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Highlights

- Electrical Load Evaluation
- Results of an Experimental Study
- Calculations of Heat Transfer
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Discovering Thoughts, Inventing Future

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Results of an Experimental Study of the Thermoelectric Generator Integrated into a Plate Heat Exchanger

By Yuriy Lobunets & Ilya Abdurakhmanov

Abstract- This paper examines the results of experimental studies of a prototype thermoelectric generator integrated into a plate heat exchanger (HX TEG). Such generators are designed to convert the energy of low-potential sources of heat and waste heat. The main objective was to validate the existing mathematical models of HX TEG in order to evaluate the reliability of the results of theoretical analysis. The results obtained confirm the accuracy of the calculations. The economic indicators are given, which allow expecting widespread use of the HX TEG for the operation of waste heat and low potential heat sources.

Keywords: thermoelectric generator, TEG, waste heat, LCOE of the TEG.

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RESULTSOFANEXPERIMENTALSTUDYOFTHETHERMOELECTRICGENERATORINTEGRATEDINTOAPLATEHEATEXCHANGER

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Results of an Experimental Study of the Thermoelectric Generator Integrated into a Plate Heat Exchanger

Yuriy Lobunets [α] & Ilya Abdurakhmanov [σ]

Abstract- This paper examines the results of experimental studies of a prototype thermoelectric generator integrated into a plate heat exchanger (HX TEG). Such generators are designed to convert the energy of low-potential sources of heat and waste heat. The main objective was to validate the existing mathematical models of HX TEG in order to evaluate the reliability of the results of theoretical analysis. The results obtained confirm the accuracy of the calculations. The economic indicators are given, which allow expecting widespread use of the HX TEG for the operation of waste heat and low potential heat sources.

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List of Symbols

Bi	Biot criterion
I	Electrical current (A)
j	Current density (A/cm^2)
J	Dimensionless current density
e	Seebeck coefficient (V/K)
E	Electromotive force (V)
λ	Thermal conductivity coefficient (W/cm-K)
r	Electrical conductivity coefficient [Ωcm]^1
h	Thermocouple leg length (cm)
n	Number of thermoelectric modules
nv	Number of thermoelectric elements in modules
s	Thermoelectric leg cross sectional area (cm^2)
To	Determining temperature (°C)
Th	Hot junction temperature (°C)
Tc	Cold junction temperature (°C)
dT	Junction temperature difference (°C)
th	Heat carrier temperature (°C)
tc	Coolant temperature (°C)
dt	Temperature difference of heat carriers (°C)
$\theta = T/To$	Dimensionless temperature
$\vartheta = t/To$	Dimensionless temperature of fluid
z	Thermoelectric figure-of-merit (K^{-1})
zTo	Dimensionless thermoelectric figure-of-merit
N	Electrical power (W)
Nx	Dimensionless power
Q	Heat power flow (W)
η	Efficiency
ηc	Carnot efficiency
α	Heat transfer coefficient (W/cm^2 K)
R	Electrical resistance (Ω)
RL	Electrical load resistance (Ω)
$m = RL/R$	Load factor
LCOE	Levelized cost of electricity ($/kWh)
V	The velocity of the heat carrier flow, (m/s)
$Y = y/h$	Dimensionless coordinate

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I. Introduction

Low-grade heat sources present a significant technical and economic potential: over 60 quadrillions BTU of energy were wasted yearly in the United States, mainly in the form of heat, [1], the huge renewable geothermal and solar thermal energy resources are also low- grade. Recovery even a small fraction of these heat resources can make a significant contribution to the energy balance. The main reason for limiting the use of these energy sources is the low-temperature potential - typically below 100°C. Not only does this substantially limit energy conversion efficiency (Carnot efficiency ηc does not exceed 20%), but it also determines the low energy flux density Q and the correspondingly high capital expenditure (CapEx) on the equipment. Two major energy conversion technologies are currently under consideration - the Organic Rankin Cycle (ORC) and the Thermoelectric Generator (TEG). ORC is the best-developed and commercialized technology - different range equipment available on the market, there are real estimates of Levelized Cost of Electricity (LCOE). At the same time, TEGs have potential benefits that can provide them with a niche in the market for low-grade heat sources. This is high reliability, low operating costs, compactness, and noiseless. Much research has been devoted to improving the economic efficiency of TEG. Reviews [2-3] provides statistics on existing devices and discuss possible ways to improve their performance. The modern paradigm of the development of thermoelectric devices is based on an increase in the thermoelectric figure of merit of thermoelectric materials *zT*, which determines the theoretical efficiency limit of TEG. However, no significant progress has been made recently in raising *zT*, and there is a reason to believe that there is a limit that has already been reached [4]. At the same time, large reserves remain for improving TEG economic performance by optimizing structures and regimes. First of all, it concerns the increase of heat exchange intensity. On the conditions of heat exchange depends on the useful temperature difference on thermocouples and their optimal height, which determine the density

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of heat fluxes and the specific power of TEG [5]. Most commonly, the sources of waste heat are liquid heat-carriers with a defined temperature. For these conditions, plate-type heat exchangers provide the best heat exchange intensity. In patents [6-8], several TEG designs integrated into plate heat exchangers (HX TEG) were proposed. The proposed TEG system provides for the high intensity of heat transfer, increase efficiency and specific power, simplify the system architecture, and reduce cost. This differs from the commonly accepted conventional TEG design, where the heat carriers are separated from the thermoelectric module by a separator plate or tube canals. The design concept consists of heat exchange plates integrated with an array of thermoelectric modules (Figure 1a), assembled into a modular stack (Figure 1b). Each plate is composed of the case in which thermoelectric modules are mounted and hermetically sealed. Gaskets are located between the plates, which form the transport channels for the heat carriers. The entire stack assembly is clamped between endplates that provide connections for the heat carriers. Electrical connections are made in parallel and series between individual thermoelectric modules and between plates, depending on the desired reliability, voltage, and current, with current collection terminals mounted into one of the stack endplates. A TEG based on this design concept can be comprised of a single stack or combine with multiple stacks into a rack-type structure for higher power output (Fig. 1c, 1d).

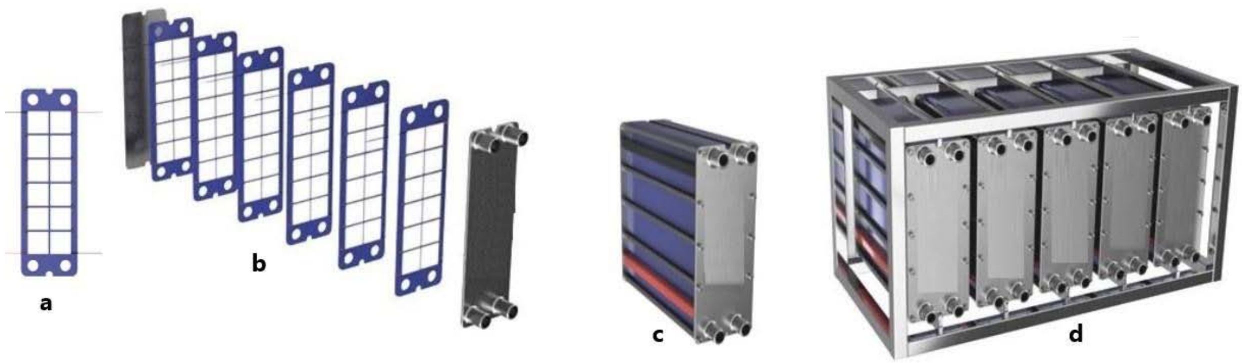

Figure 1: a-Thermoelectric plate; b - Stack Assembly; c, d -Modular Configuration

II. Theoretical Foundations

In general, the power of the TEG-HX is:

$$N = E^2 \frac{m}{(m+1)^2} \quad (1)$$

where $E = ne\Delta T$ – an electromotive force of the generator; m – load factor.

That is, in order to determine the power of HX TEG, it is necessary to know the temperature difference on thermocouples ΔT and its distribution along the channel. The mathematical models presented in [5] allow the analysis and evaluation of the economic indicators of the HX TEG based on the initial data - material properties and sizes of thermoelectric modules, assembly geometry, initial temperatures and coolant flow rates. Figure 2, below, illustrates a basic conceptual design for an HX TEG device for the purpose of discussion. In this illustrative example, heating (t_h) and cooling (t_C) fluids pass through the canals between thermoelectric modules and flow over their surface, ensuring the maintenance of a temperature difference (ΔT) on the thermoelectric modules. Due to certain irreversible losses associated with heat exchange, as well as a result of changes in the temperatures of the fluids along the length of each channel, the actual working temperature difference across a thermoelectric module will always be less than the inlet temperature difference:

$$\Delta T < dt_o = t_{ho} - t_{co} \quad (2)$$

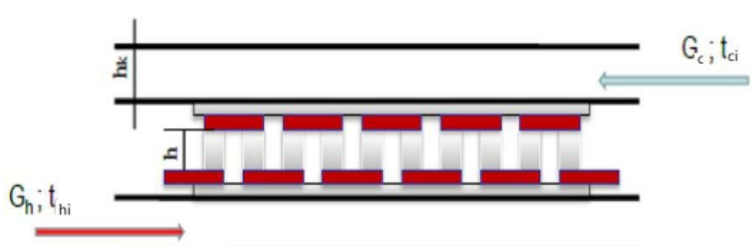

Figure 2: Conceptual design of the HX TEG

A mathematical model to determine this temperature difference contains [5]:

- The solution of the equations of heat and electricity transfer with third type boundary

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conditions:

$$\Theta(J,Y) = C_1 + C_2Y - Y2,\text{`} \quad (3)$$

where,

$$C_1 = \frac{b2Bic\theta c - b1}{J - Bih + b2(J + Bic)};$$

$$C_2 = C_1\,(J + Bi_c) - Bi_c\theta_c;$$

$$b_1 = \frac{J2}{Io} - \frac{J2(J-Bih)}{2Io}\,Bi_h\theta_h;$$

$$b_2 = J\text{-}Bi_h\,\text{-}1;$$

- criteria equations for determining the heat transfer coefficients:

$$Nu = 0.022Re^{0.8}Pr^{0.43} \quad (4)$$

The system of equations (1 - 4) allows the calculation of the temperature distribution in the thermoelectric elements and in the fluid and, respectively, to determine the characteristics of the HX TEG as a function of the operational and geometrical parameters, the properties of the thermoelectric materials, and the properties of the fluids. Since the properties of coolants depend on temperature, for the calculation of heat transfer coefficients is applied to the interpolation of tabular data of the thermo physical properties using cubic splines. The peculiarity of the calculations is that in the case of a counter-current flow pattern of the coolant, at least one of the required temperatures (the temperature at the outlet of the heat exchanger) is uncertain. The problem is solved by successive calculations of the temperature distribution in each thermocouple (or module) using the parameters of the coolant at the output of the module as input parameters for the next module. The solution is numerically finding the temperature $th(1)= thout$ that satisfies the initial conditions, i.e. $th(n)= tho$ and $tc(1)= tco$. Figure 3 illustrates the results of calculating the temperature distribution along HX TEG channels.

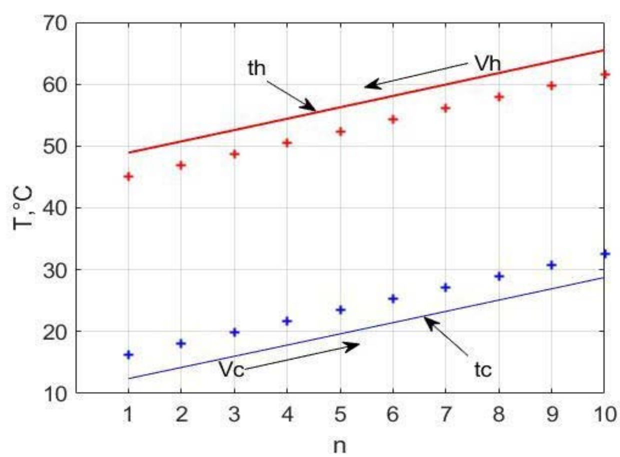

Figure 3: Temperature distribution in the HX TEG

(*markers - the temperature of modules T,* °C; *lines - temperatures of heat carriers, t,* °C).

However, due to possible errors in determining the initial data (first of all, the conditions of heat exchange), these models require verification by comparing the calculated and experimental data.

III. Study of the HX TEG at the Thermoelectric Test rig

In order to verify the mathematical model (1- 4), an experimental study of the characteristics of a laboratory prototype HX-TEG was conducted. The flows diagram of the test apparatus is shown in Fig. 4. The experimental TEG consisted of thermoelectric plates designed in accordance with the patent [10]. The dimensions of the thermoelectric plate is similar to the Alfa Laval plate of heat exchanger type T2–BFG (380 mm x 140 mm). Each thermoelectric module pack in the plate consists of 10 thermoelectric modules type MT2.6-0.8-263. The first value in the specification of the module indicates the area of the cross-section of the thermocouples (s=2.6 mm^2), the second value is the legs length of the thermocouples (h=0.8 mm), and the third value is the number of thermocouples (nv=263). The size of the module is 50 mm x 50 mm x 4 mm and the total number of modules in the HX TEG was n=40 pieces. The thermoelectric material is Bi_2Te_3, whose properties (α, σ, λ) are described as polynomials of degree 2 with sufficient accuracy. Hot and cold heat-carriers (potable water) flowed through channels with a cross-section of F=2 cm^2 (100 mm x 2 mm). The temperatures of the heat- carriers at the inlets and outlets and the electromotive force (EMF) of the HX TEG were measured. The flow rates of the heat carriers were

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measured with rotameters (varied between 0 – 1.0 kg/sec). The temperature of input coolants varied between t_{co}=3.5°C – 7°C and t_{ho}=40°C -70°C. The entire TEG assembly was constructed in an aluminum chassis. The dependences of the power output of the HX TEG on the velocity and temperature of the heat-carrier were investigated and the experimental data were compared with the results of calculations. Using the experimental data for t_h, t_c, G_h, and G_c, together with the mathematical model (1 – 4), all HX TEG parameters were calculated:

- The distribution of temperature of the heat carriers t_h, t_c;
- The distribution of temperature difference on thermoelectric modules ΔT, °C;
- An electromotive force EMF, V, and
- Power N, W.

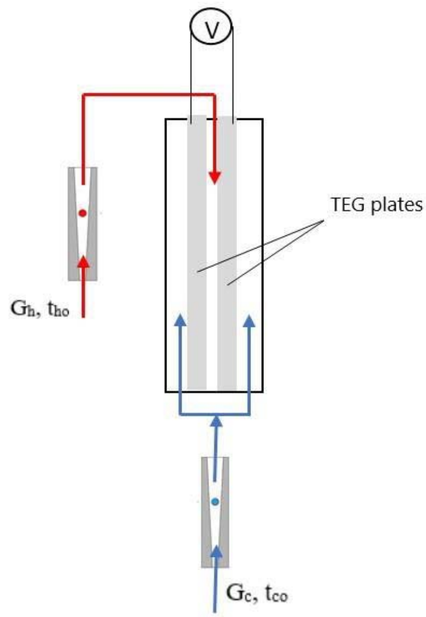

Figure 4: Flows diagram of the test rig

Since the basis for calculations is primary data (initial temperature and mass flow of coolants), the accuracy of the mathematical model was estimated by comparing the experimental data of the EMF of HX TEG with the calculation by to same conditions. The correlation between the calculated and experimental data is presented in Figure 5, below, which presents the EMF, as calculated (*Calc*) compared with actual EMF measurements (*Exp*) for the same conditions.

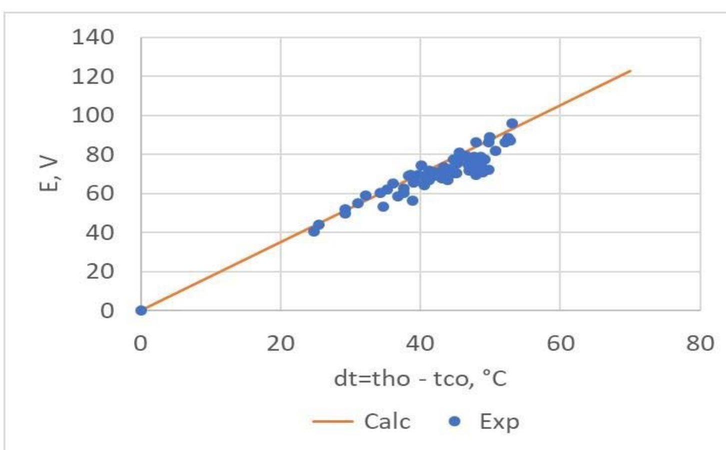

Figure 5: Comparison of calculation (Calc) and experimental (Exp) data

IV. Results and Discussion

The correlation between the calculated and experimental data is presented in Fig. 6. The results obtained confirm the high accuracy of the developed mathematical model. The error estimate in the form *Delta = (Eexp - Ecalc) / Eexp * 100%* shows that the difference between the experimental and calculated data does not exceed *Delta*≈7%, which is equal to about half of the scattering corridor of the experimental data (Fig. 7). That's quite acceptable and due primarily to the errors in the measurement of the heat carrier flows and the standard errors of the equation for the calculation of heat exchange intensity. The character of the scattering shows that the deviations are random and relate primarily to the results of the measurement, and not to the accuracy of the mathematical model.

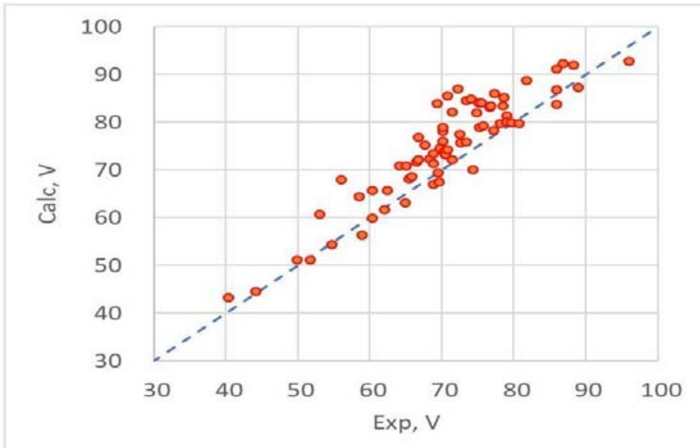

Figure 6: The correlation between the calculated (Calc) and experimental (Exp) data

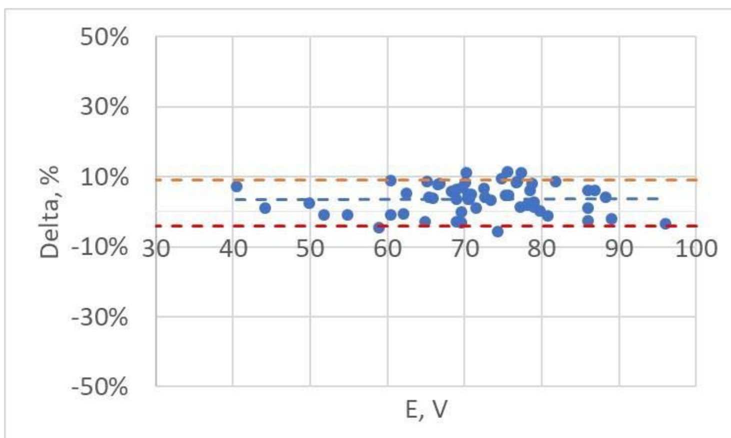

Figure 7: Deviation of experimental data compared with mathematical model for different dt

The specific power of TEG depends largely on the intensity of heat transfer, which for a fixed design is determined by the flow rate of the heat carriers. The above data were obtained for a heat carrier velocity of 1.1 m/s, which corresponds to heat transfer coefficients of about 0.22 W/cm^{2}K. Increasing the velocity of heat carriers leads to a significant increase in power of HX TEG and, consequently, to a decrease in capital expenditure (CapEx) per Watt. According to the presented in Fig.8 data, increasing the heat transfer coefficient to 1.0 W/cm^{2}K provides a double increase in power and a corresponding decrease in CapEx. For the considered design with smooth channels, such heat transfer coefficient corresponds to a speed of 8 m/s, which is not acceptable. But usually, the heat exchanger plates have a turbulent relief, thereby achieving α up to 2 W/cm^{2}K at reasonable heat carriers velocitie of V≈1 m/s. That is, existing methods allow to increase the intensity of heat transfer to the required level. The Levelized Cost Of Electricity (LCOE) estimates for the HX TEG is presented in Fig. 9. The real cost of components was taken into account in the CapEx calculations; the TEG resource is 10 years; the cost of the heat source (waste heat) and operating costs were not taken into account. Thus, the weighted price of electricity, given in Fig. 9 can be considered as a first approximation to reality.

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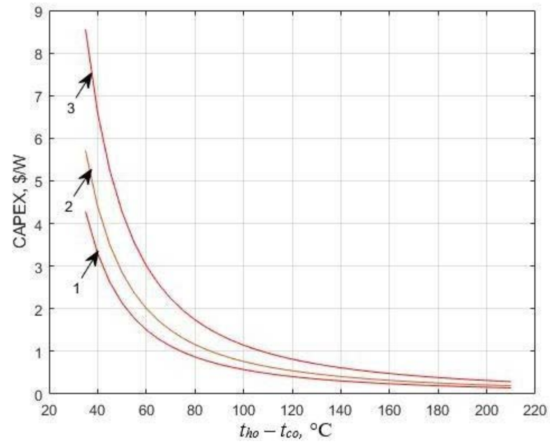

Figure 8: The dependence of CapEx on the initial temperature difference of the heat carriers. (1 – α = 1.0 W/cm^{2}K; 2 – α = 0.5 W/cm^{2}K; 3 – α = 0.22 W/cm^{2}K)

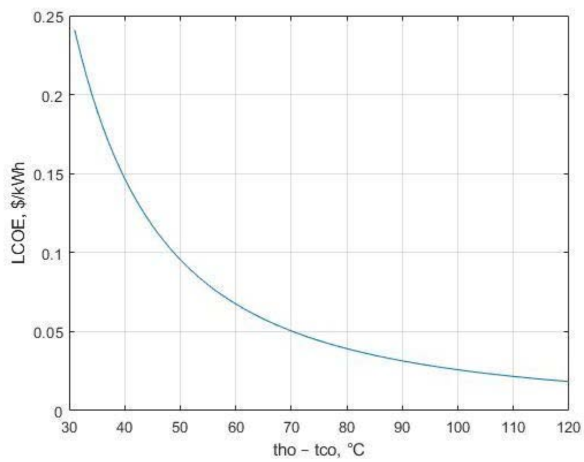

Figure 9: Levelized cost of electricity for the low-grade heat HX TEG (α = 1.0 W/cm^{2}K).

V. Conclusions

The results of the experimental study of the thermoelectric generator for utilizing low-grade heat are considered. The studies were carried out in order to verify the developed mathematical models of TEG, integrated into the plate heat exchanger (HX TEG). The results obtained confirm the accuracy of the calculations (the error is about 7%). The economic indicators of HX TEG are given. Possibility to reach the specific values of Cap Ex< 1 $/W and LCOE=3- 5 cents/kWh is demonstrated. Such technical and economic indicators allow us to expect a wide application of HX TEG for the exploitation of the waste heat and low-potential heat sources.

Acknowledgments

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Calculations of Heat Transfer in Furnaces of Steam Boilers under Laws of Radiation of Gas Volumes and Development of Innovative Designs of Furnaces

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GJRE-F Classification: FOR Code: 290901

CALCULATIONSOFHEATTRANSFERINFURNACESOFSTEAMBOILERSUNDERLAWSOFRADIATIONOFGASVOLUMESANDDEVELOPMENTOFINNOVATIVEDESIGNSOFFURNACES

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I. Introduction

In Russia on thermal power plants (fig. 1), about 2000 power units with a capacity of 30 to 1200 MW are installed. The power units include a steam boiler, a steam turbine, and a turbine generator. Dimensions of buildings of power plants in which power units are installed depending on dimensions of steam boilers. The height of steam boilers can reach up to 100 m. In the furnaces of steam boilers, 80–85% of the fuel and energy resources extracted and used in the world, including Russia, are burned.

Fig. 1: Thermal power plant

Total rated capacity of power units of the thermal power plants (TPPs) and combined heat and power plants (CHPPs) of Russia is 160,000 MW. Every hour, in the furnaces of steam boilers(SB) of thermal power plant (TPPs)and combined heat and power plants (CHPPs), 35,730 tons of fuel are burned in the form of heat equivalent in fuel oil or 600 railway tanks with a capacity of 60 tons of fuel oil, which is ten trains with 60 tanks each. A day in the furnaces of TPPs and CHPPs steam boilers of Russia burn above 240 trains of heavy fuel oil equivalent. It is significant to increase the efficiency of the furnaces of steam boilers and steam turbines, to organize the rational combustion of fuel in the furnaces since only 1% of the fuel saved per day will be 8580 tons in fuel oil equivalent or 2.4 trains. Saving of 1% of fuel per year will be 876 trains in fuel oil equivalent of 60 tanks in each or 3 million 132 thousand tons of fuel oil.

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II. The Problem of Heat Transfer Calculation in the Furnaces of Steam Boilers

In the 20th-21st centuries, widespread flaring in furnaces, combustion chambers of gaseous, liquid, pulverized fuel was widely adopted. Flaring of fuel is characterized by volumetric radiation, a three-dimensional model of radiation. Radiation heat transfer accounts for 90–98% of the total heat transfer in the furnaces of steam boilers [1, 2], torch heating [3], and electric arc steel-smelting furnaces [4, 5]. In a torch, an electric arc emits quadrillion atoms, the radiation of each atom to the calculation site must be taken into account, which is an extremely complex task. To calculate the thermal radiation of the torch to the calculation site, it is necessary to solve the triple integral equations of heat transfer by radiation [6]. There were no solutions to the triple integral equations for determining the fluxes of thermal radiation, the angular emission coefficients of the torch to the calculation site, and the average path length of the rays from the emitting atoms to the calculation site were not found.

It is believed that the problem of calculating heat transfer in torch furnaces and power plants was eliminated with the advent of computers and the beginning of the use of the numerical computational technique for integral equations of heat exchange and calculation methods Pl-approximation, Monte Carlo, Schwarzschild-Schuster, Eddington, Chandrasekhar, spherical harmonics.

Numerical and other methods are based on the law of thermal radiation of solids, the Stefan-Boltzmann law. However, long-term theoretical and experimental studies of heat transfer have shown that the thermal radiation of the gas volumes of flares does not obey the Stefan – Boltzmann law, and the calculation error is 90–180% or more [5–9].For example, the furnace of a steam boiler of a power unit with a capacity of 300 MW of a power plant is a rectangular parallelepiped with a width, depth, height of 14, 7, 35 m, respectively. When working on fuel oil in the furnace, every hour burns 67 tons of fuel. A high-temperature radiating gas volume of the torch is formed in the furnace, filling the entire space of the furnace. The torch emits all the atoms, which amount is approximately equal to the quantity of grains of sand in the Sahara Desert. The radiation of each atom to the calculation site must be taken into account, which was not done in the 20th century. Throughout the 20th century the torch in furnaces and combustors was "a black box," an unexplored object of radiation. To save fuel when burning in steam boiler furnaces, to increase the efficiency of a steam boiler, it is necessary to organize correctly combustion of liquid, powdered, gaseous fuel in the burners, to rationally place the burners on screen surfaces of fire chambers. It is possible to correctly place the burners on the screen surfaces if there is an exact methodology for calculating heat transfer in the furnaces of steam boilers, which allows obtaining a calculation result corresponding to the true heat transfer in the steam boiler furnaces.

Having performed dozens of calculations using the exact methodology with different locations of the burners in the furnace, you can find a rational arrangement of the burners at which the heat flow of the flame is aligned along the perimeter and height of the furnaces, the efficiency of steam boilers is increased, in-pipe deposits, operating costs and fuel consumption are reduced. Exact methods for calculating heat transfer in flare furnaces and combustion chambers were absent throughout the 20th century. Calculation methods that existed in Russia and other industrialized countries (zonal, numerical, Pl approximations, Monte Carlo, Schwarzschild – Schuster, Eddington, Chandrasekar, spherical harmonics) did not allow to obtain a complete picture of heat transfer in flare furnaces and combustion chambers [1– 5].

All of the above methods are based on the law of thermal radiation of blackbody, Stefan - Boltzmann solid body and the emission of gas volumes of torches does not obey the law of blackbody, the law of radiation of a solid body and the calculation error is 90-180% or more. This error led to the fact that throughout the 20th century in the textbooks, monographs, articles in Russian and foreign scientists, there was no information on the distribution of heat flows and radiation in the furnaces on the axis of symmetry of the display surfaces and their periphery (Fig. 2), on the causes of damage to the burner devices, uneven vaporization, and in-pipe deposits on the height and perimeter of the screen surfaces.

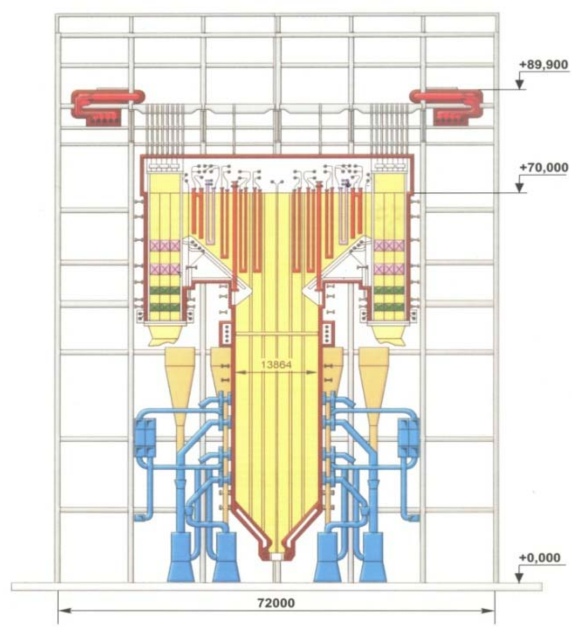

Fig. 2: Furnace of 500 MW power unit steam boiler

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Local knowledge of heat transfer was obtained in the course of numerous laborious experimental studies of heat transfer in the furnaces of the steam boiler. Expensive time-consuming and resource-consuming experimental methods of heat transfer research did not allow to obtain a complete picture of heat transfer due to its complexity, low efficiency, lack of serial devices for measuring the heat flux of radiation on the heating surfaces in flare furnaces and combustion chambers.

The lack of reliable methods for calculating heat transfer in flare furnaces and combustion chambers led to the containment of their development, improvement, creation of innovative, more advanced flare furnaces, furnaces with a different arrangement of burners and flares in them (Fig. 3). The rational location aligned to the heat flows on the heating surfaces, evaporation, and in-line sediments in torch furnaces, the heating period becomes shorter, and the fuel consumption in flaring furnaces [10, 11], reduced fuel consumption and operating costs for removing intra pipe deposits.

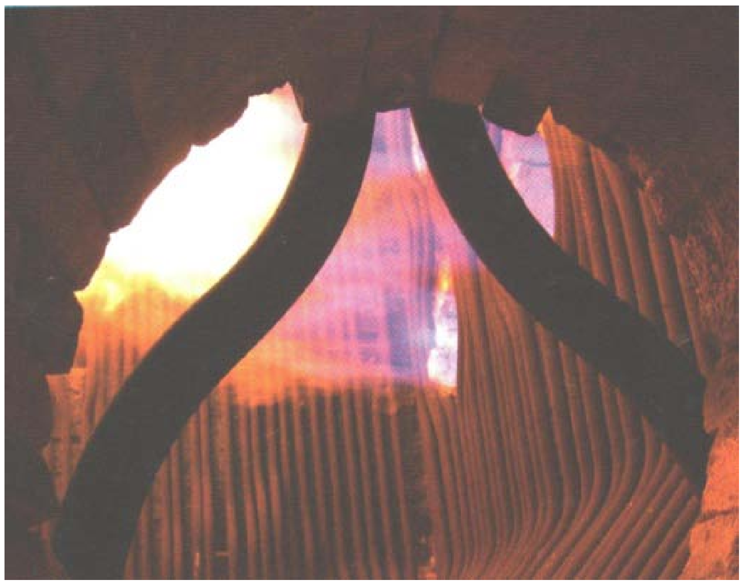

Fig. 3: Interior view of the furnace of the steam boiler, burner, torch

The lack of a reliable method for calculating heat transfer did not allow the calculation of heat transfer and to predict the creation of more advanced efficient flare furnaces [11] and combustion chambers. The design of most of the direct-flow furnaces of steam boilers and flare heating furnaces has not made any fundamental changes for several decades, contributing to the equalization of the distribution of the fluxes of radiation of the flares on the heating surfaces.

III. The Laws of Thermal Radiation of Gas Volumes of Torch Furnaces

In 1996-2001 an author discovered the laws of thermal radiation of gas volumes of flares, the laws of radiation of isothermal isochoric coaxial cylindrical and concentric spherical gas volumes [5–10]. To comply with centuries-old scientific traditions and copyright laws of thermal radiation of gas volumes of torches in a diploma for scientific discovery, articles, textbook [5-10] are similar to the laws of radiation of a black body, the laws of Stefan – Boltzmann, Planck, Wien, Bohr's postulates [9] named after the author who discovered them - the laws of Makarov. Based on the scientific discovery, a new concept for calculating heat transfer in flare furnaces of steam boilers and combustion chambers of gas turbine plants was developed [5, 10].

With the discovery by the author of the article of the laws of thermal radiation of gas volumes (Table 1) of torches, it became possible to calculate heat transfer (distribution of heat fluxes overheating surfaces) with high accuracy, to predict a change in the distribution of heat fluxes overheating surfaces with a change in the design of torch furnaces [11], furnaces, combustion chambers and the location of burners and torches in them. With the discovery of the laws of thermal radiation of gas volumes, it became possible to make changes in the design of furnaces, combustion chambers and calculate the rational arrangement of burners and torches in them, create innovative flare furnaces and combustion chambers in which heat fluxes are aligned overheating surfaces, time is reduced heating, fuel consumption, operating costs for flushing boilers from intra pipe deposits, the cost of pilot studies of the combustion chambers of gas turbine plants, the number of destruction of the combustion chambers is reduced, hence the resource of their work increases.

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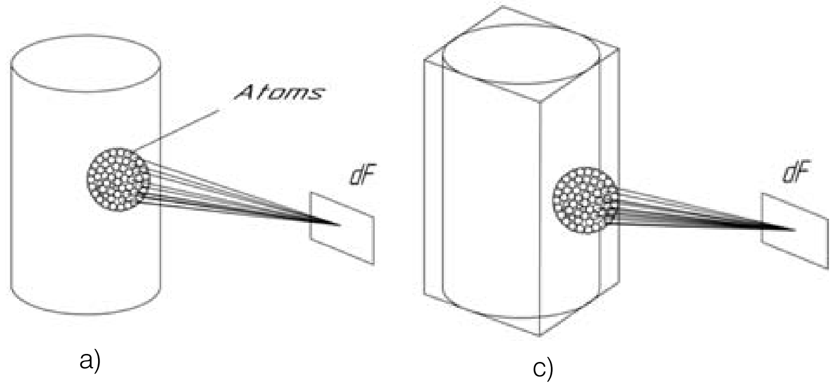

Fig. 4: Radiation to the calculation site of the df atoms of a cylindrical gas volume (a) and a gas volume in the form of a rectangular parallelepiped (c)

Fig. 4. Shows the radiation from cylindrical gas volumes to the calculated area. Mathematical notation of the laws of heat radiation from cylindrical gas volumes of the torches is given in Table 1 [6].

Table 1: Mathematical notation and formulation of the laws of heat radiation from cylindrical gas volumes

Law number	Mathematical notation of the law	Law formulation
I	$q_{FdF} = \dfrac{\varphi_{F_0dF} \cdot P_F \cdot e^{-kl}}{F_0} = \dfrac{\varphi_{F_0dF} \cdot P_F}{F_0 \cdot e^{kl}}$	Heat radiation flux density incident on the calculated area from the cylindrical gas volume is directly proportional to its power, the angular radiation coefficient and is inversely proportional to the absorption coefficient, the average beam path length from the atoms of the volume to the site and the site area.
II	$l_1 = l_2 = l_3 = \ldots = l_i = \left(\sum_{i=1}^{n} \dfrac{l_i}{n} \right) = l$	The average beam path length from radiating atoms to the calculated area is equal to the arithmetic mean distance from the symmetry axis to the calculated area.
III	$\varphi_{F_1dF} = \varphi_{F_2dF} = \varphi_{F_3dF} = \ldots = \varphi_{F_idF}$	Angular coefficients of radiation from coaxial cylindrical gas volumes to the calculated area are equal.
IV	$q_{F_1dF} = q_{F_2dF} = q_{F_3dF} = \ldots = q_{F_idF}$	Flux densities of radiation from coaxial cylindrical gas volumes to the calculated area are equal.
V	$q_{F_1dF} = \sum_{i=1}^{n} q_{F_idF}$	Flux densities of heat radiation from cylindrical gas volume of large diameter and its cylindrical axis of symmetry to the calculated area are equal when the heat capacities released in them are equal.

In Table 1 the following symbols are used : q is the density of the heat flux incident on the calculated area (CA) from the cylindrical gas volume (CGV), kW/m^2; φ is the angular radiation coefficient (a portion of the radiation) from the CGV to the CA; P is the radiation power of the CGV, kW; k is the absorption coefficient of the CGV; ι is the average beam path length from all atoms of CGV to the CA, m; F is the surface area of the CA, m^2; indices denote the numbers of gas volumes from 1 to n.

In 2011 the author of this article Makarov A. N. received a diploma for the scientific discovery [13]. According to the first law of heat radiation from cylindrical volumes, the heat radiation flux density of cylindrical gas volume to the calculated area q_{FodF} is directly proportional to the radiation power of the volume P_F, the proportion of the radiation on the calculated area φ_{FodF} of the total radiation from the volume and inversely proportional to the site area F_0, the absorption coefficient of the gaseous medium k, the average beam path length l from the atoms of the volume to the area.

The open laws of thermal radiation of ionized gas (electric arcs) and non-ionized (flares) gas volumes, as well as all fundamental laws of physics, are universal, multidisciplinary, applicable to several sectors of economic activity.

These laws are used to create innovative devices and methods in many industries: metallurgy, energy and various industries [4-11].

The open laws of thermal radiation of gas volumes make it possible to calculate with high accuracy for any calculation site the radiation of each atom and the total radiation of all atoms that make up the torch. It should be borne in mind that with the

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discovery of the laws of thermal radiation of gas volumes, the extremely complex problem of calculating, using one radiation formula of quadrillion torch atoms to any calculation site in flare furnaces and combustion chambers, was solved. Based on open laws, the author developed a method for calculating heat transfer in flare furnaces and combustion chambers, the basic calculation formulas of which are given in the table. 2 [11].

In the table. 2 the following conventions are used: q_{in} – is the density of the heat flux incident on the i-th elementary area on the heating surface, $q_{in\phi}$ – is the density of the flux of thermal radiation incident on the i-th area from the torch, taking into account the absorption of the torch radiation; $q_{ino.ф}$ – is the flux density of thermal radiation incident on the i-th area b caused by the reflection of the radiation from the torch from the walls, hearth, arch, products; $q_{inп}$ – is the flux density of thermal radiation incident on the ith site from the radiating walls, the hearth, the lid, taking into account the reflection and absorption of radiation; $q_{ino.п}$ – the flux density of thermal radiation incident on the i-th platform, caused by the reflection of surface radiation from walls, hearths, lids, ingots; $q_{iкон}$ – convective flux density of the torch and combustion products of the i-th site; q_{inn}– is the radiation flux density of the combustion products to the i-th site, $\varphi_{фji}$ – is the local angular emissivity of the j-th cylindrical source to the i-th site, $P_{фj}$ – is the power of the j-th cylindrical source, Fi is the area of the i-th elementary area, $\psi_{фjk}$ – is generalized angular emissivity of the jth volume zone (jth cylindrical source) to the kth surface, $\varphi_{фjk}$ – is the average angular emissivity of the jth cylindrical source to the kth surface, φ_{ji} – is the local angular emissivity of the jth surface on i-th platform,Q_{jc} – stream own radiation of the j-th surface, t_i = 20^{0}C - temperature of the products; tg.sr = = 1400^{0}C - average temperature of combustion products, gas; αcon - heat transfer coefficient by convection, with free convection $\alpha_{кон}$ = 11.6 W / (m^2 · ^{0}C); at the beginning of heating, $q_{iкон}$ = 16.2 kW / m^2,φ_{ncji} – is the local angular emission coefficient of the jth volume of combustion products to the ith site, P_{ncj} – is the power of the jth volume of combustion products,ε_j – is the emission coefficient of the jth surface; cs is the emissivity of a completely black body; Tj – is the surface temperature; F_j – is the area of the jth surface.

Table 2: Equations, formulas for calculating heat transfer in flare furnaces and combustion chambers [11]

S. No. p/p	Name of the formula, equation	Equation, formula	Measurement units
1	The density of the total heat flux incident on the calculation site	$q_{in} = q_{in\phi} + q_{ino.ф} + q_{inп} + q_{ino.п} + q_{iкон} + q_{inn}$,	kw/m^2
2	The share of power allocated to the settlement site	$P_1 : P_2 : \ldots : P_n = T_1^3 V_1 : T_2^3 V_2 : \ldots : T_n^3 V_n$	-
3	The density of the heat flux of radiation incident on the calculation site from the torch (the first law of thermal radiation of cylindrical gas volumes)	$q_{inф} = \sum_1^n \frac{\varphi_{фji} P_{фj}}{F_i} e^{-kl}$	kw/m^2
4	Density of the heat flux of radiation caused by the reflection of the torch radiation from the surfaces to the calculation site	$q_{ino.ф} = \sum_1^n \frac{P_{фj}(\psi_{фjk} - \varphi_{фjk} e^{-kl})}{F_k}$	kw/m^2
5	Density of a heat flux of the radiation falling on the calculation site from the radiating surfaces	$q_{inп} = \sum_1^n \frac{\varphi_{ji} Q_{jc}}{F_i} e^{-kl}$	kw/m^2
6	Density of the heat flux of radiation caused by the reflection of radiation surfaces and incident on the calculation site	$q_{ino.п} = \sum_1^n \frac{Q_{jc}(\psi_{jk} - \varphi_{jk} e^{-kl})}{F_k}$	kw/m^2
7	Density of convective flow from the torch and combustion products to the calculation site	$q_{iкон} = \alpha_{кон}(t_{г.ср} - t_{и})$	kw/m^2

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8	The density of the radiation fluxes of the combustion products to the calculation site	$q_{inc} = \sum_{1}^{n} \frac{\varphi_{ncji} P_{ncj}}{F_i} e^{-kl}$	kw/m²
9	Corresponding flux of surface radiation	$Q_{jc} = \varepsilon_j c_s (T_j/100)^4 F_j$	kw/m²

IV. Calculation of Heat Transfer in the Furnace of a Steam Boiler

According to the laws of thermal radiation of gas volumes [10, 11] (see table. 1) and the methodology for calculating heat transfer in flare furnaces and combustion chambers (see table 2) developed on their basis, the heat transfer in the furnace of a steam boiler of a power unit was calculated to be 800 MW. The calculation results of heat transfer in the furnace of a steam boiler TGMP-204 are presented in Fig. 5, 6.

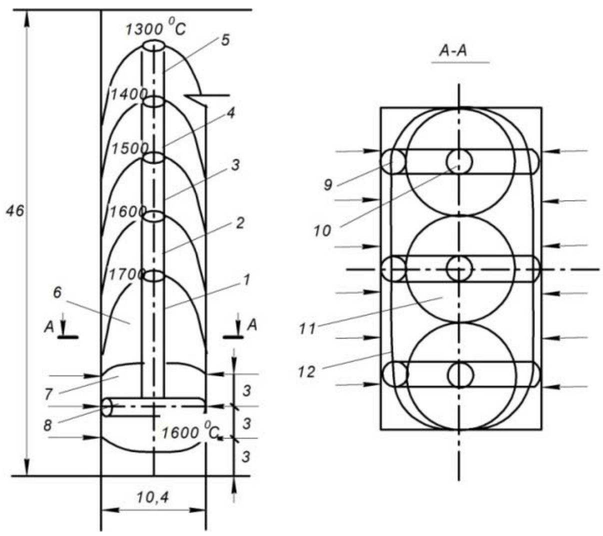

Fig. 5: Distribution of isotherms in the furnace of the steam boiler TGMP-204: 1-6, 10–12 - vertical radiating cylindrical gas volumes; 7–9 - horizontal radiating cylindrical gas volumes

The results of the calculation and measurement of the torch thermal radiation flux along the vertical axis of symmetry of the front wall are presented in Fig. 6 graphs 1 and 2. As can be seen from Fig. 6, the results of the calculation of measurements of torch radiation fluxes coincide or differ by no more than 5–8%, which confirms the high accuracy of the calculation results and the correspondence of the open laws of thermal radiation of gas volumes of the torch and the calculation methods developed on their basis for real processes of thermal radiation of the torch and heat transfer in furnaces of steam boilers. The results of heat transfer calculations in the furnaces of steam boilers showed that the components of the total heat flux incident on the calculation site (see Table 2, the first equation) are in the following ratio: the heat flux from the torch is 95%, the sum of the remaining components does not exceed 5 % of the total heat flux. The heat flux of the torch is extremely unevenly distributed along the perimeter of the furnace and varies on the front wall from 780 kW / m² on the axis of symmetry to 180 kW / m² on the periphery of the wall. Hence the variation in heat flux of the torch along the perimeter of the front wall is 4.3 times.

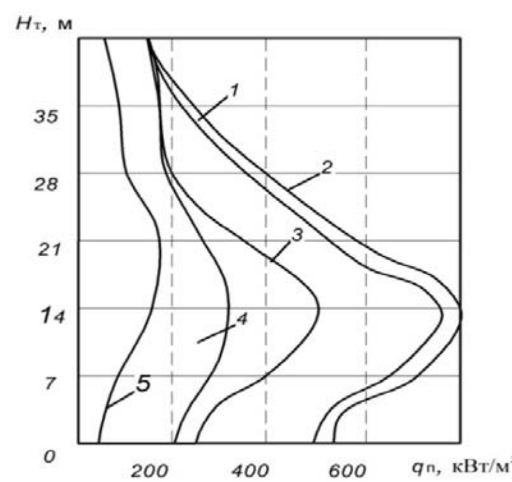

Fig. 6: The density distribution of the total radiation flux along the walls of the furnace: 1 - along the vertical axis of symmetry of the front wall; 2 - the same measurement result; 3 - along the vertical axis of symmetry of the sidewall; 4 - along the vertical axis at the periphery of the side wall; 5 - along the vertical axis on the periphery of the front wall.

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Thermal fluxes of the flame of the torch are extremely unevenly distributed along the height of the furnace, the difference in the values of heat fluxes along the height of the front wall on its axis is 490% (from 780 kW / m^2 at furnace height of 14 m to 160 kW / m^2 at height of 42 m) (see Fig. 6).The values of heat flux on the front, and side walls vary greatly. A significant difference in the distribution of thermal radiation fluxes of the torch along with the height and perimeter of the walls negatively affects the intensity of vaporization and the amount of deposits in the pipes. From Fig. 6 it follows that the maximum vaporization is characterized by the Central section of the frontal wall, located at the height of 14 m (here we have the maximum deposits in the pipes). At the height of 14 m on the periphery of the frontal wall, the heat fluxes of the torch are 4.3 times less compared to the Central site, the intensity of vaporization and the amount of deposits is also 4-5 times less compared to the Central site. Along with the height of the walls, we have a similar unevenness in the heat flux of the torch and deposits in the pipes. All this leads to a significant unevenness of vaporization and deposits in the furnace tubes. Pipe sections located at a height of 14 m intensively precipitate sediments, their inner diameter decreases and the steam boiler needs to be stopped to flush in-pipe deposits, while deposits are insignificant in the peripheral sections of the front wall and sidewalls. If the boiler continues to run without flushing, deposits on the central section of the front wall become so significant that it will be necessary to stop the boiler and replace pipes with deposits of the central sections of the front wall with new pipes.

V. Development of Innovative Furnaces of Steam Boilers

For many years, there was no accurate design information about the processes of heat transfer in the furnaces of steam boilers, so the design of direct-flow steam boilers has not changed for decades. The scientific discovery of the laws of thermal radiation of gas volumes made it possible to calculate the heat transfer in the furnaces of steam boilers and obtain complete information about the heat transfer in the furnaces, including data on the extremely uneven distribution of torch radiation fluxes along the perimeter and height of the furnace screen surfaces, to develop constructive solutions and new furnace devices, in which heat fluxes on screen surfaces and deposits in pipes are aligned, the operational costs of flushing boilers are reduced [12-15]. In fig. Figure 7 shows the innovative furnace of a steam boiler [12], in which at a distance of 0.33 the height of the furnace from the hearth, the front, rear and side walls are made at an angle of 4–6 ° with an inclination inward of the furnace with the formation of a tetrahedral truncated pyramid. When the upper part of the walls is made in the form of a tetrahedral truncated pyramid, the screens of the upper part approach the torch, the heat flows in the upper part of the walls increase, the height and perimeter are aligned (Fig. 8); vaporization is carried out evenly along the height and perimeter of the screens. The reduction of heat flow to the screens at the bottom reduces the number of deposits in the pipes, helps to slow down corrosion, increases the service life and the period between acid flushes of the boiler.

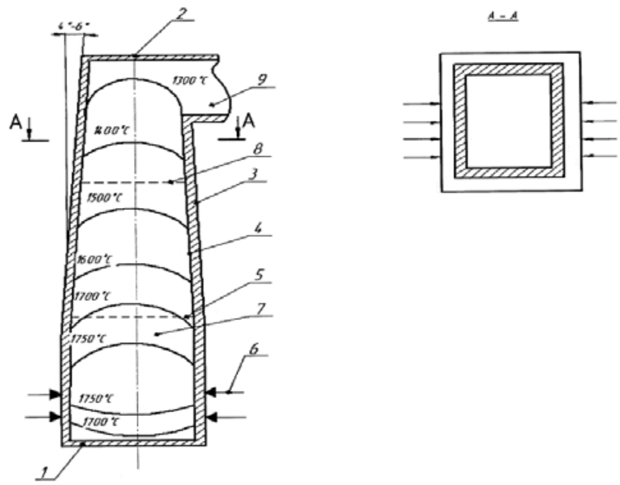

Fig. 7: The furnace of a steam boiler for combustion of gas-oil fuel with an inclination of part of walls inside: 1-under; 2-the arch; 3-walls; 4-screens; 5, 8-the lower and upper parts of the furnace, respectively; 6-burner; 7-torch; 9-flue

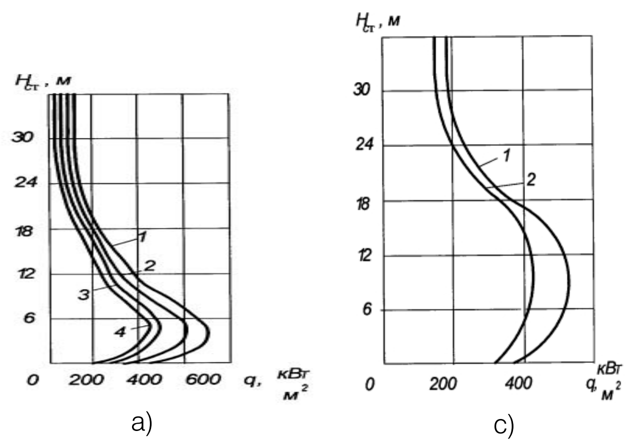

Fig. 8: The calculated distribution of the heat flux of the torch before (a) and after reconstruction (c): 1–4 is the distribution of heat fluxes along the symmetry axis of the front and side walls (a) 1, 2 is the distribution of heat fluxes on the axis of symmetry and on the periphery of the front and side walls, respectively (c)

In order to equalize the torch heat fluxes along the height and perimeter of the screen surfaces, a furnace made in the form of two truncated cones facing each other with large bases [15] (Fig. 9), as well as a

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furnace made in the form of two large bases facing each other truncated pyramids [13, 14] (Fig. 10). Patents for inventions [12-15] were obtained for the proposed furnaces.

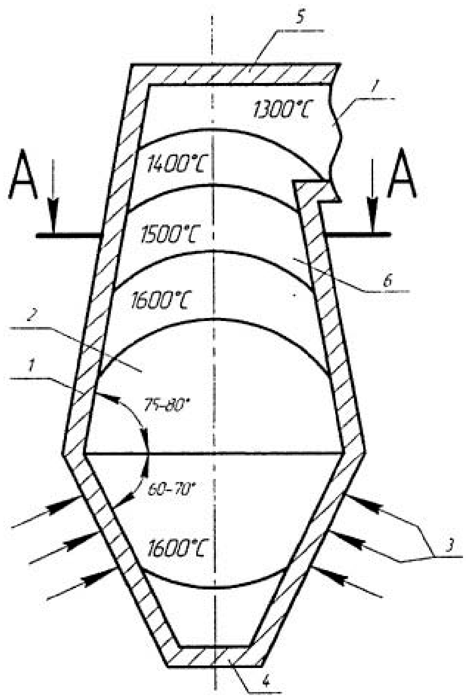

Fig. 9: Steam boiler furnace in the form of two truncated cones: 1-walls; 2 screens; 3-burners; 4- hearth; 5-arch; 6 – torch

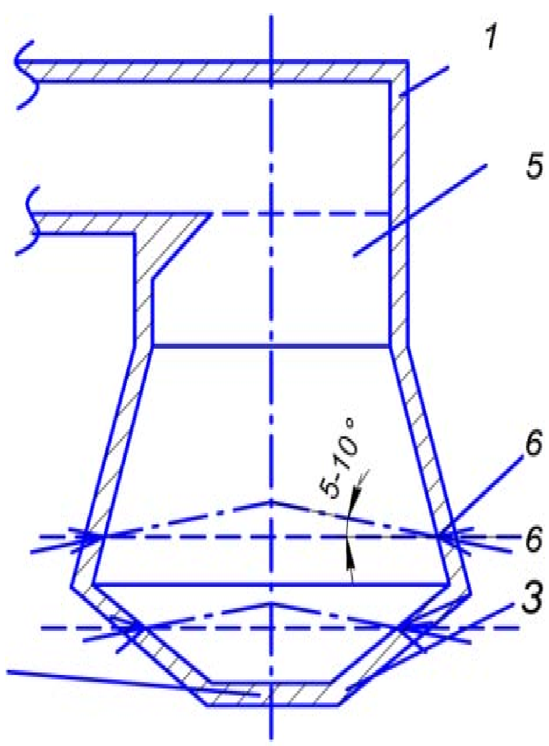

Fig. 10: Steam boiler furnace in the shape of two truncated pyramids: 1 - walls; 2 - arch; 3 - hearth; 4, 5 - screens; 6 – burners

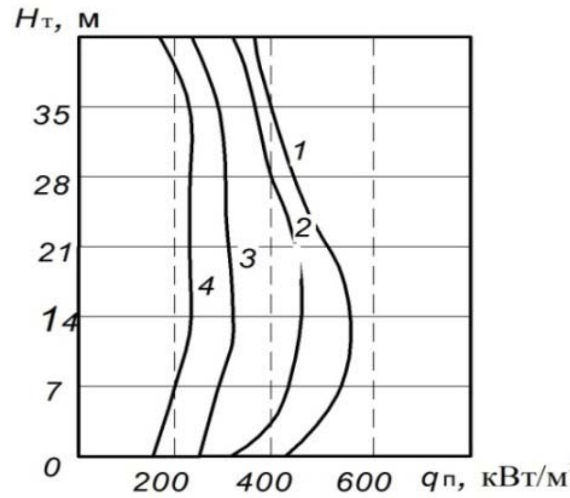

Fig. 11: Distribution heat fluxes along the height and perimeter of the walls of the furnace, shown in Fig. 10: 1–4 - the density of thermal radiation fluxes, respectively, along the axis of symmetry of the front, side walls and on the periphery of the side and front walls

The calculation according to the laws of thermal radiation of gas volumes made it possible to obtain complete information about the torch thermal radiation flows incident on the frontal, rear, side walls along the perimeter and height, on the reasons for the unevenness of deposits along the perimeter and height of the furnaces, the unevenness of vaporization in the pipes, and the reasons for burner burnout [9] and other physical phenomena occurring in the furnaces of steam boilers. Using the laws of thermal radiation of gas volumes in the design of furnaces will allow us to analyze the effect of changes in the location of the burners in the width and height of the furnaces, calculate their optimal location, achieve equalization of vaporization and deposits in pipes, increase the efficiency of steam boilers by 1-3%, reduce fuel consumption and operating costs for flushing pipes.

Fundamental laws of physics are the basis for the development of theories, calculation methods, with the help of which all existing types of engineering and technologies were created in the 20th-21st centuries, electrification, mechanization, automation, computerization of industry, agriculture and everyday life were carried out [10]. Open Makarov A.N. the laws of thermal radiation of gas volumes, like all fundamental laws of physics, have multi disciplinarity, use in various sectors of economic and economic activity: in energy, metallurgy, in various industries, in education [11].

VI. Conclusion

The open laws of thermal radiation of gas volumes and their practical use in calculating heat transfer in flare furnaces made it possible to determine with high accuracy the distribution of torch radiation fluxes along the perimeter and height of the furnaces, to

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identify the causes of burn-out nodes of burner assemblies in the furnaces and the unevenness of deposits inside the pipes around the perimeter and height of the pipes and to develop innovative furnaces of steam boilers, which eliminate the above disadvantages [12-15]. The practical use of the laws of thermal radiation of gas volumes in heat transfer calculations in flare heating furnaces made it possible to calculate the distribution of torch radiation fluxes along heating surfaces, to find out the reasons for the uneven distribution of heat fluxes on the surfaces of heated products, and to develop innovative torch furnaces with a rational arrangement of burners and torches in the furnaces at which it is aligned distribution of heat flows over heated products, reduced heating time of products, consumption fuel, increases the productivity of furnaces [11].The use of open laws and the methodology for calculating heat transfer in the combustion chambers of gas turbine plants developed on their basis makes it possible to determine the distribution of the thermal radiation flux of the torch over the surface of the flame pipe at the stage of designing the combustion chambers, to organize effective cooling of the surface of the flame pipe, onto which the maximum heat flux of the flame falls, to exclude burnout of a flame tube, increase its service life, reduce the cost of experimental studies of combustion chambers and at the design stage to create conditions for long-term reliable operation of combustion chambers [16].

With the scientific discovery of the laws of thermal radiation of gas volumes of torches and electric arcs, it became possible for the first time to calculate the heat transfer in electric arc and flare furnaces and combustion chambers with high accuracy, to improve the heat transfer and design of electric arc and flare furnaces of industrial enterprises, furnaces and combustion chambers of gas turbine plants of electric stations save million kWh of electricity and million tons of liquid, gaseous, pulverized fuel, reduce pollutant emissions, reduce technogenic load on the environment and in many cities around the world. For a similar scientific discovery by the author of the laws of thermal radiation of gas volumes, for the discovery of the laws of thermal radiation by Wine and Planck of solids, blackbody, Wine in 1911, Planck in 1918 was awarded the Nobel prize in physics [10]. In 1921, Einstein was awarded the Nobel prize in physics for the discovery of the photoelectric effect of radiation, which was of similar importance, and for the development of the theory of the atom and radiation from it.The laws of thermal radiation of gas volumes, as well as the laws of thermal radiation of solids, blackbody, belong to the fundamental laws of physics, its section "Quantum Physics of Thermal Radiation." Bohr was the last scientist to receive the Nobel Prize in Physics for discovering the fundamental laws of physics. The discovery of the fundamental laws of physics is an outstanding event in the life of humanity, which occurs once every 50-80 years. Confirmation of this fact is physics textbooks for schools and universities, which set out a little more than 30 laws discovered by humanity over 3 thousand years, starting from the III century BC. From the law of Archimedes and ending with the last fundamental laws, postulates discovered by Bohr in 1913.

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Electrical Load Evaluation in Igwuruta, Port Harcourt for Improved Distribution

By Okachi Cheta Emmanuel, Engr. Dr. S. L. Braide Ph.D & Prof. D C. Idoniboyeobu
Rivers State University

Abstract- This study of the Electrical Load Evaluation in Igwuruta, Port Harcourt for improved distribution. Electrical load analysis identities potential problems in the distribution network such as energy usage, harmonic inference, unexpected spikes that a visual inspection alone may not identify. The 33KV Old Airport feeders that supply electricity to Igwuruta, Port Harcourt was critically examined in this study. This study used Electrical Transient Analyzer Programme (ETAP) and from the simulation, the existing distribution network had overloading of transformers and low voltage profile. To solve the problems, optimal capacitor bank of 48000KVR were introduced to the entire system network to improve voltage performance and voltage upgrade on the distribution network. The simulation of the improved distribution network shows that the voltage profile has improved with the statutory limit between 95% - 105% and by the penetration of the capacitor bank in the network, the voltage was improved by 18.4% bus 2, bus 3: 18.4% and bus 27: 5.96% and all the transformer were within the normal operating condition.

Keywords: electrical loads, load evaluation, improved performance, igwuruta, port harcourt.

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Keywords: electrical loads, load evaluation, improved performance, igwuruta, port harcourt.

I. Introduction

a) Background of the Study

Load evaluation verifies whether electrical systems are safe and efficient, and that installations show no signs of overload. Load analysis highlights potential problems in the distribution network such as energy usage, harmonic inference or unexpected spikes that a visual inspection alone may not identify. Electric Power System is made up of the Generating System, Transmission Station and Distribution Stations Respectively. Electric power is transmitted by high voltage transmission lines from sending end sub-receiving and end substation. At the receiving end substation, the voltage is been stepped down to a lower value which are 33kv or even 11kv as the case may be for customer usage.(Centrica Business solution,2019).

However, in Nigeria the limiting factors to efficient and reliable power supply apart from low power generation may include poor transmission feeders, poor or inefficient voltage control system due to lack of planning, faulty distribution system on the part of the electrical supplier (PHED). Voltage drop along the line and from the distribution system due to the flow of current and load variations on the consumer end, transmission and distribution network, damage of substations, short circuit or over loading of electrical mains (supply) and tripping of power system. These factors have resulted to unreliable frequent power outages and voltage variations. The demand for electrical power always exceeds the supply in practice especially in a developing country like Nigeria resulting to the interruption of an electrical supply which can be avoided by load-shedding, thereby causing excessive load on the feeders and the generating plant, leading to epithetic power supply system.

Distribution transformers step down the voltage to the level suitable for household and commercial utilities and hence feed several customers through the secondary distribution lines (distributors) at the same voltage. Residential and commercial customers are connected to the secondary distribution line through the service drops. Although electrical power consumers are in need of higher amount of electrical power may be connected directly to the primary distribution line or the sub-transmission level.

The research gives steady state solution of the voltage at all the buses for a particular condition. In the study fast Decoupled Newton – Raphson load flow analysis was used to analyze electrical power supply to Igwuruta Town Port Harcourt because thus method gives the solution of non-linear simultaneous equation in polar form. The total time taken to get the convergent criteria is less, and the number of iterations required to get the convergent criteria are limited as it does not depend on the buses. Igwuruta is located in Ikwerre Local Government Areas of Rivers State, Nigeria. Electricity is being supplied to Igwuruta from the 33kv old Air-Port feeder, which the main source is from Port Harcourt Main Transmission Station 3x60 MVA. However, challenges such as low voltages are experiences in some areas which led to the installation of transformer without planning, resulting to overloading the of the feeder as the city expands and voltage drops are experienced in the transmission due to the distance covered by the line which serves the area. Despite these challenges, there is the insufficient megawatt from the National Grid to the state, electricity exercise control over the socioeconomic development of the state. In regards to this, this academic research will identity the numerous problems on the network and it will becomes paramount to carryout proper load flow analysis with a

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view to achieve efficient supply of power in Igwuruta area in particular and the state at large.

b) Statement of Problems

Admitting the decline nature of the power sector in Nigeria. Especially in the Igwuruta Town, Port Harcourt electricity power distribution network is faced with problem such as over loading of distributed transformers by the customer usage, low voltage experiences, voltage drops due to the distance covered by the transmission line, insufficient power supply from the National Grid, poor maintenance on the transmission and distribution line etc. But a comprehensive and proper load flow analysis using fast decoupled method will be used to achieve and restore steady and efficient supply of power in Igwuruta town and the state at large by solving the problems such as over loading of distributed transformers by the customer usage, low voltage experiences, the installation of transformer without planning etc.

c) Research Aim

The aim of this study is to conduct an analysis of electrical load evaluation in Igwuruta town, Port Harcourt for improved Distribution using fast decoupled method.

d) Objectives of the Research

The objectives of this research are considered as follows:

1. To assess the physical conditions of the electric power distribution network for Igwuruta town, Port Harcourt, in order to obtain relevant information/Data for analysis of voltage problems.
2. To carryout field survey on the distributions lines and equipment and to improve the distribution network using optimal capacitor replacement.
3. To model and to simulate the network using ETAP.
4. To improve the power using capacitor bank.
5. To validate the existing network with the capacitor bank for improved performance.

II. Literature Review

a) Importance of Load Flow Studies

Load flow studies are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic. The increasing presence of distributed alternative energy sources, often in geographically remote locations, complicates flow studies and has triggered a resurgence of interest in the research work. In a three phase as power system active and reactive power flows from the generating station to the load through different networks buses and branches. The flow of active and reactive power is called power flow or load flow. Load flow studies provides a systematic mathematical approach for determination of various bus voltage, there phase angle active and reactive power flows through different branches generators and loads under steady state condition.(Centrica Business solution, 2019). In order to obtain a reliable power system operation under normal balanced three phase steady state conditions, it is required to have the followings:

- Generation supplies the load demand and losses.
- Bus voltage magnitudes remain close to rated values.
- Generator operates within specific real and reactive power limits.
- Transmission lines and transformer are not overloaded.

According to the scholar Ahmed, 2013 pinned that load flow analysis is the solution for the operating condition of a power system. Load flow analysis is used for power system planning, operational planning and operations construct (Brown 2013) also employed in multiple assessments, stability analysis and system optimization.

b) Literature Survey/Techniques of Load Flow Analysis

In the literature, there are a number of efficient and reliable load flow solution techniques, such as Gauss-seidel, Newton – Raphson and fast Decoupled load flow. In 1967, Tinney and Hart developed the classical Newton based power flow solution method. Later work by (Stott and Alsac 1974), made the fast decoupled Newton method and the algorithm remains unchanged for different applications.

Even though this method worked well for transmission systems, but its convergence performance is poor for most distribution systems due to the high R/X ratio which deteriorate the diagonal dominance of the Jacobian matrix for this reason, various other types of methods consist of backward/forward sweeps on a ladder system. The formulation of the algorithm for those were different from the Newton's power flow method, which made those methods hard to be extended to other applications in which the Newton method seemed more appropriate.

(Tripathy et al 2004), presented a Newton like method for solving ill-conditioned power systems. Their method showed voltage convergence but could not be efficiently used for optimal power flow calculations.

c) Load Flow Analysis Using PSAT Soft for Test System Simulation

Power system analysis toolbox (PSAT) is an open source MATLAB and Graphical user interface (GUI)/octave-base software package for analysis and design of small to medium size power systems. The tool box is provided with a GUI and a Simulink editor for editing or designing a single line diagram of any power system networks. PSAT can perform power flow, continuation power flow (CPF) optimal power flow (off), small signal stability analysis.

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(Abungu and Kipkirui 2009) state that decoupled load flow method using MATLAB 7.6 (r2013b) to develop an efficient and reliable program and PSAT as a validating tool. The procedural methods calculated and analyzed a well-conditioned load study with minimal losses on the buses; branches and the minimal number of iteration required for convergence were noted. IEEE 14 bus system was used as the test system in the study.

d) Radial Distribution Network (RDN) of Load flow Algorithm

Li et al, 2014, in their view stated that algorithm have been developed to tackle the load flow power problem. They formed node-branch incidence matrix that depict the relationship between the bus injection powers and branch powers, then an estimated voltage drop and angle formulas were used along with the incidence matric to solving the load flow power. Li et al, 2016, modifies the previously mentioned algorithm to counter the fundamental error problem resulting in high precision results for both weakly meshed/meshed networks.

Jabr.et al, 2012 state that RDN used the same convex formulation to obtain the optimal configuration for minimizes its real power waste. The modeling of the load power of Radial Distribution Network as Quadratically constrained convex optimization problem (QCCOP) convexification of the continuous decision variables of the optimization problem guaranteed the global optimality of the acquired solution. Moreover, the solution was obtained using interior – point method algorithm through CPLEX optimization software after passing the parameters from MATLAB. The proposed algorithm has shown high computational efficiency, which paves the way for real time optimization problems regarding the operation of Radial Distribution Network.

e) Determination of Bus Voltages, Power Losses and Load Flow in the Northern Nigeria 33kv Transmission Sub-Grid

According to the scholar (Izuegbunamet *al,* 2011) researchers, the Nigerian Electric Power Transmission network operated by Transmission Company of Nigeria (TCN) operates at a very high pressure of 330kv while its lower transmission pressure is 132kv.

The planning, design and operation of power systems requires load flow computations to analyse the steady state performance of the power system under various operating conditions and to study the effects of changes in the configuration of equipment. In their view, the very low bus voltage and poor power magnitude obtained from this study without voltage compensation revealed the reality of the perpetual poor power supply to the North West part of Nigeria. This project which seems to be a prototype of the entire network can be solved using load flow studies which involves the use of computer programs designed specifically for this purpose.

f) A Promising Method for Uncertain Load Flow Studies

According to (Su, 2005) and (Chen et al., 2008), probabilistic methods are tools for planning studies. Though there are different short comings as a result of non-normal probability distribution and the statistical dependence of the input data as well as the problems associated with identifying probability distribution for some input data accurately. In their view (Zian Wang et al., 2009) suggested a method for solving the load flow using interval arithmetic taking the uncertainty at the nodal values. Their articles also stated that the required solution to the non-linear equations can be obtained by interval Newton operator, Krawczyk operator or Hansen-Sengupta operator.

(Barboza et al., 2004) also gave the methodology for solving the uncertain power flow problems and a mathematical representation was applied to the load flow analysis by considering Krawczyk's method to solve the nonlinear equations. It is mentioned that the existing problem of excessive conservation in solving the interval linear equation could be overcome by Krawczyk's method. In this method the linearized power flow equations should be preconditioned by an M-matrix in order to guarantee convergence. The scholar also said that (Wang et al., 2005) the set of non-linear equations were solved by Gauss-Seidel method. Preconditioning is required but if interval input is too cumbersome, convergence is not guaranteed, that is why this method cannot give an exact solution. (Yu et al., 2009) Fast Decoupled power flow using interval arithmetic has been used to obtain the solution to the power flow with uncertainty.

This algorithm converges very fast and considers retaining the midpoint of the load flow studies. This is a specific feature that ensures the convergence in accordance with the punctual load flow studies. The algorithm is effective and avoids unnecessary computation effort like preconditioning.

g) Performance of Newton-Raphson Technique in Load Flow Analysis Using Matlab

In the view of (Klingman and Hinimelbau 2008) the slack bus set the angle difference between two voltages, the angle of the slack bus is not important, although it sets the reference angles of all the other bus voltages.The main objective for the calculation of power flow study is to find the magnitude of voltage */V/* and the phase angle (δ) of the power losses at each bus section, the real and reactive power flowing in each line of the power system.It was observed that Newton-Raphson's approach has made the calculations easier because the number of buses increased while the number of iterations decreased.

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h) Electrical Load Flow Studies for Efficient Power Supply in Bayelsa State Using NewtonRaphson Technique

According to the scholars, (Idoniboyeobu and Nemine 2017), the load flow analysis is the backbone of power system analysis and design. It is the necessary for planning, operation, economic scheduling and exchange of power between utilities. The work is to determine the voltage magnitude, phase angle at the buses, real and reactive power of the transmission lines, to help the system engineering during operation and future expansion of the network.

i) Power Flow Analysis of Abule-Egba 33KV Distribution Grid System with Real Network Simulations

Load flows are required to analyze the steady state performance of the power system during planning, design and operation of electrical power systems. These load flow studies can be done using computer programs designed specifically for this purpose.According to (Abdulkareem, *et al,* 2014) model and simulation are methods used to overcome the computational problems of power flow solution using load flow iterative technique such as Newton-Raphson and Gauss-Seidel. It needs a model based on real condition. The making of this model must be based on real and valid data so that the model can represent real condition.

j) Analysis of the Load Flow Problem in Power System Planning Studies

In an electrical Power system, power flows from generating station to the load through different branches of the network. According to (Afolabi, *et al.,* 2015) states that the flow of active and reactive power is known as load flow or power flow. Power flow analysis is an important tool used by mostly power engineers for planning and determining the steady state operations of a power system. Also (Mageshvaran*et al.,* 2008) said that load flow studies is to determine the various bus voltages/phase angles, active and reactive power flow through different branches, generators, transformers, settings and load under steady state conditions. The power system is modeled by an electric circuit which consist of generation, transmission and distribution networks. Elgerd, 2012 and Kothari and Nagreth, 2007, said that the main information obtained from the load flow or power flow analysis consist of phase angles of load flow bus voltage and magnitude, reactive powers and voltage phase angles of generator buses, real and reactive power flow on transmission lines and power of the reference bus; other variables also being specified.

The load flow problem equations are non-linear and as such it requires iterative techniques such as Newton- Raphson, fast decoupled and Gauss- seidel etc. in solving it. According to Aroop et al., 2015 and Milano, 2009, the development of these methods mainlyled to the basic requirement of load flow calculation such as convergence properties, memory requirement, computing efficiency, convenience and flexibility of the implementation. However, it was concluded that in planning of a power system, Gauss-Seidel method can be used especially for a small system with less computational complexity due to the good computational characteristics it exhibited. The effective and most reliable amongst the three load flow methods is the fast decoupled method because it converges fast and is more accurate.

k) Application of Fast Decoupled Load Flow Method for Distribution Systems with High R/X Ratio Lines

(Ochi, *et al,* 2013) in their view proposed 'a fast decoupled load flow calculation method for distribution systems with high R/X ratio. The method was based on a coordinate transformation in Y-matrix for Jacobian matrix in the load flow method. But comparing it with the Newton- Raphson's method, it was found that a short computational time was realized although its convergence characteristics worsen. In a bid to solve the problem, a coordinate transformation in Y-matrix of the fast decoupled method for better convergence was employed (Ochi *et al.,* 2013).

l) Impact of Distributed Generation on the Quality of Power Supply in Nigeria; Port Harcourt Network Case Study

According to Ajabuego et al, (2017) in their work considered the impact of Distributed, Generation (DG) on the quality of electricity supply in Port Harcourt network. They gave account on the impact of both the present and the future load demand. In achieving this, power flow analysis and continuous power flow (CPF) optimization method was used to achieve the simulation. The simulation was done using MATLAB 7.9 Power System Analysis Toolbox (PSAT) Simulink environment to analyse the network. The result shows that the dispersion level of DG's among the buses increases, there was a very remarkable improvement in the voltage profile, real and reactive power and load ability of the network.

m) Load Flow Analysis of Port Harcourt Electricity Network by Fast Decoupled and Newton-Raphson Techniques

Ibeni (2017) in his work on Load Flow Analysis of Port Harcourt Electricity Network by using Fast Decoupled and Newton-Raphson methods showed that the power dispatched from the national grid network to the transmission substations were inadequate, and as such each injection substation had percentage of loading of the power available.

From the simulation results, it showed that sufficient power is required from the grid to the various injection substations via Port Harcourt Town (Z4) control transmission substation because the lack of adequate power supply from the grid to the transmission

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substations down to the distribution injection substations will result to power sharing and to address this anomaly it was recommended that: The 33KV distribution network be expanded by installing more transformers, protective systems, and capacitors banks as realized from the affected buses so as to keep the desirable voltage limits; the injection substations for the network under consideration should be made to operate at least 80 per cent of power supply to the secondary distribution network; the reactive power demanded locally at the bus injection substation can be used to minimize the line power loss associated with the network; there should be a periodic load flow analysis carried out by the Electricity Distribution Company to ascertain the status of the network without over stressing it.

n) Comparison between Load Flow Analysis Methods in Power System using MATLAB

According to Kriti (2014), in his work on the 'Comparison between Lord Flow Analysis, Methods in Power System Using MATLAB'. He stated that the analysis, designing, and comparison between different load flow system techniques such as Newton-Raphson, Gauss-Seidel etc. in power system using MATLAB was done successfully and the desired results were obtained. In Gauss-Seidel method, it was found that the rate of convergence was slow, it can be easily programmed and the number of iterations increases directly with the number of buses in the system whereas in the Newton-Raphson method, the convergence was very fast and the number of iterations is independent of the size of the system; the solution is high as obtained. It was stated as observed that in Newton Raphson method, convergence is not sensitive to the choice of slack bus. In conclusion it was practical that only the Newton-Raphson and the Fast decoupled load flow methods were the most popular methods. The fast decoupled load flow is definitely superior to the Newton-Raphson method because of its speed and storage capability (Kriti, 2014).

o) Load Flow Analysis Using ETAP Software for Network Simulation

Jayaprakash, et al, (2016) in their work on load flow analysis to investigate the performance of electrical system during normal and abnormal operating conditions, provided information needed to: minimize MW and MVar losses; optimize circuit usage; develop practical voltage profiles; develop equipment specification guidelines and identifies transformer tap settings. ETAP is a computer based software that simulates real time steady-state power system operations, enabling the computation of system bus voltage profiles, real and reactive power flow and line losses etc. (Jayaprakash, *et al.,* 2016).

ETAP offers the most accurate load flow analysis tools on the market, create and evaluate electrical system designs effectively. ETAP calculate voltage drop and power losses and efficiently build and evaluate system models using the advanced power flow analysis. ETAP system models efficiently and effectively function such as automatic device evaluation, alarms for critical and marginal units, a powerful results report comparison analyzer and intelligent, user friendly graphics make it the most reliable load flow analysis software (Ahmed 2017).

ETAP load flow software provides results, power factors for each branch, directional currents flows, and voltage drop calculations throughout each electrical system model. ETAP allows for multiple grid connections, detailed generator modeling, solar turbines and induction generators for radial and mesh networks. ETAP interactively utilizes multiple calculation methods in order to calculate the best possible results.

p) Summary of Review Literature

The problem of power losses, voltage breakdown, voltage instability etc. are major concern particularly to the distribution network at large. The rate of power voltages in the distribution network is becoming an uncontrollable situation. The major contribution of this work is that, it has identified the associated problems on the on the 33KV distribution network as a result of overload which were captured via simulation of the existing network for the purpose of overload. Based on the system overload analysis were made using optimal capacitor replacement method by optimal of sizing of capacitor bank with the capacitor of 48000KVAR were used to compensate the entire system network to improve the condition of the system (33kv distribution network). De-coupled correction method should be used when installing capacitor bank in a network.

III. Material and Method

a) Materials

The major source of data for this research work was gotten from Port Harcourt Electricity Distribution Company (PHEDC). Gathering/sourcing for an important task, various books, thesis, publications and theories have been referred to. The data gathered are: installed capacity of transmission substation, installed capacity of injection substation, examined feeders, total number and power rating of distribution transformers and single line diagram of power distribution network for Igwuruta Town, Port Harcourt (source, PHEDC).

Method: Fast decoupled method was used for computing bus voltages and the simulation on each of the feeders was done using ETAP version 16.00 in order to improve the existing system condition performance.

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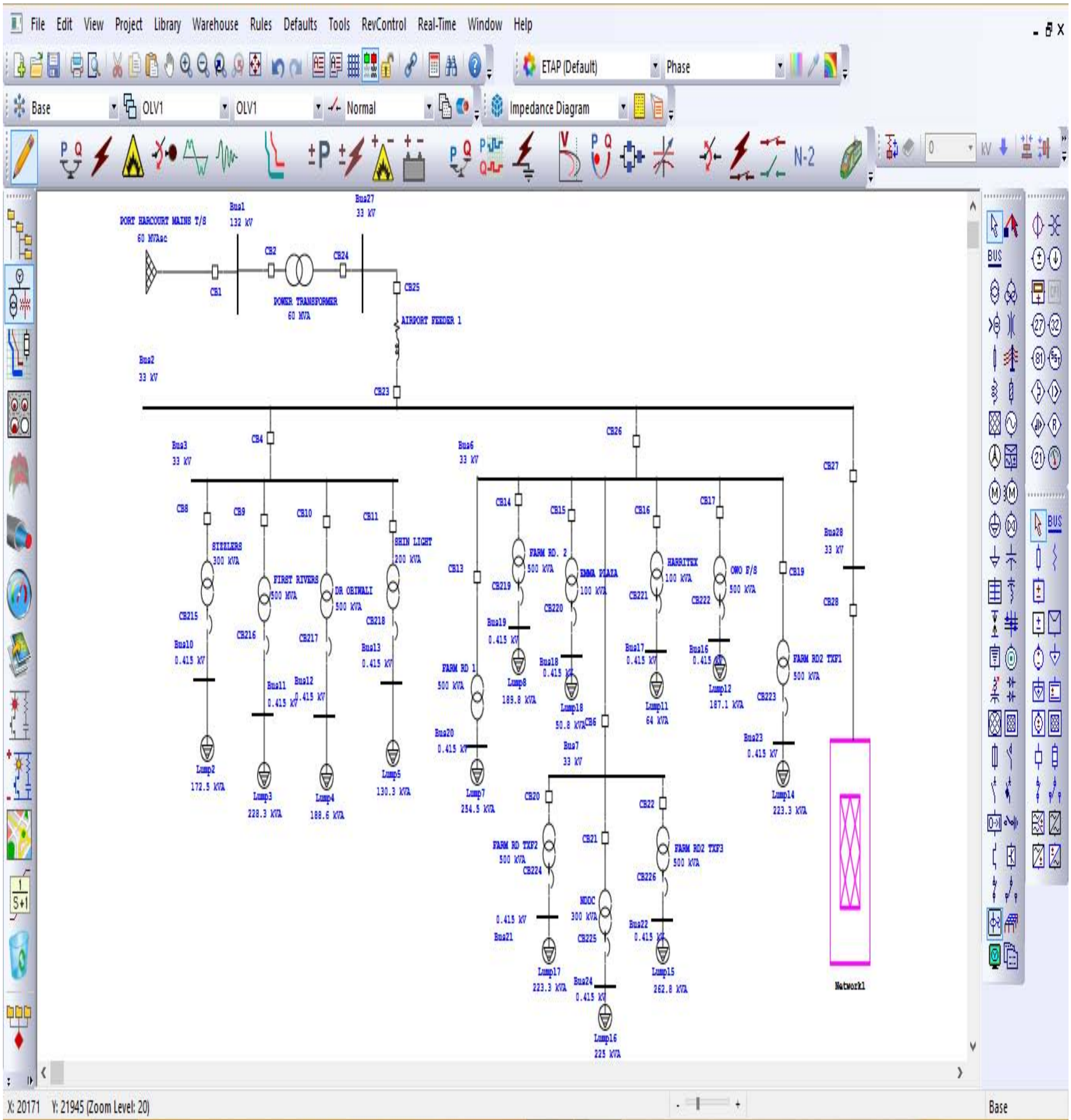

Plate 1: Systematic diagram of 33KV Old Airport Feeder from Port Harcourt main transmission station (Existing case study not simulated)

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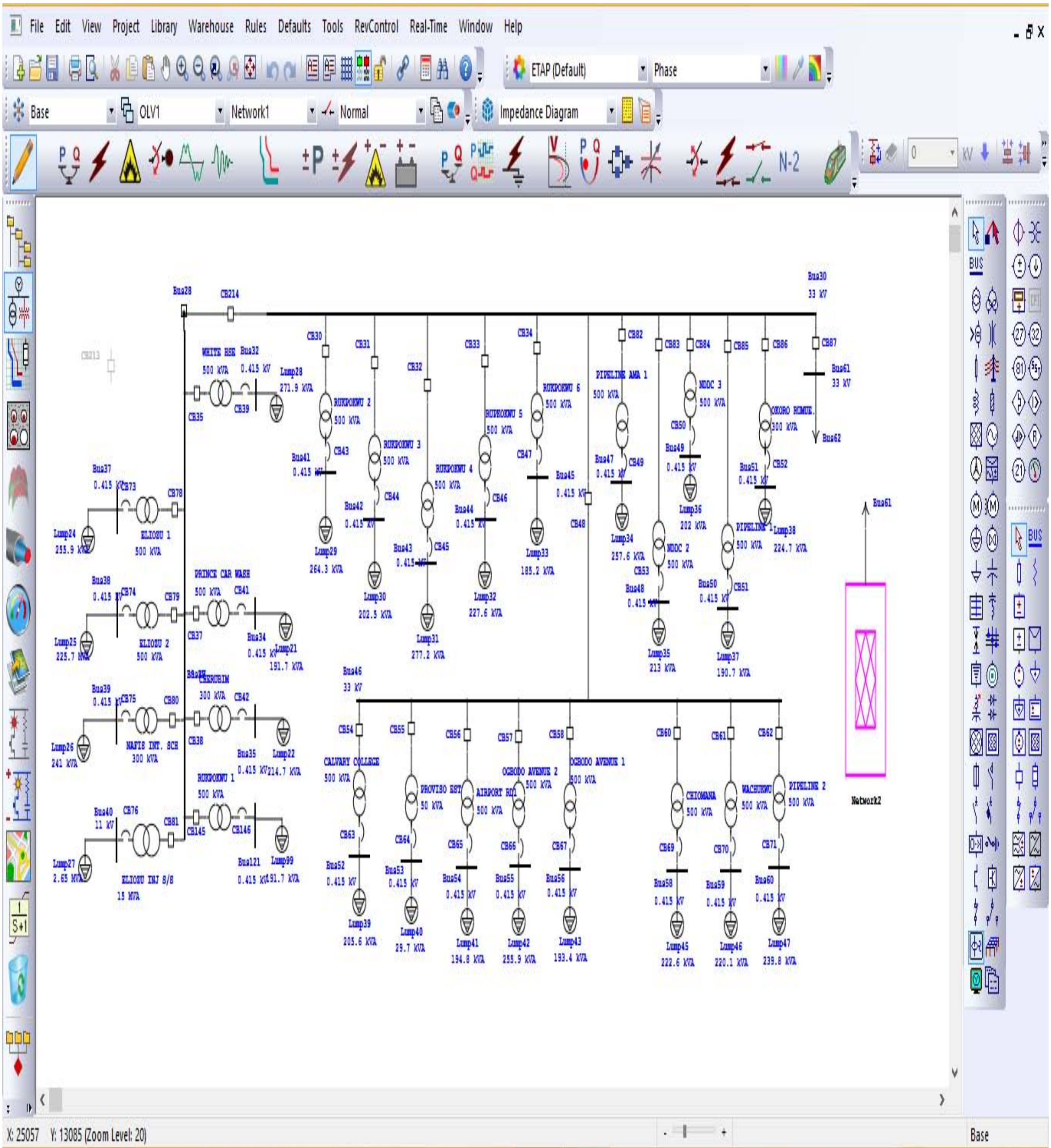

Plate 2: Existing line diagram of Old Airport Feeder (case study simulated)

Table 3.1: Some of the Transformers in Igwuruta Town, their Locations and Readings

S/N	Transformers Locations	Transformers Rating (KVA)	Red Phase (A)	Yellow Phase (A)	Blue Phase (A)	Neutral
1.	Sizzlers	300	249	218	222	31
2.	First River	500	304	298	310	41
3.	Dr. Obi Wali	500	244	253	261	29
4.	Shining Light Fast	200	162	171	194	17

Source: Port Harcourt Electricity Distribution Company (PHEDC).

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b) *Calculation of the Transformers load, Percentage Loading, Active Power, Reactive Power and Complex Power in Igwuruta Town Distribution Network.*

1. Sizzlers Transformer (300KVA)

$$\text{Current I} = \frac{I_R + I_Y + I_B + I_N}{3}$$

$$= \frac{249 + 218 + 222 + 31}{3}$$

$$= \frac{720}{3}$$

$$= 240\text{A}$$

Load SVA on the transformer

$$\text{SVA} = \sqrt{3}\ V\ x\ I$$

$$= \sqrt{3}\ x\ 0.415KV\ x\ 240A$$

$$= 1.7320 \text{ x } 0.415\text{kv x } 240\text{A}$$

$$= 172.51\text{KVA}$$

But, % loading $= \dfrac{SVA}{SMAX}\ x\ 100$

$$= \frac{172.51KVA}{300}\ x\ 100$$

% loading = 58%

Active power, $P = \sqrt{3}\ V\,I\cos = 172.51KVA$

$\cos\phi = 0.8$

∴ Active Power = 172.51 x 0.8

= 138.01KVA

Reactive Power, $Q = \sqrt{3}\ VI\sin\phi$

and, $\sqrt{3}\ VI = 172.51$

$\sin\phi = 0.6$

∴ Reactive power = 172.51 x 0.6

Q = 103.51KVA

Complex power, S = P + jQ

S = 138.01 + j103.51

$$\text{Lump load} = \frac{SMAX\ \ X\ \ \%\ \ loading}{100}$$

$$= \frac{300\ x\ 58}{100} = 174KVA$$

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c) *Presentation of calculated values of the distribution transformers in Igwuruta Town, with their locations capacity, load current, lump load, active power and reactive power.*

Table 3.2: Transformers Locations, Percentage Loading, active power, reactive power in Igwuruta Town Distribution Network

S/N	Transformers Locations	Transformers (KVA)	Load Current (A)	Lump Load (KVA)	Reactive Power (KVA_R)	Active Power (KVA)
1.	Sizzlers	300	240	174	103.51	172.51
2.	First River	500	317.67	230	137.00	182.66
3.	Dr. Obi Wali	500	262.33	190	113.14	150.85
4.	Shining Light Fast	200	181.33	130	78.20	104.27

d) *Determination of over Loaded Transformer*

The determination of the overload transformer can be done using apparent power performance index to find the percentage loading of the transformers on rating for design purpose, transformer with loadings in excess of this figures are considered overloaded.

$$\% \text{ loading} = \left(\frac{SMVA}{SMAX}\right) x\ 100$$

Where;

S_{max} is the MVA rating of the transformer

S_{MVA} is the operating MVA from power flow calculation

NT is the number of transformers.

Distribution line parameters

Resistance of line per kilometer

$$R_o = \frac{1000\ x\ \ell}{A}\ \Omega/km \tag{3.1}$$

Where;

ℓ = Resistivity of Aluminum ACSR = $3.82 \times 10^{-7}\Omega$/m

A = area of conductor = $150mm^2$

$$Y_{21} = Y_{12} = -Y_{12} \tag{3.2}$$

$$Y_{31} = Y_{13} = -Y_{13} \tag{3.3}$$

$$Y_{41} = Y_{14} = -Y_{14} \tag{3.4}$$

Bus Admittance Matrix

$$Y_{bus} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & O & O \\ Y_{31} & O & Y_{33} & O \\ Y_{41} & O & O & Y_{44} \end{bmatrix} \tag{3.5}$$

From Ohm's law the current entering only of the buses is given by;

$$[I] = [Y_{Bus}\ [V] \tag{3.6}$$

$$\begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} & Y_{13} & Y_{14} \\ Y_{21} & Y_{22} & O & O \\ Y_{31} & O & Y_{33} & O \\ Y_{41} & O & O & Y_{44} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ V_3 \\ V_4 \end{bmatrix} \tag{3.7}$$

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The current entering bus I_1 is given by;

$$I_1 = Y_{11} V_1 + Y_{12} V_2 + Y_{13} V_3 + Y_{14} V_4 \quad (3.8)$$

The current entering bus I_2 is given by

$$I_3 = Y_{21} V_1 + Y_{22} V_2 \quad (3.9)$$

The current entering bus I_3 is given by;

$$I_3 = Y_{31} V_1 + Y_{33} V_3 \quad (3.10)$$

The current entering bus I_4 is given by;

$$I_4 = Y_{41} V_1 + Y_{44} V_4 \quad (3.11)$$

Complex power injected into bus I is given by;

$$S^* = P_1 + jQ = V_1 \ I_1^* \quad (3.12)$$

$$S^* = P_1 - jQ_1 = V_1^* \ I_1 \quad (3.13)$$

Therefore, from equation (3.13)

$$I_1 = \frac{P_1 - jQ_1}{V_1^*} \quad (3.14)$$

Similarly, I_2, I_3 and I_4 injected into bus 2, 3 and 4 is given as;

$$I_2 = \frac{P_2 - jQ_2}{V_2^*} \quad (3.15)$$

$$I_3 = \frac{P_3 - jQ_3}{V_3^*} \quad (3.16)$$

$$I_4 = \frac{P_4 - jQ_4}{V_4^*} \quad (3.17)$$

Complex power injected into the ith bus is given as;

$$S_1 = P_1 + jQ_i$$

$$= V_1 \ I_1^*$$

$$S_1^* = P_1 + jQ_1$$

$$= V_1^* \ I_1$$

$$\therefore \ P_i - jQ_i = V^* \ I_i \quad (3.18)$$

But current entering the ith bus of an η bus system is given as;

$$I_1 = y_n v_1 + y_{12} v_2 + y_{13} v_3 + ... \ y_n v_n$$

$$I_1 = \sum_{k=1}^{\eta} Y_{1k} \ V_k \quad (3.19)$$

Substitute I_1 from equation (3.19) into equation (3.18)

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$$P_1 - jQ_1 = V^* \left(\sum_{k=1}^{\eta} Y_{ik} \; V_k \right) \tag{3.20}$$

Let $$V^* = V_1\ (-\delta),\ V_k = V_k\ (\delta_k)\ \ and\ Y_{1k} = Y_{1k}\ (\theta_{ik}) \tag{3.21}$$

Substitute equation (3.21) into equation (3.20).

$$P_1 - jQ_1 = V_1 \sum_{k=1}^{\eta} Y_{1k}\ V_k\ (\delta_k + \theta_{ik} - \delta_1) \tag{3.22}$$

$$P_1 - jQ_1 = \sum_{k=1}^{\eta} |Y_{1k}|\ |V_1|\ |V_k| \left[\cos(\theta_{1k} + \delta_k - \delta_1) + j \sin(\theta_{ik} + \delta_k - \delta_1)\right]$$

Separating the real and imaginary parts

Real power, $$P_1 = \sum_{k=1}^{\eta} |Y_{1k}\ V_1\ V_k| \cos(\theta_{ik} + \delta_k - \delta_i) \tag{3.23}$$

Reactive power, $$Q_1 = \sum_{k=1}^{\eta} |Y_{ik}\ V_1\ V_k| \sin(\theta_{ik} + \delta_k - \delta_i) \tag{3.24}$$

V_1 = Bus voltage of bus i

P_1 = Active power injected into ith bus

Q_1 = reactive power injected into ith bus

Y_{ik} = Off diagonal element of the Y-buss matrix

Y_{ii} = Diagonal element of the Y-bus matrix

V_i = Voltage at bus η

Fast Decoupled Method

This method is the modification of newton – Raphson, which takes the advantage of the weak, coupling between P - δandQ - /V/ due to the high X:R ratios. The Jacobian matric are obtained after partial derivatives of equations (3.23) and (3.24) are expressed which gives linearized relationship between angle. The equation can be written in matrix form as:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_3 \\ J_2 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{3.25}$$

Equation (3.25) is reduced to half by ignoring the element of J_2 and J_3, equation (3.25) is simplified as;

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & O \\ O & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{3.26}$$

Expanding equation (3.26) give two separate matrixes,

$$\Delta P\ J_1\ \Delta\delta \left[\frac{\partial P}{\partial \delta}\right] \Delta\delta \tag{3.27}$$

$$\Delta Q\ J_4\ \Delta|v| \left[\frac{\partial P}{\partial |v|}\right] \Delta|v| \tag{3.28}$$

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$$\frac{\Delta P}{V_1} = -B^I \Delta\delta \tag{3.29}$$

$$\frac{\Delta Q}{V_1} = -B^{II} \Delta|v| \tag{3.30}$$

B^1 and B^{11} are the imaginary parts of the bus admittance, it is better to ignore all shunt connected elements, as to make the formation of J_1 and J_4 simple. This allow for only one single matrix than performing repeated inversion. The successive and voltage magnitude and phase angle changes are;

$$\Delta\delta = -\left[B^1\right]^{-1} \frac{\Delta P}{|V|} \tag{3.31}$$

$$\Delta|V| = -\left[B^{11}\right]^{-1} \frac{\Delta Q}{|V|} \tag{3.32}$$

e) *Software Selection*

ETAP is a fully graphical enterprise package that runs on Microsoft ® windows ® 2003, 2008, 2012, XP, vista, 7 and 8 operating systems. ETAP is the most comprehensive analysis tool for the decision and testing of power systems available. Using its standard offline simulation modules. ETAP can utilize real-time operating data for advanced monitoring, real – time simulation, optimization, energy management systems, and high – speed intelligent load shedding.

ETAP enables engineers to handle the diverse discipline of power systems for a broad spectrum of industries in one integrated package with multiple interface views such as AC and DC networks, cable raceways, ground grid, GIS, panels, are flash, protective device coordination/selectively and AC and DC control system diagram.

Design Calculation of Capacitor Bank

The analysis and the calculation of the size of capacitor bank to used is a major tool for power improvement, therefore capacitor bank will assist to regulate, control and compensate for power loss, reactive power losses and voltage profile inadequacy. The location of the capacitor bank must be taken into consideration when depends of the location of the inductive loads and their requested reactive power.

- Centralized correction: One capacitor bank installed near the main in coming switchboard.
- Decoupled correction: Capacitor banks are installed hear distribution switchboards that supply voltage to the main consumer responsible for the low power factor.
- Local correction: Capacitor banks are installed near individual consumers.

Presentation of collected data from the system network (Igwuruta network).

The following data were collected; Bus 2, Bus 3, Bus 4 from the simulated result, the total power in KW

BUS 2 Capacitor Bank formular sizing for improve performance

$$\text{CKvar} = \text{kw}(\tan\phi_1 - \tan\phi_2) \tag{3.33}$$

Where,

Capacitor Bank in KVAr

Present power factor $(Pf)_1 = \tan\phi_1$

Desired power factor $(Pf)_2 = \tan\phi_2$

System frequency (f) = $50H_2$

From equation above, CKvar = kw ($\tan\phi_1 - \tan\phi_2$)

Total Active power KW

Present power factor $(Pf)_1$ =0.8

Desired power factor $(Pf)_2$ = 0.9

System frequency (f) = $50H_2$

From equation (3.33) CKvar = kw ($\tan\phi_1 - \tan\phi_2$)

$\cos\phi_1 = 0.8$

$\phi_1 = \cos^{-1}(0.8) = 36.87^o$

$\phi_2 = \cos^{-1}(0.9) = 25.84^o$

CKVar = 16959.410 (tan 36.87 – tan 25.84)

= 16959.410 (0.7500 – 0.4842)

= 16959.410 (0.2658)

= 4507.77KVar

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Table 3.3: Presentation of Calculated values of capacitor bank in each of the buses

Bus ID	Active power (KW)	Capacitor Bank (KVA$_r$)	No. of capacitor bank/size (KVA$_r$)	The sizes of capacitor bank per bus (KVA$_r$)
Bus 2	16959.410	4507.77	400 x 12	4800
Bus 3	415.049	110.32	200 x 1	200

After the penetration of the capacitor bank in the Igwuruta network, the percentage of voltage magnitude on Buses was improved. Bus 2: = 18.4%, Bus 3: = 18.4%, Bus 6: = 18.4%, Bus 7: = 18.4%, Bus 27: =5.96%.

IV. Results and Discussion

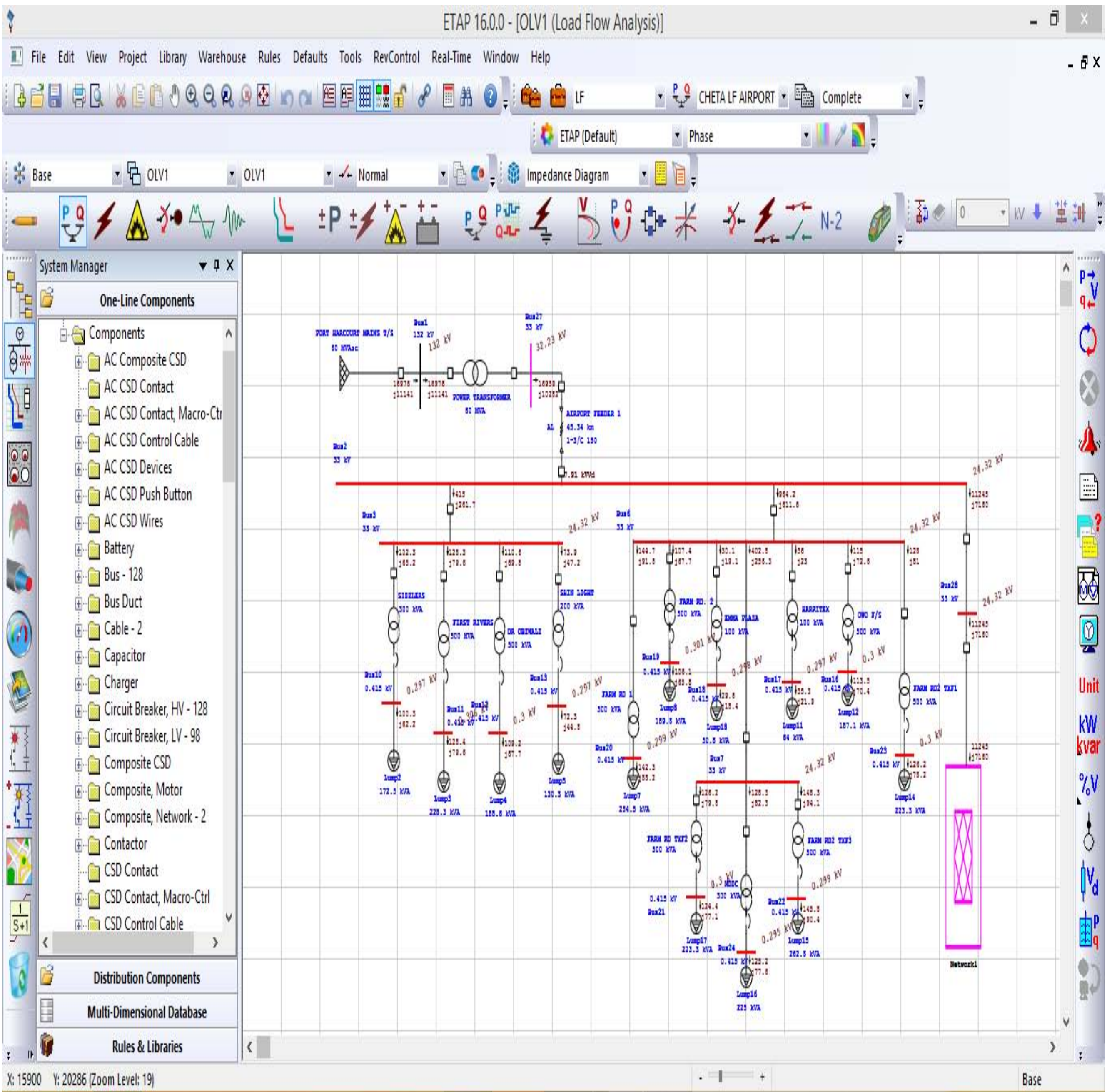

Plate 3: Improved systematic line diagram of 33kv Old Airport Feeder (using capacitor bank)

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a) *Presentation of result and discussion base on analytical methods are presented in tabular and graphical form are shown below*

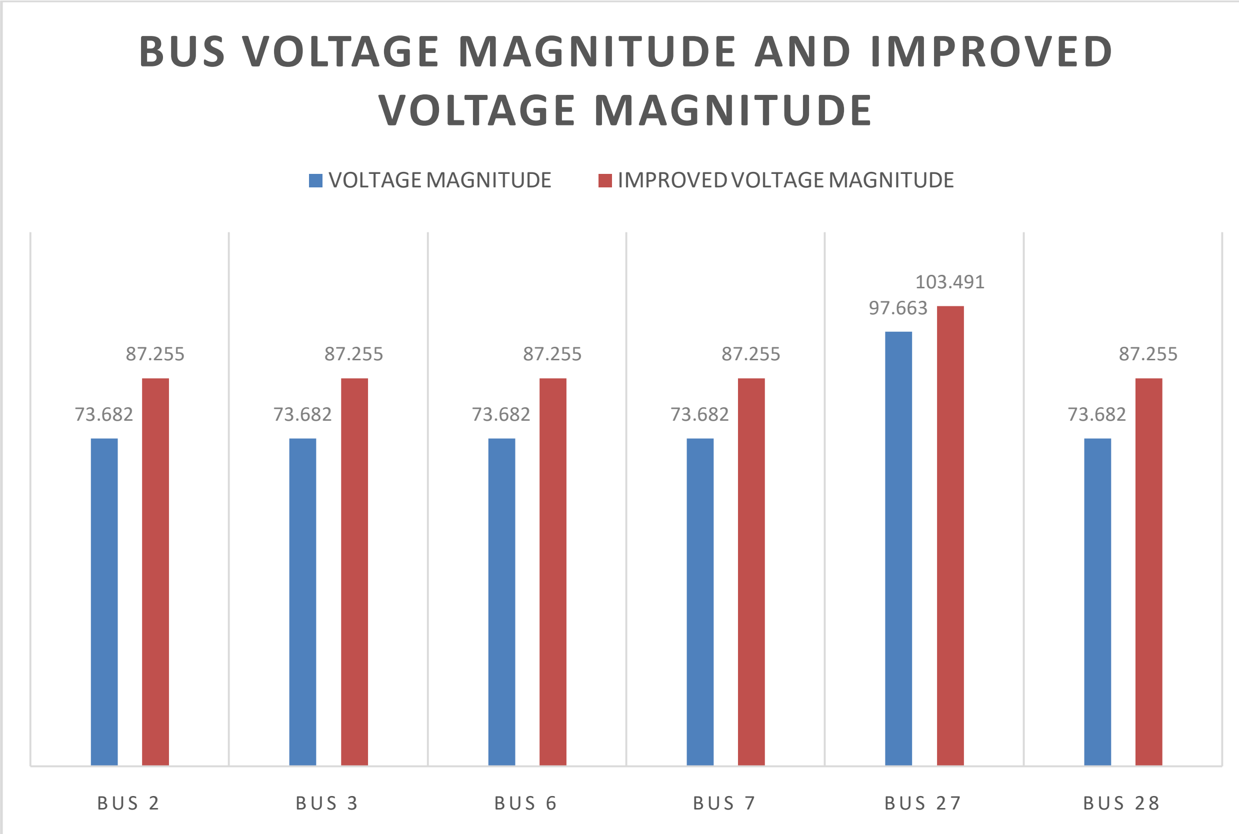

Plate 4: Plot of Bus Voltage Magnitude [Existing] and Bus Voltage Magnitude [Improved] Vs Bus Voltage Number

Table 4.1: Bus Voltage Magnitude (Existing) and Bus Voltage Magnitude (Improved) against Bus voltage Number

Bus 2	73.682	87.255
Bus 3	73.682	87.255
Bus 6	73.682	87.255
Bus 7	73.682	87.255
Bus 27	97.663	103.491
Bus 28	73.682	87.255

The above table shows the existing bus voltage magnitude and bus voltage magnitude (improved) against the bus number.

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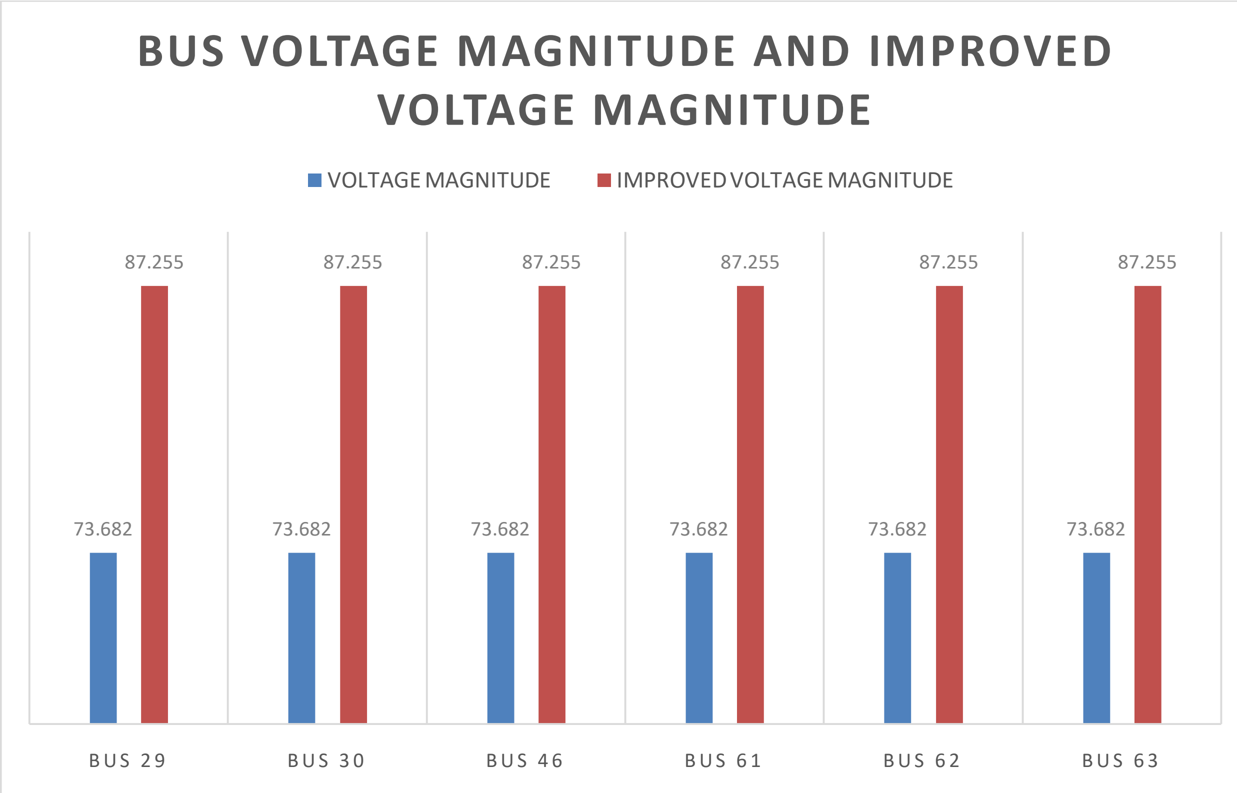

Plate 5: Plot of Bus Voltage Magnitude [Existing] and Bus Voltage Magnitude [Improved] Vs Bus Voltage Number

Table 4.2: Bus Voltage Magnitude (Existing) and Bus Voltage Magnitude (Improved) against Bus voltage Number

Bus 29	73.682	87.255
Bus 30	73.682	87.255
Bus 46	73.682	87.255
Bus 61	73.682	87.255
Bus 62	73.682	87.255
Bus 63	73.682	87.255

The above table shows the existing bus voltage magnitude and bus voltage magnitude (improved) against the bus number.

b) Discussion of Result

After simulation on the system it shows that some buses are under existing operating condition, such buses are Bus 2, 3, 6, 7, 27, 28, 29, 30, 46, 61, 62, 63, 64, 65, 66, 68 and 101 are not within the acceptable normal voltage of ± 5% of the dealed voltage as a result of overloading, poor transmission feeders, power or inefficient voltage control system due to lack of planning, faulty distribution system on the part of the electrical supplier (PHED) and as such case it creates voltage instability in the system network. The examination of the 33kv distribution network revealed the effect of poor power quality on the expected voltage of the distributed line in the study case Igwuruta, especially, the case of overload on the existing transformers and cables.

However, to improve the distribution network capacitor bank was used to reduces loss (I^2 R loss) associated with transmission and distribution of the current to the consumer's loads, improve voltage regulation, quality of power, power factor, voltage profile of the system. Therefore, capacitor bank will assist to regulate control and compensate for power loss, reactive power losses and voltage profile inadequacy.

To improve the efficiency of the system two (2) capacitor bank rated at 16000KVAR each were optimally sized and allocated to support the voltage at the critical buses (bus 62 and 63) in order to enhanced power system operation by minimizing losses and improve the profile of the voltage. It will also helped to enhanced power flow on the critical part of the system network. Therefore, the problem of voltage fluctuation and harmonies can be overcome by the penetration of the FACTS-controller. A flexible AC transmission system consisting of power electronic devices along with power system devices to enhance the controllability and stability of the distribution system and increase the power transfer capabilities. After the penetration of the capacitor bank in the Igwuruta network, the percentage of voltage magnitude on Buses was improved. Bus 2: = 18.4%, Bus 3: = 18.4%, Bus 6: = 18.4%, Bus 7: = 18.4%, Bus 27: =5.96%.

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V. Conclusion and Recommendations

a) Conclusion

After careful examination of the study case (Igwuruta 33kv distribution network), the research work showed that the existing state of the electrical power network of Iguruta 33kv distribution network taking its supply of power from 33kv Airport feeder that was transmitted from Port Harcourt main in Trans-Amadi. The research was modeled in Electrical Transient Analyzer Programme (ETAP 16.00 version) with the application of power flow equation, voltage equation sizing of capacitor equation etc, for reason of ascertaining the system (network) conditions in the areas of voltage stability (whether there is a strong mismatch between nominal declared voltage with regards to IEE regulation and the existing operating voltage) in order into enhance system performance.

Importantly, the study engaged optimal capacitor placement of improving system overload by determining the optimal size of capacitor bank required to improve the specific bus overload problem of the system (network in a view to enhance power quality, voltage profile and power factor. The fixing of the sized capacitor bank at the affected buses improved the voltage profile and performance on the network. After the penetration of the capacitor bank in the Igwuruta network, the percentage of voltage magnitude on Buses was improved. Bus 2: = 18.4%, Bus 3: = 18.4%, Bus 6: = 18.4%, Bus 7: = 18.4%, Bus 27: =5.96%.

Sequel to the findings, it is deduced that power flow studies are key for future planning of power system expansion as well as determining the best and reliable operating condition of the existing system.

b) Recommendations

Based on the analysis and findings, the following recommendations are pointed out to ensure optimal performance and reliability of the 33kv distribution.

- Replacement of undersized cables in the network.
- Fixing capacitor bank compensator where necessary in order to reduce voltage instability problems, electricity cost due to excessive losses.
- Periodic load flow analysis should be carried out by the Port Harcourt Electricity Distribution Company (PHEDC) to know the status of the network without over stressing the system (ETAP 16.00 software).
- Additional 500KVA transformer should be added in the network especially to where the system experiences critical overload.

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Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

  - Single section and succinct.
  - An outline of the job done is always written in past tense.
  - Concentrate on shortening results—limit background information to a verdict or two.
  - Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

  - Explain the value (significance) of the study.
  - Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
  - Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
  - Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

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Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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