The discussion of energy conservation of data center from the evaporative cooling technology of HPC

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Abstract - The IT industry is developing fast and more and more large scale data center and supercomputing center were built or in building, which improve scientific research and data service also bring about huge energy consumption. This paper aims to make a discussion of energy conservation of data center from the evaporative cooling technology of HPC. Firstly, the developing tendency of data center and the traditional cooling technology are introduced; secondly, much more concentration were put on the newly high performance evaporative cooling technology for HPC and we showed a prototype of the spray evaporative cooling HPC developed by IEECAS, finally, a prospective blueprint was drawn up for the future construction of data center with evaporative cooling HPC.

Keywords: Energy conservation; Evaporative cooling technology; Data center; HPC

1. Perface

During more than one hundred years since the industrial revolution, the people’s demand for the energy is dramatically increasing, which gives much more pressure to the supply of the energy and also bring about the serious environmental crisis.

With the deepening of the informationization development, the super computer or high performance computer (HPC) is developed quickly and being extensively applied in many fields.

Data center provided with lots of IT equipments especially HPC makes great contribution to the scientific researches especially in the field like astronomy and meteorology relating to a lot of data processing and computing.

Whereas, with the continuously improvement of the data processing capability, computing speed and storing ability, the data center will consume a huge amount of electricity during its daily operation and at the same time brings about serious energy consumption problem to the society.

Besides the energy consumption of the hardware in the data center, in order to secure the normal and safety operation of the IT equipment, an additional electrical energy must be used to dissipate the heat. The cooling problem of the IT equipment shows up and becomes a big challenge for the cooling technology. Among that, the energy consumption of HPC is predominant.

Aiming at the HPC cooling, the traditional method include air cooling, water cooling and heat pipe cooling etc. Water cooling and heat pipe are belong to closed loop cooling method, the manufacture technology is a little bit complex and the cost is relatively higher than others. The most important is the water cooling has the potential of leakage which will lead to an electrical accident. Air cooling is easiest and has been widely used in HPC. But the disadvantage is that is the noise is big and the cooling capability is limited. Due to its usage of air conditioner, the energy cost is very high. According to the statistic, in a nowadays air cooling data center, the minimum of 50% average carbon exhaust come from the cooling system rather that the IT equipment itself.

Recently, the research of high effective cooling technology is becoming the hot point globally and promoting the energy efficiency is a huge challenge. Evaporative cooling technology takes advantage of phase change to realize the cooling effect of the object. Its
cooling capability is far larger than the other heat transfer method using specific heat.

This cooling technology has been successfully used to the large electrical machine in china and we have priority of intellectual property right. The recent application of this technology to the large electrical machine is the world famous Three Gorges hydropower project. It’s the largest hydropower plant in the world. There are two sets of 840MVA hydrogenerators using this kind of cooling technology designed by IEECAS.

The characteristic of this cooling technology include: high efficiency for the heat transfer, high safety and most important low energy cost or zero energy cost from the cooling system itself. All of these characteristics show cases it will be very suitable for the HPC and data center.

2. The development and challenge of the modern data center

Pushed forward by the explosive increase of demand for the data services and rapidly development of IT technology, the data center has experienced a tremendous development and the increase tendency will be lasting, the annual growth rate will be no less than 10%. Whereas, the energy cost of data center becomes un-neglecting.

With the increase of demand for the computing capability, more IT equipment and more density of the equipment in the data center will be needed. The general tendency of the development of data center is limited space with as many as cabinet, high integration level, small sized chips and high density, which means more energy consumption per unit space.

According to statistics, the electricity consumption of data center is increasing annually at the rate of 15-20%, the price for the energy is soaring at the same time. So the maintaining cost for a data center is very high. It was said that the biggest single cost for Google is for the electricity. That is why they want to arrange their data center near a hydropower plant.

Among that, cooling system for data center should not be belittled and it has very close relation with the cooling technology and cooling structure.

The recently built data center and supercomputing center has more concern about the energy saving, but it’s still in a high level. Take ShangHai supercomputing center for example, since the Dawning “4000A” super computer system put into operation in August 2004, its stable load rate is relatively high, and the main CPU usage is retaining about 85%, it has a lot of consideration about the arrangement of the rack shelf and the ventilating passage design. Analysis on the basis of statistic of mean quarter operating data of whole supercomputing system showed the energy consumption in the following table1. From this table, we can see that the energy consumption of the cooling system account for more than 50% of that of IT equipment itself. See from this point of view, focusing on the energy saving of the cooling system will be obviously productive for decreasing the energy consumption of data center.

![Fig.1 Power flow in a typical data center](image)

<table>
<thead>
<tr>
<th>Cooling method</th>
<th>Real cases</th>
<th>IT hardware electricity consumption</th>
<th>Cooling system account for</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chiller 33%</td>
<td>Humidifier 3%</td>
<td>IT Equipment 30%</td>
<td>CRAC 9%</td>
</tr>
<tr>
<td>PDU 5%</td>
<td>UPS 18%</td>
<td>Switchgear / Generator 1%</td>
<td>Lighting 1%</td>
</tr>
<tr>
<td>Waste Heat OUT</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

General, the energy consumption of data center mainly covers the following aspects: high performance IT equipment itself (including CPU, RAMS, CHIPSET and external appliances), power supply equipment (power losses during the conversion of power sources) and cooling system. The typical power flow is introduced in the following Fig.1.
3. The traditional cooling method for the HPC

Recently, the cooling technology is becoming a newly researching hot point of HPC, improving the energy efficiency of the computing system and data center is a huge challenge. There are many cooling methods for tackle with the heat dissipation of HPC, but from the point of view of putting into commercial use, the most traditional or easiest realizing method is air cooling and water cooling has the potential to show up due to it high performance of heat transfer.

3.1 Air cooling

Air cooling is the most easily realizes cooling method, but it needs the use of CRWC and its cooling effect rely more on the surrounding temperature and its cooling capacity has utmost. Theoretically, the design value for the cooling capacity is 1500w/m² that means the unit computer cabinet is 6kW, the utmost is 8kW.

The most serious problem relating to the air cooling method is the fan noise and the huge energy consumption. The cooling effect and the noise of the fan is a big contradiction seems cannot be easily solved. This cooling method conform to the convective heat transfer, in order to promote the cooling effect, we must increase the speed of wind flow, so the increase of numbers of fans and the rotating speed of fans is inevitable (normally, the speed for the CPU is above 5000rpm), which lead to big noisy pollution. If for an open air cooling atmosphere, the air flow also arouse the dust flow inside the mainboard and deposited on that, bring about the decrease of safety and maintenance inconvenience.

For air cooling data center, the arrangement of the cabinets and the design for the ventilation passage is very complex, even the design is theoretically practical, and in real application, the operator of data center found that the cooling effect of different cabinet differs a lot from each other, there will appear local high temperature area and in some extreme circumstance, a few cabinet cannot working due to high temperature.

In reality, in air cooling data center and supercomputing center, up to 50% energy cost is not for computation, but for the necessary cooling system, if we concern more about the energy efficiency of the data center, this cooling method is far beyond our desire. And such problem will become more serious with the development of the chip capacity and IT cabinet integration. Lot of giant company such as IBM is struggling to solve this energy problem caused by cooling demand.

3.2 Water cooling

Due to the thermal load limit of the traditional air cooling and some other problem, the alternative is necessary. So, for large processor or supercomputing system, the water cooling method shows up the practical significant. Water is a good fluid having bigger specific heat than air, so the cooling effect can be promoted a lot. Google is programming its largest super computer with two 4-layer building used for cooling system. K-computer with water cooling system (Fig.2 and Fig.3) ranked No 1 in the last year’s world top 500 in the supercomputer field.

For cooling method itself, there is no technique knowhow and easy to be extended. But higher safety risk (water is of electrical conductivity and water leakage cannot be easily avoided due to high flowing pressure), higher manufacturing cost (technology is complex and hard to assembly and maintain) and having no positive contribution to the energy saving make it commercial prospective not very well.

![Fig.2 Cooling main board of K computer](image-url)
4. The application of the evaporative cooling technology to the HPC

The evaporative cooling takes advantage of the physical process of phase change to take away heat losses when an appropriate liquid-phase coolant becomes gas-phase coolant. The evaporative cooling technology is kinds of liquid cooling method combined with specific cooling structure design which can avoid the fatal disadvantages of the water cooling completely due to it adopt some special coolant with high insulation.

The Institute of Electrical Engineering, Chinese Academy of Sciences (IEECAS) has been doing the evaporative cooling research since 1958. During more than 50 years’ developing process, the evaporative cooling technology has experienced some stage of innovation and has been used to various electrical equipments, such as turbogenerators, hydrogenerators, electrical power transformers and power electronic component equipment etc.

Due to the urgent demand of high efficiency cooling technology for HPC, we try to use it to the HPC on the basis of our experiences on applying of it to the power electronic component equipment. Its application to the HPC not only can solve the heat dissipation problem but can obtain the goal of energy saving.

Phase change heat transfer is of high efficiency, it can realize the good cooling effect for the HPC, at the same time the stability and safety of HPC can be guaranteed due to the selection of the evaporative coolant. The evaporative coolants are all liquid material with proper boiling temperature best matched with the cooling target. It is primarily environmental protected, is of high insulation, it has on toxicity, no liable to inflame and good chemical and physical stability.

As to energy conservation, for different cooling structure, the energy saving level varies. The following will introduce two kinds of evaporative cooling HPC design. The energy saving target is different.

4.1 Spray evaporative cooling HPC

We have developed a kind of spray evaporative cooling super computer with the cooling medium directly contact with the heated chips, during the phase-changing procedure, the large amount of latent heat will be absorbed by the coolant from the heated chip without increase its temperature, so it very fit for the high density computer cabinet cooling, the cooling effect is better than air cooling at the same thermal load level, and most important effect is that the coolant circulation just need a little momentum provided by the pump, the energy consumption for this kind of cooling system is just for the energy cost of pump.

When the HPC start working, the liquid phase evaporative coolant sprayed out from the nozzle and have a direct contact with the heated chips distributed in the HPC cabinets, part of them vaporizes when absorbing heat and gas phase coolant rise to the condenser. The pump provides the momentum for the coolant circulating in the closed loop. In the equipment, the nozzle is located near the mainboard and spays liquid coolant toward the main heated chips shown in Fig.4.

We have built a prototype of spray evaporative cooling super computer in our lab (Fig.5), it unit cabinet thermal capacity is 50kW, but the max energy cost for the pump is just 3.06 kW accounting for only 6.12%. If a group of computer cabinets operate parallel, the proportion of pump energy cost will decrease due to the power of pump is non-linearly increased. So, for a data center with many hundreds of cabinet, the energy saving effect is more in evidence.

4.2 Self-circulating evaporative cooling HPC

For more energy saving cooling system, we come up with the self-circulating evaporative cooling system for
HPC, which have some thin liquid boxes attach to the heated chips and all these boxes can be connect together or form circulation branches separately.

![CPU](image1)

![RAM cluster](image2)

**Fig. 4** Spray of coolant to the heated chips

**Fig. 5** Prototype of spray evaporative cooling HPC

The self-circulating evaporative cooling HPC consists of blade units, blade cases, cabinet, condenser, liquid boxes and some connecting tubes. The principle diagram is shown in the fig.6. The liquid box shown in Fig.7 is fill with the evaporative coolant with the boiling temperature of 40-50°C. When the chip heated, it will transfer the heat to the box attached on it, the coolant inside the box absorb the heat, part of them boiling and liquid coolant becomes gas phase coolant and flow upward along the gas tube due to the density difference and flow back along the liquid tube after it is cooled into liquid phase in the condenser. So, the whole circulation system is closed loop, and the coolant flow momentum is aroused from the density difference between liquid phase and gas phase coolant, there is no need of external forcing momentum. So, there is no energy consumption at all.

The use of thin box brings about additional contact thermal resistance and a thermal conductive link along the direction of box wall thickness. For improve it, some researches on surface conductive and convective enhancement methods are underway in our lab.

In a long run, this kind of cooling system for HPC is the best choice for the data center and supercomputing center. The prototype is under construction in our lab. The cooling system itself can completely realize zero energy consumption and is self-circulating, no fan or pump noise, self-adaptive and safety. The only problem is a little higher primary investment for the fabrication of liquid box due to its odd-shaped. When it can be standardization and realize mass production, the initial investment will not be a problem anymore.

### 5. The prospect for the construction of the future low energy consumption data center

For the next generation of HPC, air cooling cannot be satisfying and water cooling was hampered by the high cost, safety and maintenance. So, introducing the high efficiency evaporative cooling technology to the IT equipment, especially the data center with centralized use of IT equipment is a good resolution for high cooling effect and lower energy consumption.

![Diagram](image3)

**Fig.6** The diagram of self-circulating evaporative cooling HPC
The evaporative cooling system is closed loop and has direct cooling effect to the heated chip, so there is no need of installation of CRWC, it can eliminate to the maximum the noisy pollution aroused from the fan of air cooling in the data center and can save a lot of money for the electricity usage relating to the cooling system. It can provide a clean, high capacity, quiet environment for the future scientific research and large scale numerical calculation. By adopt micro-force circulation and self-circulation system to realize the high-performance of cooling system, it provide more rooms for increase the density of single chip; it can also increase the density of cabinet or data center; it has more flexibility to get a good use of space of data center. Due to its low or zero energy cost, it will have a great contribution to push forward the energy conservation of data center and with no doubt will play a positive influence on the sustainable development of IT industry.

Furthermore, lower power consumption or zero power consumption evaporative cooling technology combined with the architecture energy-saving and the reasonable usage of afterheat should attract more attention when sketching the future construction of data center and some auxiliary facilities.

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