

COMPARISON OF OPERATING COSTS ASSOCIATED WITH INDUCTION MOTOR EFFICIENCY

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OBJECTIVE

The purpose of this study is to compare the operating cost due to efficiency of electric motors produced by various manufacturers. The efficiencies of the motors produced by six major manufacturers were compared. The motors considered have a horsepower range between 10 hp and 200 hp at speeds of 1200 rpm and 1800 rpm. The results are based on information provided by the manufacturers. The power factors of the motors have been considered, however a study of the cost associated with a low power factor is not part of this report. One should keep in mind that a low power factor will cost more to compensate for than a motor with a higher power factor. For this reason, charts of the power factor variation are included and are used to further distinguish manufacturers with motor efficiencies that are similar.

RESULTS

There is little difference between the efficiencies of the motors produced by US Motors, Toshiba, ABB, General Electric and Reliance. The motors produced by Teco-Westinghouse have an efficiency 1% to 2% lower than the other manufacturers in the range of 50 hp and above, see Figures 1 and 5 for a plot of efficiency vs. motor horsepower at speed of 1200 and 1800 rpm at $\frac{3}{4}$ of the full load. For the influence of the motor efficiency on annual operating cost see Figures 3 and 7 for operating speeds of 1200 and 1800 rpm at $\frac{3}{4}$ of the full load.

The annual operating cost per horsepower associated with motor efficiency drops as the motor power increases (see figures 3 and 7). This is because the efficiency increases as motor power increases.

The influence of the power factor

When the power factor is taken into account, certain manufacturers have an advantage. The motors produced by GE and Reliance have a higher power factor (see Figures 4 and 8) for operating speeds of 1200 and 1800 rpm at $\frac{3}{4}$ of the full load.

Figures 1 to 8 show the variation in efficiency, annual cost due to efficiency and power factor for motors operating at 1200 and 1800 rpm at $\frac{3}{4}$ of the full load.

The same information is presented in Figure 9 to 12 for motors operating at full load. The conclusions are essentially the same for motors operating at full load or $\frac{3}{4}$ load. What is the power factor

For a DC circuit the power is $P=VI$, and this relationship also holds for the instantaneous power in an AC circuit. However, the average power in an AC circuit expressed in terms of the RMS voltage and current is

$$P_{avg} = V I \cos \varphi = V \times I \times P.F. \quad [1]$$

where φ is the phase angle between the voltage and the current.

Instantaneous power is proportional to the instantaneous voltage times instantaneous current. AC voltage causes the current to flow in a sine wave replicating the voltage wave. However, inductance in the motor windings somewhat delays current flow, resulting in a phase shift. This transmits less power than perfectly time-matched voltage and current of the same RMS value. Power factor is the fraction of power actually delivered in relation to the power that would be delivered by the same voltage and current without the phase shift. Low power factor does not imply low or wasted power, just excess current. The energy associated with the excess current is alternately stored in the windings' magnetic field and regenerated back to the line with each AC cycle. This exchange is called reactive power. Though reactive power is theoretically not lost, the distribution system must be sized to accommodate it, which is a cost factor.

Importance of the power factor

A power factor of one or "unity power factor" is the goal of any electric utility company since if the power factor is less than one, they have to supply more current to the user for a given amount of power use. In so doing, they incur more line losses. They also must have larger capacity equipment in place than would be otherwise necessary. As a result, an industrial facility will be charged a penalty if its power factor is much different from 1.

Industrial facilities tend to have a "lagging power factor", where the current lags the voltage (like an inductor). This is primarily the result of having a lot of electric induction motors - the windings of motors act as inductors as seen by the power supply. Capacitors have the opposite effect and can compensate for the inductive motor windings. Some industrial sites will have large banks of capacitors strictly for the purpose of correcting the power factor back toward one to save on utility company charges.

Ref: <http://hyperphysics.phy-astr.gsu.edu/hbase/electric/powfac.html> and Determining Electric Motor Load and Efficiency, Department of Energy publication

ANALYSIS

The information on motor performance has been obtained from 6 manufacturers : General Electric, Toshiba, Reliance, Teco-Westinghouse, ABB and US Motors. The type of motor selected is the one that the manufacturer recommend for the pulp and paper industry. These motors have minimum characteristics that correspond to NEMA B, S.F. 1.15, cast iron frame. This type of motor is very robust and generally more efficient than the average motor used in industry (see Table 1).

The energy cost (\$COST_{EFF.}) due to motor efficiency is based on the following formula :

$$\text{\$COST}_{EFF.} = \frac{1}{1.34} P_{3/4LOAD}(hp) (1 - \eta_{MOTOR_3/4LOAD}) \times \frac{350 \text{ days}}{\text{year}} \times \frac{24h}{\text{day}} \times \frac{\text{\$0.03}}{\text{kW-h}}$$

where

$P_{3/4LOAD}$: power at $\frac{3}{4}$ of the maximum load;

$\eta_{MOTOR_3/4LOAD}$: motor efficiency at $\frac{3}{4}$ of the maximum load

\$COST_{EFF.} : operating cost due to the motor efficiency

This formula gives the difference in energy cost when operating with a motor with less than 100% efficiency compared to an ideal motor at 100% efficiency.

The operating cost is based on 350 days per year, 24 hours per day and a power cost of \$0.03 kW-h.

MANUFACTURER	MOTOR TYPE
General Electric	X\$D
Toshiba	EQX-III
Reliance	XE PREMIUM
Teco-Westinghouse	OPTIM HE PLUS
ABB	Standard
US Motors	Corro Duty

Table 1 Motor types and manufacturers considered in the study.

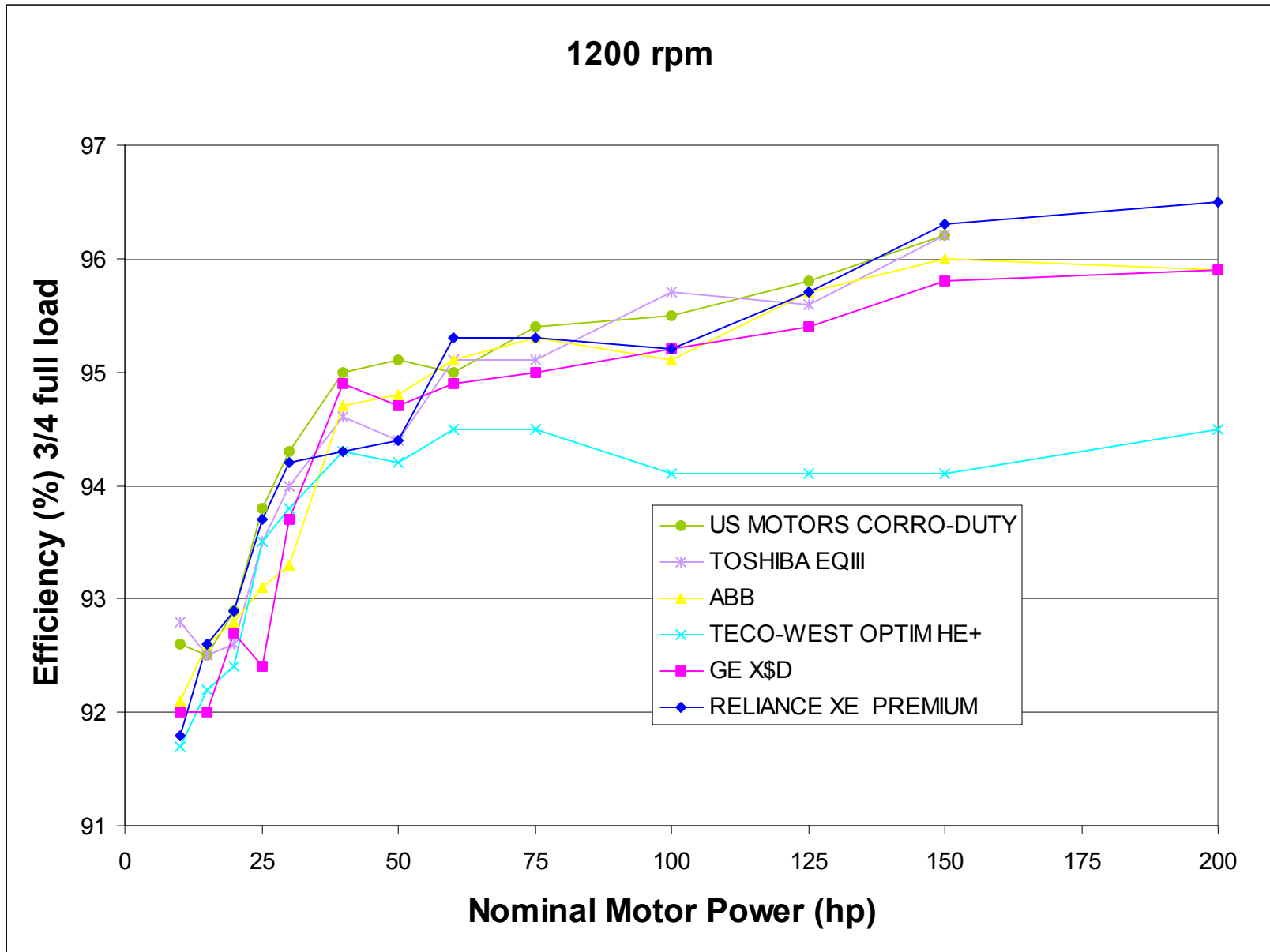


Figure 1 Efficiency comparison for induction motors (575V, 3 phase, S.F. 1.15).

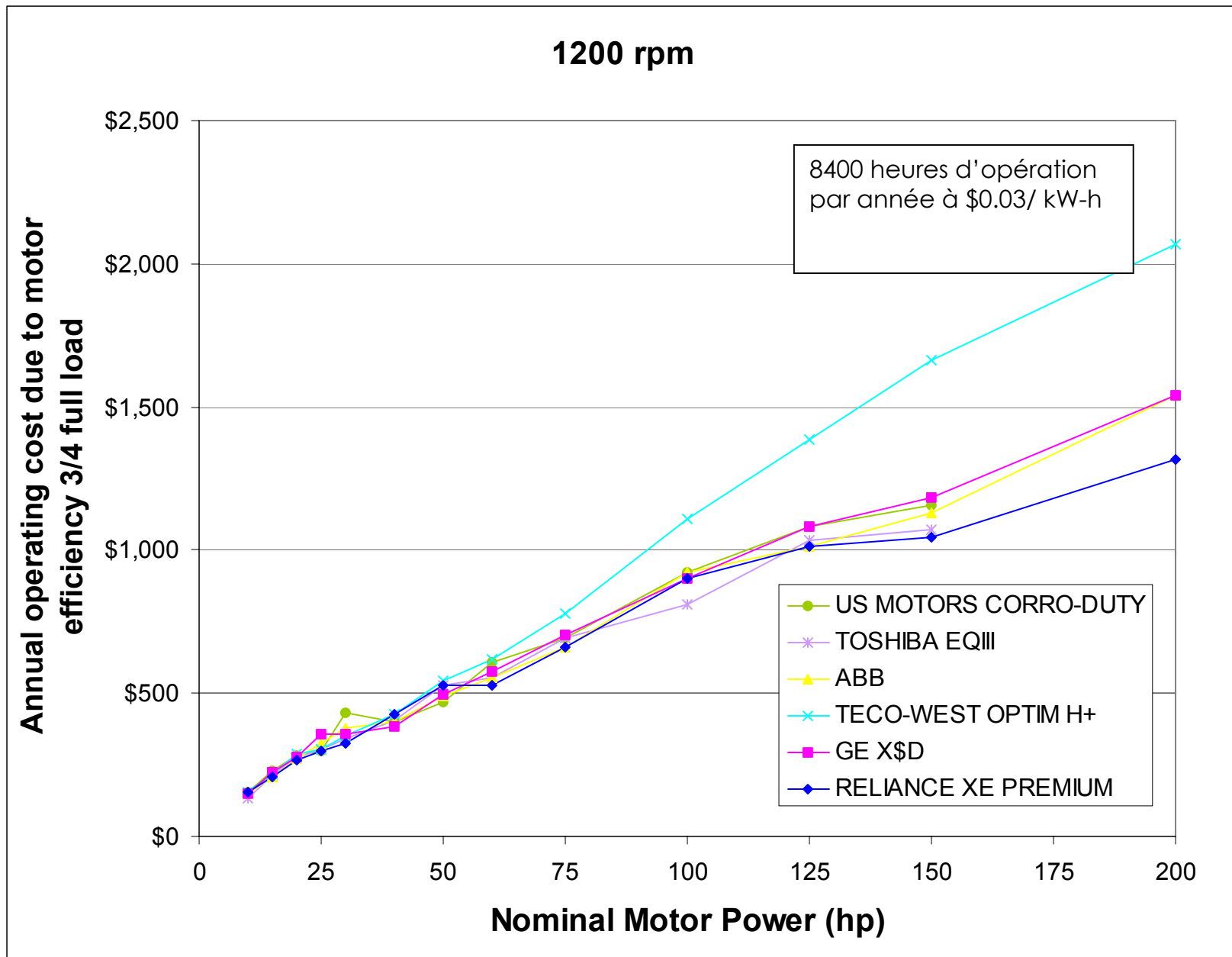


Figure 2 Annual cost due to motor efficiency (575V, 3 phase, S.F. 1.15).

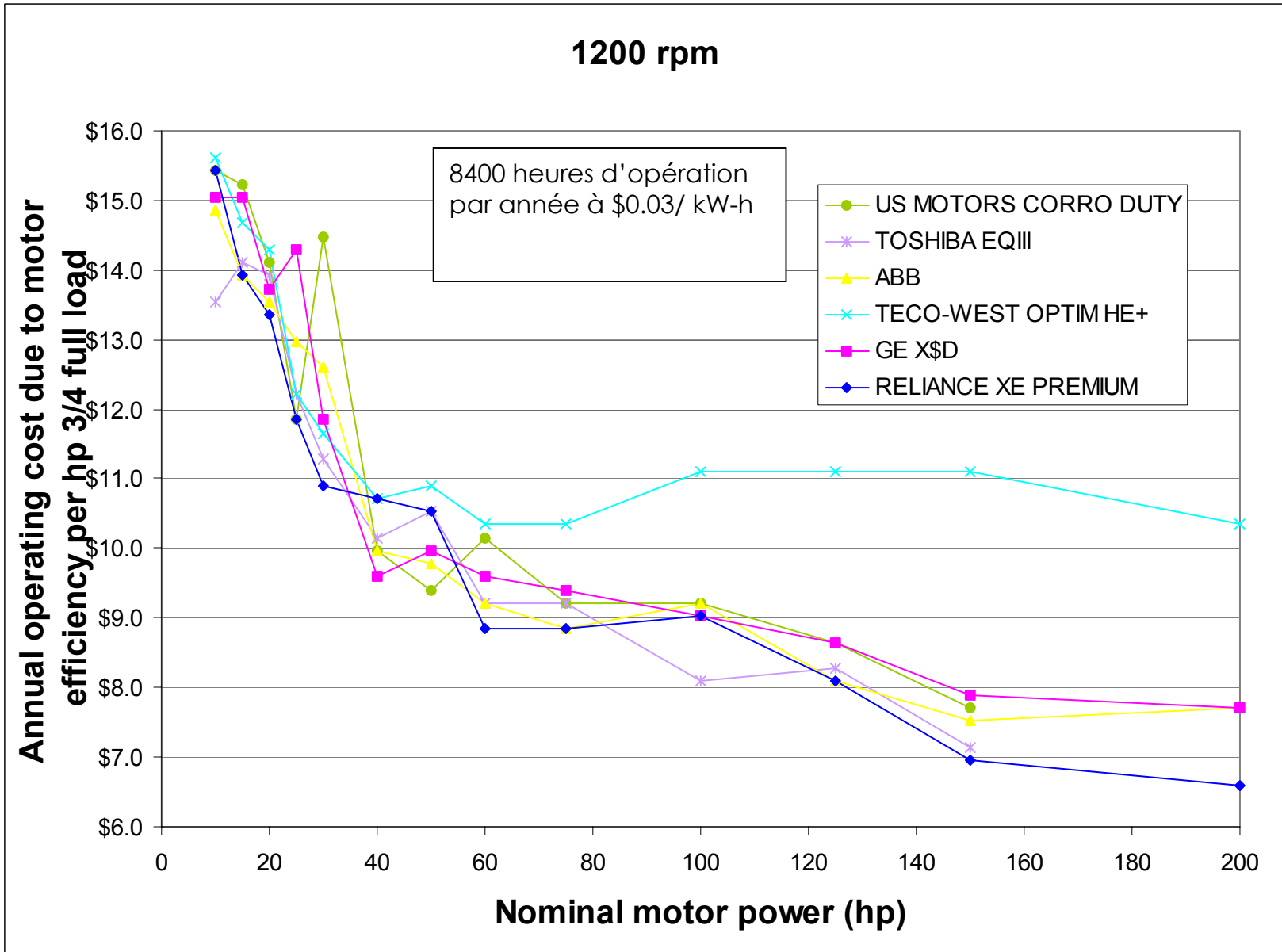


Figure 3 Annual operating cost due to motor efficiency per hp (575V, 3 phase, S.F. 1.15).

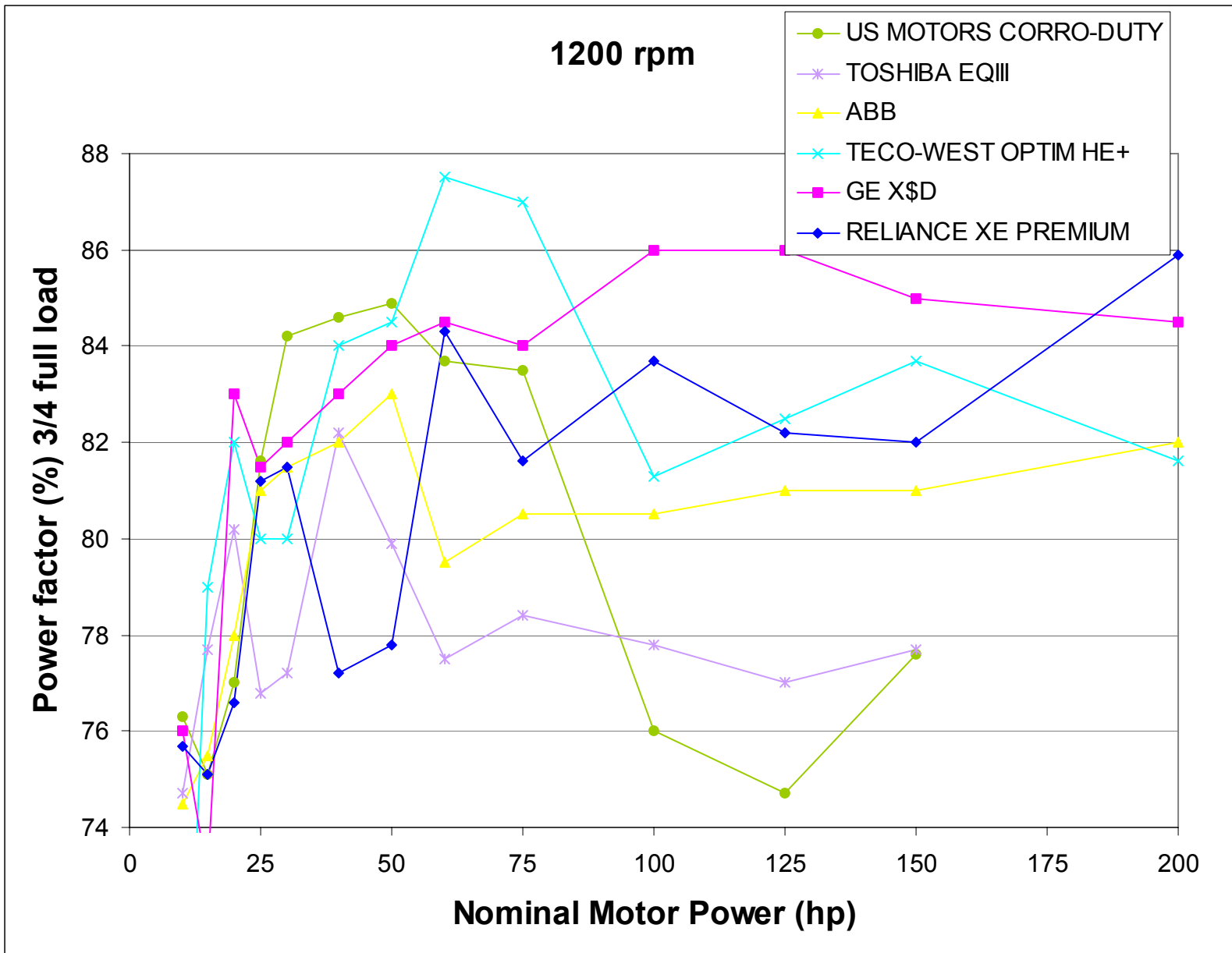


Figure 4 Power factor comparison for induction motors (575V, 3 phase, S.F. 1.15).

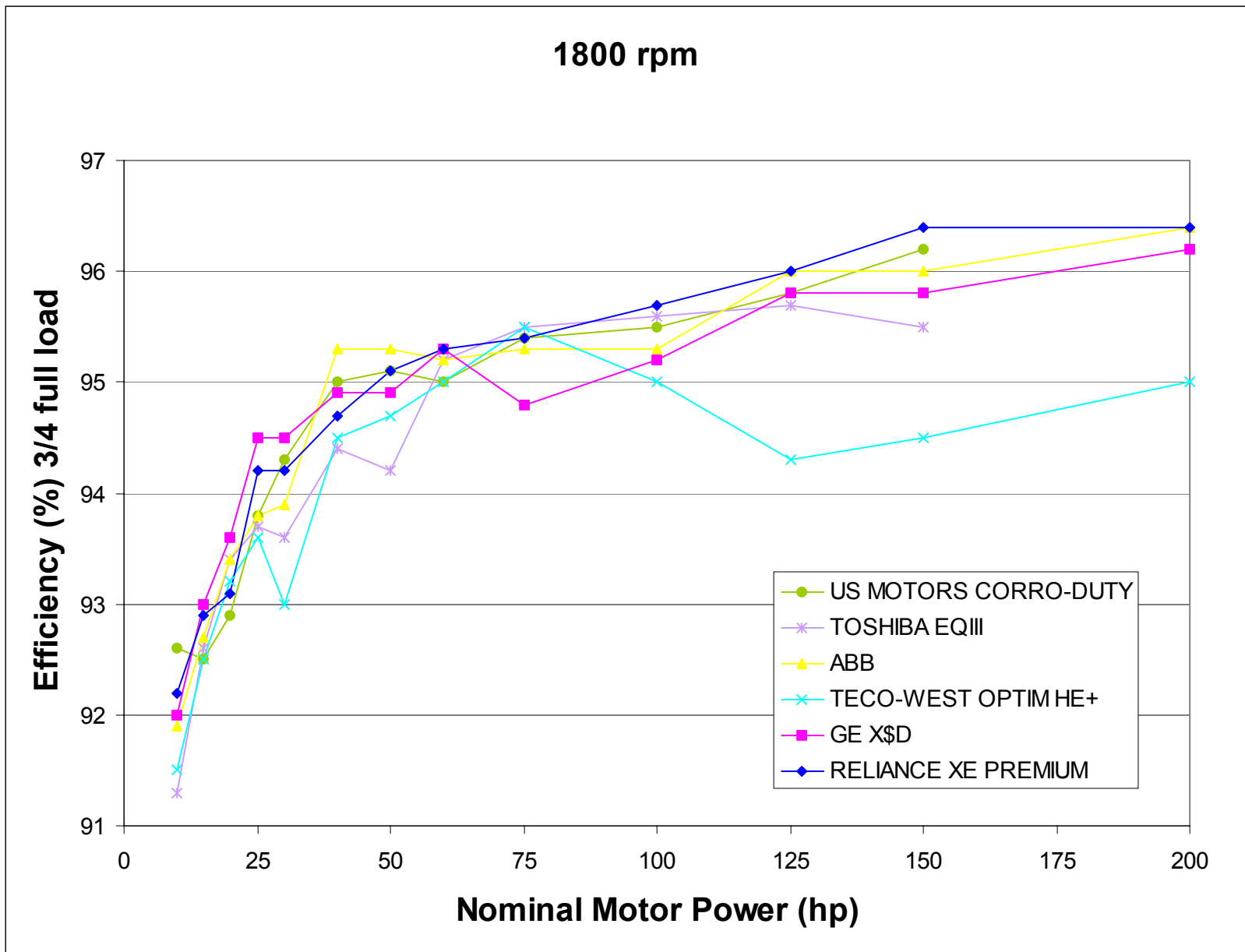


Figure 5 Efficiency comparison for induction motors (575V, 3 phase, S.F. 1.15).

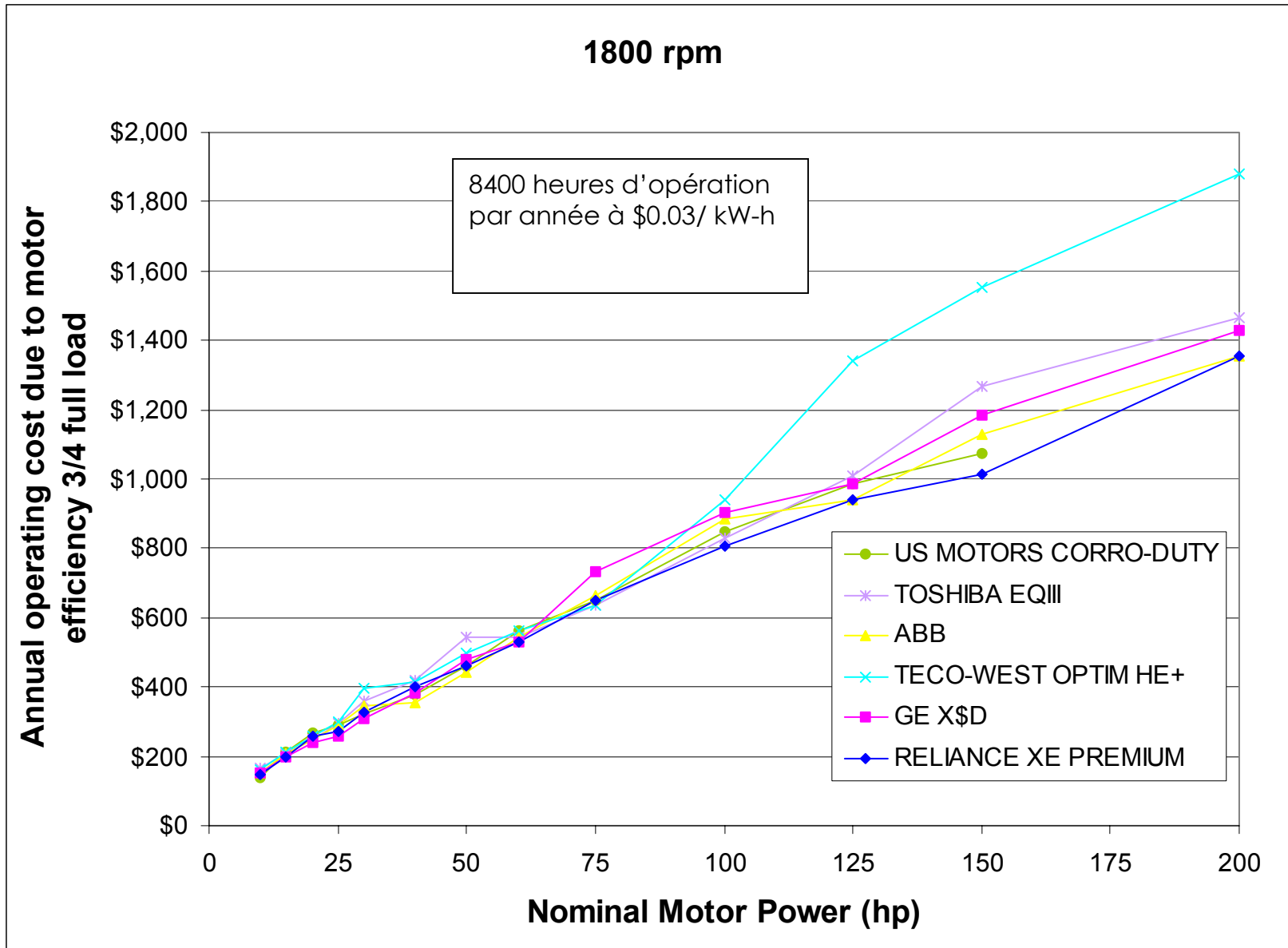


Figure 6 Annual operating cost due to efficiency (575V, 3 phase, S.F. 1.15).

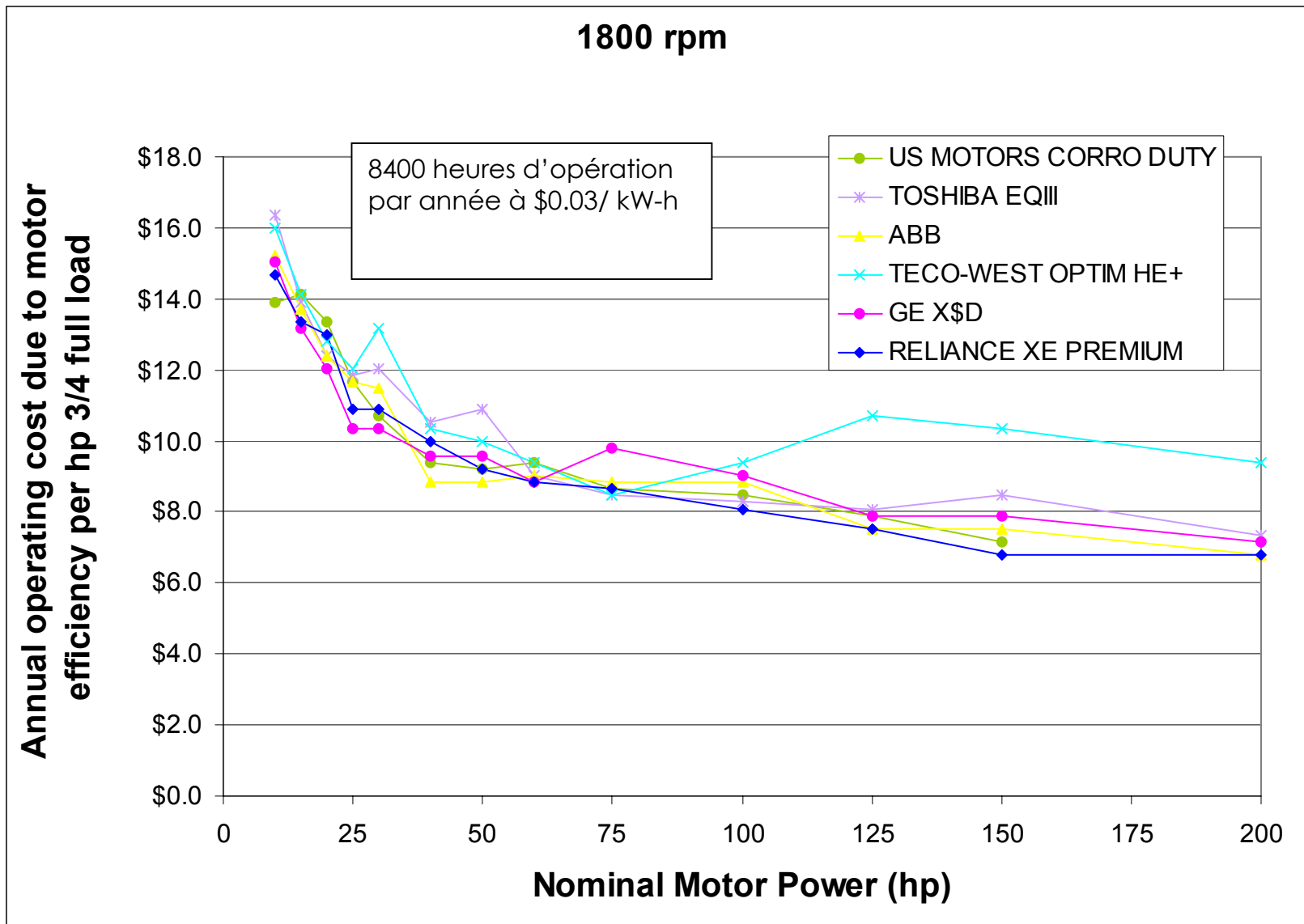


Figure 7 Annual operating cost due to efficiency per hp (575V, 3 phase, S.F. 1.15).

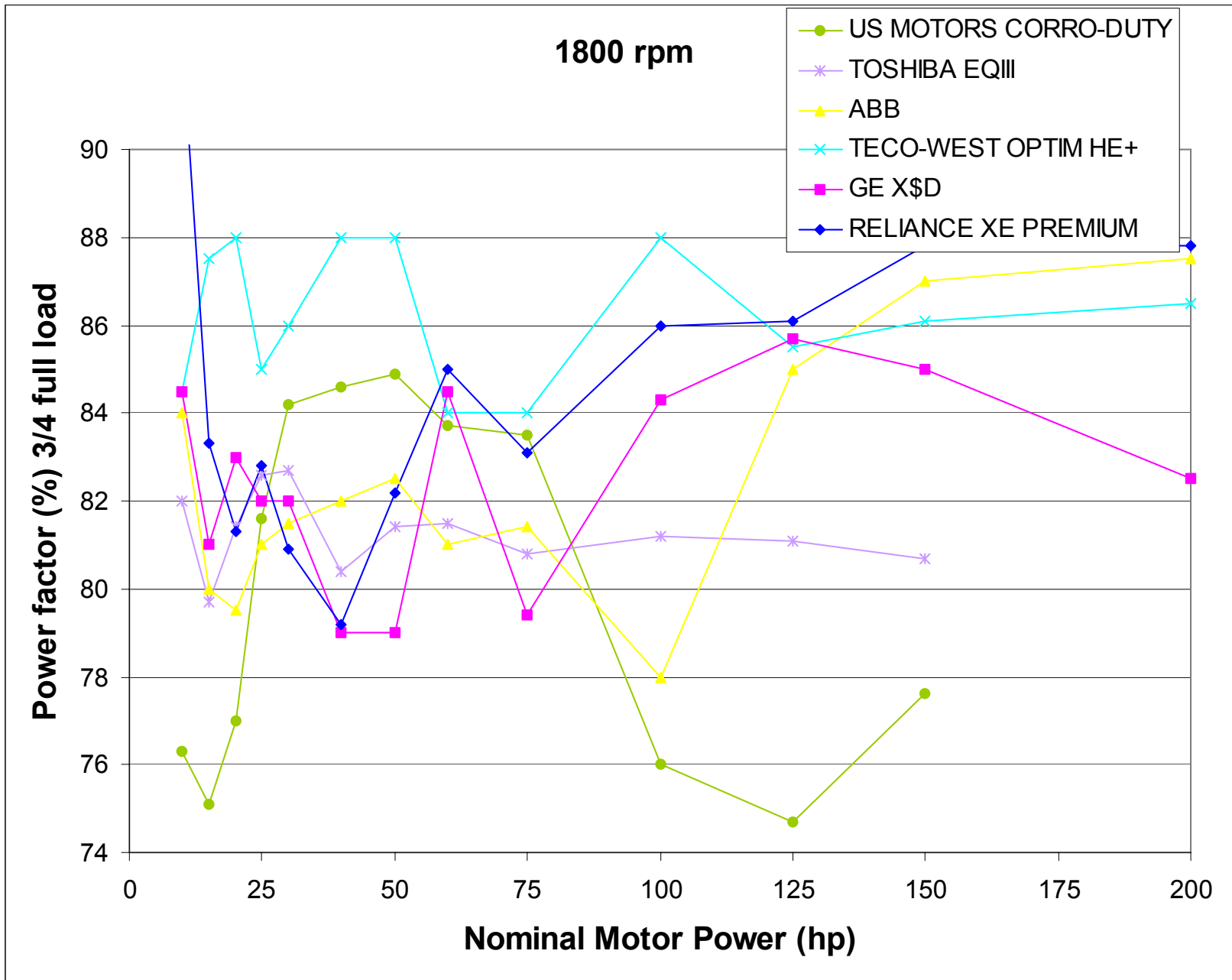


Figure 8 Power factor comparison for induction motors (575V, 3 phase, S.F. 1.15).

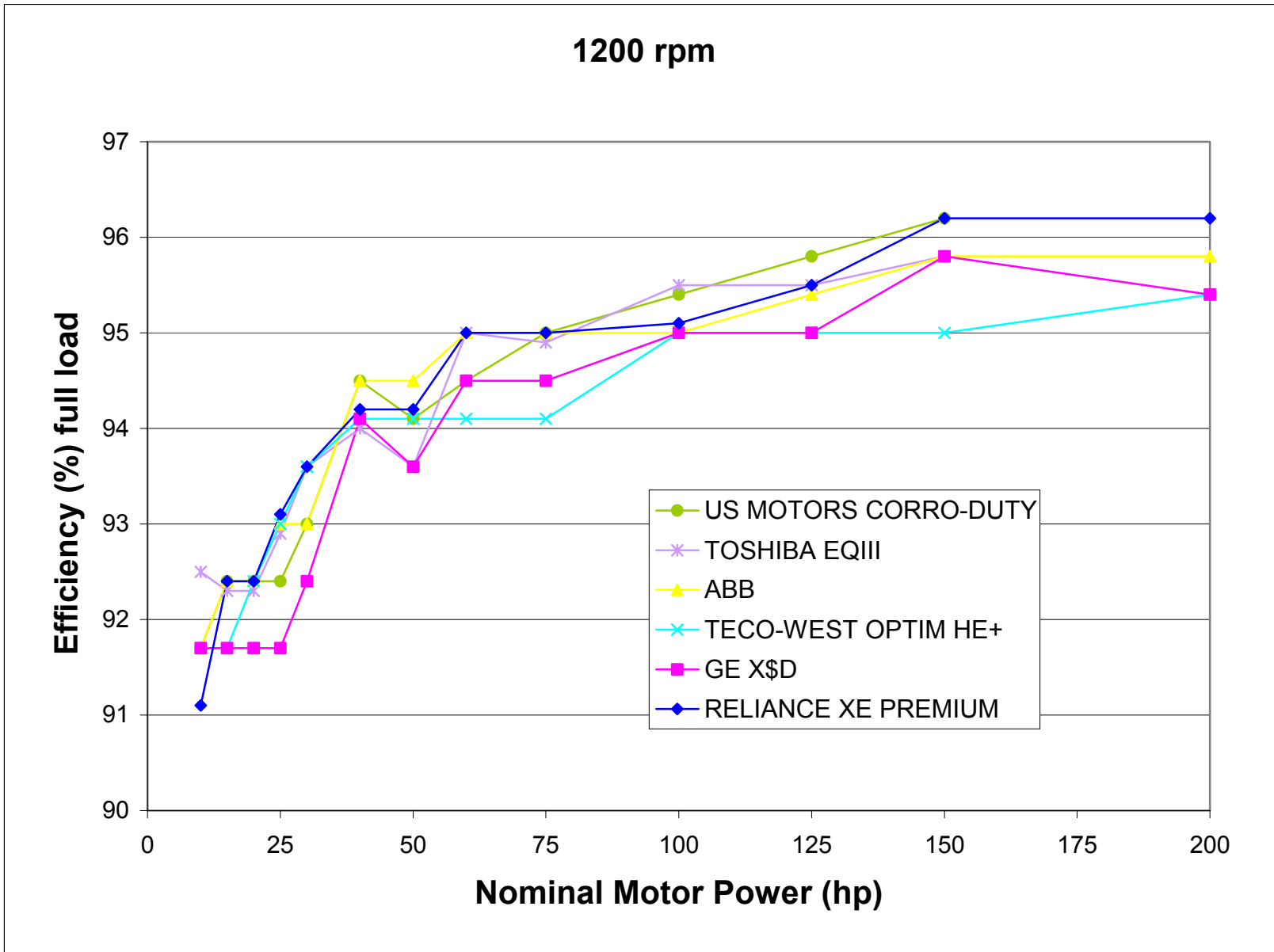


Figure 9 Efficiency comparison for induction motors (575V, 3 phase, S.F. 1.15).

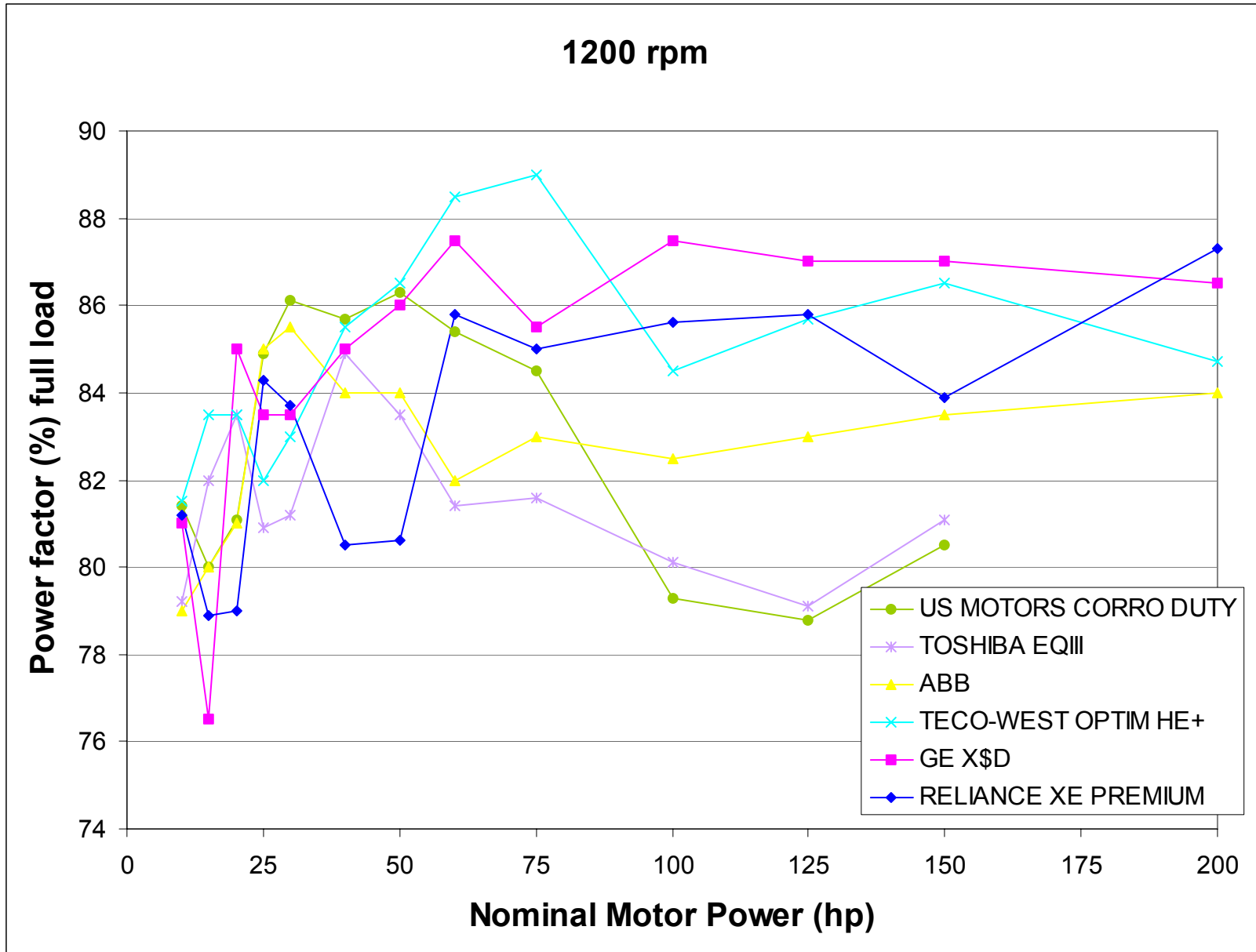


Figure 10 Power factor comparison for induction motors (575V, 3 phases, S.F. 1.15).

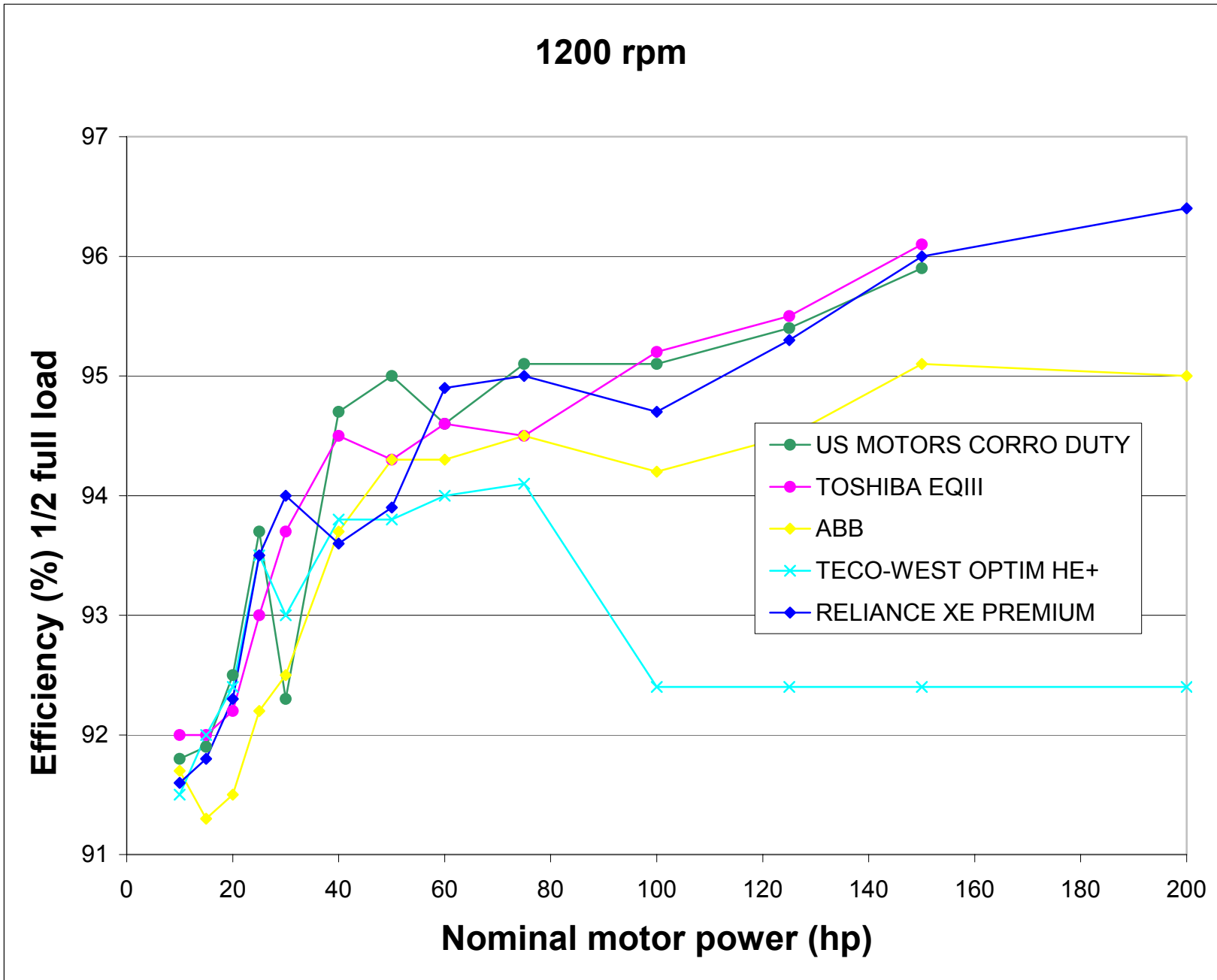


Figure 11 Efficiency comparison for induction motors (575V, 3 phases, S.F. 1.15).

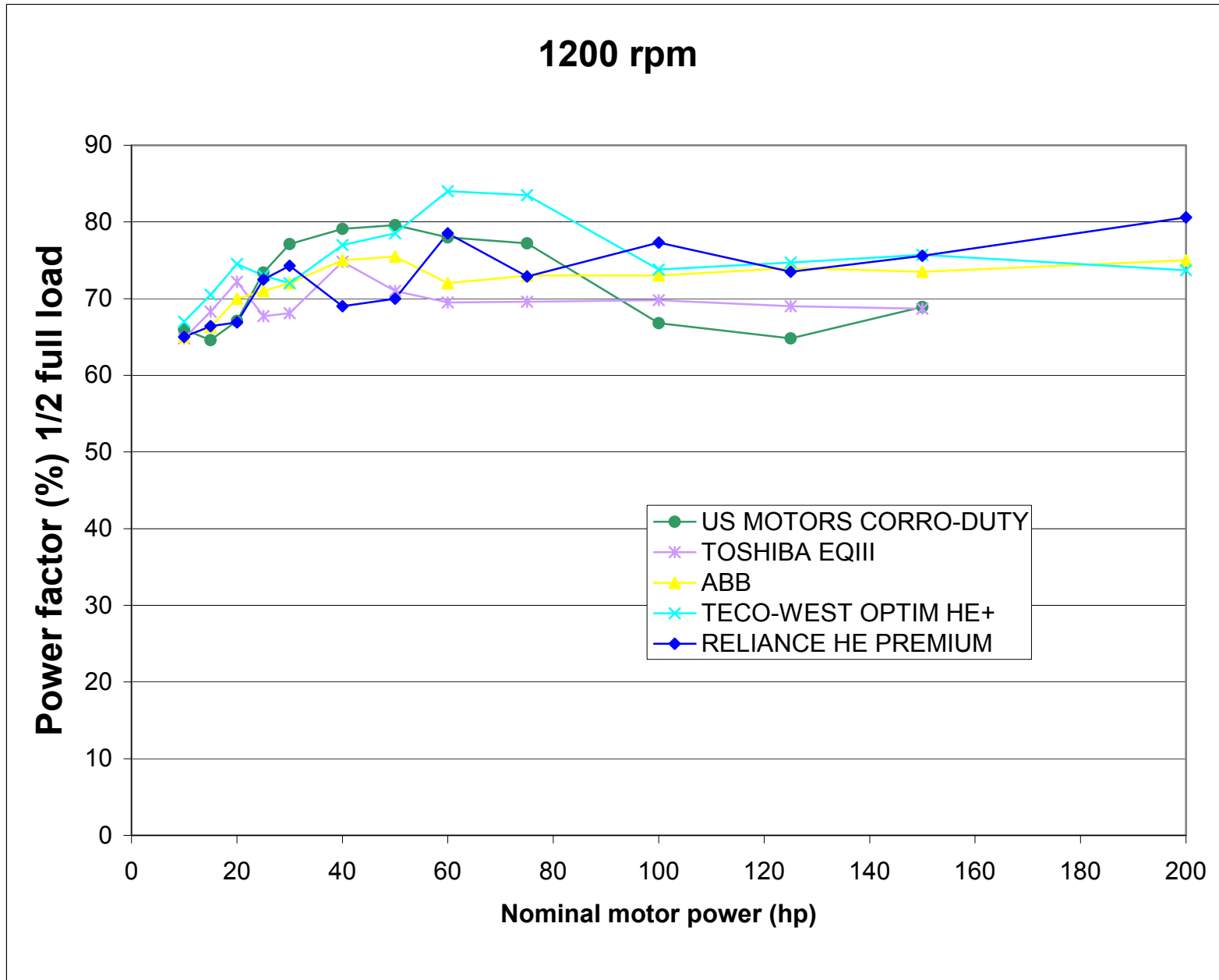


Figure 12 Power factor comparison for induction motors (575V, 3 phases, S.F. 1.15).

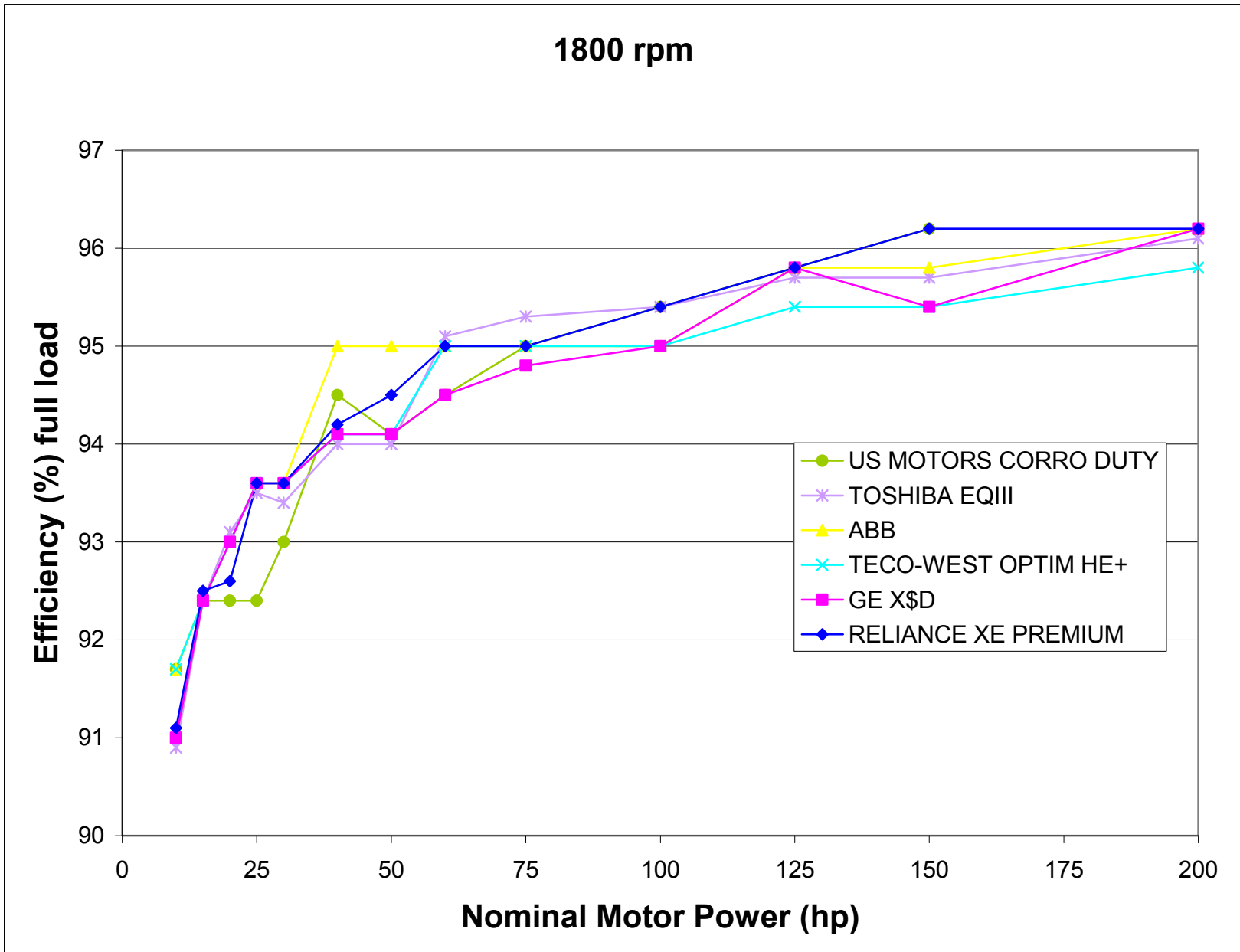


Figure 13 Efficiency comparison for induction motors (575V, 3 phases, S.F. 1.15).

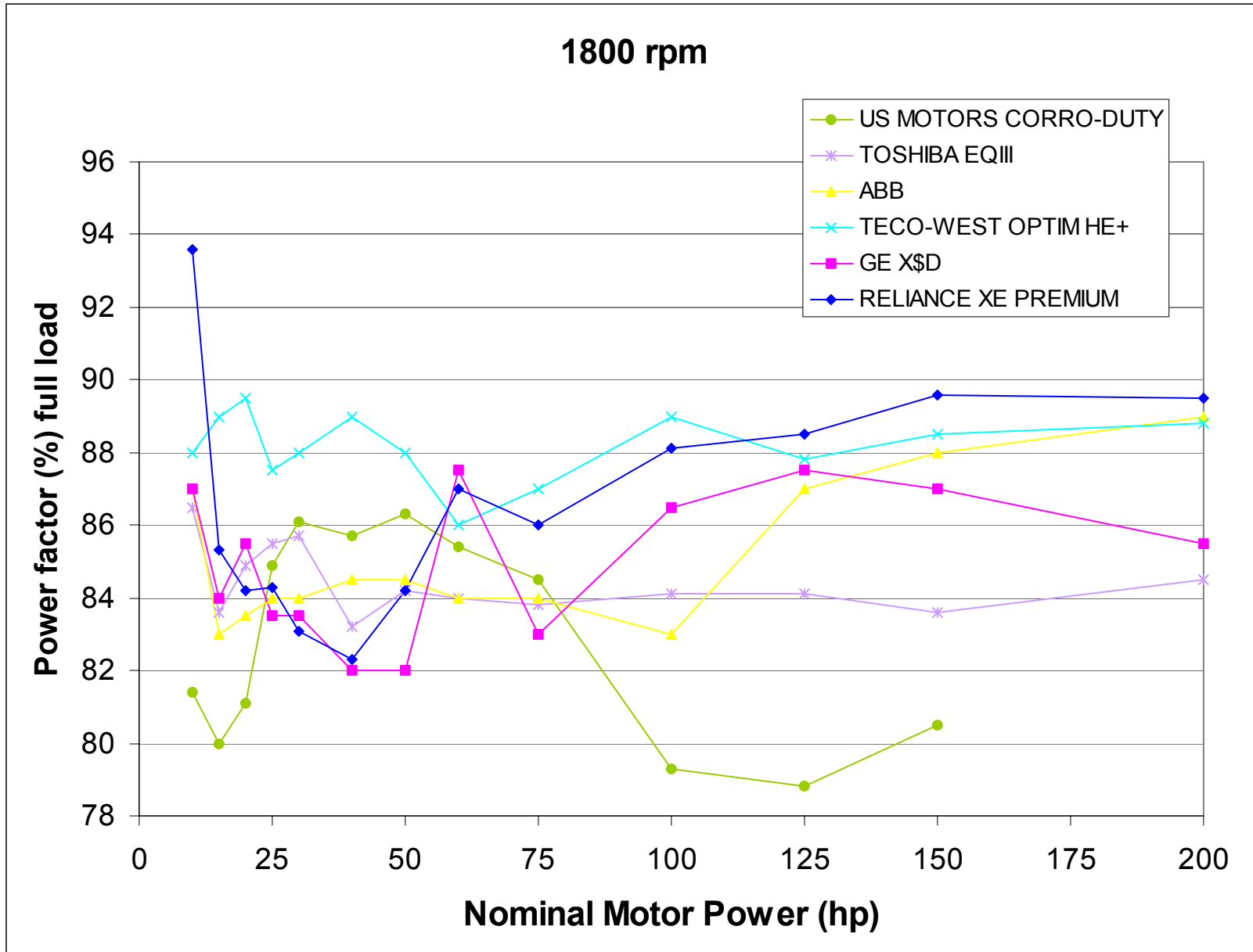


Figure 14 Power factor comparison for induction motors (575V, 3 phases, S.F. 1.15).

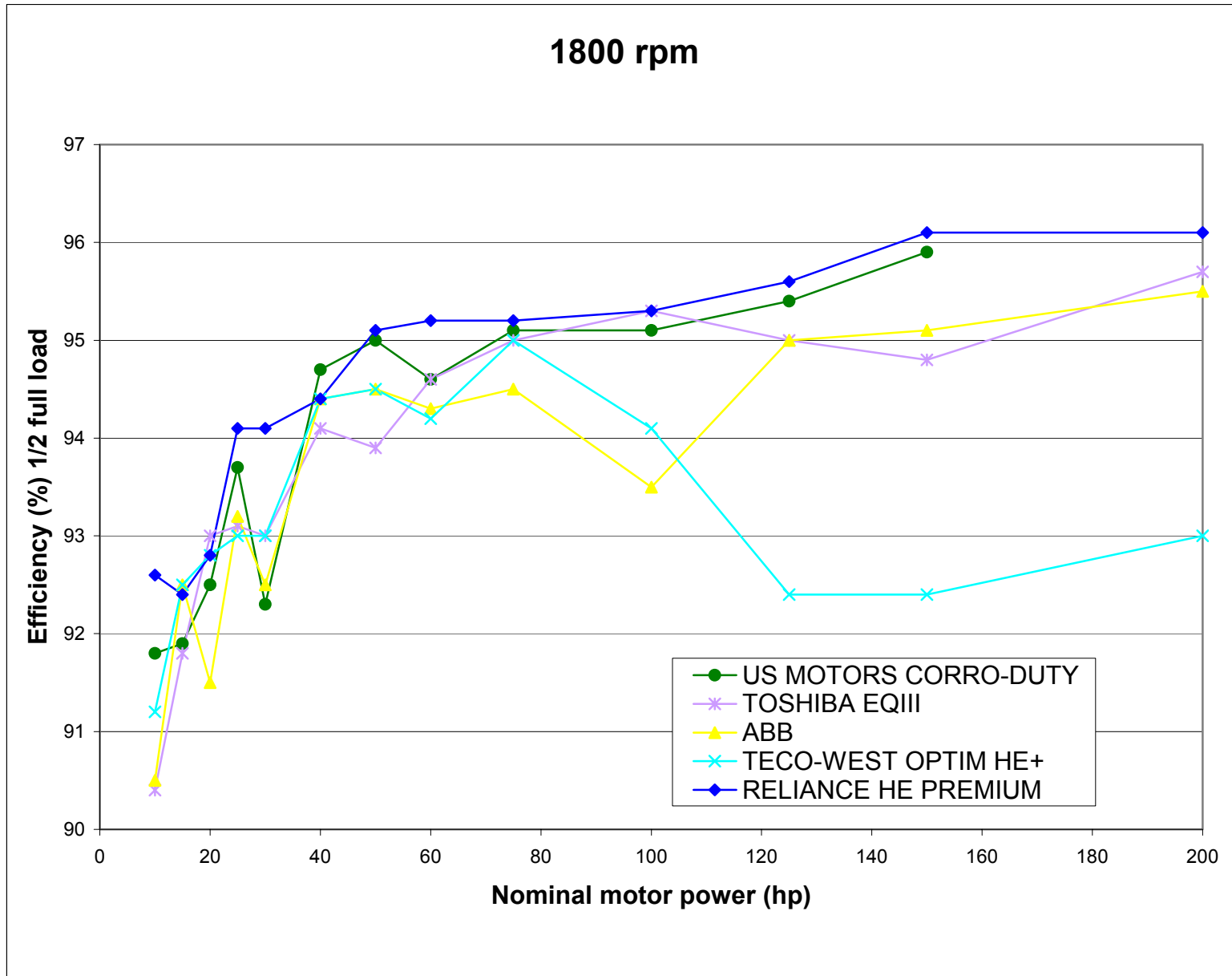


Figure 15 Efficiency comparison for induction motors (575V, 3 phases, S.F. 1.15).

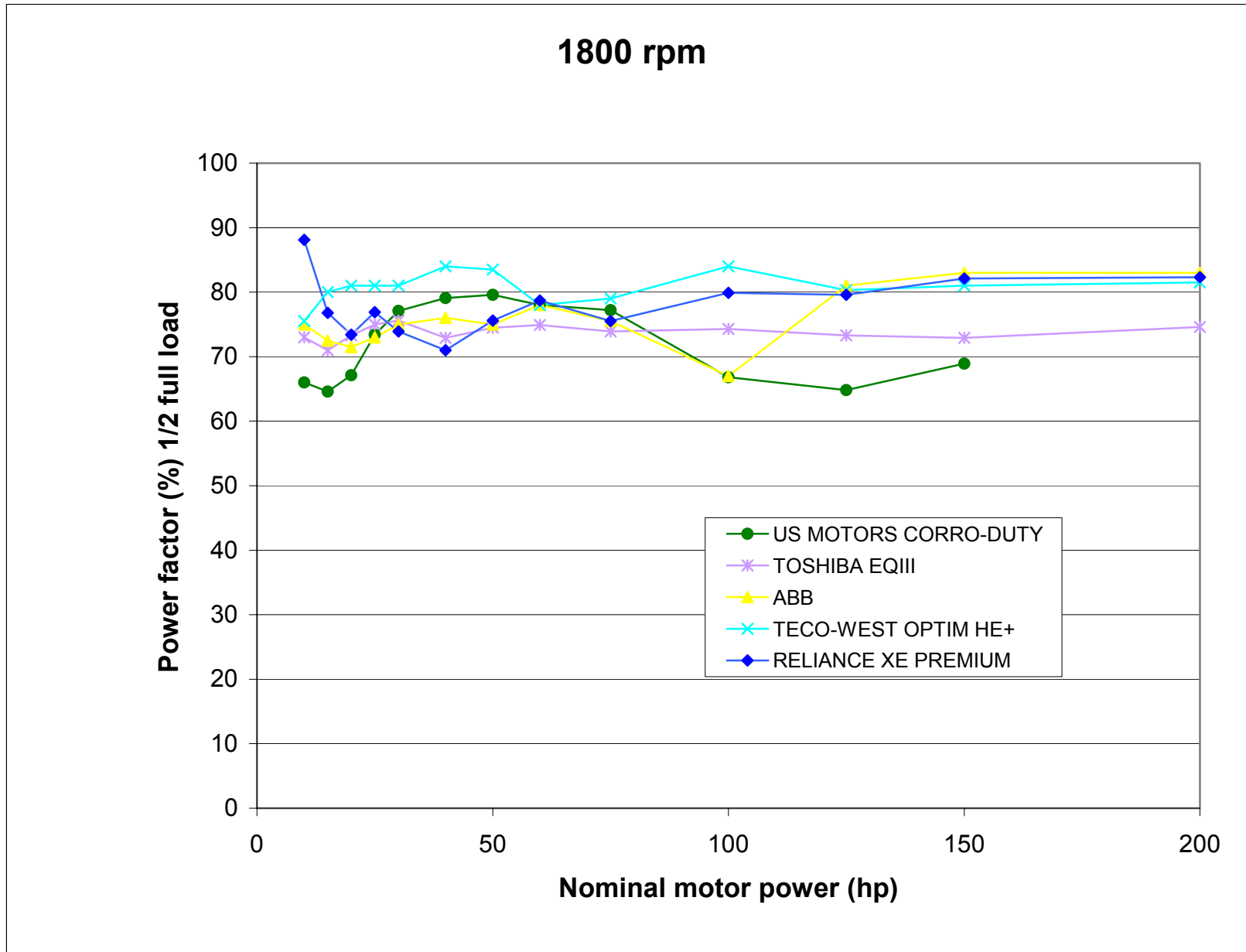


Figure 16 Power factor comparison for induction motors (575V, 3 phases, S.F. 1.15).