CERTIFICATION OF APPROVAL

Design of Two Stage Charging System for Thermal Energy Storage (TES) Tank for GDC UTP

by

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10470

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Approved by;

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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ABSTRACT

The report presents the study on the Thermal Storage tank charging system for Thermal Energy Storage (TES) System of UTP. The system supplies chilled water to UTP at 6^{o}C while the return chilled water is at 13.5^{o}C.The chilled water from steam absorption chiller (SAC) is supplied directly to UTP which only operated during the day. Chilled water from TES tank is charged by electric chillers and is used as supplementary for meeting cooling load demand during peak requirements. The current practice is to operate at night to charge the TES tank. Due to the time limitations, full charging of thermal storage tank could not be achieved. This necessity the electric chillers to run during the day to meet additional cooling load demand during peak hour. Hence the benefits of TES tank were not optimized. The current practice also does not take advantages of the availability of waste heat at night because SAC is not operating during night time. To address this issues two stage charging system is proposed. The proposed design uses both SAC and EC to charge the TES tank. The proposed system of using SAC to charge TES with input 13.5^{o}C to 9^{o}C by SAC for the first stage. EC would then continue charging the TES tank from 9^{o}C to 5^{o}C. The configuration and the operating mode of the proposed system are highlighted in this report. Based on calculation, the proposed system would be able to charge the TES tank within 7.5 hours which is 2 hours using SAC and 5.5 hours using EC. This will improve the system by 54% if compared to the current charging system which requires about 14 hours. By these result, this would benefits the whole plant utilization by increasing the SAC efficiency as well as improving the TES tank storage capacity.

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CHAPTER 1

INTRODUCTION

1.1. Background Of Study

The Gas District Cooling (GDC) plant is equipped with two gas turbines generator (GTG), each with 4.2 MW capacity, two heat recovery steam generators (HRSG) and two boilers. GDC also consists of two units of 1250RT absorption chillers, four units of 325RT electric chillers and a 10000 RTh thermal storage tank [2]. The plant is a combination of a cogeneration and district cooling plant. The process flow of the GDC plant is shown in figure 1. The green, purple, orange, blue and turquoise lines shows the electricity, fuel, steam, chilled water and cooling water respectively.

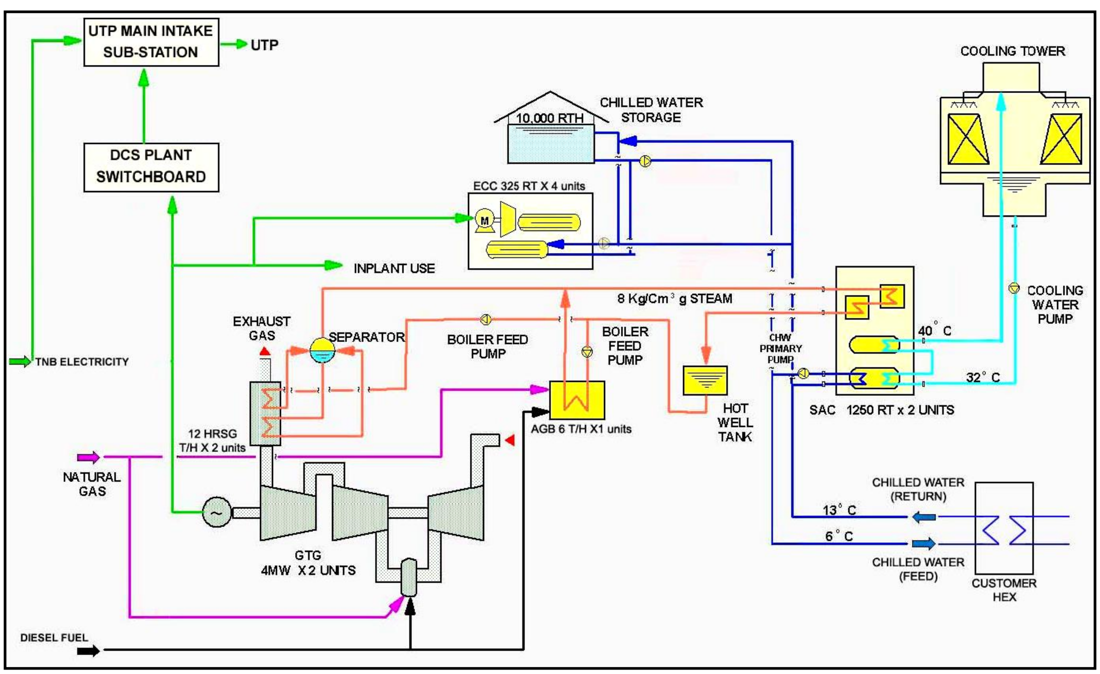


Figure 1: Process flow of GDC plant.

Thermal Energy Storage System is part of the GDC plant. Thermal energy storage (TES) system is a sensible heat storage system using water as storage media. The system is operated on a temperature different of 7^{o}C, with chilled water temperature of 5^{o}C for the supply and 13.5^{o}C for the return passages [1]. Chilled Water was supplied from TES when load exceeded steam absorption chillers capacities. The storage tank was designed to supplement the chilled water requirements during the day. The current operating schedule for the chiller was designed to support the partial load-load leveling strategies for the TES system with chilled water from absorption chiller is supplied directly to UTP and electric chiller is used to charge the thermal storage tank.

Electric Chillers (EC) will charge TES System at night until 5^{o}C. The chilled water will then discharge into the cooling system during the day. Four units of EC are available in the system. The EC is designed specifically to only charge the TES system. However, since the demand is high, and SAC are unable to supply all the cooling needed, EC are also used to supply chilled water to the campus during daytime From the data collected it is noted the current operating strategy incorporate at least two of the four units EC are operated during day time.

The inventive objective is for the thermal energy storage system is to reduce operating cost and refrigeration plant capacity requirement.

1.2. Problem Statement

Nowadays, the requirement for chilled water is increased due to increased in academics and non-academics activities in UTP. The TES tank needs to be charged during night time in order to make sufficient cool water for the next day time usage. Currently, the TES tank is charged by EC while the SAC does not charge the TES tank. But, due to time limitation, full charging of thermal storage tank could not be achieved and the electric chillers have to run during the day to meet the cooling load demand. Since there is available waste heat during the night one option to is to use steam absorption chiller (SAC) for charging of TES.   By using this method, the waste heat available at night is utilized and will benefit UTP.

1.3. Objective And Scope Of Study

Objective of the study is to:

- To design a *two stages charging system for thermal energy storage tank.* The first stage charging involves SAC and the second stage is using EC.

Scope of study covers the following:

- The research will focus on the current TES system of UTP Gas District Cooling plant.

CHAPTER 2

LITERITURE REVIEW

2.1. Thermal Storage System

2.1.1. Introduction

Thermal energy storage is a technology that reduces electric costs by shifting space cooling activities to off-peak times. Water is chilled or ice is made during the night to either replace or augment building cooling equipment during the day. Based on article write by Takasago [5], Thermal Storage System for space cooling is a relatively mature technology that is continuously improving. It has its roots in early nineteenth-century. Colorado Automatic Refrigerator Company, which began operating in Denver in late 1889, built the first Thermal Storage System.

A Thermal Storage System distributes chilled water or other media to multiple buildings for air conditioning or other uses. The cooling (actually heat rejection) is usually provided from a dedicated cooling plant. Cool storage technology can be used to significantly reduce energy costs by allowing energy-intensive, electrically driven cooling equipment to be predominantly operated during off-peak hours when electricity rates are lower. In addition, some system configurations result in lower first costs and lower operating costs.

There are several types of Cool storage technologies come in many different forms, each with their pros and cons. The storage media is most commonly water (with cold stored in the form of ice, chilled water, or an ice/water slurry), but other media (most notably eutectic salts) have also been used.

Storage media can be cooled (charged) by evaporating refrigerant or a secondary coolant (typically a water/glycol mixture). Discharge is usually accomplished directly via circulating water or indirectly via secondary coolant. At least one system has been developed that discharges storage via circulating refrigerant. District cooling is now widely used in downtown business districts and institutional settings such as college campuses [5].

2.1.2. Operating Strategies

Several strategies are available for charging and discharging storage to meet cooling demand during peak hours. These are:

- Full Storage or Load Shifting:

Full Storage strategy or Load Shifting strategy, operates by shifting the entire on-peak cooling load to off-peak hours. This system would require a large storage facility or a small cooling load. It is designed to operate at full capacity during all off-peak hours to charge storage on the hottest anticipated days. Another point to note is that this strategy is most attractive where on-peak demand charges are high or the on-peak period is short.

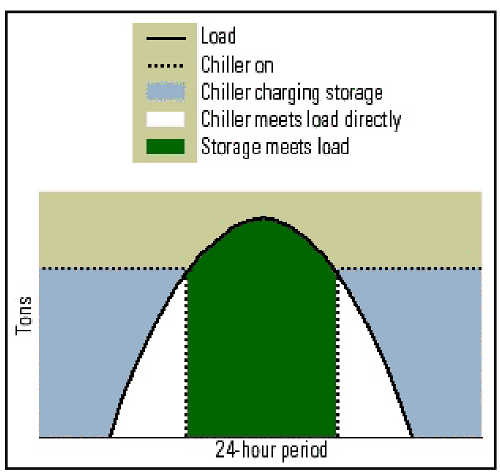


Figure 2: Full storage or load shifting (ASHREA)

- Partial Storage; Load Leveling :

As for the partial-storage system, while the chiller runs to meet part of the peak period cooling load, the remainder is met by drawing from storage. Here, the chiller has a relatively smaller capacity when compared to that of the design load. In a load-leveling system the chiller is sized to run at its full capacity for 24 hours on the hottest days. This strategy is most effective where the peak-cooling load is much higher than the average load.

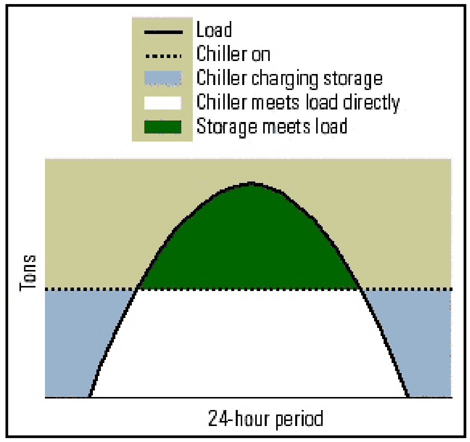


Figure 3: Partial storage; load leveling (ASHRAE)

- **Partial Storage; Demand Limiting:**

In a demand limiting system, the chiller runs at reduced capacity during on-peak hours and is often controlled to limit the facility's peak demand charge. Demand savings and equipment costs are higher than they would be for a load-leveling system, and lower than for a full-storage system.

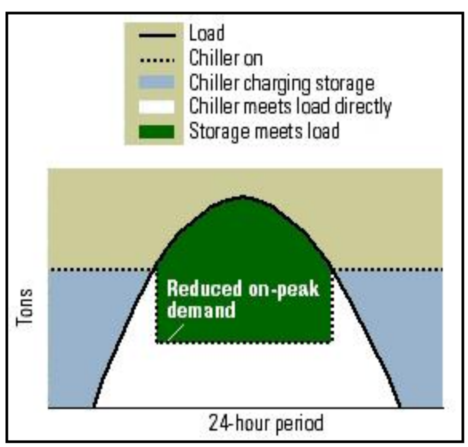


Figure 4: Partial storage; demand limiting (ASHREA)

2.1.3. Benefits of Thermal Storage System

Dincer [6] has listed the advantages of using TES system as below:

- Energy savings potential - Compared to conventional chillers TES systems provides lower energy costs and incentive savings.
- Lower capital outlays - TES tanks allow a reduction of chiller capacity. This is true for both new construction and system expansions.
- Lower maintenance costs and requirements - Less equipment translate to reduced maintenance needs
- Optional fire protection advantages - TES tanks are full at all times, availing a massive supply of water in case of fire.
- Environmental advantages - Many coolants and refrigerants face potential bans due to environmental concerns.

2.2. Main component of Thermal Storage tank charging and discharging process.

2.2.1. Stratified storage tank

i) System description

Sensible storage typically uses a stratified storage tank, employing the temperature dependence of water density, which is greatest at approximately 4°C (39°F), to separate warmer water from cooler water. Water enters and leaves the tank at equal flow rates through diffusers: warm at the top and cool at the bottom [7].

A thin thermal transition layer (thermocline) as shown in figure 5 forms at the interface between the warm and cool water and is displaced as water flows through the tank. The direction of flow is from bottom to top while capacity is being stored, and it reverses when capacity is extracted.

The thermal performance depends on the rate of degradation of the initial stratified thermocline layer during the process charging and discharging. The rate of degradation is influenced by thermal loses, mixing within the tank due to temperature differences, fluid recirculation, and natural convection between the hot and cold fluid [7].

Tank volume is affected by the separation maintained between the stored cold water and the warm return water. Natural stratification has emerged as the preferred approach, because of its low cost and superior performance. Colder water remains at the bottom and warmer, lighter water remains at the top.

A difference of 20°F is the practical maximum for most building cooling applications, although a few systems exceed 30°F. Chilled water is generally stored at 39°F to 42°F, temperatures directly compatible with most conventional water chillers and distribution systems. Return temperatures of 58° to 60°F or higher are desirable to maximize the tank temperature difference and minimize tank volume [7].

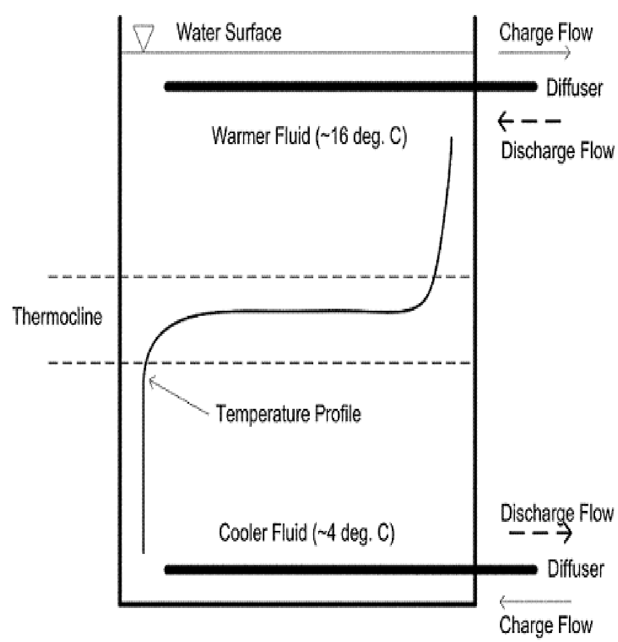


Figure 5: Schematic cross section of stratified chilled water storage tank

ii) Charging and discharging cycle.

Charging is the process of filling the storage tank with chilled water from the chiller, usually at a temperature between 40 and 45°F (4.4 and 7.2°C). Meanwhile, the warmer return chilled water from the air-handling units or terminals, usually at a temperature between 55 and 60°F (11.1 and 15.6°C), is extracted from the storage tank and pumped to the chiller to be cooled.

Discharging is the process of discharging the chilled water, at a temperature between 41 and 45°F (5.0 and 7.2°C), from the storage tank to the air-handling units and terminals. At the same time, the warmer return chilled water from the coils fills the tank by means of storage water pumps [13].

iii) Loss of cooling capacity during storage.

During the storage of chilled water, the following processes result in losses in cooling capacity:

- Stored chilled water is warmed by direct mixing of warmer return chilled water and stored colder chilled water.
- Heat from previously stored warmer return chilled water is transferred from the warmer tank wall to the stored chilled water.
- Heat is transferred through the tank wall from the warmer ambient air.

iv) Charging and Discharging Temperature versus Tank Volume

Figure 6 shows curves of chilled water temperature versus tank volume during the charging and discharging processes of a complete chilled water storage cycle in a large stratified tank. Inlet and outlet temperatures are measured at the openings of the top and bottom diffusers. During the charging process, return chilled water is extracted from the top diffusers of the stratified tank, cooled in the chiller, and charged into the stratified tank again through the bottom diffusers. The inlet temperature of the stored chilled water gradually decreases as the stored volume increases. This is due to a comparatively lower rate of heat transfer to the inlet water from the warmer ambient water, piping, and tank wall after the beginning of the charging process [13].

During the discharging process, stored chilled water is extracted from the stratified tank and supplied to the cooling coils in the air-handling units and terminals. The return chilled water is introduced to the stratified tank through the top diffusers. The outlet temperature of the stored chilled water gradually increases as the stored volume decreases. Both the outlet temperature of return chilled water during charging and inlet temperature of return chilled water during discharging should be controlled between 55 and 60°F (12.8 and 15.6°C) so that stratification can be maintained in the storage tank [13].

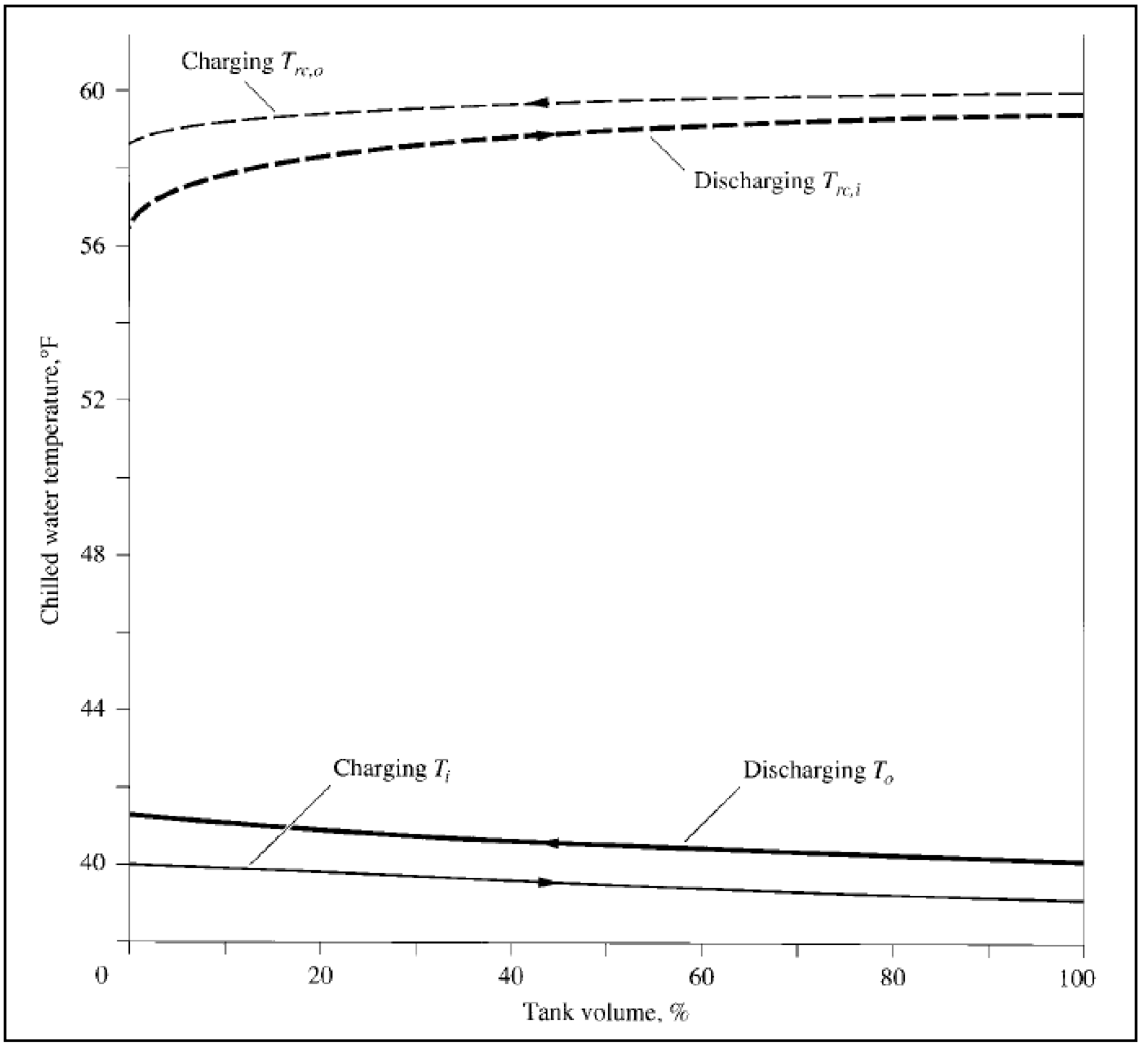


Figure 6: Chilled water temperature versus tank volume curves during charging and discharging process [13]

2.2.2 Steam absorption Chiller

The absorption chillers use heat instead of mechanical energy to provide cooling. A thermal compressor consists of an absorber, a generator, a pump, and a throttling device, and replaces the mechanical vapor compressor. In the chiller, refrigerant vapor from the evaporator is absorbed by a solution mixture in the absorber. This solution is then pumped to the generator. There the refrigerant re-vaporizes using a waste steam heat source. The refrigerant-depleted solution then returns to the absorber via a throttling device [8].

The two most common refrigerant used in absorption chillers are:

- Water with lithium bromide
- Ammonia with water.

There are several types of steam absorption chiller and generally classified as follows:

- single (direct- or indirect-fired)
- double (direct- or indirect-fired)
- Triple-effect (direct- or indirect-fired)

In direct-fired units, the heat source can be gas or some other fuel that is burned in the unit. Indirect-fired units use steam or some other transfer fluid that brings in heat from a separate source, such as a boiler or heat recovered from an industrial process. The details of each system state below:

- Single Effect

The single-effect "cycle" refers to the transfer of fluids through the four major components of the refrigeration machine - evaporator, absorber, generator and condenser, as shown in the Pressure-Temperature diagram in figure 7.

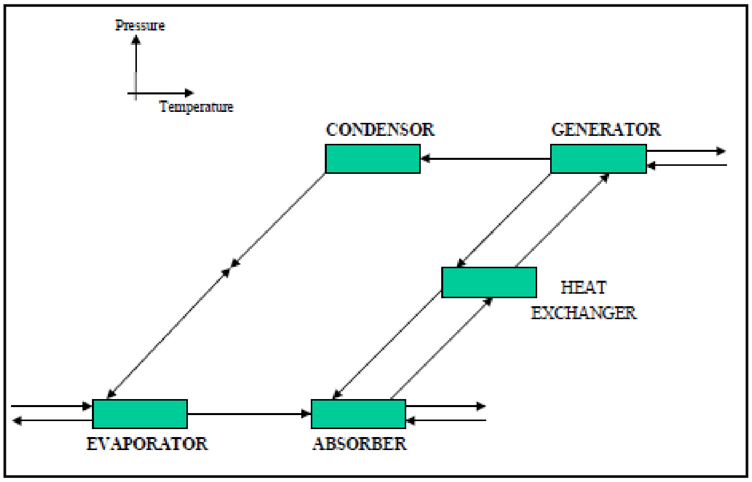


Figure 7: Single-effect absorption refrigeration cycle

Single-effect LiBr/H_2O absorption chillers use low pressure steam or hot water as the heat source. The water is able to evaporate and extract heat in the evaporator because the system is under a partial vacuum. The thermal efficiency of single-effect absorption systems is low. Single-effect chillers can be used to produce chilled water for air conditioning and for cooling process water, and are available in capacities from 7.5 to 1,500 tons.

- Double Effect

The double-effect chiller differs from the single-effect in that there are two condensers and two generators to allow for more refrigerant boil-off from the absorbent solution. Figure 8 shows the double effect absorption cycle on a Pressure-Temperature diagram.

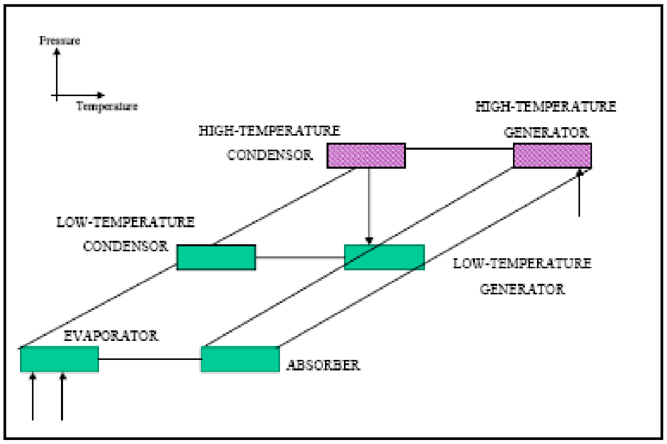


Figure 8: Double effect absorption refrigeration cycle [5]

The higher temperature generator uses the externally supplied steam to boil the refrigerant from the weak absorbent. The refrigerant vapor from the high temperature generator is condensed and the heat produced is used to provide heat to the low temperature generator.These systems use gas-fired combustors or high pressure steam as the heat source.

Double-effect absorption chillers are used for air-conditioning and process cooling where the cost of electricity is high relative to natural gas. These chillers are also used in applications where high pressure steam, such as district heating, is readily available. Although the double-effect machines are more efficient than single-effect machines, they have a higher initial manufacturing cost.

2.2.3 Electric chiller

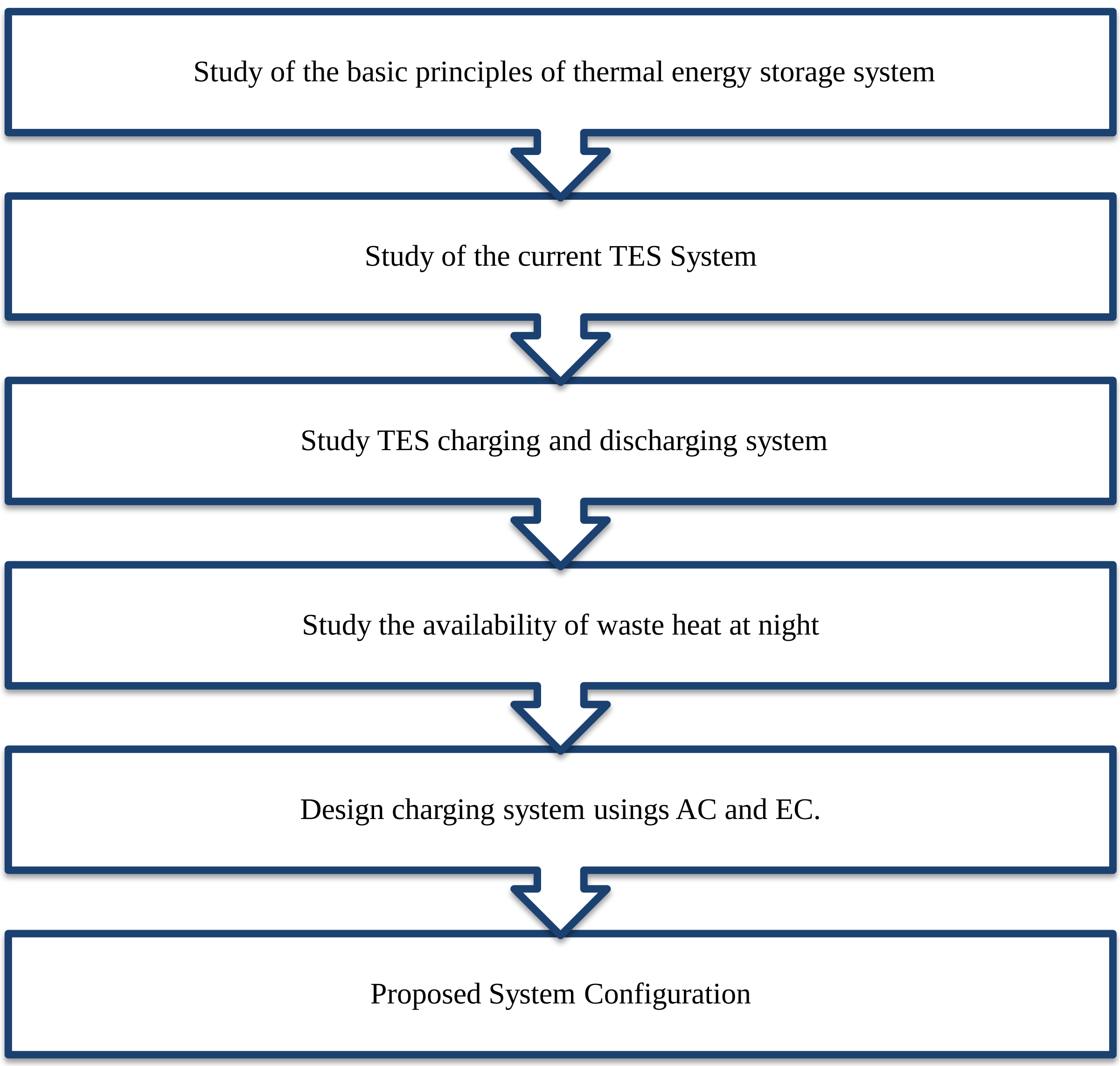
The basic cooling cycle is the same for the absorption and electric chillers. Both systems use a low-temperature liquid refrigerant that absorbs heat from the water to be cooled and converts to a vapor phase (in the evaporator section). The refrigerant vapors are then compressed to a higher pressure (by a compressor or a generator), converted back into a liquid by rejecting heat to the external surroundings (in the condenser section), and then expanded to a low- pressure mixture of liquid and vapor (in the expander section) that goes back to the evaporator section and the cycle is repeated.

The basic difference between the electric chillers and absorption chiller is that an electric chiller uses an electric motor for operating a compressor used for raising the pressure of refrigerant vapors and an absorption chiller uses heat for compressing refrigerant vapors to a high-pressure.

CHAPTER 3

METHODOLOGY

3.1. Project methodology



3.2. Project Activities

3.2.1. Study the current TES system

The UTP gas district cooling TES system is currently operate under partial storage operating strategy – demand limiting. With demand limiting operating strategy, it is designed to operate at full capacity during all off-peak hours to charge storage on the hottest anticipated days. The charging system of TES tank was fulfilled only by Electric Chillers (EC) and the charging period was done during the night. The scope of this project is focusing on the TES tank charging system that include TES tank, Steam Absorption Chiller (SAC) and Electric Chiller. The TES tank is designed to use both SAC and EC [2].

3.2.2. Data analysis

Several data analysis has been done by using the data from GDC UTP [9] as follows:

a) Current profile of Chilled Water production by GDC UTP
   - The daily analysis of chilled water production by GDC UTP for the one month period from 11th April 2009 to 11th May 2009.
   - The plotted data shows the total value of chilled water production, in plant used and supply to UTP.

b) TES holding capacity charging and discharging mode.
   - The hourly analysis of chilled water holding capacity in TES tank has been done for the 3 selected days which are 21st , 22nd and 23rd April 2009.
   - The plotted data shows the pattern of charging and discharging time of the chilled water for each day during one month period.

c) Temperature distribution profile of chilled water in TES tank for the selected day which is on 21 April 2009.

d) Chilled water generated by SAC and EC

- The hourly data analysis has been done for the three selected days which are 21, 22 and 23 April 2009. The analysis objective is to determine the pattern of SAC and EC generated of chilled water.

The findings on these analyses are discussed in the next section.

3.2.3. System Configuration

To establish system configuration, the available equipment were taken into consideration. Based on the proposed system configuration, additional equipment and accessories installation are required as an additional to the existing equipment. The additional equipment and accessories to be installed consist of pump, valves as well as new piping system. The calculations involved in design process are being explained in the next chapter.

3.2.4. Tools and Software Required

Software used to complete this project was AutoCAD 2008 for design proposes. AutoCAD is a CAD (Computer Aided Design or Computer Aided Drafting) software application for 2D and 3D design and drafting. It was developed and sold by Autodesk, Inc.

CHAPTER 4

RESULTS AND DISCUSSION

4.1. Brief description TES Configuration

TES system is designed to reduce of total chiller's capacity by using stored chilled water in TES at peak time of chilled water demand by customer. Also during high electric consumption in plant at the peak time can be deducted, due to reduction of total chiller's capacity. The operating strategies for chillers were designed to support the partial load strategy for TES system. The SACs are to be operating during the day and the ECs to be operated during the night for charging the thermal storage tank. The TES tank was design to supplement the chilled water requirement during the day. Inside the TES, there are 14 temperatures that have been taken into control and the lowest temperature has become the final temperature of chilled water supply to UTP.

4.2. Study on the GDC UTP TES System

The results on the study cover the following matter:

- Daily Chilled water production by TES
- Charging and discharging mode of TES tank
- Chilled water generated by SAC and EC

The findings of the study are discussed in details in the following Sections.

4.3. Daily chilled water production by TES

The main elements of chilled water production system consist of:

- Steam absorption Chiller, SAC
- Thermal Energy Storage, TES tank – For storing the chilled water
- Electric Chiller, EC – for charging TES tank.

The chilled water supply and return system is connected with the elements above to maintain the return and differential pressure of the system. Pressure of chilled water system is maintained at 1.4 bars. The primary pump system is provided in chilled water system, so that pumps in SAC and TES system supply directly chilled water to the customer.The chilled water is supplied to customer at $6^{o}C$ from plant, and then returned at 13.5 ^{o}C.

The analysis of overall daily chilled water production by TES and the chilled water generated by SAC and EC are shown in figure 9 and 10. The analysis was for the one month period from 11th April 2009 to 11th May 2009.

i) Overall chilled water production by TES

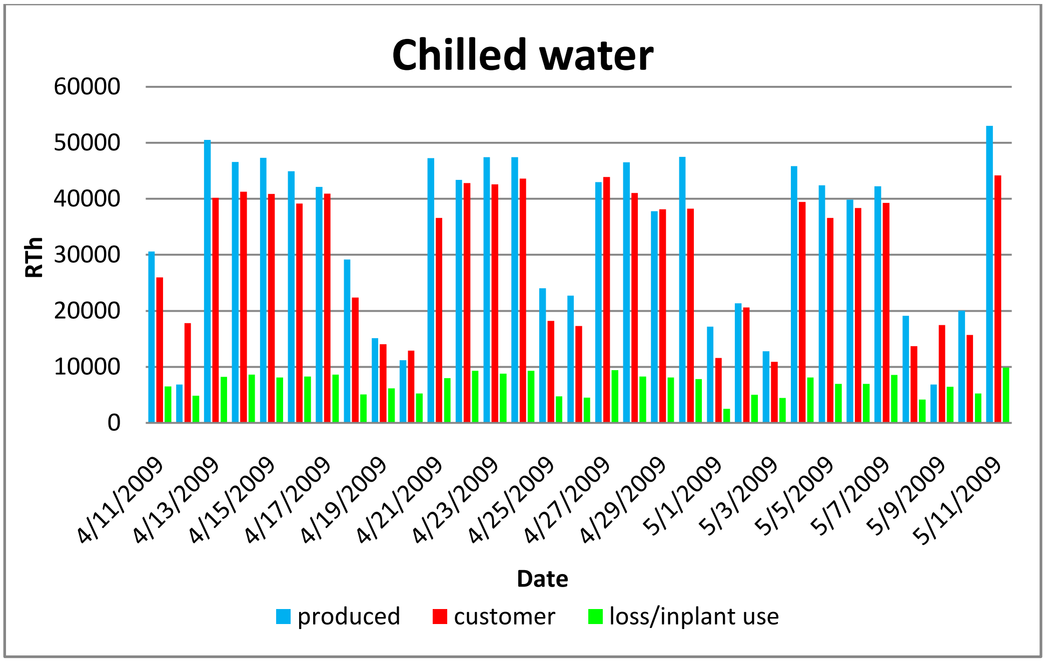


Figure 9: Chilled water production

From Figure 9 it is seen that:

- The chilled water produced was not totally supplied to customer building but also used in plant.
- The average chilled water by GDC plant of that month was about 33944RTh. 30511RTh was supplied to UTP and 6983RTh was for in plant use.

ii) Chilled water generated by SAC and EC

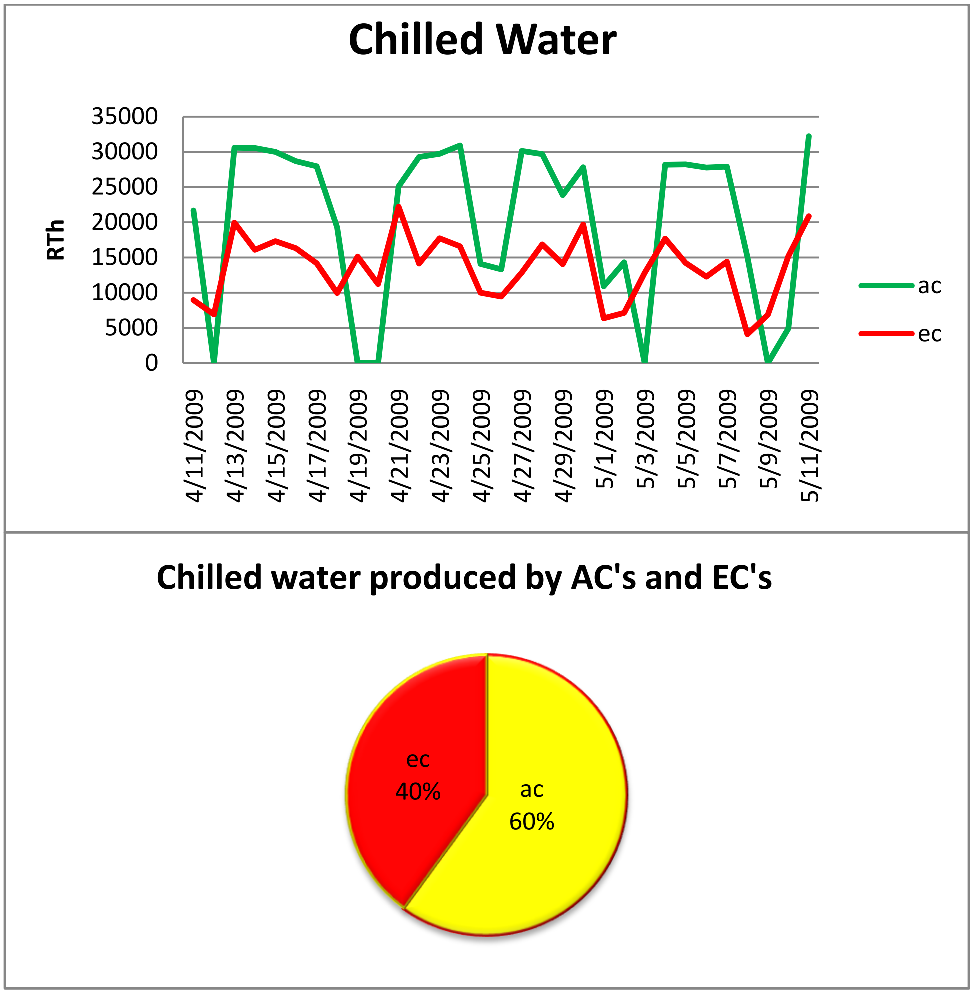


Figure 10: Chilled water production by EC and SAC for 4th - 5th April 2009

Figure 10 shows the chilled water produced by 2 units of absorption chillers and 4 units of electric chillers. The following points are note:

- The daily average production of chilled water by Absorption Chillers and Electric Chillers were 20393.16 RTh and 13587RTh respectively.
- The Absorption chillers contributed 60% of the chilled water requirement whereas only 40% fulfilled by the Electric chillers.

4.4. Current Practice Of Charging And Discharging Mode Of TES Tank

The current system is designed to use only the Electric chiller (EC) for TES tank charging purposes. The designated time operation of charging and discharging TES tank is as below:

- Charging process: 12.00 am – 6.00 am
- Discharging process: 6.00 am – 12.00 am

However, the practice was the charging period varied based on UTP daily demands. Figure 11 shows the analysis of daily holding capacity of TES tank including the charging and discharging period of TES tank. The analysis was done for the three selected days which are 21st, 22nd and 23rd April 2009.

The analysis was also done to observe the temperature distribution of chilled water in TES tank during charging and discharging cycle. The analysis was done for the data on 21st April 2009. Results obtained are shown in the Figure 11, 12 and 13.

i) TES Holding Capacity during charging and discharging cycle

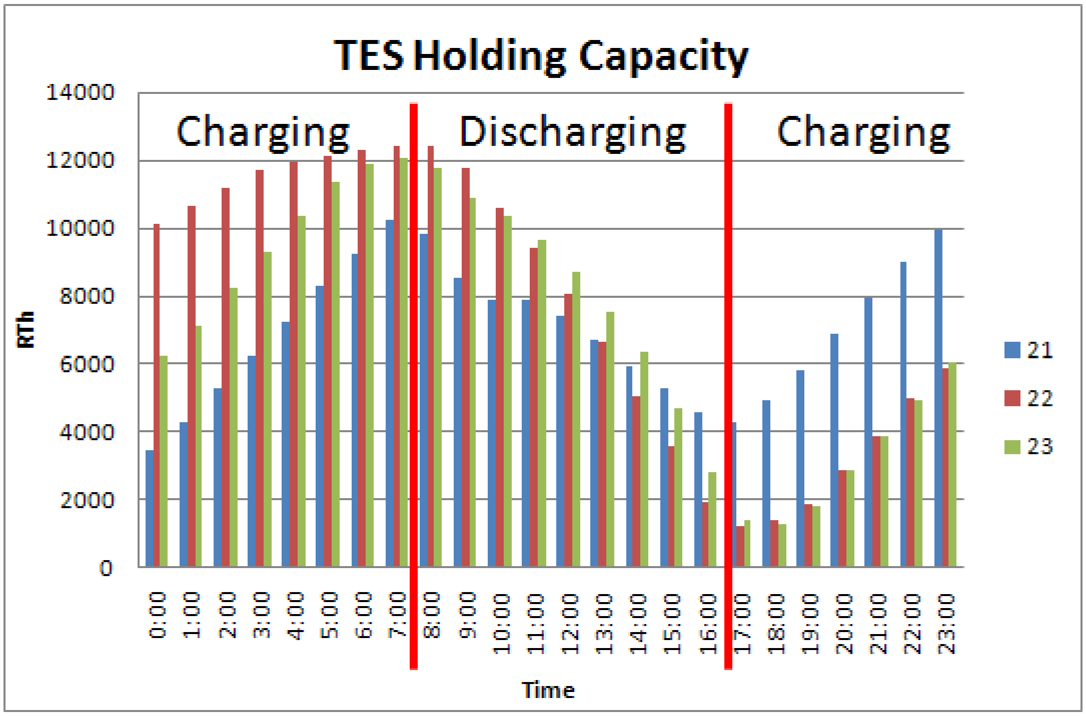


Figure 11: TES holding capacity

Figure 11 shows the hourly analysis of three selected day of TES tank holding capacity. From the Figure 11 it is seen that:

- The time of charging and discharging period varied depending on UTP daily demands. TES holding capacity of chilled water was only about 12,200RT which was at 7 am; right before TES tank started discharged chilled water for UTP demand.
- The required time to charge the TES tank to its full capacity is 14 hours. It take 8 hours more than setup time which is only 6 hours.
- Based on calculation the average holding capacity of TES tank was about 17,039.4 RT and much higher than the current system can achieve.

ii) Temperature distribution of Chilled Water in TES tank

- During Charging Cycle

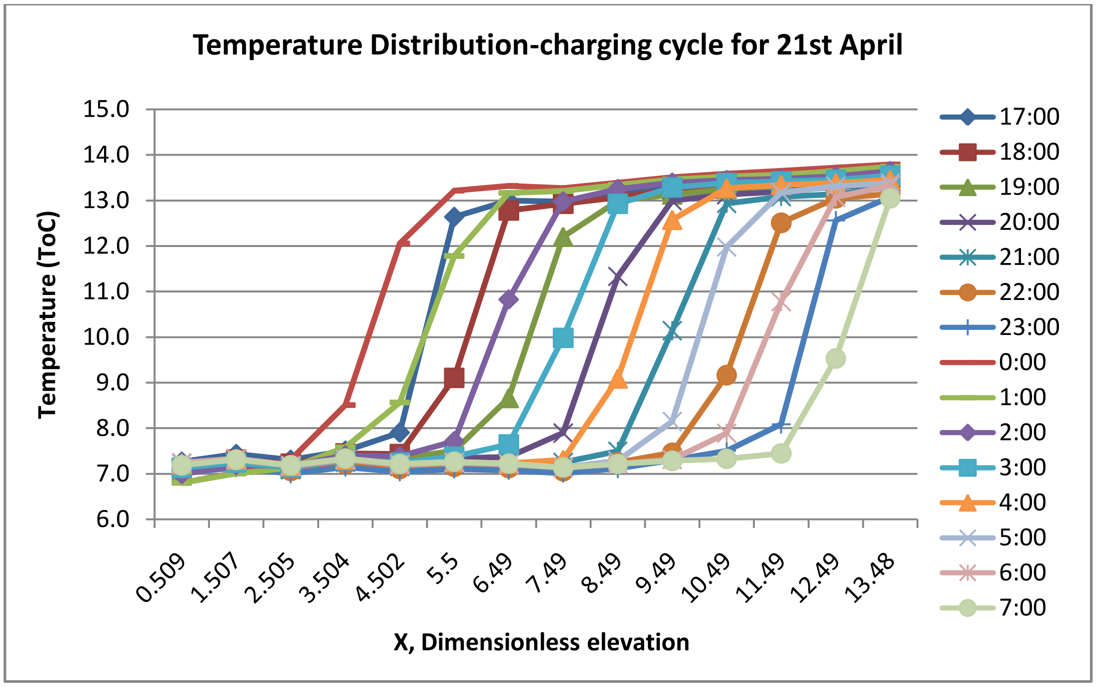


Figure 12: Temperature distribution for charging cycle

- During Discharging Cycle

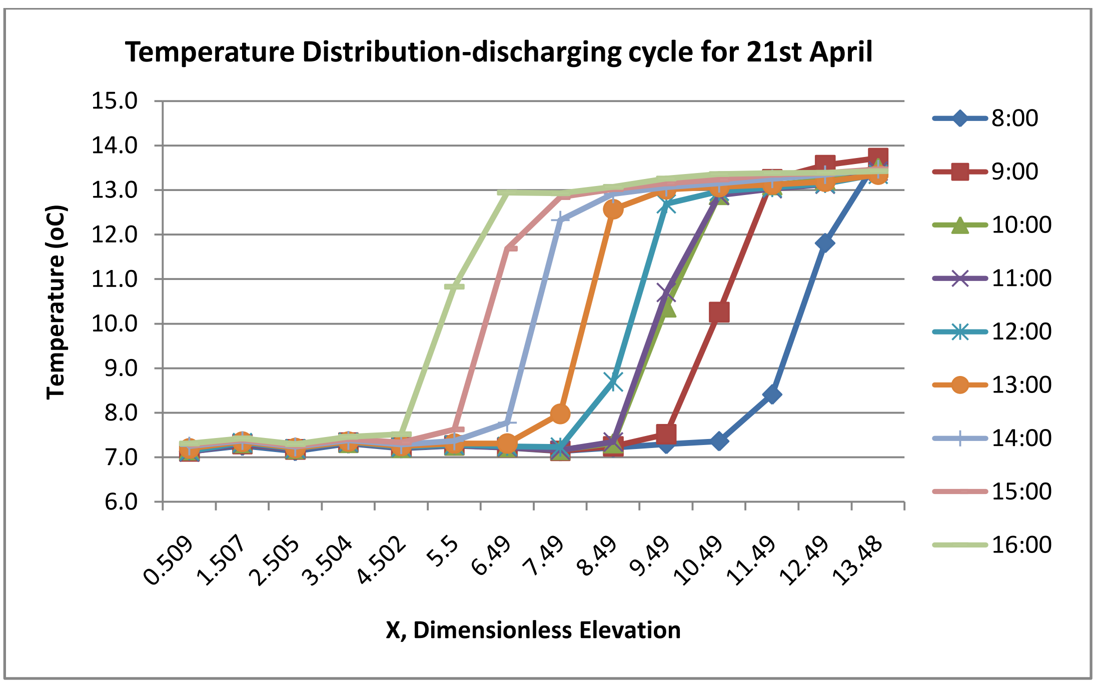


Figure 13: Temperature distribution for discharging cycle

The X variable in the Figure 11 and 12 expresses the dimensionless elevation (x.N/H), where x is the elevation of the temperature sensors (in meter), H is the effective height of the tank content of water (14.025 m) and N number of stratified layers.

Figure 12 and 13 show the temperature distribution for charging and discharging cycle. The time of charging and discharging are as follows:

- Charging cycle averagely started from 5.00 pm to 7.00am (14 hours)
- Discharging cycle averagely started from 7.00 am to 4.00 pm (9 hours)

4.5. Performance analysis of the current TES system

4.5.1. TES holding capacity

GDC plant TES tank design parameters;

- Flow rate = 262 – 604 m^3/h
- Temperature = 5 – 13.5 ^oC
- Refrigerant ton hour = 10000 RTh

Q evaluated as follows:

$$Q = \dot{m} c_p (T_{in} - T_{out}) \tag{1}$$

Where;

- $\dot{m} = mass\ flow\ rate$
- $c_p = specific\ heat\ \left(4.186 \frac{kJ}{kgK}\right) or\ \frac{1}{3.024}\ RT$
- $T = temperature$ (℃)

The calculation for TES tank holding capacity based on average flow rate:

$$average\ flow\ rate = \frac{604 + 262}{2}$$
$$= 433\ m^3/h$$

- For average holding capacity in an hour, flow rate is set to be 433 (m^3/h):

$$Q = \frac{604}{3.024}(13.5 - 5)(14\ hr)$$
$$\underline{\underline{Q = 17039.4\ RT}}$$

4.5.2. Required time to charge TES tank

The current charging system is using only Electric Chiller to charge the TES tank. Equation as state below was used to calculate the time needed to cool the TES tank by EC.

$$\boldsymbol{q = v\rho c}\ (\Delta \boldsymbol{T}) \tag{2}$$

Where;

q = sensible heat storage

v = TES tank volume

ρ = density of water

c = specific heat

$(\Delta T) = T_f - T_i$

<u>Electric Chiller</u>

$q = (5400\ m^3)(1000\ kg/m^3)\ (4190\ J/kg\ ^oC)(13.5^oC - 5^oC)$

$= 1.923 \times 10^{11}$ J

$= 192.231 \times 10^6$ kJ

Power = 1 units electric chiller – 325 RT = 1142.98 kW,

**1 TR = 3.5168 kW*

$$Time\ = \frac{work, q}{power}$$

$$= \frac{192.321 \text{ x } 10^6 \text{ kJ}}{4 \text{ x } 1142.98 \text{ kW}}$$

= 42065.70 s = <u>11.685 hr</u>

The time required by current system is <u>11.685 hr</u> for charging the TES tank.

4.6. The proposed 2-stage charging system for TES

The current systems only uses electric chiller (EC) to charge TES tank. From the previous analysis it is noted that the current system is not able to charge TES tank to its full capacity due to time limitation. Thus, the TES tank is not being fully utilized. An option to improve this problem two stage charging system is proposed. Details of the proposal are discussed in the following sections.

In this proposed charging system, Steam absorption chiller (SAC) will be used to charge the TES tank until certain temperature for the first stage and continue with Electric Chiller (EC) for the second stage. New piping and other equipment have to be installed from SAC to TES tank as to activate this system. Figure 14 shows the current system of TES tank charging system and the red dotted shows the new piping requirement.

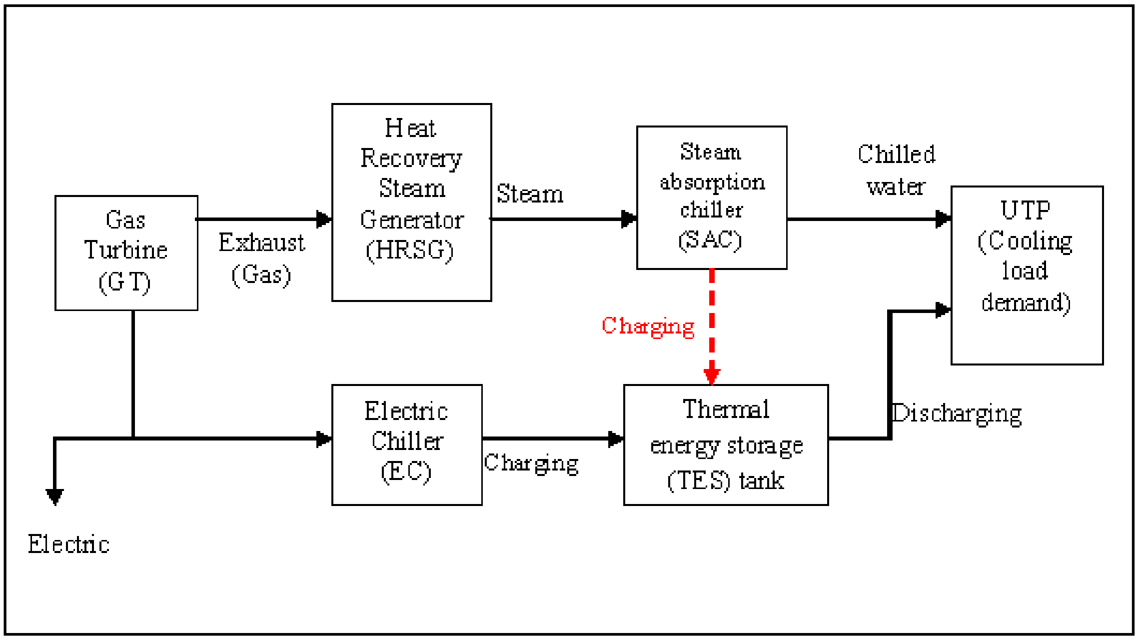


Figure 14: Proposed process flow of 2-stage charging system

The system is using absorption chiller and electric chiller for the charging process. Absorption chiller is proposed for the first stage charging system that will cool the waste heat from two unit's gas turbines to minimum temperature that can be cooled by

Absorption chiller which is 9^{o}C. After the required temperature reached, electric chiller will be automatically operated to cool the water to 5^{o}C.

Two temperature sensors is to be installed inside the tank; one at the bottom of the tank and one just under the water level. Both sensors is to be connected to temperature transmitter. The temperature transmitter will send a signal to the controller which controls both valves installed on the two lines coming from the EC and SAC. The control conditions are as follow;

T > 9°C → SAC valve is open and EC valve is closed
T≤ 9°C → SAC valve is closed and EC valve is open
T = 5°C → Both SAC and EC valves are closed.

Under design conditions, the fully charge thermal storage tank cooling capacity is 10000 RTh. The process flow of charging and discharging mode is show in the Figure 15 and Figure 16.

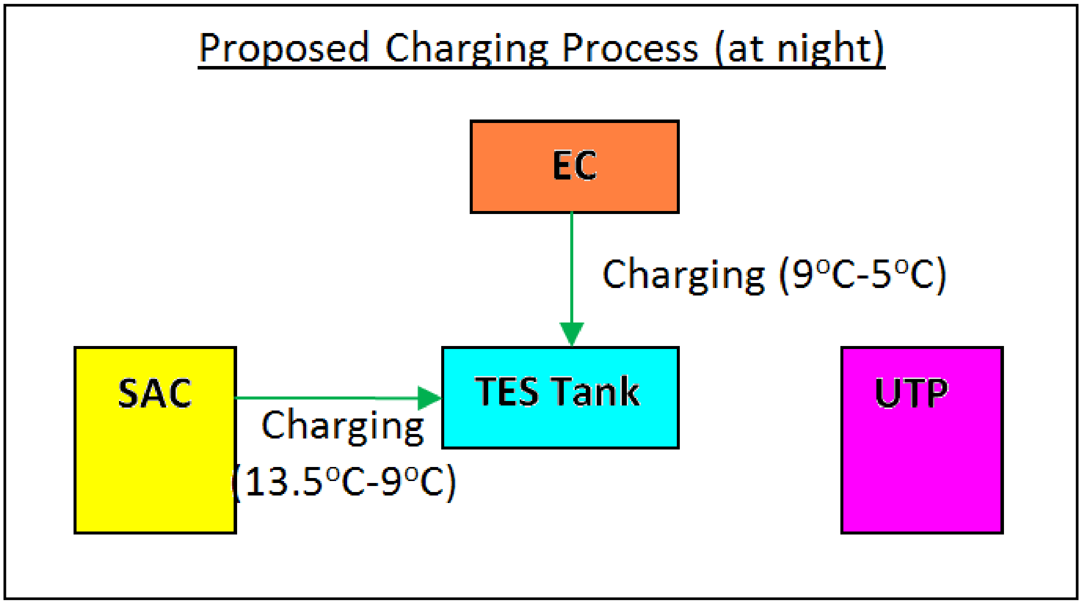


Figure 15: The process flow during the proposed charging process

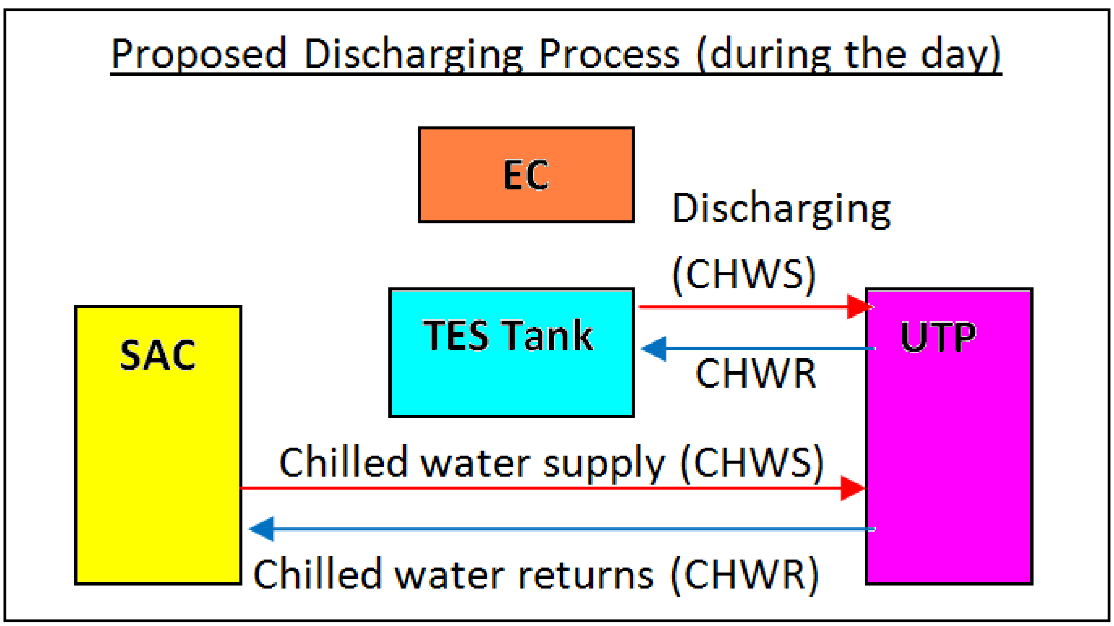


Figure 16: The process flow during the proposed discharging process

4.6.1. The proposed design

1. <u>Availability of energy from SAC</u>

The energy balance for SAC has been analyzed. The block diagram for SAC is as followed:

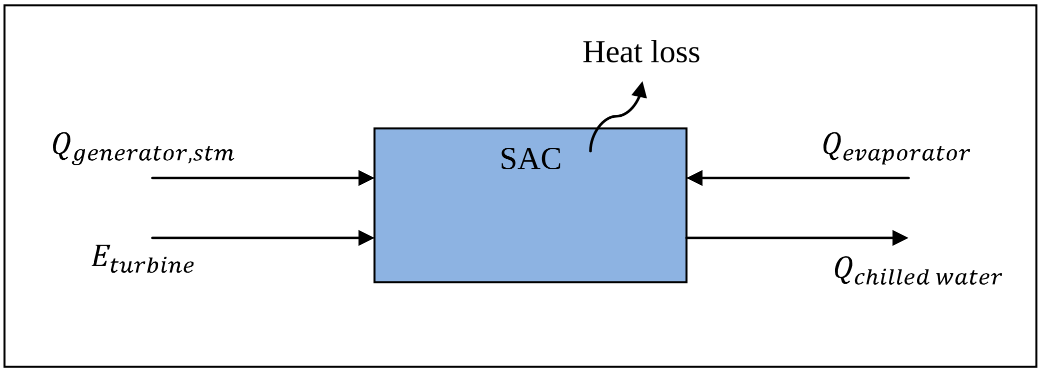


Figure 17: Block diagram for SAC

Energy balance equation;

$$\dot{E}_{in} = \dot{E}_{out} \tag{3}$$

Gives;

$$\dot{Q}_{gen} + \dot{Q}_{eva} + E_{turbine} = \dot{Q}_{cw} + heat\ loss \tag{4}$$

- $\dot{Q}_{gen}$ - The energy from the steam system which is header from Heat Recovery Steam Generator (HRSG) to Steam Absorption Chiller (SAC).
- $\dot{Q}_{eva}$ – The energy from water at cooling tower which enters the SAC. The chilled water is cooled to desired temperature inside the SAC (evaporation stage).
- $E_{turbine}$ - Power production of Gas Turbine Generator (GTG) which is the power supply for the whole system.

The design parameters for each stage are as follows:

Table 1: Design parameter of SAC

Parameter	Steam (to SAC)	Cooling tower (for SAC)	Gas Turbine generator
Flow rate (tone/h)	12.5	920	-
Pressure (bar)	8.5	25	-
Temperature (^{o}C)	90	13.5 - 6	4200

Thus, energy available in SAC is calculated below:

- 1) $\dot{Q}_{gen}$ Calculation

$$\dot{Q}_{gen} = \dot{m}_{steam}\left(h_{g@8.5\ bar} - h_{f@90℃}\right) \tag{5}$$

Where;

$$\dot{m}_{steam} = 12.5\ \frac{tonne}{h}$$

$$\dot{m}_{steam} = \left(12.5\ \frac{tonne}{h}\right)\left(1000\ \frac{kg}{tonne}\right)$$

$$\dot{m}_{steam} = 12500\ \frac{kg}{h}$$

Assume the mass flow rate in 1 hour;

$$\dot{m}_{steam} = \frac{12500}{3600}\frac{kg}{s} = 3.47\frac{kg}{s}$$

From thermodynamics properties table;

$h_{g@8.5\ bar} = 2770.5\ kJ/kg$

$h_{f@90℃} = 377.04\ kJ/kg$

Thus,

$$\dot{Q}_{gen} = \left(3.47\frac{kg}{s}\right)(2770.5 - 377.04)kJ/kg$$

$$\boldsymbol{\dot{Q}_{gen} = 8310.6\frac{kJ}{s}}$$

- <u>2) $\dot{Q}_{eva}$ Calculations</u>

$$\dot{Q}_{eva} = \dot{m}_{cw}c_p(T_{in} - T_{out}) \qquad (6)$$

Where;

$$\dot{V} = 920\frac{m^3}{h}$$

$$\dot{m}_{cw} = 920\frac{m^3}{h} x\ 1000\frac{kg}{m^3} \div 3600s = 255.6\frac{kg}{s}$$

$$c_p = 4.186\frac{kJ}{kg}K$$

$$T_{in} = 13.5℃$$

$$T_{out} = 6.0\ ℃$$

Thus,

$$\dot{Q}_{eva} = 255.6\frac{kg}{s}\left(4.186\frac{kJ}{kg}K)(13.5 - 6.0\right)℃$$

$$\boldsymbol{\dot{Q}_{eva} = 8023.2\frac{kJ}{s}}$$

- <u>3) GTG power production</u>

GTG power production is fixed at 4200 kW. Thus,

$$\boldsymbol{E_{turbine} = 4200\frac{kJ}{s}}$$

From equation 4 and assuming the heat loss is considering in the $\dot{Q}_{eva}$calculation, thus the output energy (chilled water) which is energy available to charge TES tank from SAC is:

$$\dot{Q}_{cw} = 8310.6\frac{kJ}{s} + 8023.3\frac{kJ}{s} + 4200\frac{kJ}{s}$$

$$\boldsymbol{\dot{Q}_{cw} = 20533.8\frac{kJ}{s}}$$

2. <u>SAC Performance</u>

To calculate the SAC performance, the time which SAC is currently set idle (12 am until 6am) will be used to generate chilled water which then can be supplied to charge TES tank. Steam (wate heat) properties are set as state in table below.

Table 2: Waste heat parameter

Steam (For SAC)	
Flow rate (ton/h)	12.5
Pressure (bar)	8.5
Temperature (℃)	90

The calculation of the chilled water generated using equation is as follows;

$$Q = \dot{m}c_p(T_{in} - T_{out}) \tag{7}$$

Where:

$\dot{m} = mass\ flow\ rate$

$c_p = specific\ heat\ \frac{1}{3.024}RT$

$T = Temperature$ ℃

The data was based on 22nd April 2009. A set of chilled water generated was calculated using Microsoft Excel. The result was plotted in a graph in Figure 18 to compare the performance of the current system and the proposed system.

Table 3: Comparison of chilled water generated by current practice and Proposed design.

hour	chilled water generated(current) (RT)	flow rate (m3/h)	chilled water in (℃)	chilled water out (℃)	chilled water generated (proposed) (RT)
0:00	0	504	13.2	12.1	193.40
1:00	0	504	13.7	12.5	197.56
2:00	0	504	14.2	12.9	206.15
3:00	0	504	14.6	13.3	212.66
4:00	0	504	14.9	13.6	219.50
5:00	0	504	15.2	13.9	222.78
6:00	4	504	15.0	13.8	203.61
7:00	602	504	10.8	7.1	605.84
8:00	914	504	12.5	7.0	914.35
9:00	991	504	12.8	6.8	990.07
10:00	975	504	12.8	6.9	974.36
11:00	973	504	12.8	7.0	972.46
12:00	971	504	12.9	7.1	970.11
13:00	997	503	13.5	7.6	996.48
14:00	974	503	13.4	7.5	972.21
15:00	982	503	13.6	7.7	981.56
16:00	993	503	13.4	7.4	991.63
17:00	1034	503	13.7	7.5	1032.01
18:00	982	503	13.1	7.2	980.23
19:00	978	503	12.9	7.1	976.82
20:00	992	503	13.0	7.0	990.41
21:00	969	503	12.6	6.7	969.69
22:00	278	503	12.0	10.0	344.79
23:00	0	503	12.5	11.8	111.65

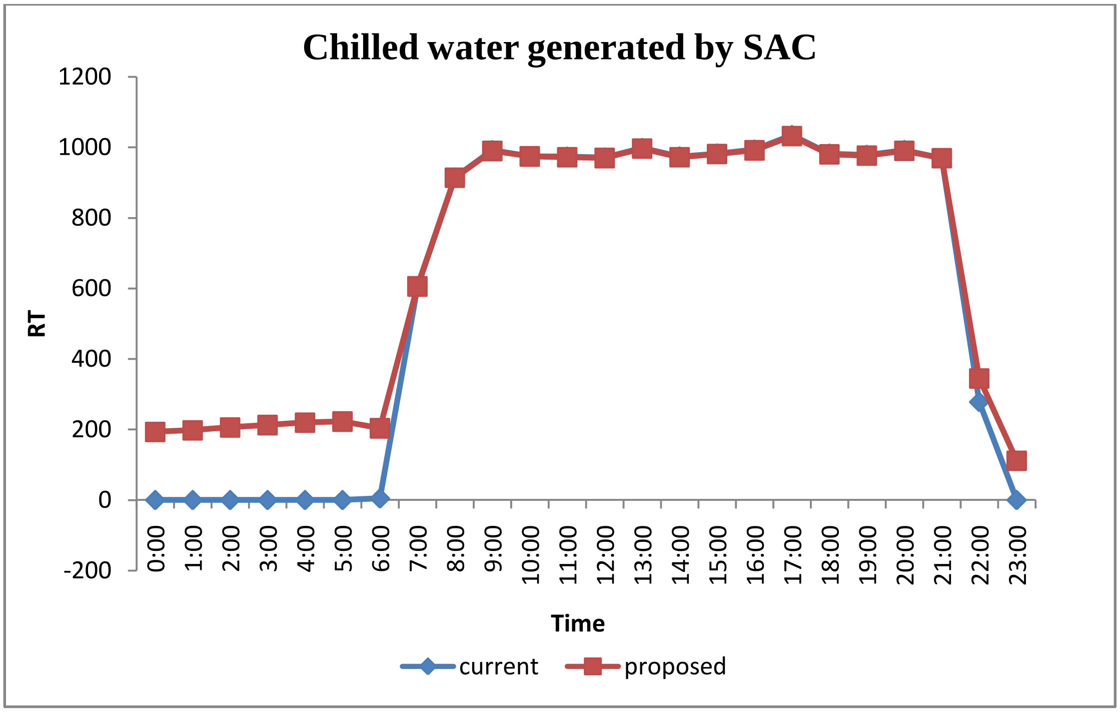


Figure 18: chilled water generated by SAC for current and proposed system

Figure 18 shows that;

- In current system, chilled water was not generated during mid-night (at 12 am until 6 am) due to no demand from customer and SAC stop their operation.
- For the proposed system, SAC is to operate for 24 hours to enable charging of the TES tank. The chilled water production is expected to increase due to the increasing demand from customer.

3. <u>Time to charge the TES Tank</u>

Time required to cool down the chilled water from 13.5°C to 5°C has been analyzed.

a) Steam Absorption Chiller

SAC design parameters are:

- Flow rate (m^3/h) = 504
- Temperature (°C) = 13.5 – 9
- Refrigerant ton (RT) = 1250

The equation state below is used:

$$Q = \dot{m}c_p(T_{in} - T_{out})(t) \tag{8}$$

Where:

Q = 1250RT

$\dot{m}$ = mass flow rate, 504 m^3/h

$c_p = specific\ heat\ \left(4.186\frac{kJ}{kgK}\right) or\ \frac{1}{3.024}RT$

T = time (hour)

T = temperature (°C)

T_{out} is set at 5°C and T_{int} will be determined by the equation 8. As state below is the sample of calculations.

For t = 1 hour,

$$T_{out} = \left(\frac{1250}{\frac{504}{3.024}}\right) + 5℃$$

$$T_{out} = 12.5℃$$

The remaining hour is calculated using Microsoft Excel. The results are shown below.

Table 4: The charging temperature of TES tank by SAC in every hour

t (hour)	Tin (^{o}C)
1	12.50
2	8.75
3	7.50
4	6.88
5	6.50
6	6.25
7	6.07

Based on the table calculated above, the time taken for SAC to cool down the temperature is only 2 hour since the minimum temperature can be cooled by SAC is only at 9^{o}C.

b) Electric Chiller

Required time by electric chiller to charge TEs tank is calculated using equation 2.

Electric Chiller

q = (5400 m^{3})(1000 kg/m^{3}) (4190 J/kg ^{o}C)(9^{o}C – 5^{o}C)

= 9.0504 x 10^{10} J

= 90.504 x 10^{6} kJ

Power = 1 units electric chiller – 325 RT = 1142.98 kW,

**1 TR = 3.5168 kW*

For 1 unit of electric chiller;

$$Time \ = \frac{work, q}{power}$$

$$= \frac{90.504 \text{ x } 10^{6} \text{ kJ}}{1142.98 \text{ kW}}$$

= 79182.488s = 21.99hr

For 2 units of electric chillers usage;

$$Time = \frac{work, q}{power}$$

$$= \frac{90.504 \text{ x } 10^6 \text{ kJ}}{2\text{x}1142.98 \text{ kW}}$$

= 39591.24s = 10.998hr

For 3 units of electric chillers usage;

$$Time = \frac{work, q}{power}$$

$$= \frac{90.504 \text{ x } 10^6 \text{ kJ}}{3\text{x}1142.98 \text{ kW}}$$

= 26394.16 = 7.33hr

For 4 units of electric chillers usage;

$$Time = \frac{work, q}{power}$$

$$= \frac{90.504 \text{ x } 10^6 \text{ kJ}}{4\text{x}1142.98 \text{ kW}}$$

= 19795.62s = 5.50hr

Total time taken by SAC and EC to charge TES tank as stated in the table below:

Table 5: Total time taken to charge TES tank by SAC and EC

No of EC	Time taken by EC, Hr	Time taken by SAC, Hr	Total Time, Hr
1	21.99	2.00	23.99
2	10.998	2.00	12.998
3	7.33	2.00	9.33
4	5.50	2.00	7.50

4. Pipe Design

- <u>Design Condition:</u>

Table 6: Design condition of new piping system

Fluid	Chilled Water
Pressure, kgf/cm^2G	1.4 -6.6
Temperature	6.0 – 13.5
Class	JIS 10K

- <u>Pipe Sizing</u>

- Current SAC piping

Designated flow rate = 504 m^3/hr

= 2 units x 504 m^3/hr

= 1008 m^3/hr x 1hr/3600s

= 0.28 m^3/s

Pipe diameter = 0.7 m

Area of pipe = $\pi/4\ (0.7)^2$

= 0.3848 m^2

$$Velocity\ =\ \frac{Flow\ rate}{volume}$$

$$Velocity\ =\ \frac{0.28\ m^3}{0.3848\ m^2} = 0.7276\ \mathrm{m/s}$$

- SAC to supply chilled water to TES tank:

TES Tank Volume: 5400m^3

Velocity = 0.7276 m/s

$$Time = \frac{Volume}{Flow\ rate}$$

Assuming we want to charge TES tank in 4 hours, the suitable pipe diameter are:

$$4\ x\ 3600s = \frac{5400\ m^3}{Flow\ rate}$$

Flow rate = 0.375 m^3/s

- Pipe Diameter.

$$Flow\ rate = \frac{\pi D^2}{4} \quad , D = diameter\ of\ pipe$$

$$D = \sqrt{\frac{4x0.375}{\pi}}$$

D = 0.691 x 10^3 mm

D = 691 mm

Based on nominal pipe diameter size Table (Appendix1),

The nearest pipe diameter is 700 mm (same with existing pipe diameter)

The material of new pipe system is based on existing pipe specification:

- Material - Welded and Seamless Wrought Steel Pipe

Based on Carbon, Alloy and Stainless Steel Pipes - ASME/ANSI B36.10/19, the possible condition of new pipe as shown in table below;

Table 7: Possible condition of new pipe design

Pipe size (inches)	Outside diameter (inches)	Identification			Wall thickness, t (inches)	Inside diameter, d (inches)
		Steel		Stainless steel schedule No.		
		Iron pipe size	Schedule no.			
28	28	-	10	-	0.312	27.367
		STD	-	-	0.375	27.250
		XS	20	-	0.500	27.000
		-	30	-	0.625	26.750

**1mm = 25.4 mm*

4.6.2. The Proposed configuration

The proposed system is designed using AutoCAD. Basically the task needed to activate the system is by installing additional piping from SAC to the TES tank, a number of valves and pumps.

General design considerations include:

- The storage tank is based on current installation
- The operating strategies is partial storage (demand-limiting)
- Temperature of the chilled water supply to the customer at 5^{o}C and the returning temperature are at 13^{o}C.
- The chiller operating conditions while charging the storage
- The inlet temperature should be maintained constant whenever possible

Detailed equipment needs to be installed are as followed:

- New piping system connecting the SAC to the TES tank for charging process and the return passage.
- 1 units of Gate valve to be installed at the new pipeline.
- 2 units of 2-ways control valve

During the night operation, the valve is opened to allow the chilled water from SAC enter the tank until the set temperature reach, which is 9^{o}C. Electric chiller will continue the charging process until the temperature in the TES tank reach 5^{o}C. The chilled water will be stored until the required demand start on the next daytime. During the discharging period (day time), the control valve will be closed and no charging system by SAC and EC will be operate. The discharging of chilled water from TES tank will be use the same piping with the current practice. The drawing of new configuration is as shown in the figure 17 below:

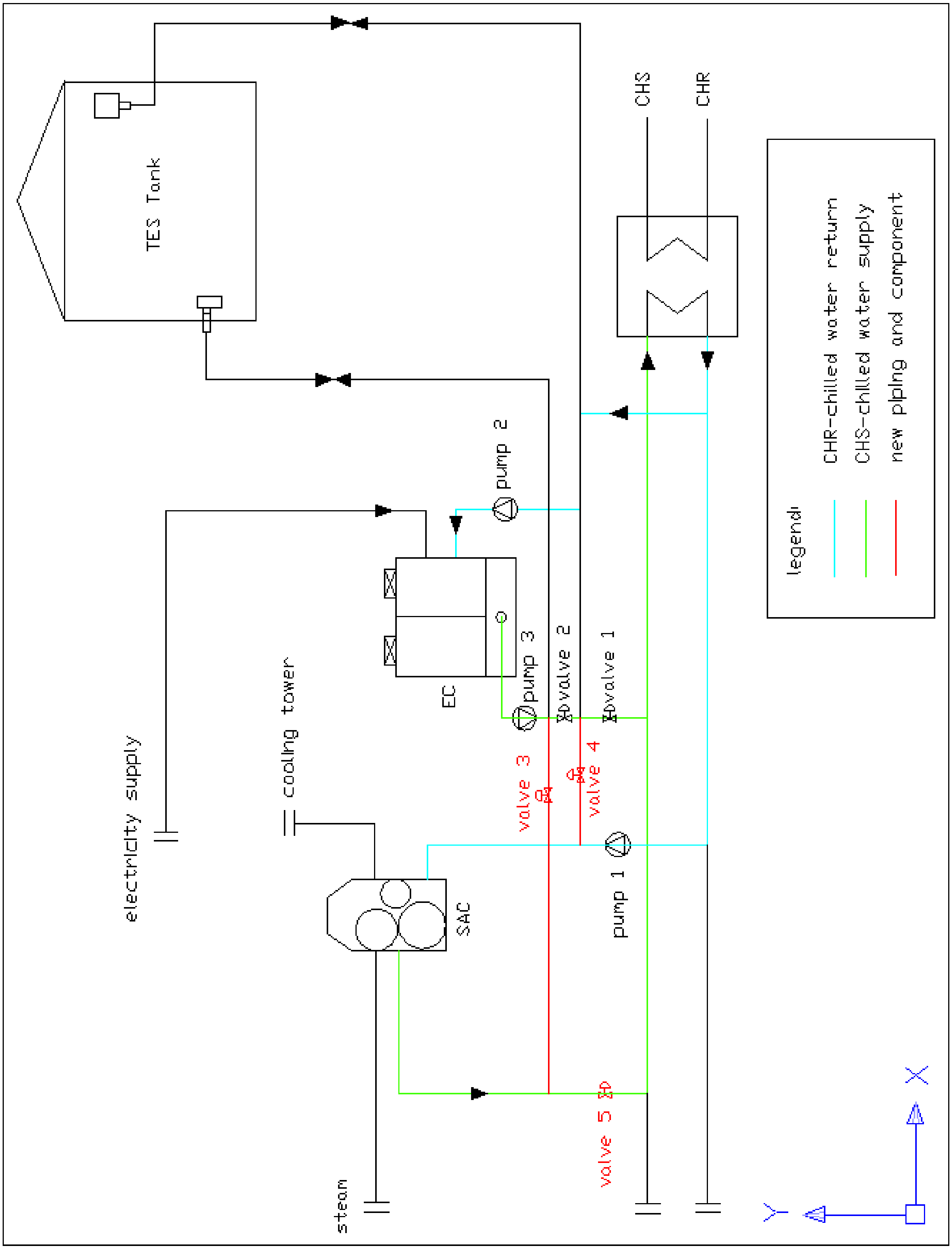


Figure 19: New configuration of design system

The summary of the proposed design operation system is as below:

Table 8: The design operation system

Equipment	Discharging Cycle	1st Stage Charging Cycle	2nd Stage Charging Cycle
Pump 1	On	On	Off
Pump 2	Off	Off	On
Pump 3	Off	Off	On
Valve 1	On	Off	Off
Valve 2	On	Off	Off
Valve 3	Off	On	Off
Valve 4	Off	On	Off
Valve 5	On	Off	Off

During the charging cycle, chilled water will return to the chiller is extracted from the top diffusers of the stratified tank, cooled in the chiller, and charged into the stratified tank again through the bottom diffusers. The inlet temperature of the stored chilled water gradually decreases as the stored volume increases.

During the discharging cycle, stored chilled water is extracted from the bottom of stratified tank and supplied to the UTP. The return chilled water is introduced to the stratified tank through the top diffusers. The outlet temperature of the stored chilled water gradually increases as the stored volume decreases. The charging and discharging flow is shown in Figure 20.

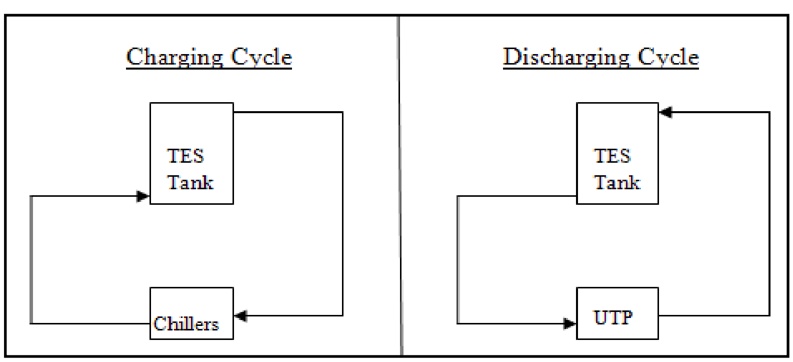


Figure 20: Illustrations of charging and discharging chilled water flow

4.6.3. Heat Recovery Steam Generator (HRSG) operating mode

The current operation of HRSG is as state below:

- HRSG A: 0600 – 2200 hrs.
- HRSG B: 0630 - 1800 hrs.
- Both HRSG is not running during weekend.

The HRSG mode operation has to be rescheduled to ensure the proposed system will operate successfully. The proposed schedule for new TES charging system is as below:

- HRSG A: 0000 – 2300 hrs.
- HRSG B: 0630 - 1800 hrs.
- HRSG B is not to be operated during weekend.

4.6.4. Steam Absorption Chiller (SAC) operating mode

The current operation of HRSG is as state below:

- SAC A: 0600 – 2200 hrs.
- SAC B: 0630 - 1800 hrs.
- Both SAC not to be operated during weekend.

The SAC operating mode has to be rescheduled to ensure the proposed system will operate successfully. The proposed schedule for new TES charging system is as below:

- SAC A: 0000 – 2300 hrs.
- SAC B: 0630 - 1800 hrs.
- SAC B not to be operates during weekend.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

The current practice is that chilled water is supplied to UTP by TES tank, from both the SAC and EC. While during night time, ECs are used to charge the TES tank. However, due to expansion cooling load demand, the current EC are insufficient to charge the TES tank.

From analysis of the existing system, improvement on charging of TES tank charging system is proposed. The proposed method to be carried out is by using two stage charging system to charge the TES tank which is using Steam Absorption Chiller (SAC) for the first stage and continue by EC to the second Stage. Further analysis to the proposed system was done and proved by calculation that the proposed system can improve the existing system.

Based on calculated results, the time required by proposed system is much lower compare to the current system with the time different of about 4.2 hrs. The proposed system requires only 7.50 hours charging the TES tank. The proposed charging process is from 2200 to 0600 in order to make full use of the waste heat generated by GTG during that period. Based on the available information from the current system, the integration of the Steam Absorption Chiller and Electric Chiller to charge the Thermal Energy Storage Tank could be undertaken.

It is suggested, the pilot tank should be built first and the data from the tank should be collected and analyzed prior implementation in the actual Thermal Energy Storage Tank.

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APPENDICES

APPENDIX 1

NPS - "Nominal Pipe Size" and DN - "Diameter Nominal"

The size of pipes, fittings, flanges and valves are often given in inches as NPS – Nominal Pipe Size, or in metric units as DN – ‘Diameter Nominel”.

It is common to identify pipes by inches using NPS or "Nominal Pipe Size". The metric equivalent is called DN or "diametre nominel". The metric designations conform to International Standards Organization (ISO) usage and apply to all plumbing, natural gas, heating oil, and miscellaneous piping used in buildings. The use of NPS does not conform to American Standard pipe designations where the term NPS means "National Pipe Thread Straight".

Diameter Nominal DN *(mm)*	Nominal Pipe Size NPS *(inches)*
6	1/8
8	1/4
10	3/8
15	1/2
20	3/4
25	1
32	1 1/4
40	1 1/2
50	2
65	2 1/2
80	3
100	4
150	6
200	8
250	10

300	12
350	14
400	16
450	18
500	20
550	22
600	24
650	26
700	28
750	30
800	32
900	36
1000	40
1050	42
1100	44
1200	48
1300	52
1400	56
1500	60
1600	64
1700	68
1800	72
1900	76
2000	80
2200	88