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Design and Installation of 300kVA 11/0.415kV Transformer for Delta State University Teaching Hospital

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ABSTRACT

This paper outlines the detailed design and installation procedure for the Delta State University Teaching Hospital (DELSUTH) 300kVA 11/0.415kV transformer for health care facility. The data used in this work is drawn from load survey, information based on related works, and onsite physical assessment. The data collected was analyzed, based on the results of design and installation of the transformer. Results obtained from pre-commissioning test show that the design and installation work agree with industry approved standards. More importantly, this work has led to improvement in operations of the health care facility.

1. INTRODUCTION

The Western Delta part of Nigeria, were DELSUTH is sited, receive power supply from public utility Company called Benin Electricity Distribution Company (BEDC). The Benin Electricity Distribution Company supplies power to the facility through 132/33KV transmission substation located at Pamo near Oghara about 10 km away. The 33kV line is stepped down to 11KV with the aid of 33/11KV, 7. 5 MVA transformer substation installed in DELSUTH premises. This power transformer then feed 11kV to the main control panel and distribute power through 11kV ring main units (RMU) which supply the 11kV to the distribution transformers located at various load centers. The distribution transformers further step down the 11kV to 415kV and supply the feeder pillar units which further distribute 3-phase (415V phase to phase) and 4 wire system (230V phase to neutral) to consumers of single and three phase loads (Agbonaye & Odiase, 2017).

However, due to load growth because of expansion of the hospital facilities the existing 300 kVA transformer feeding the ground floor of the clinical building is overloaded. To address this problem and enhance performance a new transformer is suggested. To select and install a new equipment that will meet load requirement of the affected area there is need to carry out load survey analysis to accurately determine

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its capacity. Because assumption-based installation could lead to loss of efficiency.

The transformer is an invaluable asset and indispensable part of a power system network. It helps to stabilize the network parameter during transmission and distribution of power from generating to load center. For the proper and stable operation of the power system, a step up or step-down transformer should be available at the appropriate position in a power network (Ajuwa, 2018). The invention of transformer and application has led to the production of constant power alternating current supply systems. Prior to the design and production of the transformer direct current systems were used for the supply of electricity. The use of the power transformers made the distribution system more reliable, flexible, and more efficient. Transformers are utilized in the power system network to step up or step down the voltages to required level. In power transmission system the generated voltage is stepped up and in the distribution side the voltage is stepped down to reduce system power loss or I^2R loss (Agus et al, 2019). The line current decreases with increase in voltage. Thus, the voltage must be stepped up at the transmission end to minimize the transmission losses. Also, at the distribution end the voltage is stepped down to meet standard voltage of the rating of the consumer equipment.

The working principle of transformer involves magnetic flux production in a coil whenever there is a change in current flowing through the coil. Similarly, theses changes in magnetic flux linked with the coil induces emf in the coil. When the alternating current supply is given to the primary winding side alternating flux is produced in the coil. The alternating flux produced in the primary coil of the transformer links the coils in the secondary winding and hence emf is induced in the secondary winding. The voltage produced in the secondary coil depends mainly on the numbers of the turn's ratio of the transformer (Evbogbai, 2014). The relationship between the number of turns and the voltage is given by the following equations.

$$N\_1/N\_2 = V\_1/V\_2 = I\_1 /I\_2$$

Where,

N_1 = number of turns in the primary coil of the transformer.

N_2 = number of turns in the secondary coil of the transformer.

V_1 = voltage in the primary coil of the transformer.

V_2 = voltage in the secondary coil of the transformer.

I_1 = current through the primary coil of the transformer.

I_2 = current through the secondary coil of the transformer.

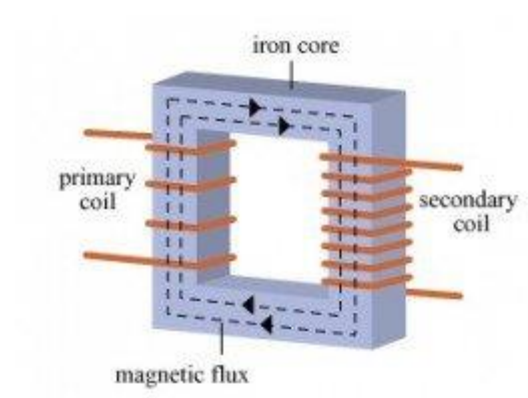

Fig 1. Schematic of a simple transformer

1.1. Basic Components of a Transformer

The basic components of a transformer include the following;

i. The core: The core is used to cover the windings inside the transformer which help to provide a low reluctance path to the flow of magnetic flux. Practically, it is made of laminated soft iron core to reduce eddy current loss and Hysteresis loss (Ewesor, 2010). The makeup of a transformer core depends on such factors as voltage, current, and frequency. The core copper contains high conductivity which minimizes losses as well as the amount of copper needed for the winding dimension. Copper also has high ductility making it easy to bend conductors into tight windings around the transformer's core, thereby minimizing the quantity of copper needed as well as the overall volume of the winding.

ii. Windings: There are two forms of windings in a transformer core that are insulated from each other. Winding may consist of several turns of copper coils bundled, stacked together and connected in series to form a winding (Gupta & Kumar, 2018).

Windings can be classified in two different categories. Based on input and output side we have;

(a) Primary windings - These are the windings to which the input voltage is applied.

(b) Secondary windings - These are the windings from which the output voltage is drawn.

Uhunmwangho et al, (2017) states that based on voltage level we have;

(a) High voltage winding - These are made of copper coil. The number of turns is the multiple of the number of turns in the low voltage windings. The copper coils are thinner than those of the low voltage windings.

(b) Low voltage windings - These have fewer turns than the high voltage windings. It is made of thick copper conductors. This is because the current in the low voltage windings is higher than that of high voltage windings. Transformers can be supplied from either low voltage (LV) or high voltage (HV) windings based on the requirement.

iii. Insulating materials: Insulating paper and cardboard are used in transformers to isolate primary and secondary windings from each other and from the transformer core. Transformer oil is another insulating material (Ajuwa, 2018) . Transformer oil can actually have two functions: in addition to insulating, it can also work to cool the core and coil assembly. The transformer's core and windings must be completely immersed in the oil. Normally, hydrocarbon mineral oils are used as transformer oil. Oil contamination is a serious problem because contamination robs the oil of its dielectric properties and renders it useless as an insulating medium (Ogunboyo et al, 2017).

iv. Conservator: The conservator conserves the transformer oil. It is an airtight, metallic, cylindrical drum that is fitted above the transformer. The conservator tank is vented to the atmosphere at the top, and the normal oil level is approximately in the middle of the conservator to allow the oil to expand and contract as the temperature varies. The conservator is connected to the main tank inside the transformer, which is completely filled with transformer oil through a pipeline (Evbogbai, 2014).

v. Breather: The breather controls the moisture level in the transformer. Moisture can arise when temperature variations cause expansion and contraction of the insulating oil, which then causes the pressure to change inside the conservator (Jennie, 2018). Pressure changes are balanced by a flow of atmospheric air in and out of the conservator, which is how moisture can enter the system. If the insulating oil encounters moisture, it can affect the paper insulation or may even lead to internal faults. Therefore, it is necessary that the air entering the tank is moisture-free. The transformer's breather is a cylindrical container that is filled with silica gel. When the atmospheric air passes through the silica gel of the breather, the air's moisture is absorbed by the silica crystals. The breather acts like an air filter for the transformer and controls the moisture level inside a transformer. It is connected to the end of breather pipe (Agbonaye & Odiase, 2017).

vi. Tap changer: The output voltage may vary according to the input voltage and the load. During load conditions, the voltage on the output terminal decreases, whereas during no-load conditions the output voltage increases. In order to balance the voltage variations, tap changers are used. Tap changers can be either on-load tap changers or off-load tap changers. In an on-load tap changer, the tapping can be changed without isolating the transformer from the supply. In an off-load tap changer, it is done after disconnecting the transformer. Automatic tap changers are also available (Igbinake et al, 2011).

vii. Cooling tube: Cooling tubes are used to cool the transformer oil. The transformer oil is circulated through the cooling tubes. The circulation of the oil may either be natural or forced. In natural circulation, when the temperature of the oil rises the hot oil naturally rises to the top and the cold oil sinks downward. Thus the oil naturally circulates through the tubes. In forced circulation, an external pump is used to circulate the oil (Igbinake et al, 2011).

viii. Buchholz relay: The Buchholz relay is a protective device container housed over the connecting pipe from the main tank to the conservator tank. It is used to sense the faults occurring inside the transformer. It is a simple relay that operates by the gases emitted due to the decomposition of transformer oil during internal faults. It helps in sensing and protecting the transformer from internal faults (Gupta & Kumar, 2018).

ix. Explosion vent: The explosion vent is used to expel boiling oil in the transformer during heavy internal faults in order to avoid the explosion of the transformer. During heavy faults, the oil rushes out of the vent. The level of the explosion vent is normally maintained above the level of the conservatory tank (Agus et al, 2019).

2. MATERIALS AND METHOD

The method adopted for this project was to first of all carry out a detailed load and site survey which culminated in the selection of an appropriately sized transformer and a suitable site for the location of the transformer. The details are provided in the following sections.

2.1. Load Survey and Analysis

This the starting point of the design work. The site is visited and interaction with the team of technical personnel to carryout preliminary survey and on the spot assessment to determine the capacity of installed loads of the affected area which consists mainly of ground floor of the main hospital building and street lights. Measurements of existing connected loads were taken at peak period at 10am when powered by 1000 kVA generator. Digital multi meter was used to take load readings at the consumer distribution panel. The average loads readings are as shown in table1.

Thus, total consumer loads in the area is 305 A.

2.2. Location of Substation

The factors considered when siting the substation include;

- A location as close to the load center as practicable for better voltage regulation.
- A located which allows future expansion of network.
- A located which allows enough space for cable laying and earthing provision.
- Accessible always for easy maintenance and operation.
- A located within the right of way for easy access for incoming transmission and distribution lines.

Table.1: Consumer load readings

Consumer	**Loads (A)**	**Phase voltage (V)**	**Line voltage(V)**
Ground floor right wing	130	200	393
Ground floor left wing	148	192	396
Street lights	27	19	395
Total	305		

2.3. Design load calculation

It is important to define the following terms that will be used throughout the calculations:

Connected load = total kilowatt load with no diversity taken into account

Demand load = total load with diversity calculated

$$kVA = 1.732\, kW \qquad (2)$$

(a) Determination of Transformer Capacity

Calculating transformer capacity is based on the maximum total installed load expected to be connect to the secondary side and then select the most appropriate next available rated kVA to match the connected or estimated loads.

Measured connected loads parameters are;

Supply line voltage (Vs) = 415V

Line current (I_s) = 305A

Power factor (PF) = 0.8

$$Total\ power\ demand = 1.732\ IV cos 0.8 \ (3)$$
$$= 1.732\ x\ 305\ x\ 415\ x\ 0.8$$
$$= 175\ kW$$

$$Allowance\ for\ future\ expansion\ of\ 30\%\ total\ connected\ load = 0.3\ x\ 175 = 52\ kW$$

Therefore,

$$Total\ estimated\ load = 175 + 52 = 227\ kW$$

$$Power\ in\ kVA = kW/P.F = 227/0.8 = 283\ kVA$$

Therefore, considering the loads demand for the hostel buildings in DELSUTH, a 300KVA, 11/0.415KV distribution Transformer is recommended.

(b) Determination of Feeder Pillar Capacity

The basic formula for determination of current carrying capacity of a feeder is as follows;

Power, P in kVA = 1.732 IV

Therefore,

300 kVA, 415V on secondary side

Thus,

$$secondary\ side\ current\ Is = \frac{kVA}{1.732V}$$
$$= \frac{(300\ x\ 1000)}{1.732x414} = 417.4\ A$$

Since we cannot get a feeder of 417.4A the nearest available in market is 600A is recommended. Thus the rating of the feeder pillar fuse shall be 200Amps for three ways in services while one reserve as spare.

(c) Cable Sizing

Determination of HV side cable linking the RMU is done as follows;

Primary current, I_p = kVA / 1.732V

= (300 x 1000) / (1.732 x 11000)

= 15 A

By referring to table 2, 150 mmsq cable which allows safety current up to 200 A from 11KV. 150 mmsq cable shall be recommended.

The size of cabling for transformer secondary side to feeder pillar is determine as follows;

Secondary current, I_s is 417 A. The cable size of 300 mmsq with current carrying capacity up to 447 A is recommended.

The cable size between 600 A, 4-way feeder pillar and consumer distribution panel is determined as follows;

The calculated feeder current is 417 A fed from transformer LV side which has three ways. This implies that the total current of 417 A is divided into 3 units which give 139 A each way. Therefore from table 2, 70 mmsq armoured cable which take up to 191 A safely is recommended.

Table 2: Current carrying capacity for armored cable.

Voltage Level	Type	Size (Mmsq)	Rating (A)
33/11/0.415KV	Armoured cable	35	113/132
		50	141/157
		70	171/191
		95	216/230
		120	249/264
		185	329/332
		150	282/293
		240	390
		300	447

(d) Bill of Engineering Measurement and Evaluation (BEME)

An important aspect of design and installation of 300 kVA, 11/0.415 kV transformer project is the preparation of BEME. This provides an estimation of the materials, labour and administrative cost required to execute the project. The cost estimate used in execution of the project is presented in the Table 3;

Table 3: Bill of engineering measurement and evaluation for installation (BEME) for 300kVA, 11/0.415 kVA transformer.

S/N	Description of Items	Quantity	Unit Cost (₦)	Total (₦)
1	300KVA,11/0.415KV Transformer	1 No		1,480,000.00
2	600Amps feeder pillar (4 ways)	1 No	125,000	125,000.00
3	4x70mmsq armoured cable	50 m	1420	71,000.00
4	1x300 mm sq armoured cable	45 m	3140	141,300.00
5	1x70 bare copper earth wire	20 m	1100	22,000.00
6	1.8m gal. earth rod	6 Nos	850	5,100.00
7	Earth math	3 Nos	3500	10,500.00
8	Cable logs, bolts and washers	Lot	lot	5,000.00
	Subtotal			**1,859,900.00**
	Labour			
9	Bush clearing	-	3000	3,000.00
	Excavation of cable route and back filling	40 m	500	20,000.00
10	BEDC testing and inspection fee	-	50,000	50,000.00
11	Transportation	-	-	30,000.00
11.	Miscellaneous expenses	-	-	25,000.00
	Total	-	-	**1,987,900;00**

(e) Installation Works

The installation of the 300KVA, 11/0.415KV transformer was carried out based on the design outlined in previous sections. Power distribution network drawing is as shown in figure 2. The installation workflow involved the following;

i. Pre-mobilization to site: This stage of the project execution involved careful study of design documents, planning, meetings with stake holders, selection of materials/appropriate tools and technical team, procurement of items, arrangement for logistics, and assignment of responsibilities and allocation/release of funds.

ii. Mobilization to site: At this stage men and materials moved to site based on approved documentation and work plan. Site preparation, meetings with all parties for smooth take-off of installation activities are in this phase. Unskilled and skill workers are drafted to site. The 300 kVA transformer along with associated equipment is received and positioned with aid of self-loader. Responsibilities are assigned based on schedule for unskilled and skilled workers.

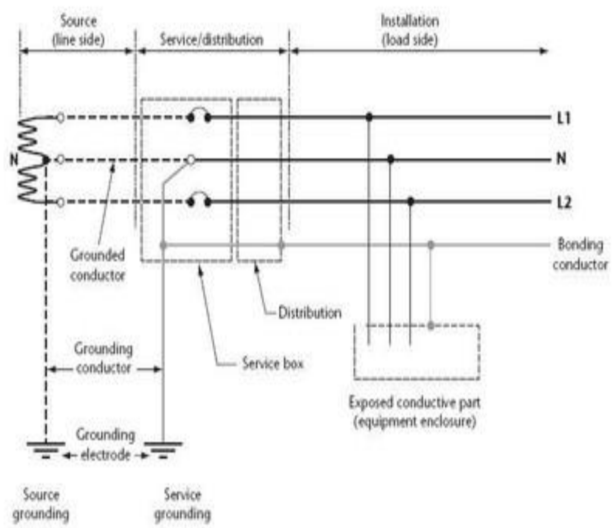

Fig. 2. Substation power distribution systems

iii. Installation details: The following procedure was adopted for the installation of the transformer;

- Prepared site and maintained the existing plinth.
- Mounted the transformer, HV side faced the 11kv RMU and LV faced the feeder pillar direction.
- 1x300mmsq PVC/SWA/PVC armored cable, logged.
- Terminated the 1x300 mmsq PVC/SWA/PVC amoured cable to transformer LV side and feeder pillar bus bar.
- Terminated 11kV 3x150 mmsq amoured cable with Raychem kit and 150mm cable log connected to the HV side of the transformer linked to the existing 11kV RMU.
- Linked the transformer neutral and the body, feeder pillar, 11kV RMU, gate to earth rod and buried with animal waste.

- Physical observation of substation cabling terminations and fastening of bolts/nuts.
- Observed the Health Safety and Environment and relevant regulations.

iv. Pre-commissioning test: On completion of the project a pre-commissioning test was carried out to ascertain the reliability of the installation work before it can be use. Instruments used include single phase tiger generator 2700, digital multimeter, clamp meter and digital insulation tester (5KV megger).

3. RESULTS AND DISCUSSION

This section presents results of the inspection and tests carried out at the completion of the project. They include the following;

i. *Physical Inspection*: Physical inspection was carried out on the materials and equipment to assess their condition before use. After the completion of the installation work assessment was carried out by team of engineers on transformer HV/LV bushings, conservator, silica gel, cables logging /terminations, and panel using the design specification document as standard. Table 4 presents the information on the transformer name plate while the results of physical inspection are presented in table 5.

Table 4: Installed transformer name plate parameter

Parameter	*Value*
Capacity	300 kVA
Primary Voltage	11KV
Primary Current	15.75A
Secondary Voltage	415V
Secondary current	417.36A
Active part weight	475kg
Oil weight	205Kg
Total weight	910kg
Year manufacture	05/2010
Insulation oil	NYNAS
Temperature 0c	25
Type	TSPH-08184/900
Cooling type	ONAN
Serial No	ILTR003827
Phase	3
Insulation level HV	75/28 V
Insulation level LV	3
Vector group	DYn1

Table 5: Results of physical inspection of transformer substation

Items	*Remarks*
HV &LV Bushings	Okay
Oil Level	Okay
Transformer body/conservator tank	Okay
Substation floor	Okay
Plinth	Okay
Fencing with gate	Okay
Cabling	Okay

ii. Insulation resistance test: Insulation requirement is of paramount and critical importance in design and installation of transformers. Voltage occurring in power supply system's due to switching, lightning strikes could be very high and may pose great danger in the event of poor insulation. Therefore, insulation resistance test using 5kV megger tester was carried out on the installed transformer to determine the present insulation level before it is use. The results of insulation resistance tests are presented in table 6 and 7.

iii. Short circuit test: Short circuit test was carried out to determine the actual capacity of the transformer. The LV side is shorted with a piece of wire and voltage is applied to the HV side and a clip-on ammeter is used to measure the circulating secondary short circuit current. The short circuit current, I_{sc} was found to be 15 A.

iv. Ratio test: Transformation ratio tests are carried out on the installed transformer to verify the voltage ratio (step up/step down). The LV winding was opened and voltage supplied to the HV side. A multimeter is used to measure the input and output voltage as recorded in table 8.

Table 6: Insulation resistance test result

Phase Connection	*11KV Side*	*0.415KV*
R-E	4500/Megohms	1500/Meg ohms
Y-E	4500/Megohms	1500/Meg ohms
Y-E	4500/Megohms	1500/Meg ohms

Table 7: Insulation resistance test of cable

Substation	*1x300 mmsq PVC/SWA/PVC (feeder) GΩ*	*4x70 mmsq PVC/SWA/PVC*
300kVA, 11/0.415kv	-	-
r-e	2.10	0.047
y-e	1.96	0.045
b-e	2.00	0.50
n-e	-	0.64

Table 8: Ratio test

Substation	**Applied Voltage Primary Side**		**Secondary Side**	**Induced Voltage**	
11/0.415kVsubstation	R-Y	Y-B	R-B	r-b	y-b
Connection	Dyn11				
R-Y	221	179	47.0	9.11	3.02
Y-B	95.0	232	132	7.02	8.16
R-B	32.5	205	214	3.74	8.98

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Table 9. Excitation test

11/0.45kv, 300kvA transformer	**LV measured Voltage (V)**	**LV measured Voltage (V)**	**LV measured Voltage (V)**	**Excitation current (A)**
r-n	231	168	70	1.5
y-n	122	230	133	0.7
b-n	71	169	231	1.4

v. Earth resistance test: Earth resistance test was carried out on the installation to know the effectiveness of the earthing system. Earth resistance tester used to measure the earthing connection. The measured earth resistance value is 3.76 Ω which is within the acceptable value.

vi. Excitation test: Excitation test was conducted to known the state of the magnetic core structure, turn to turn insulation and winding position. The result is as shown in table 9.

4. CONCLUSION

The main objective of the work is to design and install a 300 kVA 11/0.415 kV distribution transformer, based on load requirement of the electrical systems that would guarantee consumers maximum reliability and comfort. The work has carefully spelt out in clear terms the design and installation procedure for distribution transformer. Also physical inspection and test results show that the design and installation conform to global best practice and standards. The successful completion of this work has led to a tremendous improvement in power distribution to the affected load centers. Also it goes to show that using qualified and competent experts leads to the execution of engineering projects within specification and acceptable standards.

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