Schneider Electric
July 12, 2007

Comparison of Medium Voltage and Low Voltage Adjustable Speed Drive Retrofits for Water and Wastewater Facilities

By Van Wagner, P.E., Schneider Electric Water Wastewater Competency Center

Introduction

Traditional power system design practice suggests that the motor crossover from low voltage to medium voltage is in the 200 to 500 HP range. A major reason is due to the fact that the starting current at low voltage in this range can abnormally depress facility voltage. The addition of reduced-voltage motor starting can alleviate the voltage dip but at considerable extra cost.

Adjustable speed drives may have increased the upper limit of the crossover. Drives have inherent soft starting capability, and combined with increased process efficiencies at lower speeds, may have moved the crossover to a greater horsepower rating. Has the crossover changed?

This paper attempts to answer that question with a focus on water and wastewater applications. An example of low voltage and medium voltage application is compared for 300, 500 and 800 HP drives. Since installation of a drive in an existing pumping application is more commonly encountered than new applications, the example given is for a retrofit in an existing facility. The results are sensitive to the assumptions of the analysis and the assumptions are framed in a realistic scenario that could be projected to other situations.

The paper compares the installed cost, reliability and operating costs for the medium voltage and low voltage applications. Other considerations also are discussed.

Installed Costs

The design basis assumes the existing condition consists of a 4000 V motor driving a vertical pump with either across-the-line or reduced-voltage starting (Figure 1). A drive is installed to realize higher efficiency for partial flow operation. Since demolition costs will be similar in both cases, they are not included in the comparison. The existing starter would be replaced with a fused disconnect. This cost is common in either case and is not included.

In medium voltage drive situations, motors are replaced about half the time as the motor may have considerable running time and it may be decided to include a replacement as part of the capital project. Although some medium voltage drive manufacturers claim it is not needed, inverter duty motors are generally specified for drives. They have enhanced insulation to handle the substantial rate-of-change of voltage produced by the inverters. For these reasons it is assumed the motor in the medium voltage application is replaced as part of the project. The low voltage drive would use a low voltage inverter duty motor. A possible alternative would be to add a step-up transformer to the drive output and use the existing medium voltage motor. However, the transformer increases cost and space, as well as slightly decreases efficiency and reliability, and will not be considered.

Water/wastewater facilities have among the most stringent power system harmonics specifications for drives of all industries. Almost all medium voltage drives have 18-pulse or 24-pulse rectifiers to reduce the low order harmonic current components on the drive input. Therefore the low voltage drives are specified as 18-pulse. For the higher pulse drives, special transformers to create the additional phases are required and are included with the drive in one section of the drive cabinet. The low voltage drive will need a step-down transformer added to feed the drive from medium voltage.

Space is assumed available to add the drive. Most water/wastewater facilities have generous amounts of space on the pump floor in a protected environment with the switchgear room nearby.

Motors are open drip-proof, 1800 RPM, vertical frame and inverter duty. Medium voltage vertical motors are custom engineered to the pump base. Generally, low voltage motors in the horsepower range under consideration use a medium voltage frame and are also custom engineered.

Installed wiring is also included in the cost estimate. It's assumed that the conductors from the medium voltage disconnect switch to the drive and from the drive to the motor are run in overhead conduit installed as part of the project with a total distance of 100 feet. The old raceways are not used. The drive output wiring is contained in continuous conduit and shielded conductors are not needed. Wiring materials and labor costs are taken from RS Means *Electrical Cost Data*. Costs of control wiring installation is not included since it will be similar for the medium voltage and low voltage drives.

The additional equipment will add heat to the building. Drive losses will be very similar but added step-down transformer will increase the heat load by about 25 percent for the low voltage case. If the drives are installed in the pump gallery, additional cooling may not be necessary due to the large size of the room. Air conditioning may be needed for facilities in hotter climates. Some medium voltage drives are water cooled. To simplify the comparison, costs associated with additional cooling will not be considered.

The medium voltage drives use a variety of power electronic topologies and are not as consistent among manufacturers as in the low voltage case. Low voltage configurations are entirely diode rectification with pulse-width-modulated (PWM) inverters. Some of the medium voltage designs require an inverter duty motor and others do not. In addition some of the medium voltage drives do not include the cost of an isolation transformer to provide adequate source impedance to the drive. In this case, it is assumed a multi-phase transformer is included with the medium voltage drive and no isolation transformer is needed.

Equipment prices are from the manufacturers and installation costs are from *Electrical Cost Data*. As shown in Table 1, in both the 300 and 500 HP cases, the low voltage installation is 40 percent and 19 percent less expensive than the medium voltage application, respectively. In the 800 HP case, the low voltage installation is more expensive than the medium voltage.

The drives are the single greatest cost component for the installation. Except for the 800 HP case, the medium voltage drive is about twice the cost of the low voltage drive. There are several reasons for this situation. Medium voltage drives are produced at lower volumes and are more custom engineered than low voltage. The market has fewer manufacturers and is less competitive.

The 800 HP low voltage drive is outside the mass production rating for low voltage drives and reflects costs similar to the medium voltage drive market.

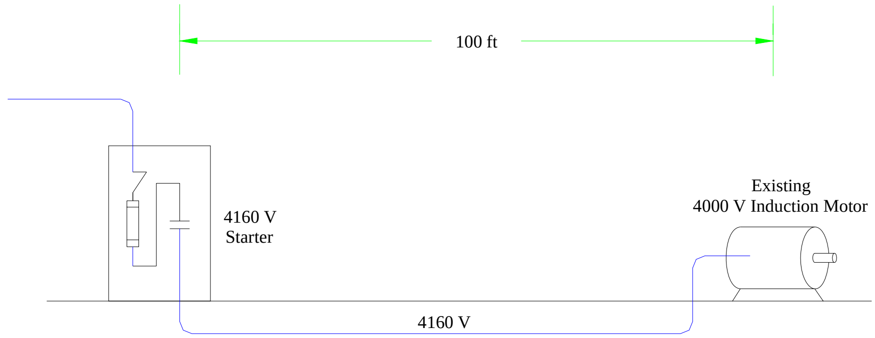
Even when the step-down transformer is added to the low voltage installation, it's still considerably less expensive than the medium voltage installation for the 300 and 500 HP cases.

There has been considerable focus on the wiring costs associated with low voltage drive installations due to the changes in the commodity price of copper. In this project, low voltage wiring is about 15 percent of the project cost and the medium voltage application is about half that value. In either case the wiring costs are a small portion of the overall project costs. Voltage drop can become an issue at distances greater than 400 feet and drive-to motor-distances are recommended to be less than 150 feet by most manufacturers. Consequently, actual lengths would not be expected to be much longer than the assumed 100 feet.

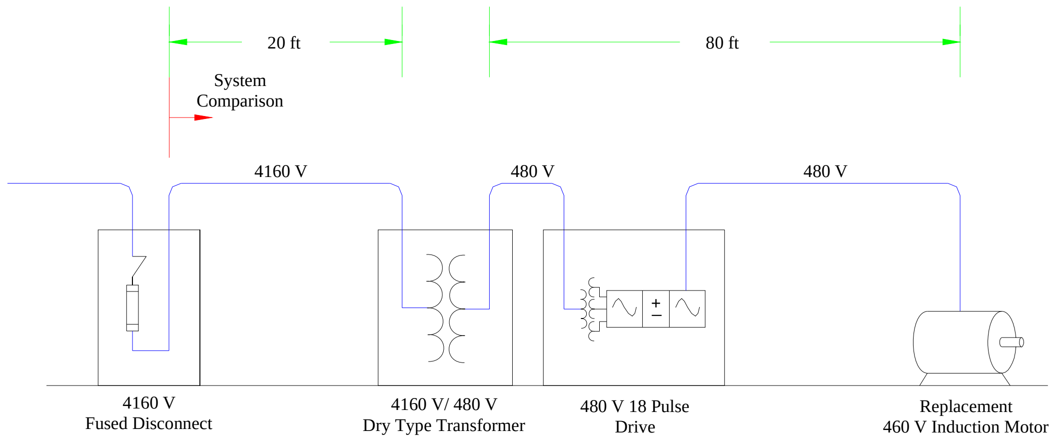
Table 1 – Installed cost comparison of low voltage and medium voltage drives

	300 HP		*500 HP*		*800 HP*	
	Medium Voltage Drive	*Low Voltage Drive*	*Medium Voltage Drive*	*Low Voltage Drive*	*Medium Voltage Drive*	*Low Voltage Drive*
Wiring	$12,600	$15,200	$12,600	$19,200	$12,600	$30,300
Transformer	NA	$22,100	NA	$26,500	NA	$35,400
Drive	$107,200	$42,200	$113,200	$57,200	$121,200	$116,500
Motor	$21,300	$19,300	$26,600	$24,100	$35,100	$31,800
TOTAL	$141,100	$98,800	$152,400	$127,000	$168,900	$214,000

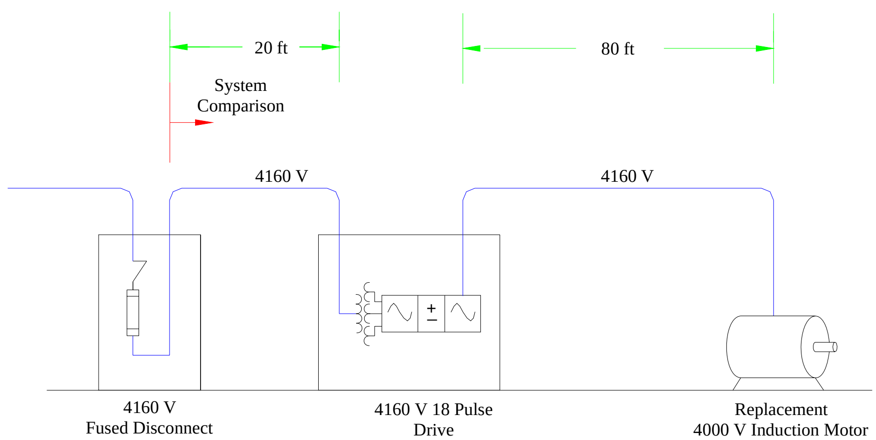
Figure 1 – Existing and proposed motor feed configurations



Medium Voltage Existing Configuration



Low Voltage Drive Configuration



Medium Voltage Drive Configuration

Reliability

The availability of power system equipment reliability data varies with the type of equipment. Manufacturers have good information on warranty returns but such information is usually not published. It has been left to industry groups and organizations to compile reliability databases. For instance, there has been a significant effort by the electric utility industry to collect data on insulated conductors.

One of the most extensive industrial databases has been the Institute of Electrical and Electronic Engineers (IEEE) Standard 493-1997, *IEEE Recommended Practice for Design of Reliable Industrial and Commercial Power Systems* (Gold Book). This standard contains data from the early 1970s. A more recent database has been published by the U.S. Army Corps of Engineers Power Reliability Enhancement Program and includes data from the 1980s.

Table 2 shows a reliability comparison of the two installations developed for the cost comparison. The table values are the failure rate per year. All the table data is from the IEEE Gold Book. The top row is the failure rate for medium voltage and low voltage conductors per 1000 feet of length. The rows beneath are the projected failure rate of the lengths of conductor in proposed installations. Conductor failure has been well researched and the rate of failure of medium voltage conductors is much higher than that of low voltage.

Similarly, motor and transformer failure data is rather extensive. Medium voltage motors have about four times the failure rate of low voltage. It is assumed that each drive has an internal multiphase transformer and the low voltage installation uses an additional step-down transformer. The data are for dry type transformers.

There is no drive reliability information in the Gold Book. The Corps of Engineers data is more recent than the Gold Book and contains drive data but likely represents first generation low voltage drives. It shows a 45 year mean time between failure (MTBF). A current consensus of manufacturers and users consider a reliability of five years MTBF as fairly realistic. Since there is no reasonable reliability data on the differences between medium voltage and low voltage drives, their reliability will be assumed identical and no data is provided in the table.

The time to repair may be longer and recommended spare parts more expensive for medium voltage drives. Although medium voltage drive manufacturers have tried to modularize the equipment to expedite repair, most users typically will request the manufacturer perform the repair. A major reason is because many water/wastewater facilities do not have trained staff for medium voltage work. It’s possible to use manuals or technical support to make a repair on low voltage drives, however, drives are sophisticated devices and users may feel more comfortable deferring repair to specialists.

(Without drive data, the low voltage installation is over twice as reliable as the medium voltage installation. The dominant factors are the conductor and motor reliabilities even though the low voltage installation uses two transformers.

Table 2 – Reliability comparison (failures per year) of medium and low voltage drive installations

Components	*MV Drive*	*LV Drive*	*Comments*
Conductors	0.049	0.00141	per 1000 ft
MV	0.0049		100 ft
MV		0.000225	20 ft
LV		0.00098	160 ft
Motor	0.0404	0.0109	
Drive			No detailed data
Transformer	0.0036	0.0072	LV has 2 xfmrs
TOTAL	0.0453	0.0193	

Operating Costs

A third factor in determining whether to install a low voltage or medium voltage drive is the operating cost of the equipment. Table 3 provides a comparison of low and medium voltage drive operating losses and associated costs based on the manufacturer's specifications. All the equipment was sized to standard industry or trade values based on drive ratings. The majority of the losses are in the motors and drives. Low voltage motors are about 0.5 percent more efficient than the medium voltage motors in this range due to increased stator copper losses. The major penalty for the low voltage drive is the loss due to the step-down transformer. Wiring losses are only a small part of the total, consisting of less than 4 percent even for the 800 HP drive case.

In each case, total losses are lower for the medium voltage installation. For a more accurate comparison, these losses must be converted to costs. It's assumed the pumps are run 30 percent of the year at 75 percent speed and the cost of electricity is $0.07/kWhr. The resulting annual costs are shown in Table 3. The assumption of 30 percent use is based on a facility with variable flow demands and rotated pump use. The electricity price is considered a representative value. The existing installed base of drives tend to be replaced after about 10 to 12 years. The trigger is a drive failure where the repair costs exceed about half the cost of a new drive. If the operating costs are projected back to present day for a 12-year operating life, the results are shown in the "12 yr difference" row.

Total drives cost consists of the installed cost and the 12-year operating costs and is depicted in Table 4. The cost advantage of the low voltage drive is 21 percent for the 300 HP scenario, and 6 percent for the 500 HP case. For the 800 HP case, the low voltage installation is 26 percent more expensive.

Table 3 – Comparison of low voltage and medium voltage drive operating losses and associated costs (*see text for assumptions)

	300 hp		500 hp		800 hp	
	Medium Voltage Drive	*Low Voltage Drive*	*Medium Voltage Drive*	*Low Voltage Drive*	*Medium Voltage Drive*	*Low Voltage Drive*
Wiring						
MV	0.09 kW	0.02 kW	0.26 kW	0.05 kW	0.65 kW	0.13 kW
LV	NA	0.75 kW	NA	0.68 kW	NA	1.83 kW
Transformer	NA	6.87 kW	NA	9.08 kW	NA	12.2 kW
Drive	8.20 kW	11.20 kW	13.60 kW	14.70 kW	21.80 kW	22.00 kW
Motor	11.3 kW	5.55 kW	14.72 kW	10.15 kW	19.62 kW	16.23 kW
TOTAL	19.58 kW	24.39 kW	28.58 kW	34.66 kW	42.08 kW	52.39 kW
ANNUAL COST*	$3,600	$4,500	$5,300	$6,400	$7,700	$9,600
12 YR DIFFERENCE	-	$10,600	-	$13,400	-	$22,800

Table 4 – Comparison of low voltage and medium voltage drive total costs

	300 hp		500 hp		800 hp	
	Medium Voltage Drive	*Low Voltage Drive*	*Medium Voltage Drive*	*Low Voltage Drive*	*Medium Voltage Drive*	*Low Voltage Drive*
TOTAL COST (000)	$184	$153	$215	$204	$262	$330

Conclusions

This paper has presented a detailed comparison of the retrofit of low voltage and medium voltage drives for water/wastewater applications. Every installation has unique characteristics. This example will not exactly correspond to an application under consideration. However, it does provide a comparison for a realistic case and a template that can be modified to compare different scenarios.

Among the results of the comparison are:

- The low voltage drive has a 21 percent cost advantage in the 300 HP range including installed and operating costs.

- In the 500 HP range, the low voltage drive has a small financial edge. Specific application details or other factors may decide the choice.

- In the 800 HP range the medium voltage drive has a 26 percent cost advantage.

- From a reliability standpoint, both types of drives are comparable. However, low voltage motors and conductors are more reliable than medium voltage counterparts. Consequently, the overall low voltage application is about twice as reliable as the medium voltage.

References

RS Means *Electrical Cost Data*, 30th Edition, 2007.

IEEE Standard 493-1997, *IEEE Recommended Practice for Design of Reliable Industrial and Commercial Power Systems* (Gold Book).

Hale, P. S., Jr., Arno, R.G, “Survey of Reliability and Availability for Power Distribution, Power Generation, and HVAC Components for Commercial, Industrial, and Utility Installations,” *IEEE I&CPS Conference Record*, Apr 2000.

Appendix
Installation Cost Details

300 hp drive

Medium Voltage

	Descp	Quant	Each	Subtotal
MV Conduit	4" GRC	100	$58.41	$5,841
MV Conductor	#2 MV90	300	$6.50	$1,950
MV Terminations	Stress cone	12	$192.00	$2,304
Misc Mat & Labor				$2,500
Motor				
Cost	Motor	1	$20,000	$20,000
Installation				$1,300
Drive				
Cost	Drive	1	$100,000	$100,000
Installation				$7,200
TOTAL				$141,095

Low Voltage

	Descp	Quant	Each	Subtotal
MV Conduit	4" GRC	20	$58.41	$1,168
MV Conductor	#2 MV90	60	$6.50	$390
MV Terminations	Stress cone	6	$192.00	$1,152
LV Conduit	3" EMT	160	$14.80	$2,368
LV Conductor	2-250 MCM	480	$10.90	$5,232
LV Terminations	Crimped	24	$100.00	$2,400
Misc Mat & Labor				$2,500
Transformer		1	$17,300	$17,300
Installation				$4,800
Motor				
Cost	Motor	1	$18,000	$18,000
Installation				$1,300
Drive				
Cost	Drive	1	$36,000	$36,600
Installation				$5,600
TOTAL				$98,810

500 hp drive

Medium Voltage

	Descp	Quant	Each	Subtotal
MV Conduit	4" GRC	100	$58.41	$5,841
MV Conductor	#2 MV90	300	$6.50	$1,950
MV Terminations	Stress con	12	$192.00	$2,304
Misc Mat & Labor				$2,500
Motor				
Cost	Motor	1	$25,000	$25,000
Installation				$1,600
Drive				
Cost	Drive	1	$106,000	$106,000
Installation				$7,200
TOTAL				$152,395

Low Voltage

	Descp	Quant	Each	Subtotal
MV Conduit	4" GRC	20	$58.41	$1,168
MV Conductor	#2 MV90	60	$6.50	$390
MV Terminations	Stress cone	6	$192.00	$1,152
LV Conduit	3" EMT	160	$14.80	$2,368
LV Conductor	2-500 MCM	480	$19.25	$9,240
LV Terminations	Crimped	24	$100.00	$2,400
Misc Mat & Labor				$2,500
Transformer		1	$21,200	$21,200
Installation				$5,300
Motor				
Cost	Motor	1	$22,500	$22,500
Installation				$1,600
Drive				
Cost	Drive	1	$51,600	$51,600
Installation				$5,600
TOTAL				$127,018

800 hp drive

	Medium Voltage					Low Voltage			
	Descp	*Quant*	*Each*	*Subtotal*		*Descp*	*Quant*	*Each*	*Subtotal*
MV Conduit	4" GRC	100	$58.41	$5,841	**MV Conduit**	4" GRC	20	$58.41	$1,168
MV Conductor	#2 MV90	300	$6.50	$1,950	**MV Conductor**	#2 MV90	60	$6.50	$390
MV Terminations	Stress cone	12	$192.00	$2,304	**MV Terminations**	Sts cone	6	$192.00	$1,152
Misc Mat & Labor				$2,500	**LV Conduit**	3" EMT	320	$14.80	$4,736
					LV Conductor	4-350 MCM	960	$16.15	$15,504
					LV Terminations	Crimped	48	$100.00	$4,800
					Misc Mat & Labor				$2,500
					Transformer			$29,700	$29,700
					Installation				$5,700
Motor					**Motor**				
Cost	Motor	1	$33,000	$33,000	***Cost***	Motor	1	$29,700	$29,700
Installation				$2,100	***Installation***				$2,100
Drive					**Drive**				
Cost	Drive	1	$114,000	$114,000	***Cost***	Drive	1	$110,900	$110,900
Installation				$7,200	***Installation***				$5,600
TOTAL				$168,895	**TOTAL**				$213,950