Energy Saving Drives for Hot Strip Mills

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Keywords: Medium Voltage Drive, Variable Frequency Drive, Energy Savings, Water Treatment, Descale

INTRODUCTION

In 2010, Tosçelik HSM located near Osmaniye, Turkey, embarked on an ambitious plan to reduce electrical energy consumption and maintenance by upgrading several fixed speed motors with variable frequency drives (VFD). Although the HSM facility is fairly new, commissioned in 2009, most of the pumps associated with water treatment, HSM descaling and HSM cooling were not designed to utilize a modern energy saving control system with variable speed drives. The pumps which were targeted for energy savings through implementation of an optimized control system and the application of variable speed drives were: Descaling pumps, Descale Booster pumps, Roll Cooling pumps, Laminar Cooling pumps, Runout Table Cooling and Side Spraying pumps, Scale Pit to Sedimentation Tank transfer pumps, and Sedimentation Tank to Direct Cooling (DC) Tank transfer pumps,. The variable speed drives and associated energy saving control system were commissioned by TMEIC in 2011. This paper will review the equipment which was selected for this upgrade and present data which quantifies the energy saving benefit realized in each system.

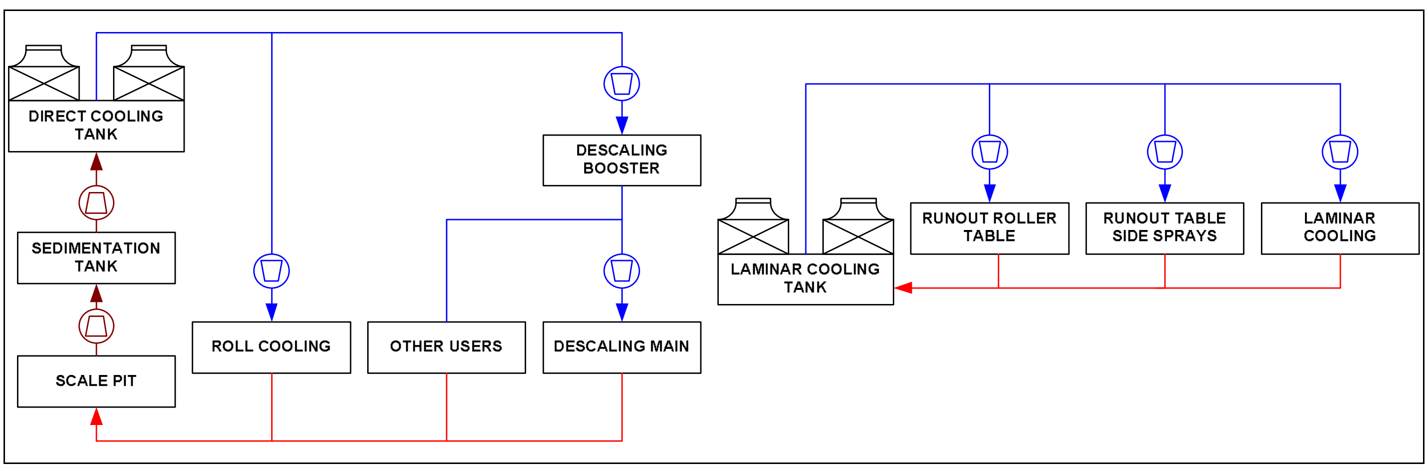

Figure 1. Descale and Cooling Water Flow Overview Showing Systems Targeted for VFD Application

BACKGROUND

There are some general rules of thumb known as "Pump Laws" or "Affinity Laws" which establish simple relationships between volumetric flow, pressure (head), and power consumption for fans and pumps. According to these laws, for a fixed impeller, the volumetric flow (Q) produced by a pump varies proportionally to the impeller speed (n), the pump head (H) varies proportionally to the square of the impeller speed, and the power consumed by the pump (P) varies proportionally to the cube of the impeller speed. These laws are based on assumptions of constant machine efficiency at the two operating points, and low static system pressure. The laws are summarized in Figure 2.

$$\frac{Q_1}{Q_2} = \left(\frac{n_1}{n_2}\right) \qquad \frac{H_1}{H_2} = \left(\frac{n_1}{n_2}\right)^2 \qquad \frac{P_1}{P_2} = \left(\frac{n_1}{n_2}\right)^3$$

Q: Flow; *H*: Pressure (Head); *P*: Power, *n*: pump speed

Figure 2. Affinity Laws

If an ideal pump is operated at 25% of its rated speed, these laws indicate that its flow rate, head, and power consumption would be reduced to 25%, 6.25%, and 1.56%, respectively. This relationship was verified at site under mill operating conditions for the Descale Pumps.

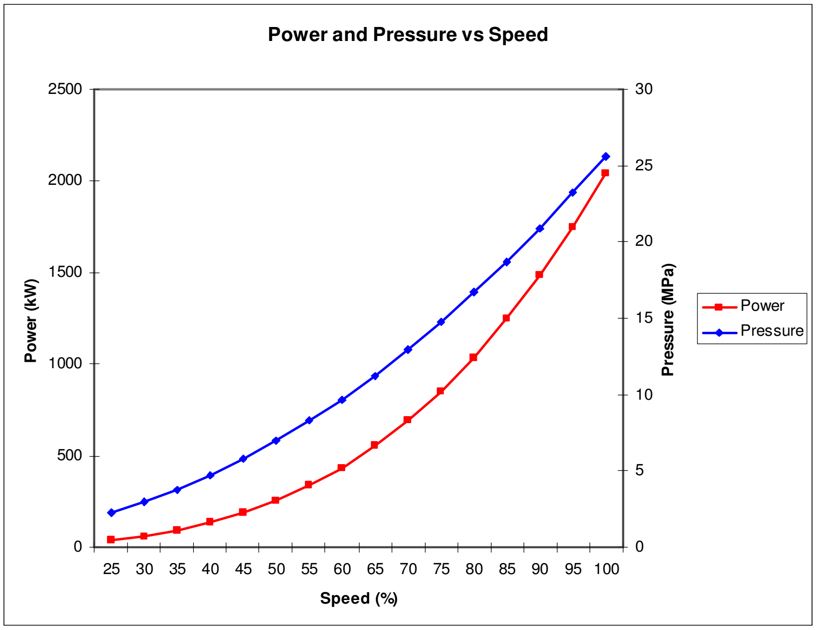

Figure 3. Measured Pump Pressure and Motor Power vs Speed

This paper will provide examples of some possible applications of variable speed drives for energy conservation, and evaluate the effectiveness of each application.

UPGRADE OVERVIEW

Applications

Descaling Pumps:

Due to the fact that the main descaling pumps are alternated on a regular basis, critical for mill production, and large consumers of electrical energy, Tosçelik installed two medium voltage drives, one for each Descale pump. When the mill tracking system indicates that a bar is approaching a descale zone and descaling is required, the running pump is accelerated to operational speed.

Table I. Descale Pump System data

Total number of Pumps	New Variable Speed Drives	Rating [kW]	Qty. of pumps running during normal operation	Method of automatic operation	Energy savings per day [kW-h]
2	2	2800	1	Mill Tracking control of speed with 3 speed setpoints	~20000

Pump at Low Idle speed of 700rpm, - when not descaling and long delay anticipated.
Pump at High Idle speed of 1100rpm, - when not descaling and short delay anticipated.
Pump at High Speed of 2900rpm, - when metal is in the Descale zones (Furnace, RM or FM), and stays at high speed until the Descale accumulator is recharged.

The original system operated one pump continuously to meet the pressure and flow requirements for descaling. Because the sprays are used intermittently and the motors are quite large, the Descale system was a prime candidate for the application of a VFD. TMEIC implemented an optimized control scheme incorporating variable speed operation based on actual Descale requirements, which does not adversely affect strip quality, but greatly reduces the energy consumption of these large motors by reducing the motor speed whenever descaling sprays are not required for the rolling process.

Descale Booster Pumps:

The Descale Booster system draws water from the DC Tank to provide a pressurized header for the suction of the main Descale pumps and supply cooling water to mill roller tables and other consumers. A pressure regulating valve at the pump discharge header maintained the correct header pressure, opening to relieve high pressure and allowing water to return to the DC tank. The original system operated one booster pump continuously to meet the system requirements.

Table II. Descale Booster Pump System data

Total number of Pumps	New Variable Speed Drives	Rating [kW]	Qty. of pumps running during normal operation	Method of automatic operation	Energy savings per day [kW-h]
2	1	630	1	Proportional Pressure Control from setpoint 0.65 mPa	~9000

The mechanical pressure regulator in the Descaling booster discharge header ensures that the system pressure is maintained between 6-8 bar. TMEIC implemented an improved control system which monitors the pressure of the discharge header and varies the motor speed to regulate pressure in the header to meet the system needs without excess water being redirected back to the DC tank.

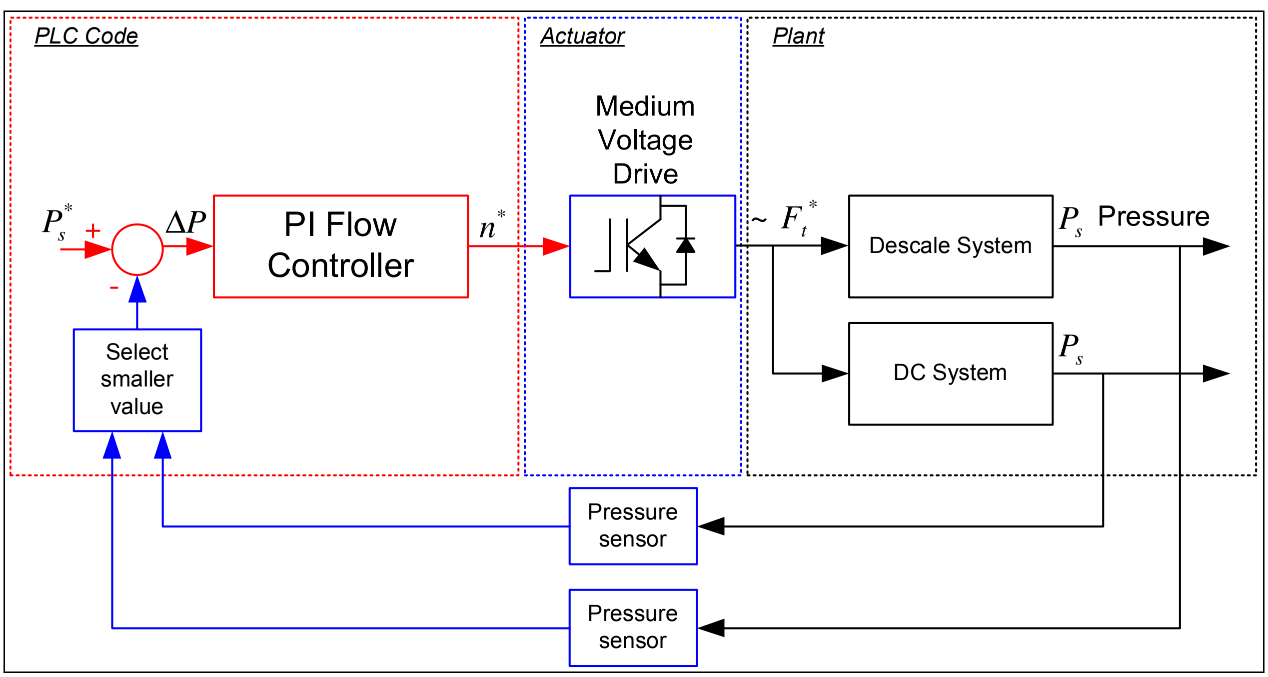

Figure 4. Descale Booster Pump Control Logic

Roll Cooling Pumps:

This system draws cooling water from the DC Tank and supplies the cooling water into the roll cooling header of the FM. The original system operated two of these pumps continuously to provide the required pressure and flow, and Tosçelik was able to turn the flow on or off for each mill stand.

Table III. Roll Cooling Pumps System data

Total number of Pumps	New Variable Speed Drives	Rating [kW]	Qty. of pumps running during normal operation	Method of automatic operation	Energy savings per day [kW-h]
4	2	630	2	Proportional Pressure Control from F1 and F7 pressure	~6000

The new control algorithm was implemented similar to the one used for the descale booster, proportional – integral pressure control.

Further energy savings were achieved by lowering the motor speed when there is less water demand.

Laminar Cooling Pumps:

The Laminar Cooling pump system draws cooling water from the Laminar Cooling tank and fills the two elevated laminar tube tanks alongside the mill Runout Table (ROT). The original system operated one or two pumps continuously, depending on the mill production rate, with excess water flowing back to the WTP via an overflow path.

Table IV. Laminar Pumps System data

Total number of Pumps	New Variable Speed Drives	Rating [kW]	Qty. of pumps running during normal operation	Method of automatic operation	Energy savings per day [kW-h]
3	1	355	1	Mill Tracking control of speed with 3 speed setpoints	~3600

Pump Stopped, - a mill long delay signal from existing tracking PLC.
Pump at Idle speed of 660rpm, - no metal in FM1 & no metal ROT & Laminar Cooling valve close and safety margin met.
Pump at High Speed of 1100rpm, - FM1 detects material or Laminar cooling valves open, or Laminar Tank level low (below 1175mm set, 1300mm reset).

The high speed value is set such that the laminar tank level will stay roughly fixed. A strict criteria to prevent laminar tank overflow. The pumps are now running at 74-75% speed (instead of 100% in the old system) when the high speed setpoint is required. Thus the system now saves energy during high speed operation as well as at idle speed.

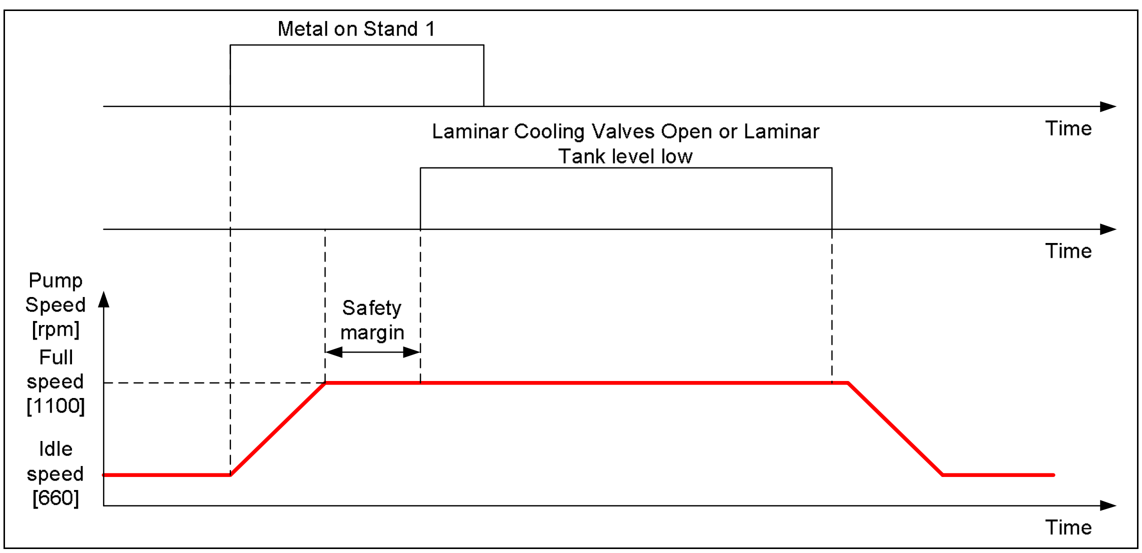

Figure 5. Laminar Cooling Pump Control Logic

Runout Roller Table Cooling Pumps:

The Runout Roller Table Cooling system provides cooling water to cool the rolls of the ROT. This system draws cooling water from the Laminar Cooling Tank and supplies the cooling water into the rolls of the runout table. The original control system operated one pump continuously, regardless of the need for cooling the runout table rolls.

Table V. Runout Roller Table Cooling Pumps System data

Total number of Pumps	New Variable Speed Drives	Rating [kW]	Qty. of pumps running during normal operation	Method of automatic operation	Energy savings per day [kW-h]
2	2	110	1 running with 1 pump in standby mode	Mill Tracking control of speed with 3 speed setpoints	~1100

Pump Stopped, - a mill long delay signal from existing tracking PLC.
Pump at Idle speed of 550rpm, - no metal in FM1 & Laminar Cooling valve close and safety margin met.
Pump at High Speed of 1485rpm, - FM1 detects material or Laminar cooling valves open.

The timing diagram is similar to figure 5. above

Runout Roller Table Side Spraying Pumps:

The Runout Roller Table Side Spraying Pump system is used to deliver cooling water across the direction of strip travel on the ROT to prevent water from accumulating on the strip. The system draws cooling water from the Laminar Cooling Tank and directs a spray of water across the strip. The original control system operated one pump continuously, regardless of the presence of strip on the ROT.

Table VI. Runout Roller Table Side Spraying Pumps System data

Total number of Pumps	New Variable Speed Drives	Rating [kW]	Qty. of pumps running during normal operation	Method of automatic operation	Energy savings per day [kW-h]
2	2	160	1 running with 1 pump in standby mode	Mill Tracking control of speed with 3 speed setpoints	~1300

Pump Stopped, - a mill long delay signal from existing tracking PLC.
Pump at Idle speed of 950rpm, - no metal in FM1 & no metal ROT & Laminar Cooling valve close and safety margin met.
Pump at High Speed of 2980rpm, - FM1 detects material or Laminar cooling valves open.

In the old system, the pumps ran at 100% speed all the time. At 100% speed, the drive consumed 101kW. Now at idle speed the power consumption is 4.4kW.

The timing diagram is similar to figure 5. above.

Scale Pit to Sedimentation Tank Pumps:

The Scale Pit to Sedimentation Tank Pumps extract strip contact cooling water from the Scale Pit after the large solids have settled out of the solution and delivers this water to the Sedimentation Tank. The existing control system used a simple hysteresis control scheme to regulate water level in the tanks.

Table VII. Scale Pit to Sedimentation tank Pumps System data

Total number of Pumps	New Variable Speed Drives	Rating [kW]	Qty. of pumps running during normal operation	Method of automatic operation	Energy savings per day [kW-h]
4	3	315	2 or 3 to meet flow demand	Proportional Scale Pit and Sed. Tank Level compensation added in to flow ref in to DC tank to give a speed reference	~3201

Proportional Level control was implemented for the Sedimentation Tank. This Sedimentation Tank level compensation (regulator output) is added to the Flow going out of the Sedimentation Tank to give the flow reference.

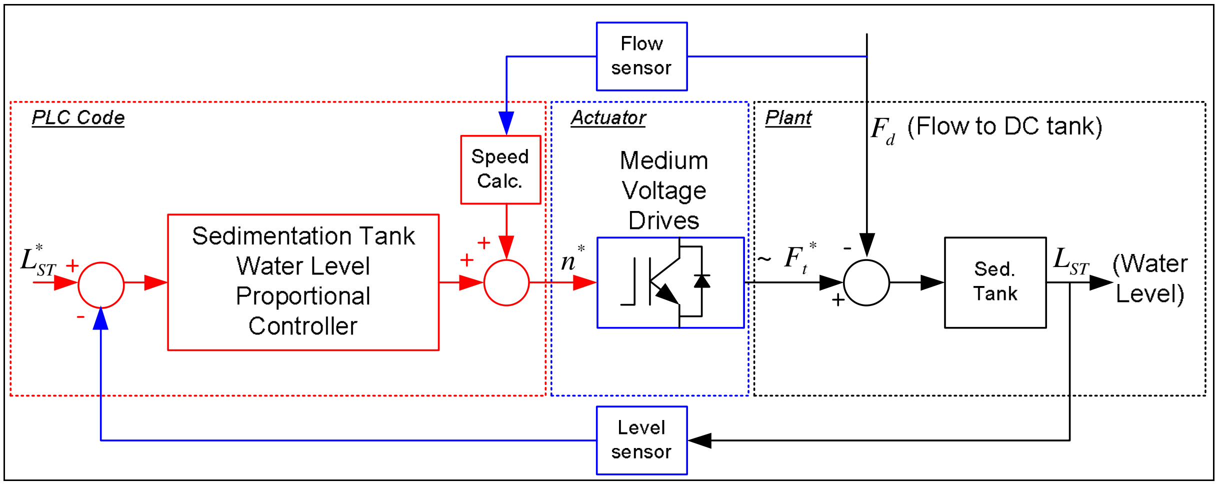

Figure 6. Scale Pit Pumps Control Logic

The pressure loss due to tank elevation restricts the available speed range for the variable speed drives to approximately 55% of the motor rated speed.

Sedimentation Tank to Direct Cooling Tank Pumps:

This system draws cooling water from the Sedimentation Tank after it has been sufficiently clarified and it delivers the water to the DC Tank, where water is circulated in the tower to be cooled by evaporation and is available for re-use. The existing control system used a simple hysteresis control scheme to regulate water level in the tanks.

Table VIII. Sedimentation tank to Direct Cooling Pumps System data

Total number of Pumps	New Variable Speed Drives	Rating [kW]	Qty. of pumps running during normal operation	Method of automatic operation	Energy savings per day [kW-h]
4	2	315	2	Proportional DC Tank Level compensation added in to flow feedback from consumers to calculate a speed reference	~3200

The pressure loss due to tank elevation restricts the available speed range for the variable speed drives to approximately 55% of the motor rated speed.

Proportional Level control was implemented for the DC Tank. This DC Tank level compensation (regulator output) is added to the speed reference calculated based on the measured Flow going out of the DC Tank (to different consumers such as Descale Booster, Roll Cooling Pumps and other users) to produce the drives speed reference.

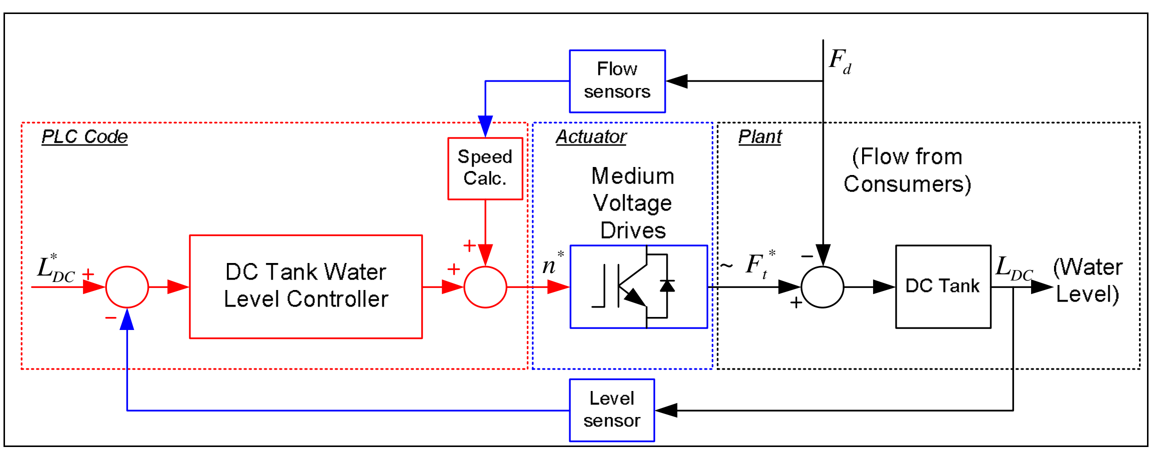

Figure 7. Sedimentation Tank Pumps Control Logic

Drive System

The medium voltage drives selected for this project were chosen to minimize the impact on the existing mill and equipment. The voltage source inverter drives are a common design with modular construction for easy maintenance, constructed from many interchangeable modules. Each module contains three phase rectifier diodes, DC link capacitors, and a single phase medium voltage IGBT inverter. Three modules are arranged to produce a three phase output, and the modules are connected in series to provide the necessary output voltage. The composition of the modules and combination required for this application is shown in Figure 8.

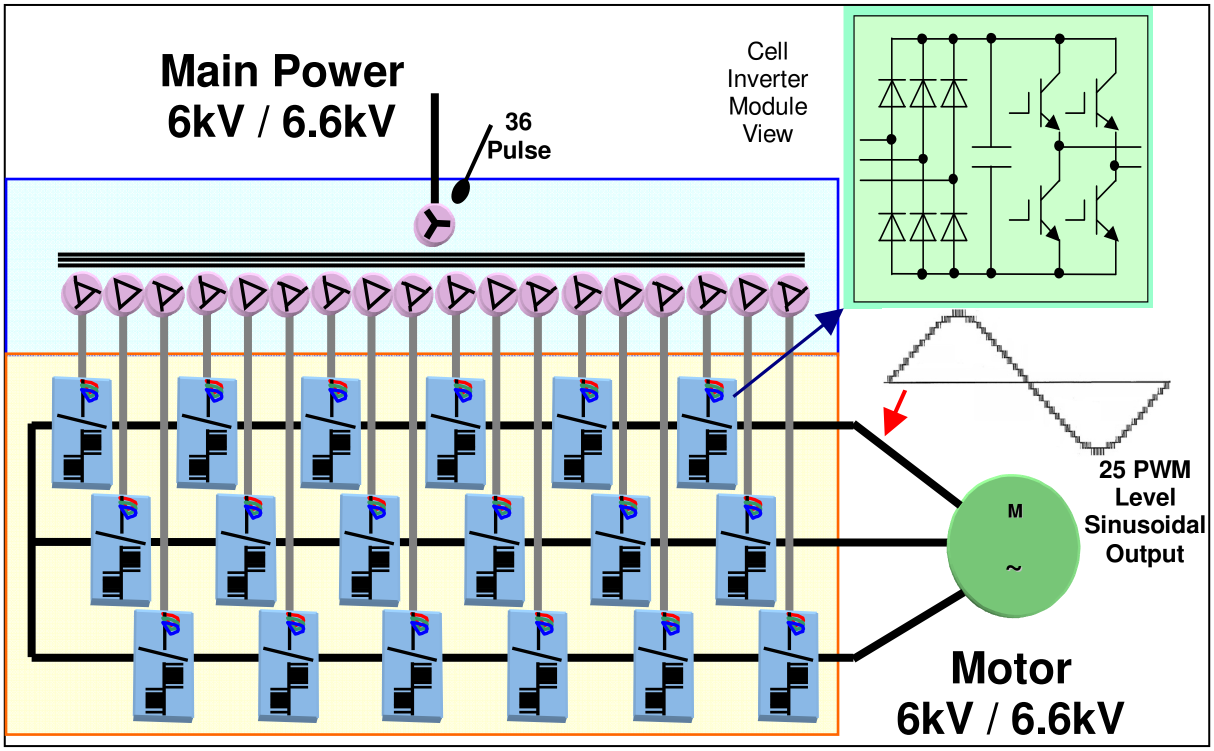

Figure 8. Medium Voltage Drive Topology

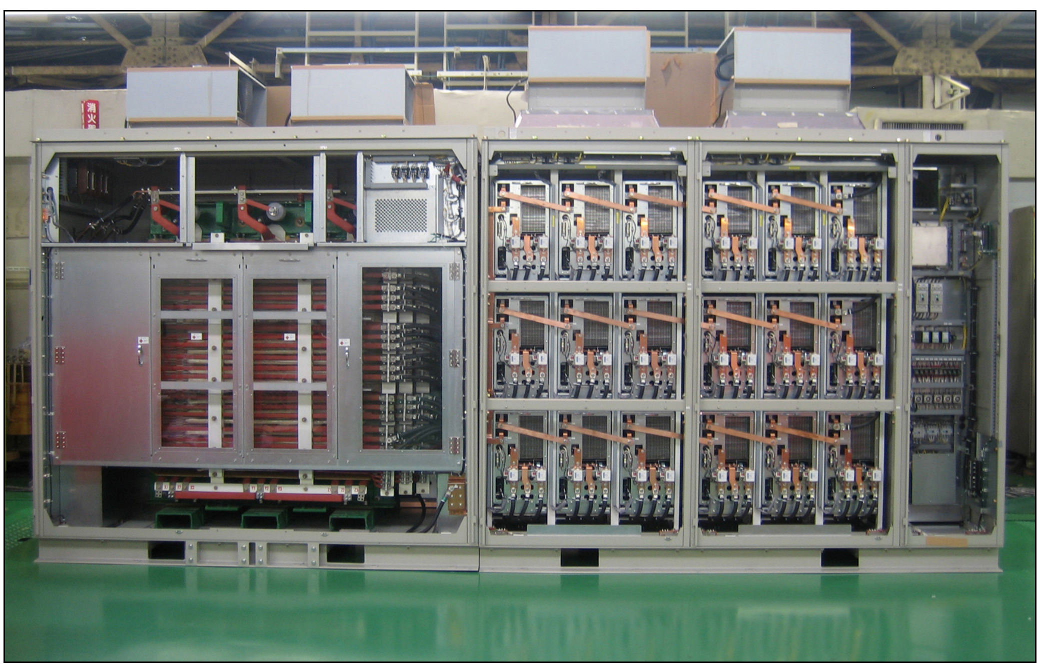

Figure 9. Medium Voltage Drive

Such modular construction results in a multi level output where the number of levels increases with the output voltage, providing a very smooth output waveform that is compatible with existing fixed speed motor designs. The drive is air cooled, which eliminates the need for a separate water system to cool the drive. The drives are constructed to require only front access for maintenance, so they may be installed in back to back lineups or against a wall.

The 6kV class of these drives features a 36 pulse diode converter, which maintains much higher power factor across all loading conditions than the existing motors, which were applied directly from the AC power bus. Additionally, the 36-pulse diode converter produces low harmonics which comply with the limitations of IEEE 519.

The 25 level output from the 6kV AC inverter produces a virtually sinusoidal waveform that is compatible with the existing motor design without the need for additional filters.

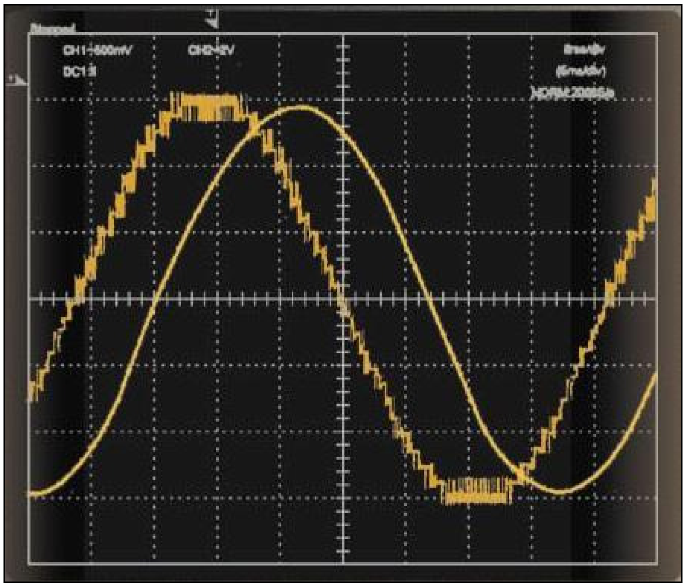

Figure 10. Medium Voltage Inverter – Output Voltage and Current waveforms

Existing Motors

The existing motors were originally designed for fixed speed operation from the utility source with low harmonics, and relatively constant voltage and frequency. To prevent any harmful effects caused by the application of a new variable voltage and variable frequency power supply, Tosçelik has plans to install grounding brushes for each motor. These grounding brushes should prevent bearing damage caused by the flow of current from the motor shaft to ground. Speed sensors were not installed on the original motors and were deemed unnecessary because the new variable frequency drives use a sensor-less control algorithm and the actual operating speed of the motors was not deemed critical to the system performance.

PROJECT RESULTS

Table IX. Typical energy saving data

	Energy Saved / day kW-h/day	Total Energy Consumed kW-h/day	Savings kW-h / ton	Percent Savings
Descale	19420	30435	6.44	38.95%
Runout Roller Table	902	653	0.30	57.98%
Side Spray	1114	860	0.37	56.44%
Laminar Cooling	3144	1629	1.04	65.87%
Scale Pit	2123	7522	0.70	22.01%
Sedimentation Tank	3149	7142	1.04	30.60%
Roll Cooling	6685	18579	2.22	26.46%
Descale Booster	7785	4309	2.58	64.37%

Note 1: Data taken from October 1st until October 31st 2011.
Note 2: above data based on an average of 3015 Tons rolled per day.

The energy saving results are presented to the operators via HMI screen.

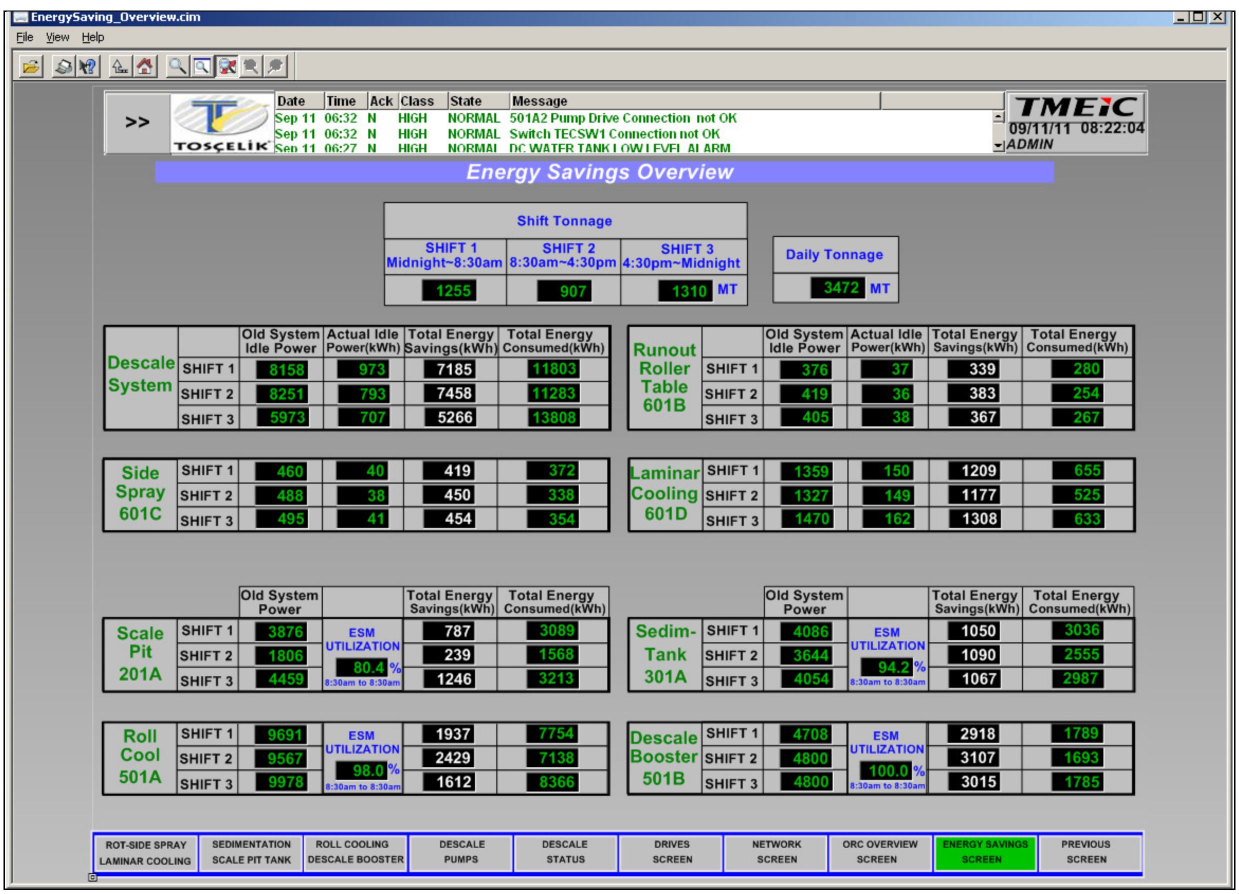

Figure 11. Energy Saving Overview HMI screen

The "Actual Idle Power" was calculated in the PLC based on drive power feedback, and includes the power during deceleration from High Speed to Idle Speed, during which time the drive still takes some power.

Figure 12, below, is a graph showing the Energy savings in kW-h for each of the systems.

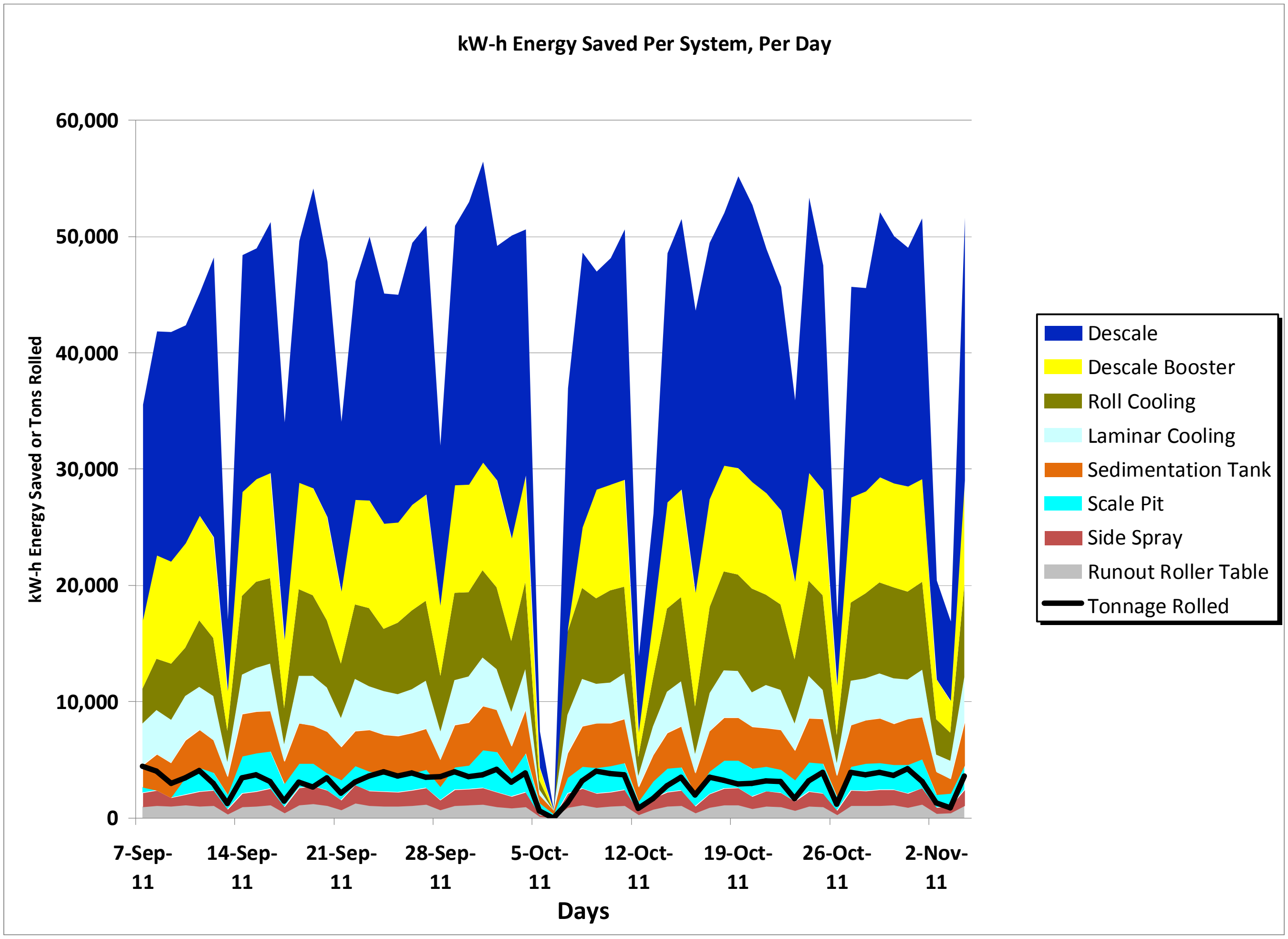

Figure 12. Energy Savings in kW-h for each system and Tons Rolled vs Time

Charts showing the energy usage before and after the Energy Saving System installation.

Figures 13 and 14 below show the Water Treatment monthly energy usage (bars), relative to the monthly tonnage shown as a line.

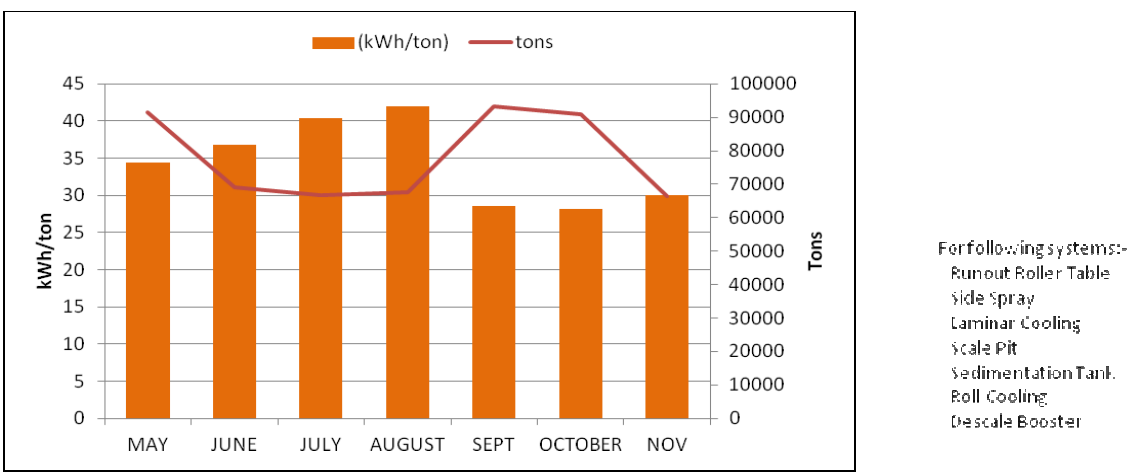

Figure 13. Water Treatment Energy Usage kWh/ton - (switchover to new system at the beginning of September)

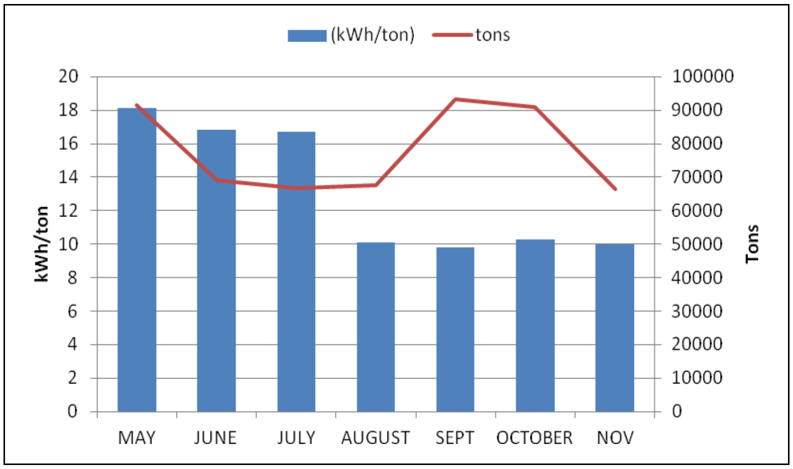

Figure 14. Descale Pump Energy Usage kWh/ton (switchover to new system at the beginning of August)

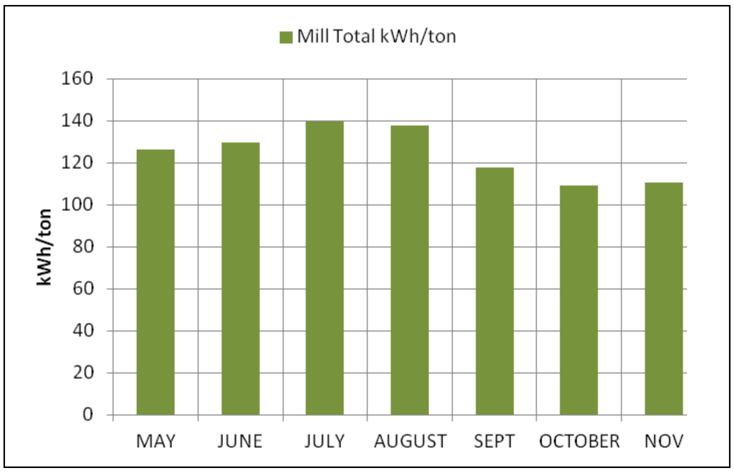

Figure 15. Energy usage for Hot Strip Mill

Data for Figures 13~15 supplied from Tosçelik reports.

SUMMARY

TMEIC achieved the goals set out in this energy saving project. Obviously the energy savings will vary, with high savings during rolling days with delays, and lower savings during high production.

However, based on energy saving data taken per shift over a period of 20 days, we can summarize below.

Based on an Energy unit cost of $0.10/kW-h

Energy savings per day	**typically 45,000 kW-h**
Energy savings per ton	**typically 14 kW-h**
Energy savings per day	**typically $4,500**

The energy savings for different energy costs can easily be extrapolated. In this case, the payback on the energy saving project investment was less than 2 years. The payback calculations include the cost of the equipment, an additional standby descale drive, spare parts and installation. The results are shown in figure 11. Although the Sedimentation Tank and Scale Pit systems are showing a much longer payback period, the customer has reported an important reduction in maintenance cost of these systems mainly because with the drives, the pumps are not subject to the start and stop sequences of the original hysteresis control.

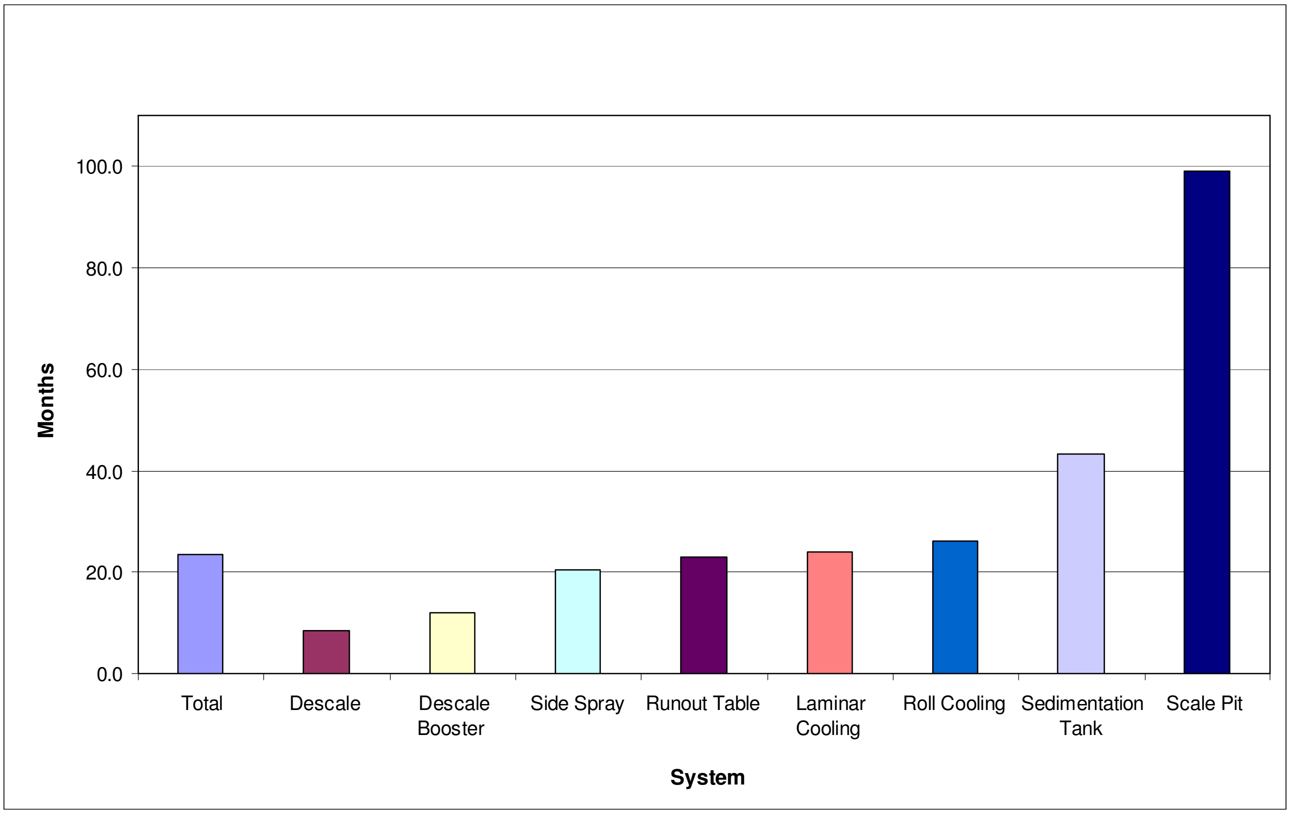

Figure 16. Payback time for each system

Other advantages

1. Less manual intervention by the operators in the control of the Water Treatment plant
2. Less stress on the motors, pumps, valves and pipes due to reduced hydraulic impact, resulting in less maintenance requirements, reduction in replacement parts, and extended equipment life time.
3. Less water circulation reducing the need for water treatment and make-up water.
4. Before the VFD installation, sometimes descale pump trips were experienced during start-up following a long maintenance shutdown due to sudden pressure changes. This was eliminated after the installation of VFD by starting up in energy saving mode and pre-filling the line smoothly at slower speed.
5. The new drives rode through the power dips that tripped the existing non-TMEIC mill drives
6. Installation of the energy saving equipment did not impact production
   Extensive pre-switchover testing in TMEIC systems test facility and at site.
   Fast new system tune-up
   Non-drive pumps were used for production during drives commissioning and uncoupled testing at site
7. Failure scenarios were factored in to the energy saving system design, to eliminate the potential for mill disruption from the new energy saving system.

a) HMI failure – Operator can run the system from existing mill HMI or local desk.
b) Drive Failure - The control system includes the ability to operate variable speed pumps in parallel with the remaining fixed speed pump in the system.

8. Reduction of the kVAR demand due to the close to unity power factor of the drives front end.

REFERENCES

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