The International Journal of Engineering and Information Technology

journal homepage:www.ijeit.misuratau.edu.ly

Using of "Mathlab Fcn." For Realistic simulation of AC Motor Overload Protection

M. B. Jannat
Misurata University.

Abstract- **Motor overload protection is a protection against overcurrent that may cause motor overheating which leads to motor damage. In overload protection relays, some techniques depend on current crossing the motor, motor thermal constants, operating time, and ambient temperature to estimate continuously the temperature of the motor. Therefore, it is closer to reality and can prevent inadvertent tripping. The paper proposes a new method to simulate this motor overload protection using MATLAB/Simulink. This method estimates continuously the percentage overtemperature of the motor. The "MATLAB Fcn" block is used to pass input values to a function in "MATLAB", to perform some calculations, and return a value in each step. This value determines whether the motor will keep running or not.**

Index Terms: **Motor overload protection, percentage overtemperature, MATLAB/Simulink.**

I. INTRODUCTION

AC motor systems play a critical role in industrial process, while consuming more than half of all the electric power produced. Due to their effectiveness, ruggedness and low maintenance requirements, these ac motors are widely used in applications of pumps, fans, mills, compressors, etc. The malfunction of a motor may not only lead to the repair or replacement of the individual motor, but also cause significant financial losses due to unexpected process downtime. Therefore, reliable motor protection is essential for minimizing the motor failure rate, increasing the mean time to a destructive motor breakdown, and prolonging a motor's lifetime.

Over the years, substantial efforts have been made in developing preventive monitoring and protection techniques for ac motors. As an important feature of any motor protection system, thermal protection is crucial for avoiding thermal overload and prolonging a motor's lifetime. As one of the major underlying root causes of motor failures, thermal overload can lead to damage of components of a motor, including stator winding insulation, bearing, motor conductors, and core, etc. During thermal overload, the stator insulation is the weakest component because its thermal limit is reached before that of any other component. About 35-40% of induction motor failures are related to a stator winding insulation failure [1]. Stator insulation failures are normally the results of long term thermal aging. A high stator winding temperature, which also depends on the insulation class, gradually and irreversibly reduces the electrical and mechanical performance of the insulation materials due to chemical reactions, and eventually leads to insulation failures. The typical thermal limits of the stator winding for different insulation classes are listed in Table 1 [1].

Table 1. The thermal limit

Insulation class	Ambient temperature (°C)	Rated temperature rise (°C)	Hot spot temperature (°C)
A	40	60	105
B	40	80	130
F	40	105	155
H	40	125	180

As a rule of thumb, it is estimated that a motor's life is reduced by 50% for every 10°C increase above the stator winding temperature limit. Therefore, a motor must be de-energized immediately when the thermal limit is reached. As a result, accurate and reliable thermal protection of ac motors is essential for prolonging a motor's lifetime and preventing unexpected process downtime [1].

It was determined that temperature kills motors. Ideally, a motor should have a relatively high insulation temperature rating, and a relatively low operating temperature for both the insulation system and bearing system. This provides for thermal margin in the event of motor overload, severe starting duty, safety margin for adjustable speed drive applications.

For protection purposes, many types of protection relays are used such as over-current relays, and thermal relays. In this work, an induction motor is simulated in Matlab / Simulink and thermal protection. Chen Li'an and

---

Received 31 July , 2022; revised 31 Aug, 2022; accepted 30 Sep, 2022.

Zhang Peiming in [2] said overload of the motor can be simulated by the Simulink. Also, Raheel Muzzammel and others simulated induction motor in Matlab/Simulink and different types of protection [3]. Much research has been done on simulation of some protections of over current. In [4], Supriyanto Suhono and others present the methodology of the simulation and implementation of overcurrent relays. Also In [5], the PSCAD/EMTDC simulation software was used to conduct simulations for the overcurrent protection scheme. A method for simulation and design of thermal bimetal was introduced in [6], which showed a multi-disciplinary design involving electrical, thermal and mechanical problems.

II. THERMAL OVERLOAD PROTECTION

Motor thermal overload is typically caused by the following reasons:

1. motor overload.
2. transient/starting.
3. unbalanced supply voltages.
4. high ambient temperature.
5. impaired cooling capability.

Since the start of the utilization of ac motors, thermal protection has drawn special attention due to the relatively severe consequences of stator insulation failures. The motor overload protection can be defined as that which is intended to protect motors, and motor branch circuit conductors against excessive heating due to motor overloads. To preventively protect the motor from winding insulation failure and extend a motor’s lifetime, the winding temperature often needs to be continuously monitored during operation. Such monitoring is particularly important for medium- to large-size motors due to relatively larger capital costs the costs of the associated process downtime due to unexpected failures.

Direct measurements of the stator winding temperature using embedded thermal sensors, such as thermocouples, Resistance Temperature Detectors (RTDs), infrared thermal sensors, etc, are the most reliable approach for thermal protection. However, their applications are limited due to economic reasons, especially for small- to medium-size motors, since the installations of the embedded thermal sensors are difficult and costly. Many different types of thermal protection devices have become commercially available, which by design are not directly measuring the motor temperature. It is found that:

a. Fractional horsepower single-phase motor overload protection may be by: the Branch Circuit Protection, a Separate Overload Device, an Integral Thermal Protector, or Impedance Protected, or a combination of these methods.
b. Overload protection for single and three-phase AC motors in the small (above 1 horsepower) and medium horsepower range is typically provided by one of two methods: Thermal Overload Relays, or Solid-state Overload Relays.
c. Overload protection for large three-phase motors is sometimes provided by Thermal Overload Relays which are connected to Current Transformers (CT’s). However, most new installations utilized microprocessor-based motor protective relays which can be programmed to provide both overload and short-circuit protection. These protective relays often also accept inputs from Resistance Temperature Detectors (RTDs) imbedded in the motor windings (usually two per phase) and the relays are capable of displaying the winding and motor bearing temperatures, and provide both alarm and trip capability.

The microprocessor-based thermal overload protective relays represent the state of the art in the thermal protection of ac motors. They typically estimate the power losses in motors using current measurements, and then calculate the winding temperature based on the thermal equation of motors. The motor is tripped immediately when a predetermined maximum permissible temperature is reached.

III. CALCULATION THE PERCENTAGE OVERTEMPERATUREE

Insulation breakdown is a common reason for motor failure. Windings in the motor are insulated with organic materials including epoxy and paper. Insulation degradation occurs when winding temperature exceeds its rating. By integrating the square of the current over time, the thermal model can predict motor temperature and react much quicker than embedded temperature devices. Thermal model has to takes into consideration the motor full-load current. The thermal model adjusts the time-to-trip depending on how much motor thermal capacity has been used. The thermal model allows operations to get the maximum work out of a motor without sacrificing available life.

In [7], an electrothermal current calculation method based on the current thermal effect is proposed. As well as in [8], an electrothermal current prediction method is proposed based on the relationship between current and temperature rise. Therefore, the warming equation of the motor can be :

$$\frac{C}{k_h}\frac{d\theta}{dt}+\theta=\frac{3RI^2}{k_h}+\theta_a \qquad (1)$$

Where:

C: the heat capacity.
k_h: the cooling constant.
t: time.
Θ: Temperature
R: the resistance of one phase.
I : the effective value of phase current.
Θ_a: ambient temperature.

The previous equation can be written in the overtemperature of the motor as:

$$\frac{C}{k_h}\frac{d\Delta\theta}{dt}+\Delta\theta=\frac{3RI^2}{k_h} \qquad (2)$$

The stationary overtemperature corresponding to the specified current is:

$$\Delta\theta_n = \frac{3RI_n^2}{k_h} \tag{3}$$

Where:

I_n : full load current.

The percentage overtemperature of the motor is:

$$\Delta\theta_{\%} = 100 * \frac{\Delta\theta}{\Delta\theta_n} \tag{4}$$

To compute percentage overtemperature of the motor, equation (2) can be integrated and written as:

$$\Delta\theta_{\%,k+1} = \Delta\theta_{\%,k} + \frac{T_{step}}{T_z}\left[100\frac{I^2}{I_n^2} - \Delta\theta_{\%,k}\right] \tag{5}$$

Where:

T_{step}: time step.

T_z: warming time constant.

IV. SIMULATION AND RESULTS

All motors come into one of the insulation category as in table (1). Every type has operating limits. Overshooting these limits will eventually destroy them. The circuit which is used to compute percentage overtemperature of the motor is compiled in Matlab-Simulink. The simulation block-diagram consists of power source (15 KV), Matlab function with thermal model, three phase motor [9-14], CTs, VT, oscilloscopes, Fourier block and circuit breaker, etc. Figure (1) shows the single line diagram of the used system.

The initial temperature of motor parts equal to ambient temperature $\theta_0 = \theta_a = 25°C$, the full load current I_n = 38.5 A, the warming time constant (T_z)=11.1 and the time step (T_{step})=0.001 sec. The system continuously calculates the motor percentage overtemperature based on the current crossing it and operating time. Protection is hence closer to the reality and can prevent inadvertent tripping.

The motor is operated under variable load situations: (1) full load, (2) starting with full load and an additional load 20% at specific time, (3) starting with full load and an additional load 30% at specific time, and (4) starting with full load and an additional load 50% at specific time.

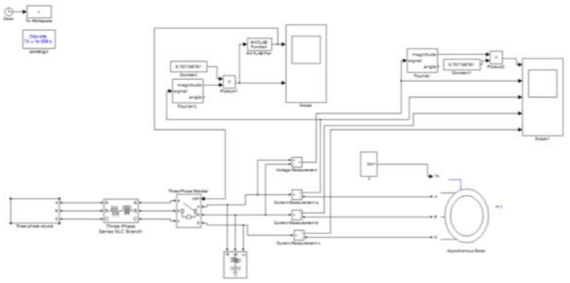

Figure 1. Line diagram.

A. At Full Load Current only

Simulation results in Matlab Simulink, using Matlab function, show that the percentage overtemperature of the motor increases from zero to a value where this value is for normal operation at full load. Figure (2) shows the percentage overtemperature of the motor, the CB signal and the current rms value. The percentage overtemperature of the motor increases from zero to almost up to 100%. The CB signal is constant at 1.

B. Starting with Full Load and an Additional Load 20% at a Specific Time

In this part, the load is increased by 20% on time of 2 sec. There is no difference from the previous state on the beginning. But after 2 sec, when the overload happened, the percentage overtemperature starts to increase depending on the increasing of overload current. When it reaches 110% at time of 5.319 seconds, the value of CB signal is changed to 0. That means the motor will be disconnected. Figure (3) shows the current rms value. It is shown that, at 5.319 the CB state was changed to 0. After this moment, the motor is turned off and the motor current be zero.

Also in this figure, the percentage overtemperature of the motor increases until 110% at time of 5.319 second. After that it starts decreasing because the current is zero.

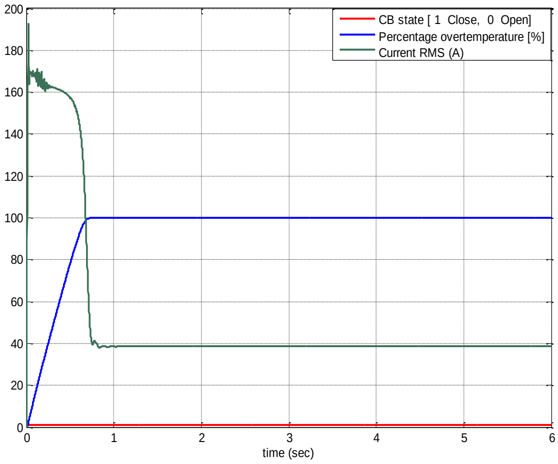

Figure 2. The percentage overtemperature of the motor, Current rms value and trip signal at full load only.

C. Starting with Full Load and an Additional Load 30% at a Specific Time

After time of 2 second, when the overload with 30% happened, the percentage overtemperature starts increasing. When it reaches 110% at time of 3.957 seconds. the value of CB signal is changed to 0. That means the motor is disconnected in time less than when the overload was 20% as in last situation. Figure (4) shows the percentage overtemperature and CB signal.

D. Starting with Full Load and an Additional Load 50% at Specific time

As in figure (5), the motor was overloaded by 50% at 2 second, the percentage overtemperature starts increasing until it reaches 110% at time of 2.989 seconds. The value of CB signal is changed to 0. It is clearly shown that, the time for disconnecting the motor is less than the time of the two previous situations.

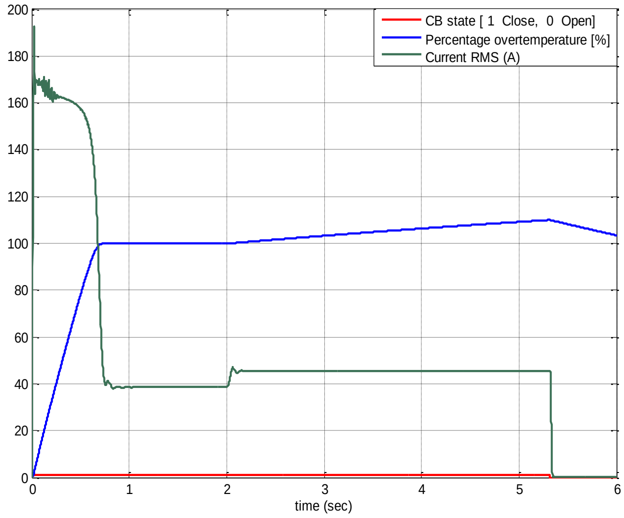

Figure 3. The percentage overtemperature of the motor, Current rms value and trip signal at 20% overload.

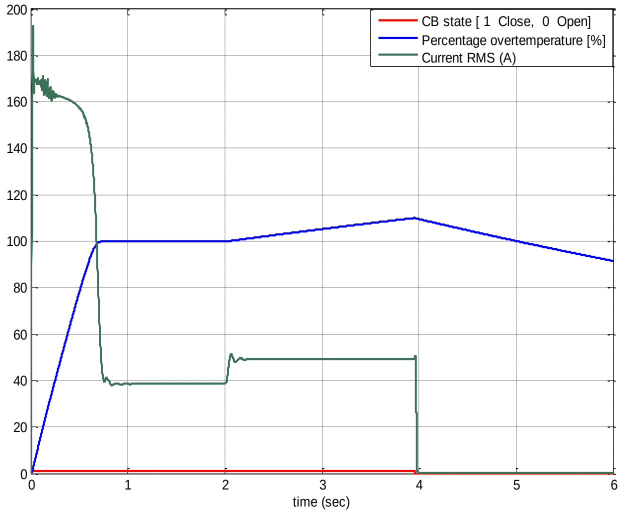

Figure 4. The percentage overtemperature of the motor, Current rms value and trip signal at 30% overload.

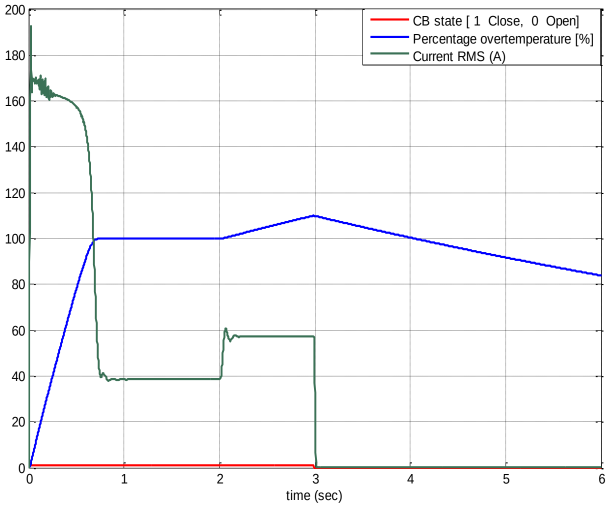

Figure 5. The percentage overtemperature of the motor, Current rms value and trip signal at 50% overload.

V. CONCLUSION

Thermal protection of ac motors is necessary for preventing catastrophic motor damage, prolonging the motor's lifetime, and avoiding financial losses. A new technique for simulating AC motor overload protection has been presented. This technique uses the motor current, motor thermal constants, operating time, and ambient temperature to estimate the percentage of overtemperature under different situations of overload. It has been clearly shown that this technique simulates reliably thermal protection of ac motors that capable of providing accurate monitoring of the motor temperature without embedded thermal sensors.

REFERENCES

[1] Pinjia Zhang and others. *"Active Stator Winding Thermal Protection For AC Motors"*. *IEEE IAS PULP & PAPER INDUSTRY* Conference in Birmingham, 2009.

[2] Chen Li'an and Zhang Peiming. " *Simulation of motor faults and protections based on MATLAB*". *ICEMS'2001*. Proceedings of the Fifth International Conference on Electrical Machines and Systems (IEEE Cat. No.01EX501). 18-20 Aug. 2001. Shenyang, China, China.

[3] Raheel Muzzammel, M. Nauman Akram, Muhammad Shehzad Ahmed, Abubakr Saleem and Muhammad Umair Muqeem " *Simulation Analysis of Fully Protected Induction Motor*". International Journal of Scientific & Engineering Research, Volume 9, Issue 10, October-2018 ISSN 2229-5518.

[4] Supriyanto Suhono and others. "*Simulator for Overcurrent Phase and Ground Fault Protection with Microprocessor Based Relays*". Conference: International Seminar of Science and Applied Technology (ISSAT 2020). January 2020. Published by Atlantis Press B.V. *Advances in Engineering Research, volume 198. Pages:117-123* DOI:10.2991/aer.k.201221.021.

[5] Jaymala D. Pradhan and others. "*Analysis and design of overcurrent protection for grid-connected microgrid with PV generation*". KeAi, Global Transactions Proceedings 3 (2022). Pages: 349-358. https://doi.org/10.1016/j.gltp.2022.03.023.

[6] XU Wenliang and HE Weilong. "*Thermal Overload Protection for Low Voltage Apparatus and Simulation of Thermal Bimetal*". Journal of Forestry Engineering (JFE). LOW VOLTAGE APPARATUS (2021), Published:13/10/2021, Vol. 0, Issue (6), pages: 41-46. DOI: 10.16628/j.cnki.2095-8188.2021.06.007.

[7] Sen Lv and others. "*Design and analysis of a novel overload current estimation method for traditional miniature circuit breaker*". IET Electric Power Applications. IET Electr. Power Appl., 2020, Vol.: 14, Iss.: 10, Pages: 1898-1905, DOI: 10.1049/iet-epa.2020.0108.

[8] Sen LYU and Ming ZONG. "*An electrothermal current prediction method for overload protection of miniature circuit breakers*". Turkish Journal of Electrical Engineering & Computer Sciences (TÜBİTAK). (2020) Volume: 28. No.: 5. Article: 11, pages: 2523 – 2537, DOI:10.3906/elk-1911-74.

[9] Aleksejs Gedzurs and Andris Sniders. "*Experimental Research and Simulation of Induction Motor Stator Winding Non-Stationary*". American Journal of Energy and Power Engineering (AASCIT). ISSN: 2375-3897. 2015.

[10] Square D Company. " *Overload Relays and Thermal Unit Selection*" Catalog No. 9065CT9701.

[11] Schneider Electric guide. "*AC motors starting and protection systems*". Chapter 4. Pages 60-91.

[12] Toshiba Company. "Temperature Rise – Insulation". Application guide #05, 2018.

[13] B. Venkataraman and others. *“ Fundamentals of a Motor Thermal Model and its Applications in Motor Protection*”. Motor Thermal Model Protection Applications.
[14] https://www.mathworks.com/products/matlab.html. 2018.