BULLARD INDUSTRIAL TECHNOLOGIES, INC.

Steam Turbines – The Original Variable Speed Drive

Background

The Affinity Laws are the result of a proven theorem that applies to centrifugal machines such as pumps, fans, blowers, compressors and chillers. The Affinity Laws state that reducing the motor speed by 25% reduces energy consumption by nearly 60% while reducing the motor speed by 50% reduces energy consumption by nearly 90%.

In today's world the most common method of increasing the efficiency of a rotating piece of equipment such as a pump, fan, compressor or blower is to use an electronic variable speed drive (VSD) to control the speed of the induction electric motor driving the piece of equipment just fast enough to meet the demand on the system. Electronic variable speed drives control the speed of the motor by changing the frequency (Hertz) of the supply power. Because of the way they function, they are sometimes called variable frequency drives (VFD). The result and only advantage of the VSD is a partial savings in electrical costs to run the motor.

However, variable frequency drives are not the only means of varying the speed of a centrifugal machine in order to reduce or totally displace the power consumption of an electric motor. Steam turbine drives can run at a constant speed or any percentage of variable speed. A steam turbine replaces the electric motor as the prime mover of the centrifugal machine and requires little or no electrical power to operate. When there is sufficient low pressure steam load in a facility, steam turbine drives are a viable alternative to variable frequency-controlled induction electric motors to drive centrifugal rotating equipment.

Steam turbines accomplish variable speed operation by utilizing hydraulic or oil relay governors that modulate the supply of steam to the turbine to achieve variable speed operation over a broad operating range. Due to their centrifugal design steam turbines will not fail when overloaded allowing them to be routinely overloaded to satisfy peak demands. Variable speed drives cannot handle such overload requirements as the motor would draw excessive currents from the VSD causing it to trip on an overcurrent fault.

Low pressure steam required for building heat, process work, feedwater deaeration, food preparation, absorption chillers, etc. that is supplied from a pressure reducing valve results in 100% of the steam lost to the low pressure system. Utilizing a backpressure steam turbine to drive a rotating machine and then using the exhaust steam for the low pressure system results in re-use of the heat in the steam for the low pressure needs and eliminates the cost of running an electric motor.

Comparison

Advantages of Steam Turbine Drives:

- Impervious to climactic conditions and virtually any severe operating conditions. Can be installed inside a building or outside in any adverse weather atmosphere. They are not affected by high or low ambient temperatures, high humidity (even rain) or even snow and icy conditions.
- Can operate as non-sparking for use in explosive atmospheric conditions.
- High starting torqued without slowing down or tripping.
- Tolerable of frequent and lengthy overloading without tripping.
- Less overall maintenance compared to a VSD driven motor.
- Will remain in operation during loss of power or power interruptions.
- As a prime mover can operate at high speeds to drive a centrifugal machine without the need for a gearbox.
- Can be used for electrical demand peak shaving, hot standby and emergency service.

Disadvantages of Steam Turbine Drives:

- Requires the availability of steam.

Advantages of Variable Speed Drives:

- Reduction in the overall power required by the motor by operating at less than 100% speed.
- Some reduction in peak electrical demand via programming gradual or soft start of the motor.

Disadvantages of Variable Speed Drives:

- Requires availability of three phase power supplied to the VSD to run the motor.
- Maximum operating temperature is @100 degrees, F.
- Higher ambient temperatures require cool, filtered air via cooling fans, air conditioning units or liquid cooling systems to maintain the temperature of the drive.
- The drive must be in a relatively clean, dry environment. Otherwise, frequent cleaning is required.
- For high starting torque applications, the VSD must have a special Torque Boosting capability feature to satisfy high inertial loads.
- The electric motor must be replaced with a specially designed Inverter Duty rated motor that is specially wound to tolerate the significant heat buildup in the motor windings from the VSD controlling the power frequency (Hertz) needed to control the motor's speed.
- VSDs require a "clean", constant power supply. They cannot tolerate voltage spikes or sags without incurring significant damage to the electronic controls.

Description	HP	Quantity	Estimated Load	Efficiency	Demand kW	Total Demand kW
Boiler Feed Pump	50	1	70%	88.5%	29.5	29.5

Existing Process Pumps Demand	29.5	kW	
VFD Parameters			
Power-to-Speed Reduction Exponent	2.5	*Range = 1.0 - 3.0*	
Safe Minimum Motor Speed	30%		
Average VFD Efficiency Penalty at Full Speed	2.0%		

IDENTIFY EXISTING METHOD OF CONTROL 1

1=No Control, 2=Fan/Blower Inlet Guide Vanes, 3=Pump Throttling or Fan/Blower Outlet Discharge Dampers

	Existing	Proposed
Annual Hours of Operation:	8,760	8760

Output Load Level	Percent of full load speed	Estimated %Time at Load	Existing w/o VFD kW	Proposed w/VFD kW	Existing w/o VFD kWh	Proposed w/VFD kWh	Energy Savings kWh
100%	100%	0%	29.5	30.1	0	0	0
95%	95%	0%	29.5	26.5	0	0	0
90%	90%	0%	29.5	23.1	0	0	0
85%	85%	0%	29.5	20.1	0	0	0
80%	80%	0%	29.5	17.2	0	0	0
75%	75%	0%	29.5	14.7	0	0	0
70%	70%	100%	29.5	12.3	258,445	108,115	150,330
65%	65%	0%	29.5	10.3	0	0	0
60%	60%	0%	29.5	8.4	0	0	0
55%	55%	0%	29.5	6.8	0	0	0
50%	50%	0%	29.5	5.3	0	0	0
45%	45%	0%	29.5	4.1	0	0	0
40%	40%	0%	29.5	3.0	0	0	0
		100%		**TOTALS**	**258,445**	**108,115**	**150,330**

The data in the table above is from a generic variable frequency drive program using a 50 hp motor driving a boiler feedwater pump for 1 year. The average load on the motor is 70% for the year. Using the drive to control the motor the annual KWH is 108,115. Considering $.06 per KWH the annual cost of running the motor with the drive is $6,486. The annual savings of using a variable frequency drive and an inverter duty rated motor to drive the pump is $9,020.

Deaerator/Steam Turbine Sizing & Cost Analysis

Cells highlighted in BLUE are to be entered by the user.		Revision date:		2/3/22
		Date last opened:		12/3/2022
Capacity (Total of all online boilers)	**60000**	lbs/hr		
Steam pressure to the deaerator PRV	**105**	psi		
Saturated steam temperature at bop	341	Degrees, F.		
Deaerator operating pressure	**5**	psi		
Saturated temp. at deaerator pressure	228	Degrees, F.		
Enthalpy of steam to the deaerator	1156.26	BTU's/lb		
Percentage of incoming makeup water	**15%**			
Temperature of incoming makeup water	**65**	Degrees, F.		
Pressure of incoming makeup water	**50**	psi		
Percentage of condensate return	85%	(See Condensate Calculations tab if unknown)		
Makeup water required	16.35	gpm		
Incoming line size (min.size)	1.3"	based on 4ft per second		
CV factor for water valve is	2.81			

Deaerator steam quantity, cost & line size requirements

Steam required by the deaerator	6,027	lbs/hr at capacity entered above in Cell B5		
Exahust steam available from the turbines	1,643	lbs/hr		
Net live steam required by the deaerator	4,384	lbs/hr		
Income line size (min. size)	3"	based on 7000 ft per minute		
Connection to deaerator (min. size)	6.9"			
Cost of live steam required	$2,104	Per day		
Cost of live steam required	$768,091	Per year		

Deaerator operating cost on live steam through a PRV

Steam cost per thousand pounds	$20.00			
Daily operating cost	$2,893.07	Using live steam from a PRV		
Annual operating cost	$1,055,970.81	Using live steam from a PRV		

Steam turbine cost savings - Example: Boiler feedwater pump

Electric cost	$0.060	kwh		Incl. demand & PF charges
Steam cost per thousand pounds	$20.00	Mlbs		
Initial (Supply) steam pressure	105	psi		
Enthalpy of supply steam	1,190.9	BTU/lb		From Steam Enthalpy tab
Operating hours	24			
Turbine efficiency	95	%		
Turbine size	50	hp		
Turbine water rate	50	lb/hp/hr		
Supply steam	1,750	lb/hr		at 70% average load
Steam required to operate the turbine	107	lb/hr		
Net turbine exhaust steam available	1,643	lb/hr		
Total turbine exhaust heat available	1,899,906	BTU/hr		
Turbine operating cost	$53.99	Per day		
Turbine operating cost	$19,706	Per year		

The table above shows the cost savings associated with using a 50 hp steam turbine to drive the same boiler feedwater pump at an average load of 70% for an entire year. (At full load the turbine can exhaust a 2,393 lbs/hr). The steam turbine is exhausting into a deaerating feedwater heater requiring 6,027 lbs/hr of steam. In this scenario the turbine can provide 1,643 lbs/hr of exhaust steam thus reducing the live steam need to 4,384 lbs/hr. At $20.00 per thousand pounds of steam, this reduces the annual operating cost of using live steam from $1,055,971 to $768,091 for an annual live steam saving of $287,880. With an annual operating cost of $19,706 the net annual savings using the steam turbine is $268,174.

Return on Investment

The cost of replacing the induction motor drive with a variable frequency drive and inverter duty rated motor is about $20,000 including labor and materials. With an annual electric savings of $9,020, the ROI would be at 2.2 years.

The approximate cost of replacing the induction motor drive with a variable speed governed impulse steam turbine is as follows:

50 hp steam turbine and base: @$45,000. Labor and materials to install steam supply to the turbine and exhaust piping to the deaerator or any low pressure steam load that can handle some or all of the exhaust steam would be @$65,000 for a total installed cost of @$110,000.
With a net steam savings of @$268,174 and an installed cost of $110,000, the ROI for the steam turbine conversion is only .41 years.

Conclusion

Steam costs lower than the example and/or electric costs higher than the example result in a greater savings and faster return-on-investment (ROI) when utilizing steam turbine drives. Larger horsepower applications also result greater savings at a comparable ratio to the 50 hp example.

The key to this cost savings feasibility is to have sufficient low pressure stem demand to accept 100% of exhaust steam available from the steam turbine drive. Low pressure steam loads to consider are: deaerating feedwater heater, fuel oil heating systems, building heating systems, large domestic water heaters supplied by steam, absorption chillers, etc.

Common applications for steam turbines are boiler feedwater, cooling water and condensing water pumps in addition to fans, blowers and compressors.

Richard L. Bullard, CEM
Email: rick@bullardindustrialtech.com
Website: www.bullardindustrialtech.com