Experimental Study and performance analysis of transformer cooling system

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***Abstract*: Transformer plays an important role in electrical power system .There are many problems associated with Power loss in transformer but in this paper mainly focuses on efficient cooling system designed for overcoming heating and insulation losses. Ever since the invention of a transformer, we have been facing the trend of increasing its nominal power. Together with the increase of nominal power, losses in transformers increase as well, while a transformer's own capability of cooling decreases. The efficiency of the cooling is a crucial factor determining the operational safety and the life span of a transformer. Based on previous research works, this paper compares four cooling methods (air natural, air forced, air forced water forced and air forced water forced with coolant cooling) with the help of experimental setup. In this experimental setup comprises copper tube, air fan, water circulating pump. And the result better found in the air forced water forced with coolant cooling method .By using this method, the temperature of transformer can be reduced in short time. According to generally adopted estimate states that if a transformer's maximum operating temperature is reduced by 6°C-10°C the thermal life of insulation system is approximately doubled. The main purpose of the experiment is to improve the cooling system of transformer, to increase the life expectancy of transformer.**

***Keywords:* Transformer, IR Controller, Copper tube, Coolant.**

I. INTRODUCTION

Energy is a priority nationally as well as internationally, regarding electricity both transmission and distribution system. Electrical transformers include the huge amount of main investment in transmission and distribution electrical systems. Since power transformers are key element in power equipment operation. The different types of faults occurring inside a transformer are overload, short circuit, over excitation, oil level fault, insulation breakdown etc. All these faults increase the heating and thereby increase the temperature of the transformer resulting in local hotspots and even the insulation failure .When the temperature of the transformer goes high, oil level in the tank decreases due to heating effect. If the oil level goes beyond marked level, it will affect the cooling and insulation of transformer. The main two parameters of cooling optimization of a transformer are the temperature and losses of the cooling system of a transformer. The temperatures in oil and windings define the loading capacity of the transformer. Large transformers thus need more intense cooling to remove thermal losses. Power losses raise the temperature of a transformer to the point whereby an equalization of cooling power with the power of losses is reached.

Transformer cooling is one of the most important factors for transformer to work properly. If the temperature of the transformer will continue to increase rapidly, it will result in the degradation of the insulation used in the transformer resulting in the damaging of the various parts and hence the failure of the transformer. Thus, proper removal or treatment of heat is necessary for the efficient working, longer life and higher efficiency of the transformer. The basic purpose of a cooling system is to limit the temperature of a transformer. Most of the transformers are designed for 55°C or 65°C rise. In each case, it is extremely important that proper temperature transfer take place. The design of the transformer relies on a specific heat transfer between the windings, oil and the radiator or cooler for heat extraction. Any increase in heat generation or any heat transfer reduction results in Transformer cooling is one of the most important factors for transformer to work properly. If the temperature of the transformer will continue to increase rapidly, it will result in the degradation of the insulation used in the transformer resulting in the damaging of the various parts and hence the failure of the transformer. Thus, proper removal or treatment of heat is necessary for the efficient working, longer life and higher efficiency of the transformer. The basic purpose of a cooling system is to limit the temperature of a transformer. Most of the transformers are designed for 55°C or 65°C rise. In each case, it is extremely important that proper temperature transfer take place. The design of the transformer relies on a specific heat transfer between the windings, oil and the radiator or cooler for heat extraction. Any increase in heat generation or any heat transfer reduction results in higher winding temperatures and shorter insulation life. Cooling system can increase the load carried by a transformer without heat damage when the critical limit of the temperature is reached, there are chances of failure of transformer as there is aging of the transformer's insulation. Thus the role of cooling system is to increase the capacity of the transformer to carry load without reaching hotspot temperature.

Methods of Cooling of Transformer

Transformer is cooled by the following methods given below-

1. Air Natural (AN)
2. Air Forced (AF) or Air Blast
3. Oil Natural Air Natural (ONAN)
4. Oil Natural Air Forced (ONAF)
5. Oil Forced Air Forced (OFAF)
6. Oil Natural Water Forced (ONWF)

7. Oil Forced Water Forced (OFWF**)**

2. LITERATURE SURVEY

A complete review of experimental approaches to the cooling of transformer coils by natural convection method performed by By E. D. taylor [1]. By Wenhao niu performed the experimental study of a novel cooling system of a power transformer in an urban underground substation [2]. Eleftherios I performed a distribution transformer cooling system improvement by innovative tank panel [3]. PLC based transformer cooling control system performed by Shreenivas Pai [4]. The transformer fault detection and protection system performed by Kowshik Sen Gupta [5].D.V. Pushpa Latha control the temperature based on millienium 3 PLC by using LM 35sensor, [6]. Based on microcontroller the transformer cooling control performed by the Bhushan S. Rakhonde[7]. M. Anand worked on microcontroller based transformer monitoring and controlling system by using Zigbee[8]. By V. M. Monsinger performed bridgment of loading transformer [9]. Kamil Dursun performed the oil and winding temperature control in power transformers [10]. Armando Guzmán performed a current-based solution for transformer differential protection[11]. Numerical study of cooling solutions inside a power transformer by Nelu-Cristian Cherechesa [12].New development in transformer cooling calculations performed by K. Eckholz. [13]. Transformer hotspot temperature calculation performed by Mohd Taufiq Ishak [14]. Study on simulation test device of transformer split type cooling system performed by Wei Bengang [15]. By O.E. Gouda performed the predicting transformer temperature rise and loss of life in the presence of harmonic load currents [16]. By L. Pierrat the Power transformer life expectancy under distorting power electronic loads performed [17].M. Srinivasan performed the prediction, of transformer insulation life with an effect of environmental variables [18]. Analyzing the impact of ambient temperature indicators on transformer life in different regions of Chinese Mainland performed by Cui-fen Bai [19].Determination of thermal life expectancy of overhead distribution transformers by Donald o Chaghead [20].

3. EXPERIMENTAL SETUP AND ITS WORKING

The experimental setup of transformer cooling is shown in figure.1

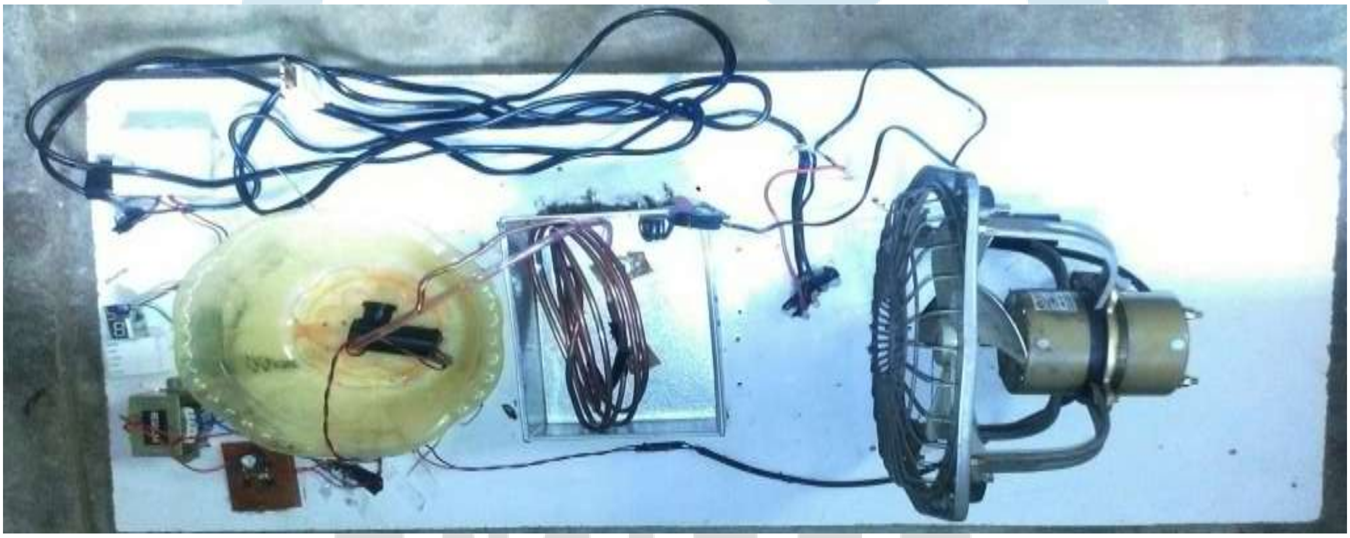

Fig.1. Experimental Setup

The following devices have been used in this experiment-

S. No.	Devices	Function of Devices
1.	Air fan	There is a 12 V DC operated fan with a speed of 2400 rpm. It operates in 8 controlling speeds.
2.	Water circulating pump	There is a 12 V DC operated water circulating pump. It operates in 4 controlling speeds.
3.	Copper tube	There is a tube of copper whose diameter is 4 mm. Water and coolant are circulating through this tube.
4.	Step down transformer	There is a 12V 2amp step down transformer .Which is used for the operation of air fan and water circulating pump.
5.	Rectifier	There is a full wave rectifier .Which has been used in setup to convert 12V AC to 12V DC.
6.	Immersion rod	There is an immersion rod (250W) used to heat transformer oil.
7.	IR controller	There is an IR controller used to control the speed of air fan and water circulating pump.
8.	Digital Thermometer	There is a digital thermometer used for temperature measurement of transformer oil.

Fig.2. DC Power Supply

Fig.3. Copper Tube

Fig.4. IR Controller

Fig.5. Digital Thermometer

3.1. Coolants

Transformer oil coolants - Transformer oil or insulating oil is oil that stable at high temperatures and has excellent electrical insulating properties. It is used in oil-filled transformers, some types of high-voltage capacitors, fluorescent lamp ballasts, and some types of high-voltage switches and circuit breakers. Its functions are to insulate, suppress corona discharge and arcing, and to serve as a coolant. Transformer oil's primary function are to insulate and cool a transformer. It must therefore have high dielectric strength, thermal conductivity, and chemical stability, and must keep these properties when held at high temperatures for extended periods. Some other alternatives of transformer oil are Polychlorinated biphenyls (PCBs), mineral oils (Pentaerythritol tetra fatty acid).

Ethylene Glycol Red Coolants -There is liquid red coolant.which chemical name is ethylene glycol. A coolant is a fluid which flows through or around a device to prevent its overheating, transferring the heat produced by the device to other devices that use or dissipate it. Coolant, which is commonly called antifreeze, is a mixture of ethylene or propylene glycol and water, usually in a 50/50 ratio. They are used today for a variety of applications, including automobiles. There properties are high thermal capacity, low viscosity, low-cost, non-toxic, chemically inert, and neither causes nor promotes corrosion of the cooling system. The freezing point of coolant is (below 0°C) and boiling point is (above 100°C). Coolant (or antifreeze) protects the engine from freezing while defending components against corrosion, as well as plays a critical role in sustaining overall engine heat balance by removing heat. Red antifreeze coolant is known as long life or extended life antifreeze .Which gives useful life to the engine. It has a different type of corrosion inhibitor. There is a combination of silicate, phosphate and borate, which makes life of coolant longer. And it contains organic acids that protect the engine from corrosion. Red type antifreezes are suitable for up to five years or 100,000 miles. The lifespan of long life antifreeze is about 2-4 years or 60,000 miles in older cars. In many older vehicles green antifreeze replaced with the red antifreeze.

3.2. The Methods Applied For Cooling of the Transformers

In this experiment, firstly transformer oil is heated through immersion rod. Hot oil is representing the loss of actual transformer. After that, the temperature of the transformer oil is reduced by using the following methods one by one.

1. Air Natural cooling

First, temperature of transformer oil is reduced by the method of air natural. In Air Natural method generated heat in the transformer is cooled by the circulation of natural air. When the temperature of the transformer becomes higher as compared to the temperature of the surrounding air, thus by the process of natural convection heated air is replaced by the cool air. This method is also known as a self-cooled method.

2. Air Forced cooling

In this method temperature of transformer oil is reduced by the method of air forced. In this method, generated heat is cooled by the forced air circulation method. With the help of fan, high velocity of air is forced on the transformer oil.

3. Air Forced Water Forced cooling

In this method temperature of transformer oil is reduced by the method of air forced water forced. In this method, generated heat is cooled by air fan and water pump. Water is circulated through the copper tube. Both the water and the air are applied by force for cooling of transformer oil.

4. Air Forced Water Forced with coolant cooling

In this method temperature of transformer oil is reduced by the method of air forced water forced with coolant. In this method, generated heat is cooled by air fan and water pump with coolant. Water and coolant circulate through the copper tube. The air and water with coolant are applied by force for cooling of transformer oil.

4. RESULT AND DISCUSSION

4.1. Comparison of cooling methods

In this experiment have used four types of cooling methods on different operating temperature .Such as Air natural, Air forced, Air forced water forced, Air forced water forced with coolant cooling. The initial temperature of transformer oil is 30°C. In this experiment we got the following results-

Table.4.1.1.When operating temperature of transformer oil is 50°C

So. No.	Initial temperature of transformer oil (in °C)	Operating temperature of transformer oil (in °C)	Time of Cooling (in minutes)	Air natural cooling (Temperature in °C)	Air forced cooling (Temperature in °C)	Air forced water forced cooling (Temperature in °C)	Air forced water forced, coolant cooling (Temperature in °C)
1.	30	50	4	49	47	42	37
2.	30	50	8	48	42	36	33
3.	30	50	12	47	38	33	31
4.	30	50	16	46	35	32	28
5.	30	50	20	45	34	31	25

According to these results the graph of the cooling methods is as follows-

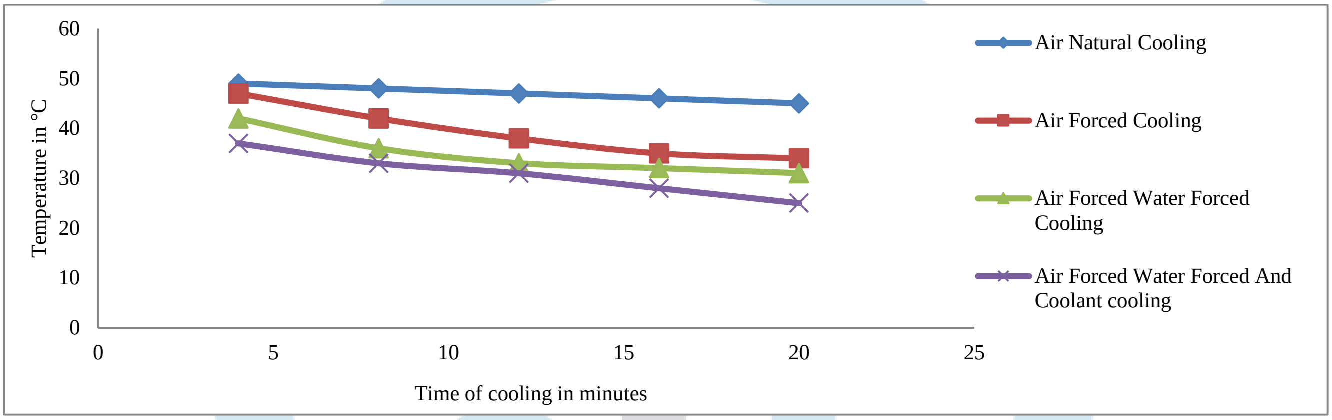

Fig.6.When operating temperature of transformer oil is 50°C

Table.4.1.2.When operating temperature of transformer oil is 60°C

So. No.	Initial temperature of transformer oil (in °C)	Operating temperature of transformer oil (in °C)	Time of Cooling (in minutes)	Air natural cooling (Temperature in °C)	Air forced cooling (Temperature in °C)	Air forced water forced cooling (Temperature in °C)	Air forced water forced, coolant cooling (Temperature in °C)
1.	30	60	4	58	56	46	42
2.	30	60	8	57	48	41	35
3.	30	60	12	56	41	37	32
4.	30	60	16	54	39	34	28
5.	30	60	20	53	36	33	25

According to these results the graph of the cooling methods is as follows

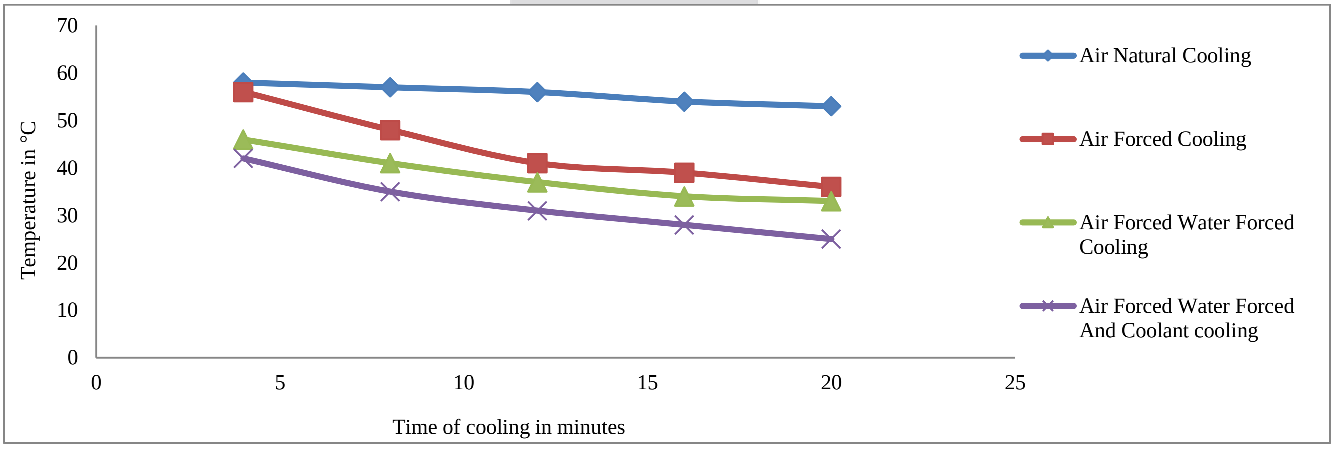

Fig.7.When operating temperature of transformer oil is 60°C

Table.4.1.3.When operating temperature of transformer oil is 70°C

So. No.	Initial temperature of transformer oil (in °C)	Operating temperature of transformer oil (in °C)	Time of Cooling (in minutes)	Air natural cooling (Temperature in °C)	Air forced cooling (Temperature in °C)	Air forced water forced cooling (Temperature in °C)	Air forced water forced, coolant cooling (Temperature in °C)
1.	30	70	4	67	63	49	45
2.	30	70	8	64	53	45	38
3.	30	70	12	62	47	41	35
4.	30	70	16	59	40	37	32
5.	30	70	20	57	37	35	26

According to these results the graph of the cooling methods is as follows-

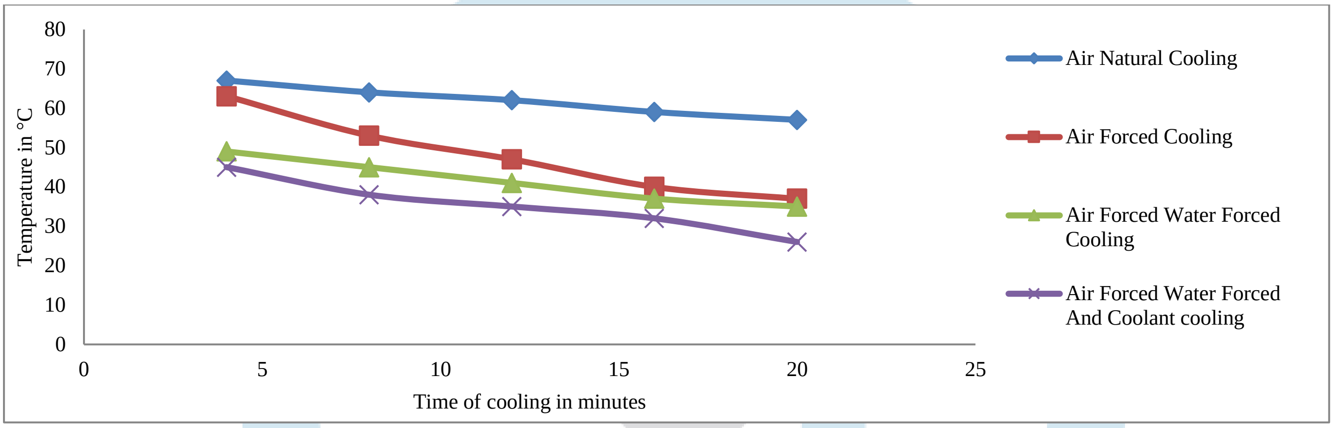

Fig.8.When operating temperature of transformer oil is 70°C

Table.4.1.4.When operating temperature of transformer oil is 75°C

So. No.	Initial temperature of transformer oil (in °C)	Operating temperature of transformer oil (in °C)	Time of Cooling (in minutes)	Air natural cooling (Temperature in °C)	Air forced cooling (Temperature in °C)	Air forced water forced cooling (Temperature in °C)	Air forced water forced, coolant cooling (Temperature in °C)
1.	30	75	4	72	65	51	46
2.	30	75	8	69	53	45	41
3.	30	75	12	66	47	42	36
4.	30	75	16	64	41	39	33
5.	30	75	20	63	37	36	27

According to these results the graph of the cooling methods is as follows-

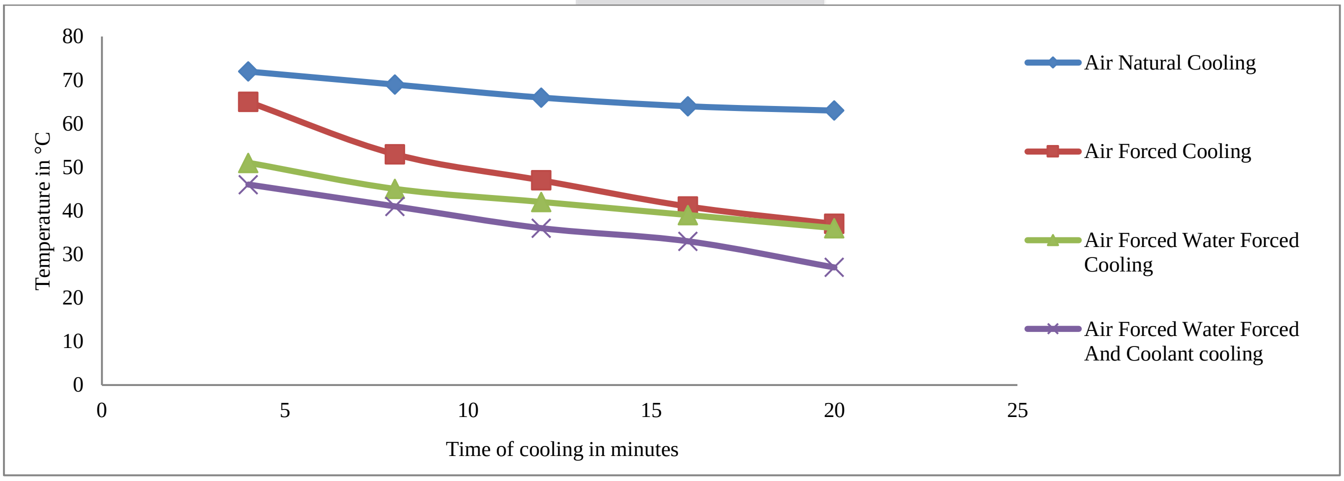

Fig.9.When operating temperature of transformer oil is 75°C

Table.4.1.5.When operating temperature of transformer oil is 80°C

So. No.	Initial temperature of transformer oil (in °C)	Operating temperature of transformer oil (in °C)	Time of Cooling (in minutes)	Air natural cooling (Temperature in °C)	Air forced cooling (Temperature in °C)	Air forced water forced cooling (Temperature in °C)	Air forced water forced, coolant cooling (Temperature in °C)
1.	30	80	4	77	66	55	50
2.	30	80	8	74	54	48	41
3.	30	80	12	71	48	43	37
4.	30	80	16	68	42	39	35
5.	30	80	20	66	38	36	28

According to these results the graph of the cooling methods is as follows-

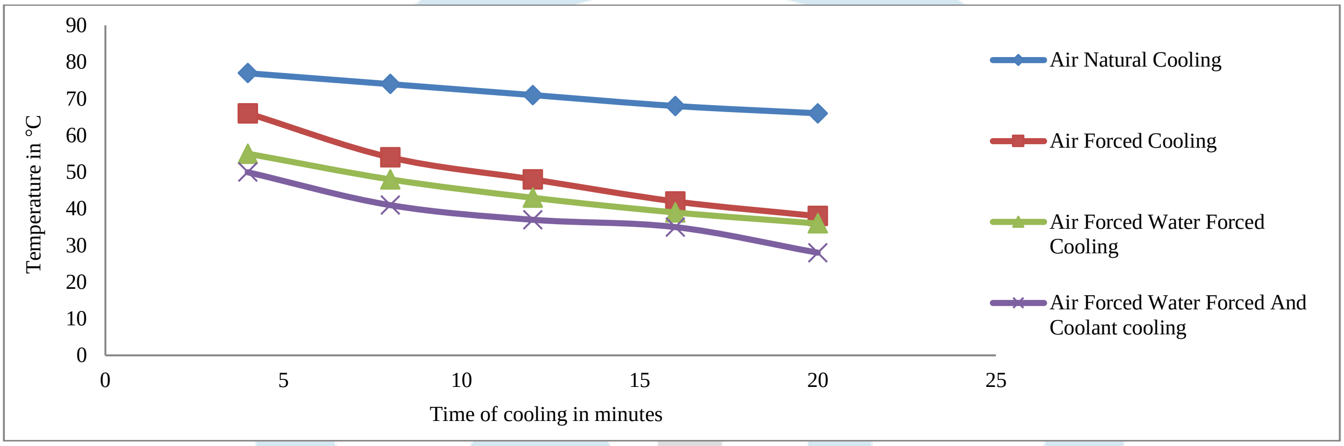

Fig.10.When operating temperature of transformer oil is 80°C.

Table.4.1.6.When operating temperature of transformer oil is 110°C

So. No.	Initial temperature of transformer oil (in °C)	Operating temperature of transformer oil (in °C)	Time of Cooling (in minutes)	Air natural cooling (Temperature in °C)	Air forced cooling (Temperature in °C)	Air forced water forced cooling (Temperature in °C)	Air forced water forced, coolant cooling (Temperature in °C)
1.	30	110	4	101	83	57	52
2.	30	110	8	92	66	50	42
3.	30	110	12	86	54	44	38
4.	30	110	16	82	44	40	36
5.	30	110	20	78	42	38	31

According to these results the graph of the cooling methods is as follows-

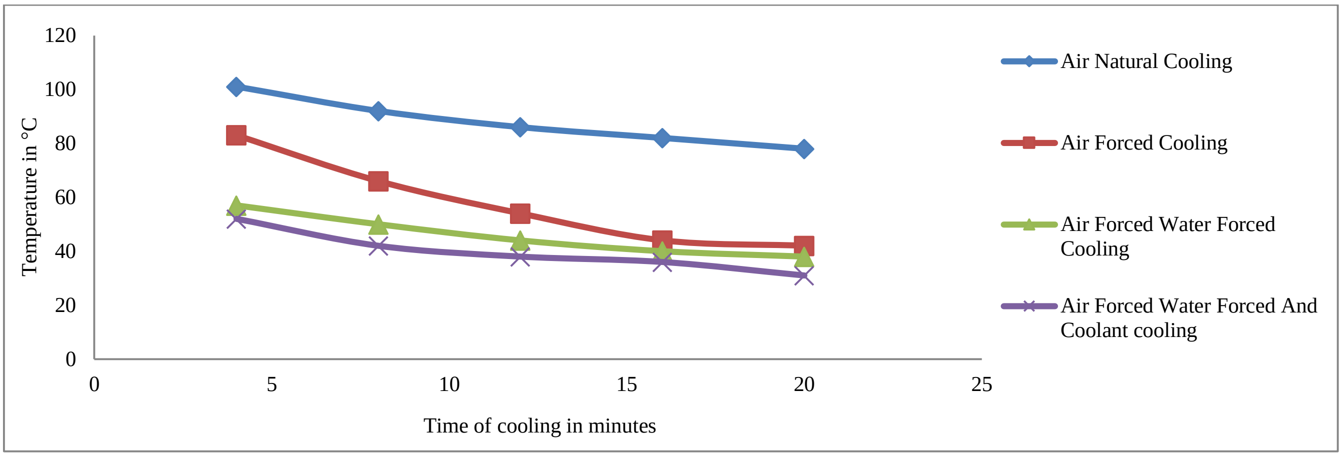

Fig.11.When operating temperature of transformer oil is 110°C.

In this experiment by comparing these four methods, it is observed that the temperature of transformer oil decreases rapidly with Air forced water forced with coolant cooling technique.

5. WORKING TEMPERATURE V/S LIFE OF TRANSFORMER

The life of a transformer depends on the life of its insulation system. The temperature has a major impact in the life of transformer. According to generally adopted estimate states that if a transformer's maximum operating temperature is reduced by 6°C, the thermal life of the insulation system is approximately doubled. Conversely, if the total operating temperature is raised by 6°C, the thermal life expectancy of the insulation system is reduced by one half (based upon the Arrhenius Equation of chemical reaction time v/s temperature can be adapted to approximate relationship between insulation life and total operating temperature**).** Arrhenius equation is used to enhance the life expectancy of insulation system. It is the backbone to enhance the life of the insulation system. The **Arrhenius equation** is a formula for the temperature dependence of reaction rates. Arrhenius' equation gives the dependence of the rate constant of a chemical reaction on the absolute temperature, a pre-exponential factor and other constants of the reaction [21].

$$k = Ae^{-Ea/RT}$$

Where
k = Rate constant
T = Absolute temperature (in kelvin)
A = Pre-exponential factor, a constant for each chemical reaction. According to collision theory, A is the frequency of collisions in the correct orientation
Ea =Activation energy for the reaction (in the same units as R*T)
R = Universal gas constant.

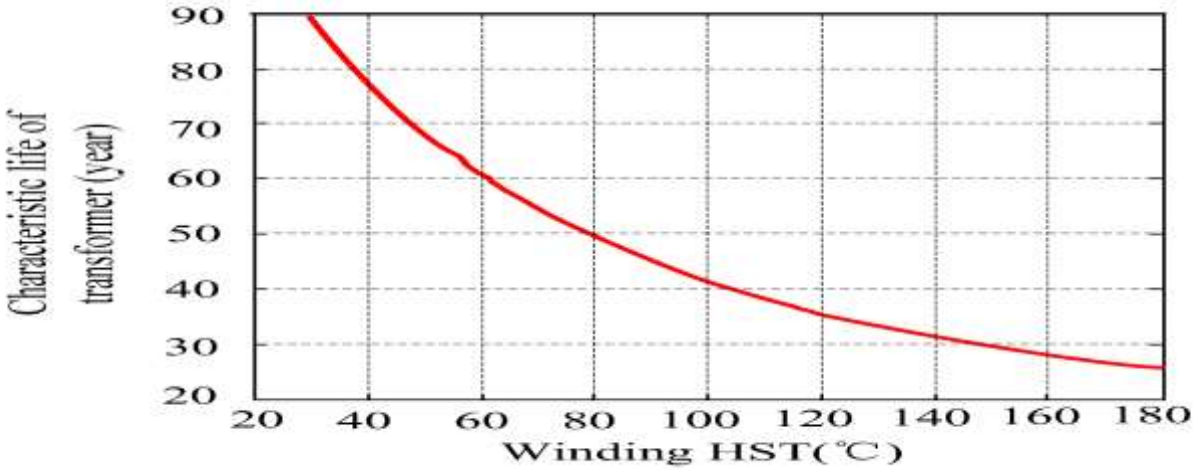

Fig.12. Working temperature v/s life expectancy of transformer

Figure.12. is showing the relation between working temperature v/s life expectancy of transformer. According to all of these, if the temperature of paper insulation or oil insulation is decreases, the life expectancy of transformer is approximately doubled [22][23].

6. CONCLUSION

Since the power transformer is very important and valuable device in power system. It is estimated that 50% of power transformer survive 50 years of use. But about 30% of power transformer failures are due to insulation Breakdown. The main causes for insulation Breakdown of power transformer is its rise in temperature. In this paper different processes of cooling of transformer oil are compared on different operating temperatures and it's analyzed the different method of cooling by experimentally as Air natural, Air forced, Air forced water forced and Air forced water forced with coolant cooling. Finally it is observed that air forced water forced with coolant method of cooling is best among all other methods. By using this technique the maximum operating temperature of power transformer is reduced and due to which the life expectancy of power transformer increases.

REFERENCES

[1]. By E. D. TAYLOR, Experimental approaches to the cooling of transformer coils by natural convection, *The Institution of Electrical Engineers Paper No. 2505 S Apr. 1958*.

[2]. Wenhao Niu, Guoqiang Zhang, The experimental study of a novel cooling system of a power transformer in an urban underground substation, *2010 International Conference on Power System Technology.*

[3]. Eleftherios I. Amoiralis, Marina A. Tsili, Antonios G. Kladas, Distribution transformer cooling system improvement by innovative tank panel geometries, *IEEE Transactions on Dielectrics and Electrical Insulation Vol. 19, No. 3; June 2012*.

[4]. Shreenivas Pai, Intelligent PLC based transformer cooling control system, *2017 International Conference on Nascent Technologies in the Engineering Field, IEEE.*

[5]. Kowshik Sen Gupta, Transformer fault detection and protection system, *Innovative Systems Design and Engineering, Vol.6, No.7, 2015.*

[6]. D.V. Pushpa Latha, Millienium3 PLC based temperature control using LM 35, *Research Journal of Engineering Sciences, Vol. 2(6), 30-34, June (2013).*

[7]. Bhushan S. Rakhonde, Microcontroller based transformer cooling control system, *IOSR Journal of Electrical and Electronics Engineering, PP 31-36.*

[8]. M. Anand, Microcontroller based transformer monitoring and controlling system using Zigbee, *International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE), Volume 3, Issue 12, December 2014*.

[9]. By V. M. Montsinger, A bridgment of loading transformers by temperature, *Presented at the Winter Convention of the A. I.E. E., New York, N. Y., Jan. 27-31, 1930.*

[10]. Kamil Dursun, Oil and Winding Temperature Control in Power Transformers, *4th International Conference on Power Engineering, Energy and Electrical Drives, Istanbul, Turkey, 13-17 May 2013.*

[11]. Armando Guzmán, "A current-based solution for transformer differential protection—part II: relay description and Evaluation*", IEEE Transactions on Power Delivery, Vol. 18, NO. 2, April 2003.*

[12]. Nelu-Cristian Cherechesa, Numerical study of cooling solutions inside a power transformer, *Science Direct Energy Procedia 112 (2017) 314 – 321. Sustainable Solutions for Energy and Environment, EENVIRO 2016, 26-28 October 2016, Bucharest, Romania.*

[13]. K. Eckholz, New development in transformer cooling calculations,*21, rue d'Artois, F-75008 Paris http://www.cigre.org Session 2004© CIGRÉ.*

[14]. Mohd Taufiq Ishak and Zhongdong Wang, Transformer hotspot temperature calculation using IEEE loading guide, *2008 International Conference on Condition Monitoring and Diagnosis, Beijing, China, April 21-24, 2008.*

[15]. Wei Bengang et.al. , Study on simulation test device of transformer split type cooling system, *Science Direct Energy Procedia 100 (2016) 556 – 560, 3rd International Conference on Power and Energy Systems Engineering, CPESE 2016, 8-12 12 September 2016, Kitakyushu, Japan.*

[16]. O.E. Gouda a, G.M. Amer b, W.A.A. Salem, Predicting transformer temperature rise and loss of life in the presence of harmonic load currents, *Ain Shams Engineering Journal (2012).*

[17]. L. Pierrat, Power transformer life expectancy under distorting power electronic loads, *IEEE 1996*.

[18]. M. Srinivasan A. KrishnanPrediction, of Transformer Insulation Life with an Effect of Environmental Variables, *International Journal of Computer Applications (0975 – 8887) Volume 55– No.5, October 2012*.

[19]. Cui-fen Bai, Wen-Sheng Gao,and Tong Liu, Analyzing the impact of ambient temperature indicators on transformer life in different regions of Chinese Mainland, *Hindawi Publishing Corporation The Scientific World Journal Volume 2013.*

[20]. Donald O Craghead, Determination of thermal life expectancy of overhead distribution transformers, *IEEE Transactions On Power Apparatus And Systems Vol. Pas-86, No. 9 September 1967.*

[21]. F. Husnayain et.al. , Transformer Oil Lifetime Prediction Using the Arrhenius Law based on Physical and Electrical Characteristics, *2015 International Conference on Quality in Research*.

[22]. Lefeng Cheng et.al., Hot spot temperature and grey target theory-based dynamic modeling for reliability assessment of transformer oil-paper insulation systems: *A Practical Case Study Energies 2018, 11, 249; doi:10.3390/en11010249 www.mdpi.com/journal/energies*.

[23]. TIM GRADNIK, Cooling system optimization and expected lifetime of large power Transformers, *Proceedings of the 2006 IASME/WSEAS International Conference on Energy & Environmental Systems, Chalkida, Greece*.