World Academy of Science, Engineering and Technology
International Journal of Energy and Power Engineering
Vol:10, No:1, 2016

Power Transformer Noise, Noise Tests, and Example Test Results

E. Doğan, B. Kekezoğlu

***Abstract*—**Voltage level must be raised in order to deliver the produced energy to the consumption zones with less loss and less cost. Power transformers used to raise or lower voltage are important parts of the energy transmission system. Power transformers used in switchgear and power generation plants stay in human's intensive habitat zones as a result of expanding cities. Accordingly, noise levels produced by power transformers have begun more and more important and they have established itself as one of the research field. In this research, the noise cause on transformers has been investigated, it's causes has been examined and noise measurement techniques have been introduced. Examples of transformer noise test results are submitted and precautions to be taken were discussed for the purpose of decreasing of the noise which will occurred by transformers.

***Keywords*—**Power transformer, noise measurement, core noise, load noise, fan-pump noise.

I. Introduction

TRANSFORMERS which are the important building blocks of the power system should be designed and operated considering both electrical parameters and environmental effects. The noise level of the transformers used especially in urban areas must be at a level that does not threaten human health. Despite that the occurrence of noise on the transformer is inevitable.

The noise can be occurred based on load and no-load on power transformers. The incidence cause of core noise which is known as no-load noise is elastic length changes in the core resulting from the magnetization. Load noise occurs from vibration generation of magnetic force caused by load currents on windings, tank walls and magnetic shield. On the other hand, the noise occurs from fan and pump which are used for power transformers as cooling equipment should be taken into account.

Case studies made so far about the noises occurred in the transformers are listed below. A. Ilo, B. Weiser, T. Booth, H. Pfützner [1] have been investigated the effects of geometric parameters on transformers in their works. B. Weiser and H. Pfützner [2] have been investigated the relationship between magnetostriction and magnetic forces and acoustic noise occurring in the transformer core. Also the single-step-lap (SSL) and multistep-lap (MSL) methods have been compared experimentally. Ishida, Okabe and Sato [3] have been investigated the effects of clamping pressure and the material used on three-phased transformer which was made from different materials packaged by SSL and MSL methods. Teeraphon Phophongviwat [4] have been investigated the effects of magnetostriction and magnetic forces on vibration and noise which occur in the transformer's core in his work. And he has been intended to determine appropriate parameters to explain the relationship between transformer's core vibration and noise. Girgis, Bernesjö and Anger [5] have been investigated the characteristics of load noise, the impact of the load noises on the overall noise, the parameters which effect the load noise and methods that can reduce noise in the work they have done. Ertl and Voss [6] have investigated the effect of load harmonics on the noise occurred in transformer in 2014.

The reasons of the noises in transformers were explained in Section II of this work. In Section III, it was explained how the noise tests should be done and examples of noise measurements are presented. The study was terminated in Section IV.

II. Power Transformer Noises

The transformers used in power systems should be designed as not to harm human health. Therefore, it is necessary to clarify the harmful noise level for human health.

Noise levels that humans are unsuitable were described in TS 9315 ISO 1996-1/T1, TS ISO 1996-2/T1 and ISO 1996-1:2003 standards. The noise level classification was given in Table I.

TABLE I
Classification of Noise Levels [12]

Noise in The First Degree (30-65 dB(A))	Discomfort, Getting Bored, Anger, Concentration and Sleep Disturbance
Noise in The Second Degree (65-90 dB(A))	Physiological Noise, Change of Heartbeat, Acceleration of The Respiration, Decreased of Pressure in The Brain
Noise in The Third Degree (90-120 dB(A))	Physiological Noise, Headache
Noise in The Fourth Degree (120-140 dB(A))	Hearing Disorders
Noise in The Fifth Degree (> 140 dB(A))	Explosion of The Eardrum

The power transformers where used in residential area have to generate noise lower than a level that affect human health. Transformer noise can be examined under three headings and these are; “Core Noise”, “Load Noise” and “Fan-Pump Noise”.

E. Dogan is with Turkish Electricity Transmission Company, Turkey, (corresponding author, phone: +90-0442 242 27 58 e-mail: edoganenerji@ gmail.com).

B. Kekezoglu is with Electrical Engineering Department, Yildiz Technical University, Istanbul, Turkey (e-mail: bkekez@ yildiz.edu.tr).

A. Core Noise

"Core Noise" occurs from voltage. Magnetostriction and vibration on the transformer are generated by magnetic forces in the core. Core noise arises from oscillation of silicon steel sheets. "Core Noise", generally is seen as the source of dominant noise. Barely at modern transformers which reduced noise components, were developed core design. At the modern transformers which are developed core design, is reduced noise components.

B. Load Noise

Noise caused by the current is load noises. The source of the noise increases proportionally with loading of the transformer. Nowadays harmonic components increase in the power grid because of the developing power electronic technologies. As a consequence of that form of the sinusoidal wave is depraved. Harmonic distortions in high frequency components are caused to vibration on transformer winding. Electro-magnetic forces created by the load current constitute leakage flux at magnetic shield with winding. And this vibration engenders load noises. For the development of core design at modern transformers, the source of dominant noise is seen as load noise. In Fig. 1, load noise frequency spectrum of a power transformer is shown.

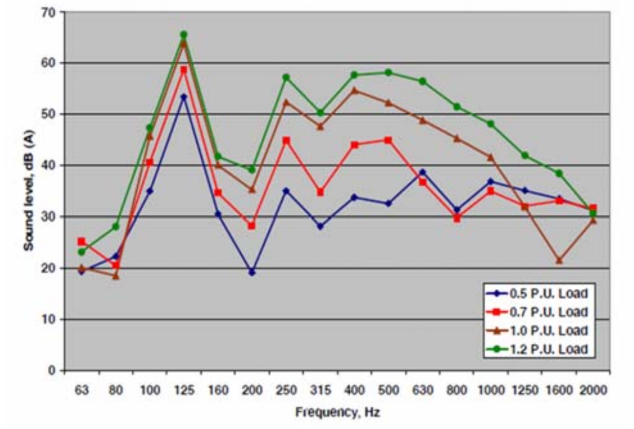

Fig. 1 The Frequency Spectrum of the Load Noise of the Power Transformer [5]

C. Fan-Pump Noise

The third factor which is effective on the transformer noise is fan and pump noise. As known magnetic induction that occurs between the nucleus and the transformer windings in the core, cause to rise in the heat level. Because of reaching very high level of heat value, the transformer needs to cooling system. Fan and pumps are used in power transformers in order to form the cooling apparatus. This pump and fans which is used to cool the transformer are effective at transformer noise even if just a bit. According to J. Pan and others fan noise is characteristically broad-band in nature. Therefore, it influences little at noise problem in around transformers [7].

In Fig. 2, it is shown that core noise (noise occurring in the unloaded condition), noise occurring under load and the noise made by fan's sound according to a 333 kVA transformer's load conditions.

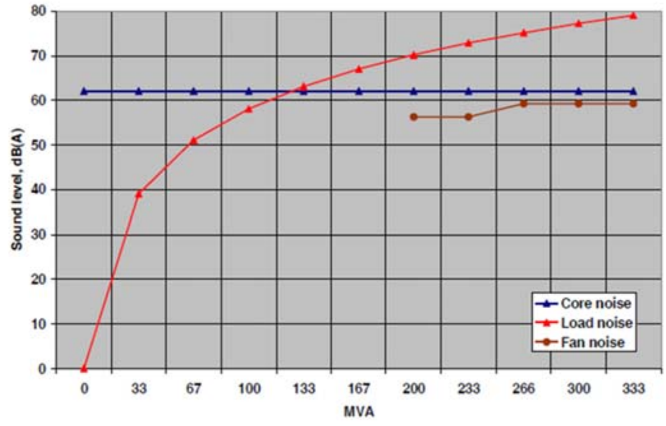

Fig. 2 Sound level of a modern low core-noised transformer under the load conditions [5]

III. Transformer Noise Tests

Before commissioning of power transformers, the essential noise tests have to be done. First tests have to be done are listed below and sample test results are presented.

A. Measurements of Noise

Consisting of sound pressure and sound intensity, there are two different measurement methods to evaluate the transformer noise. In the present study, measurements of sound pressure are described. In this sound pressure measurements are used type-1 sound level meter which is in accordance with standard IEC 60651 and calibrated with 5.2 article of ISO 3746 [8]. According to this, in the condition of forced cooling system is off the measurement has to be taken 0.3 meters away from the transformer surface. And the measurement has to be taken 2 meters away from the transformer if the cooling systems are on. If the tank height is less than 2.5 meters the measurement has to be taken from the half of the total tank height. If the tank height is greater than 2.5 meters, then the measurement has to be taken from total tank height's 1/3 and 2/3 heights.

The microphone must be positioned at the stated height and distance. In addition, a measurement must be taken from at least six microphones. The horizontal distance between the microphones mustn't be more than 1 meter.

The transformer's A-weighted sound power level and the total of core noise and load noise under nominal current and voltage is expressed as $L_{WA,SN}$ (1) [8]:

$$L_{WA,SN} = 10\lg(10^{0,1L_{WA,UN}} + 10^{0,1L_{WA,IN}}) \qquad (1)$$

Nominal current, nominal frequency and A-weighted sound power level of impedance voltage can be calculated with $L_{WA,IN}$ (2) [8]:

$$L_{WA,IN} \approx 39 + 18lg\frac{S_r}{S_p} \qquad (2)$$

"S" is the area of measurement surface and measured values gathered from 0.3 meter can be defined with (3) [8]:

$$S = 1{,}25 h l_m \quad (3)$$

"h" is for the height of the transformer tank and l_m is defined as measurement environment. 1.25 coefficient is a constant derived from experimental observations. Equivalence (4) is used for measurements gathered from 2 meters away [8].

$$S = (h + 2) l_m \quad (4)$$

Average background noise is defined in L_{bg} (5). M is the number of background measurement point between 1 and 10. L_{bgi}, i. is the background sound pressure level measured at the measurement point [9].

$$\overline{L_{bgA}} = 10log_{10}(\frac{1}{M}\sum_{i:1}^{M} 10^{0,1L_{bgi}}) \quad (5)$$

Unadjusted average sound power level is given in L_{pAO} (6). N is the number of measurement points and L_{pAi} i. is the sound power level in the measurement point [9].

$$\overline{L_{pAO}} = 10log_{10}(\frac{1}{N}\sum_{i:1}^{N} 10^{0,1L_{pAi}}) \quad (6)$$

After measurement the second background measurement should be done. If corrected A-weighted sound pressure level $\overline{L_{pA}}$, is given in (7) [9]:

$$\overline{L_{pA}} = 10log_{10}\left(10^{0,1\overline{L_{pAO}}} - 10^{0,1\overline{L_{bgA}}}\right) - K \quad (7)$$

Finally, the resulting sound power level L_{wA} it is defined in (8). S, as square meter surface area measurements and S_0 is reference area. ($1m^2$) [9].

$$L_{wA} = \overline{L_{pA}} + 10log_{10}\frac{S}{S_0} \quad (8)$$

B. Transformers Noise Test Results

In this study, Noise measurement tests performed by Turkish Electricity Transmission Company (TEIAŞ), were submitted. Noise levels are measured as appropriate to international measurement standard (IEC 6006-10). Measurements are performed by with Brüel&Kjaer 2260.

TABLE II
NOISE PRESSURE OF MEASUREMENT AREA [10]

Position	Before the Test	After the Test	Position	Before the Test	After the Test
1	48.3	47.3	6	48.7	48.2
2	49.3	47.5	7	47.1	48.2
3	48.2	47.6	8	47.9	48.3
4	47.4	48.0	9		
5	48.6	48.8	10		
Arithmetic/Average Energy, $\overline{L_{bgA}}$				48.2	48.0

250 MVA autotransformer noise measurements are given in Tables III and IV; this transformer's excitation voltages are chosen 3.675kV (%100U_n) and 4.293kV (%110U_n). Test frequency is 50 Hz, transformer's tank height is 3,61 m, microphone heights are 1.2 m and 2.41 m at respectively 1/3 and 2/3 height of the tank. Microphones are placed 2 m away from transformer. Transformer cooling system is OFAF and during measurement 7 fans and 2 pumps are service.

Noise level of testing environment in before and after of test is measured.

TABLE III
NOISE PRESSURE LEVELS IN 250 MVA AUTOTRANSFORMER [10]

Sound Pressure Level, L_{pAi}								
Test Voltage: 100% U_n; Measuring Distance, x: 2.0 m; [OFAF, 7 Fans and 2 pumps in service], MP: Measuring Point								
MP	Height (h)		MP	Height (h)		MP	Height (h)	
	(1/3)	(2/3)		(1/3)	(2/3)		(1/3)	(2/3)
1	67.0	66.5	16	67.0	66.5	31	68.7	68.3
2	66.1	67.5	17	66.5	66.5	32	68.5	67.5
3	65.1	66.6	18	65.4	65.2	33	68.7	67.4
4	65.7	65.3	19	65.7	66.3	34	68.2	67.8
5	66.5	65.2	20	66.9	66.4	35	66.9	67.6
6	65.0	67.7	21	66.6	66.3	36	66.5	67.8
7	66.5	65.7	22	67.6	67.0	37	67.6	66.4
8	66.0	66.5	23	68.1	67.1	38	67.4	66.7
9	68.9	69.4	24	68.0	67.2	39	66.4	67.5
10	66.2	69.8	25	67.6	67.0	40	67.3	66.1
11	66.4	66.5	26	66.9	66.1	41	67.3	66.5
12	67.4	67.5	27	67.6	66.7	42	67.5	66.7
13	68.4	65.8	28	67.6	66.1	43	66.4	67.2
14	65.5	66.2	29	68.6	67.2	44	66.4	66.5
15	66.0	65.7	30	68.0	67.5			
Arithmetic/Average Energy, $\overline{L_{pAO}}$							67.0 dB(A)	
$\overline{L_{pAO}}$ – max $\overline{L_{bgA}}$ (must be greater than 3dB(A))							18.9 dB(A)	
Environmental Correction, K (must be less than 7 dB)							6.7 dB	
Corrected Average Sound Pressure Level, $\overline{L_{pA}}$							60.3 dB(A)	
Guaranteed Sound Pressure Level							65.0 dB(A)	
Defined Peripheral Length							44.0	
Area of the Measurement Surface(OFAF)							246.8 m^2	
10lg(S/S_0)							23.9	
Calculated Average Noise Power Level, L_{WA}							84.2 dB(A)	

TABLE IV
MEASURED IN 250 MVA AUTOTRANSFORMER, NO LOAD HARMONIC CURRENTS [10]

Voltage (kV)	Phase	Measured (Harmonics)			
		3.	5.	7.	9.
3.674	a1	16.8%	17.5%	10.0%	1.0%
	b1	12.1%	15.3%	8.1%	1.8%
	c1	23.7%	11.3%	7.7%	3.0%

As shown in Table III, there is a difference 18.9 dB(A) between total arithmetic average sound pressure and the arithmetic average sound pressure of test environment. In this transformer 27PHD090 type 0.27 mm thickness and 30PH105 type 0.30 mm thickness siliceous sheet metals which high grain oriented (HGO) are used. The magnetic flux density of the relevant materials is given as (B8[T]) 1,90-1,91 T. With increasing material's B8 value, magnetostriction acceleration level tends to decrease. It is related to HGO material to be used and on the reasons of the high B8 value, autotransformer's core noise is reduced. However, the reason of the noise occurring in transformer may be other core parameters such as step-lap method, number of step, overlap length, length of overlap shift and air gap length; in addition, it may remain at high values of no load harmonic currents. Measured no load current harmonics are given in Table IV.

In the case of 250 MVA autotransformer's test voltage %110 U_n, the noise measurements were made in the same environmental conditions. In this statement, there is a difference 24.8 dB(A) between the total arithmetic average of sound pressure and the arithmetic average sound pressure of ambient as it is seen, in case of increasing the test voltage, approximately 6 dB(A) increase occurred. The measurement results are given in Table V.

Rated power which was built by TEIAŞ 50 / 62.5 MVA, the rated voltage of 154 / 33.6 kV and a power transformer cooling system which is called as ONAN, noise level measurements are taken of the 0.3 m and 2 m distances from the ONAN (cooling system) are given in Tables VI and VII. Noise level of environment which made measurements measured 43.5 dB (A).

TABLE V
IN THE CASE OF 250 MVA AUTOTRANSFORMER'S TEST VOLTAGE %110 U_n, OCCURRED NOISE LEVELS [10]

Sound Pressure Level, L_{pAi}
Test Voltage: 110% U_n; Measuring Distance, x: 2.0 m; [OFAF, 7 Fans and 2 pumps in service], MP: Measuring Point

MP	Height (h)		MP	Height (h)		MP	Height (h)	
	(1/3)	(2/3)		(1/3)	(2/3)		(1/3)	(2/3)
1	71.5	72.9	16	74.0	75.8	31	71.5	72.1
2	70.3	72.1	17	74.1	71.7	32	72.5	73.8
3	71.7	71.6	18	71.7	72.6	33	72.4	72.7
4	71.1	72.6	19	70.7	73.1	34	72.8	72.5
5	72.4	74.2	20	72.7	71.5	35	71.1	76.0
6	72.0	74.4	21	72.1	70.2	36	70.8	72.7
7	75.0	74.5	22	74.0	73.6	37	72.1	72.3
8	74.6	74.3	23	72.6	72.6	38	73.6	70.8
9	75.7	76.9	24	71.0	72.1	39	73.5	73.3
10	73.6	72.9	25	72.9	70.8	40	71.8	70.6
11	73.8	77.9	26	72.1	70.3	41	70.9	72.0
12	75.0	74.6	27	70.6	70.9	42	72.5	70.2
13	74.0	72.8	28	75.0	73.3	43	71.2	75.8
14	71.8	76.5	29	72.6	73.0	44	71.2	73.2
15	71.5	70.6	30	70.8	72.6			

Arithmetic/Average Energy, $\overline{L_{pAO}}$	72.9 dB(A)
$\overline{L_{pAO}} - \max \overline{L_{bgA}}$ (must be greater than 3dB(A))	24.8 dB(A)
Environmental Correction, K (must be less than 7 dB)	6.7 dB
Corrected Average Sound Pressure Level, $\overline{L_{pA}}$	66.2 dB(A)
Guaranteed Sound Pressure Level	70.0 dB(A)
Calculated Average Noise Power Level, L_{wA}	90.2 dB(A)

When examined sound pressure levels occurring in transformer, is seen in the sound pressure level of 0.3m distance lower than 2m. This situation does not coincide with the reactive near-field effect. Hardly, due to the sound pressure measurement methods cannot filter out environmental noise and increasing occurred in the noise level in the environment which is made measurement can be considered as the cause of this situation.

TABLE VI
TAKEN THE NOISE LEVELS IN 0.3 M DISTANCE [11]

Sound Pressure of Measurement Area: 43.5 dB(A)
Measuring Distance, x: 0.3 m, MP: Measuring Point

MP	Height (h)		MP	Height (h)		MP	Height (h)	
	(1/3)	(2/3)		(1/3)	(2/3)		(1/3)	(2/3)
1	55.4	55.4	10	56.6	57.5	18	55.9	55.1
2	57.0	55.7	11	56.6	54.3	19	53.8	54.5
3	60.0	57.7	12	55.1	57.2	20	57.3	54.6
4	51.0	57.1	13	57.7	57.7	21	59.8	55.3
5	58.7	56.4	14	59.7	57.6	22	56.2	54.5
6	58.2	54.2	15	59.4	57.5	23	54.0	54.9
7	57.1	55.8	16	58.4	57.4	24	58.0	54.8
8	56.5	53.2	17	59.6	55.5	25	53.2	53.0
9	58.7	55.5						

	1/3h	2/3h
Arithmetic/Average Energy, $\overline{L_{pAO}}$	57.5 dB(A)	55.9 dB(A)
Environmental Correction, K (must be less than 7 dB)		2.37 dB
Corrected Average Sound Pressure Level, $\overline{L_{pA}}$		54.3 dB(A)
Guaranteed Sound Pressure Level		60.0 dB(A)
Defined Peripheral Length		23.2
Area of the Measurement Surface(OFAF)		104.7 m^2
10lg(S/S_0)		20.2
Calculated Average Noise Power Level, L_{wA}		74.5 dB(A)

TABLE VII
TAKEN THE NOISE LEVELS IN 2 M DISTANCE [11]

Sound Pressure of Measurement Area: 43.5 dB(A)
Measuring Distance, x: 2 m, MP: Measuring Point

MP	Height (h)		MP	Height (h)		MP	Height (h)	
	(1/3)	(2/3)		(1/3)	(2/3)		(1/3)	(2/3)
1	63.9	61.3	14	62.4	62.8	26	63.8	63.3
2	63.4	63.1	15	62.8	63.5	27	63.1	63.3
3	63.4	63.4	16	63.8	63.3	28	63.9	61.8
4	63.9	63.4	17	63.5	63.4	29	63.4	61.4
5	63.8	63.5	18	63.5	63.3	30	63.0	61.0
6	63.7	63.8	19	63.5	63.4	31	62.4	62.5
7	63.0	62.9	20	63.3	63.8	32	62.2	62.9
8	63.9	62.3	21	63.6	63.3	33	61.9	63.1
9	62.9	61.6	22	63.0	63.3	34	62.9	63.3
10	62.5	61.8	23	63.1	63.4	35	63.7	63.4
11	62.0	61.7	24	63.8	63.4	36	63.3	63.5
12	63.4	61.5	25	63.2	63.1	37	63.5	63.1
13	62.1	61.4						

	1/3h	2/3h
Arithmetic/Average Energy, $\overline{L_{pAO}}$	63.2 dB(A)	62.9 dB(A)
Environmental Correction, K (must be less than 7 dB)		3.86 dB
Corrected Average Sound Pressure Level, $\overline{L_{pA}}$		59.2 dB(A)
Defined Peripheral Length		36.8
Area of the Measurement Surface(OFAF)		206.4 m^2
10lg(S/S_0)		23.2
Calculated Average Noise Power Level, L_{wA}		82.4 dB(A)

IV. CONCLUSION

Transformers which are indispensable of power systems are formed on noise levels should not affect the human health. In this reason, suppression of noise sources of the transformer constituting the physiological and psychological effects in humans will play an important role in reducing the environmental noise. In this study revealed transformer noise sources and transformer noise measurement methods are described. It was examined and interpreted noise tests which was given by TEIAŞ.

In the light of detected information, the design of modern transformers and as a result of the development of materials which is used core noise (no-load noise) usually ceased to be the dominant noise problem. Pump and fan noise is not considered as dominant source of noise due to less influence of noise from no-load condition. Transformer noises' dominant noise source is usually the load-noise with occurring magnetic leakage flux under load. In this direction, harmonics which is found in load current must be damped and transformer mustn't be overload.

REFERENCES

[1] A. Ilo, B. Weiser, T. Booth, H. Pfützner, Influence of Geometric Parameters on the Magnetic Properties of Model Transformer Cores, 1996.
[2] B. Weiser, H. Pfützner, Member, IEEE, and J. Anger, Relevance of Magnetostriction and Forces for the Generation of Audible Noise of Transformer Cores, 2000.
[3] M. Ishida, S. Okabe, K. Sato, Analysis of Noise Emitted from Three-Phase-Stacked Transformer Model Core, 1998.
[4] Teeraphon Phophongviwat, Wolfson Centre for Magnetics Cardiff School of Engineering, Investigation of the Influence of Magnetostriction and Magnetic Forces on Transformer Core Noise and Vibration, 2013.
[5] Ramsis S. Girgis, Mats Bernesjö, Jan Anger, Comprehensive Analysis of Load Noise of Power Transformers.
[6] Michael Ertl, Stephan Voss, the Role of Load Harmonics in Audible Noise of Electrical Transformers, 2014.
[7] R.S. Ming, J. Pan, M. P. Norton, S. Wende, H. Huang, the Sound-Field Characterisation of a Power Transformer, 1999.
[8] IEC 60076-10, Power Transformers-Part 10: Determination of Sound Levels, 2001.
[9] Ake Carlson, Jitka Fuhr, Gottfried Schemel, Franz Wegscheider, Testing of Power Transformers, 2003.
[10] TEİAŞ 250 MVA Ototransformatörün Gürültü Ölçümü, 2012.
[11] TEİAŞ 50/62.5 MVA Güç Transformatörünün Gürültü Ölçümü, 2011.
[12] S. Bilgili, E. Gürtepe, E. Türkel, A. M. Altınoluk, N. Hüsmen, A. Bütün, H. Ertorun, Çevresel Gürültü Ölçüm ve Değerlendirme Klavuzu, T.C. Çevre ve Orman Bakanlığı Çevre Yönetimi Genel Müdürlüğü, 2011.

Erdi Dogan was born in Elazıg, Turkey, in 1989. He graduated in electrical and electronic engineering at the Fatih University, Turkey in 2011. In 2015 he joined Turkish Electricity Transmission Company (TEİAŞ) in Erzurum, Turkey and he is currently working as an electrical engineer at the Load Distribution Manager. He is currently studying Master of Science as electrical engineer at Yildiz Technical University, Turkey.

His research interests power transformers, power transmission system and power quality.

Bedri Kekezoglu was born in Istanbul, Turkey, in 1982. He is currently working as an Assistant Professor at the Electrical Engineering Department of Yildiz Technical University, Turkey.

His research interests include analysis of power systems, wind energy systems and power quality.