Reduction in Carbon Dioxide Emission by Adopting Variable Frequency Drives in Steel Mills

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ABSTRACT

This Project is an attempt in using modern technology for conservation of electrical energy and subsequently reducing the emission of green house gases from thermal power plants. In India the average rate of Carbon Dioxide emission is 0.93 KG per KWH of electrical energy. Thus any reduction in electrical energy will have significant impact on emission of green house gases. In this project the capability of Variable Frequency Drivesis explored in reduction of power requirement of various equipment in a conventional steel mill. The conventional direct on line starters for AC motor control were replaced by Variable Frequency Drivesand comparison study was done to measure the benefits of Variable Frequency Drives. This project focuses on efficient way of operating motor driven equipment in steel mill primarily by using Variable Frequency Drive. The comparative values of conventional control and VFD control were analyzed and discussed.

I. INTRODUCTION

1.1 Greenhouse Effect

Some atmospheric gases absorb and re-emit infrared energy from the atmosphere down to the Earth's surface. This process is known as greenhouse effect. The Earth has a natural greenhouse effect due to trace amounts of water vapour (H_2O), carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) in the atmosphere. These gases let the solar radiation reach the Earth's surface, but they absorb infrared radiation emitted by the Earth and thereby lead to the heating of the surface of the planet. There is a difference between the natural greenhouse effect and the enhanced greenhouse effect. The natural greenhouse effect is caused by the natural amounts of greenhouse gases, and is vital to life. In the absence of the natural greenhouse effect the surface of the Earth would be approximately 33°C cooler. The enhanced greenhouse effect refers to the additional radioactive forcing resulting from increased concentrations of greenhouse gases induced by human activities.

Greenhouse gases trap heat and make the planet warmer. Human activities are responsible for almost all of the increase in greenhouse gases in the atmosphere over the last 150 years. The largest source of greenhouse gas emissions from human activities is from burning fossil fuels for electricity, heat, and transportation.

CO_2 Emissions from Power Plants: Approximately 40% of global CO_2 emissions are emitted from electricity generation through the combustion of fossil fuels to generate heat needed to power steam turbines. Burning these fuels results in the production of carbon dioxide (CO_2)—the primary heat-trapping, "greenhouse gas" responsible for global warming. Applying smart electric grid technologies can potentially reduce CO_2 emissions. Per Capita CO_2 Emission is shown in Fig 1.5.

India's coal-based thermal power sector is one of the country's biggest emitters of carbon dioxide (CO_2). It spews out 1.1 gigatonne of CO_2 every year; this is 2.5 per cent of global GHG emissions, one-third of India's GHG emissions, and around 50 per cent of India's fuel-related CO_2 emissions. Coal is the primary fuel for electricity generation in India and its usage is continuously increasing to meet the energy demands of the country.

Coal is the major fuel for the electricity generation in countries like India and China. Abundant supply of coal locally and sustained high prices for imported natural gas and oil make coal-fired generation of electricity more attractive economically. Coal is approximately 90% of the total fuel mix for electricity generation. Fig. 1.4 shows the percentage of generating capacity of all categories that includes natural gas, diesel, nuclear, hydro, and renewal energy sources like biomass power, urban and industrial waste power, and wind energy. Coal and lignite based power plants have approximately 54.42% of the total electric power generation capacity in India. However, relatively lower calorific value, coupled with high ash content and inefficient combustion technologies aggravates emission of greenhouse gases and other pollutants from India's coal and lignite based thermal power plants.

Main emissions from coal fired and lignite based thermal power plants are CO_2, NO_x, SO_x, and air-borne inorganic particles such as fly ash, carbonaceous material (soot), suspended particulate matter (SPM), and other trace gas species. Thermal power plants, using about 70% of total coal in India4 (Garget. al., 2002), are among the Large Point Sources (LPS) having significant contribution (47% each for CO_2 and SO_2) in the total LPS emissions in India.

The above facts call for saving electrical energy so that carbon footprint can be reduced.

1.2 Role of Variable Frequency Drives (VFDs) in reducing CO_2 emission

A Variable Frequency Drive (VFD) is a type of motor controller that drives an electric motor by varying the frequency and voltage supplied to the electric motor. Other names for a VFD are variable speed drive, adjustable speed drive, adjustable frequency drive, AC drive, micro drive, and inverter.

Frequency (or hertz) is directly related to the motor's speed (RPMs). In other words, the faster the frequency, the faster the RPMs go. If an application does not require an electric motor to run at full speed, the VFD can be used to ramp down the frequency and voltage to meet the requirements of the electric motor's load. As the application's motor speed requirements change, the VFD can simply turn up or down the motor speed to meet the speed requirement.

1.2.1 Benefits of a Variable Frequency Drives

1. Reduce Energy Consumption and Energy Costs: If an application that does not need to be run at full speed, then it can cut down energy costs by controlling the motor with a variable frequency drive, which is one of the benefits of Variable Frequency Drives. VFDs allow matching the speed of the motor-driven equipment to the load requirement. There is no other method of AC electric motor control that allows accomplishing this.

Electric motor systems are responsible for more than 65% of the power consumption in industry today. Optimizing motor control systems by installing or upgrading to VFDs can reduce energy consumption in facility by as much as 70%. Additionally, the utilization of VFDs improves product quality, and reduces production costs. Combining energy efficiency tax incentives, and utility rebates, returns on investment for VFD installations can be as little as 6 months.

2. Increase Production through Tighter Process Control: By operating your motors at the most efficient speed for application, fewer mistakes will occur, and thus, production levels will increase, which earns your company higher revenues. On conveyors and belts it can eliminate jerks on start-up allowing high through put.

3. Extend Equipment Life and Reduce Maintenance: Equipment will last longer and will have less downtime due to maintenance when it's controlled by VFDs ensuring optimal motor application speed. Because of the VFDs optimal control of the motor's frequency and voltage, the VFD will offer better protection for motor from issues such as electro thermal overloads, phase protection, under voltage, overvoltage, etc. When starting a load with a VFD this will not subject the motor or driven load to the "instant shock" of across the line starting, but can start smoothly, thereby eliminating belt, gear and bearing wear. It also is an excellent way to reduce and/or eliminate water hammer since it can have smooth acceleration and deceleration cycles.

In the absence of VFDs, the fixed AC motor speed and torque mean that the equipment these motors drive operate at constant speed and torque as well and system control is achieved through dissipating (wasting) energy by mechanical means. In the case of the HVAC fan, if the air supply demand decreases, and the energy input from the fan remains constant, then in order to reduce the supply of air to the space being conditioned the energy in the flow must be dissipated using vents or valves or air must be diverted and dumped elsewhere. Either way, energy is being wasted to deliberately reduce the supply of air and the efficiency of the system is reduced.

With a VFD, the output of the system (air supply in this case) is controlled by directly changing the speed or torque of the motor. At low demand the motor runs slowly and the power consumption decreases in proportion to the demand resulting in increased efficiency and energy savings.

In addition, since the fan runs at constant speed it must be sized to deal with the maximum possible demand. This demand would typically only occur for a few hours of the year and so for the rest of the time the system is oversized and operating at reduced efficiency.

Since the VFD can be used to run the system at higher than rated speeds, the whole system can be sized according to more common conditions and the extreme demand conditions can be serviced by running the system at over-speed. The overall energy efficiency of the system is thus further improved.

4. Energy saving function: The operating point of the motor is optimized so that the power consumption is kept to a minimum.

- Quadratic V/f characteristic in the case of control of an asynchronous motor
- DC-link connection
- Energy-optimized braking

PID controller (technology controller): When the reference value is reached, the motor is switched off.

- External DC 24 V power supply. Power supply can be switched off while the system is not in operation.
- Temperature-controlled fans
- Automatic switching frequency changeover
- In the variable frequency drive, special energy saving circuitry is integrated

- Variable frequency drive energy saving function
- The operating point of the motor is optimized so that the power consumption is kept to a minimum and energy saving is maximized.

The energy saving function is suitable for:

- partial load operation of a VFD
- VFDs without high or frequent load variations
- The energy saving function is not suitable for operation of a synchronous motor.
- Variable frequency drive sensorless control (V/f characteristic)
- In the case of the sensorless control of an asynchronous motor according to the V/f characteristic, the optimum operating point of the motor is adjusted in order to keep power consumption to a minimum.

Variable frequency drive sensorless field oriented control (FOC): In the case of the field oriented control of an asynchronous motor, the optimum operating point of the motor is adjusted in order to keep power consumption to a minimum.

Quadratic V/f characteristic: For applications where the torque increases quadratically to the speed, e.g. control of a fan, the power consumption can be reduced and energy can be saved. In the low speed range where the full torque is not required, energy is saved.

The quadratic characteristic follows the function: $|U| \sim f_2$.

DC-link connection: By DC-link connection of several variable frequency drives, energy can be saved, as the energy recovered when one motor is decelerated can be used for accelerating the other VFD. In this case, the acceleration energy does not have to be taken from mains supply.

If the deceleration energy from a motor is not used for accelerating the other motor it will be used for covering the consumption of the coupled variable frequency drives.

Energy-optimized braking: The voltage controller can be set up such that the kinetic energy recovered during deceleration operations is not converted to heat in a brake resistor. The brake ramp will be adjusted automatically such that the DC-link voltage does not exceed a certain value. The motor is decelerated in an energy saving way. The consumption of the variable frequency drive is covered by the deceleration energy of the VFD, so that no energy is taken from mains supply.

PID controller (technology controller): Saving energy when the reference value is reached. The PID controller (technology controller) can switch off the motor when the reference value (PID desired set value) is reached. Saving energy is possible particularly in the case of asynchronous motors, as these motors consume the magnetizing current even when they are at a standstill. The function can be used for filling level controls, for example.

External DC 24 V power supply: Via an external 24V power supply, the control component of the variable frequency drive can be powered independent of mains supply. The variable frequency drive can be disconnected from mains supply via contactor, for example. Even with mains supply switched off, parameterization is still possible, the function of inputs and outputs and the communication are maintained.

The power consumption of the variable frequency drive during extended interruptions of operation can almost be reduced to zero.

Temperature-controlled fans: The VFD fans are controlled in two stages. This is done for the inside fan and the heat sink fan together. If the inside, capacitor or heat sink temperature set via Switch-On Temperature is exceeded, the heat sink fan and the inside fan are switched on at half power. The VFD fans will be switched off again as soon as the temperatures have dropped below the Switch-On Temperature 39 by 5 °C again.

If the internally defined maximum inside, DC-link capacitor or heat sink temperature thresholds are reached (5 °C below maximum temperature), the VFD fans are switched to full power. If the temperature drops to 5 °C below the switch-on threshold again, the fans return to the half-power stage.

Automatic switching frequency changeover: The power losses of semiconductor components depend on the switching frequency and the level of the switched current. In the case of a high current load, e.g. during VFD acceleration of high loads, the switching frequency of the pulse width modulation may be reduced temporarily in order to reduce the losses of the variable frequency drive. If the current drops again after the acceleration phase, a higher switching frequency will be set automatically.

Circuitry measures integrated in VFD: The following energy saving measures were integrated in the variable frequency drive and do not require any setup.

The integrated power supply a unit supplying the internal assembles are optimized to ensure minimum power losses.

Low-loss current measurement: The own consumption of the measuring system is optimized to ensure minimum power losses.

1.3 Energy scenario in India

Energy is one of the major inputs for the economic development of any country. In the case of the developing countries, the energy sector assumes a critical importance in view of the ever increasing energy needs requiring huge investments to meet them.

Energy can be classified into several types based on the following criteria:

- Primary and Secondary energy
- Commercial and Non commercial energy
- Renewable and Non-Renewable energy

Coal dominates the energy mix in India, contributing to 51% of the total primary energy production. Over the years, there has been a marked increase in the share of natural gas in primary energy production to 6% in 2020. There has been a decline in the share of oil in primary energy production from 20% to 15% during the same period. Energy Supply Coal Supply India has huge coal reserves, at least 107,396 million tonnes of proven recoverable reserves (at the end of 2016). This amount to almost 9.6% of the world reserves and it may last for about 111 years at the current Reserve to Production (R/P) ratio. In contrast, the world's proven coal reserves are expected to last for 192 years at the current R/P ratio.

Electrical Energy Supply: The all India installed capacity of electric power generating stations under utilities was 3.95,075 MW as on 31st Jan 2022, consisting of 46,512 MW- hydro, 2,03,900 MW - thermal and 6,780 MW- nuclear and 40,100 MW- wind (Ministry of Power). Nuclear Power Supply Nuclear Power contributes to about 1.7 per cent of electricity generated in India. India has ten nuclear power reactors at five nuclear power stations producing electricity. More nuclear reactors have also been approved for construction. Hydro Power Supply India is endowed with a vast and viable hydro potential for power generation of which only 11% has been harnessed so far.

1. Total Installed Capacity (As on 31.01.2022) - Source: Central Electricity Authority (CEA)

Table 1: Installed Generation Capacity (Sector Wise) as on 31.01.2022

Sector	MW	% of Total
Central Sector	98,327	24.9%
State Sector	1,05,314	26.7%
Private Sector	1,91,434	48.5%
Total	**3,95,075**	**100.0%**

Table 2: Installed Generation Capacity (Fuelwise) as on 31.01.2022

Category	Installed Generation Capacity (MW)	% of Share in Total
Fossil Fuel		
Coal	2,03,900	51.6%
Lignite	6,620	1.7%
Gas	24,900	6.3%
Diesel	510	0.1%
Total Fossil Fuel	**2,35,929**	**59.7%**
Non-Fossil Fuel		
RES (Incl. Hydro)	**1,52,366**	38.5%
Hydro	**46,512**	**11.8 %**
Wind, Solar and Other RE	1,05,854	26.8 %
Wind	40,101	10.2 %
Solar	50,304	12.7 %
BM Power/Cogen	10,176	2.6 %
Waste to Energy	434	0.1 %
Small Hydro Power	4,840	1.2 %
Nuclear	6,780	1.7%
Total Non-Fossil Fuel	**1,59,146**	40.3%

II. PROBLEM IDENTIFICATION

The problem identification starts with study and comparison of technology adopted, operational parameters, regulation standard and work practices by different steel plants in production and operation of steel mill to control energy consumption.. Since the study is based on BSP Rail steel mill, it is imperative to study the existing equipments, technology, processes, practices and operating parameters followed to achieve the desired techno-economic parameters.

2.1 Rail and Structural Mill (Bhilai Steel Plant)

Introduction: The Bhilai Steel Plant, a unit of Steel Authority of India Ltd. and a public sector undertaking was conceived under aegis of Indo-USSR Treaty in the 2nd Five year plan in 1959. The plant is located at the central position of India, which is one of the major iron belts of India and is about 40 kilometer from Raipur, capital of the newly born state of Chhattisgarh. With a production capacity of 7.0 million tons of steel, it is the largest steel plant in India.

Process Description of Rail and Structural Mill: Rail and Structural Mill of Bhilai Steel Plant, SAIL is the world's largest producer of rails with an installed capacity to produce 500 000 tons of rails and 250 000 tons of structurals.

Steel Inputs of RSM: The Rail Steel making process at Bhilai Steel Plant is one of the most advanced. Hot metal from blast furnaces is desulphurised. Rail steel is made in BOF converters at SMS 2 and processed through RH degasser and ladle furnace etc. The steel thus obtained is very clean and has hydrogen in liquid steel less than 1.6 ppm a world benchmark. It is continuously cast into blooms, which are flame cut to specified length and weight, and sent to Rail and Structural Mill for rolling.

Rolling Mill Area: It constitutes of the following areas:

1. Reheating furnaces, Roughing Stand. Intermediate Stands, Finishing Stands, Hot saws, Stamping Machine and Cooling beds

Rail Finishing Area: There are two rail finishing areas one for finishing of 13 and 26 m rails and one for finishing long rails. The details of both are elaborated below:

A. 13/26 M Finishing Area: It constitutes of the following areas:

1. Rail straightening, Online NDT,Rail finishing and inspection

Long Rail finishing complex constitutes of the following areas:

1. Precambering and walking beam cooling bed, Rail straightening, Online NDT, End finishing / straightening and inspection, Welding, Rail Handling

2.2 Areawise Energy Input Output Diagrams and Process Description

2.2.1 Reheating Furnaces

There are three reheating furnaces of 75 T/Hr each. They are continuous pusher type end charging end discharging type recuperative furnaces using mixed gas of calorific value ~ 1850 Kcal/NM^3 as fuel. Roll tables driven by electric motors are employed for charging blooms in to the furnace (CRTs) and discharge roll tables (DRTs) for evacuating the bloom discharged from the furnace. To eliminate jamming, these roll tables are to be in continuous operation even when there is no bloom on the roll tables. 6 nos. of CRTs and 5 nos. of DRTs are employed each with 37 KW motor.

2.2.2 Rolling Mill

The mill constitutes the following rolling stands:

- One number two high reversing 950 mm roughing mill driven by a 4000 KW DC motor.
- Two number three high 800 mm intermediate stands with a common drive of 7200 KW DC motor.
- One two high finishing 850 mm finishing mill driven by a 1800 KW DC motor.

The mill also has the following facilities:

- 7 numbers hot saws
- Stamping machine and cooling beds

2.2.3 Finishing and Shipping

Finishing: There are three finishing lines:

- For finishing of 13/ 26 M rail finishing
- For finishing of long rails

- For finishing of structurals

The various finishing lines have the following facilities:

- Precambering
- Straightening machines
- Online NDT and inspection
- Cutting / milling/ presses
- Welding

End forging facilities: These constitute induction furnace, forging and milling machine.

Shipping: It constitutes cranes and telpher for loading.

2.3 Identification of Various Energy Sources

Table 3: Sources of Energy in RSM

S. No.	Name of energy used	Form of energy	Usage area	Name of equipment / usage area
1	Thermal energy	By-product gaseous fuels(Mixed gas- Coke oven + Blast Furnace + LD)	Reheating Furnaces	Bloom Heating
2	Power	Electrical	All areas	Equipments Driven by Elect Motors
3	Diesel	Liquid fuel	Transportation	Loco transport
4	Steam	Steam generated at Power Plant	Reheating Furnaces	Purging of gaslines

2.4 Consumption and Energy Trend Analysis

Table 4: Consumption 2020-21

SL No	Name of Energy	Units	Quantity	Consumption / unit production	Heat Value (Mcal / unit)	Gcal / Ton of production
1	CO gas	‘000 M3	77286	0.09	4295167	0.391
	BF gas	‘000 M3	11663	0.01	1700000	0.023
	LD Gas	‘000 M3	199501	0.24	786000	0.185
2	Electricity	MWH	52135	0.06	2400000	0.147
3	Diesel	Klit	131	0.00	9417000	0.001
4	Steam	Ton	1737	0.00	690000	0.001

Table 5: Energy use trend analysis

S. No.	Name of Energy / Parameter	2018-19	2019-20	2020-21	Best in previous 3 years
1	Heat Mcal / Ton of input	715	674	564	564
2	Power KWH / Ton	59.8	59.4	61.4	59.4
3	Diesel (G Cal / T)	0.001	0.001	0.001	0.001
4	Steam (Tons / T)	0.001	0.001	0.001	0.001

2.5 Significant Energy Analysis

Table 6: Significant Energy Use

SL No	Name of Energy/ Parameter	Energy Con (Gcal)	Percentage	Rank
1	Heat	0.599	80.08	1
2	Power	0.147	19.65	2

SL No	Name of Energy/ Parameter	Energy Con (Gcal)	Percentage	Rank
3	Diesel	0.001	0.13	3
4	Steam	0.001	0.13	3
	Total	**1**	**100.00**	

Table 7: Assessment of potential of reduction in energy use

SL. No.	Name of Energy / Parameter	2017-18	2018-19	2019-20	Best in previous 3 years	Gap	Potential in %	Rank
1	Heat Mcal/Ton of input	715	674	563	563	0	0	2
2	Power KWH / Ton of HS prod	59.8	59.4	61.4	59.4	2	3.25	1
3	Diesel KL/T	0.001	0.001	0.001	0.001	0	0	2
4	Steam	0.001	0.001	0.001	0.001	0	0	2

Table 8: Composite of assessment of energy use

SL. No.	Name of Energy/ Parameter	Rank (Energy use) X	Rank (Potential) Y	Composite Value (X x Y)	Rank
1	Heat	1	2	2	1
2	Power	2	1	2	1
3	Diesel	3	2	6	2
4	Steam	3	2	6	2

Based on the above analysis Heat and Power identified as key contributors for significant energy usage.

Carbon dioxide (CO_2) formed as the result of electrically switched machines predominantly contributes to global warming. Electrical operated machines such as pumps, fans, Roll Tables used in the mill, are run by electric drives. In an effort to minimize CO_2 emissions due to mill, it was decided to focus on reducing the electrical consumption as the means of reducing CO_2 carbon foot prints.

III. METHODOLOGY

3.1 Segregation and Identification of High Impact Electrical Equipment

To control/reduce the power consumption it is necessary to identify the source, quantify and measure so that it can be controlled and managed effectively.

1. Segregating the equipments of power consumptions according to the applications.
2. Measuring the power consumption in segregated categories..
3. Identifying variable factors effecting energy use.
4. Modifications in the system to reduce electrical consumption.
5. Identification of relevant variables in electrical energy use.
6. Identification of Significant Electrical Energy usage in Equipments

Table 9: Segregation of Equipment

S. No.	Name of Equipment	Usage area	Estimated Energy Consumption (in KWH)	% energy consumption of total energy consumption	Rank based on energy consumption
1	Main Drives	Mill	3,74,91,180	42.66	**1**
2	Conveyors and Drives	Mill + Finishing	1,79,40,080	20.41	2
4	Mill-Pumps + Fans	Mill + Finishing	13249887	15.08	3
8	Lighting	Mill + Finishing	1,28,84,500	14.66	**4**
9	Cranes	Mill + Finishing	48,41,225	5.51	6
10	Air Conditioners	Mill + Finishing + Welfare Building	14,70,690	1.67	8

Based on the above main drives, conveyors, pumps and fans(% energy above 14% of total consumption) identified as key contributors for significant electrical energy usage and accordingly action plans are taken in these areas.

3.2 On further study following were the understanding

1. Mill drive is Rank 1 in significant electrical usage, but found marginal scope for in term of saving potential. Mill main drives are prime movers for the main rolling stands. The main role of rolling stands is to gradually convert the input rectangular metal bloom in to the shape of rails. As this is the main activity of rail mill so very less scope of energy saving unless high value investment is done and cannot be done at individual level.. Already proposal to upgrade the mill drive system has been initiated by management.
2. Conveyors and drives are Ranked 2 and Pumps and fans are Ranked 3. On further studies and undertaking literature survey, it was felt that significant energy savings can be achieved by implementing small scale in-house up-gradation. From the research done, use of Variable frequency drive (VFD) was found to be of having significant impact on energy saving. So it was decided to take a pilot project in lab. A 5KW VFD was arranged and connected to 3KW Motor. System was setup and put in operation for 6 days. Energy readings recorded for each day and are tabulated in Table.

Table 10: KWH Readings with and without VFD for 5Days

Days	**With VFD (KWH)**	**Without VFD (KWH)**
5 Days	**3886**	**5430**

From the data it can be concluded that there is net saving of (5430-3886) of 1544 KWH i.e., 29% saving in energy consumption.

Fig. 1: Lab Setup for Pilot Project

Based on the encouraging results from the above experiment done in lab, a further study of load pattern, process requirement and energy consumption was conducted. It was observed that these equipment have the maximum potential of energy saving. So it was decided to install VFDs in following equipment during appropriate shutdown.

1. Furnace Charging Roll Table No. 6 (CRT6)
2. Furnace Charging Roll Table No. 7 (CRT7)
3. Booster Pump No.1
4. Booster Pump No.2
5. Rail Cooling Fan
6. Furnace delivery Roll Table No.5 (DRT5)
7. Furnace delivery Roll Table No.6 (DRT6)
8. Furnace delivery Roll Table No.7 (DRT7)
9. Furnace delivery Roll Table No.8 (DRT8)
10. Furnace delivery Roll Table No.9 (DRT9)

Fig. 2: Furnace Charging Roll Tables

As shown in photograph, furnace charging roll tables are used to transport bloom up to the mouth of the furnace. Once blooms are positioned, then they are pushed inside the furnace by 300T pusher. These roll tables are to be run continuously and for positioning inching operation is required.

Fig. 3: Furnace Delivery Roll tables

As shown in the photograph is the furnace delivery roll table (DRT). The furnace pushing sequence is FIFO (First in First Out). That is, when one cold bloom is pushed inside furnace, one hot bloom is pushed out of the furnace on the delivery roll table. To avoid jamming, these roll tables have to run continuously even on no load. During bloom jamming inching operation is required.

Fig. 4: Booster Pumps 1 and 2

Water Booster Pump 1 and 2: As shown in the photograph is the water booster pumps 1 and 2. These pumps run continuously and output is throttled by diverter valves.

6 KWH Measurements Before and After VFD installation: The energy consumption of these equipment before installing VFD and after installing VFD is shown in following tables:

The Data: The Energy consumption of equipment was measured last 3 yrs and is tabulated below.

Table 11: Furnace Charging Roll Tables energy Consumption YR 2019 in KWH

Months(12)	CRT6	CRT7	Booster Pump1	Booster Pump2	Rail cooling fan
Average	11162.5	11186.5	36534.17	36559.83	8878.917
Total	133950	134238	438410	438718	106547

Table 12: Furnace Discharging Roll Tables energy Consumption YR 2019 in KWH

Months(12)	DRT5	DRT6	DRT7	DRT8	DRT9
Average	11231.42	11215.67	11204.17	11242.83	11245.08
Total	134777	134588	134450	134914	134941

Table 13: Furnace Charging Roll Tables energy Consumption YR 2020 in KWH

Months(10)	CRT6	CRT7	Booster Pump1	Booster Pump2	Rail cooling fan
Average	**11179.89**	**11184**	**36467.11**	**36443.67**	**8819**
Total	**100619**	**100656**	**328204**	**327993**	**79371**
Shutdown in November 2020					
Nov	6624	6690	19913	20089	3778
After VFD installation in November 2020					
Dec	7389	7330	22209	22389	5252

Table 14: Furnace Discharging Roll Tables energy Consumption YR 2020 in KWH

Months(10)	DRT5	DRT6	DRT7	DRT8	DRT9
Average	**11184.8**	**11207.5**	**11192.5**	**11199.3**	**11182.5**
Total	**111848**	**112075**	**111925**	**111993**	**111825**
Shutdown in November 2020					
Nov	6576	6691	6580	6599	6675
After VFD installation in November 2020					
Dec	7370	7394	7466	7450	7444

Table 15: Furnace Charging Roll Tables energy Consumption YR 2021 in KWH after VFD Installation

Months(12)	CRT6	CRT7	Booster Pump1	Booster Pump2	Rail cooling fan
Average	**7291.583**	**7253.083**	**19460.08**	**19464.25**	**5120.5**
Total	**87499**	**87037**	**233521**	**233571**	**61446**

Table 16: Furnace Discharging Roll Tables energy Consumption YR 2021 in KWH after VFD Installation

Months(12)	DRT5	DRT6	DRT7	DRT8	DRT9
Average	**7306.667**	**7331.083**	**7303**	**7320.333**	**7324.167**
Total	**87680**	**87973**	**87636**	**87844**	**87890**

3.3 Implementation Strategy

After encouraging results observed from the experiment done in lab and identification of equipment for installation of VFDs, specification of VFDs was made from following data:

Table 17: Motor Ratings and VFD selection

Equipment	Motor KW	Full Load Current (Amps)	Ambient Conditions	VFD selection KW After derating
CRT5	30	56	Harsh	60
CRT6	30	56	Harsh	60
CRT7	30	56	Harsh	60
Booster Pump1	55	80	Normal	90
Booster Pump 2	55	80	Normal	90
DRT5	37	68	Harsh	75
DRT6	37	68	Harsh	75
DRT7	37	68	Harsh	75
DRT8	37	68	Harsh	75
DRT9	37	68	Harsh	75

Catalogs of VFD manufacturers were referred and centralized procurement department ETL (Electro Testing Lab) was consulted for the availability of VFDs as per requirement. It was learned that 75KW VFD is a standard VFD and 10Nos are available but of different makes. In view of this, it was decided to install 75KW VFDs for all equipment. This will help in achieving standardization and ease of maintenance. Long duration repair of year 2020 was chosen for commissioning of VFDs in the selected equipment. Pre-shutdown, Shutdown and post shutdown activity chart was prepared. During long repair of Nov 2020, the VFDs were installed and commissioned and put in service. Pre-shutdown, Shutdown and post shutdown activities meticulously planned. Resources arranged and all VFDs were successfully installed and commissioned within stipulated time.

Fig. 5: VFDs Furnace Delivery Roll Tables DRT 9 and 10

Fig. 6: Earlier Conventional control Motor breaking energy dissipated in resistance boxes

Fig. 7: Drive for Booster Pump 1

IV. RESULTS AND DISCUSSIONS

4.1 Results after Variable Frequency Drive installation

The energy consumption was compared before VFD and after VFDs installation and is tabulated below.

Comparison table of average energy consumption before VFD and after installation of VFD

Table 18: Comparison energy consumption before and after VFD Installation

	Average Energy KWH Before VFD installation / Month	**Average Energy HWH After VFD installation / Month**	**Reduction in Consumption / Month KWH**	**Yearly reduction in CO_2 emission KG**
CRT6	11171.195	7291.583	3879.612	43296.47
CRT7	11185.25	7253.083	3932.167	43882.98
Booster Pump 1	36500.64	19460.08	17040.56	190172.64
Booster pump 2	36501.75	19464.25	17037.5	190138.5
rail cooling fan	8848.9585	5120.5	3728.459	41609.60

Table 19: Comparison energy consumption before and after VFD Installation

	Average Energy KWH Before VFD installation / Month	**Average Energy HWH After VFD installation / Month**	**Reduction in Consumption / Month KWH**	**Yearly reduction in CO_2 emission KG**
DRT5	11208.11	7291.583	3916.527	43708.44
DRT6	11211.585	7331.083	3880.502	43306.40
DRT7	11198.335	7303	3895.335	43471.93
DRT8	11221.065	7320.333	3900.732	43532.16
DRT9	11213.79	7324.167	3889.623	43408.19

In the above table, yearly reduction in CO_2 emission is also calculated.

As per the studies following are the emissions from coal power plants in India.

Table 20: Emission from Coal Power Plant

CO_2 Kg / KWH	SO_2 g / KWH	NO g / KWH
0.93	630	4.34

Also in India, more than 65% electrical energy is produced by coal fired thermal power plants. So by installing VFDs, significant reduction in energy consumption is observed. This will reduce considerably the CO_2 emission which is the major greenhouse gas.

Energy efficiency plays the most important role in CO_2 emission reductions, accounting for up to 53% of total CO_2 emission reductions. In pump and fan applications using Variable Frequency Drives (VFD) can cut the energy consumption for these applications by as much as 60%. In addition to reduction in CO_2 emission following are the advantages of installing VFD.

4.2 Discussions

As shown in table 5.1 and 5.2, the total KWH saving is 7,81,212 KWH per year, which is quite significant. Also CO2 emission reduction is 726527Kgs per year. The results are in tune with the results obtained in experiment done in lab. Maximum savings are achieved in Booster Pumps. As booster pumps are fan type of loads, so decrease in current requirement is square of the reduction in speed of pump. After installing the VFD, the water flow was regulated by reducing the speed of pump and not by diverting the flow, significant saving of 46% is achieved. Even in the constant torque application like roll tables, 34% of energy savings is achieved. The energy savings in roll table can be attributed to the capability of VFDs to optimize the magnetizing current of the motor. It has demonstrated the Field oriented control capability of VFDs. So it can concluded that significant energy savings can be achieved by installing VFDs irrespective of the type of load. The cost of VFDs of 75KW is approx. Rs. 2,25,000. Total cost of VFDs was approx. Rs. 22,50,000. Cost saved by energy saving is Rs. 46,87,272 / year recurring. Payback period is approx. 6 months. Thus VFD installation not only saves cost but also have significant positive impact on environment.

V. CONCLUSION AND FURTHER SCOPE OF WORK

5.1 Conclusion

Since pumps and fans typically run at partial load, huge energy savings can be achieved by controlling their speed with variable speed drives. A small reduction in speed can make a big reduction in the energy consumption. A pump or a fan running at half speed may consume as little as one eighth of the energy compared to one running at full speed. By employing variable speed drives on centrifugal pumps and fans instead of using throttling, damping or inlet guide vanes, the energy bill can be reduced by as much as 60 percent. Consequently, electric variable speed drives also help to reduce NO_x and CO_2 emissions. VFDs for constant torque applications like roll tables also help in reducing magnetic current of motor and thereby huge saving in energy consumption. VFDs also give Soft starting Accelerating rotating machinery with heavy load torque or high mass moment of inertia, such as high inertia roll tables, Hot Saw disk drives, furnace blowers, imposes large stress on the electrical supply network and on the mechanical parts of the shaft string. A direct-on-line started electric motor can cause starting currents of up to six times the nominal current. This will cause a voltage drop that is likely to disturb the process, especially if the supply network is weak. Variable speed drives act as soft starters reducing the stress on the network, motors, pumps and fans. During the starting process, the variable speed drive progressively increases the motor speed and smoothly accelerates the load to its rated speed. Soft starts eliminate high starting currents and voltage dips which can generate process trips. With soft starts, maintenance costs will be reduced and the lifetime of the equipment extended.

The electricity savings derived from the use of VFDs represent a direct reduction in CO2 emissions if the electricity is generated on-site or an indirect reduction if the electricity is bought from the grid. Multiple types of research have reported the CO_2 reductions achieved by the implementation of VFDs. The reduction in emission strongly depends on the emission factors of the specific location where the implementation of VFDs is taking place. In India, as more than 60% electricity is produced by coal based thermal power plants, so small amount of saving in electricity can have huge impact on CO_2 emission. But in Nordic countries, almost 90% of electricity is produced from non-coal based power plants. So the impact of electricity saving is not very significant on CO_2 emission.

The benefits of variable speed pumping have long been recognized, including reduced power cost, reduced mechanical wear and process optimization.

In today’s economy and environmental awareness, a significant reduction of a company’s carbon footprint can now be added to the list of benefits.

Electromagnetic drives can often prove to be the best path to achieve these results, and can be shown to pay for themselves over a long period of service.

5.2 Further Scope of Work

The energy saving benefit of VFDs has been demonstrated in this project work. Following impact of VFDs may be studied for further improvements

The harmonic effects of VFDs. It is claimed that the VFDs with active front end has unity power factor. VFDs with active front end and without active front end can be compared for suitable application with cost.

Benefits of networking VFDs with PLC automation system. VFDs are capable of communication with PLC automation system. Study can be done on benefits of networking VFDs with PLC.

Impact of IIoT on VFD and its use. The concept of Industrial Internet of Things is getting advanced. Benefits of VFDs with IIoT can be explored further.

Application of VFDs in HVAC system (Heating, ventilation, and air conditioning). There is large scope of VFD utilization in HVAC system. Currently VFDs are not used in HVAC system. Advantaged of using VFDs in HVAC system can be studied.

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