ENERGY SAVING IN AIR SUPPLY UNIT BY IMPLEMENTING VARIABLE FREQUENCY DRIVE.

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ABSTRACT

In Air Supply application required variable flow control of air. In the traditional method of such flow control, induction motor is run at full speed and then control the flow by damper control method. But this method has few drawbacks i.e. limited adjustment of flow; it increases the resistance to flow, not energy efficient method. As per the fan affinity law where the load torque and power vary with the square and cube, respectively of the speed. So Air Supply Unit can save energy when they are operated at variable speed operation, by implementing variable frequency drive. Such energy saving method is used in variable torque centrifugal fan application, where the load torque and power vary with the square and cube, respectively of the speed. This change gives a large power reduction compared to fixed speed operation for a relatively small reduction in speed. Also by Using a variable frequency drive to control the air flow with a fully open damper saves a considerable amount of power. As most of the drives operate at part load most of the time, the accumulated energy saving may be substantial over a prolonged period of time. Because this type of air flow control is common in industry, widespread application of variable-frequency drives with power electronics area can help in large energy conservation. The main propose of this paper is to save the energy in air supply unit by the implementation of VFD and hence the proper control of air flows is achieve.

Keywords- *Variable frequency drive1, Adjustable speed drive2, Variable voltage variable frequency drive3, Energy conservation4, Affinity law5*

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1. INTRODUCTION

There has been an enormous increase in the global demand for energy in recent years as a result of industrial development and population growth. Since, our conventional sources of energy or fossil fuels are running short; it is now the cry of the day to work harder for the development, improvement and up gradation of renewable sources of energy with protection, conservation and existing conventional sources. The reduction in the amount of energy consumed in a process or system, or by an organization or society through economy and elimination of wastage is called as energy conservation.

Energy conservation is necessary because with the ever increasing demand, need for electrical power can only be meet by conserving electrical power in addition to installation of new generating units. A major proportion of electrical power in a plant is consumed by electrical derives. Significant amount of electrical energy can be saved by the use of efficient and rigid type of electrical drives. Variable frequency drive is one of the many well-known energy efficient drives.

The growing popularity of variable frequency drives is due to its ability to control the speed of induction motors. Induction motors are the most commonly used in industries. Traditionally, an induction motor is used for constant speed and constant torque applications and when variable speed or torque is required, a DC motor or wound ac motor is used. But now AC induction motors with Variable Frequency Drives are used for variable speed applications. Such drives reduce the energy consumption of motors and increase the energy efficiency of plants.

Energy conservation is necessary because increasing demand, need for electrical power can only be meet by conserving electrical power in addition to installation of new generating units. Variable frequency drive is applicable for the air flow control to air supply unit(ASU). ASU is used in industries for ventilation purpose or maintain temperature and humidity on the shop floor. At present, the air flow is controlled by a damper control mechanism associated with constant speed induction motor. The replacement of damper control mechanism by means of a variable frequency drive or variable speed drive reduces the energy consumption of motor. A variable-frequency drive is a system for controlling the rotational speed of an alternating current electric motor by controlling the frequency of the electrical power supplied to the motor. It is a specific type of adjustable-speed drive.

Variable-frequency motors on fans save energy by allowing the volume of air moved to match the system demand. In variable speed applications, power required varies roughly with the cube of the speed. This is referred to as the "Affinity laws", which define the relationships between speed and power. The implementation of Variable Frequency Drive helps the ASU to save about 23% of electrical energy consumption.

ASU is nothing but a centrifugal fan driven by high power three phase induction motor. Fans generate a pressure to move air against a resistance caused by ducts, dampers, or other components in a fan system. The fan rotor receives energy from a rotating shaft and transmits it to the air.

Fig-1 ASU Centrifugal Fan and Motor.

A variable frequency drive (VFD) is a type of adjustable speed drive used to control the rotational speed of an alternating current electric motor by adjusting the frequency and voltage applied to the motor. Although ASU can generally operate at velocities less than the maximum design speed, motors typically drive ASU at a constant rate. A variable frequency drive provides a more efficient way to control varying flow rates and pressures.

1.1 Benefits of using VFD.

The use of variable frequency drive control offers several advantages. The most significant benefit is potential to reduce electrical energy consumption, reduce demand from motor-driven processes, smooth starting, reduces starting current, reduces the wear and tear, increase the life of motor.

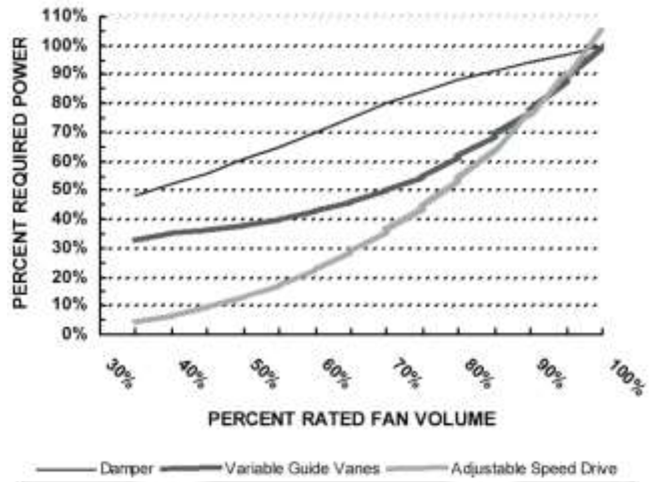

Fig-2 Comparison of Various Volume Control Methods.

Comparison of various volume control methods with respect to power consumption (%) required power is shown in Fig.no.2. Fig. 2 compares the relative power requirements of a fan at different flow rates, using three types of throttling control: outlet damper control, variable inlet vane control, and VFD control. Although VFDs save far more energy than throttling, the technology has not yet achieved widespread adoption.

Variable frequency drives also have the potential to reduce system maintenance and related costs. Control with a VFD affords the capability to "soft start" a motor, which means the motor, can be brought up to its running speed slowly rather than abruptly starting and stopping. Similarly, running the motor at lower speeds extends the lifetime of other equipment components, including shafts and bearings.

In addition to enabling precise speed control of ASU is possible, air flow is accurately controlled. Hence the implementation of VFD improves the power factor of the system. In addition to this VFD provides good dynamic response. This can be achieved by rapid adjustment of speed, torque and power and hence gives better control in high speed applications.

The other advantage of VFD is that it is possible to interface VFDs to wider process control systems such as supervisory control and data acquisition (SCADA) systems and building management systems (BMS). Hence VFD is able to compute intelligence and communication systems.

2. ENERGY SAVING PRINCIPLE IN ASU.

Fans law:

The fans operate under a predictable set of laws concerning speed, power and pressure. A change in speed (RPM) of any fan will predictably change the pressure rise and power necessary to operate it at the new RPM.
i) Flow is directly proportional to speed;

$$\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$$

ii) Torque required is proportional to speed squared;

$$\frac{T_1}{T_2} = \left(\frac{N_1}{N_2}\right)^2$$

iii) Power is proportional to the cube of the shaft speed;

$$\frac{P_1}{P_2} = \left(\frac{N_1}{N_2}\right)^3$$

As per the law small reduction in speed, power requirement is highly reduced. Normally if speed is reduced by 10%, decreases power requirement by 27% & decrease 19% static pressure.

Most AC equipment is designed to perform during peak load. These loads occur rarely during the operating year. To control flow during off-max load conditions, flow control devices such as dampers, valves, inlet guide vanes and bypass systems are used. These devices are effective but not energy efficient. Using VFD varies the speed of fans and pumps, referred to as the "fans laws", allows the ASU to meet the partial load requirement and save energy.

2.1 Energy saving as per fans law.

The potential of energy savings from installing a VFD is illustrated by the following. ASU motor rating in industry is 125hp/ 90 kW motor that drives a centrifugal fan. No any provision for speed control. The fan operates at full speed for 12 hours for each day. The operational cost is calculated with the following formula:

$$\text{cost per day} = \text{Motor kW} \times \text{running time} \times \text{cost per kw}$$

If there is no VFD motor run at 100% speed. Cost per kWh is 8 Rs.

Then,

$$\text{cost per day} = 90 \times 12 \times 8 \text{ Rs.}$$
$$= 8640 \text{ Rs.}$$

Power and speed relation:

$$\frac{\text{Kw1}}{\text{Kw2}} = \left(\frac{\text{N1}}{\text{N2}}\right)^3$$

Where kW= Power, N=Speed in rpm

Reading of ASU motor at 50 Hz frequency:

Table -1 Reading of motor

V_{ph}	V_L	I_L	Power	Freq.	Speed
V	V	A	kW	Hz	Rpm
239	416	107	63	50	1490

Find the slip of motor,

$$\text{Ns} = \frac{120\text{f}}{\text{p}} = \frac{120 \times 50}{4} = 1500 \text{ rpm}$$

$$\text{Sl} = \frac{\text{Ns} - \text{Nr}}{\text{Ns}} = \frac{1500 - 1490}{1500} \times 100 = 0.66\%$$

If frequency is reduced 45 Hz,

So, Ns=Synchronous speed $= \frac{120\text{f}}{\text{p}} = \frac{120 \times 45}{4} = 1350$ rpm

Assume slip is constant 0.66%=0.006

Find Nr at 45 Hz freq.

$$\text{Nr} = \text{Ns} - (\text{Sl} \times \text{Ns}) = 1350 - (0.006 \times 1350) = 1341 \text{ rpm}$$

As per fans law,kW1=63, N1=1490, N2=1341, find kW2=?

$$\text{kW2} = \frac{\text{kW1} \times (\text{N2}^3)}{(\text{N1}^3)} = \frac{63 \times 1341^3}{1500^3} = 45.01 \text{ kW}$$

Power requirement is 45 kW at 45 Hz frq.

Reduction in power requirement =63-45.01=17.98 kW

As pre above example calculated energy saving for different frequency & speed.

Table-2 Energy and cost saving.

Sr. No.	Freq. (Hz)	Ns (rpm)	Nr (rpm)	Required Power (kW)	Save power (kW)
1	50	1500	1490	63	0
2	45	1350	1341	45.01	17.98
3	40	1200	1192	32.25	30.75
4	35	1050	1043	21.60	41.4
5	30	900	894	13.60	49.4
6	25	750	745	7.875	55.125
7	20	600	596	4.032	58.968

3. WORKING OF VFD:

AC supply applied to the stator windings it produces a rotating magnetic field that rotates at synchronous speed. i.e. $N_s = \frac{120\,f}{p}$, Where N_S is synchronous speed, f= supply frequency, p = no. of stator pole. So speed control of induction motor is depends on frequency and no. of stator pole. A no. poles are fixed so speed control is performed by adjusting the supply frequency. For the adjusting frequency variable frequency drive (VFD) is used. VFDs convert the fixed-frequency supply voltage to a continuously variable frequency, thereby allowing adjustable motor speed. When the frequency applied to an induction motor is reduced, the applied voltage must also be reduced to limit the current drawn by the motor at reduced frequencies. Variable speed AC drives will maintain a constant volts/hertz relationship from 0-50 Hertz. Constant v/f ratio makes the torque and air gap flux constant. VFDs convert the fixed-frequency supply voltage to a continuously variable frequency, thereby allowing adjustable motor speed. The conversion process is works in three stages:

Rectifier stage: A full-wave uncontrolled three- phase converter supplied from a standard 50Hz 440v, utility supply to convert fixed 580v DC voltage.

Inverter stag**e:** Electronic switches (IGBT/MOSFET) rectified DC on and off, and produce a current or voltage waveform at the desired new frequency.

Control circuit: An electronic circuit receives feedback information from the driven motor and adjusts the output voltage and frequency to the selected values. Output voltage is regulated to produce a constant ratio of voltage to frequency (V/Hz). Converting fixed DC supply to variable frequency AC supply is achieved using an inverter. Pulse width modulation (PWM) is mostly used in currently available inverter because the output current waveform is approximates close to sine wave.

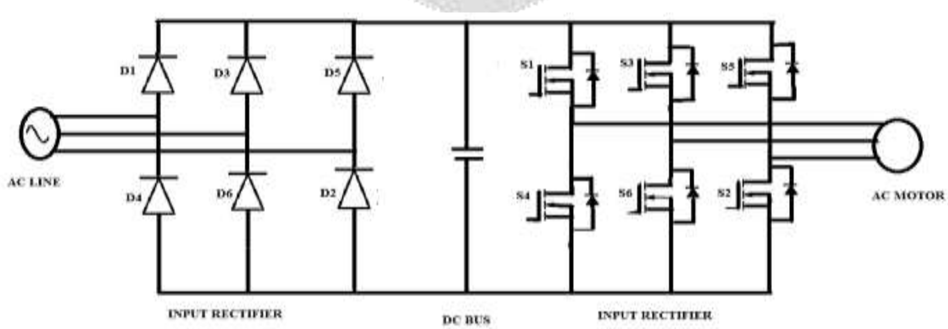

Fig-3 VFD power circuit.

5. SIMULATION RESULTS:

Simulation result of the VFD fed induction motor is done by Matlab simulink and the results are presented. The induction motor is fed by voltage source PWM inverter. The speed control loop uses a proportional-integral controller. IGBT is used as controlled switch. Constant V/F ratio method is used for the speed control of induction motor.

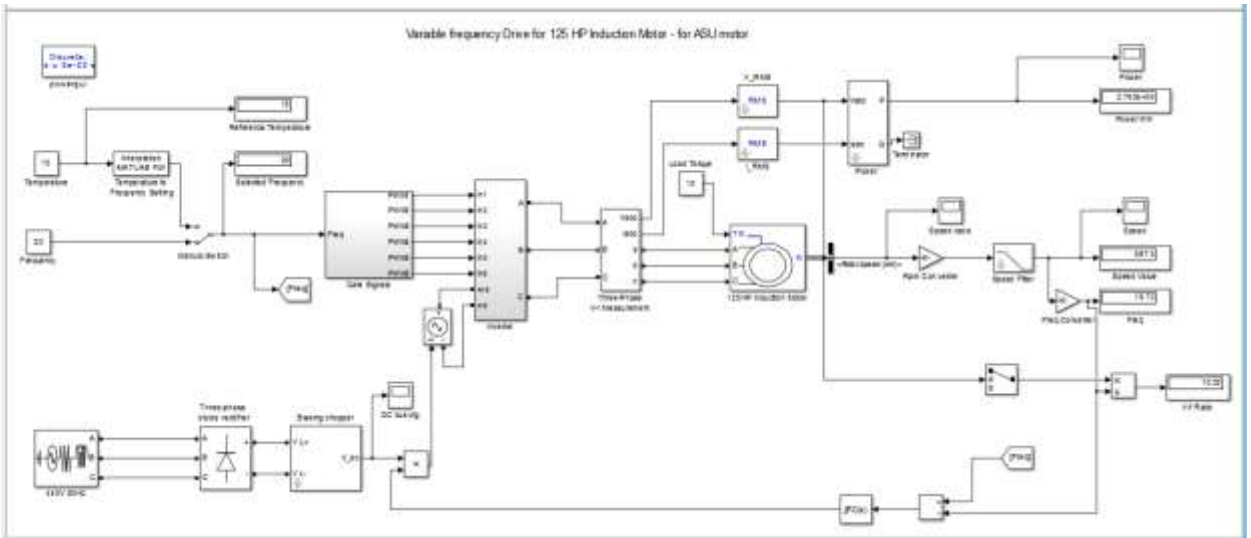

Fig-5 Matlab simulation of 90kW Induction Motor control

The circuit diagram for V/F speed control of Induction Motor using VFD is shown in Fig. . The specifications used for simulation are phase-phase (rms) voltage = 415V, input line frequency=50Hz, the induction motor machine parameter is about 125 hp (90kw), 415V, 50 Hz, 1495 rpm and 65 Nm.

The gating signals are shown in Fig. shows the simulation result for the applied frequency is about 50 Hz. Here 120 degree mode of conduction is applied. In this type of control, each switch conducts for 120°. Only two switches remain on at any instant of time. The conduction sequence of switches is 6-1, 1-2, 2-3, 3-4, 4-5, 5-6, & 6-1.

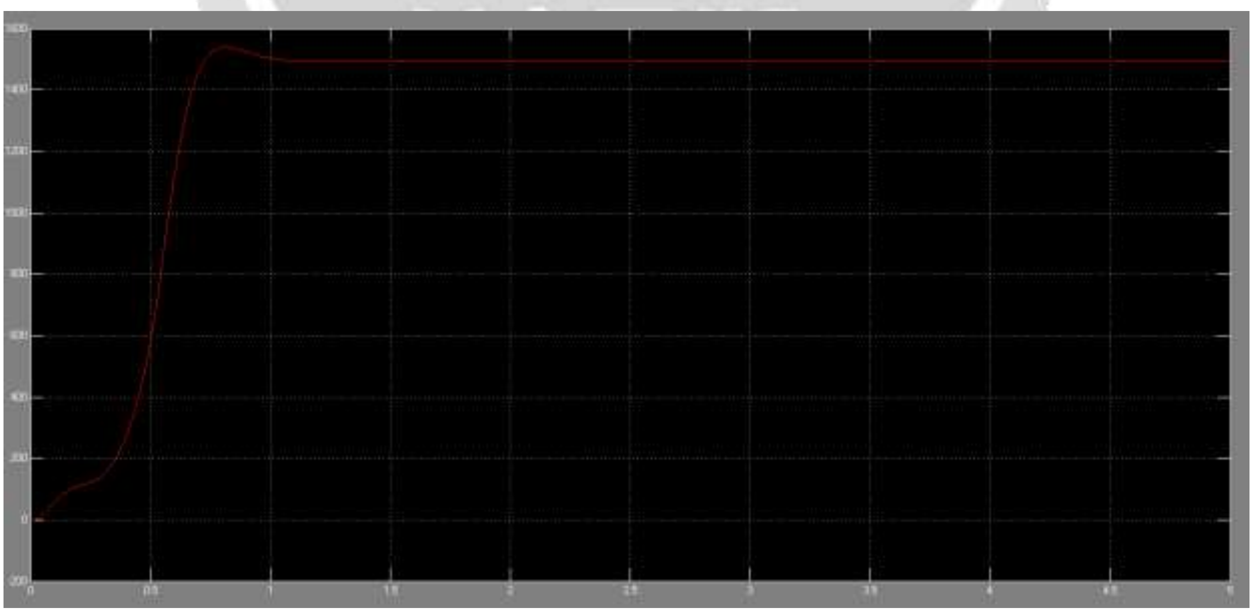

Fig-6 Speed vs Time graph at 50 Hz, 415 v supply.

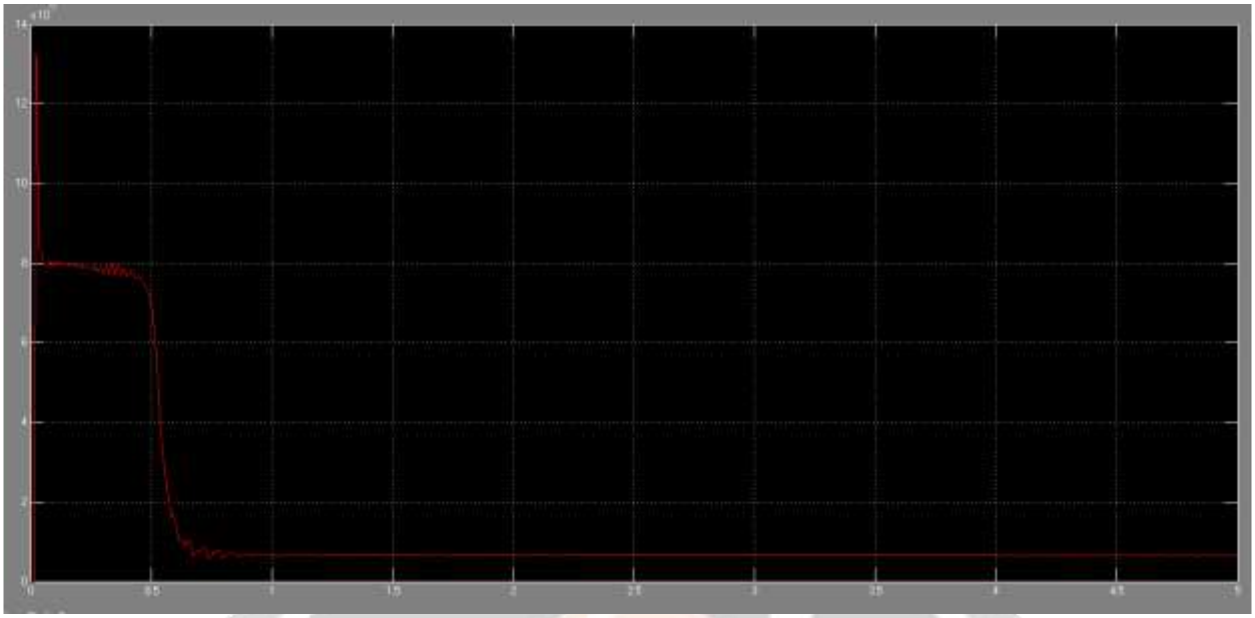

Fig-7 Power vs time graph at 50 Hz supply.

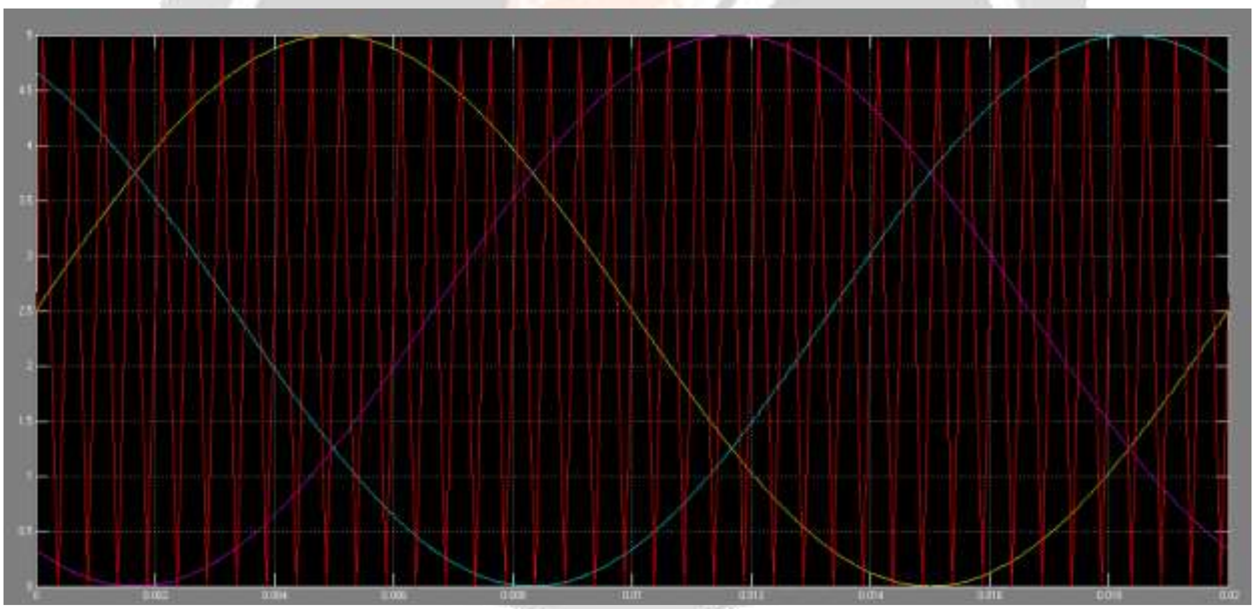

Fig-8 SPWM inverter gating signal.

Motor rating is taken 125 hp/ 90kW, given supply frequency is 50 Hz figure shows the speed and power. The above fig a& b represents the speed and the power waveform of the three phase induction motor respectively. The frequency given to the motor is about 50 Hz. Hence the time period will be T=1/50 = 2ms. When supplying this frequency, in accordance with the motor specifications, the motor is assumed to be held constant at 1495 rpm and the power consumption is nearly about 63 kW.

Table-3 Simulation Result

Sr. No.	Freq.(Hz)	Speed(rpm)	Power(kW)
1.	50	1497	63.7
2.	45	1345	54.7
3.	40	1195	48.2
4.	35	1045	23.0
5.	30	895	20.45

6. HARDWARE IMPLEMENTATION

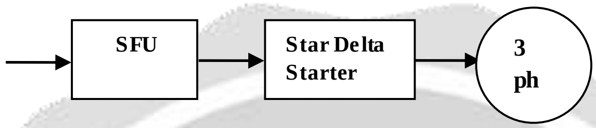

Fig-9 Existing ASU system

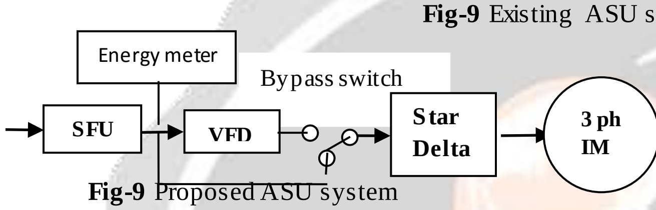

Fig-9 Proposed ASU system

6.1 Power Circuit Diagram

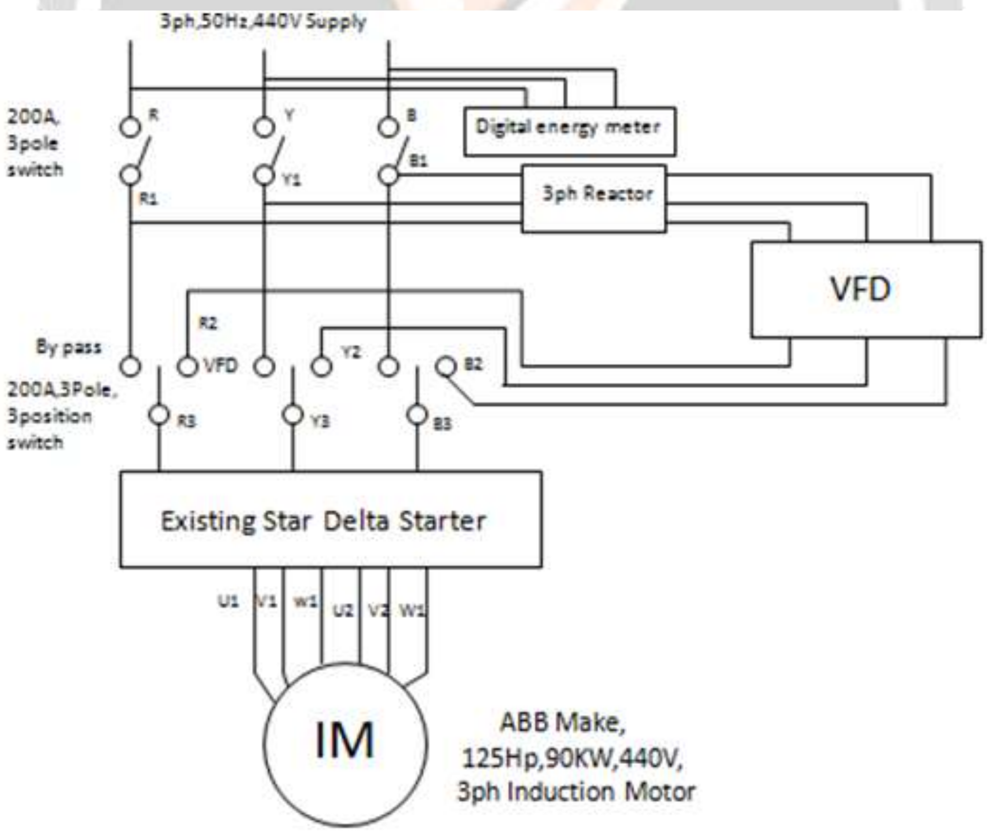

Fig-10 power circuit diagram

VFD Selected: Mitsubishi FR-F740-00770-EC 90kW.

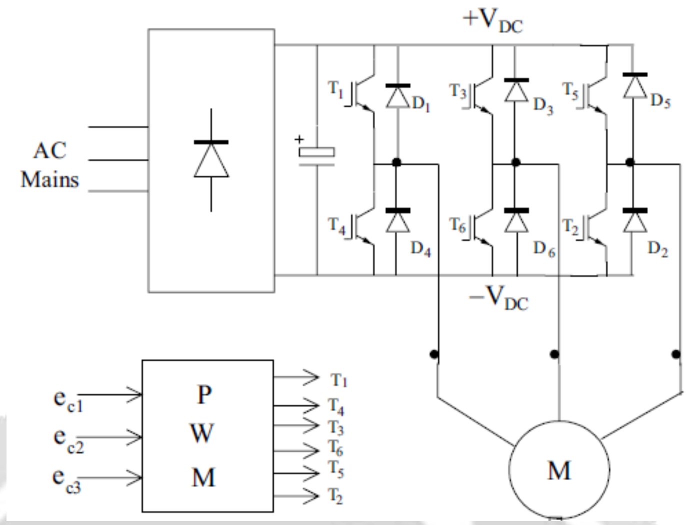

Fig-11 VFD circuit

Three Phase Uncontrolled rectifier is used for AC to DC converter. Motor rated current is 157 Amp. So safety factor (1.5) is taking in consideration, requirement of diode current is 250 amp and voltage 1200 v.

Power Diode selected: Mitsubishi Diode Modules, Rm250/dz -24, High power general use, Insulated type.

IGBT selected: Mitsubishi IGBT Modules, CM300DY-24A, CM- IGBT, 300- max collector current, D- Dual IGBT or One leg, Y- connection, 24- Max gate emitter voltage

Line reactor selected: 3% Impedance Line Reactors, 220 Amp, 90 kW, 3ph, Choke, 0.105 mh, make- raj electrical products.

Micro Processor Selected: NEC Japan make, V850E/ME2, 32-Bit Microprocessor Core.

Controller card no. BC186A750G59 Mitsubishi 53B4H

Firing card no. BC186A73OG52.

Fig-12 VFD Panel

Fig-13 VFD used

6.2 Hardware Circuit Result:

Table.4 ASU hardware readings

Sr.no.	Freq.	Speed (rpm)	Power kW	Power save	V_{ph}	V_L	I_L	Total Volume (m^3/s)
1	50	1490	63	0	239	418	105	255
2	45	1340	47	16	240	417	67	207.48
3	40	1215	35	28	242	420	50	192.5
4	35	1026	22.27	40.73	243	422	31.5	170
5	30	874	13.75	49.25	243	424	20.9	156
6	25	759	9.7	53.3	244	425	14.4	130
7	20	606	5.3	57.7	244	428	8.1	97.5

ASU run 12 hours per day. All the time in a day air requirement is not same it varies with temperature. If ASU run 25% time on each speed 50, 45, 40 & 35Hz frequency.

$$\text{So energy saving per day} = (0 \times 3) + (16 \times 3) + (28 \times 3) + (40.73 \times 3) = 254.19\ kWh$$

Energy charge is 8 Rs per kWh, then cost saving per day is 2033.52 Rs.

Cost of VFD installation is Rs.4 lakh, so simple payback period is 7.9 months (avg. 25 working days in month).

7. CONCLUSION:

In this paper it is found that, as per requirement the speed control of ASU using VFD can save energy according to fans (affinity) law. According to this a small reduction in speed can save a large amount of energy. So the cost saving is large and Payback period is small. Apart from speed control and energy savings, the uses of VFD provide soft start, reduction in starting current, reduce tear and wear and increases the life of motor. This method gives infinite variability in speed and performance of the ASU can be predicted.

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