THE EFFECT OF UNBALANCED LOADS IN DISTRIBUTION TRANSFORMERS AND GROUND NETWORK ON ELECTROMAGNETIC FIELDS

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ABSTRACT

Electrical energy is one of the most important energy sources in our life. The need for electrical energy is rapidly growing with developing technology and increasing population.

Due to the growing population, the cities considerably expanded and electrical network has to lie within the living spaces. Especially, uses of medium voltage transformers for distribution systems become widespread in such areas.

Electrical energy is supplied for the end users through transmission lines and distribution transformers to meet this energy demand.

Medium Voltage (MV) to Low Voltage (LV) transformers are one of the last steps in the distribution process of electrical power. Distribution transformers generate magnetic and electric fields of the load current through the medium and low voltage panels of this distribution transformer. Magnetic and electric fields occur around the medium and low voltage panels.

It is known that this magnetic and electric field strength becomes greater with increasing of load current.

INTRODUCTION

This paper presents a case study of the 11/0.4kV transformer where the measures for reducing the magnetic and electric field levels were implemented and aims to study the effect of unbalance of distribution transformers and bad ground network on electric and magnetic fields.

In this paper work process measurement of the areas of electric and magnetic fields on distribution transformer room during both the morning and the evening peak is carried out.

Generally accepted guidelines have been established for safe public and occupational exposure to power-frequency EMFs. The reference levels for general public exposure to 50/60-Hz electric and magnetic fields are, according to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) guidelines update are as follows:

For electric field strength, $E < 5$ KV m^{-1}

For the magnetic flux density, $B < 200\ \mu$ T

These levels for occupational exposure are:

For electric field strength, $E < 10$ KV m^{-1}

For the magnetic flux density, $B < 1000\ \mu$ T.

The ICNIRP raised the magnetic field exposure level for general public guideline which conflict with findings from some epidemiological research showing an apparent correlation between an approximate doubling in the very low risk of childhood leukemia and long-term exposure to average fields greater than 0.4 μT.

Many researchers studied the ELF magnetic field emitted from transformer substations and overhead lines, but there is limited data available for the effect of unbalanced loads in distribution transformers and ground network on electromagnetic fields emitted in transformer room.

BASIC THEORY

In classical theory, the laws of electricity and magnetism are described by Maxwell's equations. These represent the result of a synthesis of several existing theories and experimental observations by James Clerk Maxwell (1831-1879). In effect, Maxwell's equations are a set of relations linking the values of a number of quantities that describe electric and magnetic fields. These are the electric flux density D, the magnetic flux density B, the electric field strength E, the magnetic field strength H, and the current density J.

All are vector quantities, and are functions not only of the three spatial coordinates x, y and z but also of time t. Of these parameters, D, B, E and H are the most important to high frequency electromagnetic theory. In this regime, they are essentially 'inventions'; they are not directly observable, but are linked by a self-consistent set of equations, which correctly predict the magnitudes of other measurable quantities (like the flow and distribution of power).

ELECTRIC FIELD

To evaluate the electric field generated by this type of installation is necessary to consider all possible sources, So it is essential to know the location of each feeder and the current.

Usually low voltage loads are unbalanced, this causes currents for the neutral conductor, the influence of the values of the electric field depends also of the magnitude and phase angle of this current.

Often, different representations are used for the fields; for example, it is common to separate their time- and space-variation. The electric field strength E may therefore be written alternatively as:

$$E(x, y, z, t) = E(x, y, z)\, f(t) \qquad (1)$$

Here E accounts for the spatial variation of the field, and f(t) for temporal changes.

It is also common to refer to individual elements of the vectors concerned. In Cartesian coordinates, Fig.1 shows the electric force between 2 charges at distance R12 we may write the time-dependent electric field E as:

$$E(x, y, z, t) = [\ E_x(x, y, z, t)\ ,\ E_y(x, y, z, t)\ ,\ E_z(x, y, z, t)\ ] \qquad (2)$$

Alternatively, the time-independent field E could write as:

$$E(x, y, z) = [E_x(x, y, z)\ ,\ E_y(x, y, z)\ ,\ E_z(x, y, z)] \qquad (3)$$

Here Ex refers to the x-component of E, and so on.

$$R_{12} = |\mathbf{r}_2 - \mathbf{r}_1| = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2} \qquad (4)$$

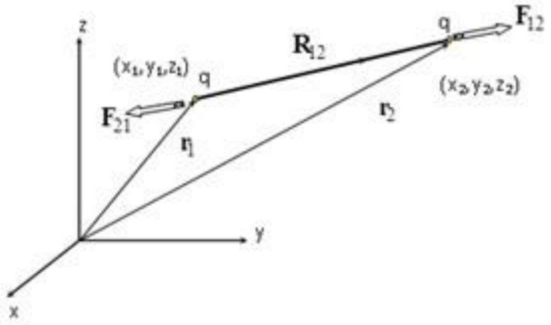

Fig.1 Electric Force Between 2 Charges At Distance R12

MAGNETIC FIELD

In power systems, magnetic fields occur around the conductors which carry currents. When the current increases, the magnetic field is also strengthened proportionally. Magnetic field induces a voltage in conductors and dielectric materials placed within the field This induced voltage causes to flow current in an object which harms the livings. Limiting values are defined to keep human health in a safe. It is important to consider these values while designing a system which consist current carrying conductors.

At a specified distance, the magnetic field value of a current carrying conductor can be calculated by Bio-Savart equation given in Eq. (5).

$$H = \frac{I}{2\pi r}\ [\ A/m] \qquad (5)$$

Where,

H = Magnetic Field Strength

I = Current [A]

r = Distance [m]

As it is known that magnetic field strength (H) is a vectorial magnitude. So, a current carrying conductor at point K causes to occur both horizontal and vertical magnetic field component. With vectorial sum of these components, resultant magnetic field (H) at point P is acquired as shown in Fig. 2

According to the Fig.2, horizontal and vertical components of magnetic field strength (H) at point P can be calculated with the formulas given in Eq. (6) And (7) respectively.

$$H_x = \frac{I}{2\pi} \cdot \frac{y_j - y_i}{r^2} \qquad (6)$$

$$H_y = \frac{I}{2\pi} \cdot \frac{x_j - x_i}{r^2} \qquad (7)$$

Here, x_i and y_i are the coordinates of point K while x_j and y_j are the coordinates of point P. r is the distance from the current source defined as,

$$r = \sqrt{(x_j - x_i)^2 + (y_j - y_i)^2} \qquad (8)$$

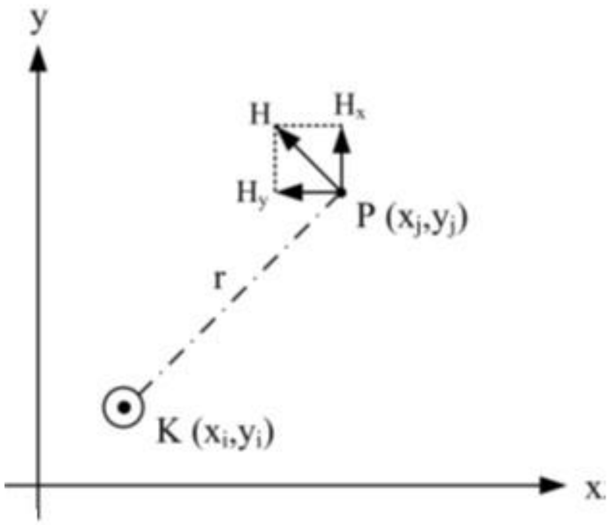

Fig 2 Magnetic Field Strength Of A Conductor (K) At Point P

To calculate resultant magnetic field strength, horizontal and vertical components are vectorial added. If there are n conductors in a system, resultant magnetic field strength can be calculated with the Eq. (9).

$$H = \sqrt{(\sum_{i=1}^{n} H_{xi})^2 + (\sum_{i=1}^{n} H_{yi})^2} \qquad (9)$$

Magnetic flux density (MFD) can be calculated by multiplying the magnetic field strength (H) and magnetic permeability of vacuum or air ($\mu_0 = 4\pi * 10^{-7}$[H/m]) as given in Eq. (10).

$$B = \mu\ H \qquad (10)$$

In Eq. (10), B is the magnetic flux density or magnetic induction in Wb/m^2 or Tesla.

Magnetic field exposure levels depend on many factors such as distance from the magnetic field source, exposure duration, strength and frequency of the magnetic field.

Therefore, limit values for magnetic fields at different frequencies are specified by the ICNIRP.

SITE DESCRIPTION

North Delta Electricity Distribution Company (NDEDC) is one of nine distribution companies in Egypt and it has a big network, which contains a lot of transformer room installed in this network one of them shown in Fig.3.

ELECTRIC AND MAGNETIC FIELD MESUREMENTS METHOD

The electric and magnetic field measurements were performed at height of one meter above the ground of the transformer room between transformer, low voltage panel and medium voltage panel at a distance (0.5m - 1m - 2 m) from these components of this transformer room as shown in Fig.3.

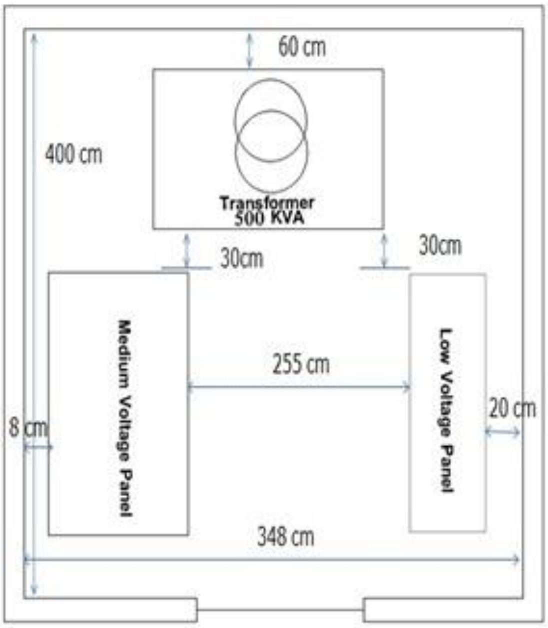

Fig. 3 Transformer Room Layout

The spot measurements were recorded by using 3DH device/E Field Meter German-made over frequencies allowed measurement (5 Hz to 400 KHz), The ESM-100 3D H/E Field Meter is a unique, patented, hand held measuring instrument which allows easy measuring of alternating electric and magnetic fields at the same time, independent of direction and corresponding to one common point, Fig.4 shows the measurement device.

Fig.4 Measurement Device

CASE STUDY

The EMF measurements were performed in a transformer room on 10th May 2016, during the morning and the evening peak and this measurement before taking any action.

Low and medium voltage panels and transformer before taking any action It was as follows

All ground points were not connected to any rods on earth of transformer room, and bad contact between low voltage panel and its cables.

The measures of load current in the morning peak on a low voltage panel and measures of EMF at the same time, which had taken before taking any technical action are presented in Table1 and Table2.

For all feeders in Table1 and Table3 unbalance current percentage exceed 10% which permissible limits.

Table1: The load current in the morning peak in amperes

Feeder name	R	S	T	N	Unbalance %
Main C B	305	405	365	85	24 %
Rommana	100	130	120	16	14%
Moalmeen	135	170	130	30	21%
Atef	70	105	115	40	41%

The electric and magnetic fields were high at a distance of 0.5m and at a distance of 1m and 2m from low voltage panel was not high as shown in Table2

Table2: The measurements of magnetic and electric fields in the morning peak

Distance of measure	Low Voltage panel		Transformer		Medium Voltage panel	
	M F (H_{3D}) (µT)	E F (E_{3D}) (V/M)	M F (H_{3D}) (µT)	E F (E_{3D}) (V/M)	M F (H_{3D}) (µT)	E F (E_{3D}) (V/M)
0.5m	480.55	1515.6	86.26	261.8	3.93	827.1
1 m	36.63	222.9	49.39	267.8	6.85	418.5
2m	16.57	283.9*	20.26	64	33.84	288

*The electric field at a distance of 2m is greater than that at the distance of 1m because of the interference of some cables beside the point of measure.

Fig.5 shows the curves of magnetic and electric field from the measurement device at a distance of 0.5 m from the low voltage panel in the morning peak.

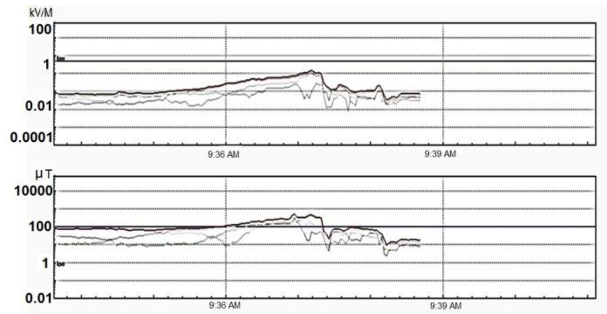

Fig. 5 The Curves Of Electric And Magnetic Fields At A Distance Of 0.5m From Low Voltage Panel In The Morning Peak.

The measurements of load current in the evening peak on a low voltage panel and measures of EMF at the same time, which had recorded before taking any technical action are presented in Table3 and Table4.

Table3: The load current in the evening peak in amperes before taking any action

Feeder name	R	S	T	N	Unbalance %
Main C B	405	420	375	74	19
Rommana	160	145	100	23	17
Moalmeen	170	180	205	26	14
Atef	75	95	70	29	36

Table4: The measurements of magnetic and electric fields in the evening peak

Distance of measure	Low Voltage panel		Transformer		Medium Voltage panel	
	M F (H_{3D}) (μT)	E F (E_{3D}) (V/M)	M F (H_{3D}) (μT)	E F (E_{3D}) (V/M)	M F (H_{3D}) (μT)	E F (E_{3D}) (V/M)
0.5m	560.25	614.8	135.6	349.6	11.19	280.4
1 m	36.68	133.6	102.9	109.2	18.76	88.1
2m	25.57	214.8*	62.23	158.9	22.48	168.2

* The electric field at a distance of 2 m is greater than the distance of 1 m because of the interference of some cables beside the point of measure.

Fig.6 shows the curves of magnetic and electric field from the measurement device at a distance of 0.5 m from a low voltage panel in the evening peak.

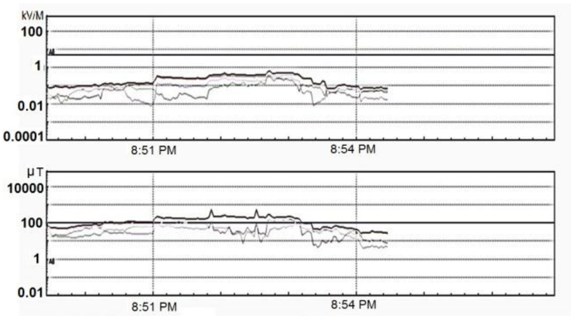

Fig.6 The Curves Of Electric And Magnetic Fields At A Distance Of 0.5m From Low Voltage Panel In The Evening Peak.

PROCEDURE

After these measurements some technical measures had made on the transformer, low and medium voltage which is maintenance for low voltage panel, separate the neutral preventive ground, installation grounds, according to technical and change the connector ground to 35 mm^2 copper also balance of loads on the transformer were achieved.

The measures of load current in the morning and the evening peak on a low voltage panel and measures of EMF in the same time after taking some actions are presented in Table 5, Table 6, Table 7 and Table 8.

Table5: The load current in the morning peak in amperes after taking some actions

Feeder name	R	S	T	N	Unbalance %
Main C B	369	364	390	31	8
Rommana	110	70	60	7	9
Moalmeen	130	174	200	13	8
Atef	129	120	130	15	12

Table6: The measurements of magnetic and electric fields in the morning peak after taking some actions

Distance of measure	Low Voltage panel		Transformer		Medium Voltage panel	
	M F (H_{3D}) (μT)	E F (E_{3D}) (V/M)	M F (H_{3D}) (μT)	E F (E_{3D}) (V/M)	M F (H_{3D}) (μT)	E F (E_{3D}) (V/M)
0.5m	122.5	99.1	103	289.8	20.37	448.2
1 m	92.34	119.4	115.4	185.3	16.14	175.9
2m	78.65	225.7	29.91	64.4	71.21	159.7

Fig.7 shows the curves of magnetic and electric field from the measurement device at a distance of 0.5 m from a low voltage panel in the morning peak after taking technical actions.

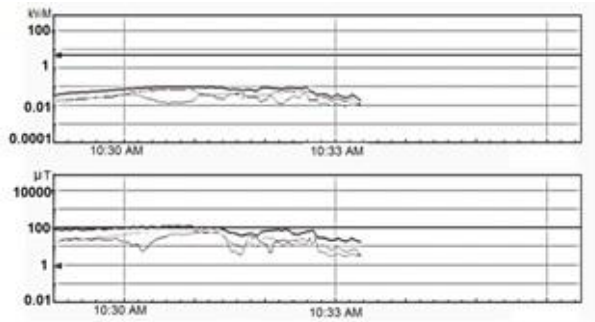

Fig.7 The Curves Of Electric And Magnetic Fields At A Distance Of 0.5m From Low Voltage Panel After Taking some Technical Actions In The Morning Peak.

Table7: The load current in the evening peak in amperes after taking some actions

Feeder name	R	S	T	N	Unbalance %
Main C B	470	455	465	33	7
Rommana	135	130	90	11	9
Moalmeen	220	190	220	12	6
Atef	115	135	155	17	12

Table8: The measurements of magnetic and electric fields in the morning peak after taking some actions

Distance of measure	Low Voltage panel		Transformer		Medium Voltage panel	
	M F (H_{3D}) (μT)	E F (E_{3D}) (V/M)	M F (H_{3D}) (μT)	E F (E_{3D}) (V/M)	M F (H_{3D}) (μT)	E F (E_{3D}) (V/M)
0.5m	187	128	135.6	349.6	16.89	17.3
1 m	120.8	253.6	102.9	109.2	33.55	55.4
2m	76.32	327.2*	62.23	158.9	79.52	112.5

*The electric field at a distance of 2 m is greater than the distance of 1 m because of the interference of some cables beside the point of measure

Fig.8 shows the curves of magnetic and electric field from the measurement device at a distance of 0.5 m from a low voltage panel in the evening peak after taking technical action.

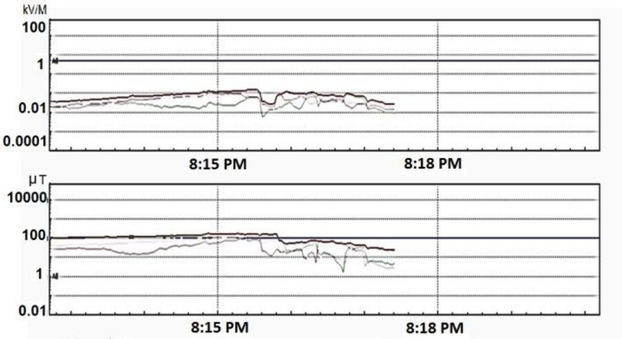

Fig.8 The Curves Of Electric And Magnetic Fields At A Distance Of 0.5 m From Low Voltage Panel In The Evening Peak After Taking Some Actions.

After all above measurements with another time measurements were taken on 17th May 2016, during the morning and the evening peak and improvement of electric and magnetic field were achieved despite the increase in atmospheric temperature that led to overload the transformer.

RESULTS AND ANALYSIS

All the measured magnetic flux density values in this paper had high values according to INCPR and before making any maintenance for low voltage panel.
The measured values of magnetic field at a distance of 0.5m from low voltage panel improved from 480.55 µT to 122.5 µT during the morning peak and from 560.25 µT to 187 µT during the evening peak after making maintenance for low voltage panel..
The measured values for electric field at a distance of 0.5m from low voltage panel improved from 480.55 µT to 122.5 µT during the morning peak and from 560.25 µT to 187 µT during the evening peak after making maintenance for low voltage panel.
This maximum value in the room of the transformer was at a distance of 0.5 m from low voltage.
The unbalance current significantly decrease after maintenance and redistributed the cable from 24% to 8% in the morning peak and from 19% to 7% in the evening peak.

CONCLUSION

There is a relationship between the value of the magnetic and electrical field and load balance for distribution transformers and system ground. There is a clear reduction of the intensity of the magnetic field with the implementation of the balance and the quality of the ground system.
Measurements were taken into another time in the conditions of high temperature that led to increase the morning loads by 28%, but the magnetic and electric fields within safe limits after taking the previous actions and thus make sure a positive balance load and installation of ground system accordance with the technical assets.
NDEDC puts excess maintenance planning during one year for 4649 transformer rooms as sequence process do in a case study in this paper.

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