Thermal Limit Curve Calculation for Squirrel Cage Induction Motor Based Thermal Equivalent Circuit

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Background

During starting of squirrel cage induction motor, the skin effect due to slip frequency operation causes the rotor resistance to exhibit a high value. Squirrel cage induction motor for high inertia load applications has long starting time, so it has to be designed considering thermal reliability of the rotor bar. Although thermal limit curves (overload, locked rotor, accelerating) are defined in IEEE Standard 620-1996, Guide for the Presentation of Thermal Limit Curves for Squirrel Cage Induction Machines, the guide gives no information as how the curves are constructed.

Objectives

- Construct 3-dimensional thermal equivalent circuit considering the skin effect in the rotor bar.
- Present calculation algorithm of thermal limit curve (locked rotor, accelerating)

Conclusion

- 3-dimensional TEC considering skin effect in the rotor bar of squirrel cage induction motor is constructed to predict temperature rise of the rotor.
- Thermal limit curves (locked rotor, accelerating condition) calculation flow using 3-dimensional TEC is presented.
- Temperature rise in the rotor bar is measured under locked rotor condition.
- TEC calculation result is compared with the test result to verify accuracy of the 3-dimensional TEC.

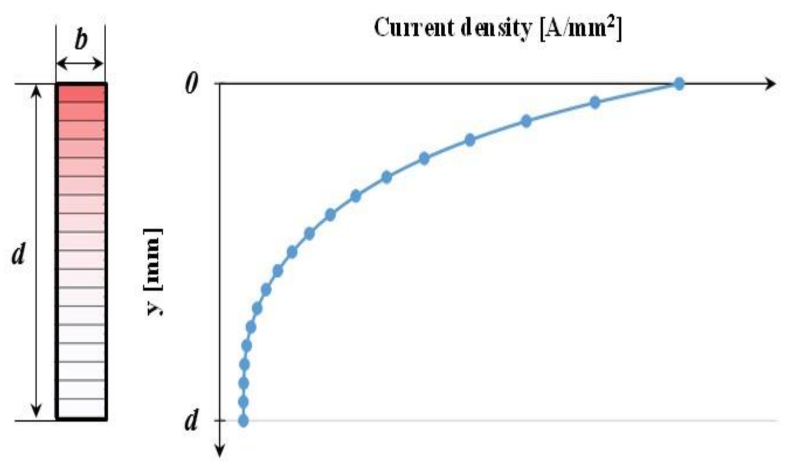
Methods

3-dimensional Thermal Equivalent Circuit (TEC)

3-dimensional TEC for a rotor of squirrel cage induction motor is constructed.

Rotor core and cage winding are subdivided into thermal capacity elements and connected with thermal resistance.

Losses are calculated considering skin effect in the rotor bar elements



$$J\left(y,T,sf,I_b\right)=\frac{\gamma_0 I_b}{b}\left[\frac{\cosh\left(\gamma_0\cdot(d-y)\right)}{\sinh\left(\gamma_0 d\right)}\right]$$

Parameter definition to construct matrices :

$$i,\ j\in 0,1,\cdots,k\cdot(2m+2n)+m+(2m+4)+k$$
$$h\in 0,1,\cdots,k-1$$

Thermal Capacitances in the subdivided rotor elements :

$$[C]_{i,i}=V_i\cdot\rho_i\cdot c_i\left(T_i\right)$$
$$where,\quad 0\le i\le k\cdot(2m+2n)+m+(2m+4)+k$$

Losses in the rotor bar elements :

$$[L]_{i,0}=b\cdot\Delta L\cdot\rho_b\left(T_i\right)\cdot\int_{[i-y\cdot(2m+2n)]\cdot\Delta d}^{[(i+1)-y\cdot(2m+2n)]\cdot\Delta d}J^2\left(y,T_i,sf,I_b\right)dy$$
$$where,\quad h\cdot(2m+2n)\le i\le m-1+h\cdot(2m+2n)$$

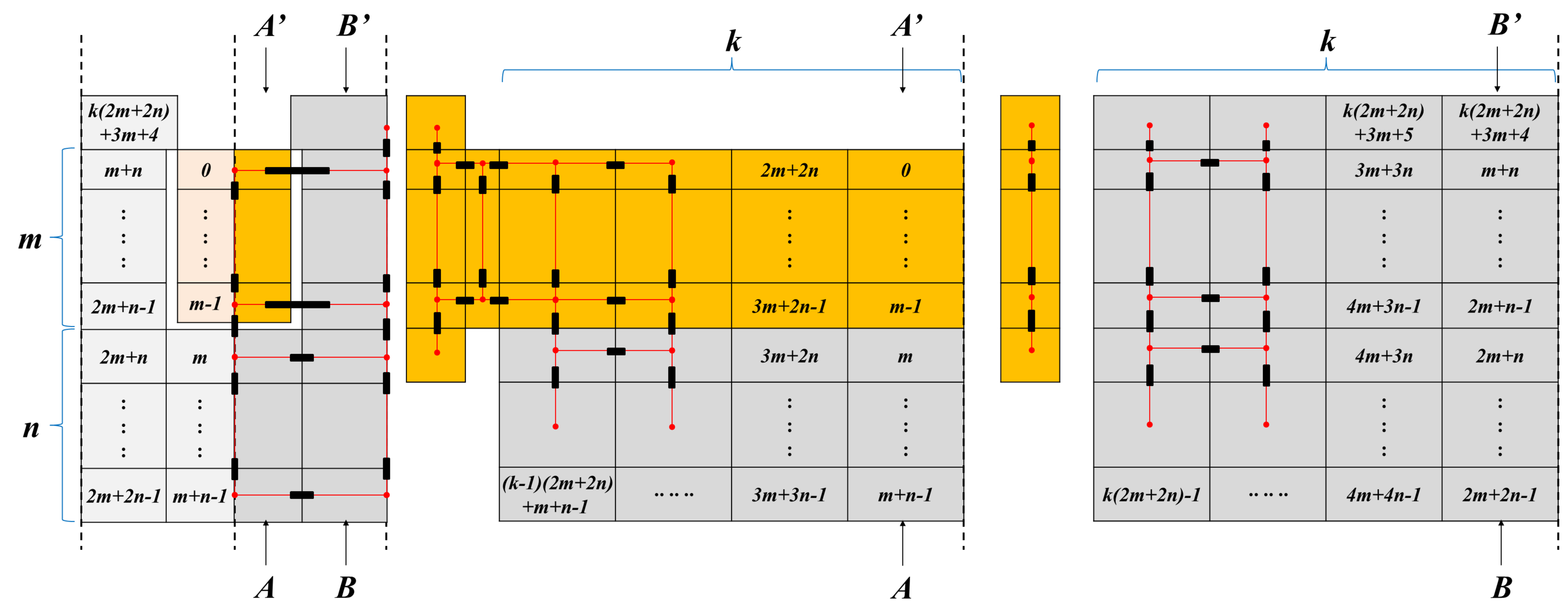
Thermal Resistances between rotor bar elements :

$$[R]_{i,i+1}=\frac{\Delta d/2}{k_c\left(T_i\right)\cdot b\cdot\Delta L}+\frac{\Delta d/2}{k_c\left(T_{i+1}\right)\cdot b\cdot\Delta L}$$
$$where,\quad h\cdot(2m+2n)\le i\le h\cdot(2m+2n)+m-2$$

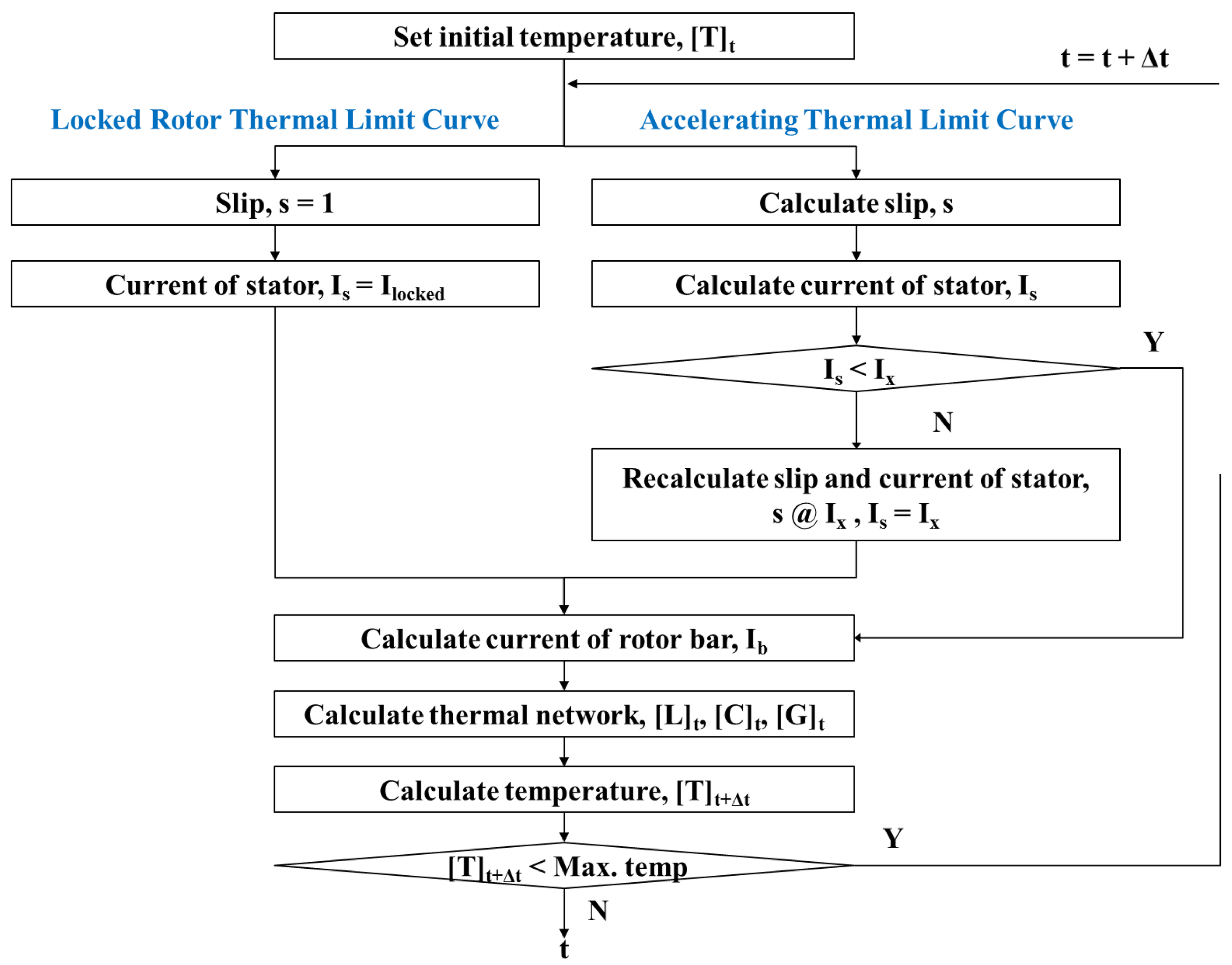
$$[R]_{i,i+1}=\frac{\Delta d/2}{k_c\left(T_i\right)\cdot b\cdot L_1}+\frac{\Delta d/2}{k_c\left(T_{i+1}\right)\cdot b\cdot L_1}$$
$$where,\quad h\cdot(2m+2n)\le i\le h\cdot(2m+2n)+m-1$$

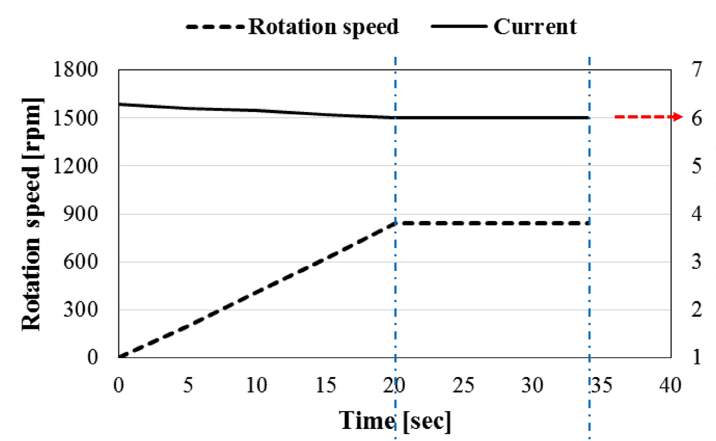
$$[R]_{i,i+2m+2n}=\frac{\Delta L/2}{k_c\left(T_i\right)\cdot b\cdot\Delta d}+\frac{\Delta L/2}{k_c\left(T_{i+2m+2n}\right)\cdot b\cdot\Delta d}$$
$$where,\quad h\cdot(2m+2n)\le i\le h\cdot(2m+2n)+m-1,\ h\ne k-1$$

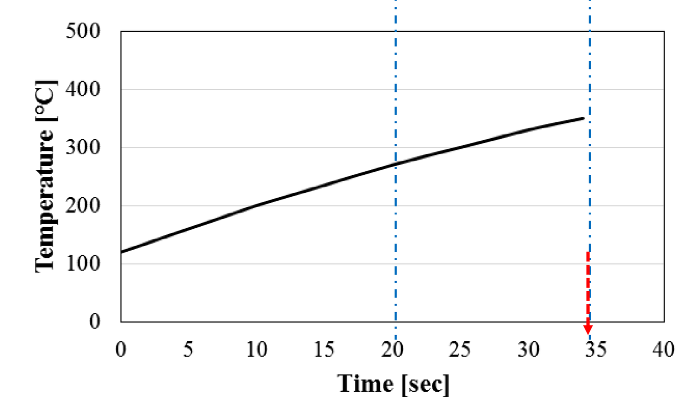
$$[R]_{i,i+2m+2n}=\frac{\Delta L/2}{k_c\left(T_i\right)\cdot b\cdot\Delta d}+\frac{L_1/2}{k_c\left(T_{i+2m+2n}\right)\cdot b\cdot\Delta d}$$
$$where,\quad (k-1)\cdot(2m+2n)\le i\le(k-1)\cdot(2m+2n)+m-1$$

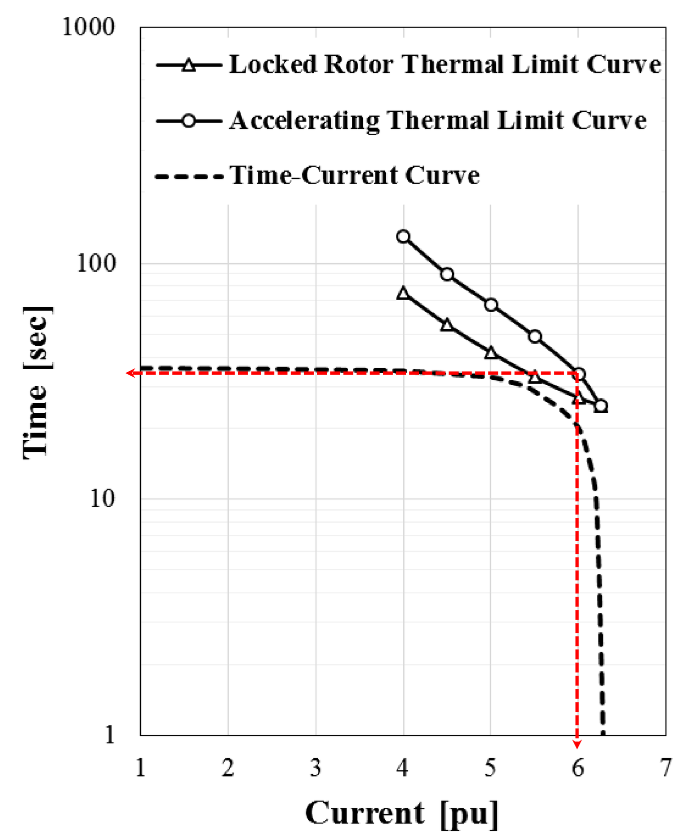


Thermal Limit Curve



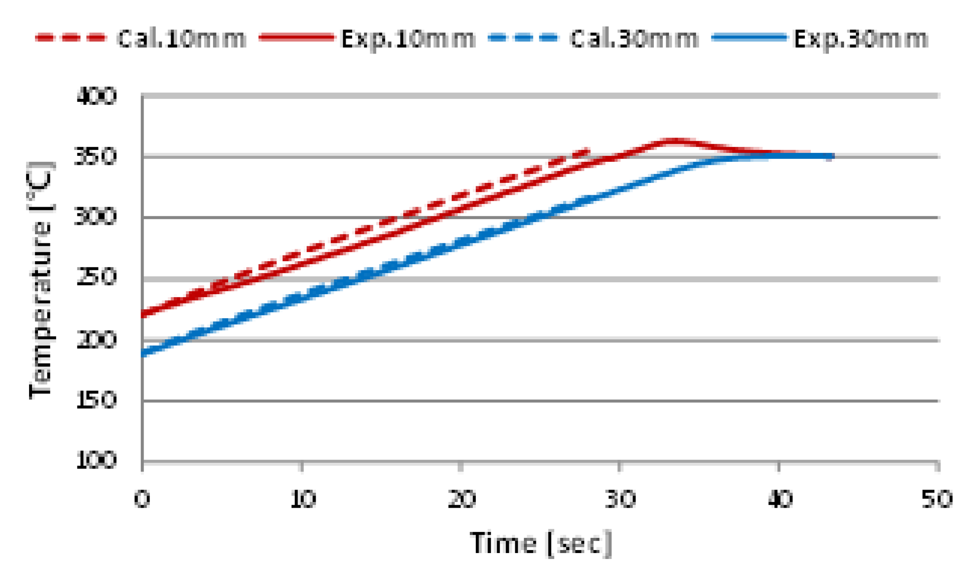


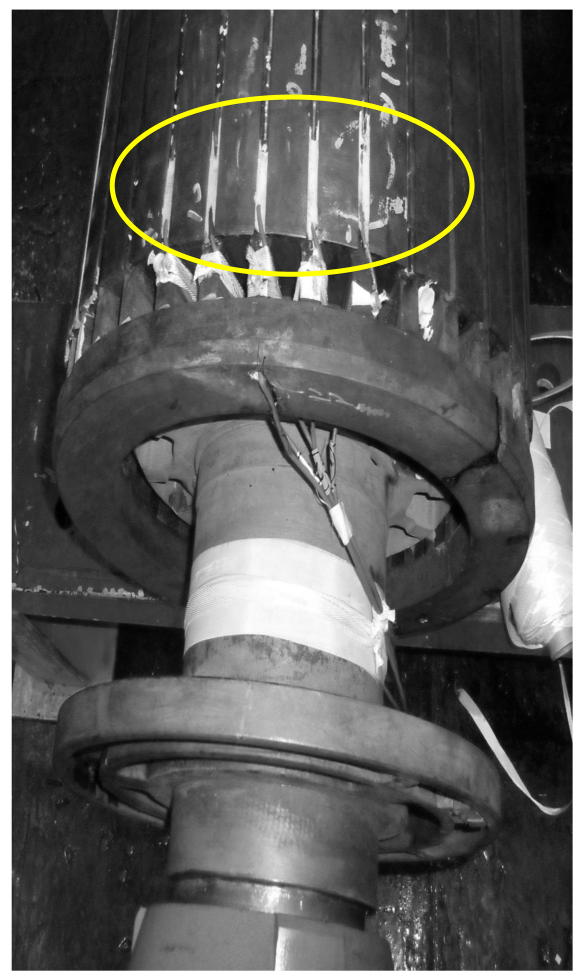




Experiment

Temperature rise in the rotor bar





Thermocouples are inserted in the rotor bars which are 10mm, 30mm depth below the rotor bar surface.

Temperature rise under locked rotor condition is measured and compared to the that of TEC calculation.