

## Consideration of the Safety-related Motor Design Verification for Nuclear Power Plants

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### 1. Introduction

A nuclear power plant utilizes large numbers of electric motors ranging in size from fractional horsepower to many thousands of horsepower. Unanticipated failure of motors in critical service not only may result in equipment damage but affect plant safety and availability.

Design verification for safety-related motors in nuclear power plants was investigated according to the related requirement for safety-related motor operation during plant normal and accident conditions. This paper describes the result of review for the test procedures and project designation sheets based on regulatory requirement and industry standards, suggesting recommendations about deficiencies against nuclear safety criteria.

### 2. Requirements and Verifications

Class 1E motors as essential electrical equipment have to meet their design purpose during plant transient and accident conditions. Electric motor performance is vital to the reliable and efficient operation of nuclear power plant, required an enough power to its loads such as pumps, fans and dampers.

In addition, the failure of one or more critical motors could cause lost capacity and excessive repair and maintenance cost. Therefore, we need an accurate design verification of motors to get the more reliable operation and cost reduction.

#### 2.1 Motor Starting Torque

Three-phase Induction Motors are used in many industrial sections as a leading element to convert electrical energy to mechanical energy. In nuclear power plant, electric motors are key plant components. The most widely used motor in industry is the three-phase, squirrel cage induction motor. Nearly 95% of motors in service at a nuclear power plant are of squirrel-cage construction.

Final Safety Analysis Report (FSAR) requires the followings;

- The motor starting torque is capable of starting and accelerating the connected load to normal speed within sufficient time to perform its safety function for all expected operating conditions, including the design minimum terminal voltage.
- Safety-related motors are specified with accelerating capability with 75% rated voltage at their terminals.[1]

The ability of motor starting could be checked by locked-rotor torque and torque-speed curve. The locked-rotor torque is taken as the minimum torque developed at rest in all angular positions of the rotor. The torque may be measured with a scale or force transducer with a rope and pulley, or with a brake or beam or it may be measured directly using an in-line torque transducer. If the locked-rotor torque is not measured directly as mentioned above, the approximate locked-rotor torque may be calculated as shown in Equation.

$$T = \frac{C_1 k_2 (P_{SI} - P_{SIR} - P_h)}{n_s}$$

Where  $T$  is torque, in N·m,  $P_{SI}$  is the input power to stator, in W,  $P_{SIR}$  is the stator I<sup>2</sup>R loss, in W, at the test current,  $P_h$  is the core loss, in W, at test voltage,  $n_s$  is the synchronous speed, in r/min,  $C_1$  is a reduction factor to account for nonfundamental losses,  $k_2$  is 9.549 for torque in N·m. [2]

IEEE Std 112-1996 provide four methods of the procedure to obtain data for a speed-torque curve but manufactures used circle diagram method instead of these.

The single-phase equivalent circuit can be used to determine a wide variety of steady-state performance characteristics of polyphase induction machine. Mechanical torque of induction motor  $T_{mech}$  is:

$$T_{mech} = \frac{P_{mech}}{\omega_m} = \frac{n_{ph} V_{1,eq}^2 (R_2 / s)}{\omega_s}$$

From the Thevenin-equivalent circuit:

$$T_{mech} = \frac{1}{\omega_s} \left[ \frac{n_{ph} V_{1,eq}^2 (R_2 / s)}{(R_{1,eq} + (R_2 / s))^2 + (X_{1,eq} + X_2)^2} \right]$$

Where  $P_{mech}$  is power,  $\omega_m$  is angular velocity,  $\omega_s$  is the synchronous mechanical angular velocity,  $V_1$  is stator line-to-neutral terminal voltage,  $S$  is slip,  $R_1$  is stator effective resistor,  $R_2$  is referred rotor resistance,  $V_{1,eq}$  is equivalent voltage source,  $n_{ph}$  is number of stator phase,  $X_1$  is stator leakage reactance. [5]

In case of Shinwolsung NPP, motor manufactures plotted the torque-speed curve with design parameter using computer program supported by Mitsubishi, which was not considered dip bar effect in the program. We confirmed the result of the calculation, a containment spray pump motor torque-speed envelopes

a required load curve with having more than 30 percent margin in all speed span at 75 percent level of normal bus voltage.

## 2.2 Starting Acceleration Time

Emergency diesel generator supplies a power to the safety-related equipment in the event of the loss of offsite power condition so that the equipment are operable any conditions of transient but the generator need time intervals due to prevention of the voltage drop by large motor starting.

Reg. Guide 1.9 1979 describes that the diesel generator unit design should be such that at no time during the loading sequence should the frequency and voltage decrease to less than 95 percent of nominal and 75 percent of nominal, respectively. A voltage on the safety bus should be restored to within 10 percent of nominal within 60 percent of each load-sequence time interval. In order to meet this, motor design data require a total time to accelerate the load under 75 percent motor rated voltage condition to maintain within 3 seconds. [3]

Motor manufacture submit a calculation report which provide a general formula for motor acceleration time and design data, including a table about motor specification and times established the average acceleration torque for each time interval.

The most common practice for torque measurement on large machines is by the acceleration method described in section 7.3.2.2 of IEEE 112-1996. In this test, the rate of change of speed is measured over either a fixed or measured time interval and from knowing the  $WR^2$  of the rotating element, the torque can be calculated by

$$T = \frac{WR^2 \Delta s}{(9.549 \times \Delta t)}$$

Where  $T$  is average torque over the time interval in N. m,  $WR^2$  is inertia of rotating element in kg m,  $\Delta s$  is change in speed over the time interval in r/min,  $\Delta t$  is time interval during the change in speed in s.

Containment spray pump motor in Shinwolsong NPP was investigated as a sample calculation to verify the motor acceleration ability at 75 percent of rated bus voltage. The calculated parameters of the motor are shown in Table 1. The motor acceleration time submitted by manufacture meets the 3 second limit.

**Table 1. Containment Spray Motor Parameters as an Investigation Sample.**

Output	671.4Kw	Rated Torque	367 Kg-m
Pole	4 p	Motor Inertia	81.2 Kgm <sup>2</sup>
Volt	4000 v	Load Inertia	9.7 Kgm <sup>2</sup>
Speed	1782 rpm	Acceleration Time at rated 75% Voltage	2.1 sec [calculation] 1.61 [testing]

## 3. Results and Discussion

The regulatory requirement and actual data for the sample motor were compared to verify the ability of motor torque-speed characteristic and acceleration time which are very important design factors.

Torque-speed characteristics show a motor operability over all speed spans against a load torque and the curve at lower voltage is simply plotted by voltage squared ratio.

Full voltage starting results in a large initial current surge, known as inrush, which is typically 600% to 700% rms of the full-load current drawn by the motor. In reality, the first half-cycle current is considerably higher in magnitude, but is short in duration. This large inrush can cause problems for the connected electrical system. 3 second limitation at acceleration time is to prevent the problems in the safety-related load bus under plant transient condition.

## 4. Conclusions

Most manufactures provide torque-speed characteristic plots using design data and parameter measurement by tests based on the standards and manufacture's calculation program. As the review of overall processing to get the plots and acceleration time results, the following recommendations were suggested.

- Manufacture need to improve procedures that describe critical steps to confirm a measurement, processing and test results, including environment factors in the testing facilities based on the related standards.
- State-of-the-art technique, calculation program and standards, have to be applied to the calculation and measurement of a torque, speed, slip and so on, providing accurate features to guarantee safety-related equipment in nuclear power plant.

## REFERENCES

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