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Development of a failsafe protection system for safety of water cooledchiller machine

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ABSTRACT
Chiller Compressor is used in a large plant where there is a requirement of bulk amount of chilled water supply. These machines are very costly and adequate protection of the machine needs to be ensured. The machine has certain sequences of operation which must be followed before the main compressor is given power. Even a minor mistake in sequence of operation may lead to a detrimental effect to the compressor whose repair cost as well as downtime is very high. A protection system has been designed to protect the compressor of the chiller machine to prevent it getting damaged due to any kind of mal-operation. Being heart of a chiller plant it is necessary to provide a good monitoring system. A SCADA based monitoring system has been provided for round the clock monitoring of the machine. A system has also been introduced utilised commonly available technology to get the performance analysis of the machine electrical parameters.

KEYWORDS: Compressor, Chiller, Release, Relay, Contactor, Lock out, Trip Circuit supervision, Condenser

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I. INTRODUCTION

Large buildings Air conditioning system cannot be possible by Split AC. Large buildings have high amount of cooling requirement. In industrial building there are multiple processes which demand cooling for its various processes. Such buildings have a central air condition plant. It employs Compressor, Condenser, thermostatic expansion valve, Evaporator to produce chilled water which is used for air conditioning and process cooling [1], [2]. It has 4 basic cycle i.e. Refrigeration cycle, Condenser Water Cycle, Chilled Water Cycle, Air Cycle.[2]. Refrigeration Cycle has 4 parts Compressor, Salient tube type Condenser, expansion valve, salient tube type chiller. Compressor Compresses high pressure and high vapour refrigerants and sent through discharge line to salient tube type condenser. High pressure, high temperature refrigerants come to the shell side of condenser. Condenser tube contains water or any other liquid. Condenser water is at low temperature than refrigerants. It absorbs the heat from the refrigerants. Refrigerants getscondensed. Liquid refrigerant comes to expansion valve which lower the pressure of refrigerant. It goes to chiller. Tube side.Chillers shed side contains water and shell side contains low pressure and low temperature refrigerant. Liquid refrigerant absorbs the heat from the water and refrigerant vaporises and goes to compressor and thus refrigeration cycle gets completed.

3rd cycle is condenser water cycle which contains condenser water pump, condenser, cooling tower .Condenser water pump suck the low temperature water of cooling tower. Shell contains high pressure and high temperature water. Water temperature increases and goes to cooling tower. Cooling tower is kept at free space and it employs air. Water is sprinkled and with air heat exchanges water gets completed. And water is circulated in condenser Chilled water cycle contains chilled water pump, air handling unit and expansion tanks, salient tube type chiller. Chiller sucks the cooled water to cooling coil of air handling unit. cooling coil of air handling unit contains cooled water. AHU suck the return air from rooms. Return air heat is absorbed in cooling coil. Cooling coil water temp increases and it sent to chiller for cooling. This water comes in the shell side of chiller. Chiller tube contains low pressure and low temperature liquid refrigerants. . Refrigerant temp is low. It absorbs the heat of shell water. Shell water gets cooled and go to AHU. When chiller gets cooled its

volume gets reduced. It need more water which is controlled by expansion tank.

Air cycle contains AHU, supply air duct, diffuser, supply air duct, fresh air duct and AHU room. When motor runs blower starts rotating. AHU blower suck room return air it is passed through filter. Filter air comes in contact with chilled water of cooling coil. Cooling coil temperature is low .it cools air and the air go the supply air duct. Supply duct sends the air to room. Supply air diffuser spreads the air to room. This air comesback through return air duct. When return air comes to AHU it contains less oxygen. Fresh air is mixed with AHU.

A typical arrangement of chiller plant is shown in figure 1 and such arrangements are employed in most of the water cooled chiller plants.

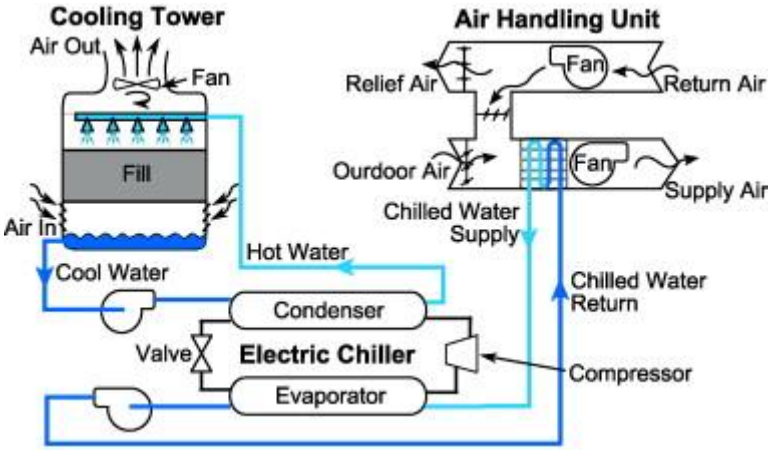

Figure 1: Typical chiller plant scheme

The 4 cycle has critical processes and in any stage if there is a malfunction compressor must be switched OFF. Chiller machine manufacturer provides a control system for the Compressor, condenser , evaporator and chiller unit which comes as a combined package. In general they employ sensors for protection and control, loading-unloading algorithm. Various sensors employed are for following purpose: (a) Evaporator leaving water temperature, (b) Evaporator entering water temperature, (c) Compressor suction temperature, (d) Condenser fluid line temperature, (e) Condenser entering water temperature, (f) Condenser leaving water temperature, (g) Percent unit of Ampere drawn, (h) Compressor discharge temperature, (i) Oil feed temperature, (j) Oil Sump Temperature, (k) Oil Vent Pressure, (l) Evaporator Refrigerant Pressure, (m) Condenser Refrigerant pressure, (n) Oil Feed gauge pressure, (o) Transducer power voltage ratio

Although the main chiller machine is controlled by a microprocessor based control panel there are peripheral equipments such as chilled water pumps, condenser water pumps, cooling tower fans. In a large plant these equipments happens to be of quite big size and is separately controlled. Chiller machine detects whether these equipments are running or not with the help of sensors employed in the line. In the event of non-availability of these equipments and incapability of the peripheral devices it is necessary to switch off the compressor motor on immediate basis. There are set of sequences which must be followed before the main compressor is witched ON. In large chiller machine the swrchgears are kept outside the main chiller control system. If compressor is switched ON without following the sequences the compressor will get damaged in various parts. During running condition if any peripheral services such as chilled water flow, lubricating oil flow, condenser water flow etc. fails the machine has to be stopped. For chillers of higher capacity these motors happens to be of big size and needs a separate circuit breaker external to the chiller machine control panel part. If any of the internal parameters of the chiller machine has exceeded its upper or lower limit it is necessary to switch of the compressor on immediate basis. It has happened in many plant where any internal process or the external process of the chilling operation has failed but the chiller machine did not get tripped due to miscellaneous reasons. This leads to detrimental effect to the chillercompressor. A lot of repair works needs to be carried out if such events occurs. These repair works found to be very costly affairs as the chiller machine itself is a very costly equipments among the various HVAC equipments of any plant. As per the reported events it has been found that almost all these incidents has happened due to mal-operation done by operator and due to failure of protection system of the switchgear.

This paper describes a chiller machine switchgear protection employed with built in safety features for three nos of 450 TR chiller machine installed at BARC. A part of photograph of the existing chiller machine is shown in Fig 2 and 3. The protection system is employed over old chiller machines and it takes care of the operator inadvertence on process side of the chiller machine. It also employs redundancy in protection part. The protection system provides a tools to check the performance of the motor during starting as well as running to analyse the electrical parameters which is very helpful for performance analysis of the compressor motor. The machine produces large amount of noises due to which it is tedious to monitor them on continuous basis. Even frequent round for the machine is also difficult. Hence a SCADA based monitoring system has also been provided for all the machines which facilitates a continuous monitoring station from the control room away from the plant.

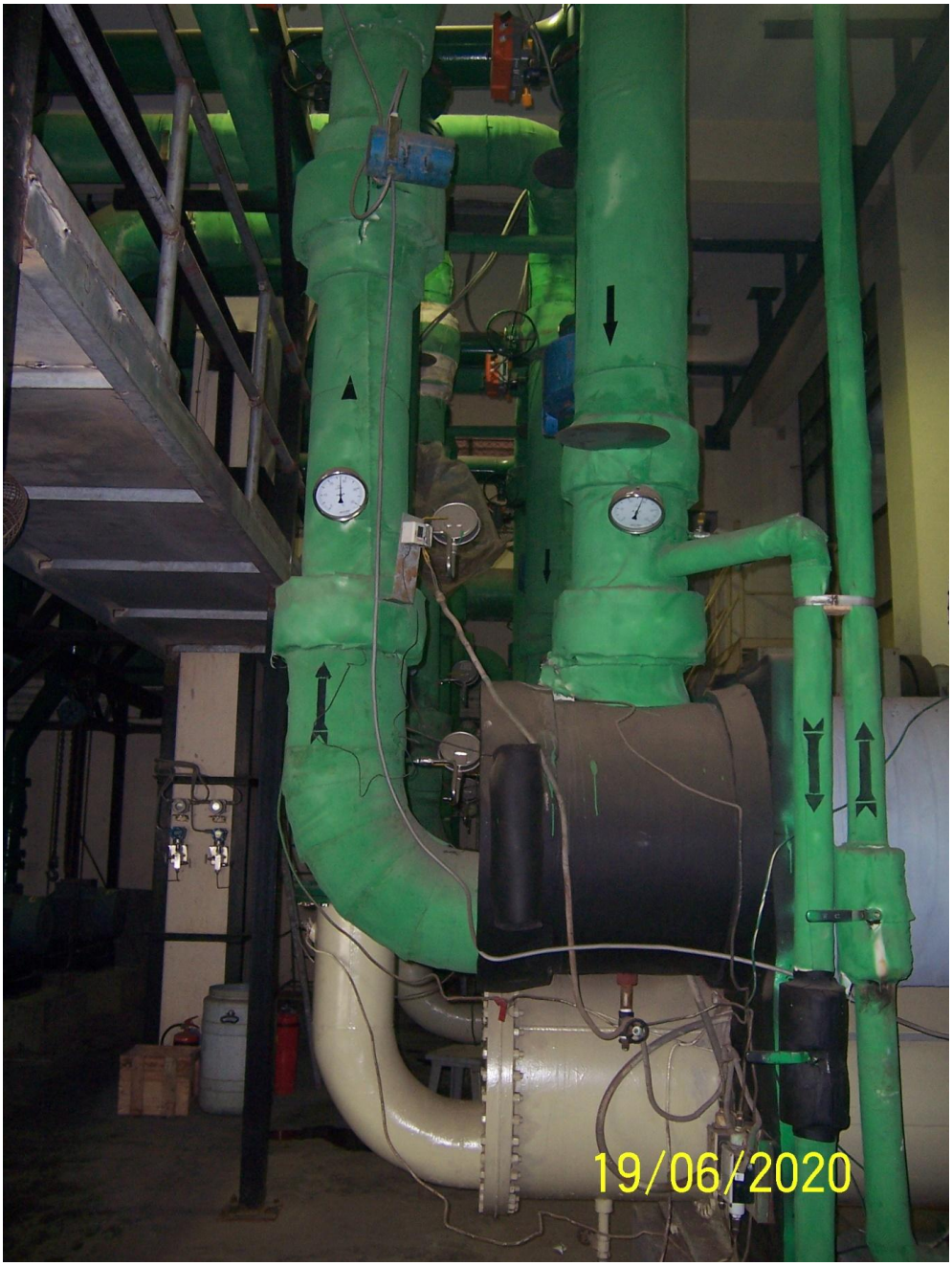

Fig 2: Photograph of the existing chiller plant with One of the chiller machine end and its supply, discharge piping

Fig 3: Existing chiller machine front side.

1 Description of the Chiller Plant

The chiller machines used are installed at BARC. There are three nos of machines with following specification

(a) Make :KirloskarMacquay Ltd, (b) Compressor : Model No L087MAW47K, (c) Evaporator: Model No E3016-SE-2A, (d) condenser: C3016-SNYY-2A, (e) Control Panel: Microtech [Figure 6] which has been later upgraded with K Smart panel, (f) Capacity 450TR

Chilled water pumps, condenser water pumps, cooling tower etc. along with the chiller machine as available at plant is shown in Figure4 . There are three nos of chiller pumps and three nos of condenser water pumps and 3 nos of cooling tower fans which is used in any combination to get better availability of the plant. Actual photograph of the chilled water and condenser water pumps are shown in Figure 5.

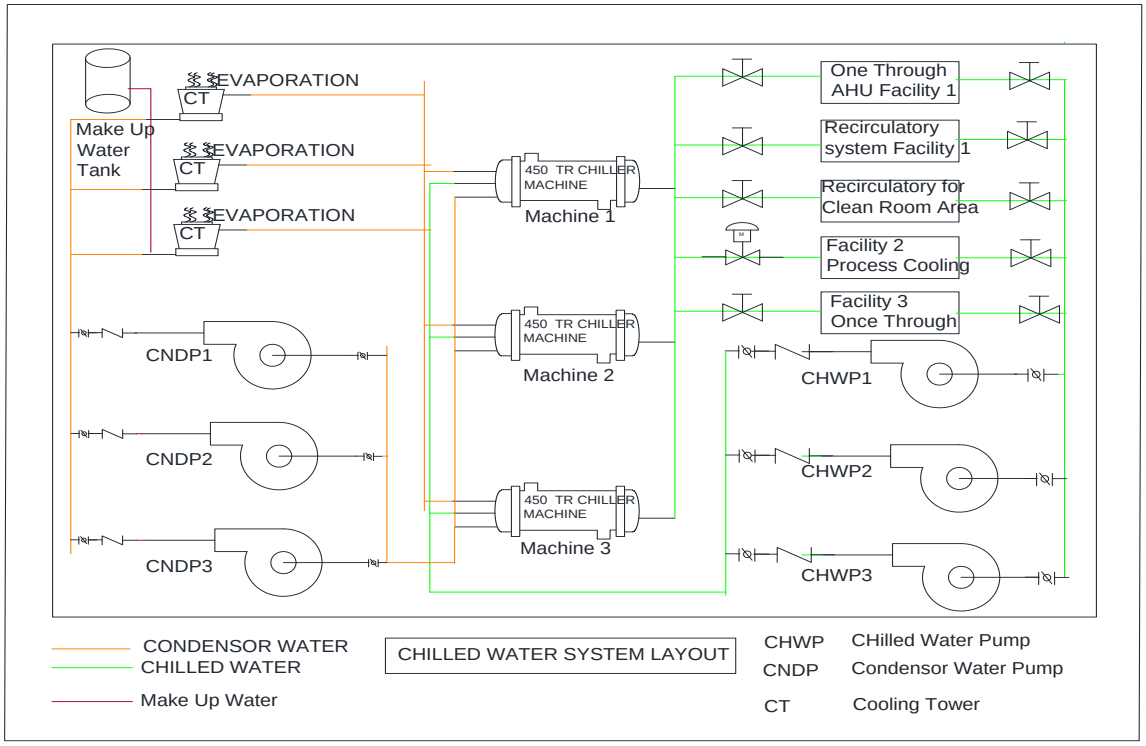

Figure 4: Process Flow Diagram of the Chiller Plant in the subject Plant

Figure 5: Chilled water and condenser water pumps used in the chiller plant

Figure6: Microtech control panel fit with the chiller machine

2 Design of a Protection System for the machine

Chiller Machine is provided with a Microprocessor based Control Panel which takes care of the gradual start up of the machine in unload condition, sequential operation, loading and unloading based on heat load. The control Panel takes feedback from field sensors for generation of alarm, warning etc. in the control panel display. However there are process parameters which if goes out of thelimit,the machine needs to be protected before any detrimental effect happens. These are called cut outs of the chiller machine. Parameters are as follows

(a) Condenser Water flow (Differential cut out) , (b) Chilled Water flow (Differential cut out), (e) Condenser High Discharge Pressure cut out, (f) Condenser Low Suction pressure cut out, (g) Low Oil differential Cut-out, (h) Chilled water Overcool(Antifreeze Cut-out), (i) Starter/Breaker Safety Cut-out.(motor unhealthy)

There was earlier switching system for the machine which was not found adequate in various conditions and resulted in detrimental effect to the machine. There was earlier a protection system where chiller machine control panel used to give a ready signal when all the peripheral services such as chilled water low, condenser water flow, lub oil circuit , oil heater is witched ON and gives OFF command when any of these system goes OFF. A motor protection relay which used to take care of the motor related parameters in case of any abnormality. However following concerns were there which had resulted in failure of costly machine in few occasions.

a. Chiller control panel does not respond quickly the whole machine can get damaged as the main compressor is still getting the power

b. The machine is directly switched ON pressing the mechanical close button of the breaker

c. The trip circuit command is in open condition.

d. The trip circuit coil is unhealthy and the machine is witched ON

e. Chiller control panel power is in OFF condition but the breaker has been switched ON

f. There is no power to the trip coil to trip the breaker in between running condition.

Incidents have happened in various plants where the system did not trip immediately due to certain abnormalities and has resulted into damage to the machine. All these causes has been eliminated and a robust protection system has been designed which can take care of the machine in case of multiple failures of the control system. The protection system comprised of the following components. Figure 7 shows all components.

a) 800A Draw out type Air Circuit Breaker with 110V DC closing coil, 110V DC shunt release (tripping circuit), 415 V under voltage release (U/V)

b) Microprocessor based motor protection release

c) Trip circuit supervision relay

d) Lockout Relay

e) Interposing relays-3 nos for monitoring chiller machine auxiliary power supplies.

f) Current transformer for protection and metering

g) Control contactor for multiplication of safety cut-outs of the machines

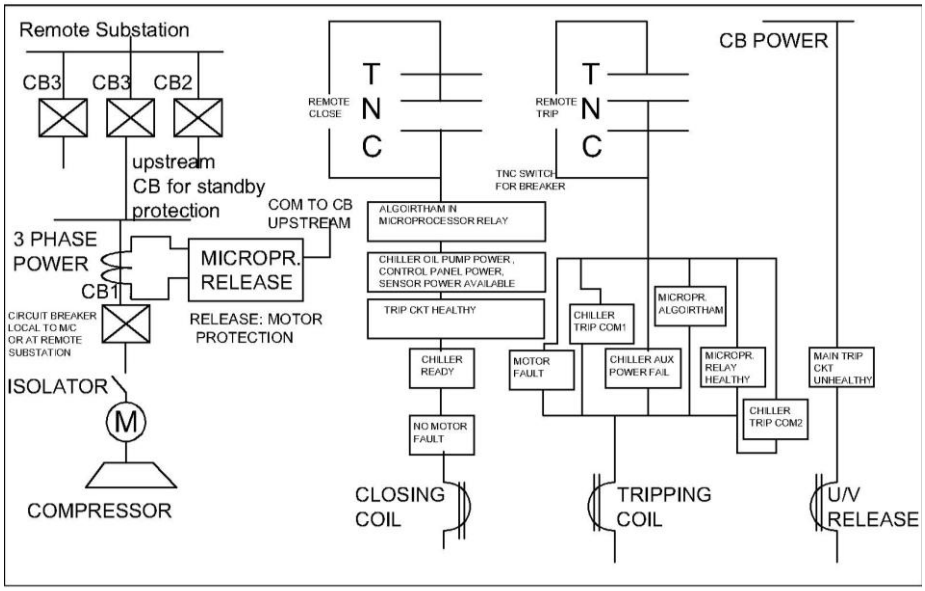

Figure7: Power and control circuit of the Chiller machine Breaker

Functions of various components along with its role in the protection system is given in subsequent sections. Actual photograph of the circuit breaker along with all process related protection is given in Figure 8. This has been designed and replaced in the same place of the old protection and switchgear system used for the chiller machines.

Figure 8: Chiller machine external Circuit Breaker and their protection system panel

2.1 Circuit Breakers

Air Circuit breaker has been used for the machine for switching ON and OFF. Closing circuit and tripping circuit both are from Class I power supply system (110V DC). An under voltage coil has been used which detects presence of availability of trip circuit power. When the machine is in OFF condition and the trip circuit power is not available it will not be possible to close the breaker. However in running condition if the trip circuit power is not available the under voltage coil will unlatch the breaker contacts which will not require any other protection system. The closing circuit is ready when all the processes are ON. IF the processes are not ON it will not be possible to give any electrical command to the breaker. The manual closing command of the breaker is prevented by a lock and key arrangement additionally attached over the clos push button of the breaker

2.2 Microprocessor based protection release

A microprocessor based protection release (Numerical Relay) has been used to monitor the motor current and voltage parameters [Figure 9]. These protection rlease has the capability to keep a track of the breaker health status to obtain predictive information [3]. Three phase voltage is given to the release directly with a MPCB in between. Three phase currents are given with the help of current transformer. Additionally circuit breaker position, machine process feedback , breaker ON and OFF feedback, status of power of the chiller control panel, status of trip circuit supervision relay is given to the release. The numerical relays are programmable and it is programmed with desired logic . The closing and tripping logic is given in Figure 10 and 11. An algorithm has been developed in the release for close the breaker in safe condition only and trip during any unsafe condition. This is in addition to hardwired interlock.

Figure 9: Photograph of the chiller machine microprocessor based relay used.

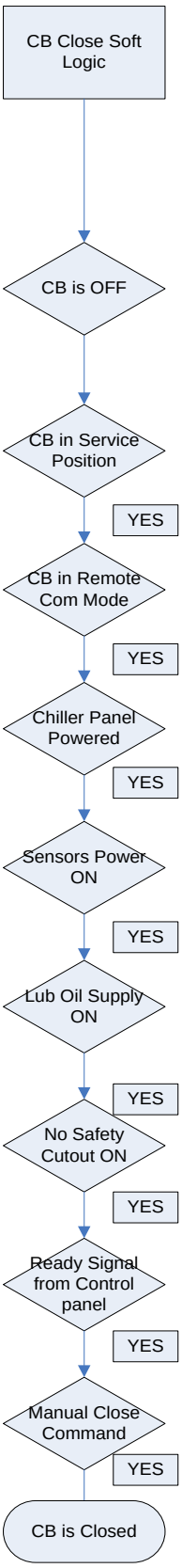

Figure10: Closing Sequence of Circuit Breaker (CB)

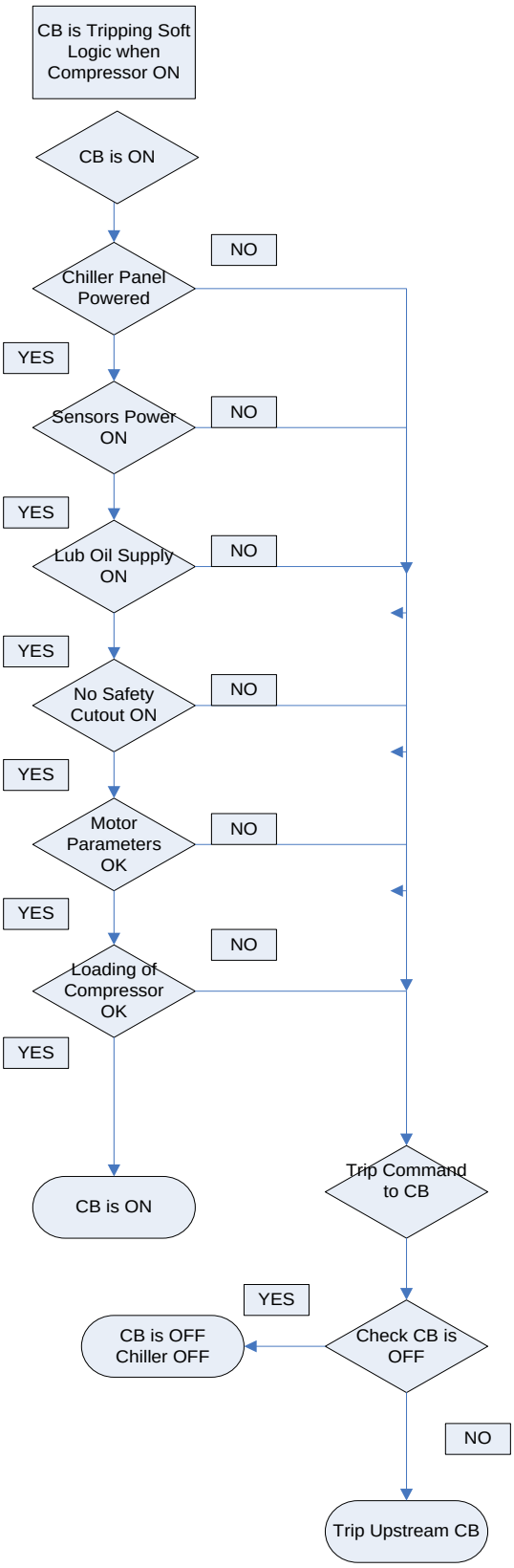

Figure11: Tripping Soft Logic for the CB

2.3 Trip circuit Supervision relay

This relay is normally used with any breaker to monitor the status of the trip circuit whether shorted or opened. However for this protection system it has been connected to the close circuit in such a way that if it is unhealthy no close command can be initiated. During running condition if the trip circuit is unhealthy and it cannot trip the breaker a provision has been made with the help of microprocessor based relay algorithm to trip the upstream breaker of remote substation after 5 seconds delay.

2.4 Lockout Relay

This relay is normally used in the power system where no auto reset of alarm cannot be allowed.[4]It is very useful for process based protection system [4] . In this protection system when there is a fault with respect to the compressor motor which is observed in the microprocessor relay the lockout relay will get latched. Unless this relay is reset locally by an operator the machine cannot be switched ON second time.

2.5 Interposing Relay

There are 24 V AC, 110 V AC and 230 V AC power used in the chiller machine. 230V AC derived from class II power supply system is given to the chiller control panel. From the chiller control panel a a parallel tapping has been taken and given to a relay . The NO and NC contact of the relay is given to microprocessor based release as well as in the hardwired based close and trip circuit as per functional requirement. It ensures that the chiller control panel is in powered up condition during start up and automatically trip if it is not powered ON. The lub oil circuit requires 110 V AC which is given by using a transformer in between. Availability of 110 V AC is also ensured in similar way. 24V AC is used for various sensors which are used for monitoring purpose in the chiller control panel. Availability of 24 V AC is ensured with the help of similar interposing relay.

2.6 Current transformer for protection and metering

A local energy meter has been provided and is connected to a metering Current transformer (CT). Separate protection CT is used for giving the current feedback signal to release. A core balance transformer is used in the outgoing section to ensure the machine currents are in balanced condition. Microprocessor based relay ensures the same. A measuring CT is used for checking the loading and unloading of the machine. After the machine is started there should be current flow within 15 seconds. If there is no current feedback the chiller control panel generates a low motor current feedback based on which the machine is automatically tripped.

2.7 Control contactor for multiplication of safety cut-outs of the machines

In the machine following sensors switches have been used

(a) Condenser inlet water flow, (b) Chilled water inlet flow, (c) Condenser discharge pressure high, (d)Lub oil pressure low (e) Low oil level (f) antifreeze

All these switches contacts have been duplicated with the help of control contactor. Total three set of NO and NC contacts haven derived. One set is given to the chiller control panel which generates a separate command for the trip circuit. One set of contact is given to hardwired based close and trip circuit (NO and NC position has been used as failsafe for the close and trip circuit) of circuit breaker. One set has been given to microprocessor based release.

3 Details of the SCADA based Monitoring System provided for the machine

Machine protection is ensured with the help of the robust protection system designed. However it is also necessary to monitor the system efficiently to ensure its performance remains in good condition over the period. Hence the chiller control panel has been upgraded and the new control panel is procured and installed which provides a Modbus TCP/IP based interface to monitor the process parameters(Figure 13) . The raw parameters are calculated to derive various other parameters and these are shown in control room SCADA, Trends have been developed for these parameters to check the performance deterioration (if any) over the period. The contacts of the safety cut outs and the status of the breaker, release etc is given to PLC to show the live status in SCADA. The extracts of the monitoring screens pertaining to the specific sections are given in fig 14 to 15. Temperature , pressure and flow instruments are put at various piping locations and those are taken into SCADA platform for better monitoring of the plant.

Figure 13: New Chiller Control panel with provision for local display for 11 parameters and remote monitoring provision in Modbus

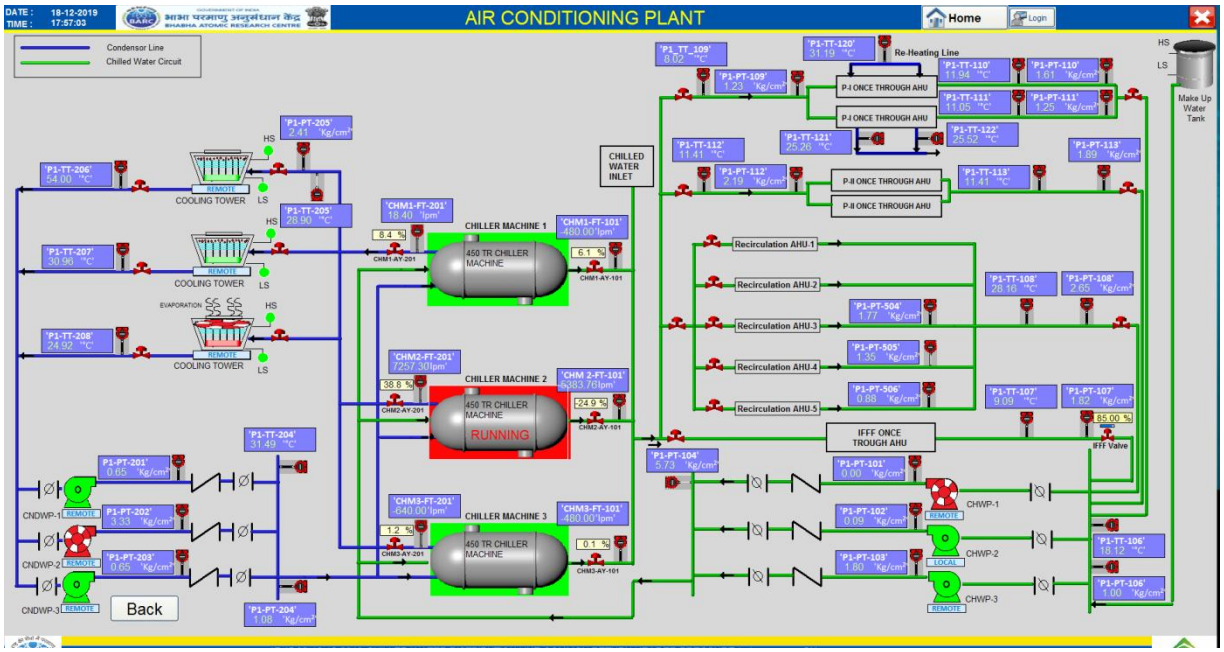

Figure 14: Complete Chiller Plant shown in SCADA system

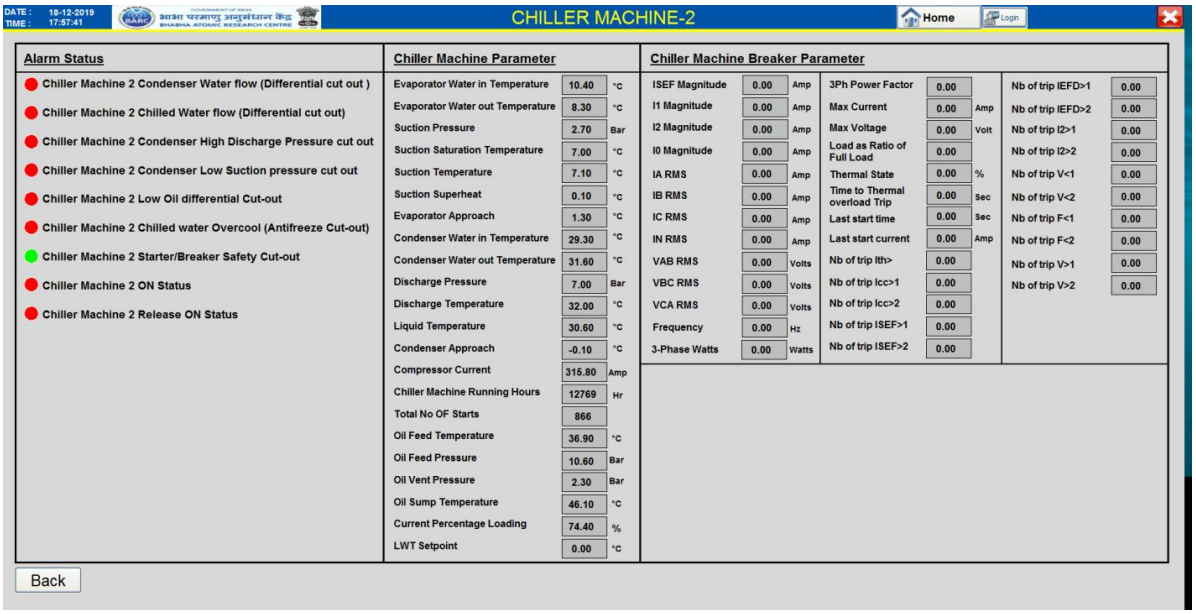

Figure 15: Chiller Machine Detailed Parameters recorded in SCADA system

4 Starting performance parameter Recorder

In the microprocessor based release a recorder has been programmed to record the starting currents and voltages and fault voltages and currents along with the waveform. The data is automatically stored in the release for 10 seconds starting from breaker ON. This helps to carry out performance analysis of the large sized compressor motor. The snapshots of the ready waveforms plotted with the stored data are given in fig 16. The figure show the voltage in R, Y B phase (VA, VB, VC), current in three phases (IA, IB, IC) , derived unbalance currents before starting of the machine, during starting and after settling. The raw data helps to analyse the various harmonics components drawn by the machine. Event diagnosis and disturbance event reports are possible with advanced numerical relays [5]. Whenever any fault is generated this event recorder is configured with the help of a disturbance recorder which stores pre-fault and fault current data for a few seconds. Analysis of the currents is not discussed in this paper.

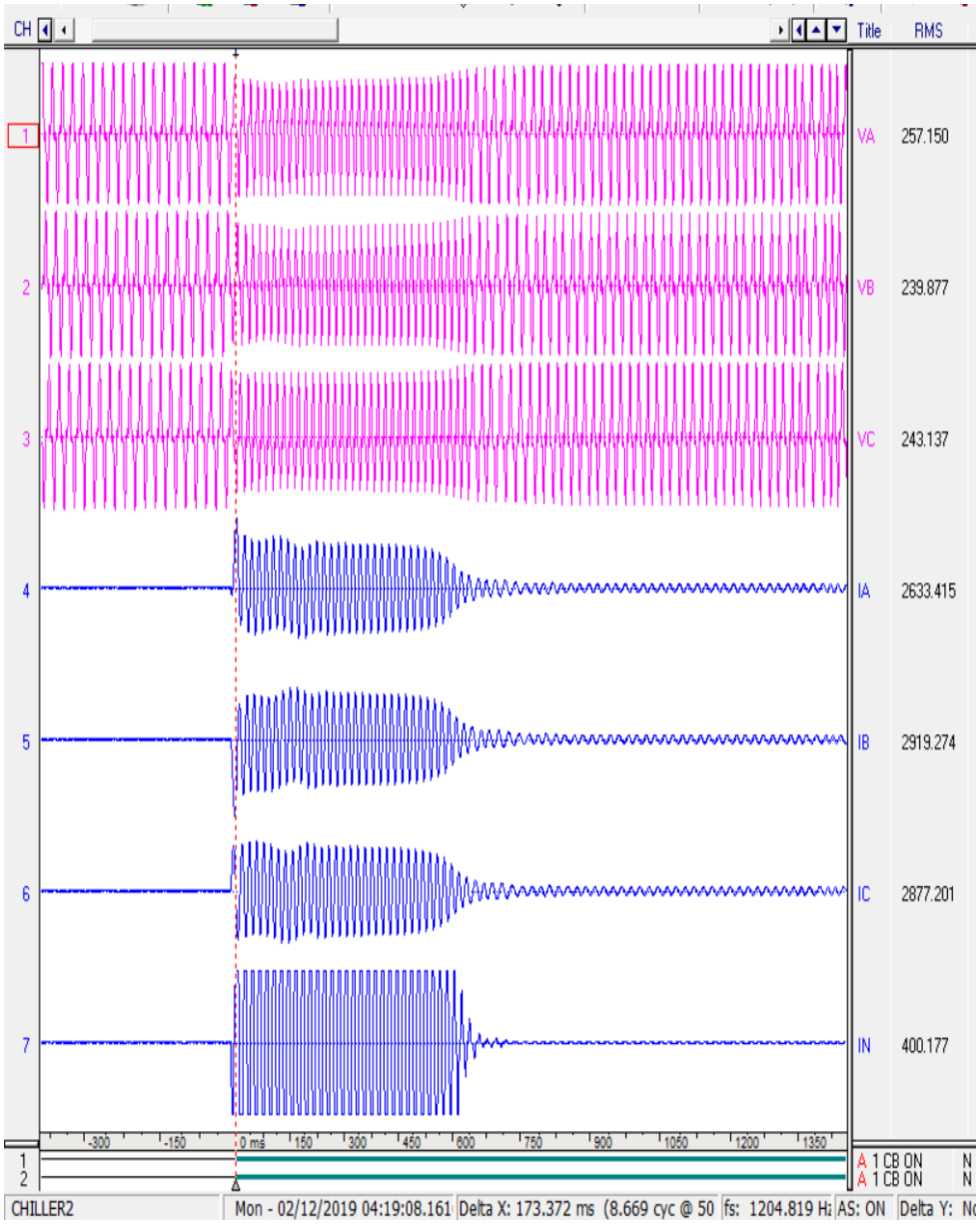

Figure 16: Starting Voltage and current parameters of the chiller machine main compressor

5 Results and Discussion

The Complete system developed for the chiller machine has been tested with multiple situation .Earlier in same plant few accidents had happened. This scheme was implemented for one chiller machine which was later extended to all three machine. The machines are running successfully without any single accident for past few years. The protection system has at least dual redundancy for every abnormal conditions. Failure of only one component does not disable the protection of the machine. Only monitoring and storage of starting currents is very much helpful tool for the motor performance analysis and condition monitoring. Wherever there is an external breaker used for protection of large rotating equipment along with sequential process such protection system can be adopted.

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