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Increase in Loading of Motors due to Restricted Cooling

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Abstract

Improving the efficiency of induction motors, which are the workhorse of industry and consumes 80 % of the power generated can lead to a quantum jump in energy saving. The efficiency can be increased by improving cooling performance. As most of the loads of a petrochemical industry are consist of motors of different sizes, unnecessary switchgear loading can be avoided by proper maintenance practices. This paper presents the relationship between the efficiency or the losses and the surface temperature of motors with experiments.

Keywords: Induction motor, ventilation, surface temperature, Stefan Boltzmann Law, radiation, emissivity, insolation.

Introduction

Inadequate ventilation and cooling of motors can significantly increase losses and lead to unreliable operation. Providing adequate ventilation and keeping motor cooling surfaces clean can help dissipate heat to reduce excessive losses. The life of the insulation in the motor reduces by half with every 8^{0}C increase in motor operating temperature. in motor operating temperature over the recommended peak, the time before rewinding would be needed is estimated to be halved. Insufficient cleaning of air cooling passages can cause deterioration in motor efficiency over time. Ambient conditions can also have a detrimental effect on motor performance. For example, excessively high temperatures, high dust loading, corrosive atmosphere, and humidity can impair insulation properties. However, with adequate care, motor performance can be maintained.

This paper presents the relationship between the efficiency or the losses and the increased surface temperature due to inadequate cleaning of the motor surface leading to higher body temperature.

Problem formulation

The heat dissipated by radiation from the surface of a motor depends upon its temperature and its other characteristics like color, roughness etc.

Heat radiated per unit surface is given by Stefan Boltzmann Law:
$q\ rad = 5.7 \times 10^{-8} e\ (T_1^4 - T_0^4)\ W / m^2$ — Equation -1

Where:
T_1, T_0 = absolute temperature of the emitting surface and the ambient medium respectively.
Θ_1, Θ_0 = temperature of the emitting surface and the ambient medium respectively, degree C.
e = co- efficient of emissivity

As Equation – 1can be written as
q rad =
$5.7 \times 10^{-8} e\ (T_1 - T_0)(T_1^3 + T_1^2T_0 + T_1T_0^2 + T_0^3)\ W / m^2$ — Equation-2
Now $(T_1 - T_0) = (273 + \Theta_1) - (273 + \Theta_2) = \Theta_1 - \Theta_0 = \Theta$

The term $(T_1^3 + T_1^2T_0 + T_1T_0^2 + T_0^3)$ varies relatively very less within the operating temperature limits for electrical motors , hence this equation can be written as :
$q\ rad = 5.7 \times 10^{-8} e\ K_r(T_1 - T_0)\ W / m^2$ — Equation-3

Where $K_r = (T_1^3 + T_1^2T_0 + T_1T_0^2 + T_0^3)$
In electrical motors as radiation is also accompanied by convention following expression may also be used:
$q\ rad = 2.9\ e\ \Theta^{1.17}\ W / m^2$ — Equation-4
Hence from Equation 3 and Equation 4 we see that heat evacuation from a motor depends on two factors :
e , emissivity of the surface
and
Θ, the temperature difference between the emitting surface and the ambient medium.

Typical value of co-emissivity for dull metallic paint is 0.9 while for polished metal it is 0.15. Hence all electrical motors are painted with dull metallic paints (usually grey in color) in order to have large heat dissipation due to radiation.

The motors also absorb heat from sun by Insolation. The Earths outer atmosphere receives about 1.3 kW/m2 and under good climatic condition about two third of this energy may reach the earths surface. In case of a high absorption factor of the motor surface, it may absorb large energy by insolation thereby its temperature rises by a few degrees. However if the absorption factor is small the suns radiation is re-emitted.

Results based on Practical Experiments

Calculation of Total Heat Radiated by Motor when the Motor is Clean

In the calculation sheet shown below we have calculated total heat radiated from a 160 kw, motor by using Stefan Boltzmann Law (Equation-1). The calculations were simplified by taking only motor body temperature taken at only one point and taking emissivity as 0.95.

Rated Power (KW)	160
Rated Amps (A)	274
Load Amps (A)	120
Power Drawn on load (KW)	68.6
Percentage Loading Of Motor (%)	42.875
Motor DE side temperature (deg C)	53
Motor NDE side temperature (deg C)	41
Motor Body temperature (deg C)	55
Ambient temperature (deg C)	27
Absolute temperature of the emitting surface (T_1)	328
Absolute temperature of the ambient medium (T_0)	300
Emissivity of the clean motor (e)	0.95
Surface Area Of Motor (M^2)	3
q rad in W / m^2	188
Total Heat radiated (Watt)	564

Calculation of Change in Emissivity when the Same Motor is in Dirty Condition

In the calculation sheet shown below we have calculated change in emissivity from the same 160 kw motor by using Stefan Boltzmann Law (Equation-1). The calculations were simplified by taking only motor body temperature taken at only one point and taking heat radiated same as the results found in the previous calculation..

Rated Power (KW)	160
Rated Amps (A)	274
Load Amps (A)	124
Power Drawn on load (KW)	69.3
Percentage Loading Of Motor (%)	43.3125
Motor DE side temperature (deg C)	62
Motor NDE side temperature (deg C)	53

Motor Body temperature (deg C)	64
Ambient temperature (deg C)	28
Absolute temperature of the emitting surface (T_1)	337
Absolute temperature of the ambient medium (T_0)	301
Surface Area Of Motor (M^2)	3
q rad in W / m^2	188
Total Heat radiated (Watt)	564
Emissivity of the dirty motor (e)	0.8068

Calculation of Total Heat Radiated by Motor considering both radiation and convection

When the Motor Is Clean

In the calculation sheet shown below we have calculated total heat radiated from a 160 kw, motor by using expression of total heat radiation considering both radiation and convection(Equation-4). The calculations were simplified by taking only motor body temperature taken at only one point and taking emissivity as 0.95.

Rated Power (KW)	160
Rated Amps (A)	274
Load Amps (A)	120
Power Drawn on load (KW)	68.6
Percentage Loading Of Motor (%)	42.875
Motor DE side temperature (deg C)	53
Motor NDE side temperature (deg C)	41
Motor Body temperature (deg C)	55
Ambient temperature (deg C)	27
Absolute temperature of the emitting surface (T_1)	328
Absolute temperature of the ambient medium (T_0)	300
Emissivity of the clean motor (e)	0.95
Surface Area Of Motor (M^2)	3
q rad in W / m^2	135.92
Total Heat radiated (Watt)	407.77

When the Same Motor is in Dirty Condition

In the calculation sheet shown below we have calculated change in emissivity from the same 160 kw motor by using expression of total heat radiation considering both radiation and convection(Equation-4). The calculations were simplified by taking only motor body temperature taken at only one point and taking heat radiated same as the results found in the previous case.

Rated Power (KW)	160
Rated Amps (A)	274
Load Amps (A)	124
Power Drawn on load (KW)	69.3
Percentage Loading Of Motor (%)	43.3125
Motor DE side temperature (deg C)	62
Motor NDE side temperature (deg C)	53
Motor Body temperature (deg C)	64
Ambient temperature (deg C)	28
Absolute temperature of the emitting surface (T_1)	337
Absolute temperature of the ambient medium (T_0)	301
Surface Area Of Motor (M^2)	3
q rad in W / m^2	135.92
Total Heat radiated (Watt)	407.77
Emissivity of the dirty motor (e)	0.708

Calculation of cooling coefficient considering only loss from outer surface of the motor

As we know that

$\Theta_s = Q\, c / S$ —— Equation-5

Where:

Θ_s= Surface temperature rise in degree C

Q = Power loss or heat developed in Watt.

c = Cooling coefficient

S = Outer surface area of motor in m2

In this case:

Outer cylindrical surface of the stator core

= S= 3 m2

Cooling coefficient for outer surface = c

Q = Increase in loss in terms of watt due to less cooling = 69.3 – 68.6 = 0.7 Kw = 700 watt

Temperature rise = $\Theta_s = 64 - 55 = 9$ degree C

Hence using Equation-5

$\Theta_s = 700 / (3 / c)$

$9 = 700 / (3 / c)$

c= 27/700 = 0.03857

Hence cooling coefficient for outer surface

= c = 0.03857

As we know value of cooling coefficient for outer surface varies between 0.025 to 0.04

The value 0.03857 is in higher side in the range given.
Further from equation-4 it also can be concluded that higher the cooling coefficient, higher will be the temperature rise of the motor.

Determination of increase in winding temperature

As we know that
$R_2/R_1 = (\Theta_2+235)/(\Theta_1+235)$ — Equation-6
Where,
R_2 = Measured resistance of the winding when the motor is hot. = 0.69 ohm.
R_1 = Measured initial winding resistance of the cold motor = 0.6 ohm.
Θ_1= Ambient temperature = 28 degree C.
Θ_2= temperature of the winding after temperature rise.

Hence, $\Theta_2 + 235 = (\Theta_1+235) R_2/R_1$
$\Theta_2 = ((\Theta_1+235) R_2/R_1) - 235$
$= (1.16 \times 263) - 235$
= 70.08 degree C

In this method the temperature of the winding is determined by increase in resistance of the winding. Therefore, this method involves the measurement of the resistance, both cold and hot, and estimating the average temperature rise by use of the resistance temperature co-efficient. This method is used for windings only.

Here also we can see that the value of Θ_2 is 70.08 degree C is slightly more then the measured motor body temperature of 64 degree C. Considering accuracy level of measuring instrument the winding temperature is comparable with the measured body temperature. Any way measured temperature is of motor body and calculated temperature is of motor winding. Θ_2 will be on higher side then the measured body temperature of the motor because of cooling system of the motor.

Calculation of Energy savings by cleaning motors

From I and II we can calculate that there is a energy saving of 0.7 KW if we keep the motor clean. This 0.7 KW savings is for a 160 kw motor.

Considering similar motor condition for a big industrial plant having connected load of 7 MW having induction motors if different sizes, this savings will be as high as 30.625 KW or 268275 KWHR for 1 year.

Considering unit price of Rs 6 / unit ,the savings will be more then Rs 16 lakhs per year.

Conclusion

In case of a dirty motor emissivity of the motor decreases, resulting less heat dissipation by radiation which further resulting to increase in motor body temperature. In case of a dirty motor absorption factor is also high , hence the motor will also absorb energy by insolation thereby its temperature may rises by a few more degrees . In case of a dirty motor cooling coefficient of the motor is also in the higher side. Comparing the calculated increase in winding temperature and the measured increase in motor surface temperature of the dirty motor, we can conclude that high winding temperature will lead to even more loss.

This high temperature of motor will also lead to inefficient running of motor. The decreased efficiency will also result into unnecessary loading on switchgear feeding the motor. More the numbers of such motors connected to the same switchgear more will be the loading on the switchgear.

Thus by regular proactive rounds in field and regular cleaning of the motors we can increase the efficiency of the motors and decrease loading on the switchgear, thereby converting the Electrical System into an “Energy Efficient Electrical System”.

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