Measurement of Power Frequency Electric and Magnetic Fields nearby Power Facilities in Several Countries

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Abstract--**To evaluate the power frequency electric and magnetic fields (EMF) inside and around power facilities quantitatively, it is important to measure actual values of them. However, there seems to have been no systematic research of this kind.**

Under such a circumstance, the authors have planned and been carrying out international cooperative research among various countries on power frequency electric and magnetic fields measurements. This paper describes the results of the EMF measurement inside and around power facilities in Colombia, Cuba, Indonesia, Japan, Mexico, Thailand, and USA.

***Keywords*--electric and magnetic fields; power facilities; power frequency.**

I. INTRODUCTION

A lot of calculation results of power frequency electric and magnetic fields have been reported, which are generated by power facilities such as transmission lines [1-3], substations [4-5] and so on [6-7]. Magnetic field mitigation method has been also discussed based on calculation [8]. However, there seems no systematic research on measurement of electric and/or magnetic field measurements inside and around power facilities. It is important to actually measure power frequency electric and magnetic fields (EMF) nearby power facilities to quantify electric and magnetic environment and if necessary to compare them with those given in the international and/or domestic guidelines or standards on EMF.

Under such circumstance, the authors planned international cooperative research on power frequency EMF inside and around power facilities among various countries [9]. In order to enable comparison of results obtained, the identical measuring equipments were used and measurements were carried out by following the identical procedures, which is quite important in such an international cooperative research.

This paper summarizes the EMF measurement results of the activities which were carried out inside and around 500-, 400-, 275-, 230-, 220-, 115-, and 110-kV power facilities in seven countries; Colombia [10], Cuba [10], Indonesia [11], Japan [9], Mexico [12], Thailand [13], and USA [14].

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II. LOCATION OF MEASUREMENTS

As Table I is indicated, measurements were conducted at 23 power facilities with 110-kV to 500-kV system voltage in 7 countries.

TABLE I
LOCATIONS OF MEASUREMENTS

Country	Location	System voltage, kV
Colombia	In substation	500
		230
	Under transmission lines	500
	Under transmission lines	115
Cuba	In substation	220
		110
	In substation	220
		110
	Under transmission lines	220
Indonesia	In substation	500
	Under transmission lines	500
Japan	In substation	500
	Under transmission lines	275
Mexico	In substation	400
	In substation	400
	Under transmission lines	400
	Under transmission lines	400
Thailand	In substation	500
	Under transmission lines	500
U.S.A	In substation	500
	In substation	500
	Under transmission line	500
	Under transmission line	500

II. MEASURING METHOD

In such an international cooperative research, it is quite important to use the identical measuring equipments and to follow the identical measurement procedures. EMF was measured by spot and continuous measurements in the present study.

A. Spot Measurement

Electric and magnetic fields at given location and time are available by spot measurement, where a measurement instrument is fixed at a location of interest and only one measurement is carried out.

For spot measurement of electric and magnetic fields, Furukawa's electric field meter and Enertech's magnetic flux density meter were used respectively. The specifications of the equipments are shown in Table II. Resultant magnetic flux density (indicated as magnetic field hereafter) in root mean square was obtained with the meter. EMF values were measured at approximately 1 meter above the ground.

In substations, measurements of EMF were conducted at every 1 meter along two straight paths orthogonal to each other, as indicated in Fig. 1, which shows an example in 500-kV substation.

TABLE II
SPECIFICATIONS OF EQUIPMENTS FOR SPOT MEASUREMENTS

	Electric field strength meter	Magnetic flux density meter
Model	EFM-309	EMDEX-II
Geometry of sensor	Two separated plates with 100 mm distance	Three coils
Component	Vertical only	3-axes and/or resultant
Range	0 – 90 V/cm	0.01 – 300 μT
Insulating Rod	Acrylic resin	-----
Manufacturer	Furukawa Electric Co., Ltd.	Enertech Consultants

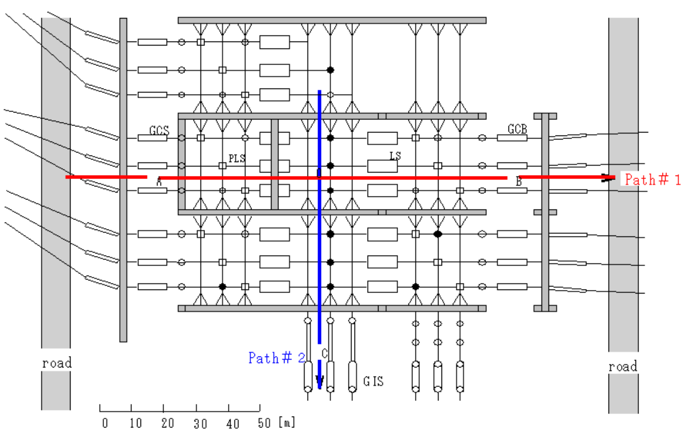

Fig. 1. An example of measurement paths in a 500-kV substation.

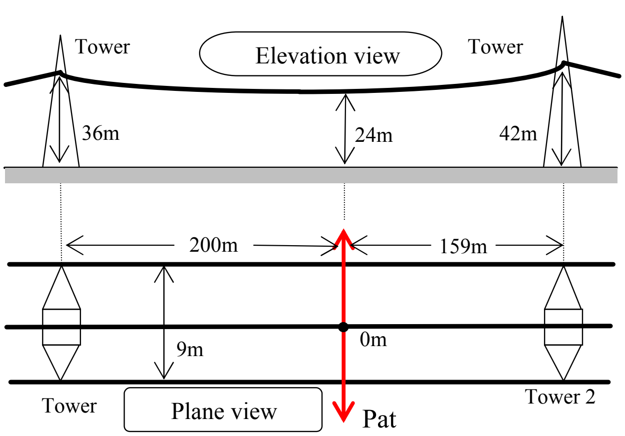

Fig. 2. An example of measurement path under transmission lines.

Measurement under transmission lines were carried out at every 1 meter along a path perpendicular to transmission lines at the lowest clearance. Measurement procedures were in accordance with the guideline prescribed in IEEE Standard 644-1994[15]. Fig. 2 shows an example of a measurement path under transmission lines.

B. Continuous Measurement

In the continuous measurement, an instrument is fixed on the body of a volunteer who walks around. Thus, a portable and light weight equipment is desirable. An EMDEX II was selected because of the portability, simultaneous measurement ability of electric and magnetic fields, and the software availability for data analysis. The specifications of EMDEX II are summarized in Table III. However, since no portable electric sensor was available in the market, a portable sensor was developed using a stainless mesh so as to be fixed on shoulder as shown in Fig. 3 [16]. Since the electric field strengths are enhanced on shoulder, the detected electric field by this sensor was corrected to those for 1 meter high from the ground. Magnetic field was directly measured with sensors inside the equipment installed on waist corresponding to approx. 1 meter high. EMF values were recorded every 3 seconds during measurement and recorded. After measurement was finished, data recorded were transferred to a personal computer and then analyzed with the software.

A volunteer carried with him the electric field sensor on his shoulder and EMDEX II at his waist. He did not stay at a given location but walked around inside a substation or under a section of transmission lines. Thus, he was sometimes very close to a transformer and sometimes far from any power conductor.

TABLE III
SPECIFICATION OF EQUIPMENT FOR CONTINUOUS MEASUREMENTS

Model	EMDEX II	
Field	Electric field strength	Magnetic flux density
Size, mm	170×70×40	
Weight, g	340	
Sensor	Mesh	Three coils
Component	One direction	Resultant
Range	1-200 kV/m	0.01-300 μT
Meter reading	Charging Current	Magnetic flux density

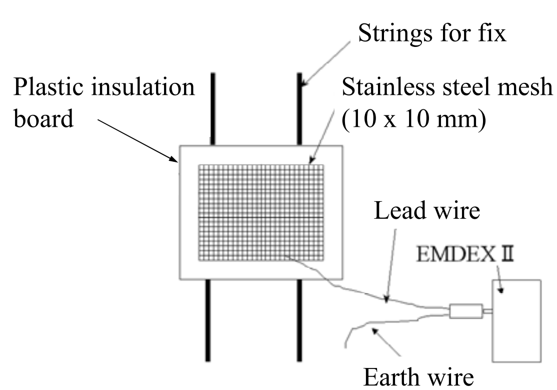

Fig. 3 A sensor used for continuous measurement of electric field together with EMDEX II.

IV. Spot Measurement Results

Figs. 4 and 5 are typical examples of EMF profiles measured along with Path 1 and Path 2 inside the 500-kV substation shown in Fig. 1, respectively. Electric field of 90V/cm was observed under bus lines. The highest magnetic field of 21μT was observed near GCS and GIS.

Results obtained in another 500-kV substation are shown in Figs. 6 and 7.

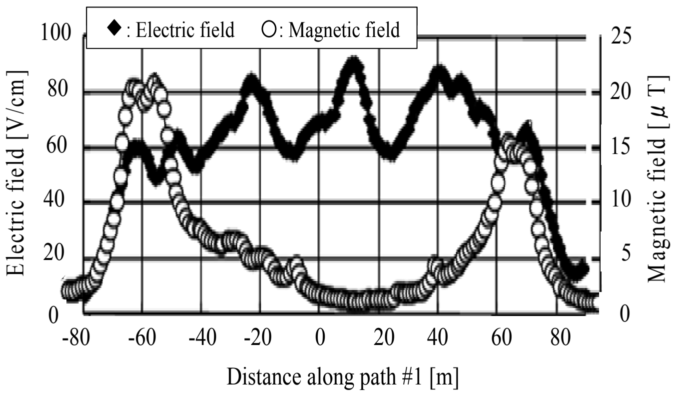

Fig. 4 Electric and magnetic field profiles inside 500-kV substation obtained by spot measurement along with Path 1 in Fig. 1.

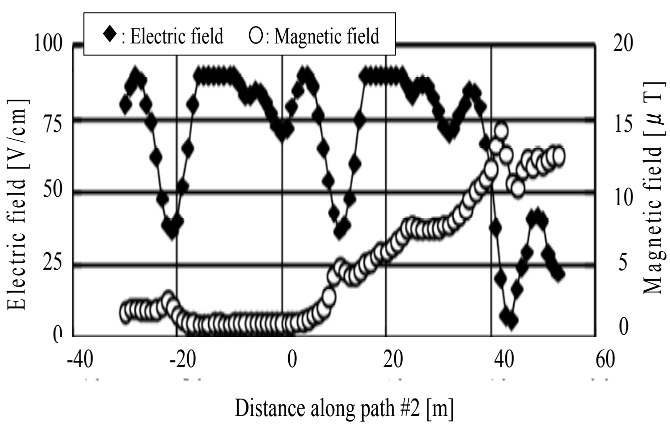

Fig. 5 Electric and magnetic field profiles inside 500-kV substation obtained by spot measurement along with Path 2 in Fig. 1.

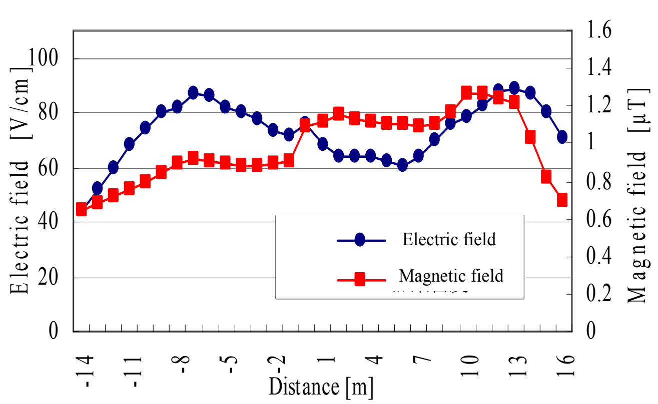

Fig. 6 Electric and magnetic field profiles inside 500-kV substation obtained by spot measurement along with Path 1.

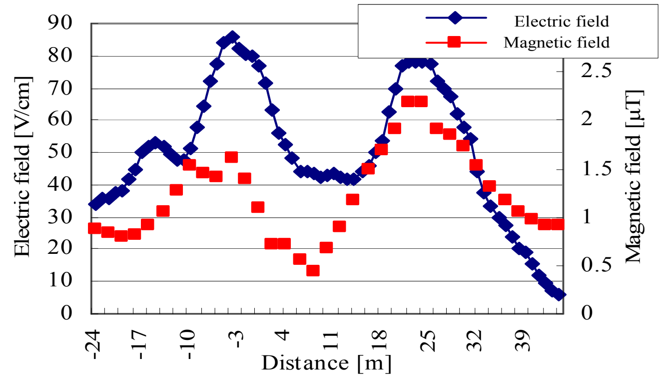

Fig. 7 Electric field and magnetic field profiles inside 500-kV substation obtained by spot measurement along with Path 2.

Fig. 8 is EMF profiles under 500-kV transmission line with the calculated values. The maximum value of 50 V/cm for electric field was observed just below the conductors. The maximum magnetic field of 2.0 μT was observed almost at the center of right-of-way. The calculation was conducted with software programmed with Visual Basic.The measured and calculated values are identical for both electric and magnetic fields.

Figs. 9 and 10 shows the electric and magnetic field profiles measured under a section of 275-kV transmission line shown in Fig. 2), together with calculated values, respectively. The maximum value of 3.5μT for the magnetic field was obtained under conductors. The measured values are also close to calculated for both electric and magnetic fields.

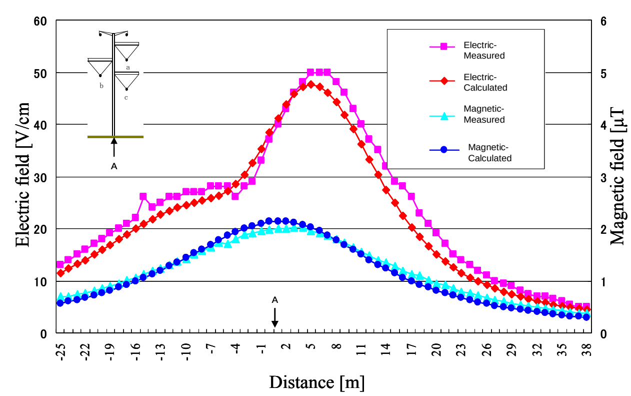

Fig. 8 Example of electric and magnetic fields under 500 kV transmission lines.

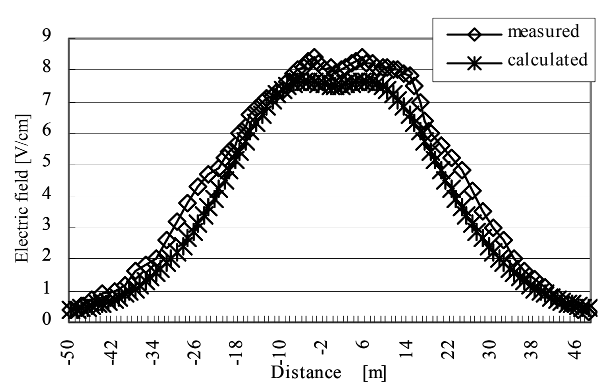

Fig. 9 Electric field profiles under a section of 275-kV transmission line by spot measurement.

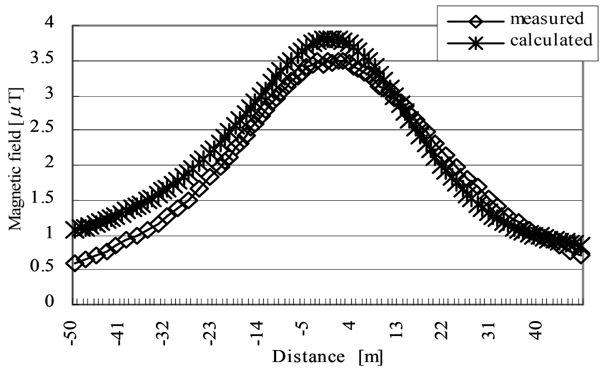

Fig. 10 Magnetic field profiles under a section of 275-kV transmission line by spot measurement.

V. CONTINUOUS MEASUREMENT RESULTS

A. Inside Substations

Figs. 11 and 12 are examples of time variation of electric and magnetic fields, respectively, obtained inside a 500-kV substation. As described above, it should be noted that these were not obtained at a fixed point. EMF values are indicated which a volunteer was subjected to during walking around. The electric field was corrected to that 1 meter above the ground [8].

Figs. 13 and 14 summarize the cumulative percentage data of electric and magnetic fields obtained by continuous measurement inside substations, respectively. As for electric field curves indicated in Fig. 13, a dependency of system voltage can be recognized. As magnetic field is affected by current, there is no relation between it and system voltage.

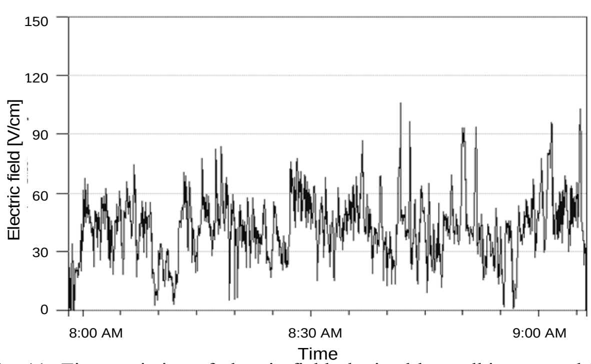

Fig. 11 Time variation of electric field obtained by walking around inside a 500-kV substation.

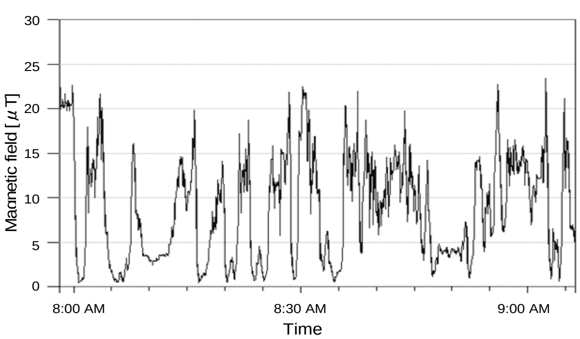

Fig. 12 Time variation of magnetic field obtained by walking around inside a 500-kV substation

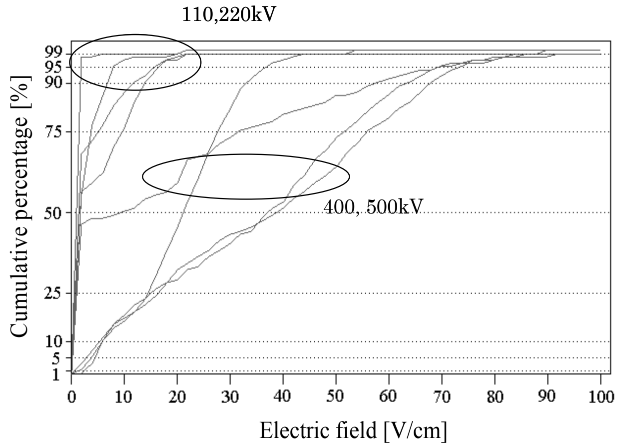

Fig. 13 Comparison of cumulative percentage of electric field obtained by continuous measurement in substations.

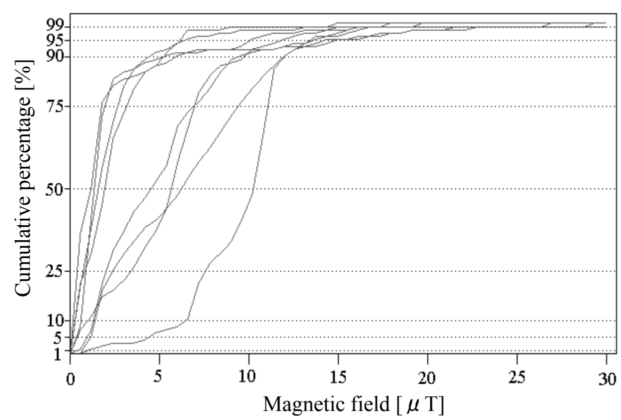

Fig. 14 Comparison of cumulative percentage of electric field obtained by continuous measurement in substations.

B. Under Transmission lines

Continuous measurement of EMF was also conducted under transmission lines following procedures similar to those inside substations. Figs. 15 and 16 show examples of time variation of electric and magnetic fields, respectively, obtained under 500-kV transmission lines.

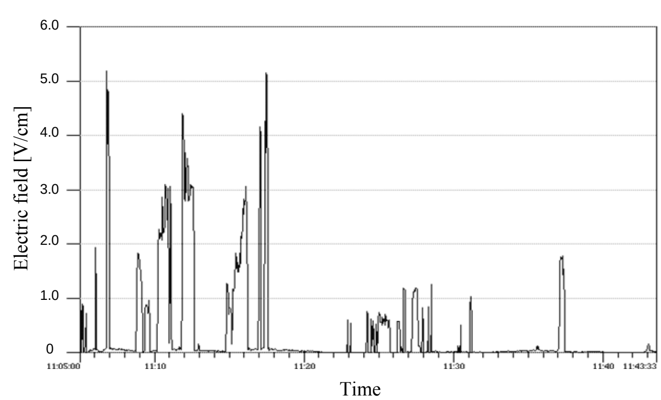

Fig. 15 Time variation of electric field obtained by continuous measurement under 500-kV transmission line.

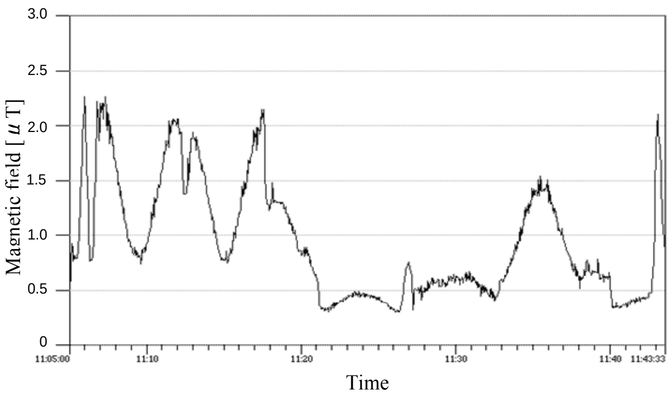

Fig. 16 Time variation of magnetic field obtained by continuous measurement under 500-kV transmission lines.

VI. Discussion

Figs. 17 and 18 summarize the maximum values of electric and magnetic fields obtained in substations, respectively in spot measurements. Figs. 19 and 20 summarize the maximum values of electric and magnetic fields obtained under transmission lines, respectively in spot measurements. In these Figures solid bar graphs indicate 60 Hz whereas white ones are for 50 Hz in grid frequency.

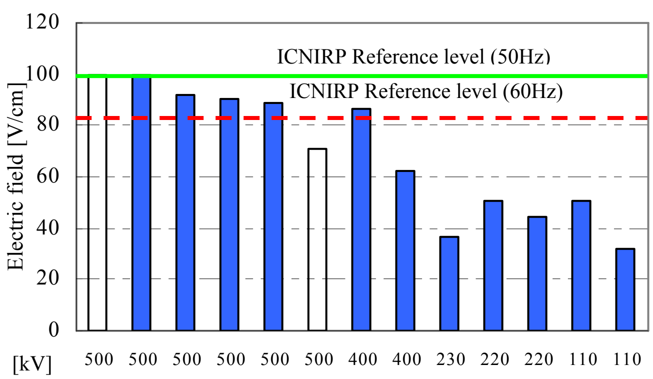

Fig. 17 Maximum electric field obtained in substations by spot measurement.

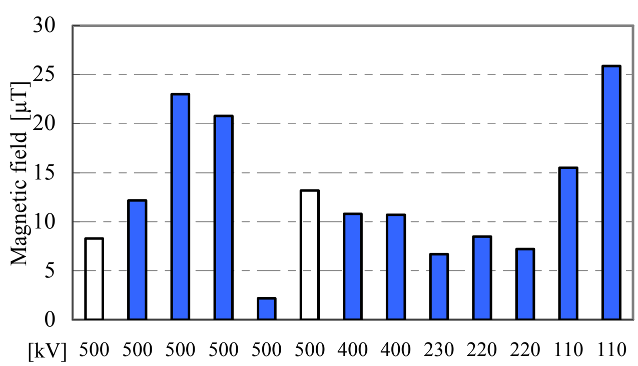

Fig. 18 Maximum magnetic field obtained in substations by spot measurement.

In most of areas inside substations and under transmission lines, electric fields were below the ICNIRP reference level [9] for occupational. Only at limited locations such as nearby a transformer in substations, electric fields were found a little higher than the reference level. All magnetic fields recorded in substations as well as under transmission lines were far below the ICNIRP reference level of 500μT and 420μT for 50Hz and 60Hz, respectively. This is the case for results obtained by continuous measurements.

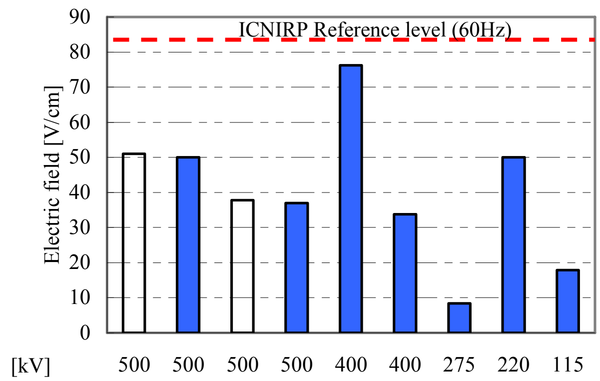

Fig. 19 Maximum electric field obtained under transmission lines by spot measurement.

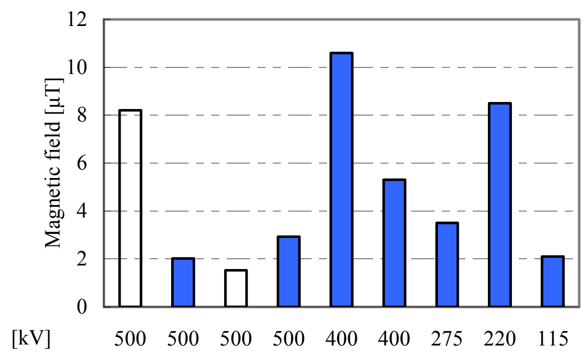

Fig. 20 Maximum magnetic field obtained under transmission lines by spot measurement.

VII. Conclusions

Power frequency electric and magnetic fields were quantified inside substations and under transmission lines by international cooperative research among seven countries. Most of values observed were found lower than the existing reference level indicated in ICNIRP Guidelines. However, in a limited area inside substations, electric field values were a little higher than the ICNIRP reference level whereas it is not considered that a maintenance worker stays at such high electric field areas for a long time.

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IX. Biographies

Kenji Tanaka (M'89) was born in Osaka Prefecture, Japan, in 1959. He received the B.Sc. and M.Sc. degree in electrical engineering from Nagoya University, in 1982 and 1984, respectively.

In1984, he joined NGK INSULATORS, LTD. He first served as a design engineer of insulators. Then, he worked as an application engineer of NGK-LOCKE, INC., USA from 1989 to 1994. And he worked as a manager of NGK-LOCKE POLYMER INSULATORS, INC., USA from 1997 to 2002. He is now a manager of Power Business Group in Japan. And, he is also a graduate student of Graduate School of Engineering, Nagoya Institute of Technology. He is a member of the Institute of Electrical Engineers of Japan

Yukio Mizuno (M'90) was born in Aichi Prefecture, Japan, in 1958. He received the BS, MS and the Ph.D. degrees, all in Electrical Engineering from the Nagoya University in 1981, 1983 and 1986 respectively.

From 1986 to 1993, he was employed as a Research Assistant at the Toyohashi University of Technology. In 1993, he joined Nagoya Institute of Technology as an Associate Professor at the Department of Electrical and Computer Engineering and was promoted to a Professor in 2003. He is now a Professor of Graduate School of Engineering, Nagare College, Nagoya Institute of Technology. He has been engaged in the research on electrical insulation diagnosis, high voltage insulation, superconducting power cable, quantification of power frequency electric and magnetic fields, etc.

Prof. Mizuno is a member of the Institute of Electrical Engineers of Japan and Cryogenic Association of Japan.

Katsuhiko Naito (M'66-S'80-F'90) was born in Aichi Prefecture, Japan, in 1934. He received the BS, MS and the Ph.D. degrees, all in Electrical Engineering from the Nagoya University in 1958, 1960 and 1976 respectively.

He joined NGK Insulators, Ltd. in 1960. He served as General Manager of Design Department, General Manager of NGK High Voltage Laboratory, and later as Executive Chief Engineer of Power Business Group of the Company. He left the Company in 1991 and joined the Nagoya Institute of Technology (NIT), a government university, as a full-time Professor. In 1998, he retired from NIT and joined Meijo University (MU) as a full-time Professor. In 2006, he retired from MU and currently he is Technical Consultant at N. S. Co., Ltd. His field of interest includes insulator contamination, insulation strength of long insulators and large air gaps, partial discharge, non-ceramic insulators and EMF problems.

Prof. Naito is a Life Fellow and a Distinguished Lecturer of IEEE, a Distinguished Member of CIGRE and a Life Member of the Institute of Electrical Engineers of Japan.