Copper-Rotor Motors + Variable Frequency Drives Maximize Savings at Water Treatment Plant

The Menands, New York, treatment plant operated by the Albany County Sewer District was one of two facilities selected by NYSERDA to evaluate ultra-high efficiency, copper-rotor motors. As in other industrial settings, motors account for much of the plant's electrical energy consumption.
Photo: Albany County Sewage District

The New York State Energy Research and Development Authority, NYSERDA, seeks to reduce the state's energy consumption. Among its many activities, the authority supports incentives to purchase high-efficiency motors. Ultra-high efficiency, copper-rotor motors (CRMs) have been available for several years, but NYSERDA lacked industrial data on them. The authority therefore initiated an R&D program in 2006 comparing the new motors' performance and cost benefits with those of old but fully serviceable motors. In addition, the program measured operating temperatures of several motors under known loading conditions.

NYSERDA selected two industrial sites for tests: the Rome, New York, brass mill owned by Revere Copper Products, Inc., and the Albany County Sewage District's (ASCD) North Plant in Menands, an Albany suburb. The Copper Development Association administered the contracts and, in turn, engaged the services of Advanced Energy Corporation, a Raleigh, North Carolina-based certified laboratory, to conduct the analyses.

This summary report describes results observed at the treatment plant. A companion summary report describes results of a CRM evaluation program conducted at the brass mill. The full reports are available from NYSERDA or CDA.[1]

Experimental Plan

Two motors, rated at 10 hp and 20 hp, respectively, were chosen for study at the ACSD facility. Both drove pumps. Ages of the motors are unknown, but their relatively low efficiencies (see below: **Speed-related Losses**) suggest they were pre-EPAct, standard-efficiency models, probably installed before the 1990s.

Measurements were taken on the motors' in-service kW consumption, current, voltage, power factor, time-load profiles, operating and ambient temperature, along with flow rate of the attached pumps. The same data were later taken on the new CRMs. ACSD recorded data in 10-minute intervals over a period of four hours. Motor operating temperatures were measured using infrared pyrometers.

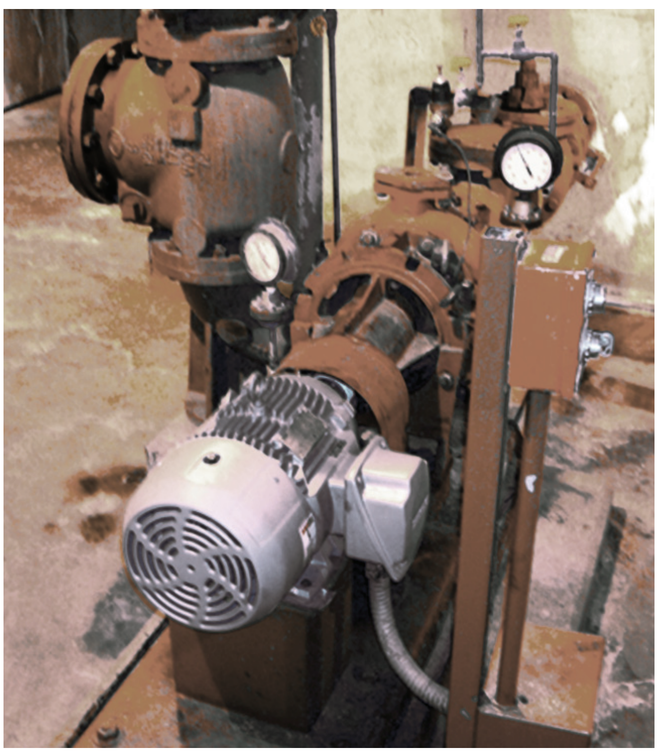
Following reference data collection, the old motors were sent to Advanced Energy's laboratory for physical characterization, including efficiency testing to IEEE Standard 112, Method B, and determination of energy-load profiles. This action was taken because the motors may have been rewound one or more times, and nameplate data, where available, were considered unreliable. Energy-load profiles for the CRMs were provided by the manufacturer (Siemens AG).

Speed-related Losses

Nameplate efficiency of the 10-hp motor was 85.0%; that of the 20-hp motor was 87.5%. The measured, in-service full-load efficiencies of the motors were 86.0% and 88.2%, respectively. Calculated operational efficiencies under service load were 86.60% and 89.55%, suggesting that the motors were sized correctly for their loads.[2]

Nameplate efficiency of the 10-hp replacement CRM was 91.7%; that of the 20-hp replacement was 93.6%. Measured full-load efficiencies were 92.40% and 93.99%, which is in keeping with CDA's earlier finding[3] that Siemens rates its motors conservatively. Calculated operating load factors were 46.73% and 97.8%, respectively, yet the calculated operating efficiencies were 93.29% and 94.01%, indicating that the load-efficiency curves for these copper motors is relatively flat over a wide load range.

Despite the advantage of a 6.69-percentage-point (93.29% - 86.60%) higher efficiency, the 10-hp CRM projected an annual operating energy savings of only 2.1% and a dollar savings of just $102.32. The new 20-hp CRM, operating at 94.01% efficiency, yielded a net loss of 21,491 kWh and a net dollar loss of $3,008.81 at $0.14/kWh. The slightly higher speed of the CRM had been identified at the outset of the project as a possible mismatch in this replacement motor demonstration. The demonstration clearly showed how severe the effect can be.



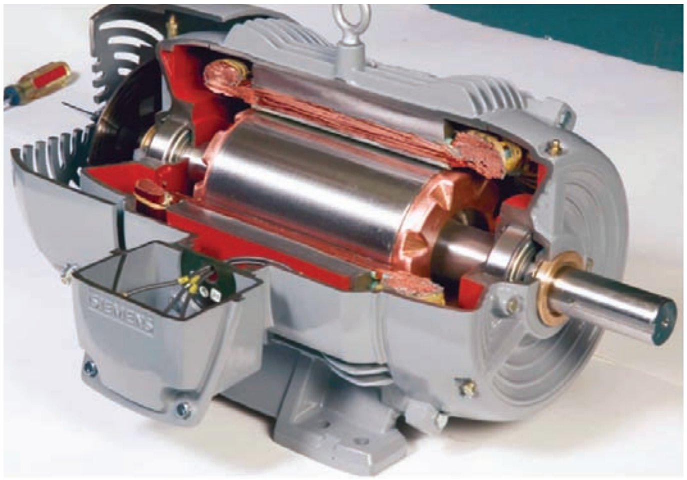
A new, 10-hp Siemens copper-rotor motor installed on an excess activated sludge pump at the ACSD Menands plant. Not shown in the photo is the variable frequency drive, that, when used to control the motor's speed and the pump's throughput, resulted in significant energy savings. Payback for the motor-VFD combination was well less than one year.
Photo: Copper Development Association

Watch Those Centrifugal Loads

Speed mismatch is known to be an issue when driving centrifugal loads such as the pumps in this plant. When driving centrifugal loads, a motor's shaft power is proportional to the cube of its rotational speed, a phenomenon known as the *cube rule*. The catch here is that, because of the higher conductivity of copper compared with aluminum, CRMs operate with lower slip and therefore higher speed than conventional motors. The higher speeds of the CRMs caused them to draw more power thanks to the cube rule, which offset or wiped out the savings from their higher efficiencies.

Fortunately, there are relatively simple fixes for this problem. For centrifugal loads such as fans or blowers, rotational speed can often be controlled by the belt drive wheel ratio, an inexpensive, quick solution. Pump output is often controlled by a throttle valve to control flow, and that, in fact, was the practice at ACSD for many years. However, a more efficient way to control motor speed and therefore flow is with a variable frequency drive (VFD). Adding the VFD negates the slip/speed penalty and maintains the economic benefits of the more-efficient motor. The project scope was expanded to include field measurements with a VFD drive installed on the 20-hp CRM.

ACSD operators previously controlled the flow of the pump driven by the 20-hp motor at 210 gpm using a throttle valve. This same practice was initially retained after the CRM was installed. Operating without a VFD, with flow governed by the valve, the CRM drew 26.7 A, consuming 17,693.3 W. The CRM was running faster than the motor it replaced; the cube rule prevailed, and the expected savings became a significant loss. The bright side was that the situation provided an excellent opportunity to demonstrate the value of a VFD.



A Siemens 10-hp induction motor of the type used in the evaluation program described here. The motors incorporate a die-cast copper rotor with other design modifications to reduce losses, thereby increasing efficiency by as much as several percentage points above those of average NEMA Premium® motors of comparable sizes. Photo: Siemens AG

A second measurement taken with the pump driven by a CRM, but without a VFD, yielded an annual energy cost $2,936.57 higher than that of the old motor/pump/valve combination. (This differs slightly from the $3,008.81 measured earlier, probably because of varying line voltage.) The VFD/CRM/pump combination was next tested with the valve maintaining flow at 210 gpm and the VFD matching the new motor's speed to that of the old motor. Under these conditions, the CRM drew 25.9 A, consumed 14,306 W and a yielded a savings of $1,150, which, coincidentally, is very close to the cost of the VFD.

Additional power savings were achieved when the system was operated with the throttle valve fully open and the VFD alone controlling flow. Current draw dropped to 17.6 A, power consumption fell to 9,198 W, and annual cost savings jumped to $6,534.66, *which is more than enough to pay back the cost of the CRM-VFD combination in well less than a year.*

Projected savings were calculated using a VFD with the 10-hp CRM and operating at the same speed as the old motor it replaced. The results showed this CRM would also generate a positive annual cost savings.[1]

Payback and Long-term Savings

A two-year payback is generally acceptable in industrial settings. The VFD increases initial cost and extends the payback period. The payback period (at $0.14 per kWh) for the VFD-controlled 20-hp CRM discussed above (total purchase price $2,471.00) would be 25.8 months if the valve controls flow and the VFD simply slows the CRM. On the other hand, payback falls to only 4.6 months when flow is controlled entirely by the VFD, which is clearly the optimum operating method.

Payback times are valuable, but the long-term (say, 10-year) savings offered by CRMs are at least equally important. This long-term, "life-cycle" view is based on the fact that CRMs operate a lot cooler than conventional motors. It is an accepted industry rule of thumb that a motor's life is halved for every 10-degree Celsius rise in operating temperature, the decrease being attributed to degradation of the windings' insulation.

Conversely, a 10-degree decrease in operating temperature could double a motor's life. The NYSERDA study therefore looked at projected 10-year savings resulting from replacement of old motors by copper-rotor Ultra-NEMA Premium® motors, and, in addition, for replace-

Payback Times and 10-year Savings for Various Replacement Scenarios

Scenario	Replacement Cost ($)	Ann. Energy Savings (kWh)	Ann. Energy Cost Savings ($)	Electricity Rate ($/kWh)	Payback Period (Yrs / Mos)	10-year Cost Saving ($)
Discard and Replace Old ACSD 20-hp Motor						
Replace with CRM + VFD — control flow with throttle valve	1,273	8,221	1,150.94	0.14	2.15 / 25.8	9,038
	+ 1,198		759.78	0.09242	3.25 / 39	5,127
As above — open valve, control flow with VFD	2,471	46,677	6,534.78	0.14	0.38 / 6.9	62,877
			4,313.88	0.09242	0.57 / 6.9	40,668
Replace with EPAct motor	737	5,909	827.26	0.14	0.89 / 0.7	7,536
			546.11	0.09242	1.35 / 16.2	4,724
Replace with average NEMA Premium® motor	1,286	6,823	955.22	0.14	1.34 / 16.2	8,266
			630.58	0.09242	2.0 / 24	5,020
Discard and Replace Old ACSD 10-hp Motor						
Replace with CRM + VFD	914 + 765	2,330	326.20	0.14	5.1	1,583
			215.39	0.09242	7.8	475

Source: Advanced Energy Corporation and Copper Development Association ment with conventional NEMA Premium and EPAct motors.[4] For replacement with a CRM, the 10-year cost saving is more than $9,000 for the valve-throttled case but nearly $63,000 when the VFD alone controls speed and flow.

Replacement costs are reduced by about half with EPAct or conventional NEMA Premium motors because a VFD is not required. Payback periods are reduced by a few months, but at the expense of the 10-year cost savings, which are reduced by about $1,500 for EPAct motors and $800 for NEMA Premium.

Replacing the smaller, 10-hp motor at ACSD with a CRM + VFD combination saves less money than the 20-hp motor combination because energy savings are correspondingly reduced. The 5-plus-year payback period reduces the value of the CRM + VFD + valve option, although the 10-year cost savings is still nearly $1,600. Using the VFD alone would be better, but that action was not examined. Results for all scenarios investigated are tabulated below. Energy savings and payback periods were calculated using *MotorMaster+*, versions 3.0 and 4.00.06 for EPAct and NEMA Premium motors, respectively.

Centrifugal loads *must* be taken into account when replacing old motors with faster, more efficient models. Correcting for the higher speed of the faster copper motor with a VFD significantly increases energy savings but requires a larger up-front capital expenditure. For large motors with high duty cycles, the copper rotor motor leads to larger 10-year energy savings than replacement with either an EPAct or NEMA Premium motor. For motors with low duty cycles driving centrifugal loads, the CRM + VFD combination does not appear to be cost effective at the utility rates considered here.

A Bonus: Lower Operating Temperatures

Temperature measurements were taken while the new and old motors were operating at what were believed to be nearly identical loads. Identical temperature guns were used for the measurements. The 10-hp CRM operated 7.1 degrees Fahrenheit (4 degrees Celsius) cooler than the existing standard motor, a reasonable improvement for a relatively small motor. On the other hand, the 20-hp CRM ran an impressive 41.2 degrees Fahrenheit (23 degrees Celsius) cooler than its standard-efficiency counterpart. If conventional wisdom holds, the difference implies that the replacement CRM's windings could enjoy a 20-year longer life.

Measured Motor Operating Temperatures and Temperature Rise Above Ambient

MOTOR	MOTOR TEMP, ºF	AMBIENT TEMP, ºF	TEMP RISE, ºF
Copper-Rotor, 10-hp	91.5	67.2	**24.3**
Old, 10-hp	101.2	66.9	**31.4**
Copper-Rotor, 20-hp*	95.4	68.4	**26.3****
Old, 20-hp	134.5	67.0	**67.5****

*Speed matched to that of existing motor with VFD
**Temperature measured on shaft end
Source: Mohawk Valley Predictive Technologies

Bottom Line

The NYSERDA evaluation program conclusively showed that ultra-high efficiency, copper-rotor motors can provide substantial energy and cost savings, both over the short and long terms. The program underscored the need to evaluate specific motor replacements carefully, especially where centrifugal loads are encountered. On the other hand, the program also showed that concurrent installation of a VFD with a CRM, while adding to initial cost, can result in very significant 10-year savings. Finally, there are strong indications that the CRM's lower operating temperatures will result in longer service lifetimes, thereby extending the savings that these highly efficient machines offer.

References

[1] The New York State Energy Research and Development Authority, *In-Plant Demonstration of Electrical Energy Savings Realizable with the Copper-Rotor Motor*, Contract No. 10241, Joseph, C. Borowiec, NYSERDA Project Manager, Prepared by Dale T. Peters, Copper Development Association Inc., August 2009.

[2] For calculation methods, see Reference 1 and Agamloh, Emmanuel B., *The Partial-Load Efficiency of Induction Motors*, IEEE Trans. on Industrial Applications, Vol. 45, No. 1, January/February 2009.

[3] *Copper Motor Rotor Update*, Copper Development Association, November 2006, www.copper-motor-rotor.org/update/Nov_06/index.html

[4] *The Energy Independence and Security Act of 2007* raises mandated motor efficiency standards from those of EPAct 2002 to NEMA Premium levels effective in December 2010. Data for EPAct motors in the table assume such motors are available from inventory.