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Improving the Efficiency of Auxiliary Cooling Water Pump and Auxiliary Sea Water Booster Pump in Thermal Plant using Variable Frequency Drive

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Abstract*: Thermal power stations are one of the main source of electricity in India. In Thermal Plant Existing Auxiliary Cooling Water Pumps(ACW) and Auxiliary Sea Water Booster Pumps(ASWB) maintain constant water flow rate Irrespective of the cooling required (cooling required will be more during hot summer and is less during Winter). Our Project aims to Control the Water Flow rates of Auxiliary Cooling Water Pumps(ACW) and Auxiliary Sea Water Booster Pumps(ASWB) according to the Cooling required. PID controller can be used to control motor speed that lead to reduce the energy consumption. The main aim of this modelling is to reduce the energy consumption according to the environment temperature degree by the implementation of Variable Frequency Drive (VFD) and hence the proper control of fluid flows.

Keywords: Auxiliary Cooling Water Pumps(ACW); Auxiliary Sea Water Booster Pumps(ASWB); PID Controller; Variable Frequency Drive(VFD) ; Flow Control;

I. INTRODUCTION

We Examined the North Chennai Thermal Power Station (NCTPS) Stage-I and we observed that, the cooling water systems are usually designed with full capacity flow rate to cope with the all possible situation where the machinery is running at full load. Because of this the majority of cooling systems are oversized in relation to the actual requirements. If one can measure the actual requirement and regulate the pump's pressure or flow so that it matches the current requirement, the pump will use less energy and this therefore, does not need to be produced on board, with less fuel being consumed as a result. About a third of the world's electrical energy is consumed by electric motors in fixed-speed centrifugal pump, fan and compressor applications. The processes, in the form of liquid or gas flow, are typically driven by large electric motors with the power demand following affinity laws. Pumps are devices that deliver a pressure increase to liquid and it’s a largest consumer of energy in the industrial sector. The pump provides the energy necessary to drive the fluid (water) through the system and overcome friction and any elevation difference.

Driving the pumps with fixed speed motors and controlling them at partial loads either by throttling or mechanically by fluid coupling decreases the power plant’s efficiency tremendously. When large flows must be controlled and motor energy consumption is significant, varying the motor’s speed is the answer. In order to reduce maintenance costs and further improve the plant ‘s efficiency, the pump drive systems were upgraded with a variable speed converter (VFC) system or called a variable frequency drive (VFD). Controlling pumps by adjusting speed avoid wasting energy. Variable speed drives in a pump system are now a mature technology, which can generate large benefits to the user in cost savings and reliability improvements, in the right applications. Pump’s drive means a sequence of energy conversions from electrical input power to mechanical output power and then to hydraulic power (figure 1). Each conversion is described by his specific equations and reference frames. [1,2,3,4,5,6]

The theory of operation of pumps can be characterized by the affinity laws:

A. Liquid flow is linearly proportional to the pump speed (equ.1)
B. Head changes with square of the ratio of speed (equ.2)
C. Power demand changes with cubic of the ratio of speed (equ.3).

$$\frac{Q1}{Q2} = \frac{N1}{N2} \quad (1)$$

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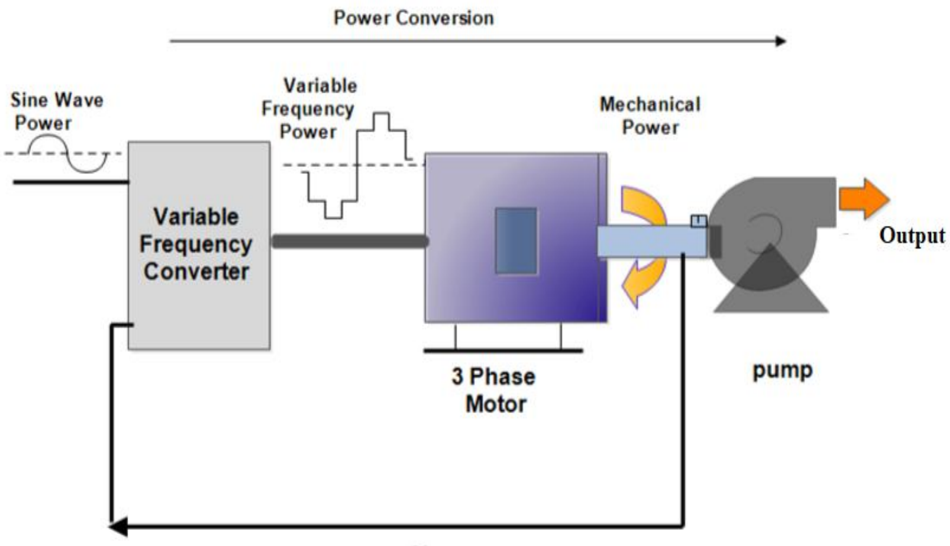
$$\frac{H1}{H2} = \left(\frac{N1}{N2}\right)^2 \quad (2)$$

$$\frac{P1}{P2} = \left(\frac{N1}{N2}\right)^3 \quad (3)$$

When a centrifugal pump is used with an adjustable speed AC drive, the energy costs can reduce by (10 to 60) % of full energy if the pump is designed to operate between (40 to 80) % of full speed [7,8].



II. AUXILIARY COOLING WATER PUMP

The auxiliary cooling water system is a closed loop system, using DM water in circulation. The bearing coolers, oil coolers etc. are being cooled by the Auxiliary cooling water. After cooling the equipment and various coolers, the hot water returns to the suction header of the ACW pumps, for recirculation. It is pumped back to the equipment through heat exchangers, to be cooled by seawater. The losses in the system will be made up from the surge tank located at the deaerator floor (27.5 mL). The level in the surge tank shall be maintained steady, from condensate extraction pump or from boiler fill pump.

The DM water is used for the Auxiliary cooling water system in order to minimize corrosion and scaling in the heat exchanger / cooler tubes, so that efficiency and life expectancy of the system will be more. Being a closed loop system, the make up to the system will be very little. The suction to the ACW pumps is the return water from all the equipment / coolers.

For maintaining a constant suction pressure to the pumps and for making up the losses in the system, the makeup line is connected from the ACW surge tank to the suction header. Any loss will automatically be drawn from the tank by gravity. A line is also provided from boiler fill pump for emergency make up.

There are 4 Nos ACW pumps, out of which 3 Nos will be in service, normally. The water is pumped through plate type heat exchangers and then distributed to the coolers and equipment. Seawater is taken from the inlet pipes of the condensers, and its pressure is boosted in seawater booster pumps. Before being admitted to the plate type heat exchangers, the seawater is filtered in `GIA (INDIA) self-cleaning seawater strainer, to avoid presence of debris in seawater to heat exchangers. There are 4 Nos. pumps out of which 2 Nos. are sufficient for cooling the DM water.

III. AUXILIARY SEA WATER BOOSTER PUMP

The Auxiliary Sea Water Booster Pump system is a closed loop system, using Sea water in circulation. The auxiliary cooling water absorbs the heat from the equipment to be cooled. The Hot demineralized water after cooling the equipment and various coolers is passed to Plate Heat Exchanger. This Hot Demineralized water is cooled by sea water. The Auxiliary Sea Water Booster Pump, pumps Sea water from sea water channel to plate heat exchanger. The exchange of heat transfer between sea water and auxiliary cooling water takes place at Plate Heat Exchanger. The Flow of Auxiliary cooling water and Sea Water is in opposite direction to each other.

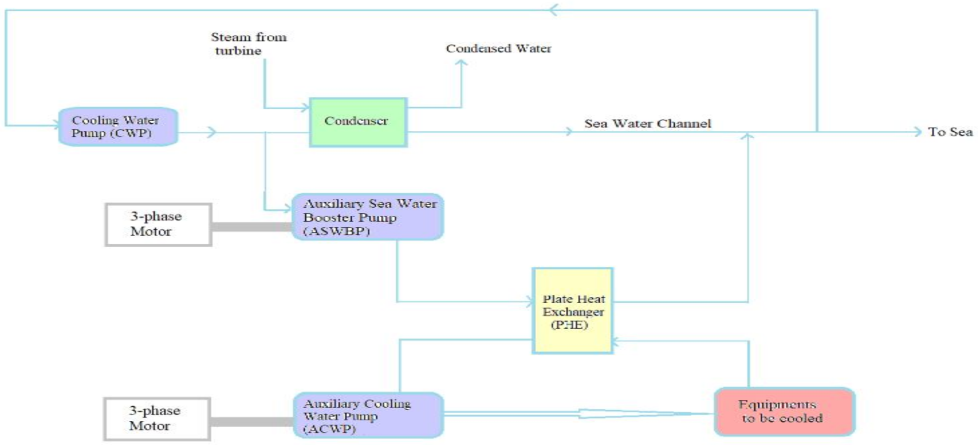
IV. PLATE HEAT EXCHANGER

There are 3 Nos. heat exchangers installed for each unit. Two Nos are to be kept in service and one no. is standby. For connecting DM water inlet / outlet and seawater inlet / outlet, 4 Nos flange connections are provided. Counter flow pattern is employed for better cooling effect. ACW water is flowing from top to bottom, whereas seawater is admitted at the bottom and outlet taken from top. Titanium is employed for plates and pipe connection on seawater side. The piping of seawater on suction and discharge line of seawater booster pumps is M.S rubber lined. The seawater after the heat exchanger is connected to the condenser outlet tunnel. In the outlet, one tapping is taken for the suction of 2 Nos of ash water pumps.

V. PROBLEMS ASSOCIATED WITH THE CURRENT SYSTEM

A. The current flow rate of water in ACW pump is 900 m3/hr.
B. The flow rate of water in ASWB pump is 1100 m3/hr.
C. These Rating are in regards with North Chennai Thermal Power Station (NCTPS) Stage-I.
D. This flow rate is maintained constant irrespective of the temperature of outlet hot water from Equipment.
E. During winter season, the heat associated with the outlet water is quite less than the usual heat.
F. This can be observed from the readings taken from the Plate Heat Exchanger(PHE).
G. Hence the system can be optimized here.

VI. EXISTING SYSTEM

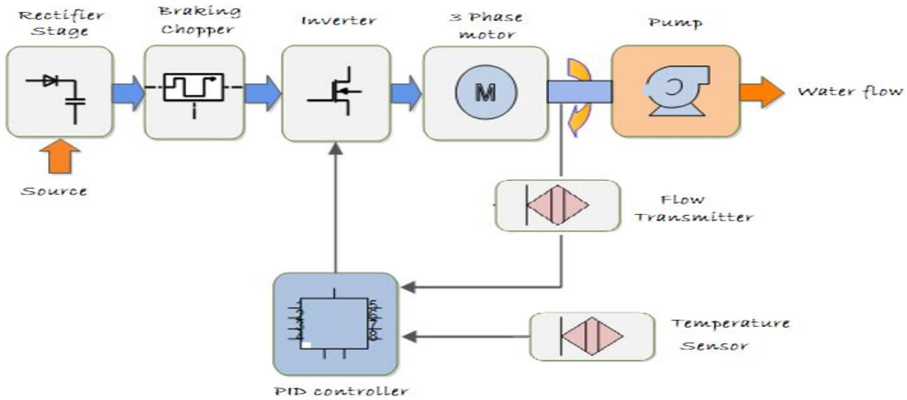


VII. OPTIMIZING TECHNIQUE

A. The Temperature of the outlet water, after cooling the Equipment can be measured with the help of a temperature sensor.
B. Flow rate measurement is done with the help of a Flow transmitter.
C. Flow transmitters is placed in the outlets of Auxiliary Cooling Water(ACW) pump and Auxiliary Sea Water Booster (ASWB) pump.
D. The Values of temperature sensor and Flow Transmitter are sent to a PID Controller.
E. PID controller controls the VFD accordingly, to control the Speed of the motor, thus controlling the flow rate of the pump.
F. Thus, by taking a temperature and flow rate feedback signal from the outlet water, the flow of water can be accordingly controlled by using VFD.

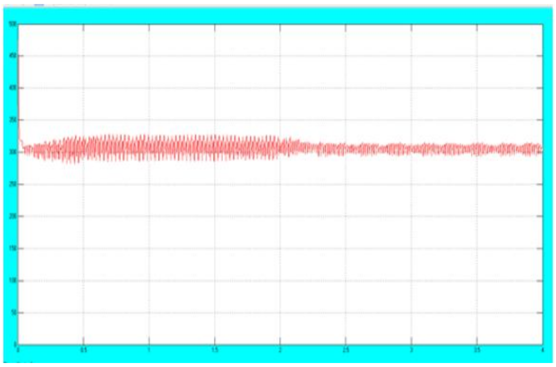
VIII. INTRODUCTION TO VFD

The variable speed electrohydraulic drive uses a variable speed electric motor to drive a hydraulic fixed displacement pump, by adjusting the electric motor speed to regulate the hydraulic pump output flow rate so as to meet the load-demand. [7, 8]. The VFD is a system for controlling the rotational speed or torque of an alternating current (AC) electric motor by controlling the frequency of the electric power supplied to the motor. So that the two major functions of a variable frequency drive are to provide power conversion from one frequency to another, and to enable control of the output frequency [9, 10]. Power 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 [7]. Frequency Drives are used for variable speed applications reduce the energy consumption of motors and increase the energy efficiency of plants [8]. Many fixed-speed motor load applications that are supplied direct from AC line power can save energy when they are operated at variable-speed, by means of VFD. Such energy cost savings are especially used in variable-torque centrifugal fan and pump applications, where the load's 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. The hydraulic motor is an important actuator in a hydraulic system. It was used mostly in the pump controlled-motor drive system, which normally responds badly and has poor control precision [7]. the proposed model of pump drive system, it's consists of these main units:



A. Rectifier Stage

A full-wave, solid-state diode rectifier converts three- phase 50 Hz power from a standard 220 or higher utility supply to either fixed or adjustable DC voltage. The system may include transformers if higher supply voltages are used [9]. The DC bus comprises with a filter section where the harmonics generated during the AC to DC conversion are filtered out [7, 9, 11].



Sample output of a Rectifier

B. Braking Chopper

Sometimes also referred to as braking unit, is used in the D.C voltage intermediate circuits of frequency converters to control voltage when the load feeds energy back to the intermediate circuit.

C. Inverter

Converting DC to variable frequency AC is accomplished using an inverter, the inverter controlled by pulse width modulation (PWM) from smart controller, so that the output current waveform closely approximates a sine wave (quadrature-axis). Electronic power switches (IGBT) Insulated Gate Bipolar Transistor, switch the rectified DC on and off, and produce a current or voltage waveform at the desired new frequency to controls the motor torque. The amount of distortion depends on the design of the inverter and filter [7, 9, 10, 11].

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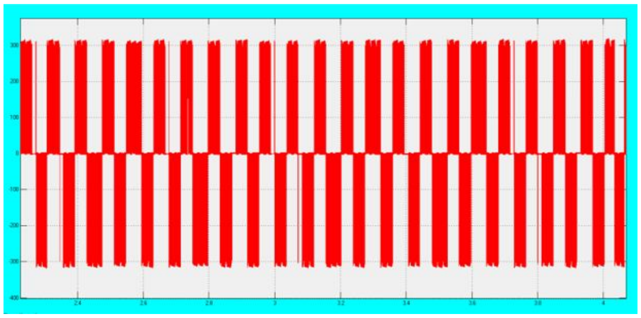


Sample output of Inverter

D. Induction motors (IM)

The three phase induction motor works as a converter of electrical energy to mechanical energy that exerts the electromagnetic torque to centrifugal pump [10].

Squirrel-cage induction motors (I.M) are the workhorse of industries for variable speed applications in a wide power range that covers from fractional watt to megawatts. However, the torque and speed control of these motors is difficult because of their nonlinear and complex structure [12, 13, 14,16].

E. Sensor

The environment temperature degree is measured by a sensor as a criterion and is transmitted to PID controller. The Current Flow rate is measured by using a Flow transmitter and is also transmitted to PID controller.

F. Pid Controller

A proportional–integral–derivative controller (PID controller) is a generic control loop feedback mechanism (controller) widely used in industrial control systems – a PID is the most commonly used feedback controller. A PID controller calculates an "error" value as the difference between a measured process variable and a desired set point. The controller attempts to minimize the error by adjusting the process control inputs. In the absence of knowledge of the underlying process, PID controllers are the best controllers. However, for best performance, the PID parameters used in the calculation must be tuned according to the nature of the system – while the design is generic, the parameters depend on the specific system. The PID controller calculation (algorithm) involves three separate parameters, and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D[16,17]. The proportional value determines the reaction to the current error, the integral value determines the reaction based on the sum of recent errors, and the derivative value determines the reaction based on the rate at which the error has been changing. The weighted sum of these three actions is used to adjust the process via a control element such as the position of a control valve or the power supply of a heating element. Heuristically, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change. By tuning the three constants in the PID controller algorithm, the controller can provide control action designed for specific process requirements. The response of the controller can be described in terms of the responsiveness of the controller to an error, the degree to which the controller overshoots the set point and the degree of system oscillation. Note that the use of the PID algorithm for control does not guarantee optimal control of the system or system stability. Some applications may require using only one or two modes to provide the appropriate system control. This is achieved by setting the gain of undesired control outputs to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions [15,16]. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral value may prevent the system from reaching its target value due to the control action.

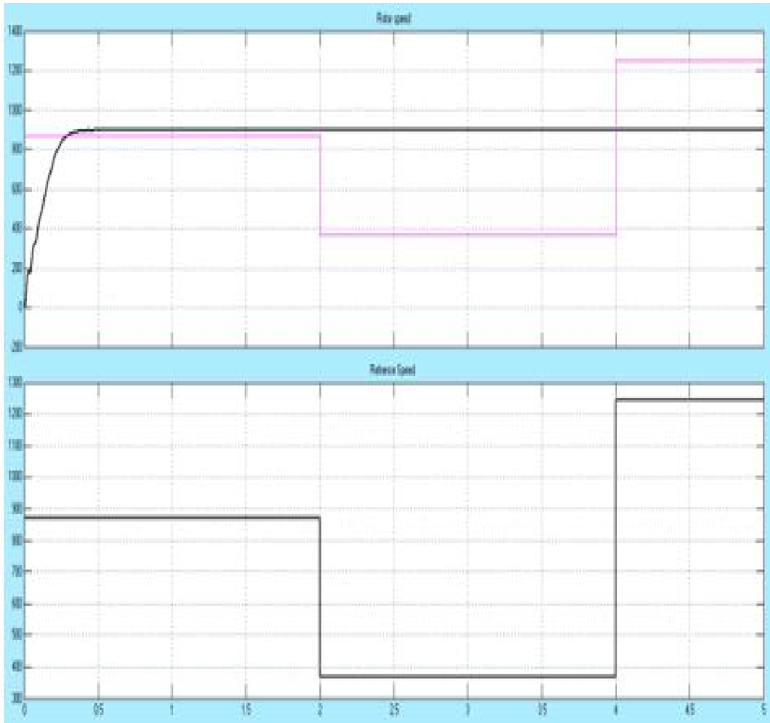
G. PWM Inverter

The PWM technology corrects the output voltage, according to the value of the load by changing the Width of the switching frequency in the oscillator section. As a result of this, the AC voltage from the Inverter changes depending on the width of the switching pulse. To achieve this effect, the PWM Inverter has a PWM controller IC which takes a part of output through a feedback loop. The PWM controller in the Inverter will makes corrections in the pulse width of the switching pulse based on the feedback voltage. This will cancel the changes in the output voltage and the Inverter will give a steady output voltage irrespective of the load characteristics.

IX. OPEN LOOP VS CLOSED LOOP SPEED WAVEFORM

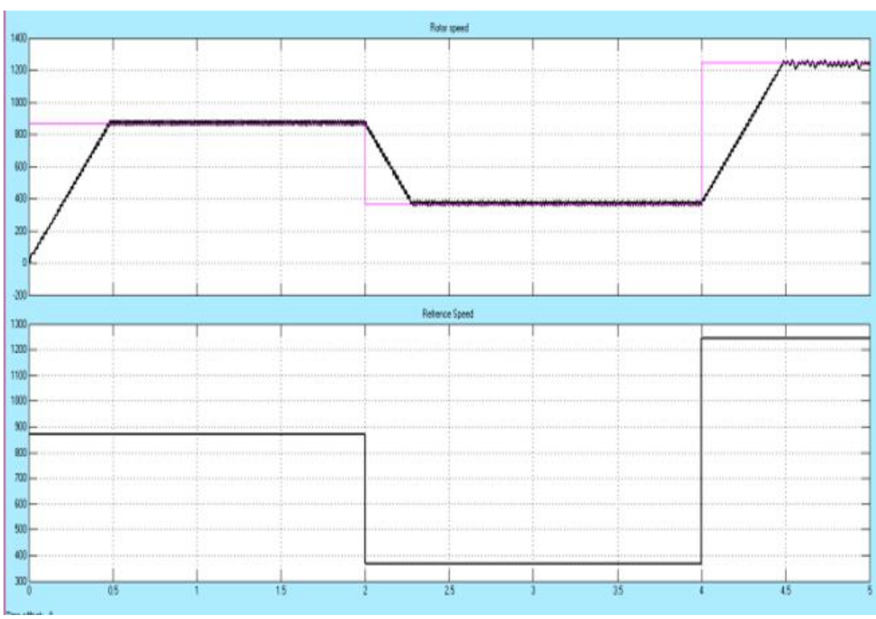
A. Open Loop Speed Waveform Of Motor

In this type of control, Figure shows the rotor speed and the reference speed with open Loop control, it is clear that the rotor speed is constant and don’t vary with the environment temperature degree.



B. Closed Loop Speed Waveform Of Motor

The simulation result and gating signals for closed loop are shown in figure 13 and 14, from the analysis and figure 13 it is clear that the frequency variation leads to the change in the speed of rotor. Where the frequency is a function of the environment temperature degree



X. ENERGY SAVING CALCULATION

A. Auxiliary Cooling Water Pump

1) Power saving calculation

Flow rate, $Q = \frac{3960*WHP}{H}$

Q- Flow rate or Discharge.
H-Total Head in meter.
WHP-Water Horse Power.

2) Present Running Condition

Current flow rate, Q1 =900 cum/hr.
Q1 =3962.58 gal/min.
Water head, H1 =35 m.
H1=114.829 ft.

$WHP1 = \frac{Q*H}{3960}$

$WHP1 = \frac{3962.58*114.829}{3960}$

WHP1 = 114.9038 HP.
WHP1 = 85.68 KWH.

3) After Optimizing

Required flow rate, Q2 = 650 cum/hr (Assumption).
Q2 = 2861.83 gal/min.
Water head, H2 = 35 m.
H2 = 114.829 ft.

$WHP2 = \frac{Q*H}{3960}$

$WHP2 = \frac{2861.86*114.829}{3960}$

WHP2 = 82.9861 HP.
WHP2 = 61.86 KWH.

Power Saving = WHP1-WHP2.
= 85.68-61.86
Power Saving for one pump = 23.82 KWH.
= 23.82 * 24 KWH/day.
= 571.68 KWH/day.
= 571.68 * 365 KWH/year.
= 2,08,663.2 KWH/year.
Power Saving for 6 pumps = 2,08,663.2 * 6
(2pumps running per unit)
= 12,51,979.2KWH/year

Generation cost per unit = 3.44 INR.
Cost saving per year = 12,51,979.2 * 3.44
= 43,06,808.45 INR.

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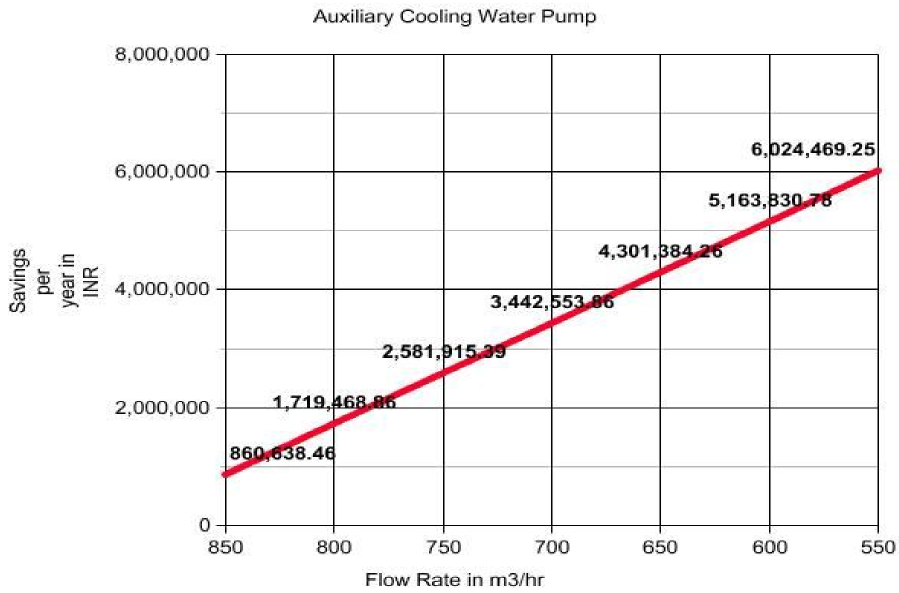


B. Auxiliary Sea Water Booster Pump

1) Power saving calculation

Flow rate, $Q = \frac{3960*WHP}{H}$

Q- Flow rate or Discharge.

H-Total Head in meter.

WHP-Water Horse Power.

2) Present Running Condition

Current flow rate, Q1 = 1100 cum/hr.

Q1 = 4843.15 gal/min.

Water head, H1 = 14 m.

H1= 45.93 ft.

$WHP1 = \frac{Q*H}{3960}$

$WHP1 = \frac{4843.15*45.93}{3960}$

WHP1 = 56.17 HP.

WHP1 = 41.91 KWH.

3) After Optimizing

Required flow rate, Q2 = 770 cum/hr (Assumption).

Q2 = 3390.21 gal/min.

Water head, H2 = 14m.

H2 = 45.93 ft.

$WHP2 = \frac{Q*H}{3960}$

$WHP2 = \frac{3390.21*45.93}{3960}$

WHP2 = 39.32 HP.

WHP2 = 29.33 KWH.

Power Saving = WHP1-WHP2.

= 41.91-29.33

Power Saving for one pump = 12.58 KWH.

= 12.58 * 24 KWH/day.

= 301.92 KWH/day.

= 301.92 * 365 KWH/year.

= 1,10,200.8 KWH/year.

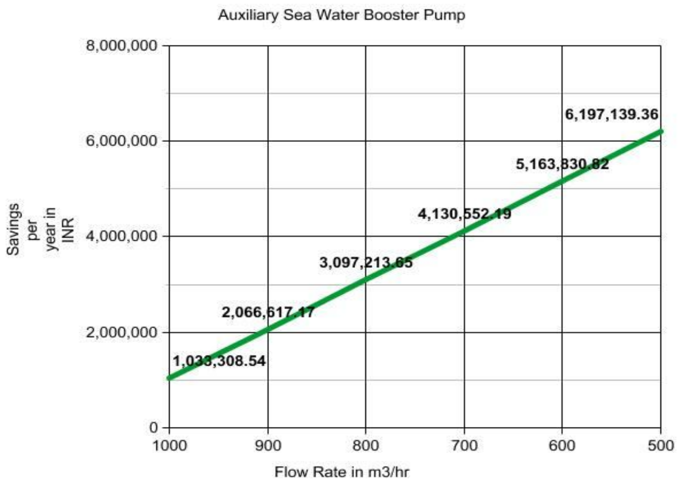
Power Saving for 9 pumps = 1,10,200.8 * 9
(3pumps running per unit)

= 9,91,807.2 KWH/year

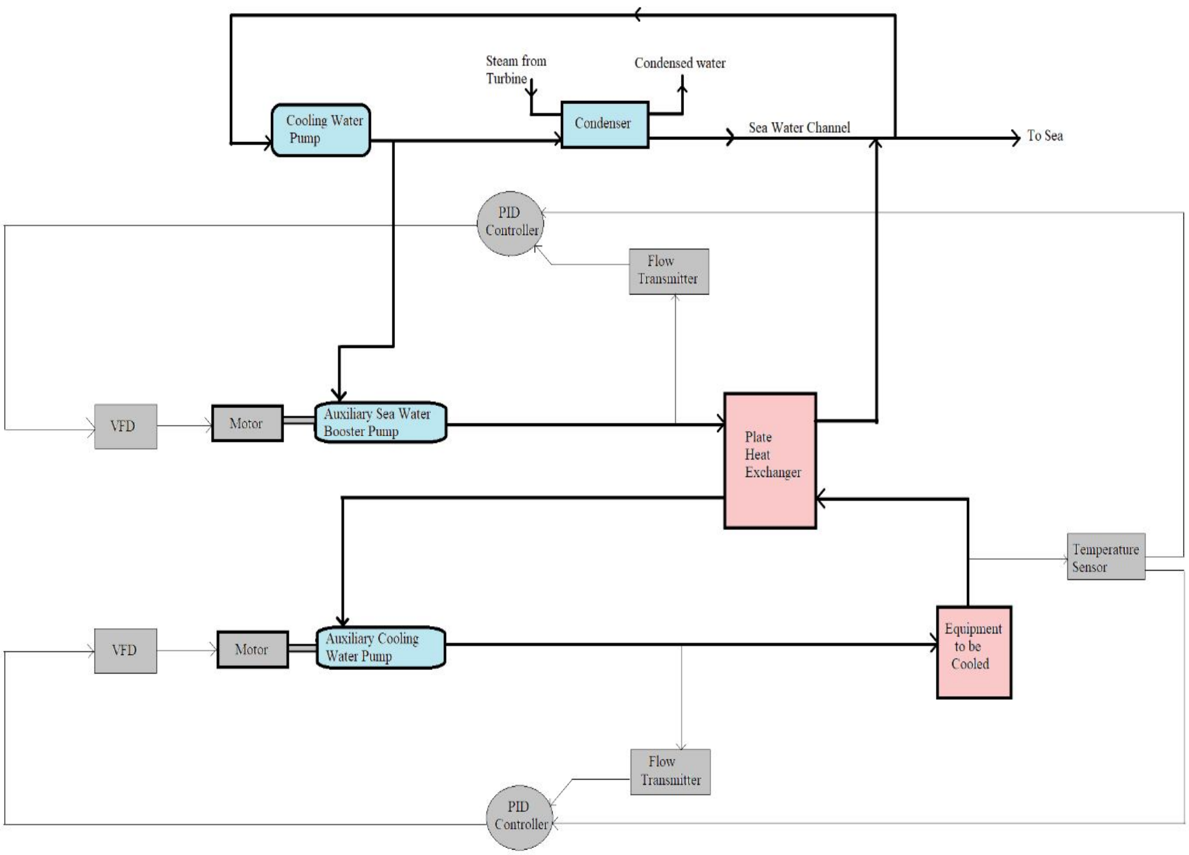
Generation cost per unit = 3.44 INR.

Cost saving per year = 9,91,807.2 * 3.44

= 34,11,816.77 INR.



XI. PROPOSED MODEL



XII. CONCLUSION

A. The effect of applying variable frequency drive controls the speed of the motor so that the flow rate will be a function of environment temperature degree.

B. The speed control of induction motor using VFD can save energy according to affinity law.

C. Large amount of energy is saved in proportion to small reduction in speed.

D. The decrease in energy consumption from conventional energy sources leads to conservation of energy and reduce service life of motor.

E. The VFD unit is a good solution for improving the response and control precision of hydraulic motor.

F. Using a PID controller will increase the cost of the drive system and control complexity but achieves the expected energy savings target.

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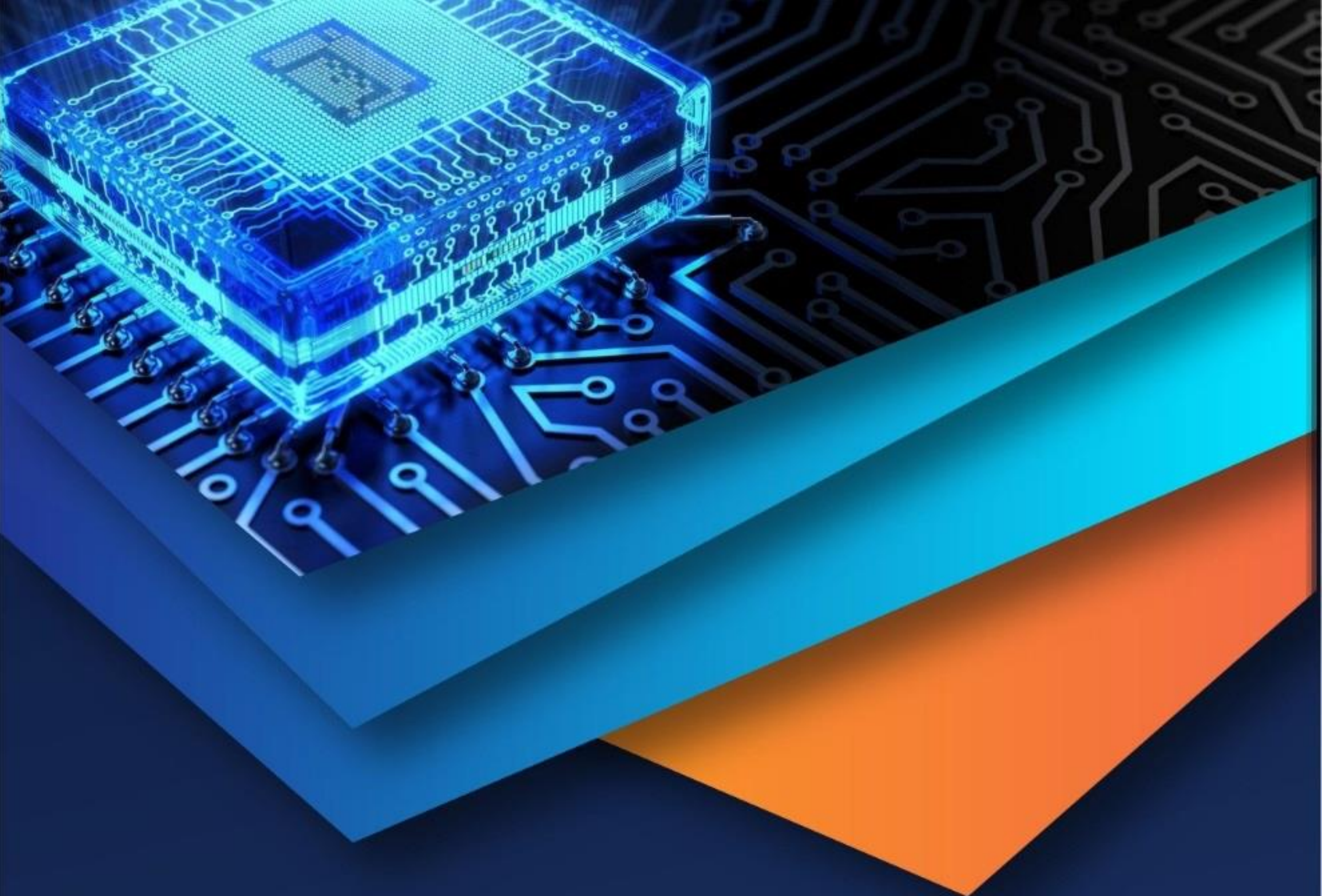

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