**TELKOMNIKA**, Vol.10, No.1, March 2012, pp. 43~54
ISSN: 1693-6930
accredited by DGHE (DIKTI), Decree No: 51/Dikti/Kep/2010

# Comparasion between Oil Immersed and SF6 Gas Power Transformers Ratings

**Osama Elsayed Gouda*, Mohamed Dessoky Ali, Ali-Hassan**
Department of Electrical Power and Machines, Faculty of Engineering, Cairo University, Egypt
Electricity Transmission Company, Faculty of Engineering, El-Azhar University, Qena
e-mail: d_gouda@yahoo.com , mohamed_dessoky@hotmail.com, drali_mansour@yahoo.com

### *Abstrak*

*Transformator daya menjadi porsi terbesar pada investasi kota, dan menyisakan minyak terendam yang menjadi potensi bahaya kebakaran di lingkungan perkotaan dan metropolitan. Setelah studi yang cermat dari berbagai alternatif teknologi transformator konvensional untuk menghasilkan sebuah transformator daya terisolasi gas dengan peningkatan pada laju mega volt-ampere, sebuah transformator terisolasi gas dikembangkan menggunakan gas SF6 yang tidak mudah terbakar. Untuk mengubah bahan isolasi dari minyak ke gas SF6 dilakukan sebuah studi komparasi antar tipe-tipe transformator ini. Pada makalah ini, disarankan dua model matematika dan disimulasikan dengan program komputer untuk mengkalkulasi suhu media pendingin dan gulungan transformator. Hasil yang diperoleh adalah sesuai dengan nilai yang diukur di lapangan.*

***Kata kunci:*** *gas SF6, minyak trafo, trafo daya, trafo daya terisolasi gas*

### *Abstract*

*Power transformers present the largest portion of the capital investment in addition the power transformer remains oil immersed which presents a fire hazard that is particularly objectionable in urban and metropolitan environment. After careful studies of various alternatives to conventional transformer technology to produce a gas insulated power transformer with increased mega volt-ampere ratings, gas insulated power transformer has been developed with a use with non flammable SF6 gas. For changing the insulating material from oil to SF6 gas a comparative study between these types of transformers should be made. In this paper two mathematical models are suggested and simulated by computer programs to calculate the temperature of the cooling mediums and transformer windings. The obtained results are in agreement wit the measured values in the field.*

***Keywords***: *gas insulated power transformer, oil transformers*, *power transformer*, *SF6 gas*

## 1. Introduction

The energy losses in transformer are classified as no load losses and load losses which divided into $I^2R$ and stray losses. The insulating medium (oil or SF6) is used for insulation and to remove heat from the winding and core assembly to surrounding [1]. The heat generated inside transformer must be transfers to the insulating medium and further to surroundings via tank and heat exchanger. Although the winding copper holds its mechanical strength up to several hundreds degree Celsius and transformer oil dose not significantly degrade below about 140 °C.The paper insulation deteriorates very rabidly if it s temperature exceeds 90 °C [2].It has been reported that from 90 to 110 °C the tensile strength aging rate is doubled for approximately each 8 °C increase in temperature [2]. Other authors have observed that the life of different transformer insulation materials is halved by an increase in temperature ranging from 5 to 10 degrees [3].The IEC 60354 loading guide for oil immersed power transformers [4], and the IEEE guide for loading mineral oil immersed transformer [5], indicate how oil immersed transformers can be operated in different ambient conditions and load levels without exceeding the acceptable deterioration limit of insulation due to thermal effects.

To increase transformer operational efficiency and minimize the probability of an unexpected outage, several on-line and off-line monitoring systems have been developed [6], [7-8], [9-10], and [11-12].

*Received November 29th, 2011; Revised February 5th, 2012; Accepted February 15th, 2012*

Direct measurement of actual transformer winding temperatures using fiber optic probes has been increasing since the mid-1980s [13],[14],[15],[16].

## 2. Thermal Models of Power Transformers

### 2. 1. Thermal Model of Oil Power Transformer

The final thermal over all model for oil immersed power transformer is given in Figure 1 based on the thermal-electrical analogy and heat transfer theory [17], [18], [19].

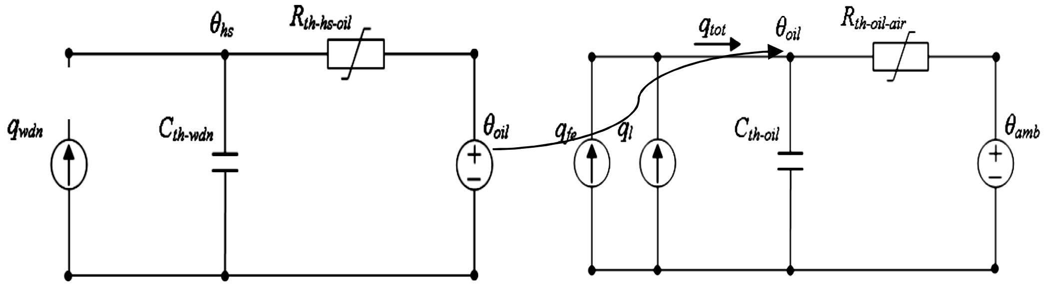

Figure 1. Thermal over all circuit models

where: $q_{tot}$ is the total losses; $q_{fe}$ is the heat generated by no load losses; $q_{wdn}$ is the heat generated in the winding; $R_{th\text{-}oil}$ is non linear oil thermal resistance; $\theta_{amb}$ is the ambient temperature; $\theta_{hs}$ is the hot spot temperature; $\theta_{oil}$ is the top-oil temperature; $R_{th\text{-}hs\text{-}oil}$ is the non linear winding to oil thermal resistance; $C_{th\text{-}wdn}$ winding thermal capacitance and $Cth_{\text{-}oil}$ is the oil thermal capacitance. The heat generated by both no-load and load transformer losses are represented by two ideal heat sources [19], [20].

The ambient temperature is represented as ideal temperature source [19], [20]. The nonlinearities i.e., oil viscosity and other transformer oil parameter changes and loss variation with temperature are taken into account by employing non-linear thermal resistances [17].

The differential equations of the thermal circuits that given in Figure 1 for modeling both the top oil temperature and the hot spot temperature respectively are as follows [17]:

$$\frac{1+R\times Pl,pu(\theta e)\times K^{2}}{1+R}\times\left(\frac{\mu pu^{n}}{\beta pu^{n}\times\rho pu^{n}\times Coilpu^{n}\times k^{(1-n)}}\right)\times\Delta\theta oil,rated=$$
$$\left(\frac{\mu pu^{n}}{\beta pu^{n}\times\rho pu^{n}\times Coilpu^{n}\times k^{(1-n)}}\right)\times\tau oil,rated\times\frac{d\theta oil}{dt}+\frac{(\theta oil-\theta amb)^{1+n}}{\Delta\theta oil,rated} \tag{1}$$

$$\left\{K^{2}\times Pwdnpu(\theta hs)\right\}\times\left(\frac{\mu pu^{n}}{\beta pu^{n}\times\rho pu^{n}\times Coilpu^{n}\times k^{(1-n)}}\right)\times\Delta\theta hs,rated=$$
$$\left(\frac{\mu pu^{n}}{\beta pu^{n}\times\rho pu^{n}\times Coilpu^{n}\times k^{(1-n)}}\right)\times\tau wdn,rated\times\frac{d\theta hs}{dt}+\frac{(\theta hs-\theta oil)^{1+n}}{\Delta\theta hs,rated} \tag{2}$$

Where:

R is the ratio of rated load losses and no load losses [21];
K is the load factor [21];
μpu is the oil viscosity per unit value [17];
Coilpu is the specific heat capacity of oil in per unit value;
βpu is the coefficient of thermal cubic expansion in per unit value;
kpu is the thermal conductivity of oil in per unit value;
ρpu is the oil density in per unit value;

θamb is the ambient temperature ;
θoil is the top oil temperature;
Δθoil is the rated top oil temperature rise over ambient temperature;
Δθhs,is the rated hot spot temperature rise over top oil;
Pl, pu (θe) is the temperature dependence on the load losses in per unit value;
Pwdnpu (θhs) is the winding losses dependence on temperature losses in per unit value;
τoil,rated is the rated oil time constant [22];
Twdn, rated is the rated winding time constant and
n is constant equal to 0.25 [17].

The winding loss's dependence on temperature, ***P**wdn,pu*(***θ**hs*), is as follows:

$$P_{wdn,\,pu}(\theta_{hs}) = P_{dc,\,pu} \times \left(\frac{\theta_{hs}+\theta_k}{\theta_{hs,\,rated}+\theta_k}\right) + P_{eddy,\,pu} \times \left(\frac{\theta_{hs,\,rated}+\theta_k}{\theta_{hs}+\theta_k}\right) \tag{3}$$

***P**dc,pu*(***θ**hs*) and ***P**eddy,pu*(***θ**hs*) describe the behaviour of the DC and eddy losses as a function of temperature. The DC losses vary directly with temperature, whereas the eddy losses vary inversely with temperature. ***θ**k* is the temperature factor for the loss correction ***θ**k* = 235 for copper.

The temperature dependence of the load losses, ***P**l,pu*(  *e*), is also taken into account as follows:

$$P_{l,\,pu}(\theta_e) = P_{dc,\,pu} \times \left(\frac{\theta_e+\theta_k}{\theta_{e,\,rated}+\theta_k}\right) + P_{a,\,pu} \times \left(\frac{\theta_{e,\,rated}+\theta_k}{\theta_e+\theta_k}\right) \tag{4}$$

where:

| | |
|---|---|
| ***P**dc,pu* | is the DC loss per unit value; |
| ***P**a,pu* | is the additional loss (i.e., equal to the sum of eddy and stray losses) per unit value; |
| ***θ**e* | is the temperature at which the losses are estimated $^{o}$C; |
| ***θ**k* | is the temperature factor for the loss correction, ***θ**k* = 235 for copper. |

### 2.2. Thermal Model of SF6 Power Transformer

The theoretical thermal model consists of three basic energy balance equations. A single equation results from an energy balance on each of the three major transformer components. Considering the first component of the gas insulated transformer under the transient condition, the energy generated within the core and coil assembly is equal to the energy stored in it plus the heat loss through convection to the insulated gas. The energy balance equation is:

$$W_{gen} = (mC_p)_c \times \frac{dT_c}{dt} + W_{conv,\,cg} \tag{5}$$

***W**gen* is the total energy generated within the core and coil assembly of the transformer.
***W**conv,cg* is the convection heat transfer rate between the core and coil assembly and the insulating SF$_6$ gas**= *h*cg *A*c (*T*c - *T*g).**

$$Wgen = \left[\frac{load.in.VA}{full.load.in.VA}\right]^2 \times copper.loss(w) + [iron.loss(w)] \tag{6}$$

The natural convective heat transfer coefficient between the core and coil assembly and surrounding gas (***h**cg*) is given by classic Nusselt number correlation's as [23],[24].

$$hcg,\,free = \frac{kgas \times Nu\ cfree}{H\ c} \tag{7}$$

where the Nusselt number for the laminar flow is ***:***

$$Nuc,\,free = \left[(Nul)^6 + (Nut)^6\right]^{\frac{1}{6}} \tag{8}$$

$$Nul = \frac{2}{ln\left[1+\frac{2}{Nur}\right]} \tag{9}$$

$$Nu_r = cl \times Ra_{gas}^{\frac{1}{4}} \tag{10}$$

$$Nu_t = \frac{C_t \times Ra_{gas}^{1/3}}{(1 + 1.4 \times 10^9 \frac{Pr_{gas}}{Ra_{gas}})} \tag{11}$$

$$Ra_{cg} = \frac{g \times \beta_{gas} \times \rho^2_{gas} \times (T_c - T_g) \times H_c^3}{\mu^2_{gas}} \times Pr_{gas} \tag{12}$$

$$Pr_{gas} = \frac{\mu_{gas} \times C_{pgas}}{k_{gas}} \tag{13}$$

$$C_l = \frac{0.671}{[1 + (0.492 \ / \ Pr_{gas})^{9/16}]^{4/9}} \tag{14}$$

$$C_t = \frac{0.13 \times Pr \ gas^{0.22}}{(1 + 0.61 \times Pr_{gas}^{0.81})^{0.42}} \tag{15}$$

For transformer loading in excess of half of its rating, the mode of heat transfer along the core and coil assembly become forced convection. The convective heat transfer coefficient in this case takes the form [25]:

$$h_{cg,\ forced} = \frac{k_{gas} \times Nu_{c,\ forced}}{H_c} \tag{16}$$

Where the Nusselt number for the turbulent flow is as follows:

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$$nu_{c,\ forced} = 0.029 \times Pr_{gas}^{0.43} \times Re_{cg}^{0.8} \tag{17}$$

$$Re_{cg} = \frac{\rho_{gas} \times V_{gas} \times H_c}{\mu_{gas}} \tag{18}$$

$$h_{cg} = \left[(h_{cg,\ free})^4 + (h_{cg,\ forced})^4\right]^{0.25} \tag{19}$$

For the $SF_6$ insulating gas, the energy transferred by convection from the core and coil assembly is equal to the energy stored in the $SF_6$ insulating gas plus the energy transferred through convection to the tank inner wall and to the cooling radiators system. Thus, the energy conservation equation under transient conditions is:

$$W_{conv,cg} = (mC_p)_g \times \frac{dT_g}{dt} + W_{conv,gt} + W_{conv,gr} \tag{20}$$

***Wconv,gt*** is the convective heat transfer rate between the tank inside surface and the insulating $SF_6$ gas ***= hgt At (Tg-Tt)***

***Wcon,gr*** is the convective heat transfer rate between the radiators inside surface and the insulating $SF_6$ gas ***= hgr Ari (Tg-Tt).***

The convective heat transfer coefficient between the $SF_6$ insulating gas and the inside of the transformer tank, ***hgt***, can be evaluated using similar procedure equations (12) to (20) still apply without modification, however the Rayleigh number are determined from the expression:

$$Ra_{gt} = \frac{g \times \beta_{gas} \times \rho_{gas}^2 \times (T_g - T_t) \times H_t^3}{\mu_{gas}^2} \times Pr_{gas} \tag{21}$$

$$Pr_{gas} = \frac{\mu_{gas} \times Cp_{gas}}{k_{gas}} \tag{22}$$

$$Re_{gt} = \frac{\rho_{gas} \times V_{gas} \times H_t}{\mu_{gas}} \tag{23}$$

where ***Ht*** is the height of the transformer tank and the convective heat transfer coefficients are given by:

$$h_{gt,\,free} = \frac{k_{gas} \times Nu_{ti,\,free}}{H_t} \tag{24}$$

$$h_{gt,\,forced} = \frac{k_{gas} \times Nu_{ti,\,forced}}{H_t} \tag{25}$$

The following correlation has been proposed for conditions which result in combined free and forced convection between the tank inside surface and the $SF_6$ insulating gas [23]:

$$h_{gt} = \left[(hgt\,,\,free\,)^4 + (hgt\,,\,forced\,)^4\right]^{0.25} \tag{26}$$

Convection heat transfer coefficient (*hgr*)

$$h_{gr\,,\,free} = \frac{k_{gas} \times Nu_{gr\,,\,free}}{D_r} \tag{27}$$

Where Dr is the cooling tube diameter

$$Nu_{gr\,,\,free} = 1.86\,(Re_{gr\,,\,free} \times Pr_{gas})^{1/3}\left(\frac{D_r}{H_r}\right)^{1/3} \tag{28}$$

$$Re_{gr\,,\,free} = \frac{\rho_{gas} \times V_{gas\,,\,free} \times D_r}{\mu_{gas}} \tag{29}$$

The natural or free convection velocity V*gas,free* was measured using laser velocimeter [24] and found to be about 0.3 m/sec. The following relation for evaluation of the Nusselt number in flow through along tube is recommended [26]:

$$Nu_{gr,\,forced} = 0.023 \times Re^{0.8}{}_{gr,\,forced} \times Pr_{gas}{}^{0.4} \quad \textbf{\textit{For turbulent}} \tag{30}$$

$$Nu_{gr,\,forced} = 1.86 \times (Re_{gr,\,forced} \times Pr_{gaS})^{1/3} \quad \textbf{\textit{For laminar}} \tag{31}$$

$$Re_{gr\,,\,forced} = \frac{\rho_{gas} \times V_{gas\,,\,forced} \times D_r}{\mu_{gas}} \tag{32}$$

The heat transfer coefficient in this case can be determined using the expression:

$$h_{gr\,,\,forced} = \frac{k_{gas} \times Nu_{gr\,,\,forced}}{D_r} \tag{33}$$

The following correlation has been proposed for conditions which result in combined free and forced convection between the inside of the cooling tubes and the $SF_6$ insulating gas [23]:

$$h_{gr} = \left[(hgr\,,\,free\,)^4 + (hgr\,,\,forced\,)^4\right]^{0.25} \tag{34}$$

At the out side surface of the tank and the cooling radiators, the energy transferred through convection to the tank and cooling radiators from the insulating $SF_6$ gas, are balanced by the energy stored in the tank plus the convective and radiative energy losses to the atmosphere. Therefore, the energy conservation equation is:

$$W_{conv,gt} + W_{conv,gr} = (mC_p)_t \frac{dT_t}{dt} + W_{conv,ta} + W_{conv,ra} + W_{rad,ra} + W_{rad,ta} \tag{35}$$

where

***W**conv,ta* is the rate of heat flow by convection between the transformer tank outside surface and the ambient air = $h_{ta} \times A_t(T_t - T_a)$.

***W**conv,ra* is the rate of heat flow by convection between the outside surface of the radiators and the ambient air = $[h_{ro} \times A_{ro} + h_{ri} \times A_{ri}](T_t - T_a)$

***W**rad,ta* is the rate of heat flow by radiation from the transformer tank outside surface to the ambient air $= \sigma \times A_t \times \varepsilon_{to} \times (Tt^4 - Ta^4)$

***W**rad,ra* is the rate of heat flow by radiation from the outside surface of the radiators cooling system to the ambient air $= \sigma[A_{ro} \times \varepsilon_{to} + A_{ri} \times F_u](T_t^4 - T_a^4)$

The free convection heat transfer Nusselt number can be approximated by the expression [25]:

$$Nu_{ta,free} = \left[0.825 + \frac{0.387 \times Ra_{ta}^{1/6}}{\left[1 + \left(\frac{0.492}{pr_{air}}\right)^{9/16}\right]^{8/27}}\right] \tag{36}$$

where

$$Ra_{ta} = \frac{g \times \beta_{air} \times \rho_{air}^2 \times (T_t - T_a) \times H_t^3}{\mu_{air}^2} \times \Pr_{air} \tag{37}$$

The convective heat transfer coefficient for free convection between the outside of the tank and the air is given by:

$$h_{ta,free} = \frac{k_{air} \times Nu_{ta,free}}{H_t} \tag{38}$$

In case of forced convection the following expression can be used to evaluate the average Nusselt number for turbulent flow over the external surface of the tank [26]:

$$Nu_{ta,forced} = 0.029 \times Pr_{air}^{0.43} \times Re_{ta}^{0.8} \tag{39}$$

Where the Renold’s number, ***Re*** is defined as:

$$Re_{ta} = \frac{\rho_{air} \times V_{air} \times H_t}{\mu_{air}} \tag{40}$$

The convective heat transfer coefficient for forced convection between the tank outside surface and the air is:

$$h_{ta,forced} = \frac{k_{air} \times Nu_{ta,forced}}{H_t} \tag{41}$$

The following correlation has been proposed for conditions which result in combined free and forced convection between the outside enclosure of a tank and outside air [23]:

$$h_{ta} = [(h_{ta,free})^4 + (h_{ta,forced})^4]^{0.25} \tag{42}$$

Heat transfer for the outer fins is evaluated by [27]:

$$Nu_{ra} = \left[ 0.825 + \frac{0.387 \times Ra_{ra}^{1/6}}{\left[ 1 + \left( \frac{0.492}{pr_{air}} \right)^{9/16} \right]^{8/27}} \right] \quad (43)$$

$$Ra_{ro} = \frac{g \times \beta_{air} \times \rho_{air}^{2} \times (T_t - T_a) \times H_r^{3}}{\mu_{air}^{2}} \times Pr_{air} \quad (44)$$

The convective heat transfer coefficient for free convection between the outside of the radiators and the air is given by:

$$h_{ro} = \frac{k_{air} \times Nu_{ro}}{H_r} \quad (45)$$

Heat transfer from the interior fin passages is evaluated by [27]:

$$Nu_{ri} = \frac{Ra_{ri}}{\psi} \left\{ 1 - \exp \left[ - \psi \times \left( \frac{0.5}{Ra_{ri}} \right)^{3/4} \right] \right\} \quad (46)$$

Where:

$$\psi = \frac{24(1 - 0.483 \times \exp(-0.17/a))}{\left\{ (1 + a/2) \times \left[ 1 + \left( 1 - e^{-0.83a} \right) \times \left( 9.14 a^{1/2} \times e^{vs} - 0.61 \right) \right] \right\}^{3}} \quad (47)$$

$$\left. \begin{aligned} v &= -465 \\ a &= \frac{s}{L_r} \\ r &= \frac{2 \times L_r \times s}{2 \times L_r + s} \\ Ra_{ri} &= \left( \frac{r}{Hr} \right) \times Gr \times Pr_{air} \end{aligned} \right\} \quad (48)$$

$$hri = \frac{kair \times Nuri}{r} \quad (49)$$

The amount of heat transferred by a radiation depends upon a number of factors including surface temperature and emissivity. The radiation exchange factor for rectangular U-channel radiator ***Fu*** may be calculated following the same procedure described in [27].the factor ***Fu*** takes the form:

$$F_u = \frac{2 C_{net}}{H_r (S + 2 l_r)} \quad (50)$$

**Cnet** is the net radiation conductance. It is a function of the U-channel can be found is [27].

## 3. Results and Dissection

### 3.1. Oil immersed transformer

The suggested thermal model is applied on 66/11 kV transformer. The applied load as a function of time is given in Figure 2. The obtained results are compared with the measured values and agreement between them is noticed as shown in Figure 3.

### 3.2. SF6 Transformer

The SF6 gas transformer thermal model is applied on transformer 66/11. The measured temperature was in agreement with the calculated temperature as shown in Figure 5 .The load applied to this transformer as shown in Figure 4. The transformer component temperatures are affected by circulation speed of the gas, the higher gas speed the lower transformer component temperature. For comparison between gas insulated gas cooled power transformer and oil immersed power transformer, 66/11 kV 25 MVA, 1200 Amp transformer insulated by oil and another transformer insulated by $SF_6$ gas. The effect of changing gas pressure and gas circulation velocity on the transformer components temperature as shown in Figures 6 and 7 by applying the load cycle given in figure 8 on the SF6 and oil type transformer the temperature distribution is given in figure 9.The reason of higher temperatures of $SF_6$ transformer is due to the heat transfer coefficient of $SF_6$ gas is lower than the heat transfer in oil at stated gas pressure and forced gas velocity, also the thermal capacitance of oil is higher than that of $SF_6$ gas.It can be noticed that the transformer component temperature decreases with the increase of $SF_6$ gas pressure. This is because the increase in gas pressure causes an improvement in thermal capacity of the SF6 gas.

As given in Conti Elektro-Berichte [28] the heat transfer in $SF_6$ gas is equal to the heat transfer in oil at $SF_6$ gas pressure = 2 MPa and gas velocity = 4.5 m/s, it is noticed that the relationship between the $SF_6$ gas component temperatures and gas pressure and also with forced gas velocity, when $SF_6$ gas pressure or velocity increased, the $SF_6$ gas temperature also increased and transformer windings temparatures are decreased, and vise versa. For increasing the heat transfer and lowering the $SF_6$ gas transformer component temperature the gas pressure should be increased from 0.24 to 2 MPa and forced gas velocity from 1.5 to 4.5 m/s.

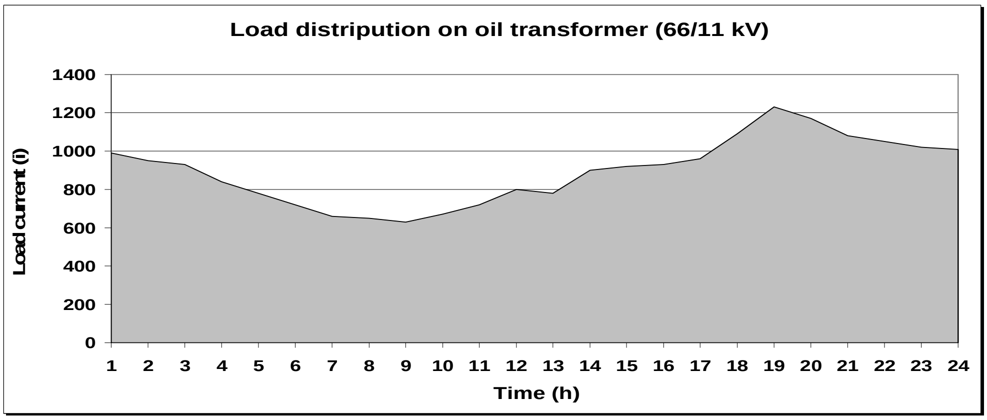


Figure 2. Load distributions on oil transformer (66/11 kV)

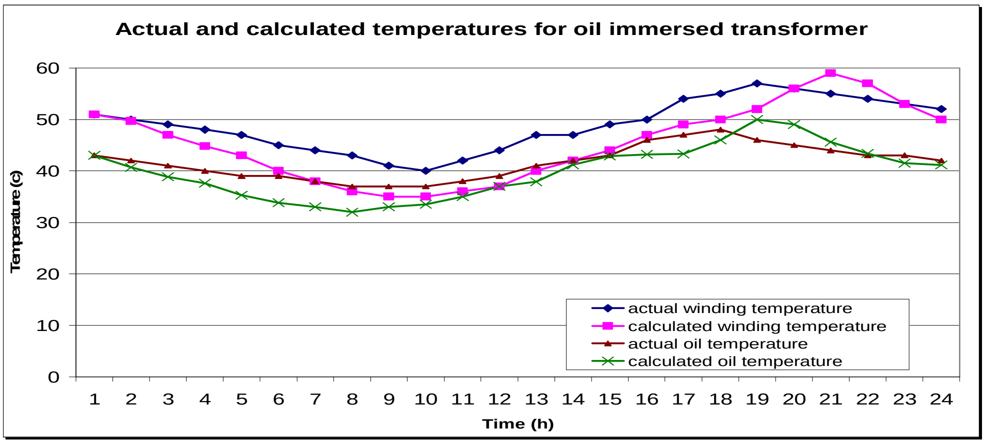


Figure 3. Calculated and measured of oil and winding oil immersed transformer

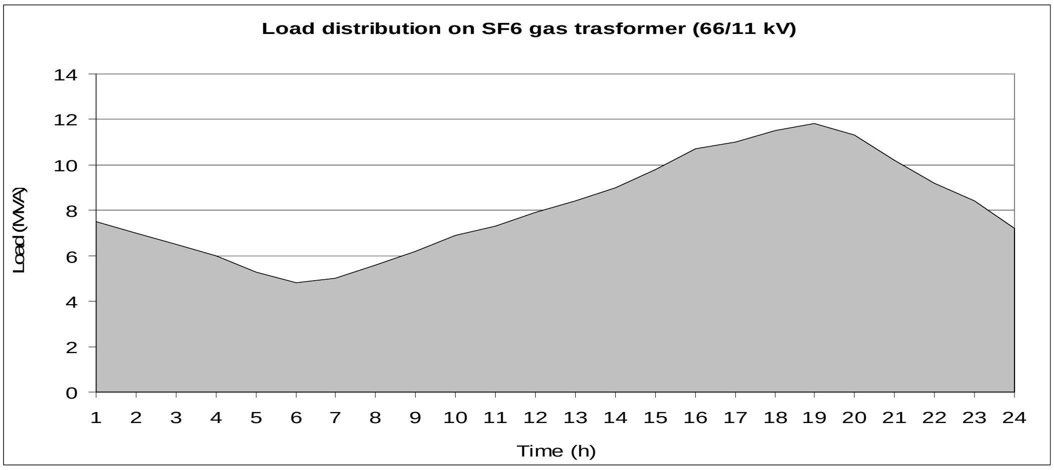


Figure 4. Load distributions on SF6 gas transformer

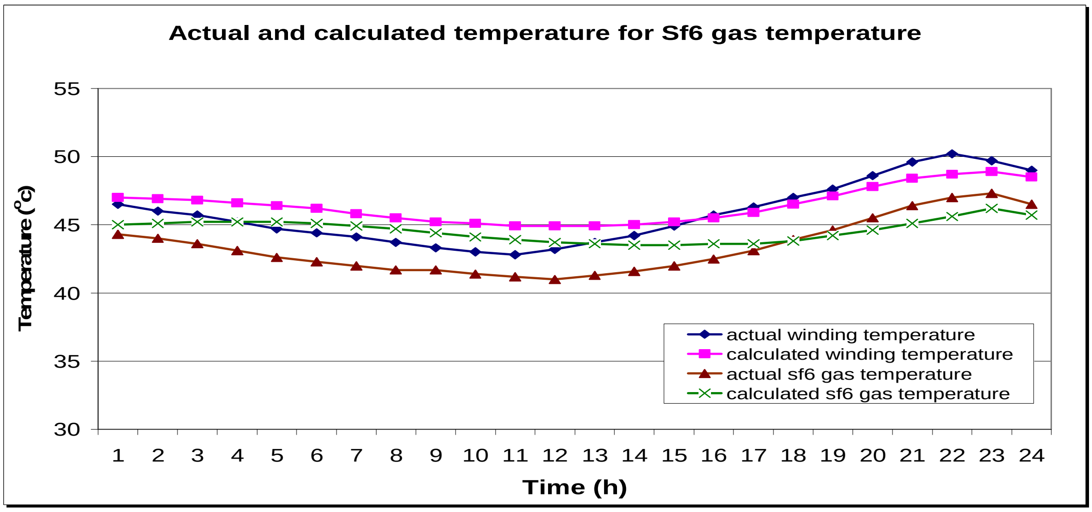


Figure 5. Actual and calculated temperature for SF6 gas temperature and winding temperature

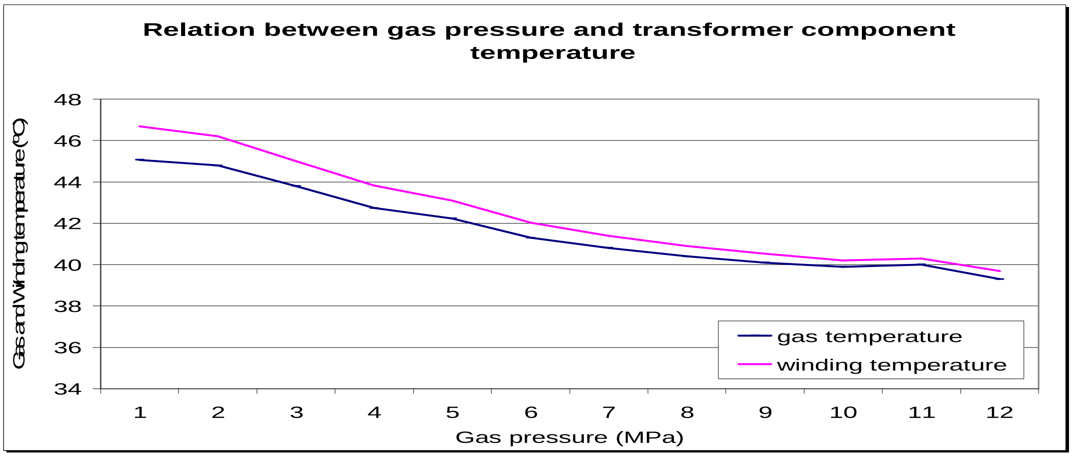


Figure 6. Relation between gas pressure and sf6 transformer temperature

Figure 10 shows the temperatures of oil and $SF_6$ gas temperature after increasing gas pressure from 0.25 to 2 MPa and gas velocity from 1.5 to 4.5 m/s. From this figure it is noticed that the $SF_6$ temperature is reduced to be in the range between 47 $^{o}$C to 55 $^{o}$C but still the oil has the advantage that having lower temperature, on the other side. The change in the gas temperature with the variation in the load with time is very small compared with the change of oil temperature with the change in the load cycle, also decrease the winding temperature. The two transformers have the same losses "iron losses and copper losses" and at the same conditions "ambient temperature and load". The suggested load distribution applied on both transformers is as shown in the Figure 9.

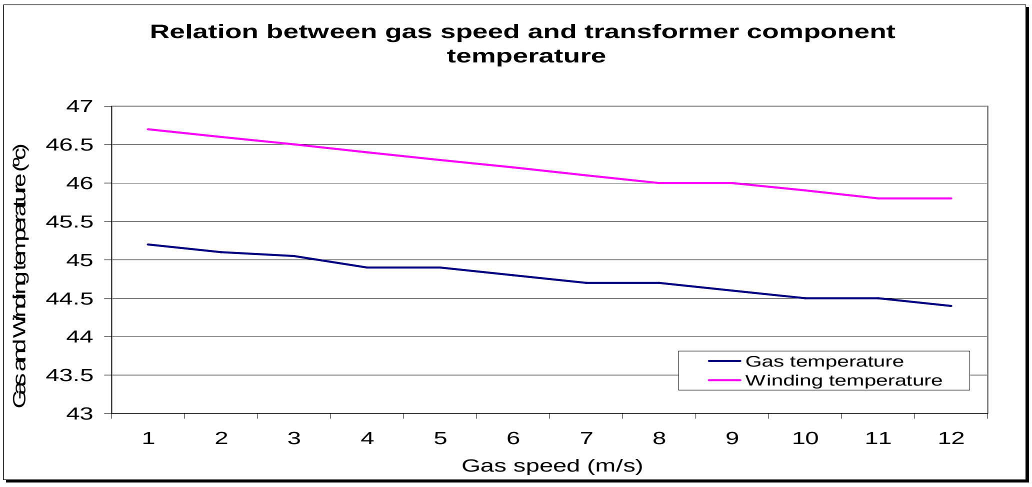


Figure 7. Relation between gas circulation speed and transformer temperature

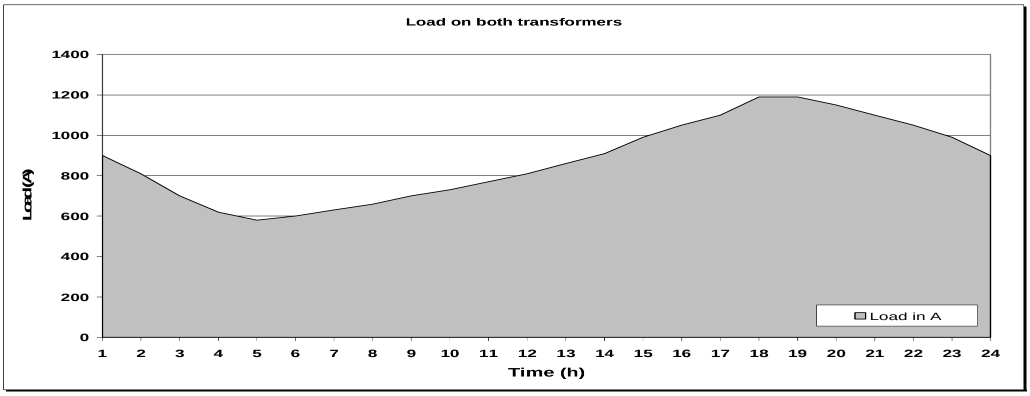


Figure 8. Load distributions on both transformers

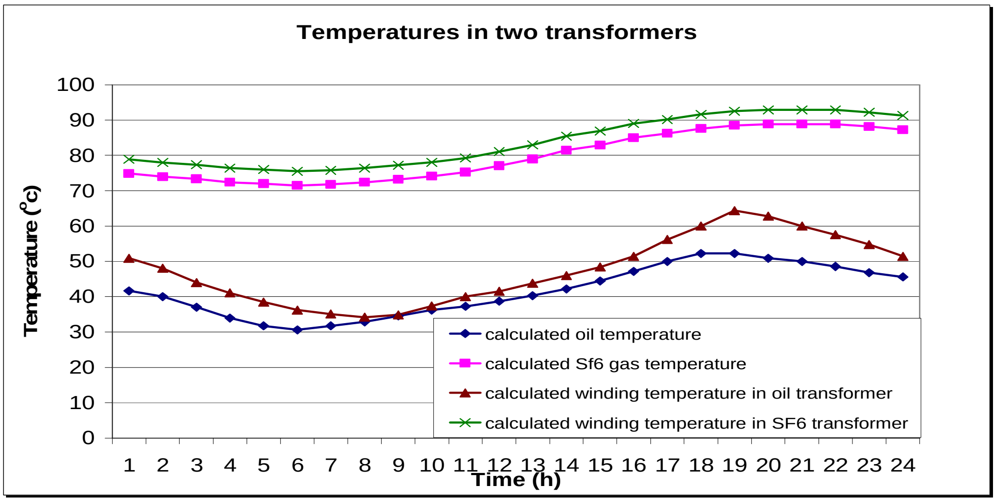


Figure 9. Temperatures in two transformers

From Figure 10 it is noticed that the temperature of $SF_6$ gas transformer components is higher than the temperature of oil immersed power transformer components. This difference is between 30 $^oC$ and 42 $^oC$ depending on the load cycle at $SF_6$ gas pressure is .24 MPa and its velocity is 1.5 m/s

### 3.3 Verification of the obtained results by using QUICK FIELD program

By using quick field program we verify the obtained results by using MATLAB program in case of oil immersed transformer and SF6 gas transformer. This program gives the temperature distribution of the transformer components in contour lines; it means that the temperature at any point in the transformer can be calculated.

Figure 11 (a) and (b) give samples of the obtained results It is noticed that the calculated temperature using quick field program is closed to the actual temperature of the transformer component, moreover quick field programs shows temperature distribution inside transformer.

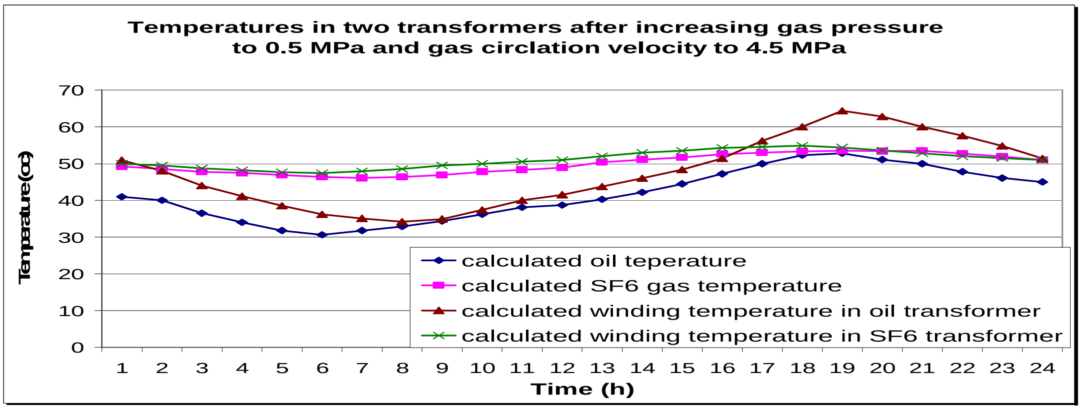
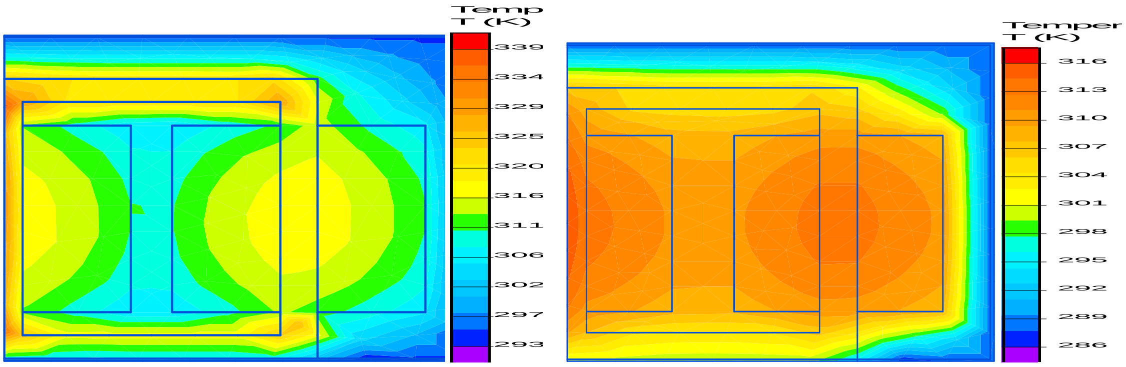


Figure 10. Temperature in two transformers after changing gas pressure and circulation



(a) ( b)

Figure 11. (a) Temperature distribution in oil transformer at load 9.3 MVA (66/11 kV) and (b) temperature distribution in $SF_6$ transformer (66/11 kV) at load = 4 MVA

## 4. Conclusions

Two thermal mathematical models to simulate the heat flow and to calculate the cooling medium temperature and the winding temperature of oil and $SF_6$ transformers are presented and simulated by computer programs. The obtained results from the used models are in agreement with that measured in the field. Due to the higher thermal capacitance of the oil than that of $SF_6$ gas, the heat transfer coefficient in oil is higher than that of $SF_6$ gas, so the temperature of oil immersed power transformer component is lower than the temperature of $SF_6$ gas insulated gas cooled power transformer components having the same ratings.In SF6 transformer the winding temperaturs are affected by gas pressure and temperature

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