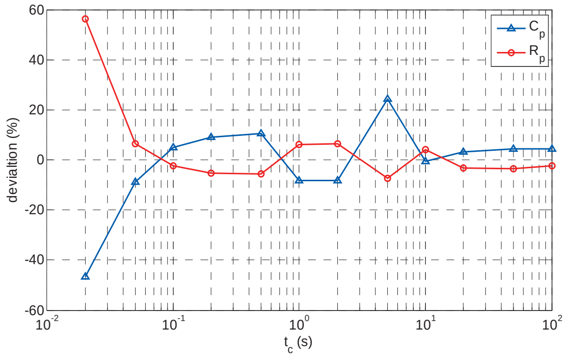

Fig. 11. Deviation of polarization capacitance and resistance (GA fitting of measurement results)

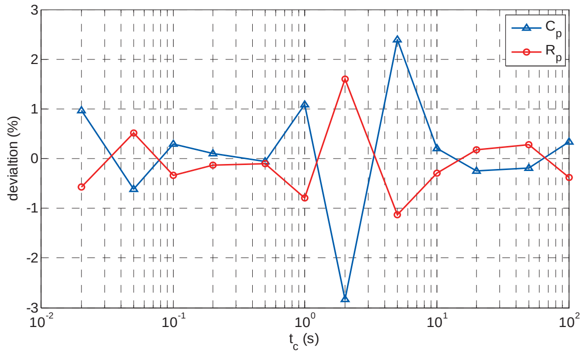

Fig. 12. Deviation of polarization capacitance and resistance (GA fitting of calculation results)

The change of the fitness value throughout the generations, for the GA fitting of calculation results, is shown in Fig. 13. For t_c=0.02 s the fitness limit of 0.5 % was reached after 26 generations.

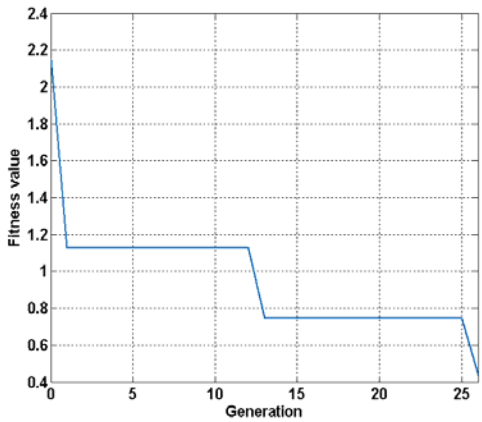

Fig. 13. Change of fitness value throughout generations for GA fitting of calculation results (t_c=0.02 s)

V. Application of the Method for Calculation of Polarization Parameters of Transformer Insulation

After the method was successfully tested, it was used to determine the R_pC_p elements from the results of the RVM that was performed on the power transformer 6.3/35 kV, 8 MVA, YNd5. R_i=5900 MΩ and C_g=13178 pF of the transformer were obtained from [25]. Fig. 14 shows the test arrangement for the RVM. DC voltage of 2000 V was applied on LV windings, while HV windings were short-circuited and grounded.

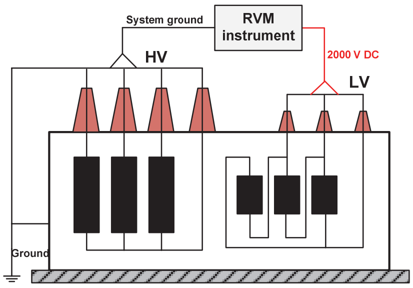

Fig. 14. Test arrangement for RVM

Measurement was performed with the RVM instrument [26], and the results are shown in Table I and Fig. 15.

TABLE I
RVM RESULTS - 8 MVA POWER TRANSFORMER

t_c (s)	U_{max} (V)	t_{peak} (s)	S_r (V/s)
0.02	12.4	0.695	130
0.05	27.2	0.995	171
0.1	49.8	1.200	208
0.2	90.6	1.300	280
0.5	187	1.490	467
1	288	1.680	649
2	362	2.100	730
5	343	3.590	559
10	278	8.000	338
20	230	17.50	188
50	200	40.60	94.7

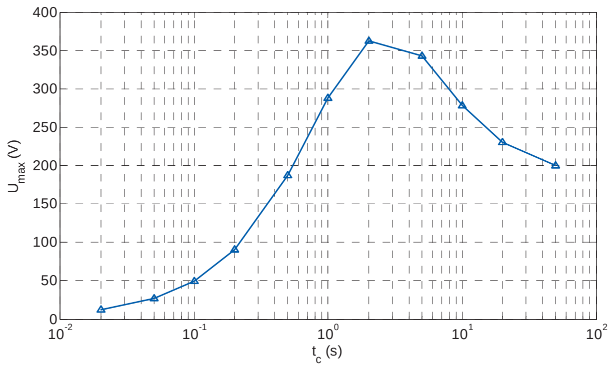

Fig. 15. Measured polarization spectrum curve

The GA was used for fitting of RVM results shown in Table I. In each simulation the population size was 10000. Polarization capacitance and resistance in real transformer are not constants, and they change for each charging time, due to the effect of polarization (Figs. 16 and 17). τ_p varies from 0.11 s to 31.04 s (Fig. 18). Changes of fitness value throughout generations for the GA fitting of measurement results are shown in Fig. 19. For t_c=0.02 s, fitness limit of 0.5 % was reached after 158 generations.

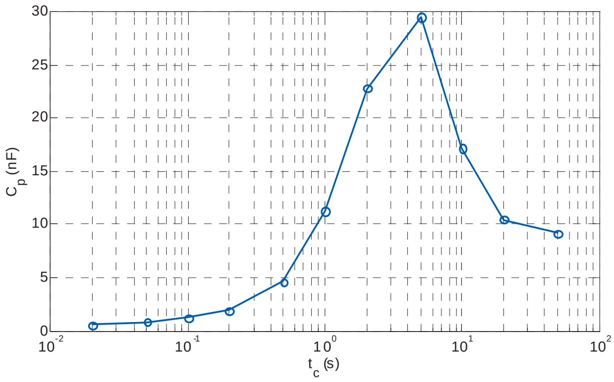

Fig. 16. Polarization capacitance as a function of charging time

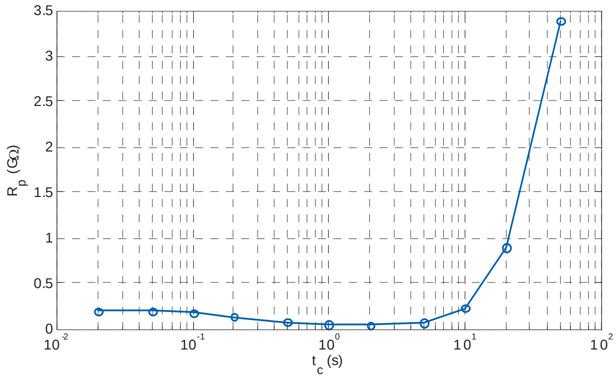

Fig. 17. Polarization resistance as a function of charging time

The average temperature of the transformer oil during the recovery voltage measurement was 42˚C. Analysis of the measurement results and the oil temperature showed a significant moisture level equal to 2.8 % in the insulation system of a power transformer.

Since this power transformer had a significant moisture level after more than 40 years in operation, the drying of the insulation system was suggested. The best fitness values were less than 0.3 % (Fig. 20) and the number of generations needed to obtain ε_{best}≤0.5 % was less than 600 for all simulations (Fig. 21).

The new method was also applied on RVM results obtained from the power transformer 12/123 kV, 35 MVA, YNd5. Measurement results are shown in Table II and Fig. 22.

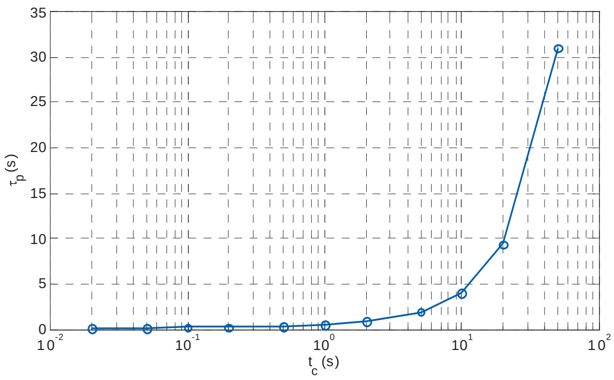

Fig. 18. Polarization time constant as a function of charging time

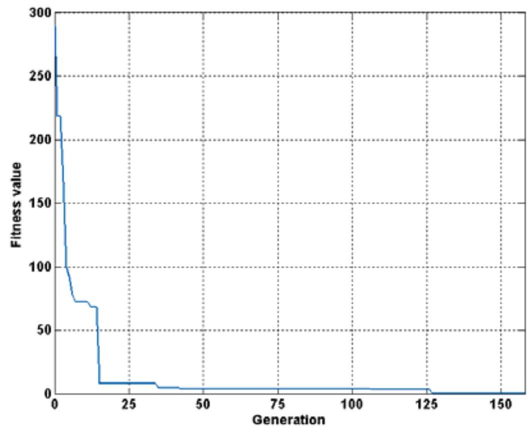

Fig. 19. Change of fitness value throughout generations for t_c=0.02 s

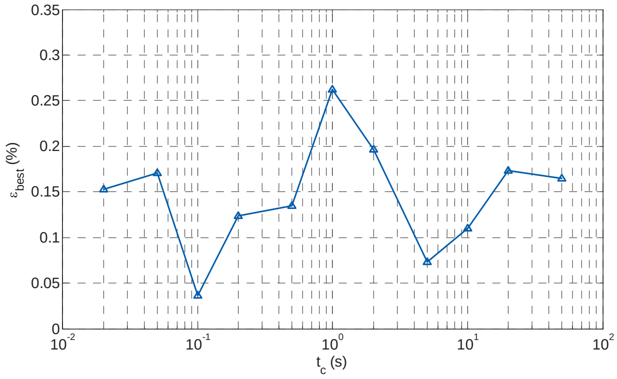

Fig. 20. Best fitness value as a function of charging time

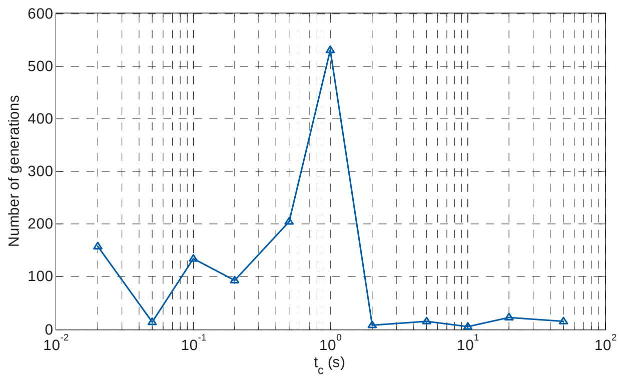

Fig. 21. Number of generations needed to obtain ε<0.5 % for each t_c

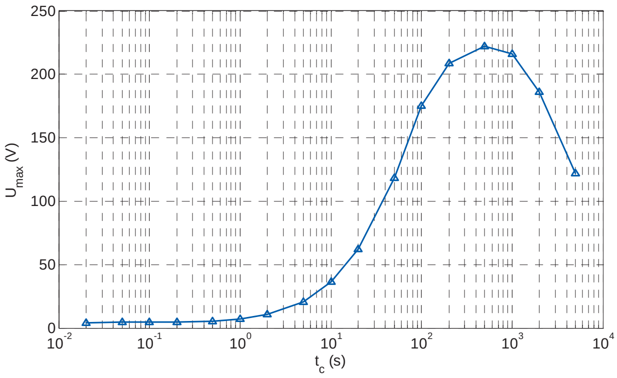

Fig. 22. Measured polarization spectrum curve

R_i=6190 MΩ and C_g=17.664 pF of the transformer were obtained from [27].

TABLE II
RVM RESULTS - 35 MVA POWER TRANSFORMER

t_c (s)	U_{max} (V)	t_{peak} (s)	S_r (V/s)
0.02	3.83	0.996	48.6
0.05	4.38	1.59	46.2
0.1	4.67	2.59	36.4
0.2	4.81	4.49	23.7
0.5	5.36	10.7	11.1
1	6.95	30.3	6.3
2	10.4	60.7	3.6
5	20.6	95.5	2.34
10	36.5	103	2.02
20	62	118	2.16
50	118	139	3.15
100	175	152	4.41
200	209	186	4.51
500	222	232	3.74
1000	216	307	2.87
2000	186	388	2.10
5000	122	417	1.29

The calculated polarization capacitance and resistance are shown in Fig. 23 and Fig. 24. τ_p varies from 0.15 s to 30009 s (Fig. 25).

The average temperature of the transformer oil during the recovery voltage measurements was 20°C. Based on the results of the RVM measurement and the oil temperature, the acceptable moisture level of 1.3 % was obtained in the insulation system of the power transformer which has been in operation for 4 years.

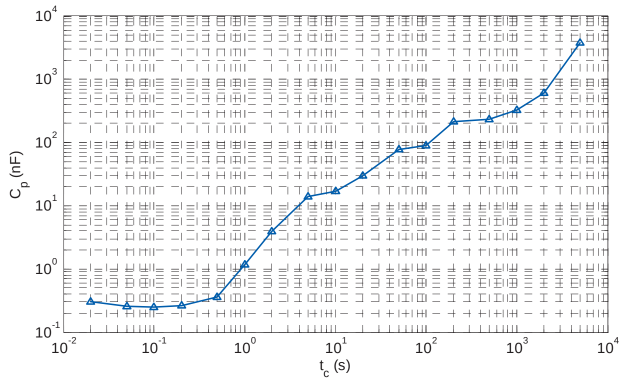

Fig. 23. Polarization capacitance as a function of charging time

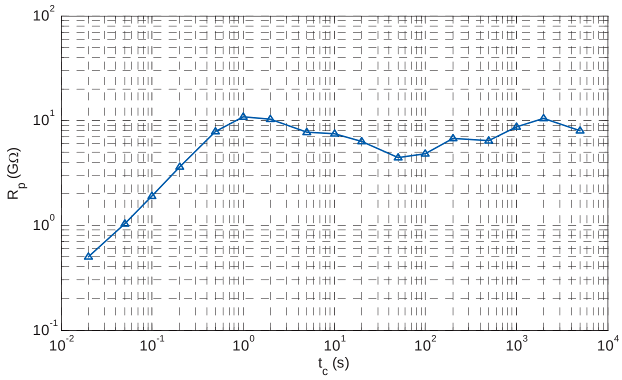

Fig. 24. Polarization resistance as a function of charging time

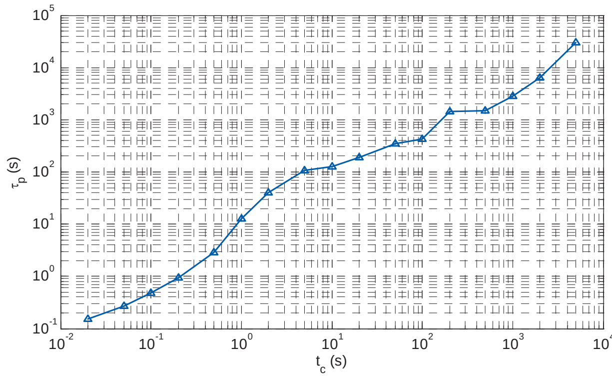

Fig. 25. Polarization time constant as a function of charging time

VI. Conclusion

The RVM method was mathematically described using the Laplace transform. The polarization process was represented using a single polarization branch with variable R_pC_p elements. Simple measuring circuit describing the polarization behavior of an insulation system was used to test the calculation method based on the Laplace transform. The calculated and measured maximum values of U_{max}, t_{peak} and S_r showed good agreement.

After the GA was successfully tested on a simple measuring circuit, it was used for determining the polarization elements from the RVM results of two power transformers located in hydropower plants. In the end, the influence of t_c on polarization elements was analyzed. This analysis showed that the polarization elements depend on the t_c and the moisture level that is present in the transformer insulation system. The polarization time constant τ_p increased with the increase of the t_c. It was pointed out by the authors of [28] that R_pC_p elements may be a function of t_c. Therefore, the ED model has to be modified by taking into account the effect of the parameter t_c. The proposed method can be used to identify the equivalent circuit that takes into account the polarization process within the transformer insulation system. Polarization process is represented by a single RC branch with variable elements, taking into account the effect of t_c on those elements. Analysis of change of insulation polarization elements at different stages of transformer life can improve the knowledge about the effect of moisture ingress and aging on the insulation time constants. The analysis presented in this paper can lead to more accurate information about the polarization processes in the insulation by simple use of the polarization spectrum.

References

[1] J. Słowikowski, The transformer moisture: reasons, consequences, modern assessment criteria, *International Conference on Power Transformers "Transformer 03"*, Pieczyska, Poland, pp. 96-105, 2003.

[2] A. C. Gjaerde, L. Lundgaard, E. Ildstad, Effect of temperature and

moisture on the dielectric properties of oil-impregnated cellulose, *9th International Symposium on High Voltage Engineering*, Graz, Austria, paper 1060, 1995.

[3] M. Kuschel, R. Plath, W. Kalkner, Dielectric Response – a Diagnostic Tool for HV Apparatus, *10^{th} International Symposium on High Voltage Engineering*, Montreal, Canada, vol. 4, pp. 393-396, 1997.

[4] Junhao Li, Yanming Li, Influencing Factors Investigation of Polarization and Depolarization Current Measurements on Assessment Aging Condition of Power Transformer, *International Review of Electrical Engineering (IREE), vol. 5 n. 6*, December 2010, pp. 2637-2643.

[5] W. S. Zaengl, Dielectric Spectroscopy in Time and Frequency Domain for HV Power Equipment (Transformers, Cables etc.), *12^{th} International Symposium on High Voltage Engineering*, Bangalore, India, 20-24 August 2001.

[6] A. A. Shayegani, E. Gockenbach, H. Borsi, H. Mohseni, Investigation on the Transformation of Time Domain Spectroscopy data to frequency domain data for impregnated pressboard to reduce measurement time, *Electrical Engineering, vol. 89 n. 1*, June 2005, pp. 11-20.

[7] R. Patsch, J. Menzel, Ageing and Degradation of Power Transformers – How to Interpret Return Voltage Measurements, *Proceedings of 2008 International Symposium on Electrical Insulating Materials*, Yokkaichi, Mie, Japan, September 2008.

[8] T. K. Saha, M. Darveniza, D. J. T. Hill, T. T. Ie, Electrical and chemical diagnostics of transformer insulation part A: Aged transformer samples, *IEEE Transactions on Power Delivery, vol. 12*, pp. 1547–1554, October 1997.

[9] V. der Houhanessian, W. S. Zaengl, Time domain measurements of dielectric response in oil–paper insulation systems, *Proc. IEEE Int. Symp. EI*, Montreal, QC, Canada, 1996.

[10] A. Helgeson, U. Gäfvert, Calculation of the dielectric response function from recovery voltage measurements, *Proc. CEIDP*, Virginia Beach, VA, 1995.

[11] U. Gäfvert, G. Frimpong, J. Fuhr, Modeling of dielectric measurements on power transformers, *Proc. Cigre*, 1998, paper 15-103.

[12] S. M. Islam, P. R. S. Jota, M. Stace, Detection of oil–paper equilibrium moisture content in power transformers using hybrid intelligent interpretation of polarization spectrums from recovery voltage measurements, *Proc. IEEE Int. Symp. EI*, Arlington, VA, 1998.

[13] J. P. van Bolhuis, E. Gulski, J. J. Smit, Monitoring and diagnostic of transformer solid insulation, *IEEE Transactions on Power Delivery*, Vol. 17, No. 2, April 2002.

[14] P. Osvath, H. Poell, Polarization spectrum analysis for diagnosis of oil/paper insulation systems, in *Proceedings of the Nordic Insulation Symposium*, Vaasa, Finland, 1994.

[15] Tettex Switzerland, Polarizationsspektrumanlyze für eine isolierzustandsiagnostiek, Tettex, Switzerland, Tech. Rep. 096 062-DE-o.D.

[16] G. Csepes, I. Hamos, I. Brooks, V. Karius, Practical foundations of the RVM (recovery voltage method for oil/paper insulation diagnosis), *Proceedings of the Conference on Electrical Insulation and Dielectric Phenomena*, vol. 1, pp. 345-355, 1998.

[17] A. Bognar, L. Kalacsai, G. Csepes, E. Nemeth, J. Schmidt, Diagnostic Tests of High Voltage Oil-Paper Insulation Systems (in Particular Transformer Insulation) Using DC Dielectrometrics, *Proceedings of CIGRE Paris Session*, Paris, Paper no. 15/33-08, 1990.

[18] P. R. S. Jota, S. M. Islam, F. G. Jota, Modeling the Polarization in Composite Oil/Paper Insulation Systems, *IEEE Transactions on Dielectrics and Electrical Insulation*, vol. 6, no. 2, pp.145-151, April 1999.

[19] T. K. Saha, P. Purkait, F. Muller, Deriving an Equivalent Circuit of Transformer Insulation for Understanding the Dielectric response Measurements, *IEEE Transaction on Power Delivery*, Vol. 20, No. 1, pp. 149-157, January 2005.

[20] J. P. van Bolhuis, *Applicability of recovery voltage and on-line partial discharge measurements for condition assessment of high voltage power transformers*, Ph.D. dissertation, University of Technology Delft, 2002.

[21] M. Eslami, H. Shareef, A. Mohamed, M. Khajehzadeh, Damping of Power System Oscillations Using Genetic Algorithm and Particle Swarm Optimization, *International Review of Electrical Engineering (IREE), vol. 5 n. 6*, December 2010, pp. 2745-2753.

[22] J. Barati, S. S. Mortazavi, A. Saidian, Analysis and Assessment of FACTS-Based Stabilizers for Damping Power System Oscillations using Genetic Algorithms, *International Review of Electrical Engineering (IREE), vol. 5 n. 6*, December 2010, pp. 2745-2753.

[23] *User's Guide*, Genetic algorithm and direct search toolbox 2, The MathWorks, Matlab 2009.

[24] R. L. Haupt, S. E. Haupt, *Practical Genetic Algorithms*, (Wiley & Sons, second edition, 2004).

[25] Končar - Electrical Engineering Institute, Report on testing of power transformer 6.3/35 kV, 8 MVA, No. 030005.

[26] *Tettex Instruments Manual - Automatic Recovery Voltage Meter (RVM) Type 5461*, version 2.13 (IM 5461-E- 930514).

[27] Končar - Electrical Engineering Institute, Report on testing of power transformer 12/123 kV, 35 MVA, No. 017799.

[28] S. Birlasekaran, Yu Xingzhou, Relaxation Studies on Power Equipment, *IEEE Transactions on Dielectrics and Electrical Insulation Vol. 10, No. 6;* December 2003.

Authors' information

[1]Faculty of Electrical Engineering and Computing,
Department of High Voltage and Power Systems,
University of Zagreb,
Unska 3, HR-10000 Zagreb, Croatia.

[2]Končar Electrical Engineering Institute,
Transformer Department,
High Voltage Laboratory,
Fallerovo šetalište 22, HR-10002 Zagreb, Croatia.

Božidar Filipović-Grčić (M'10) was born in Sinj, Croatia, in 1983. He received his B.Sc. degree from the Faculty of Electrical Engineering and Computing, University of Zagreb, in 2007. Presently he is working at Faculty of Electrical Engineering and Computing (Department of High Voltage and Power Systems) and following doctoral studies. His areas of interest include power system transients, insulation co-ordination and high-voltage engineering. He is a member of IEEE society and Croatian Committee of CIGRÉ.

Dalibor Filipović-Grčić was born in Sinj, Croatia, in 1980. He received his Ph.D. from the Faculty of Electrical Engineering and Computing, University of Zagreb, in 2010. Presently he is the head of High Voltage Laboratory at Končar Electrical Engineering Institute (Transformer department). His areas of interest include optimization of condenser type oil-paper insulation and high-voltage laboratory testing. He is a member of technical committees HZN/TO E 38 Instrument Transformers and HZN/TO E 42 High voltage test techniques.

Ivo Uglešić (SM'08) was born in Zagreb, Croatia, in 1952. He received Ph.D. degree from the Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia, in 1988. Presently, he is a Professor at the Faculty of Electrical Engineering and Computing (Department of High Voltage and Power Systems), University of Zagreb. Dr. Uglešić is the head of High-Voltage Laboratory at the Faculty of Electrical Engineering and Computing. His areas of interest include high-voltage engineering and power transmission.