Design of Two-Stages Charging of Sensible Thermal Energy Storage

By

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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(Ir Dr M Amin Abd Majid)

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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 originality work contained herein have not been undertaken or done by sources or persons.

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ABSTRACT

The Gas District Cooling (GDC) plant at Universiti Teknologi PETRONAS (UTP) is responsible for supplying chilled water to the main campus, where it is used as the source of chilled water for air conditioning. Current operations at GDC, electric chillers (EC) are used to charge the Thermal Energy Storage (TES) at night and then discharge the chilled water during the day to support chilled water requirements during peak period. Steam Absorption Chiller (SAC) operation is to supply the chilled water during the day and not during operation at night. However, this practice does not take the advantage of 24 hours operation of gas turbine that produced waste heat. This project is focus on using the SAC to charge the TES tank during night to support EC in order to optimize the use of waste heat. A two-stage charging is proposed. Current configuration is charging the TES tank from 5 p.m. to 7 a.m. only by EC. The proposed wo-stage configuration, the TES tank is charged by SAC as the first stage to cool the chilled water from 13°C to 9°C, then, the second stage is charged by EC to cool the chilled water from 9°C to 6°C. The time of the both charging process is maintained from 5p.m. to 7a.m. The operation of two-stage based on one SAC in operation and three EC's in operation.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Gas District Cooling Plant supply electric power and chilled water to Universiti Teknologi PETRONAS. The electric power is supplied by the gas turbines. The chilled water is supplied by the Steam Absorption Chiller, Thermal Energy Storage and Electric Chiller. The main production of chilled water is from SAC. There are two SAC's which have same capacity which is 1250RT. The SAC is operated by steam from Heat Recovery Steam Generator (HRSG). The waste heat from turbine will enter the HRSG to produce the steam. The steam then is collected on the steam header before entering the SAC. In here, thermal energy storage system is consisted with equipment such as thermal energy storage tank (TES), four Electric Chillers, and pumps. The TES has a capacity is able to store chilled water of 5,400 m^3 or 10 000 RTh. The TES tank is charged during night by EC and discharged the water during daytime. There are 4 EC's in the plant. Each of EC have capacity of 325 RT. The EC is charging the TES tank at night. However, nowadays the EC is operated during the day because of the requirement for chilled water has increased.

The TES system use at UTP is sensible heat system and it using water as the storage media. The steam required for the operation of the absorption chiller is supplied by 2 units of Heat Recovery Steam Generator (HRSG) which operate using waste heat from 2 units of Gas Turbine Generator (GTG). The system operates on a temperature differential of 7°C, with chilled water temperatures of 6°C and 13°C for the supply and return passages. TES system includes distribution chilled water system, TES system, and SAC system to be taken into consideration.

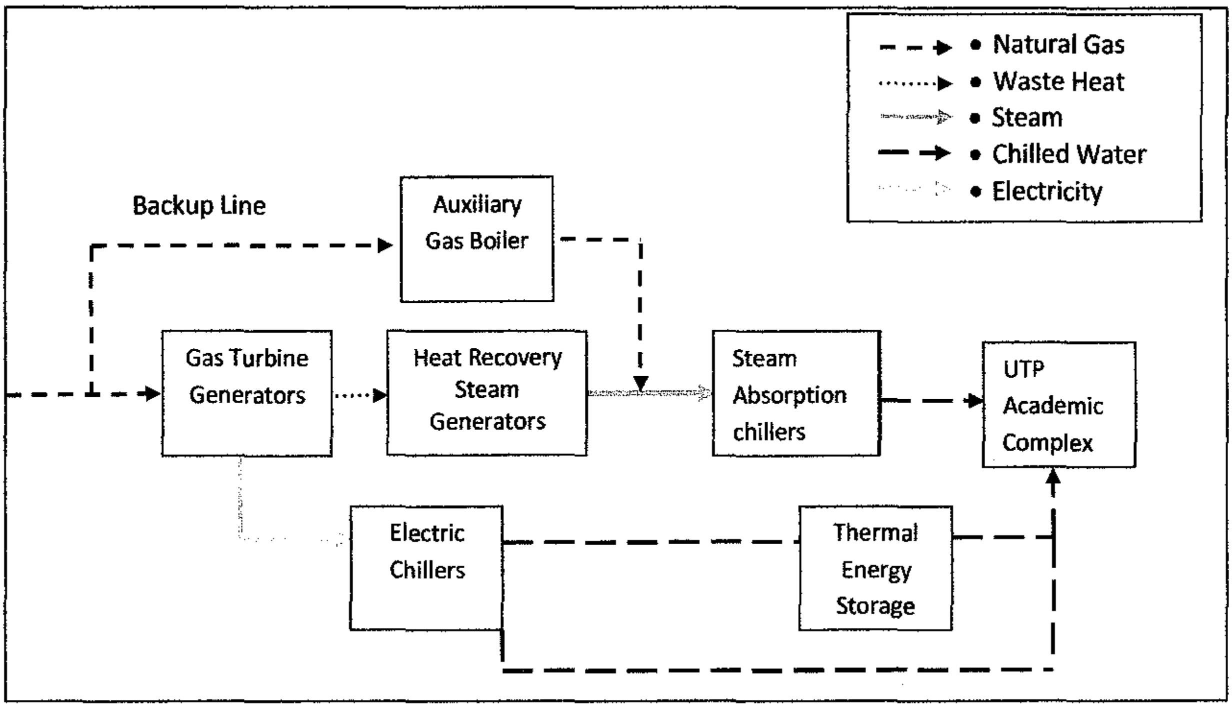

Figure 1: UTP Cogeneration / District Cooling Plant

1.2 Problem Statement

The current charging system for chilled water storage tank at UTP GDC plant is using Electric Chillers (EC). As per designed the Electric Chillers are to charge the tank at night. However, due to limited period and increase in academic and non-academic activities in academic complex, the requirement for chilled water has increased; therefore the tank is not able to achieve maximum capacity during the period of charging. This is due to insufficient capacities of the Electric Chillers. Currently the Thermal Energy Storage (TES) is charged by EC and the available steam absorption chillers (SAC) are not incorporate into the current charging system. The current practice does not take advantage of availability of waste heat at night which can be used to charge TES. To enhance the charging, SAC should be incorporated into charging system function directly supply chilled water for cooling demand and also to be used for charging the TES.

1.3 Objective

The main objective for this project is to design a two-stage charging for sensible thermal storage system using SAC for the first stage and EC for the second stage.

1.4 Scope of Study

The first stage of charging is to charge the TES tank from 13°C to 9°C using SAC. While the second stage of charging is from 9°C to 6°C using EC. Both of charging will cover from 5 p.m. to 7 a.m. From this design, one SAC and three EC will be used to charge the TES tank. During the night, only one gas turbine is operated, therefore only one SAC can be used to charge. The capacity of the steam required for SAC operation is depend on HRSG. The waste heat is supplied to HRSG and converts to steam before use by SAC. The calculation is focus on energy required to charge the TES tank, and also the time to charge the TES tank for single stage and the two-stage. Based on the calculation, the cumulative graph is produces to show the pattern of the charging.

CHAPTER 2

LITERATURE REVIEW

District Cooling Plant is needed because of large and growing demand for cooling within modern large buildings include in Universiti Teknologi PETRONAS. This situation occurs caused by growth in the use of cool-producing office and class environment. There are environmental and economic benefits from district cooling. There is the avoidance of use chemicals that destroy the stratospheric ozone layer. Another advantage is avoidance of the increases in ambient temperatue, humidity, and noise that occur outside buildings. District cooling system consist of sub-system to move overall operation, this chapter will describe the sub-system.

2.1 Energy Storage System

Energy storage (ES) media are matter that store some form of energy at a later time to perform some useful operation. ES systems have a potential to increase the effectiveness of energy conversion equipment and for substitutions of the fuel usage in the world's economy. Explained by I. Dincer and M.A Rosen [1], ES provides an alternative method of supplying peak energy demands. Therefore, ES system can improve the operation of cogeneration, solar, wind, and run-of-river hydro facilities. Some details on these applications follow [1]:

- **Utility** – Relatively inexpensive base load electricity can be used to charge energy storage systems during evening or off-peak weekly or seasonal periods. The electricity is then used during peak periods, reducing the reliance on conventional gas and oil peaking generators.
- **Industry** – High temperature waste heat from various industrial processes can be stored for used in preheating and other heating operations
- **Cogeneration** – Since the closely coupled production of heat and electricity by a cogeneration system rarely matches demand exactly, excess electricity or heat can be stored for a subsequent use.

- **Wind and run of river hydro** – Conceivably these system can be operate around the clock, charging an electrical storage system during low-demand hours and later using that electricity for peaking purpose. ES increases the capacity factor for these devices usually enhancing their economy value.
- **Solar system** – By storing excess solar energy received on sunny days for use on cloudy days or night, ES system can increase the capacity factor for solar energy systems.

There are several methods to store the energy. ES device can be classified and categorized in other ways. Each category considers the storage of one form of energy. Below are the several possible storage options [1].

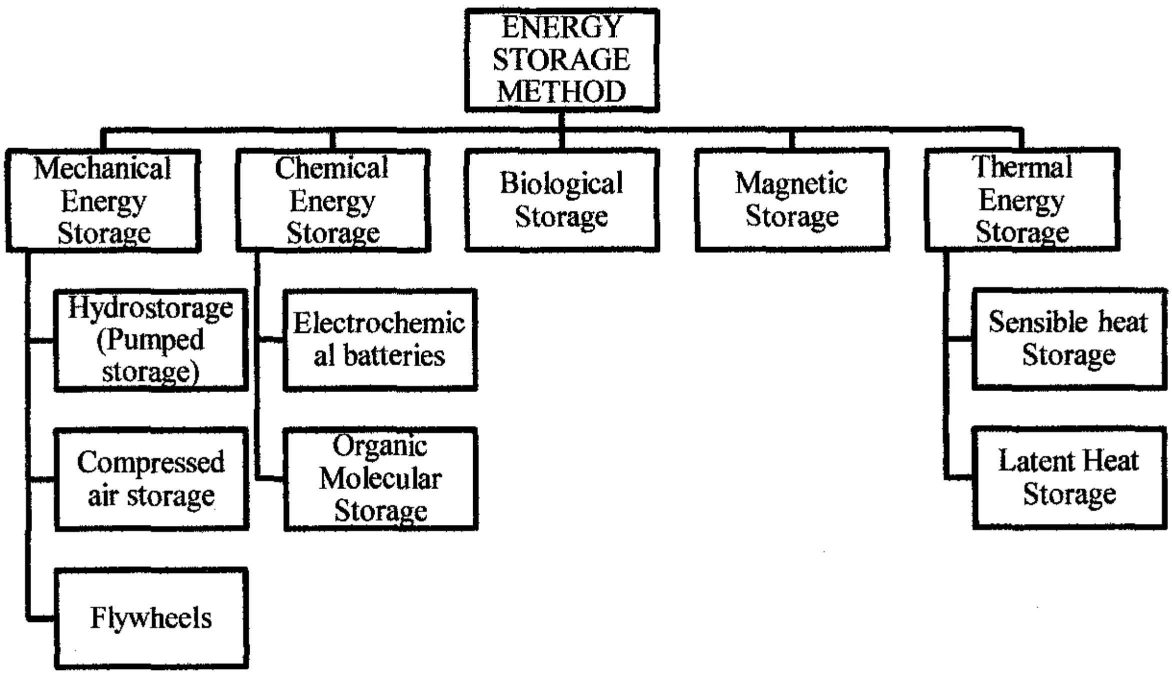

Figure 2: Classification of Energy Storage Method [1]

Development of ES can make a huge different to the world because it sustain advantages more than conventional energy that being use now such as fuel and gas. The benefits of using ES system are:

- Reduces energy costs
- Reduce energy consumption
- Improved indoor air quality
- Increased flexibility of operation
- Reduced initial and maintenance costs

In addition, I.Dincer et al (1997a) [1] point out some further advantages of ES:

- Reduced equipment size
- More efficient and effective utilization of equipment
- Conservation of fossil fuels
- Reduced pollutant emission

2.2 Chiller

A chiller is a machine that removes heat from a liquid via a vapor-compression or absorption refrigeration cycle. The basic different between the Electric Chillers (EC) and Absorption Chiller (AC) that an EC use an electric motor for operating a compressor used for raising pressure of refrigerant vapors and AC required thermal energy (steam or hot water) as the primary source energy. The rejected heat from the power-generation equipment (e.g. turbines, micro turbines, and engines) may be used with an AC to provide cooling in the system. AC has fewer and smaller moving parts and it is quieter during operation than EC.

2.2.1 Electric Chiller

The Electric Chiller can cool the inlet air to much lower temperatures and maintain any desired inlet air temperature down to as low as 42^{o}F [12]. The systems could be driven by electric motors. Drawing the inlet air across cooling coils, in which either chilled water or refrigerant is circulated, cools it to the desired temperature. The chilled water can be supplied directly from a chiller or from a TES (Thermal Energy Storage) tank that stores ice or chilled water [8].

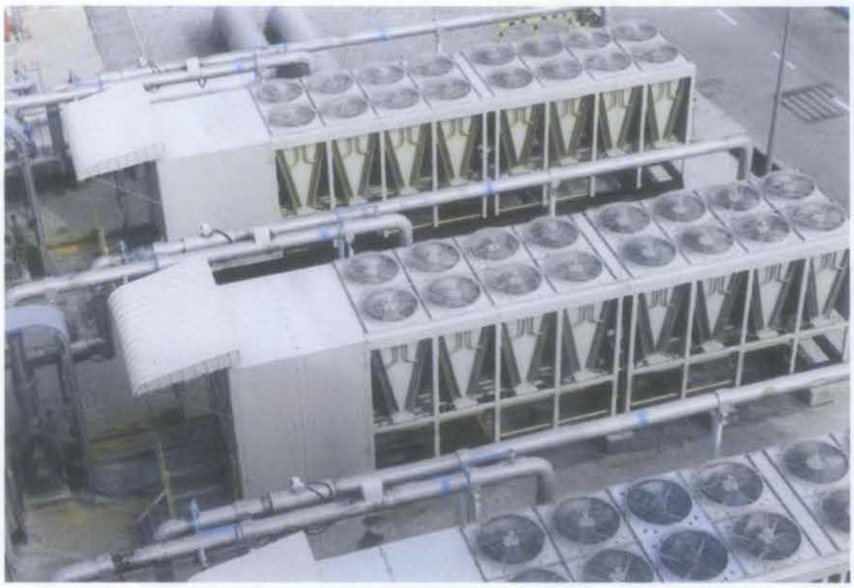

Figure 3: Electric Chiller at District Cooling Plant

Electric Chiller system have the essential components of a simple vapor-compression refrigeration system, are as follows [8]:

- **Evaporator**. This is the device where there is heat exchange for providing refrigeration, and therefore it boils the liquid refrigerant at a low temperature, which causes the refrigerant to absorb heat.
- **Suction line.** This is the tube between the evaporator and the compressor. After the liquid has absorbed the heat, the suction line carries the refrigerant to the compressor. In this line, the refrigerant is a superheated gas.
- **Compressor.** This device separates the low-pressure side of the system from the high-pressure side and has two main goals: (i) to remove vapor from the evaporator to keep the evaporator's boiling point low and (ii) to compress the low-temperature refrigerant vapor into a small volume, creating a high-temperature, high-pressure superheated vapor.

- **Hot gas discharge line.** This tube connects the compressor with the condenser. After the compressor has discharged the high-pressure, high-temperature superheated refrigerant vapor, the hot gas discharge line carries it to the condenser.
- **Condenser.** This device is used for heat exchange, similar to the evaporator, except that its job is to expel heat, not absorb it. The condenser changes the state of the superheated refrigerant vapor back into a liquid. This is done by creating a high pressure that raises the boiling point of the refrigerant and removes enough heat to cause the refrigerant to condense back into a liquid.
- **Liquid line.** This line connects the condenser with the refrigerant control device, including the expansion valve. Only liquid refrigerant should be in this line. Also, the line will be somewhat warm because the refrigerant is still under high pressure.
- **Refrigerant control.** This last control works as a metering device. It monitors the liquid refrigerant that enters the evaporator and makes sure that all the liquid is boiled off before the refrigerant goes to the suction line. If liquid refrigerant enters the suction line, it will enter the compressor and cause it to fail.

There are pros and cons of using electric chiller. Operation and maintenance costs for this type of chiller will vary by sizing, application and compressor type. Screw and scroll type compressors generally are more costly to purchase, however are more durable and last longer reducing replacement and maintenance costs. Other advantage of electric chiller is they do not require the space or area to locate the liquid cooled chiller. This allows installation for limited space applications.

2.2.2 Steam Absorption Chiller

Based on the book written by Ibrahim Dincer, the absorption cycle is a process by which the refrigeration effect is produced through the use of two fluids and some quantity of heat input, rather than electrical input as in the more familiar vapor-compression cycle [8]. In Absorption refrigerant chillers system (ARS), a secondary fluid (i.e., absorbent) is used to circulate and absorb the primary fluid (i.e., refrigerant), which is vaporized in the evaporator. The success of the absorption process depends on the selection of an appropriate combination of refrigerant and absorbent. The most widely used refrigerant and absorbent combinations in ARSs have been ammonia-water and lithium bromide-water.

Absorption cooling systems can be used to cool the inlet air to about 50°F. These systems can be employed with or without chilled water TES systems. Absorption chillers can be single-effect or double-effect chillers. The single-effect absorption chillers use hot water or 15-psig steam (18 lb./hr.RT) while the double-effect chillers require less steam (10 lb./hr.RT) but need the steam at higher pressure (115 psig) [6]. Refer to the book written by Y.A. Cengel and M.A. Boles, absorption chiller perform best when the heat source can supply the heat at a higher temperature with little temperature drop [7]. The chillers perform at lower temperature, but their cooling capacity decreases sharply with decreasing source temperature.

Main production for chilled water in chilled water system is from Steam Absorption Chiller. There are two SAC which have same capacity, consisted with cooling water system, steam system, and steam condensation water system, and these systems are operated at the same time. Chilled water return at 13.5°C from distribution pipe is sent to SAC by pump, and it is cooled to 6°C in SAC, and then the chilled water supply from SAC is supplied to distribution pipe.

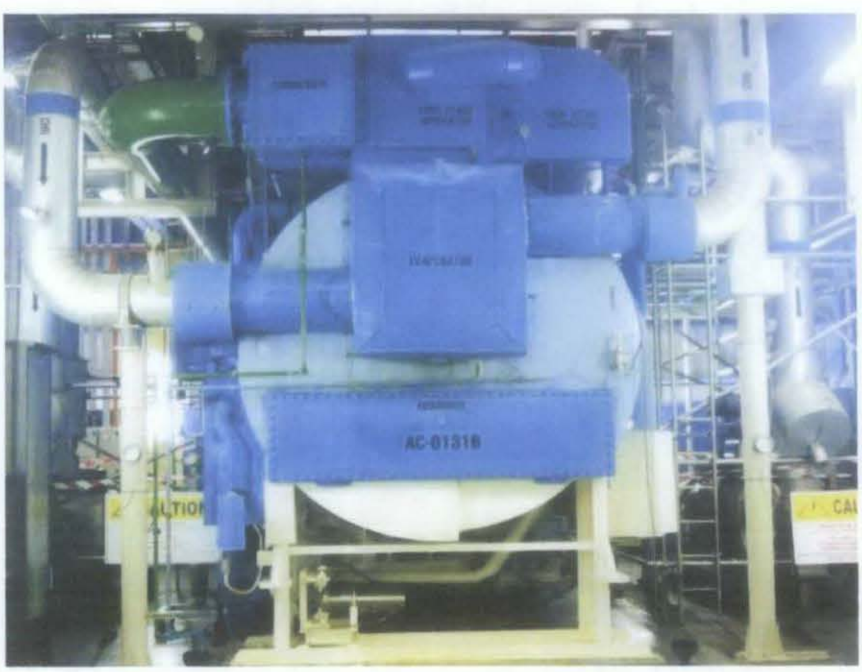

Figure 4: Steam Absorption Chiller at District Cooling Plant

Based on Keith, Reinhard and Sanford [12], the process is started when the liquid is pumped from the low pressure in the absorber to high pressure in the generator. The heat at the generator is supplied from external. The required temperature level is governed by the properties of working fluid. The reason is the solution, the heat have to boil the water or the absorbent. When heat is applied in the generator, the vapor is generated and vapor flows to the condenser. Remaining liquid solution exist in the generator and flows back to the absorber. This process is partial evaporation. The concentrated LiBr leaving the generator passes through a solution leaving the absorber.

At heat exchanger, the processes occur between two liquid and involves only sensible heat. The purpose of the internal heat exchanger is to reduce the external heat input requirement by utilizing energy available within the equipment. The consequence of using internal heat exchanger is to reduce the heat rejected. Then the solution is steam is return to absorber. The team gives up energy in the solution heat exchanger and arrives at the flow restricted sub cooled.

In the absorber, the concentrated salt solution is brought into contact with vapor supplied by the evaporator. The absorption process occur if the absorber is cooled by the external sink or cooling tower. Since vapor is absorbed into the solution, the mass flow rate of liquid leaving the absorber is greater than the liquid entering the absorber. This process is vice versa for generator.

The lithium bromide-water pair is available for air-conditioning and chilling applications (over 4 ^{o}C, because of the crystallization of water). Ammonia-water is used for cooling and low-temperature freezing applications (below 0 "C).The absorption cycle uses a heat-driven concentration difference to move refrigerant vapors (usually water) from the evaporator to the condenser. Heat is then used to drive off these refrigerant vapors thereby increasing the concentration again. [9]

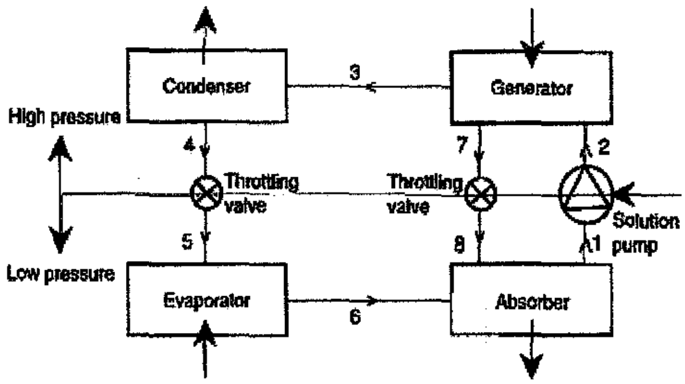

Figure 5: A basic Absorption Refrigeration Systems [1]

The connection of TES and SAC occur at the evaporator. Thus to measure the heat absorb by the SAC, it is suitable to calculate the heat transfer rate at evaporator. However, it is important also to measure the hold power generate from the equipment. At the evaporator the calculation is [11];

$$Q_e = \dot{m}_i h_i - \dot{m}_o h_o \qquad [1.1]$$

Where $\dot{m}_i = \dot{m}_o$, the mass flow rate of the system. h_i is the enthalpy input from the condenser and h_o is enthalpy water from the evaporator to the absorber.

At the condenser, the energy equation used is as the same from the evaporator;

$$Q_c = \dot{m}_j h_j - \dot{m}_k h_k \qquad [1.2]$$

The $\dot{m}_j = \dot{m}_k$ and equal to $\dot{m}_i = \dot{m}_o$. The flow rate is considerably constant through all the system. h_j is the enthalpy of water from the generator and h_k is enthalpy water from the condenser. Therefore h_k and h_o is the same enthalpy taken from temperature of the condenser.

2.3 Thermal Energy Storage

Thermal energy storage (TES) function is to store the energy in certain amount of time and release when it is needed. This equipment is one of the oldest technologies in energy management, and now considered one of the important advanced technologies. The function of TES for thermal applications such as space and water heating, cooling and air conditioning has gain more attention to the world. Explained by Brian Silvetti about [2], Thermal energy is stored by adding or removing energy. The main application of TES at hot climate is cold storage, because of the large electricity peak demands and consumptions for air conditioning. Most of conventional cooling system has two major components which are chiller and distribution system. Function of chiller is to cools water or other fluid while distribution system is to transport the cold fluid from the chiller to the where it is needed.

At District Cooling Plant provided for the purpose of reduction of total chillers capacity, by utilizing stored chilled water inside TES tank to serve customer cooling load demand during peak hours. Electric consumption by the plant at these peak hours can be deducted, due to reduction of total chillers capacity. The thermal energy storage (TES) system purpose is to stored chilled water in TES at peak time of customer chilled water demand and also reduced electric consumption in the plant at peak time due to reduction of total chiller's capacity. The thermal layer storage tank is type of thermal energy storage used in this plant; therefore the chilled water is stored from bottom part in tank by difference of the specific gravity for chilled water temperature.

There are four pumps to discharge chiller water from TES to chilled water distribution pipeline for distribute the chilled water to the customer. Inlet nozzle is made from 20" Nominal Pipe Size (NPS) while outlet nozzle has dimension of 12" NPS

At District Cooling Plant provided for the purpose of reduction of total chillers capacity, by utilizing stored chilled water inside TES tank to serve customer cooling load demand during peak hours. Electric consumption by the plant at these peak hours can be deducted, due to reduction of total chillers capacity.

Figure 6: Thermal Energy Storage at District Cooling Plant

2.3.1 TES Process

A complete storage process involves at least three steps: charging, storing and discharging [1]. This step must be taken onto consideration for an exact energy and analysis.

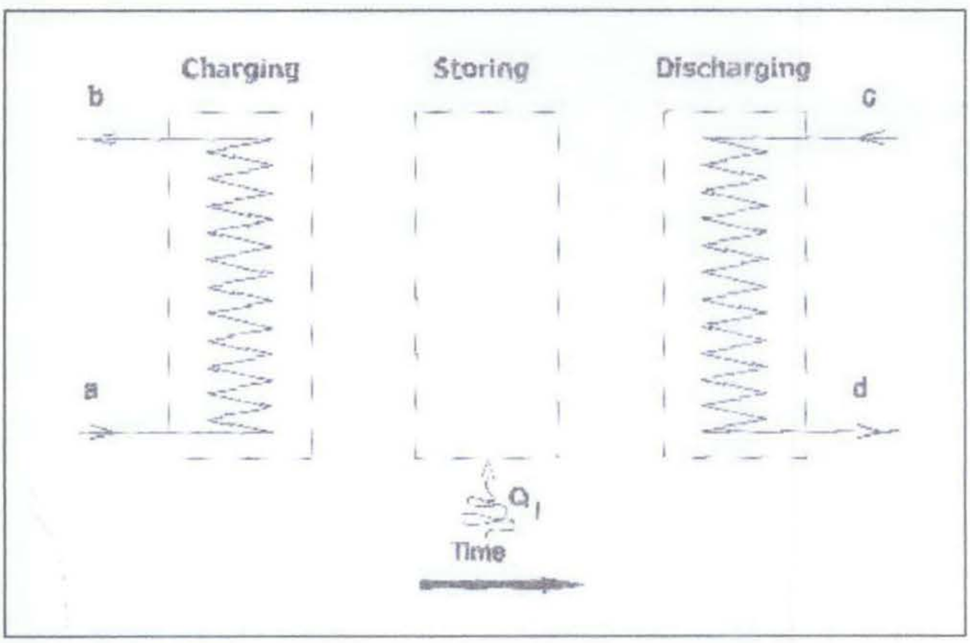

Figure 7: Process of Cooling Capacity [1]

A general balance for a quantity in a system may be written as

Input + Generation – Output – Consumption = Accumulation

Input and output refer respectively to quantities entering and exiting through system boundaries. Generation and consumption refer respectively to quantities produced and consumed within the system. Accumulation refers to build up of the quantity within the system.

Following energy balance for the overall storage process can be written as

Energy input – [Energy Recovered + Energy Loss] = Energy Accumulation

Or

$$(H_a - H_b) - [(H_d - H_c) + Q_l] = \Delta E \qquad [1.3]$$

Where H_a, H_b, H_d, H_c are the total enthalpies of the flows at states a, b, c and d, respectively; Q_l denotes the heat losses during the process and ΔE the accumulation of energy in the TES. In Equation ( ) $(H_a - H_b)$ represent the net heat delivered to the TES and $(H_d - H_c)$ the net heat recovered from the TES. The quantity in square brackets represent the net energy output from the system. The terms ΔE and Q_l are given by

$$\Delta E = E_f - E_i \qquad [1.4]$$

$$Q_l = \sum_{j=1}^{3} Q_{l,j} \qquad [1.5]$$

Here E_i and E_f denote the initial and final energy contents of the storage, and $Q_{l,j}$ denotes the heat losses during the period j, where j = 1, 2, 3 corresponding to the charging, storing and discharging periods, respectively. In the case of identical and initial and final states, $\Delta E = 0$ and overall energy balances is simplifies.

The net rate of energy transfer to or from the storage tank due to water flow through the inlet and outlet is termed as instantaneous capacity. For charging and discharging instantaneous capacity can be expressed as

$$Q = mc_p(T_a - T_b) \qquad [1.6]$$

Where m, T_a and T_b all may be the function of time.

For charging:

T_a = Temperature start of charging

T_b = Temperature out of the chiller

For discharging

T_b = Temperature start of discharging

T_a = Outer water temperature at cooling coils

2.3.2 TES Charging

TES charging is when the energy (heat) is removed from the thermal energy storage (cold storage). One of the device to done this operation is the chiller water, if the is the storage medium. Chilled water storage can shift part of the cooling requirement to off-peak hours, resulting in improved utility load factors, in addition to allowing the chillers to operate during the cooler night temperatures, resulting in improved coefficient performance [1]. Since the equipment does not have to handle the peak load its size is minimized, resulting in savings in capital investment. As been written by Kurt Roth, when the building requires cooling during the day, the chilled water line passes through the TES tank to chill the water and provide cooling, decreasing the chiller's load during the day [9]. That is, instead of installing two chillers two operate at full load during peak hours and at partial load during the rest of the demand period, we may install a smaller single chiller operating 24 hours per day to charge the storage tank during of demand period. The tank in turn assists the chiller during the demand period. Therefore, at night when the demand is low and the air is cool, water chilled and stored for use during daytime peak demand period.

Principle of charging operation is based on the natural process of stratification; it involves both forced and natural convection. In cold storage, based on Dincer and Marc [1] the hot fluid is withdrawn from the top of the tank is cooled at the chiller or cooled sources and replaced by cold water introduced at the bottom. The incoming flow processing momentum will tend to mix with the fluid in the tank. The flow momentum tend to blend the incoming fluid with the fluid in the tank while the buoyancy acting downward to make the incoming stream flow in a gravity current form below the relatively warmer fluids. As more fluid is introduced, the fluid in the mixing region is pushed up, leaving behind a region of uniform temperature equal to the inlet temperature. The region of intermediate temperature separating this uniform temperature region is thermo cline. It is defined as the region of steepest temperature gradient separating the hot and cold fluid in the region. Thus, the thermocline is act as physical barrier. The thickness of the thermocline region is an important indicator on how well stratified tank is designed.

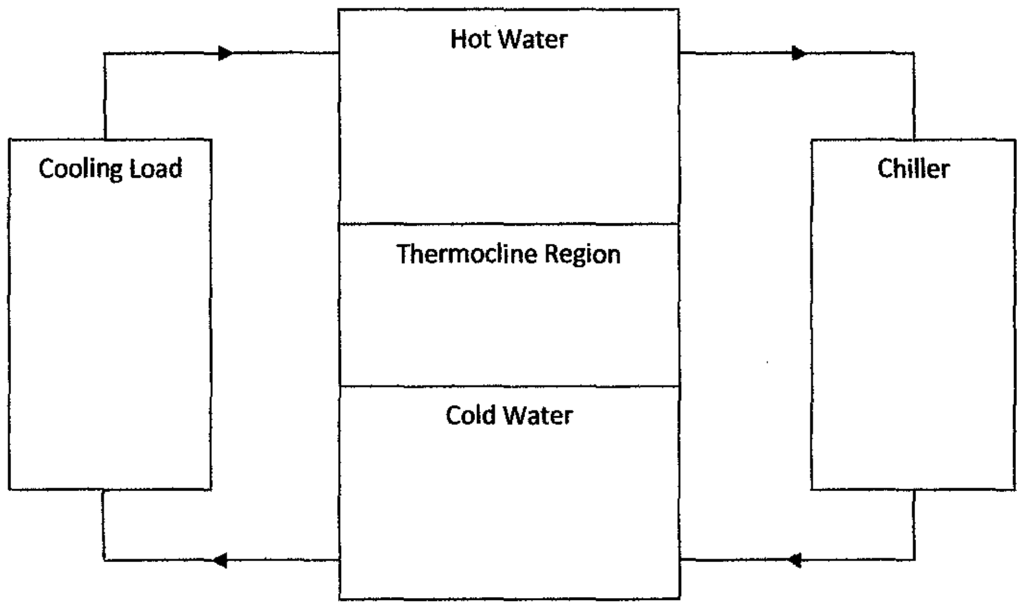

Figure 8: Schematic diagram of TES tank [1]

The charge cycle is achieved by charging the chilled water from the chiller into the storage tank that content warm water through the diffuser until all the warm water completely replaced by chilled water.

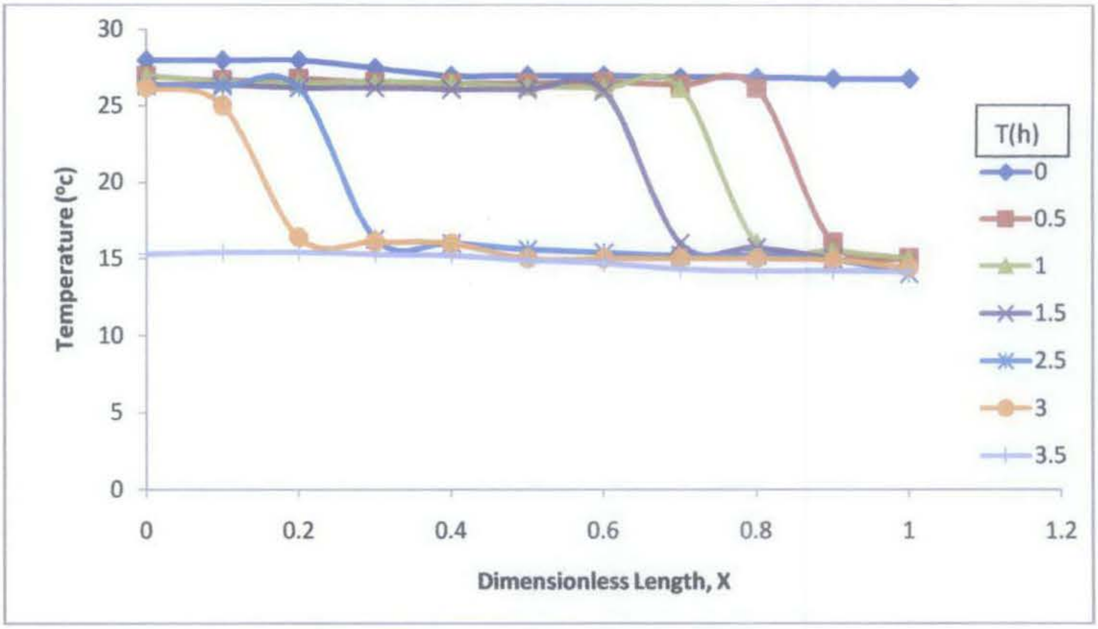

Figure 9: General temperature profile [1]

Figure 6 show the general temperature profiles in a stratified storage tank during a charge cycle. The chilled water at a temperature 14°c is charged through the bottom of the diffuser in to the tank at the same rate as the warm water is displaced through the top of the storage tank. The thermocline forms at the bottom and slowly moves up to the top as charging is continued. During charging, the available cooling capacity of charged water degrades due to mixing of the charged with stored water.

CHAPTER 3

METHODOLOGY

The methodology implement in this project to achieve the objective based with the development of models for two stages charging of TES tank.

3.1 The Charging Models

The model that involve is based on temperature change to charge the TES tank. The charging models were discussed in term of charging parameters and development of the models for single stage and enhancing for two-stage of charging stratifies TES tank. The charging parameters based on temperature taken at the tank. The steps in the design are the following:

i. Single stage Charging model.
ii. Two-stage charging model were obtained from enhancement of the single stage charging.

The methodology step in this research is presented in Figure 3.1. The single stage charging model was verified using data of operating stratified TES system. The historical data was also used a basis for a selection temperature distribution function.

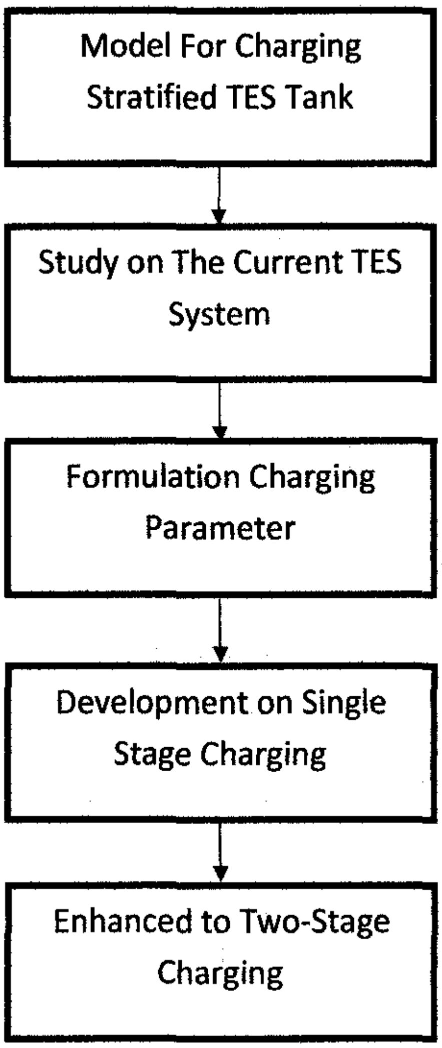

Figure 10: Methodology Steps

3.2 Historical Data of Operating TES Tank

TES tank from Gas District Cooling plan acquired for this study. The designed TES tank has a capacity of 10 000RTh (35 161.7kWh) which also consist of two steam absorption chillers has designed capacity of 1250RT (4932kW) and electric chillers (ECs) which has designed capacity of 325RT (1142.8kW). The designed plant of district cooling plan is to provide cooling load in demand of facilities at Universiti Teknologi PETRONAS. On usual day, cooling demand is supplied during on-peak by circulating chilled water from steam absorption chillers and discharging TES tank within working hours.

The TES tank has cylindrical vertical tank with inside diameter and height of 22.3 m and 15 m. The volume of the tank is 5400 m^3 water storage capacities. Lower pipe nozzle which has diameter of 20" Nominal Pipe Size (0.508 m) located at 1.842 m height, while the upper pipe nozzle is 12" Nominal Pipe Size (0.305 m) at elevation of 12.3 m. Both nozzles has equipped with diffuse on its end connection in the storage tank. Overflow line is connected at elevation of 14.025 m. The entire tank is insulated with polystyrene of 300m thickness at the external. In the internal, the tank is coated with epoxy paint. SACs has specification of 504 m^3/hr flow rate while ECs has designed flow rate of 131 m^3/hr. Both SACs and ECs have designed inlet and outlet temperature of 13.5°C and 6°C.

The tank is installed with 14 temperature sensors, installed at approximately 1 m vertical interval for measuring the water temperatures inside of the tank. The lowest temperature sensor is located at 0.51 m elevation. All temperatures are hourly recorded with acquisition data system.

3.3 Formulation of the Design

The design of the two stage design is based on the right formulation to develop function analysis of stratified TES tank. Based on literature review the net energy transfer is calculated using equation [1.2];

$$Q = mc_p(T_a - T_b) \tag{3.1}$$

However, to develop based on data from the TES Tank, the formula should be changed first so that appropriate with the condition of the tank. The value of mass of water will be exchange with the volume, and have to multiply with density of water to balance the equation. Therefore the formula will become

$$Q = V\rho c_p(T_a - T_b) \tag{3.2}$$

Another important equation involve is RTh. This equation use to determine the time needed to completely charge the TES tank. The complete equation is

$$RTh = RT\, x\, h \tag{3.3}$$

Based on the energy equation, another parameter that involve in the calculation is charging capacity. Charging capacity is the value of energy equipment can deliver over a time. The formulation of the charging capacity is similar to equation of power.

$$Charging\ Capacity = Q/second \qquad [3.4]$$

3.3.1 Parameters of the Equation

The volume of the tank is constant for both configuration single stage and two-stage.

$V = 5400\ m^3$

$\dot{Q} = 10\ 000$ RTh

Current configuration (Single Stage of Charging);

Find the energy operation using equation 3.2

$Q = V\rho c_p(T_a - T_b)$,

$T_a = 13^oC$

$T_b = 6^oC$

The TES tank is charging by EC which have capacity of 325 each. Based on 3.3 equations, we can find suitable unit to charge the TES tank. There are four EC operated at the plant.

EC/unit = 325 RT

Time of charging = 14 hours (5 p.m. – 7 a.m.)

Design configuration (Two-Stage of Charging);

Find the energy operation using equation 3.2

First Stage of Charging using SAC;

$Q = V\rho c_p(T_a - T_b)$,

$T_a = 13^oC$

$T_b = 9^oC$

The TES tank is charging first by SAC which have capacity of 1250 each. Based on 3.3 equations, we can find suitable unit to charge the TES tank. There are two SAC operated at the plant.

EC/unit = 1250 RT

Time of charging = using only one SAC until reach 10 000 RTh (from 5 p.m. – calculated time)

Second Stage of Charging using EC;

$Q = V\rho c_p(T_a - T_b'),$

$T_a = 9^oC$

$T_b = 6^oC$

The TES tank is charging first by SAC which have capacity of 325 each. Based on 3.3 equations, we can find suitable unit to charge the TES tank. There are four EC operated at the plant.

EC/unit = 325 RT

Time of charging = using suitable SAC until reach 10 000 RTh (remaining time after SAC charging)

3.4 Developing Single Stage Charging

The TES charging is the process of introduce the cool water at the bottom of the tank or lower nozzle then mix in the middle to create thermocline region and the warm water will be withdrawn at the upper nozzle. The system is called open charging system because of the outlet charging water is not re-circulated in to the lower nozzle.

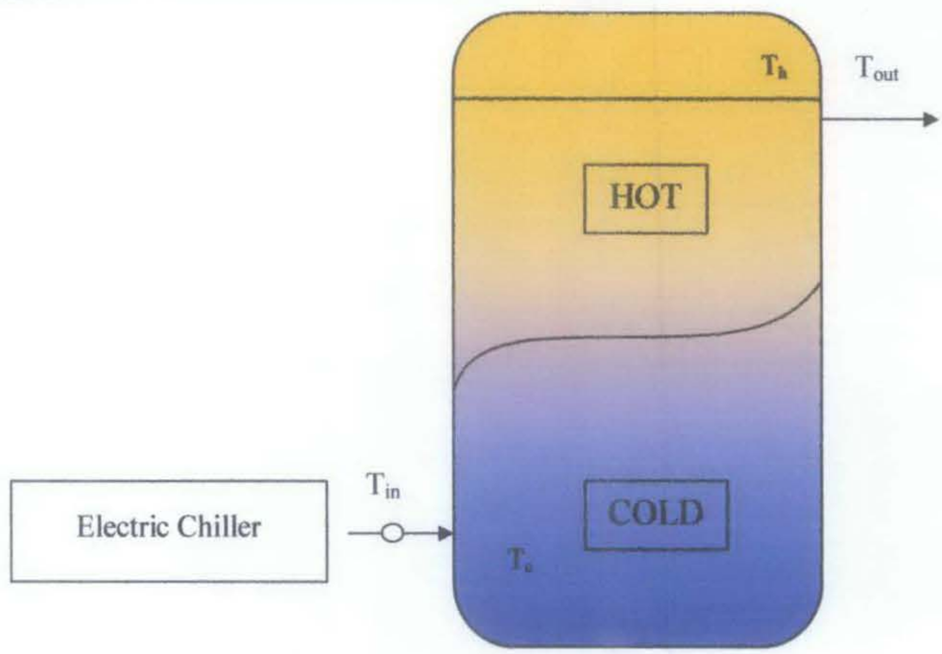

Figure 11: Schematic Flow of Single Stage Charging

As shown on figure above, charging is performed by Electric Chiller to introduce the cold water in the lower part of the TES tank, with inlet temperature T_{in}. The inlet from the EC is equal to average cool water temperature, hence T_{in} is equal to T_c. The hot water temperature T_h also similar to T_{out} which will be withdrawn back to the chiller.

i. Assumptions of the single stage charging

   The assumptions during the single stage charging are like below

   a. Temperature T_{in} and T_{out} is similar throughout the charging process. Therefore the parameters of average cool and warm temperature are constant
   b. The volume of the water in the tank is constant even though the cool water depth is increases with respect to time.

ii. Charging parameters of single charging

Formulation as described in section is used to determine energy use for charging of the single stage model. The charging parameters are cool water temperature and hot water temperature, charging duration and charging capacity.

a. Cool water temperature and hot water temperature are the temperature range in the TES tank during the charging. Cool water temperature is the introduced water from the chiller to the warm water in the TES tank. The chiller for the single stage charging is electric chiller, and the temperature of the cool water is similar to T_{in} from the chiller. The formula use is equation 3.2 and 3.4
b. Charging duration is defined as time required for performing charging from initial state to final state. It was determined based on energy to charge the tank and the full capacity of the charging. In this stage the equation 3.3 and 3.4 will be used.

3.5 Two-Stage Charging Model

This step is focus on enhancing the single stage charging to two-stage charging model. The modified from single stage is adding SAC and EC to charge the TES tank sequentially.

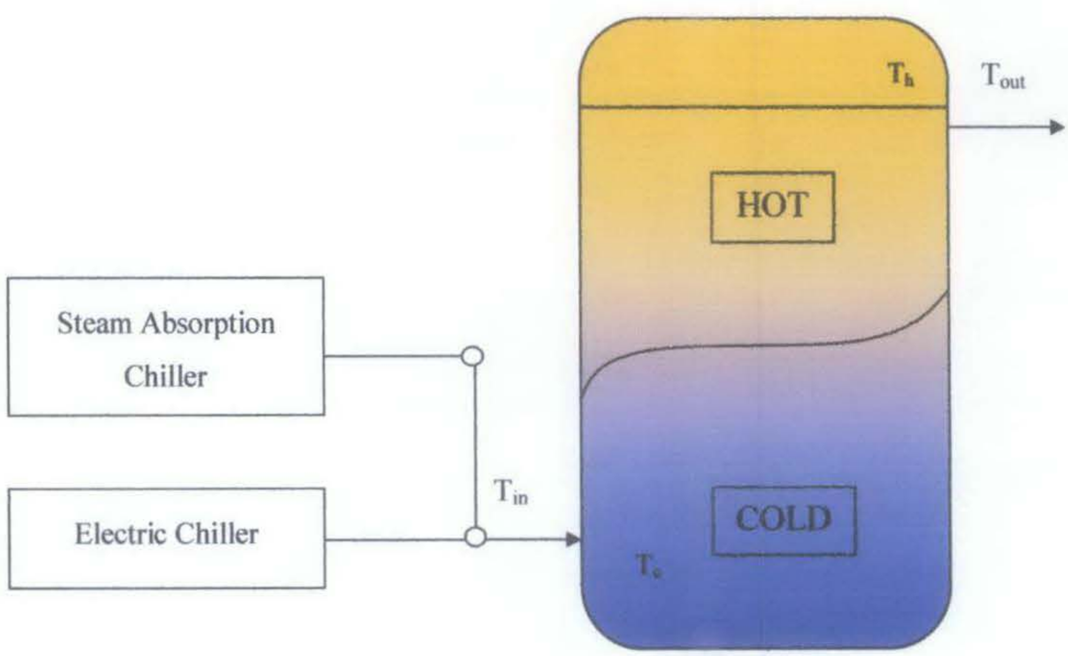

Figure 12: Schematic Flow of Two-Stage Charging

The model is enhanced for implementation with two-stage of charging stratified TES tank. On this operation, SAC will charge the TES tank first as the first stage, while EC in the second stage charging. The reason of this configuration is because of limitation temperature on SAC. The limit temperature in the absorption can be considered as change state between the first and second stage charging.

The steps in two stage charging model is similar to first stage charging with additional energy calculation. The parameters that are determined in the process namely cool water temperature and hot water temperature, charging duration and charging capacity.

i. Cool water temperature and hot water temperature are the temperature range in the TES tank during the charging. There are two range of the temperature because of the two-stage charging. The temperature difference is based on limitation temperature of the SAC. Cool water temperature is the introduced water from the chiller to the warm water in the TES tank. The formula use is equation 3.2 and 3.4
ii. Charging duration is defined as time required for performing charging from initial state to final state. It was determined based on energy to charge the tank and the full capacity of the charging. In this stage the equation 3.3 and 3.4 will be used.

CHAPTER 4

RESULT AND DISCUSSIONS

4.1 Current Configuration (Single Stage)

The single stage charging only uses Electric Chiller to introduce cool water to the TES tank. The charging takes duration from 10p.m. to 7a.m. every day before discharge to the user. For four EC's, the design capacity for each equipment is 325RT and to charge the TES tank to reach 10 000 RTh for complete charging. The calculation of the current charging is:

RTh = RT x h

= (325 x numbers of EC) x hours of charging

The first calculation using 2 EC's during charging, result of the equation is based on graph below.

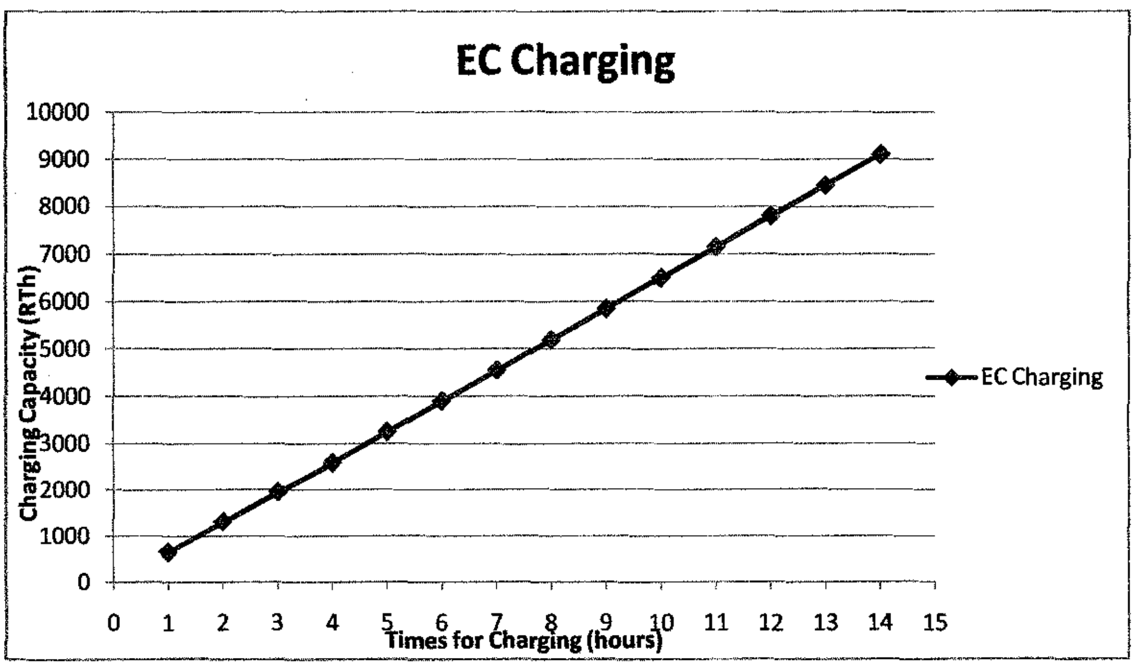

Figure 13: Graph of 2 EC's charging, Times of charging versus charging capacity

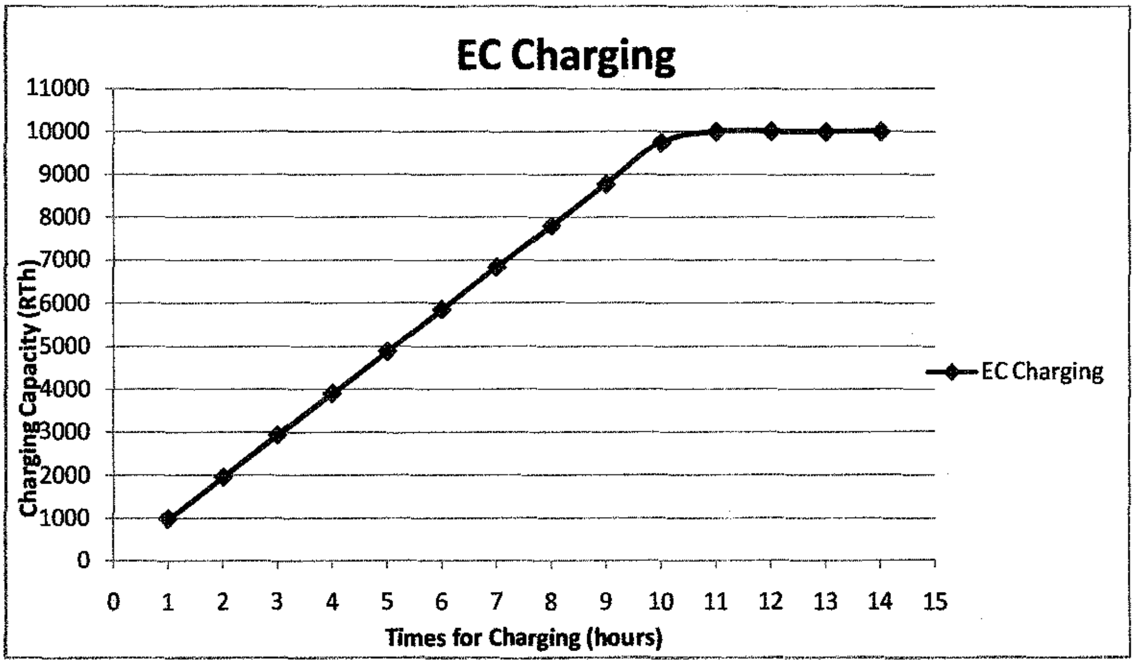

Figure 14: Graph of 3 EC's charging, Times of charging versus charging capacity

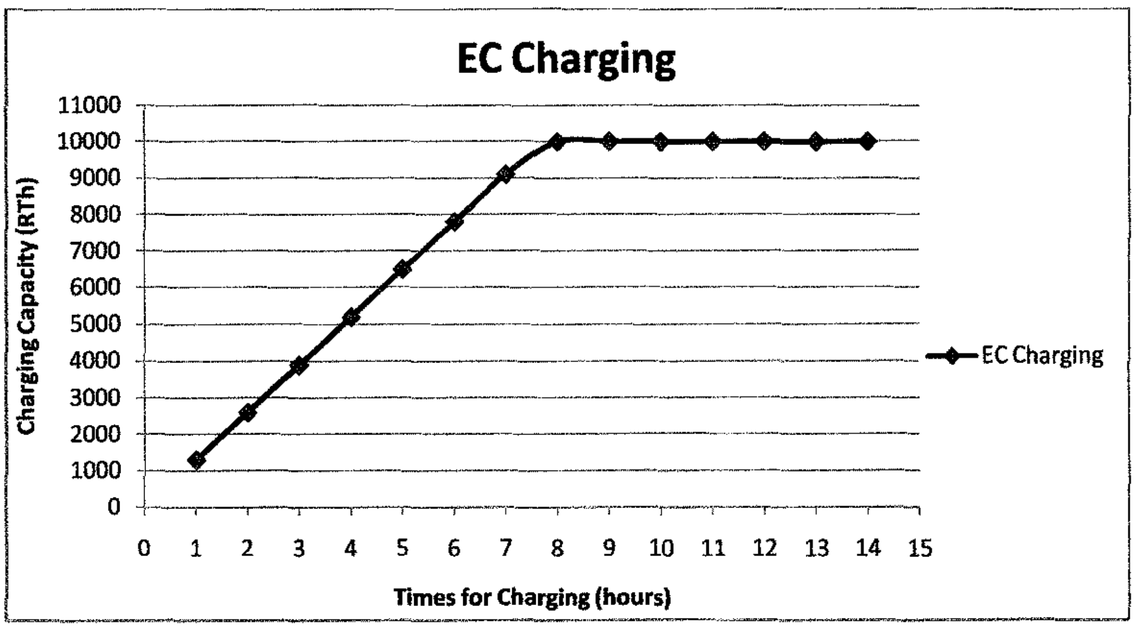

Figure 15: Graph of 4 EC's charging, Times of charging versus charging capacity

The comparison between these three graphs shows the charging time is less when using 4 EC's (1300 RT) rather than 2 (650 RT) and 3 EC's (975 RT). However when use 3 EC's, the charging still reach the capacity within 14 hour. Therefore, it is sufficient to use only 3 EC's during charging

Then next calculation is to determine the energy needed to reduce the water temperature in the TES tank and the capacity of the charging for the time given.

Parameters of the TES tank:

Volume (m^3)	**= 5400**
Temperature (°C)	**= 6 (T_{in}) and 13 (T_{out})**
Density of water (kg/m^3)	**= 999.1026 at 13°C and 999.7026 at 6°C**
1 kJ/s	**= 0.2843 RT**

Below show the calculation for the energy to charge the TES tank for the single stage by electric chiller based on equation (3.2):

$$Q = V\rho c_p(T_{in} - T_{out})$$

Where:

V = volume of space

ρ = density of the water

C_p = specific heat (4.186kJ/kg.K)

T = Temperature (°C)

For single stage charging, the energy use to charge the TES tank by EC:

Q = (5400) (999.7026) (4.186) (13-6)

Q = **158,183,742.2 kJ**

After find the charging energy, another way to find the charging capacity can be found based on charging duration.

Time to charge = 5p.m. – 7a.m. (14 hours = 50,400 sec)

Charging Capacity = Q/second

Charging Capacity = 158,183,742.2 kJ / 50,400

= 3138.6 kJ/s = 892.45 RT

Based on the finding, the best configuration is to use 3 EC's to charge in 10 hours to reach the maximum capacity of TES tank which is 10 000 RTh. If 2 EC's is used, the time to charge the TES tank exceeds the design time to charge the TES tank which is 15 hours. If 4 EC's is used, the charge can reach the capacity of TES tank quickly, but waste the energy to run the EC. The energy needed to charge the TES tank is 158,183,742.2 kJ and the charging capacity is 3138.6 kJ (892.45 RT). If compare to design capacity of EC, which are 1142.8 kW (325 RT) each (there are 3 EC), the total capacity is 3428.9 kW (975 RT). These calculations show the 3 EC's able to charge the TES tank alone.

4.2 Proposed Configuration

The enhancement of the charging at two-stage charging SAC will be charge the TES tank as the first stage and EC as the second stage. The reason of this configuration is because of limitation temperature on SAC until 9°C. The calculation will find the energy needed for both equipment and the charging capacity for the configuration.

4.2.1 1st Stage SAC

After that, to enhanced further to two-stage of charging, the calculation need to be done to find the separation time of charging SAC and EC. The equation use for determine charging hour for SAC is

RTh = RT x h

= (1250 x numbers of SAC) x hours of charging

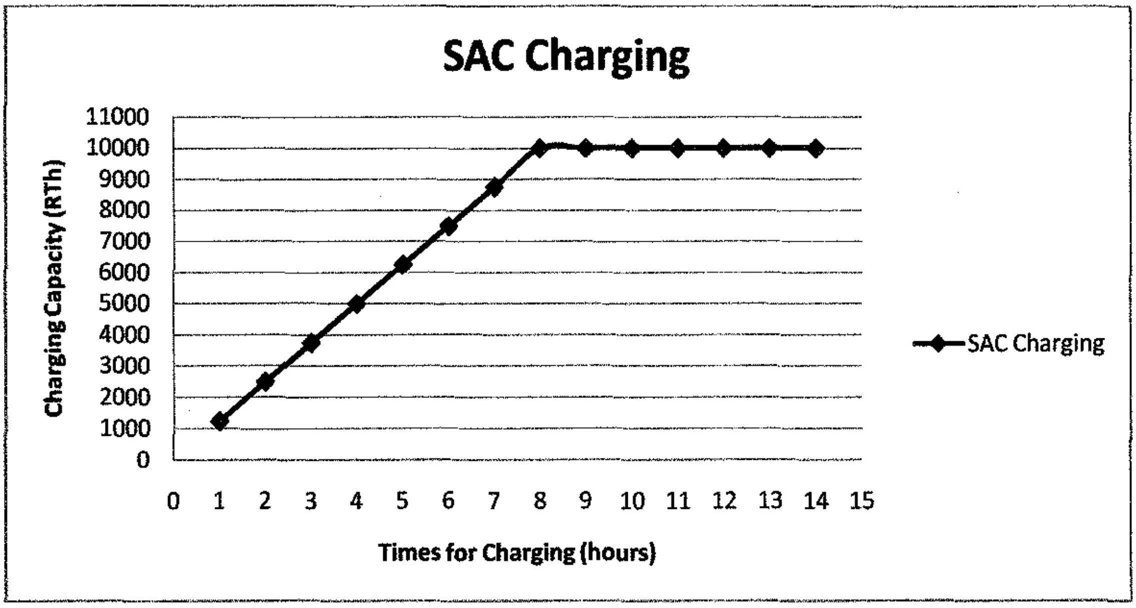

Figure 16: Graph of 1 SAC charging, Times of charging versus charging capacity

Based on the graph, using one SAC to charge the TES tank is required seven hours. The remaining time to charge the TES tank from 9°C to 6°C is seven hours also. If two SAC's is use during first stage charging, the result is below.

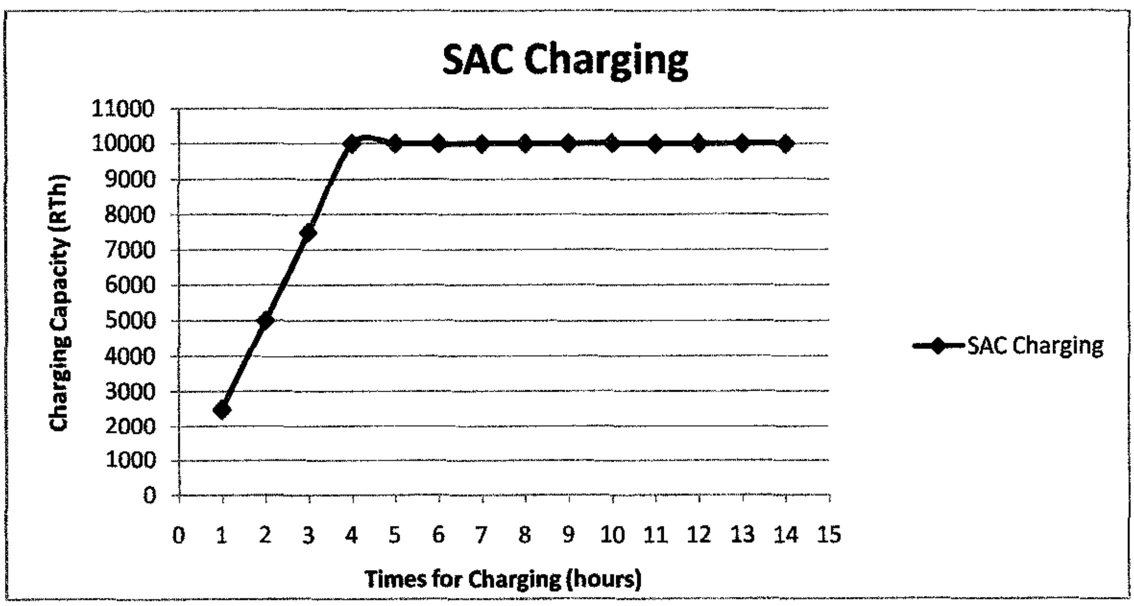

Figure 17: Graph of 2 SAC's charging, Times of charging versus charging capacity

After change to two SAC's, the charging of TES tank is faster than using one SAC's. The graph show significant change from 10 hours to 4 hours of charging. However, because at night only one gas turbine is operated, only one SAC is sufficient enough to charge the TES tank. This is because it still in the hour of charging. EC will be operate for the remaining time of charging.

Then the energy to charge the TES tank by SAC is calculated from 13°C to 9°C.

Parameters of the TES tank:

Volume (m^3) = **5400**

Temperature drop (°C) = **9 (T_{in}) and 13 (T_{out})**

Density of water (kg/m^3) = **999.1026 at 13°C and 999.7026 at 6°C**

$$Q = V\rho c_p(T_{in} - T_{out})$$

For first stage charging, the energy use to charge the TES tank by SAC:

Q_{SAC} = (5400) (999.1026) (4.186) (13-9)

Q_{SAC} = **90,336,459.3 kJ**

After find the charging energy, another way to find the charging capacity can be found based on charging duration.

Time to charge = 7 hours = 25,200 sec

Charging Capacity = Q/second

Charging Capacity = 90,336,459.3 kJ / 25,200

= **3584.78 kJ/s = 1019.31 RT**

4.2.2 2nd Stage EC

The remaining 7 hours needed for EC to charge the TES tank for the second stage.

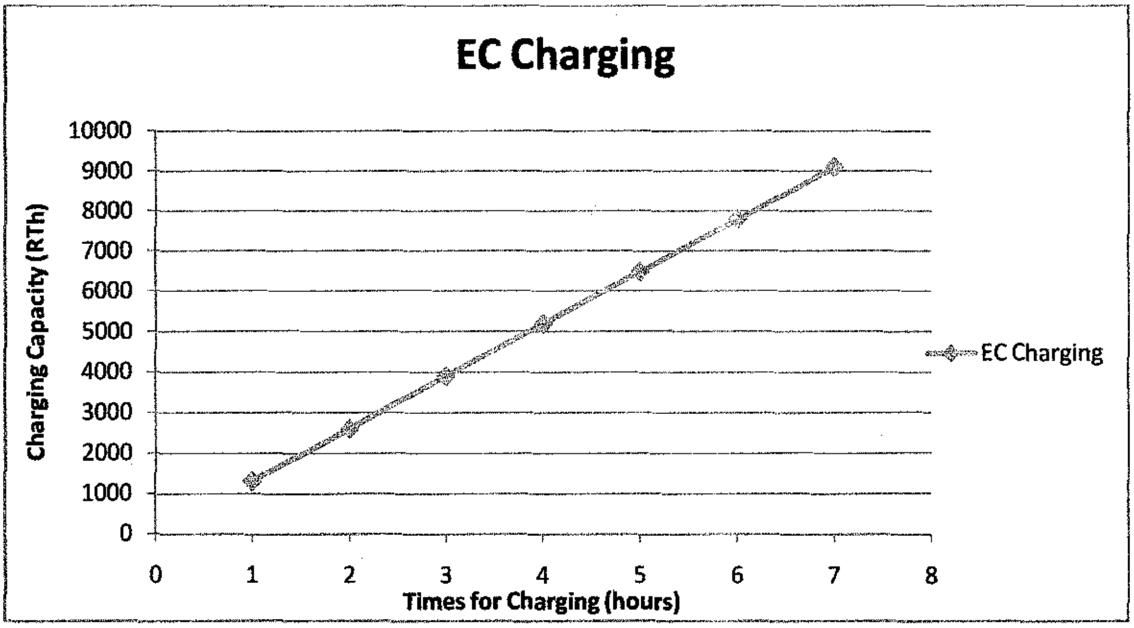

Figure 18: Graph of 4 EC's charging, Times of charging versus charging capacity (second stage)

Therefore, the energy to reduce the temperature from 9°C to 6°C is calculated below. Parameters of the TES tank:

Volume (m^3) = **5400**

Temperature drop (°C) = **6 (T_{in}) and 9 (T_{out})**

Density of water (kg/m^3) = **999.1026 at 13°C and 999.7026 at 6°C**

$$Q = V\rho c_p (T_{in} - T_{out})$$

For second stage charging, the energy use to charge the TES tank by EC:

Q_{EC} = (5400) (999.7026) (4.186) (9-6)

Q_{EC} = **67,793,032.4 kJ**

After find the charging energy, another way to find the charging capacity can be found based on charging duration.

Time to charge = 7 hours = 25,200 sec

Charging Capacity = Q/second

Charging Capacity = 67,793,032.4 kJ / 25,200

= 2690.2 kJ/s = 764.95 RT

4.2.3 Charging Capacity based on Energy equation

Another method to find the charging capacity is using try and error method. This method use the current energy result from the calculation above and divide with separated time between EC and SAC to get suitable charging capacity with the design capacity from the equipment. The equation is equation 3.4. Value of Q is taken from the calculation above divide by time.

Charging $\text{Capacity}_{SAC} = Q_{SAC} / t_{SAC}$

Charging $\text{Capacity}_{EC} = Q_{EC} / t_{EC}$

t_{EC} = total time - t_{SAC}

Q_{SAC} = **90,336,459.3 kJ**

Q_{EC} = **67,793,032.4 kJ**

Total time = **14 hours**

The result of the calculation shows at table below.

Charging hours				Charging Capacity SAC (kJ/s)	Charging Capacity EC (kJ/s)
Times for SAC (hours)	Times for SAC(sec)	Times for EC (hours)	Times for EC (sec)		
1	3600	8	28800	25093.4609	2353.924735
2	7200	9	32400	12546.73045	2092.377542
3	10800	10	36000	8364.486967	1883.139788
4	14400	11	39600	6273.365225	1711.945261
5	18000	12	43200	5018.69218	1569.283156
6	21600	13	46800	4182.243484	1448.569067
7	25200	14	50400	3584.780129	1345.099848

Table 1: Charging Capacity for SAC and EC based on Charging Hours

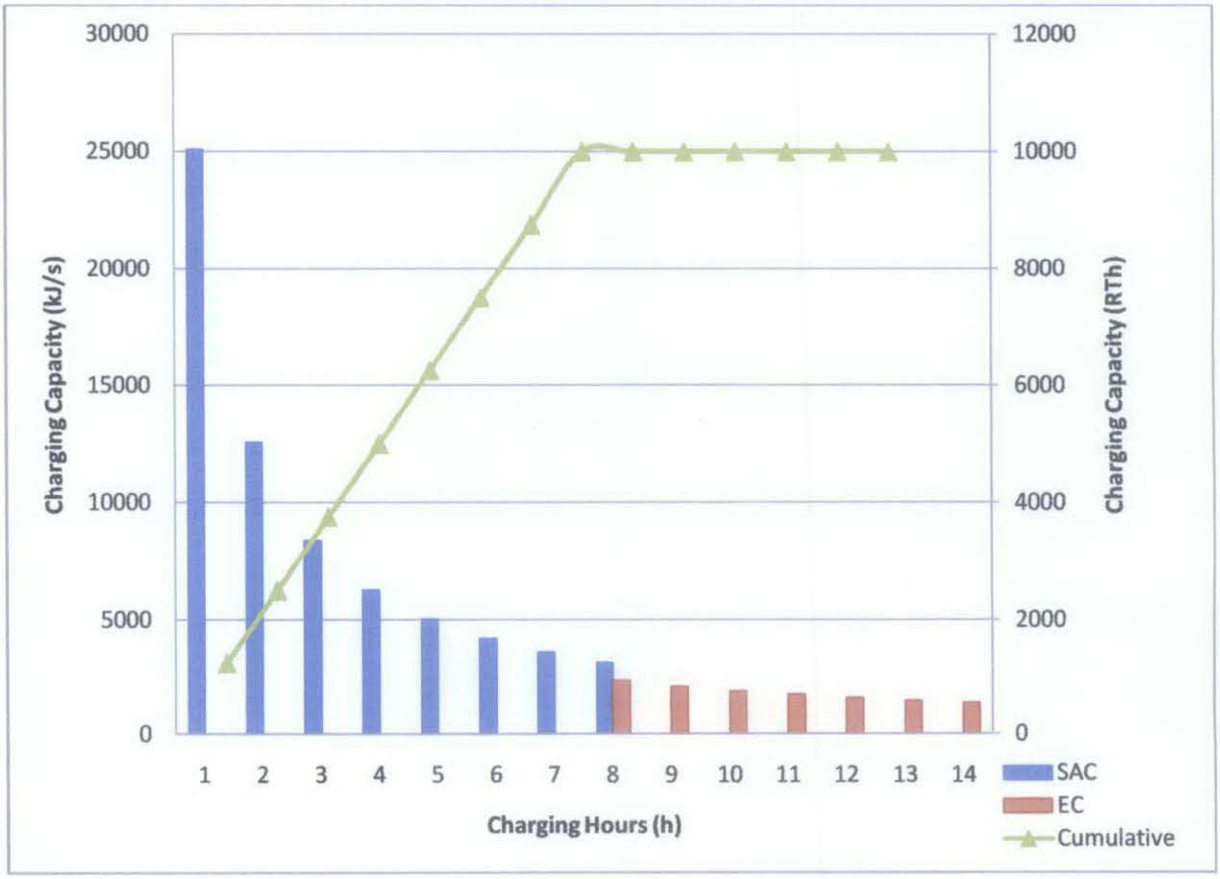

Figure 19: Graph of Charging Capacity by Charging Hours by SAC and EC

The graph shows the possibility of charging capacity for SAC and EC. The vertical axis mean if the charging hours for SAC is 7 hours, therefore the charging hours for EC is 7 hours. Based on the graph the first hour of charging, the power required to reduce the temperature of chilled water is high. However, the energy is reducing because of from time to time, the chilled water become cooler and the charging capacity is reduced. The charging capacity from EC is continued to reduce from 9°C to 6°C for next seven hours

Discussions

The calculation of both single stage and two stage shows the change of energy use and charging capacity if the SAC is incorporated with the charging the TES tank. The result for energy use for charging for single stage is 158,183,742.2 kJ. Based on the design capacity of EC (325 RT), the time to charge the TES tank for single stage is required 10 hours to fully charge using three of EC's. However, if the two-stage charging is applied for this configuration, the energy will reduce to 90,336,459.3 kJ for SAC and 67,793,032.4 kJ for EC. The decreasing of energy use shows the benefit for equipment because operation to reduce the temperature for EC can be given to SAC. The SAC charge the TES tank faster from 13°C to 9°C which is around 7 hours. The remaining charging will be taken by EC to reduce to 6°C

For the charging capacity, the single stage charging needs the value of 3138.6 kJ/s (892.45 RT) electric chiller to charge the TES tank for 14 hours. According to the design capacity, an electric chiller can produce 1142.8 kJ/s (325 RT) charging capacity, therefore 3 EC can produce exactly 3428.93 kJ/s (975 RT). Based on the calculation its show that current configuration for charging is meet the requirement design. The enhancement to two-stage design shows that the the Electric Chiller charging capacity can be reduced. The first stage, one SAC charging for seven hours required 3584.78 kJ/s or 1019.31 RT. This capacity below the design capacity of single SAC which is 1250 RT or 4396.07 kJ/s. SAC run by excess waste heat produce by gas turbine. The second stage, 3 EC's use to charge the TES tank for next seven hours, the capacity of the operation is 2690.2 kJ/s or 764.95 RT. The value also meet the requirement of design capacity EC's.

The two stage charging configurations also reduce the usage of EC alone to charge the TES tank. It reduce dependant on electricity use to operate the EC. However, SAC operation use the waste steam from the Gas Turbine Generator, the source of energy to run the equipment is always available because GTG run 24 hours to supply electricity to UTP.

iii. Design System

The two stage of charging is modified by installing new pipe system from SAC to the TES tank with a few numbers of valve and pump. General design consideration like below:

1. The stratified TES tank is based on design and current configuration
2. The temperature of chilled water is similar from the single stage which are chilled water leaving the tank at 6°C and warm water return at 13.5°C
3. The SAC and EC operating hour based on the optimum charging capacity
4. The SAC will charge the TES tank first until 9°C than EC will take place for further charging

At the new piping system, the valve from SAC to academic complex will be close and the valve to TES tank is opened to flow the chilled water for charging the TES tank. The chilled water will be stored until the temperature at the TES tank reach 9°C then the charging continues by the EC. At this moment, the valve to flow the water to TES tank is closed and wait until demand is high to open the valve flow the chilled water to the academic complex (day time).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Based on results, the two-stage charging reduces the energy and time use to charge the TES tank. The energy required to charge the TES tank for two-stage charging is 90,336,459.3 kJ for SAC and 67,793,032.4 kJ for EC. This value is lower than current configuration which needs 158,183,742.2 kJ for EC's only to charge the TES tank. This value shows that the two-stage charging use less energy to charge compare to single stage. The calculation also shows the optimum configuration use only one SAC and three EC to charge the TES tank from 5 p.m. to 7 a.m. The best configuration is charging using SAC for 7 hours and EC's for the next 7 hours. Based on the graph, the two-stage configuration completes charging the TES tank in eight hours. The time for single stage to complete charging using three EC' is ten hours. The value shows two-stage charging charge TES tank faster than single stage. The advantage of less time charging is the energy to charge the TES tank is reduces. For the conclusion, the propose project of two-stage charging give more advantages compare to the current single stage configuration. The advantages are in time to charge the TES tank and energy used to charge.

The recommendation for this project is to include efficiency of Heat Recovery Steam Generator and gas turbine in the calculation. The efficiencies of HRSG and gas turbine will give more accurate result of energy use and time to charge for the two-stage charging propose project.

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