INCREASE COMPETITIVE LEVEL BY REPLACING STEAM TURBINES WITH ELECTRIC ADJUSTABLE SPEED DRIVE SYSTEM

Paper No. PCIC-2004-3

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Abstract - A Refinery in Argentina has a large number of rotating equipment trains powered by steam turbines. At the time of installation this was the best technology to obtain the speed and power requirements of different applications. However, due to high operational and maintenance costs, aging steam turbines were identified as poor performers for refinery's EII (Energy Intensity Index) improvement goals. To increase its competitive level, and its strong commitment to quality, the refinery analyzed the feasibility of replacing the steam turbine with an electric adjustable speed drive (EASD) system. The study results indicated clear and significant advantages of electric adjustable drive system over existing steam turbine. The replacement of steam turbine with an electric drive was managed via a turn key project. This paper highlights, as a case study, the motivation of the refinery owner for the replacement of steam turbine with EASD, the integration of selected EASD into the existing plant, and the experience gained in first year of operation.

Index Terms --- Electric Adjustable Speed Drives, Variable Speed Drives, Productivity Increase

I. INTRODUCTION

With a nominal processing capacity of 31,000 m^3 / d (200,000 bbl/d), the refinery is one of the largest refineries within the international holding. Located 60 km from the Buenos Aires City, Argentina, it has 35 different process units on 75 acres. The refinery has a large number of pumps and fans powered by steam turbines, which were the best technology at the time of installation to obtain the speed and power requirements. Whereas steam turbines served well in the past, the aging systems were causing operational inefficiencies, and higher maintenance costs. Key factors attributed to steam turbines were:

- The cost of steam is higher compared to electricity.
- Higher maintenance costs.
- High flow rates of coolant water circulating through the surface condensers.
- Low efficiency .

To reduce operating costs, and increase its competitive levels, La Plata Refinery initiated several productivity improvement projects. Of these, the most significant was the replacement of 2980 kW, 4100 rpm steam turbine of JC-401 T blower of the FCCU "A" catalyst cracking unit. There were several reasons to consider this replacement:

- The purchase of a spare rotor for JC 401 T and JC 401 AT twin turbines was required to increase the operating reliability levels of the units
- The production of medium pressure steam could be reduced to 23 tons/hour
- Removing the surface condenser would lead to a 1000 m^3 /hour of coolant water circulation reduction.
- The aging of the speed controller would not allow the JC-401 T turbine to adjust the speed in the required range of 3700 to 4100 rpm, forcing to vent the excess air.

By replacing, the JC 401 T turbine could also become a source of spares for the JC-401 AT, adding further value to the project.

The replacement project feasibility study was based on following economic considerations:

1. Comparative costs of electric and other types of drives
2. Efficiency of electric drive systems compared to other systems
3. Coolant water costs
4. Savings derived from adjusting the flow by speed switching
5. Maintenance costs

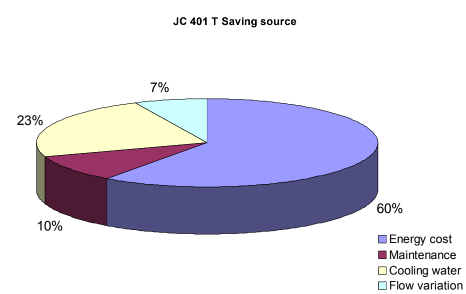

Fig. 1 JC 401 T Savings Sources

The study indicated that replacing the JC 401 T Turbine with EASD will help lower the Solomon Energy Intensity Index (SII), a validated and standardized measure of energy usage, of the plant by 1.4 points. Project evaluation estimated savings from maintenance and operating costs as listed in Table I, and represented in Fig. 1. Basis of calculations are shown in Appendix A.

TABLE I
ESTIMATES OF YEARLY COST COMPARISONS, IN US$

Type	Steam Turbine	EASD
Energy	$1,146,373	$866,265
Maintenance	$50,000	$1,200
Coolant water	$107,310	$2,575
Variable Speed operation	$0	($114,913)

II. PROJECT CONSIDERATIONS

Once the decision had been made to replace steam turbine with Electric Adjustable Speed Drive, from the user's point of view, the refinery operations and maintenance team identified the following issues to be addressed:

A. Equipment Requirements
B. Installation Requirements

A. Equipment Requirements.

The scope of of the equipment supply would include isolation power transformer, frequency converter, motor, and commissioning.

B. Installation Requirements

1) <u>Electrical Engineering</u>: Since there was not enough power at the FCCU "A" unit, the EASD would need to be connected at Central Distribution Place II, approximately 200 meters away from erection location. The work would include revamping of an existing Medium Voltage (MV) cell at Central Distribution Place II, and laying 13.8 kV cables from the substation to the converter building. The Low Voltage (LV) power for auxiliary equipment would require two independent feeders and automatic transfer, and UPS power for control boards. MV cabling to and from isolation transformer, and to the drive motor, as well as control signals to distributed control system was required. The distance between Central Distribution Place II and the EASD transformer is approx. 500 m. The distance between the frequency converter and the motor is approx. 30 m. See Appendix B.

2) <u>Civil Engineering</u>: The project would also require new building for frequency converter, street crossings for MV and control cables, and a foundation for the isolation transformer.

3) <u>Mechanical Engineering</u>: Weight and vibration analysis needed to be carried out in order to ensure that the turbine foundation was strong enough for the motor, which must fit into new mounting arrangement. In addition, a lubrication system according to API 614 was required. This included redundant pumps, power supply from two different feeders, elevated emergency shut down tank, motor coolant water, converter coolant water, assembly of motor, converter, and all auxiliary equipment.

To accommodate all aspects of the project, electrical, civil, mechanical, and successful integration into existing system, the owners' management team decided that the project be executed as a Turn Key.

III. TECHNOLOGY AND VENDOR SELECTION

The management team established the following criteria for vendor selection:

- Vendor's capabilities to take ownership of a Turn Key project.
- Latest but proven technology.
- Highest reliability and availability.
- High overall efficiency, including auxiliaries.
- Lowest life cycle costs.
- Compliance with IEEE 519-1992.
- Fully factory tested.
- Full compliance with international standards including EN (IEC), CE, IEEE, and UL.

Three leading EASD manufacturers were invited to a technology evaluation, and capabilities session. Each vendor offered a unique design using different technologies.

Bids and reliability data were solicited from each vendor. The selection committee evaluated each proposal based on above criteria.

The selected solution was evaluated to offer best value for the owner. Key factors favoring the selected proposal were:

- Cost of turn key project.
- Vendor capabilities for system design, and major equipment in-house manufacture.
- Turn key project ownership.
- Full compliance with IEEE 519-1992.
- Latest technology in Direct Torque Control (DTC), allows accurate and high performance control of both motor speed and torque.
- High level of flexibility for isolation transformer installation location.
- A frequency converter based on a voltage source inverter (VSI), providing sinusoidal output obtained by a three level inverter bridge, and a built in low pass output filter.

The most recent supplier history, including replacement of steam turbine and pump with a 2500 HP / 690 V electric adjustable speed drive, confirmed their project execution capabilities. Turn key contract was awarded to selected supplier on June 29, 2000.

IV. ASD SYSTEM DESCRIPTION

The selected design is shown in Fig. 2. The installed drive is a 2980 kW / 4100 rpm medium voltage AC drive with transformer, Voltage Source Inverter (VSI), and induction motor. The 3-phase AC line voltage is supplied through the

3-winding converter transformer to two rectifier bridges. In order to obtain 12-pulse rectification, appropriate phase shift is necessary between the secondary windings of the transformer. The 12-pulse diode rectifier keeps the network harmonics below IEEE 519-1992 limits and the input power factor constant at 0.96 over entire speed range. The two rectifier bridges are connected in series, such that the DC voltages are added up.

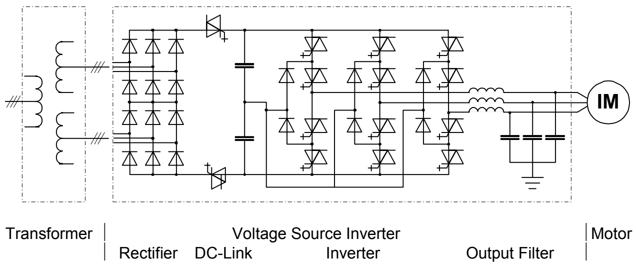

Fig. 2 Adjustable Speed Drive System Basic Diagram

Each leg of the 3-phase inverter bridge consists of a combination of only two IGCTs (Integrated Gate Commutated Thyristor) for 3-level switching operation: with the IGCTs the output is switched between positive DC voltage, neutral point and negative DC voltage. Hence both the output voltage and the frequency can be controlled continuously from zero to maximum. At the converter output a LC filter is used to reduce the harmonic content of the 3.3kV output voltage. With this filter, the voltage and current waveforms applied to the motor are nearly sinusoidal (Fig. 3). Therefore, standard motors can be used at their nominal rating. This means particularly that the motor will operate at nominal efficiency just as direct on line, no additional harmonic losses from frequency converter operation apply. Further on, due to the stochastic firing pattern of the Direct Torque Control DTC and the LC filter, no audible modulation noise is present. The filter also eliminates all high dv/dt effects and thus voltage reflections in the motor cables and stresses to the motor insulation are totally eliminated.

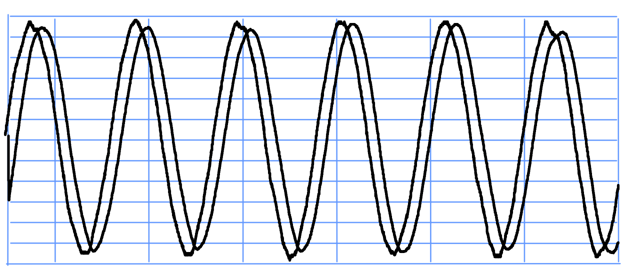

Fig. 3: Voltage and current waveform at motor

Core technologies used in the VSI are:

- The IGCT power semiconductor which combines the high switching frequency of an IGBT (Integrated Gate Bipolar Transistor) with the low on-state losses of a GTO (Gate Turn Off Thyristor). The use of IGCTs minimizes the number of components because no series connection, no snubbers and no fuses are required. Benefits of the low on state losses are high efficiency (98%) and of the low part count are high reliability and small converter volume per power
- The DTC (Direct Torque Control) allows accurate and high performance control of both motor speed and torque without the use of encoder feedback from the motor shaft.

Fig. 4 shows the water cooled converter, at supplier factory, for 2980 kW/3.3kV motor.

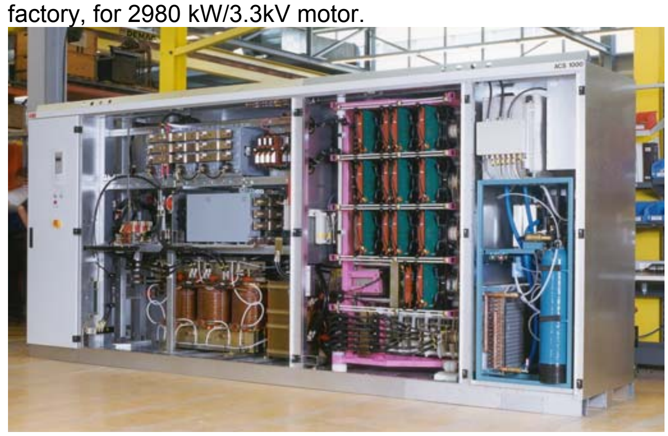

Fig. 4: Water cooled frequency converter
1: Control
2:Output Filter and DC-link components
3: Rectifier and Inverter stacks
4: Water cooling unit

The speed control range of the motor is 3700 - 4100 rpm. The selected 2-pole induction motor is running below the first lateral critical speed. Sufficient separation margin between the first lateral critical speed and the maximum operating speed was assured

Appendix C lists nameplate data of major components: Isolation Transformer, frequency converter, and the drive motor.

V. PROJECT EXECUTION

A. Work at the refinery prior to equipment delivery

While the EASD system major components were being built, the refinery was being prepared for equipment installation.

A pressurized room was built near the FCCU "A" to house the frequency converter and the auxiliary equipment: MV cell with circuit breaker and transformer integral protection, LV cabinets with double supply connections to control the (redundant) pressurizing blowers, converter water pumps and water cooling system, and UPS for control boards.

Next to this building, a foundation was made to install the isolation power transformer, and the water cooling towers. As this building was located across the street, cable crossing bridges were built for power and control cabling. See Appendix B, showing the cable and water line run between variable frequency drive and motor.

At Central Distribution Place II, one existing MV cell was revamped with a new circuit breaker, a multiple variable meter (power and power quality data were connected to the information system of the plant in order to make it available at engineering and maintenance personnel's PCs, as well as in DCS for operating personnel). Cable connections terminals and grounding switch were also replaced. After MV cell revamp, the power cables were laid from Central Distribution Place II to the converter room.

The new lubrication system was manufactured to comply with the higher lubricant flow requirements imposed by the electric motor. Lubrication system included higher flow redundant pumps with pressure sensors and automatic transfer, larger storage tanks, elevated emergency shut down tank, and redundant supply with automatic commutation.

B. Combined System Test

To meet the performance requirements of turn key project, a combined system test at operational conditions, was performed using project designed major equipment: transformer, frequency converter and drive motor. As energy consumption had been a major evaluation criteria, efficiency data was to be confirmed during combined system test. The test system was assembled at EASD manufacturer's facility. A generator was employed to provide mechanical load and re-generate power back to the network. Appendix D shows one line diagram of combined system test arrangement. Fig. 5 shows actual test site.

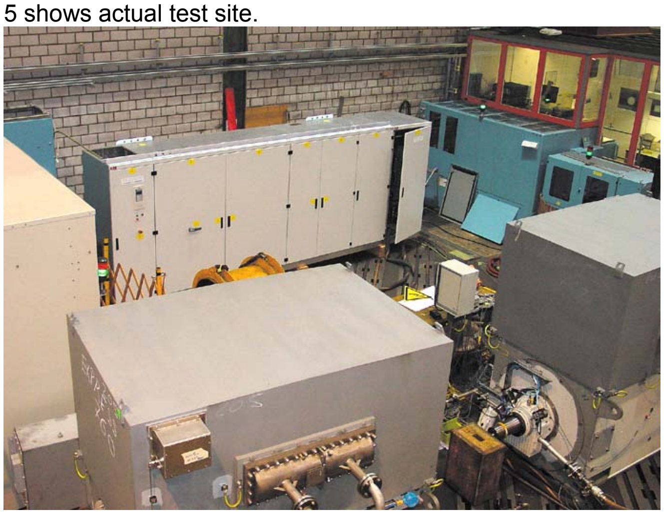

Fig. 5 Combined System Test Arrangement

Table II compares efficiency measured data with proposed / guaranteed values.

TABLE II
EFFICIENCY COMPARISON: TEST vs PROPOSED

Equipment	**Proposed values**	**Test Values**
Transformer	99%	
Converter	98%	98% 1)
Motor	95.9%	96.3%
System performance	93.13%	94.44%

1) During test, transformer and converter efficiency were measured together.

Current and voltage waveforms were also checked at the motor connections, giving the following results at full speed and load (2980 KW / 4100 rpm), as shown in Figures 6 a, b

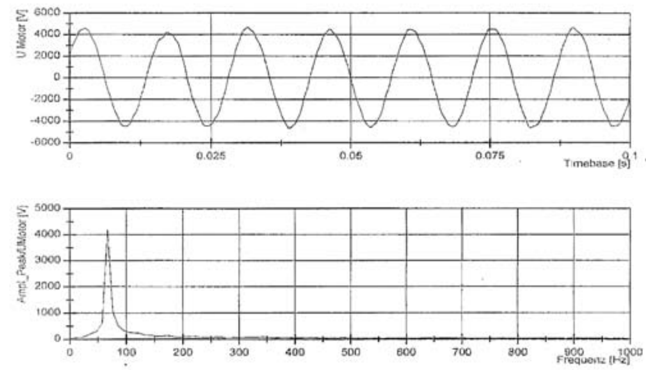

Fig. 6 (a) Voltage waveform at full load and speed

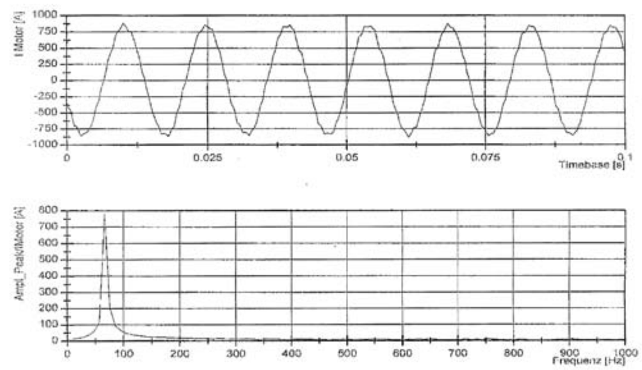

Fig. 6 (b) Current waveform at full load and speed

C. Installation at the refinery and commissioning

To meet project objective of minimizing the downtime of JC 401T blower, the frequency converter and the isolation transformer were installed and wired prior to removing the steam turbine.

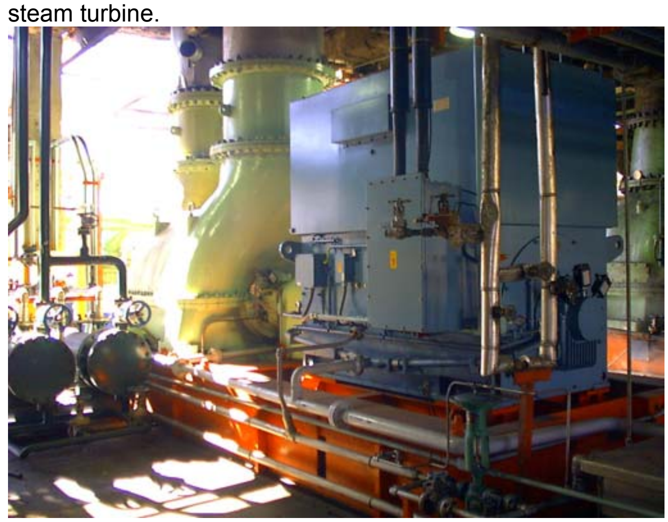

Fig. 7 (a) Drive Motor Installation

With the converter ready to run, the turbine was then removed, and packed to be used as spare for JC 401AT blower. Turbine foundation was modified to accommodate new motor installation. The drive motor, and lubrication system were installed, including vibration detection system. At the same time, changes were made to the Catalyst Cracking's control system to conform to the new electric drive system's operational, maintenance and protection circuitry.
Finally, the power cables between frequency converter and motor were laid, and system installation completed. Figures. 7 (a,b,c,d) show major equipment, as installed.

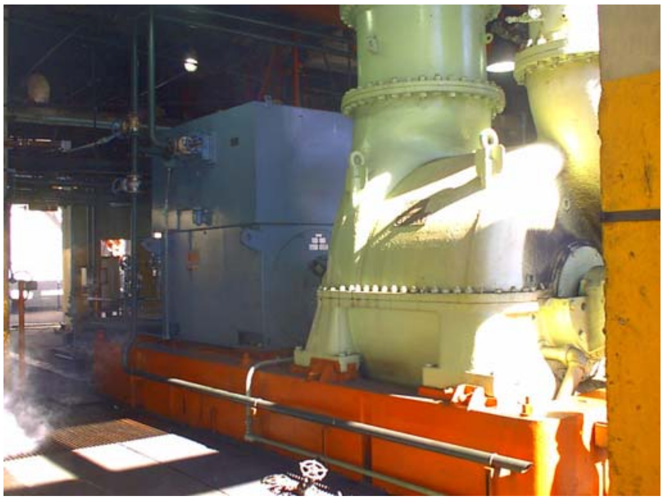

Fig. 7 (b) Drive motor - as viewed from converter

Fig. 7 (c) Frequency Converter enclosure

New EASD system was commissioned according to manufacturer's standard commissioning procedures, and to meet the refinery's process performance requirements, including alignment of drive motor with blower, no load and full load testing. The 401T blower was put back into operation on Feb. 25, 2001, as per schedule. The turn key project was completed, on schedule, and under budget by joint efforts of EASD supplier, and the refinery.

Fig. 7 (d) Isolation transformer next to converter building

VI. OPERATING EXPERIENCE AND RESULTS

The JC 401 AT blower, driven by an electric adjustable speed drive system, was commissioned in Feb., 2001, and placed into service on Feb. 25, 2001. The total JC 401 T blower shut down was 33 days (time between shut down the steam turbine and commercial operation of the EASD), all while the refinery was in full operation. Since then the unit has operated trouble free, and without any down time.

Prior to the replacement, all three blowers at FCCU "A" were driven by steam turbines. Any steam pressure drop, such as due to power failure at boiler's water feeder pumps or fuel pumps, led to serious operating difficulties at FCCU "A". The installation of EASD at JC 401T blower has eliminated this problem, because of the power loss ride through capability of the frequency converter. To-date, several power loss events, including a large 600 ms power loss, has been handled without a single trip.

In extreme case of total power failure, the EASD system has much faster response time than steam pressure recovery, This allows for an immediate availability of the electric drive, and air circulation in line C4, preventing the catalyst from cracking. In event of catalyst stacking it needs to be removed with steam, taking up to 6 hours of work and polluting the atmosphere with catalyst. Additionally turbine warm up time after each such occurrence is approx. 1 hour. The higher availability of the blower driven by EASD is impressing the operating staff at the refinery.

Another feature of the installed system, relating to the availability, that had not been considered during project decision making, and evaluation, comes from the fact that having different blowers driven by different types of energy (steam and electricity) gives more operational flexibility. This new set up allows to keep the unobstructed air lines in event of failure of one of the energy systems, again minimizing the down time.

The performance of installed system has met or exceeded established criterion, as summarized below:

- Lower EII, Energy Intensity Index. EII of FCCU "A: was reduced by 13 points, a 10.5% reduction within one year of operation, – equivalent to 27 tons of fuel-oil saving. Reduction of EII at the refinery was 1.42 points, equivalent to 1.3%.

- The savings derived from energy, cooling water, maintenance and flow variations for the first year of operation recovered 33% of the costs of the project. This is excluding savings derived from not having to buy a spare rotor (for turbine).
- Measurements made on the 13.8 kV bus in Substation II showed that harmonic distortion THD (V) level to be at 0.9%- value significantly lower than IEEE 519-1992 limits.

In addition to the quantified results, as listed above, the operating staff at the refinery highlight following improvements:

- Operational and process control has significantly improved due to continuous and infinite air flow control.
- Much accurate and infinite speed control with electric adjustable speed drive as compared to turbine drive.

VII. CONCLUSIONS

The paper has presented a case study of evaluation, selection criteria and approach to successful integration of an electric adjustable speed drive system in retrofitting steam turbines.

Test results and operating experience has shown the significant improvements to overall process control, and efficacy of EASD features. After almost three years of operation, the new installed system has proved to be extremely reliable, energy efficient, and offers simplicity of operation and maintenance.

Present day technology and the economic advantages of electric adjustable drive systems lend them to offer significant operational and maintenance savings over aging steam turbines. For successfully integrating the drive system into the process control, careful coordination and combined efforts between EASD manufacturer and user are required to minimize process interruption and down time during installation and commissioning. Experiences gained at the refinery can be directly used for similar retrofit applications of steam or gas turbines.

VIII. NOMENCLATURE

FCCU: Fluidized bed Catalytic Cracking Unit
EASD: Electric Adjustable Speed Drive
IGCT: Integrated Gate Commutated Thyristor
EII: Solomon Energy Intensity Index. EII indexes the energy efficiency of a plant or process unit, using a technology explicit computer model that determines the standard energy efficiency of a plant (or process unit). A Solomon EII value of 100 is considered “standard”. Lower value indicates higher efficiency.
V_{line}: Line voltage
I_{line}: Line current
P_{line}: Line power
F_{line}: Line frequency
V_1: Input voltage
I_1: Input current
P_2: Output power
N_2: Output speed
F_{max}: Maximum frequency

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X. VITA

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Appendix A

Savings Calculations

Operating Costs (fixed Speed):	**Steam**	**Electric**
Power requirements	23.4 Ton/h	2980 kW
Energy price	5.5925 $/Tn	0.031 $/kWh
Working hours/year	8760	8760
Efficiency	1	0.93
Coolant Water	1000m^3/h	24 m^3/h
Water Costs	0.01225 $/m^3	

Annual Operating Costs:		
Energy:	$1,146,373	$866,265
Maintenance:	$ 50,000	$ 1,200
Water Costs:	$ 107,310	$ 2,575

Variable Speed Savings Estimates:

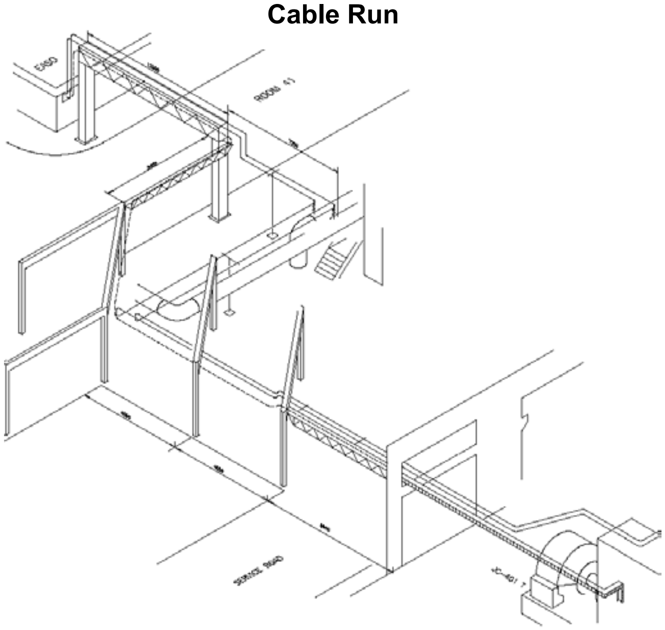
RPM	Time	Power	Usage (kWHrs)
3700	10%	73%	1905650
3800	25%	80%	5220960
3900	30%	85%	6656724
4000	25%	92%	6004104
4100	10%	100%	2610480

Total Variable Speed Energy usage: 22397918
Total Fixed Speed Energy usage: 26104800

Savings in energy: 3706882 kWHrs.
Savings in $$s: $114,913

Appendix B

Cable Run



Appendix C

Name Plate Data of Major Equipment

Isolation Transformer:

Type:	Mineral Oil Cooled
Voltage:	13,800 / 2*1905 V
Current:	184 / 2*666.8 A
Size:	4400/2200/2200 kVA
Frequency:	50 Hz

Frequency Converter:

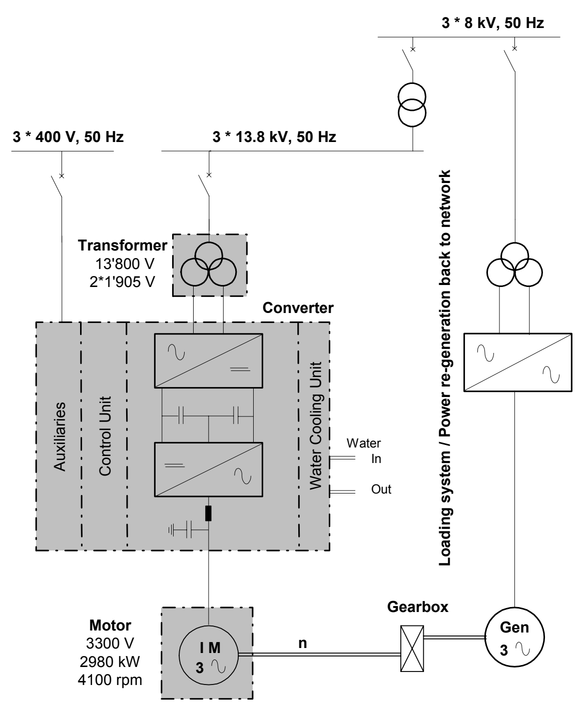
Type:	Water Cooled, Voltage Source Inverter
V_{line}:	2*1902 V
I_{line}:	631 A
P_{line}:	3150 KW
F_{line}:	50 Hz
V_{motor}:	3300 V
I_{motor}:	755 V
F_{max}:	75 Hz
$V_{aux.}$:	3*400 V
F_{aux}:	50 Hz

Asynchronous Drive Motor:

Type:	Induction Motor
V_1:	3300 V
I_1:	590 A
P_2:	2980 KW
p.f.	0.92
N_2:	4100 rpm

Appendix D

Combined Test Arrangement



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