Assessment of Power Transformer cooler with FEMLAB

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Abstract- The significance of overload in power system has increased substantially due to of consumption and ambient temperature rise. An important consideration when evaluating the impact of overload is their on power system ambient tem-and load. Transformers are major components in power systems. The increase useful lifetime and hence abnormal temperature rise.
Existing standards give a procedure to determine the capability of an existing transformers subject to overload problem and ambient temperature rise based on conservative assumptions .in addition, the temperature oil rise of power transformer due to overloading and ambient temperature are estimated based on power and cooling system, and the average daily or monthly temperatures to which a transformer would be subjected while in service. it is the purpose of this research of this effort to quantify the decreased life time due to overloading and the corresponding temperature rise in transformers. This is accomplished using a 2-D FEMLAB Model adapted for cooling simulation in power transformers. [20-24].

Keyword: Transformer, Overload, temperature, Ambient, cooling Femlab

NOMENCLATURE

q : Temperature ($°C$)
HX: Heat exchanger
$q_h(t)$: The windings hot-spot temperature
$q_a(t)$: The ambient temperature
$\Delta q_h(t)$: The hot-spot temperature rise, depending on the load, nameplate rating and type of cooling of the transformer
T : is given degrees Celsius (° c)
M/s: Meter per second
U: fluid velocity
P: pressure field
ρ : density
h : Viscosity
C: specific heat capacity
Q: heat power per unit volume
2-D: two dimensions

Introduction

LOading of power transformers at their nameplate capacity does not always match their loading capacity. In [1], an effort to determine loading capability of power Transformer based on their maximum windings temperature and not on their rating nameplate capacity, various simulation thermal models have been developed up to now to determine the windings hot-spot temperature .This temperature is being used not only for the calculation of the permissible overloading but for the aging of the power transformers as well [2, 3, 4]. IEEE Thermal aging of power transformers is a result of their insulation deterioration .This deterioration is cumulative, depending on the temperature and the corresponding time interval, this is why the variation of the windings hot-spot temperature vs. time should be taken into account, and not only its maximum value, to determine transformer ageing. This variation is given from the expression:

$\theta_h(t) = \theta_a(t) + \Delta\theta_h(t)$…….. (1)

Rise in electric power consumption increased the power transformer loads by %16.3 during year 2006 in provinces of Mazandaran. Over loading generates high temperature within the power transformers. Over loading and over heating of power transformers combined with high ambient temperature caused long black outs and major equipments damages in province of Mazandaran during summer of 2006.

Maximum allowable loading and overloading are the most important parameters for the power transformers. Depending on how long a power transformer is under a certain load or overloaded and ambient temperature rise they generates a considerable amount of heat internally. The internal heat generated in turn reduces the life of the power transformer insulation this reduces the life of the power transformer. Rise in internal temperature depends on amount of load, the time that the transformer is under load or amount of over load and the ambient temperature.

This paper shares general and practical information concerning observation of heat generation in power transformers due to overloading. It evaluates the effect of ambient temperature on over heated power transformers. To carry out these tasks IEC-354 standard were used. Data collected from regional meteorological center was used to evaluate the effect of the ambient temperature on the power transformer performance.

The ageing rate of power transformers determined using IEC & BS standard and guidelines for loading of the oil filled power transformers.

1-overload and ambient temperature

1-1-2-Loading beyond nameplate Rating

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With the exception of generator-transformers .the load imposed on transformers varies between a higher level within the day and during the year .the most critical limitation in the loading of a transformer is the temperature reached in the hottest area of the winding, named Hot-spot temperature, Every effort should be made to determine this temperature with accuracy .As the size of transformer increases. The hot-spot temperatures are more difficult to determine correctly.

With loading values beyond the nameplate rating, are not exceeded for current I, hot-spot temperature $q\,h$ and metallic parts in contact with insulating materials and top-oil temperature.

The loading of the transformers beyond the nameplate rating cause the aging of the nameplate rating cause the aging of the insulation materials and the loss of the life expectancy, which is discussed in the next parts . As shown in table (1) below, overloading is the biggest problem in M.R.E.C. [19]

Table (1): transformers overload in (M.R.E.C) sub-station [19]

row	No. of transformers	transformers 63/20(kv)	transformers 230/63(kv)	transformers 400/230(kv)
1	No. of transformer in iran	2304	467	95
2	No.of transformer in mazendran	130	20	8
3	No. of transformer in more than nominal load mazendran	61%	65%	76%
4	No. of transformer over load more then(120%)	37%	34%	27%

Fig [1]: A power transformer in a 63/20 KV substation, West of Mazandaran

1-2- Ambient temperature in M.R.E.C

Regional meteorological center in Mazandaran province have total of 23 Synoptic stations, 183 rain evaluation stations and 27 climatology stations. These stations collect meteorological data from environment hourly bases. Meteorological stations in Ghaemshar, Ramsar, Noshar, Babolsar, Gorgan and Gonbad store the meteorological data of past 25 years from Mazandaran province.

Ambient temperature is an important factor in determining the load capability of a transformer since the temperature rise for any load must be added to the ambient to determine operating temperature. Transformer ratings are based on a 24h average ambient of 20°c. whenever the actual ambient can be measured ,such ambient should be averaged over 24h ,and then used in determining the transformer's temperature and loading capability of the ambient air temperature seen by a transformer and the air in contact with in radiators or heat exchangers.

It is often necessary to predict the load that a transformer can safely carry at some future time in an unknown ambient. The probable ambient temperature for any month may be approximated from data in reports prepared by the national or local atmospheric authority for the sections of the country where the transformer is located. [8, 9]

At different locations on earth, the average of variations in the ambient temperatures over a day, month or the whole

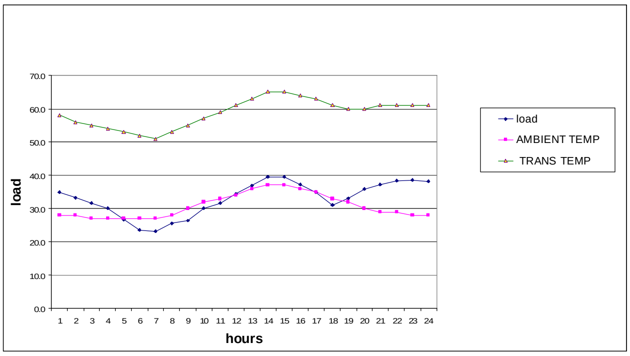


Fig [2]: Load, ambient temperature and transformer temperature M.REC substation

Year varies due to the rotation of the earth on its own axis in

24h and around the sun in a year. The temperature variations over a day are plotted for the most of the world, but in Mazandaran state the variation observed are found close to sinusoidal.

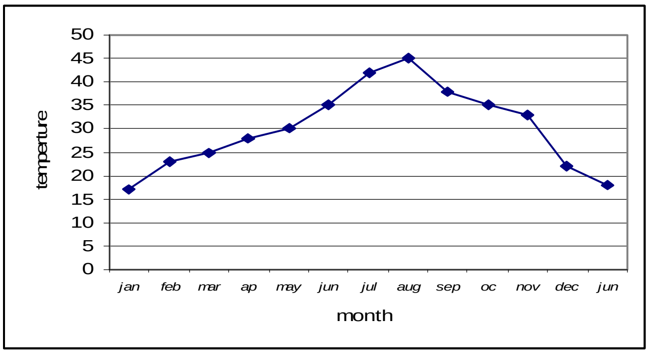


Fig [3]: Typical monthly ambient variation

That will appear as 365 sinusoidal ripples on the yearly sinusoidal variations which is very bad news for M.R.E.C.

1-3- Effect of ambient temperature on useful life of the power transformers

The most important parameters in computation of temperature build up in power transformers dielectric are the ambient temperature and the cooled airflow from the cooling system. Unfortunately, when ordering a power transformer most companies indicate the maximum absolute temperature as ambient temperature.

They believe that loading the ordered power transformers with maximum absolute temperature and nominal power is possible during the predicted lifetime of the power transformer. Based on IEC-354 standards, if hot spot temperature of the wire winding hot spot at the time of the loading is 98°C regardless of ambient temperature the relative aging of the power transformer is one.

For every 10°C increase in wire winding hot spot temperature within limit of 98°C < Y_h < 140°C, either caused by ambient temperature or by loading conditions the aging rate of the power transformer doubles. Oil temperature and wire winding hot spot temperature of power transformers should not exceed 105°C and 140°C respectively. In order to derive the aging rate of the power transformers to one, power transformers must operate within the average yearly ambient temperature with specified nominal loading. When ambient temperature drops below average yearly ambient temperature the aging rate also drops blow one. In this condition it is possible to load the power transformers beyond the specified nominal loading so long as the wire winding hot spot temperature does not exceed more than 98°C. If ambient temperature is higher than average yearly ambient temperature transformer load must be reduced to keep the wire winding hot spot temperature at 98°C.

If the above loading pattern during a year is not acceptable. If it is desired to keep the loading of the power transformer at nominal during all seasons of a year; Then in hours of a year when ambient temperature is lower than average yearly ambient temperature the aging rate of the transformers are less than one and vice versa. This gives the total aging rate of one for the year that the power transformer load kept at nominal constantly. In another word over loading a power transformer operating in its designed environment accelerate its aging rate. It is not recommended by any standards including the IEC. Power transformers designed to operate at higher ambient temperature than their geographic location have capacity to accept load more than their stated nominal load.

For power transformers to live for 30 to 40 years given they operate at 98°C which is equivalent to 20°C at nominal loads, IEC-354 standard gives the allowable loading limit in per unit for power transformers in different ambient temperatures according to their nominal power [1]. Loading guideline is for power transformers according to IEC-354/1991 for hot spot temperature less than 140°C. Fig 2&3 presents the temperature variation of the different area for provinces of Mazandaran

2-.Technique for simulation of temperature [20-24]

The principal factor in determining the thermal rating, and thus the loading capability and ambient temperature of transformers, was the average rise of the winding. This temperature rise was determined by simulation and the change when in oil temperature when the oil velocity was increasing to the transformer. The temperature rise was changed when it was discovered that the hottest-spot winding temperature gives a better indication of how the load affects the life expectancy of a transformer [20-23].

However, the hottest-spot temperature cannot be measured directly because of the hazard of inserting temperature sensors directly into the windings. As a result, numerous methods have been developed to calculate the hottest-spot temperature, but these are very complicated. The winding and oil temperature of a transformer are measured with a fiber optic temperature measurement system. Although the sensors are not located directly in the hottest-spot of the winding, significant results can be obtained. Assuming a conventional ONAN transformer design according standard using cellulose insulation and mineral oil also of life table can be constructed for a rang of overloads and varying periods of timeout overload. Table (4),

Table 4, loss of life in power transformer[25]

load % rated	Hot spot temp, °c at amb.20° c	Top oil temp .°c	% Time at over load		
			5	10	20
100	98	76	0	0	0
110	104	78	1.5	2.5	5
120	110	85	2.5	5	10
130	116	87	5	10	20
140	122	94	10	20	>40
150	127	98	20	>40	>40
			loss of life in years over normal Power transformers life of 29 years.		

3- Cooling transformers

The transformer is normally cooled by natural convection (via the ambient air) or forced convection (a fan attached to The wall of the radiator)

The efficiency of the air – side heat transfer in a transformer radiator is a primary consideration when determining the best heat exchanger for a particular application. Further more, air–side heat convection is typically the limiting factor affecting heat performance of a heat exchanger. The convective heat transfer equation is proportional to surface area of the fins or bodies subjected to the airflow.

In order to improve the modeling of the natural convection problem, an independent geometrical model of the surrounding air will be created and considered separately. The continuity of mass flow, temperature and heat flux a long the interface between transformer and air will be enforced by an iterative procedure. This procedure will allow us to calculate and then prescribe local heat fluxes to the external walls of the transformer. The numerical results obtained with the numerical model will compared with experimental measurements .On the basis of hydrodynamic theory and of data obtained by simulated with FEMLAB a method will be presented for calculating the overall flow and its components through the transformer Radiator. Following a hydraulic calculation .It is possible to suggest suitable design adjustments to render the temperature - rise increments, thus achieving optimum utilization of the circulating oil. The calculated oil velocities in the transformer radiator permit the heat - transfer coefficients to be determined reliably; the oil/air temperature gradients can be established from the known rates of oil flow through the ducts of the coolers.

The optimal configuration will be approached by determining the optimal radiator geometry. In brief, optimal means to have a batter heat exchanger that those are currently available in the market. In addition to high efficiency and thermal performance issues such as manufacturing cost, ease of manufacturing, as well as weight and size reduction Of the HX must be taken into consideration.

4- Prepared program in FEMLAB software [24]

Using the equations and data collected from ambient temperature changes, overloading data collected from the power transformers and also power transformer specifications, a computer program was developed to simulate the hot spot location and the oil temperature rise.
The model uses two stationary application modes to simulate the problem:
1- Non-Isothermal flow
2- General heat transfer
"It simulates non –isothermal flow with the Navier-stokes equations that describe the fluid velocity and pressure field, in this case density and viscosity are temperature dependent"

$\rho(u.\nabla) u =\nabla.[-PI+ \eta[(\nabla u+(\nabla u)] – (2\eta/3)$
$(\nabla.u)T] + \rho g\ \nabla. (\rho u) =0$ ……. (6)

The General heat transfer application mode is based on a general energy balance:

$\nabla . (-k\nabla T)=Q- \rho\ Cp\ u. \nabla T$ ……… (7)

Following are the temperature dependencies of viscosity, density and specific heat capacity in this model (this information comes from the producer of the transformer oil)

$*P =875.6-0.63\ T$

$*y = \rho 10^{-4.726\ -0.0091\ T}$

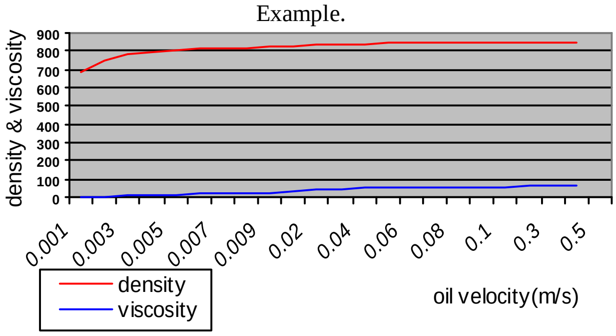
$*Cp = 1960+4.005T$

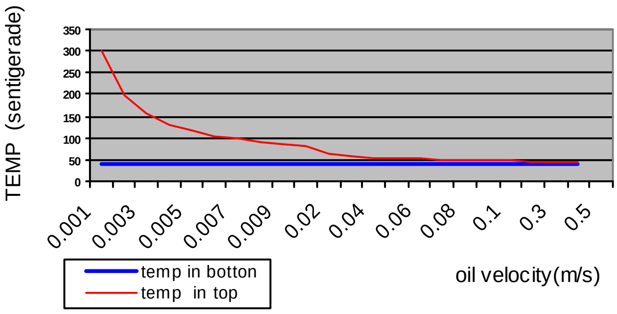
1-4.Design approche

Using the equations and data collected from ambient temperature changes, overloading data collected from the power transformers and also power transformer specifications, a computer program was developed to simulate the hot spot location and the oil temperature rise.

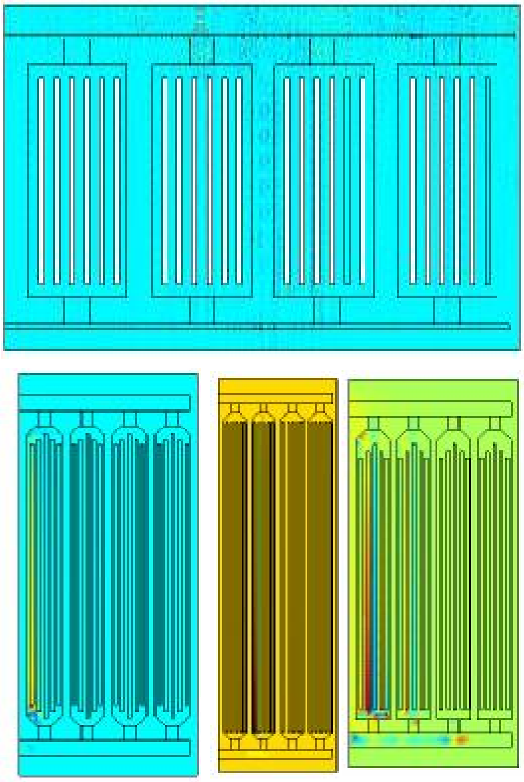
The developed program helped to find a suitable cooling system for overloaded power transformers for nine areas in Mazandaran province of Iran. This program helps us to distinguish the kind of the applicable cooling in different ambient conditions and transformer load. For this case we clarify the cooling kind for transformers, sub transmission and transmission substation with the entering ambient temperature and kind of insulation in order to make us able to calculate aging insulation rate; for example; the hot spot is obtained at 98 $^{\circ C}$ and aging rate is obtained at 0.092. With consideration to plot temperatures a function of oil velocity, for the simplified model used in this example the temperature characteristics is plotted in Fig [4] as a function of oil velocity in cooling. Oil temperature will be decreased and oil velocity started of 0.001 [m/s] and continue until 0.4 [m/s]. Proposed stop at
0.2 [m/s] that maybe, practicing beholds relay at over than 0.2[m/s] oil velocity .with decreased oil temperature in power transformer modify viscosity and density. Shown in fig [4].By using various simulation software's such as FEMLAB , we can reach the provided primary design. For preventing the reduction of power transformers normal life we have to use novel cooling system. {According to Figures [5, 6, and 7], Transformer cooling [2] This has been developed to provide an alternative, Non-invasive Solution to the problem of overload and ambient temperature rise .rather than significantly altering the morphological level of the novel cooling system. Novel cooling utilizing the base of parametric understanding of the phenomenon, together with recent advances in morphological level and software level of simulation in FEMLAB environment.[2].changes only the operation of the system .[3,4]with fig [8] could modify exist cooling system .

Fig [4]: plot of temperature as a function of oil velocity for the Example.





options/constants		
name	**expression**	**value**
T_0$^\circ C$	105	105
eta -air	60-6+4e8*2018e-6	6.00E-06
K-air	10000	10000
Cp-air	1006	1006
R-air	2000	2000
Po	1.00E+05	1.00E+05
Q-SOUR	1	1
kfl	0.125	0.125
ks	383	383
Vo(M/s)	0.008	0.008
Qs	1	1
rho-air	p/(R-air*T-air)	2.5
P	100000	1.00E+05
V-air(M/s)	10	10
T-air $^\circ C$	20	20



Fig[8]: topic of simulated radiators
With FEMLAB software

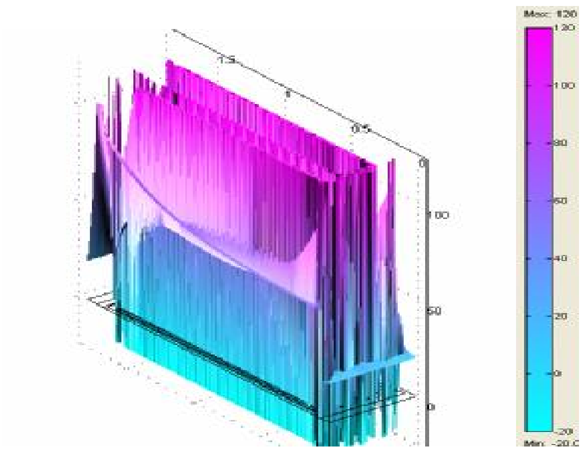


Fig [6]: simulation surface: temperature Height: temperature of power transformer cooling In FEMLAB

1-5. Boundary conditions-General heat transfer [24]

There is a power transformer module in FEMLAB software.. We used of FEMLAB Environment. and put boundary conditions General heat transfer in software FEMLAB. This program set according to table (3). of course whit consideration to IEC- 354/standard.

1- From the metaphysics menu select General heat transfer

2- From the physics list choose 1, then in the boundary condition

Edit field select axial symmetry.

3- Select boundaries, and assign them the temperature boundary Condition. In the to edit field for temperature enter T-0

(Note that the value of T-0 is given in degrees Celsius).

4- Select boundaries, and assign them the convective flux

Boundary condition.

5- Select boundaries, and assign them the thermal insulation Boundary condition. They click "Ok"

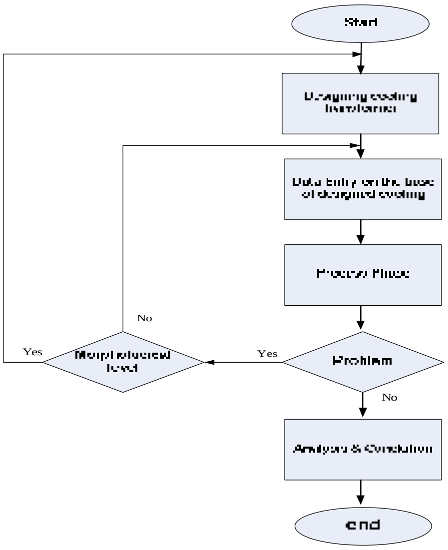


Fig [7]: simulation of power transformer cooling
In FEMLAB

CONCLUSION

Overloading the power transformers according to IEC-354 standard especially in emergency situations for long or short period of time at high ambient temperature can weaken the power transformers and reduce its effective life.

It can generally be said that one of the most important reasons early aging of transformers insulation system, is the problem of over current and overheat due to the increase of environmental temperature.

By using the FEMLAB simulation software, can somewhat improve the existing cooling system to prevent insulation early aging in transformers.

With the help of temperature simulation in FEMLAB software, a design can be implemented so that we may have heat without early aging of the insulation.

1. Than, we can conclude that the simulation project will help remarkably the transformer cooling system

2. Considering the kind of material the morphological level and the dimensions of Radiators can totally modify %17 the cooling system.

3. If more studies are carried out on the design of cooling system a cooling system can be designed to modify %45 the situation. In this case the existing cooling system should be changed to a greater extent.

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