Automation of Rotary Kiln using Frequency Converters

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***Abstract*—This case study based on the automation of rotary kiln using frequency converters. This study also mentioning the disadvantageous of speed control using DC motor in hazardous industries. Here the speed control by DC drives, which were put to drive the kiln was replaced by AC drives as a step for continuous production. Variable Frequency AC Drive (VFD) is recently making tremendous impact in the industrial nations. The main purpose of VFD is to reduce energy costs and prolong the life equipment by adjusting motor speed to meet load requirements. This case study also deals with automation process. Automation is achieved by coordinating the activity of VFD using Distributed control System (DCS). The DCS acts as the deciding body which compares the result with pre-set values and sends appropriate analog signals to VFD which executes the instruction.**

***Keywords* ---Variable Frequency Drive (VFD), Distributed Control System (DCS)**

I. INTRODUCTION

In Indian industries more than 60 % of the total energy consumption is used by rotating equipment, out of which 75% of which is consumed by various types of motor**.** The automation of rotary kiln is mainly used in the industrial plants. This paper is intended to serve as an introduction to VFD, how they are applied to AC Induction motors in the chemical industry and specific design considerations for motors operated with VFD's.

This chemical industry is the world's first fully integrated Titanium Dioxide plant and also the India's first and only manufacturer of rutile Grade Titanium dioxide by chloride process. Rotary kilns, which are pyro processing devices used to raise the temperature of materials to a higher ranges are deployed in continuous production process. Here Beneficiated ilmenite (90% content of TiO_2) is produced from rawilmenite (50% content of TiO_2) with the help of rotary kilns and subsequent treatments at different levels.

Here Ilmenite Beneficiation Plant of chemical industry consists of Roaster and Calciner sections for the production of beneficiated ilmenite. Roaster section handled the production with Roaster and Cooler kilns by regulating the speed of kilns using thyristor drives and dc motors, and Calciner section also same as Roaster section. Production outages faced in both sections due to failure/outages of thyristor drives and also the maintenance outages of dc motor. In view of this problem, production was not attained the targeted quantum.

In house study was conducted and suggested to improve the system providing the following modifications to attain the production in full.(i)Replace the existing motor with inverter duty AC motors. (ii) Provide variable frequency to start the AC motors. (iii) Change field wise control room operation to distributed control system to enable the process operations at one control room and getting up to date status of all equipment'son all operations.

II SPEED CONTROL OF DC MOTOR AND AC MOTOR

In industries, motors should satisfy very strict speed characteristic requirements, both with respect to the range and smoothness of control and also with respect to economical operation. From the view point of speed control characteristics, induction motors are inferior to dc motors. The speed of a dc shunt motor can be adjusted between wide range with good efficiency and speed regulation, but in induction motors speed cannot be varied without losing efficiency and good speed regulation. But still ac motors are preferred for their continuous production applications.

A. V/F THEORY

Motor speed can be controlled by varying supply frequency. Voltage induced in stator is proportional to the product of supply frequency and air gap flux. If stator drop is neglected, terminal voltage can be considered proportional to the product of frequency and flux. Any reduction in supply frequency without a change in the terminal voltage causes an increase in the air gap flux. Induction motors are designed to operate at the knee point of the magnetization characteristics to make full use of the magnetic material. Therefore the increase in flux will saturate the motor. This will increase the magnetizing current, distort the line current and voltage, increase the stator copper loss and produce a high pitch acoustic noise. Therefore the variable frequency control below the rated frequency is generally carried out at rated air gap flux by varying terminal voltage with frequency so as to maintain V/f ratio constant at the rated value.

$$T_{max} = \frac{K\left(\frac{V}{f}\right)^2}{\frac{R_s}{f} \pm \left[\left(\frac{R_s}{f}\right)^2 + 4\pi^2\left(L_s + L_r{'}\right)^2\right]^{\frac{1}{2}}} \quad \ldots\ldots (1)$$

Where K= constant.
L_s= stator inductance.
$L_r{'}$ = stator referred rotor inductance.
R_s= stator resistance

Positive sign is for motoring operation and negative sign is for breaking operation.

Equation becomes

$$T_{max} = \pm \frac{K\left(\frac{V}{f}\right)^2}{2\pi\left(L_s + L_r{'}\right)} \quad \ldots\ldots\ldots\ldots (2)$$

It suggests that, with a constant V/f ratio, motor develops a constant maximum torque except at low speeds. Motor therefore operates in constant torque mode.

The variable frequency control provides good transient and running performance because of following features.(i)Speed control and braking operation are available from zero speed to above base speed.(ii)During transients (starting, braking and speed reversal) the operation can be carried out at the maximum torque with reduced current giving good dynamic response.(iii)Copper losses are low, and efficiency and power factor are high as the operation is restricted between synchronous speed and maximum torque point at all frequencies.

III ROTARY KILN

A rotary kiln is a pyro processing device used to raise materials to a high temperature in a continuous process. Materials produced using rotary kilns include cement, lime, alumina, titanium dioxide etc. The kiln is a cylindrical vessel, inclined slightly to the horizontal, which is rotated slowly about its axis. The material to be processed is fed into the upper end of the cylinder. As the kiln rotates, material gradually moves down towards the lower end, and may undergo a certain amount of stirring and mixing. Hot gases pass along the kiln, sometimes in the same direction as the process material (co-current), but usually in the opposite direction (counter-current). The fuel for this may be gas, oil or pulverized coal.

Fig.1 Rotary Kiln

The kiln is usually turned by means of a single Girth Gear surrounding a cooler part of the kiln tube, but sometimes it is turned by driven rollers. The gear is connected through a gear train to a variable-speed electric motor. This must have high starting torque in order to start the kiln with a large eccentric load. A 6 x 60 m kiln requires around 800 kW to turn at 3 rpm. The speed of material flow through the kiln is proportional to rotation speed, and so a variable speed drive is needed in order to control this. These have the advantage of developing extremely high torque. In many processes, it is dangerous to allow a hot kiln to stand still if the drive power fails. Temperature differences between the top and bottom of the kiln may cause the kiln to warp, and refractory is damaged. This turns the kiln very slowly, but enough to prevent damage.

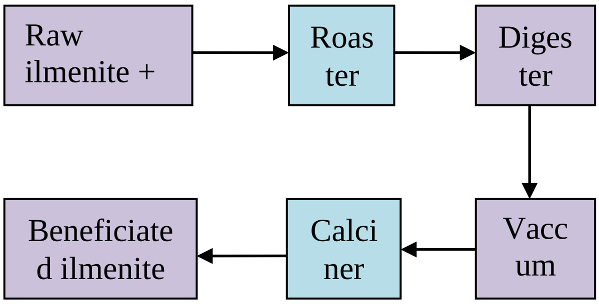


Fig.2 Block Diagram Representation of Roaster and Calciner Sections

Both Roaster and Calciner are rotary kilns used for the production of beneficiated ilmenite in the Ilmenite Beneficiation Plant (IBP). In Roaster, the raw ilmenite is reduced to remove the iron impurities and in Calciner leached ilmenite is converted to beneficiated ilmenite.

IV BRIEF DESCRIPTION OF PROCESS

A.ROASTER **:**The function of the Roaster is to reduce the Fe_2O_3 in the ilmenite to FeO. This is done by burning a mixture of ilmenite and lecofines (type of coke) in the Roaster, with furnace oil as fuel.Burning is done under reducing conditions with 100 -110% oil stoichiometric air, being supplied as combination air through the burner.Lecofines added to the ilmenite is to maintain reducing conditions in the Roaster.

A minimum 70% of the Fe_2O_3 in the feed is converted to Feo. The material is heated to 875–900ºC, then it is discharged into the Cooler. The reaction Fe_2O_3 to FeO is endothermic. In the Cooler, the reduced ilmenite is cooled down to 150ºC (max). Some amount of lecofines fed remainunburnt and are present in the form of carbonaceous matter, which is later burnt completely in the Calciner, after the ilmenite is leached.

The reducing condition to the maintained can be judged by an analysis of the exit gas.

$C + O_2 \longrightarrow CO_2$ (Exothermic)

$C + O_2 \longrightarrow 2CO$ (Endothermic)

$TiO_2 . FeO_3 / FeO + CO \longrightarrow TiO_2 . FeO + CO_2$

$Fe_2O_3 + CO \longrightarrow Fe_2O_3 + CO_2$

$TiO_2 . Fe_2O_3 / FeO + C \longrightarrow TiO_2 . FeO + CO$

$Fe_2O_3 + C$ (Direct Reaction) $\longrightarrow Fe_2O_3 + CO$

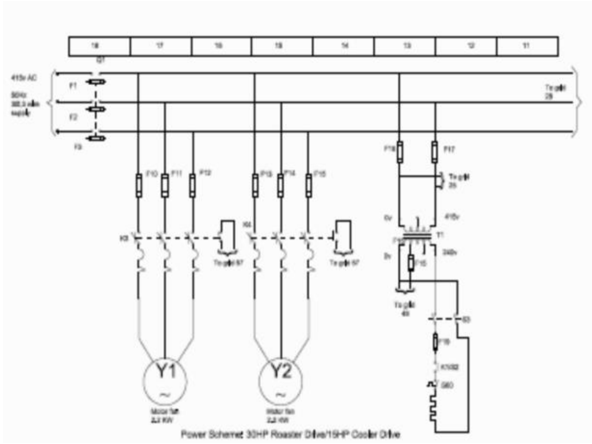
(IndirectReaction)

B.CALCINER : The Calciner is designed to calcine leached ilmenite wet cake from the belt fitter toremove moisture from leached ilmenite and to burn out any residual carbonaceous matter thatare carried by the roasted and leached ilmenite. The temperature to which the material is to be calcined is 850ºC. Then the Hcl and also the ferrous and Ferric chlorides are removed. The red hot beneficiated ilmenite is cooled in a counter current manner with air in the Rotary Cooler to a temperature of maximum 120º C. The waste gases from the Scrubber are then let out to the atmosphere by the exhaust gas fan through the Exhaust Stack.

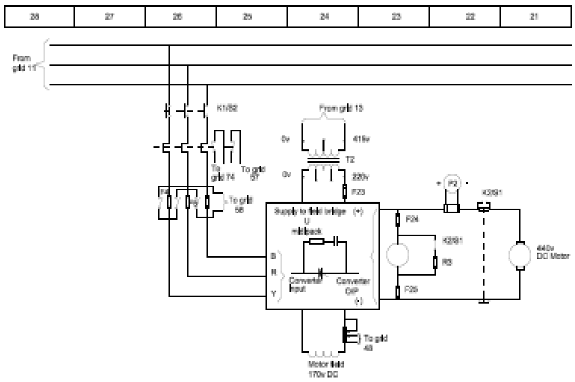
V DC MOTOR DRIVE SYSTEM

The main component of the system is the Midipack. The Midipack is a self-contained complete dc drive package with protection features, interlocking's and reference interfacing. The Midipack features either a 3 phase fully controlled bridge (SE) or two 3- phase fully controlled bridges connected in anti-parallel configuration (DE), complete with $\frac{dv}{dt}$ protection and transient over voltage suppression, for conversion of the incoming three phase ac supply into a steplessly controllable dc variable output voltage, suitable for dc motor speed control. Speed amplifier as the outer main loop nesting the current amplifier as the innerloop.These power packs have been designed for normal industrial application. However, due considerations must be paid to hostile environment condition which may cause premature failing/malfunctioning, and all efforts must be made to avoid these during receipt, storage, handling and installation.

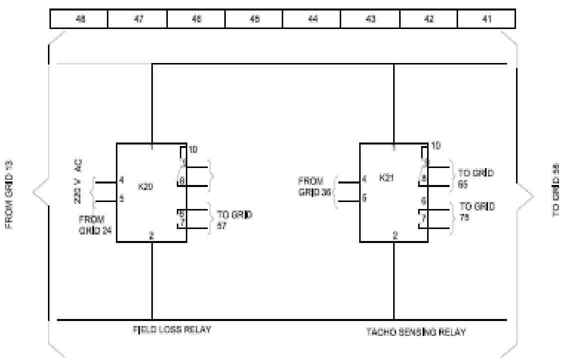
VI POWER SCHEME AND CONTROL SCHEME OF DC MOTOR DRIVE SYSTEM



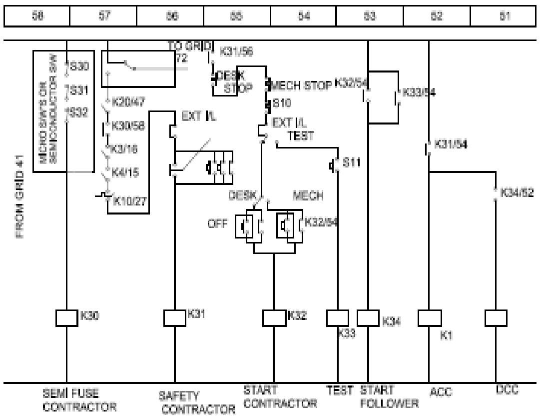
Three Phase supply is fed through switch fuse unit. . From the main three phase power bus, two numbers of 2.2 KW cooling motors are fed through power contactors K_4 and K_3 respectively. The 240V control supply for the thyristor panel is derived using the control transformer T_1.



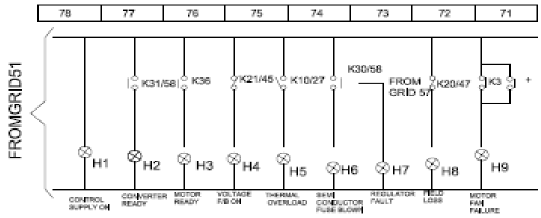
Three phase supply for thyristor converter is fed from the three phase bus through power contactor, thermal overload relay and semiconductor fuse. An alternate current supply of 220V is given to the midipack for rectifcation and feeding to the field winding of dc motor. Shunt(P_2) is used to measure the current to the armature of DC motor.



Field loss relay and Tacho relay are auxiliary relays, which sense the loss of power to the field winding and rotation of the motor shaft respectively.



Semiconductor fuse contactor K_{30} is provided to identify the healthiness of semiconductor fuse, provided in the control circuit. Safety contactor initiates the starting operation of the DC motor in both remote and local operations (desk and mechanical). A mechanical interlock is provided to inhibit the operation of both Start and Safety contactors at the same time is used to ensure the healthiness of control circuit. Start follower K_{34} is used to power up or energise the DC contactor K_2 feeding power to the armature of the DC motor. Stop push button from the local,remote and panel will be connected in series arrangement, where as the start from local and remote will be in parallel arrangement.



Numerous indication for identifying the status of motor and converter operations are provided in the panel.

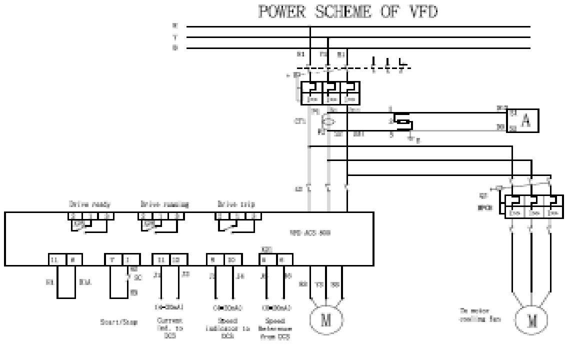
VII DEMERITS OF USING DC MOTORS

In industrial areas, the dc motor drive equipment's are not subjected to (i) Ambient operation temperature range beyond 0 to 65 degrees of the powerpack. (ii)Excessive dust, Sulphurous/corrosive fumes, other corrosive chemicals, metallic dust suspended in finely vaporised oil etc. (iii) High frequency signals as might be generated by capacitive current breaking or by inductive current breaking as a part of or in the vicinity of the electronic control circuit of the powerpack. (iv)These drives cannot be operating in explosive and hazard conditions.

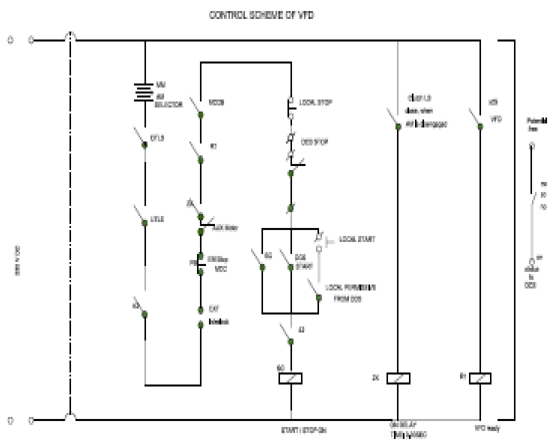
VIII VFD SELECTION

The squirrel cage motor has a number of advantages over a dc motor. Because of the absence of commutator and brushes, it requires practically no maintenance, it can be operated in an explosive and contaminated environment and can be designed for higher speeds, voltage and power ratings. It also has lower inertia, volume and weight. Though the cost of a squirrel cage motor is much lower compared to that of a dc motor of the same rating, the overall cost of the variable frequency induction motor drives, in general are higher. But because of the above advantages variable frequency drives are preferred over dc motors for most applications.

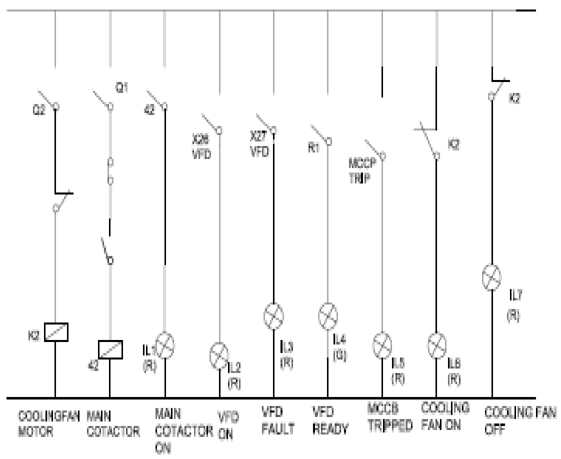
IX POWER AND CONTROL SCHEME OF VFD



Power to ABB make ACCS 800 VFD is supplied through MCCB, Q_1 and power contactor 42 from the three phase power distribution bus. Current transformer CT_1 is provided for metering the current at input side of VFD. Cooling fan motor for the kiln main drive is energized through MPCB, Q_2 and power contactor K_2. Drive Ready, Drive Running and Drive Trip indications are wired from terminal block X_{25}, X_{26} and X_{27} internal relay contacts of the VFD. Drive START/STOP is achieved through NO contact of start contactor SC. Two no's: of analog inputs and one no: of analog input are used for controlling the VFD.



Control used for controlling the VFD operation is 230V AC. For energizing the Start contactor SC, a sequential of interlocks such as Travel limit switches of kiln , Auxilory Motor(AM) or Main Motor(MM) selector switch, cooling fan motor power contactor interlock, MCCB ON interlock , AM ON interlock, push button stop interlock. NO contact of SC is used for holding the Start contactor after initial starting. Contact for permitting start operation from field is also interlocked in the circuit. SC contactor energizes only when the input contactor 42 is switched on. Relay R_1 is used for contact multiplication.



Main contactor 42 is energized only when the MCCB, Q_1 is switched on and cooling fan motor contactor K_2 energized. Several indications showing the status of VFD and equipment's are wired through their respective control contacts.

X DISTRIBUTED CONTROL SYSTEM:

Controllers: Most industrial processes require certain variables, such as flow, temperature, pressure and level that remain at or near some reference value, called set point. The controller looks at a signal that represents the actual value of the process variable, compares this signal to the set point and acts on the process to minimize any difference between these two signals. Here, control action is distributed and monitoring action is centralized. The benefit of digital control application can include**:** (i) Control function is distributed among multiple CPUs (Field Control Stations). Hence failure of one FCS does not affect the entire plant. (ii) Redundancy is available at various levels. (iii) Instruments and interlocks are created by software. (iv)Generation and modifications of the interlocks are very simple. (v) Information regarding the process is presented to the user in a simplified way. (vi)Field wiring is considerably less. (vii)Maintenance and troubleshooting becomes very easy. (viii) Cost effective in the long run.

XIDCS COMPONENTS

The two important stations of DCS are (i) Human Interface Station (HIS). (ii) Field Control Station (FCS).Human Interface Station (HIS)**:** The HIS is mainly used for operation and monitoring purposes. It displays process variables, control parameters, and alarms necessary for the users to quickly grasp the operating status of the plant. The operator station is based on Windows XP or Windows 2000 (Both are selectable).Field Control Station (FCS):The FCS controls the plant. This is the component where all the control functions are executed and hence it is a very important and critical component in the overall system.

Fig.3: Field Control Station

Here, control action is distributed and monitoring action is centralized.

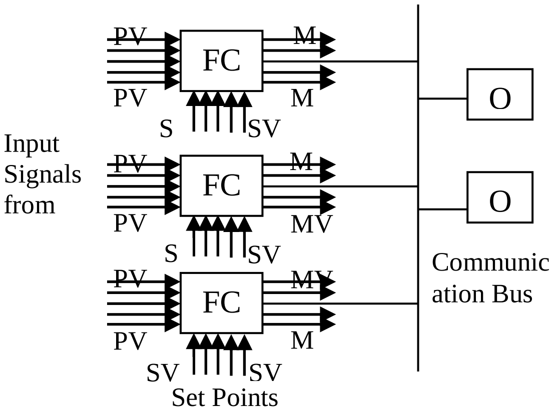


Fig.12.2: Distributed Control System

XII DCS HARDWARE

A.SYSTEM CABINET

All circuitary concerned with DCS systems can be arranged within Cabinets, placed in air conditioned room. Each Cabinet can be opened from both sides. So each Cabinet have front and rear sides. The first Cabinet is named System cabinet. The Processor lies within this Cabinet. There are two Processors. One for redundancy ie; if one of the Processors fails, then the other will function and the system will not be disturbed.

System Cabinet also contains Communication Cards, both Analog and Digital. For each Card there are 32 channels. System Cabinet comprises of nodes, which in turn contains the slots and the Cards are inserted into these slots. A node interface unit (NIU) is used for transferring all data from several nodes to FCS (processor). Data from nodes are transferred to FCS through RIO bus. There are two RIO buses. One is meant for redundancy. From FCS data is transferred to HIS (Human Interface Stations) through ethernet cables. Human Interface Stations may be Engineering Station, Operating Station or View Station.

a. Engineering Station: Modifications within the system if any are done in Engineering Station. Engineering Stations are handled by authorized persons and are protected by password.
b. Operating Station: By means of this Station, Operator controls the equipments within various plants. Here manipulation of system is not possible.
c. View Station: Here no manipulation and operation is possible. Only viewing is possible.

B ANALOG MARSHALLING CABINET

All analog signals such as current, voltage etc (both input & output) are terminated in Analog Marshalling Cabinet. Transmitters connected with equipments in the field will be terminated in junction box. From junction box, multi core cables are drawn to terminal block on rear side of Analog Marshalling Cabinet. For the working of the circuitry within Analog Marshalling Cabinet, power supply is received from Power Distribution Cabinet.

C DIGITAL MARSHALLING CABINET

Digital input and output signals are handled by this Cabinet. There are mainly two Cabinets.

(i)DIGITAL INPUT MARSHALLING CABINET

Digital input signals are handled by Digital Input Marshalling Cabinet. Digital input signals include motor run feedback signals, output from pressure switches, level switches contacts etc. Digital input signals are terminated in the terminal block in the front side of the Digital Input Marshalling Cabinet..

(ii) DIGITAL OUTPUT MARSHALLING CABINET

Digital output signals like DCS START, DCS STOP, DCS SELECTOR (R/L) signals are handled by this unit. From MCC, connections are given to terminals blocks on rear side (RZ) of the Cabinet through multi core cables. These cables are used for transmitting the digital output signals. From the terminal blocks connections go to the 32 channel relay board (YB board) on front side of the Cabinet. The relay board consists of very small relays. From the relay board, connections are given to DO card of System Cabinet through prefab cables. For redundancy two set of prefab cables are used. For each of the digital output signal there will be a specific relay.

There will be three relays for a specific motor.
(a)START (b) STOP (c) REMOTE/LOCAL SELECTION

D POWER DISTRIBUTION CABINET

Its function is to distribute power to various modules in DCS for their working. It has two sides, a front side and a rear side. At the front side incoming 110V ac supply is taken from the UPS. Then the phase and neutral of this supply is given to a breaker. Then the phase taken out from the breaker is given to the phase bus bar and the neutral taken out from the breaker is given to neutral bus bar. The out from the individual breaker is given to front side terminal block (FZ). From this terminal block connections are taken and given to the modules wherever 110V ac is necessary.

At the rear side of Power Distribution Cabinet 110V ac is converted into 24V dc and it is supplied to those modules which need 24V dc for their working. At first the phase and neutral wire of 110V ac is given to a power supply unit. This power supply unit converts the 110V ac into 24V dc. The positive terminal of 24V dc taken from the out of power supply unit is given to positive bus bar and negative terminal is connected to negative bus bar.

XIII AUTOMATION OF ROTARY KILNS

START / STOP Operation and REMOTE / LOCAL selection fromDCS:The START and STOP operation of the motor can be performed either from the field or from the DCS. Hence a selection for REMOTE / LOCAL operation is required. This selection is done from the DCS. We can START and STOP the motor from the field only when the selection from the DCS is in LOCAL mode. For a specific motor (drive), there will be three relays. (i) START (ii) STOP (iii) REMOTE / LOCAL SELECTION.

START / STOP OPERATION FROM DCS:We can give the START / STOP command from the PC provided in the Engineering Station. This digital output signal is transferred to the Digital Output Card in the System Cabinet. The System Cabinet contains FCS and Communication Cards (Digital Input Card, Digital Output Card and Analog Input/Output Card). Inside the System Cabinet, the Communication Cards are connected through the communication cables called Extended Serial Bus (ESB cables).

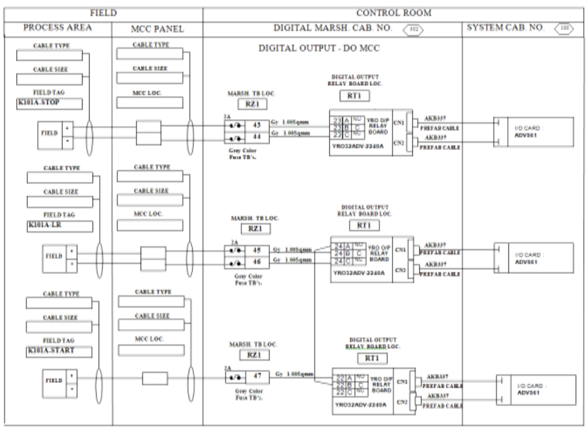


Fig.4: START / STOP Operation andREMOTE / LOCAL Selection

The Digital Output Marshalling Cabinet comprises of 32 channel relay boards. The relay board contains Micro relays. Each relay has two type of contacts viz Normally Closed (NC), and Normally Open (NO). Once the START / STOP command reaches the relay board, the relay specified for START / STOP operation gets energized. For stopping the motor, the stop relay at DCS has to be actuated and this leads to power outage to the equipment.

REMOTE / LOCAL SELECTION :REMOTE / LOCAL selection can be done from the DCS. A relay is provided for this selection. In the Engineering station, the required selection can be made. From there, the signal is transferred to the Digital Output Card in the System Cabinet. As in the case of START / STOP operation a particular relay is allocated for REMOTE / LOCAL operation among the microrelays in the relay board. When selected for remote operation, the relay specified for REMOTE / LOCAL selection gets energized and then the drive gets ready to be operated from DCS. The interface between DCS and VFD Panel is made up using the same multi core control cables used for START / STOP operation. This is how the REMOTE / LOCAL selection is done from the DCS.

The logic for START, STOP and REMOTE / LOCAL selection can be created in the DCS graphics using logic gates, control blocks and function blocks provided in the software.

XIV SPEED CONTROL FROM DCS

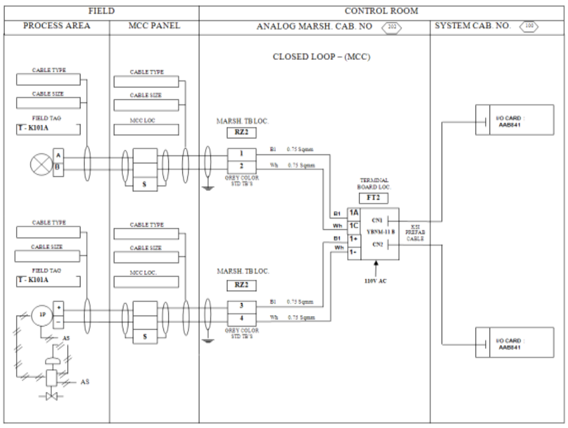


Fig.5: Speed Control from DCS

(a) Manual Mode**:** We can increase or decrease the speed to maintain a constant speed manually. Here there will be no reference speed.(b) Auto Mode**:** In this mode, irrespective of the variations in load, the speed has to be maintained constant.(c) Cascade Mode**:** In this mode, the operation of another equipment determines the speed variation of the required equipment. i.e., interlocking action. If the speed of the first equipment falls, then the second equipment speed should also come down. This action can be achieved in Cascade mode. All these speed variation operation output is given to the Analog Input/output Card and finally it reaches the VFD. (d) Speed Feedback**:** The output of VFD (Run Feedback Signal) is transmitted to the rear end of Analog Marshelling Cabinet at DCS through control cables from MCC to DCS.

XV RESULTS

A Performance of VFD

Table 1 : Motor Speed, Kiln Speed and Gear Ratio

Equipment Name	**Motor rpm**	**Gear Ratio**	**Gear Output rpm**	**Girth Gear Ratio**	**Kiln rpm**
Roaster	1475	1/64	23.03	1/483	0.2 - 3
Roaster Cooler	1473	1/62	23.80	1/173	0.2 – 8
Calciner	1478	1/64	23.03	1/483	0.2 – 3
Calciner Cooler	1473	1/56	26.40	1/480	1.2– 3

B Readings of Roaster Main Drive

Time	**Frequency (Hz)**	**Current (A)**	**Power (%)**	**Torque (%)**	**Reference Speed (rpm)**
9.00 A.M	14.10	38.57	10.01	38.12	415.81
10.00 A.M	14.11	39.71	10.77	38.29	415.90
11.00 A.M	14.90	38.12	10.52	38.92	415.21
12.00 P.M	14.12	40.53	12.51	44.35	414.92
1.00 P.M	14.10	42.33	12.60	45.00	415.30
2.00 P.M	14.13	42.52	12.55	43.60	415.63

Table.2: VFD Readings

These readings are taken when the feed rate is 6.5 tones per hour. As the feed rate changes, the speed of the kiln needs to be varied proportionally.

XVI CONCLUSION

In India, it is more considerable about the cost of any product. Since we have energy crisis, we have more energy consumption than generation. So energy conservation is more important for developing country. In this project, we can make a conclusion that for hazardous industries like Titanium industries, speed control of DC motor is not applicable. With the installation of two more ac drives in the Roaster and Calciner sections each, the production has increased and so the targeted production can be achieved.

The Distributed Control System controls and enhances the production process scattered over different units and safe operation of plant. DCS's are designed with reluctant processors to enhance the reliability of the control system.

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