Demand Response Management of a District Cooling Plant of Mixed Use Development

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Abstract:

The objectives of this paper are to investigate the technical feasibility of Demand Response (DR) program of a District Cooling Plant (DCP) and provide recommendations based on Demand Response Management principles for managing customer demand. This work focuses on some of the DR objectives which have the potential to implement DCP of a mixed-use city. The general published data on mixed use city developments and a specific city in Dubai was taken as a case study to show the usefulness of DRM objectives. This study primarily addressed the issues related to load management. The findings are: DRM creates greater flexibility in demand management without compromising service levels. Also it reduces the operating cost and impacts on the environment. However, implementation is a challenge. Therefore, implementation strategies are also proposed as a part of the recommendation which includes a generic model for demand response management. Moreover, a review is provided on key enabling technologies that are needed for effective demand response management. Demand response management is technically feasible for a district cooling plant.

Key Words: Mixed-Use City, District Cooling Plant, Demand Response Management.

Introduction:

Rapid economic and social developments and advancement of technology in the last few decades improved the lifestyle and living conditions, and changed the habits of people. Consequently, it increased the demand for energy services in residential, commercial and industrial sectors of the cities [1]. This problem has been deepening with the rapid growth of cities around the world. More than 50% of the world population lives in urban environments. Urbanization is one of the primary causes for many problems such as depletion of natural resources and environmental degradation [2]. The main drivers of future city development are population density and sustainability (Energy, Environment and Economy). In many mega cities around the world, mixed-use development is becoming increasingly essential for the creation of an attractive and sustainable environment that promotes economic vitality, social equity and environmental quality [3].

As mentioned above, technology development and innovation have improved the living condition of people. Providing thermal comfort is one such example where technological development and innovation have made it a common feature in any urban environment. Demand for cooling has been increasing around the world for last couple of decades due to the various reasons, and it is continuing to increase in the future particularly in developing countries. For instance, in Dubai 60% of peak electrical power is contributed by cooling demand during summer months [4]. Refrigerant technologies including air conditioning presently account for 15% worldwide electrical energy use [5]. Most refrigerants that are used for cooling are predominantly depleting the Ozone layer and/or produce Green House Gases (GHG), which contribute to climate change when released to atmosphere.

Cooling Demand in Mixed-use City Development

Traditionally, the cooling demand has been met by decentralised, electrically driven appliances. Ever increasing cooling requirements, especially during summer, increase the demand for electricity and push the electrical systems to their limits, thus increasing the risk of outages.

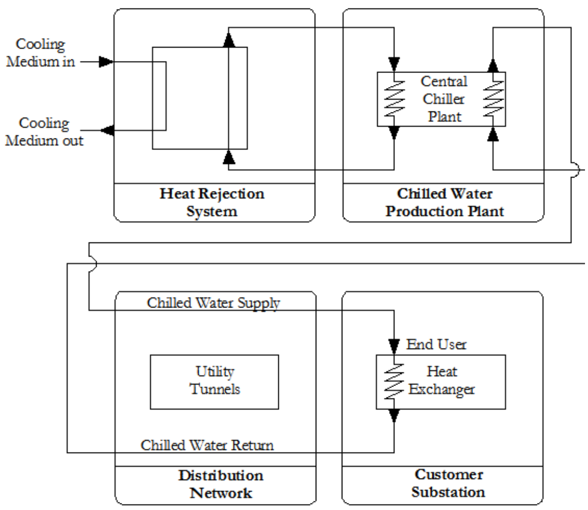
District Cooling (DC) is an innovative alternative approach to provide for comfort cooling. DC reduces the impact on the environment and the burden to the electricity utility. Further it provides opportunities for the energy business, its customers and society [6].

DC is becoming an essential infrastructure in modern city development owing to many benefits compared with its counterpart. Figure 1 shows the schematic diagram of a district cooling system. The supply-side consists of chilled water production, bulk transmission and distribution. The demand-side results from consumption to support the economic and non-economic activities. Water is used to extract heat from customer installations and it is rejected to atmosphere.

Traditionally, customer demand growth of almost all the energy systems is met by utilities by taking action on utility side of the meters. These options require increase in capacity, and hence the increase of capital and operational expenditure. They also tend to have adverse environmental consequences. The peak load capacities have to be reserved to mitigate the problems of energy security. The associated capital and operational cost are high owing to the nature and ability of these reserves to match the fluctuations during peak-load condition.

Conversely, Demand Side Management (DSM) programs aims to change customer load shapes and reduce the total cost of energy for program participants [8]. DSM, especially DRM brings more benefits to energy systems than Supply-side Management (SSM) [11]. The significant cost benefits to customers and utilities together with reduction in emissions are the two areas which SSM have failed to capitalize on.

Figure 1 - Schematic Diagram of a Typical DCP with Chilled Water as Energy Carrier [7].



Traditionally DSM is applied to electrical energy supply systems. Nevertheless the principle is applicable to any energy system. Application of DRM concept is far advanced in electrical energy systems which undoubtedly, is most preferred form of energy in the modern world. DRM system is considered to be a critical infrastructure component to control, operate and monitor an electrical grid especially Smart Grid. However, technical feasibility of DRM for DCP has not been attempted before.

The objectives of this paper are to investigate the technical feasibility of DR program of a DCP and provide recommendations based on DRM principles for managing customer demand. The expected outcomes of this work were measure by developing a DR model for managing demand and verification of the model using actual building load profiles for different building types that would comprise a mixed development as well as a specific case of a mixed development.

Method:

A comparative study and a case study are the methods used to achieve the study objectives. Purpose of the comparative study was to develop electrical analogy to DCP and to develop a DR model. The purpose of the case study was to assess the DR potential in managing demands especially peak demand in a mixed use development and to validate the model. The results of the literature survey and the case study are described below.

Results:

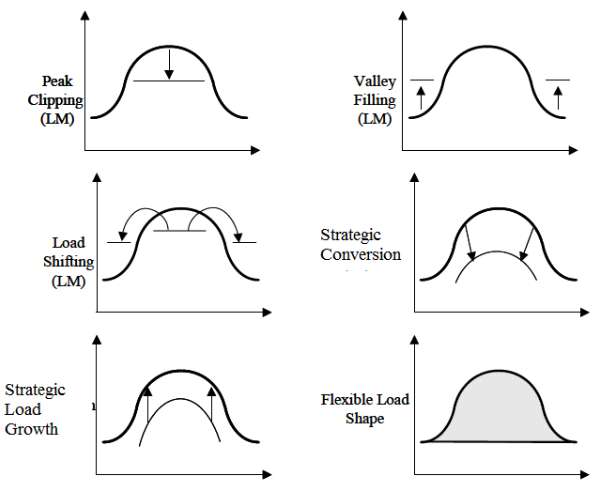
DRM – Electrical Analogy to DCP

A comparative study was carried out to develop an electrical analogy for district cooling. This work mainly reviewed the background of DRM in electrical network; principle of operation, needs, implementation options and benefits to customers and utilities were included in the review.

Principle of demand management is balancing supply and demand. If demand exceeds supply, it will result in undesirable consequences such as a black out. For this purposes, the supply conditions are always kept above maximum demand condition which has a high in magnitude and a short duration in the load profile of any energy system. Traditionally, the demand has been met by building new power plants and expanding transmission and distribution capacity. However this strategy failed to capitalize due to constrains such as energy security, economy and environmental problems. Soon it was realized that change of energy use behavior in the demand side could solve the problems of load management and it is known as Demand Side management (DSM). Six load shape objectives are classified for DSM programs as illustrated in Figure 2, which further can be classified as basic level (peak clipping, valley filling and load shifting) and advanced level (strategic conservation, strategic load growth and flexible load shape) [9].

Demand Response (DR) is a subset of demand side management (DSM). The objective of DRM is load management on demand-side by using economical and technical measures to reshape the load profile into a desired shape (Hong, 2009). This mechanism has arisen in recent times to describe a set of pricing structures, programs, and related technologies and services that provide options for customers to change their electricity demand in response to signals from the electric utility industry [13]. Challenges and uncertainties of an electrical power system make DR a valuable asset for utilities.

Figure 2 - Six Load Shape Objectives for Load Management Program [9, 15].



In electrical energy systems, the demand response may consist of any combination of the following six intertwined actions either by manual actions or by some automated system as shown in Figure 2 [10];

- Demand reduction during peak load periods (Peak Clipping)
- Filling of valleys of off-peak demand to improve load factor (valley filing and smoothing).
- Shifting of load from peak to off-peak between time of day or season (load shifting) through embedded and domestic storage schemes.
- Strategic Conservation is the modification of overall electricity usage by customers (e.g. Energy Efficiency).
- Strategic Load Growth is the development of new applications, markets and customers.
- Flexible load growth is inducing demand variations or making desired load shapes in responsive to reliability conditions.

These actions are applicable to all the energy systems including district cooling, however scalability differs from systems to systems. Load shifting using large central storage schemes are popular approaches in district heating and cooling systems. However in electrical systems, this option is limited to domestic schemes.

DR Programs
Type of DR can be broadly classified as load responsive and price responsive, both providing financial benefits to the customers.

Load Responsive Programs
Sometime these programs are called as incentive based DR programs. There are several load responsive programs operative in the electricity market across the globe. These programs can be grouped under four major categories as explained below.

Direct Load Control (DLC)
DLC allows the utility to control the customer loads remotely subject to a mutually agreed contract. Under this agreement, utilities shed customer loads by switching the equipment on and/or off directly. In return, the utility provide incentive payments to customers. This program targets the small commercial and residential

consumers usually with less than 100 kW of demand [9].

Load Curtailment (LC)
These programs are designed to provide tariff discounts or bill credits to customers for agreeing to reduce load to pre-specified levels during system contingencies. This program traditionally has been offered to largest industrial and commercial customers [11].

Emergency Load Responsive (ELR)
In these programs, customers are paid incentives for measured load reduction during emergency conditions. The incentive rates are very high for these programs and levy no penalties for non compliance of the enrolled customers. These two factors make the programs very attractive particularly among industrial customers [11].

Capacity Market Programs (CMP)
In capacity market programs, customers commit to provide pre-specified load reductions when contingencies arise and subjected to penalties when they do not respond. Customers typically receive notice of events a day ahead. Incentive payments usually consist of upfront reservation payments, determined by capacity market prices, and additional energy payments for reductions during events [11].

Price Responsive Programs

Time-of-use (TOU)
This is the basic type of price-based DR programs. The unit price of energy varies in different time intervals. Generally, peak rate is higher than off-peak rate, and it reflects average cost of generation and distribution during those time periods. TOU rates are in use for many years and found widespread use among large industrial and commercial customers.

Real-Time Pricing (RTP)
Real-time pricing is a tariff option in which energy prices fluctuate hourly according to the changes in the wholesale price of energy. The rates are usually communicated to customers on a day-ahead or hour-ahead basis. This program is recognized as the most direct and efficient approach to achieve DR objectives in electricity markets.

Critical Peak Pricing (CPP)
CPP rate is a pre-specified high rate designed to use during critical peak period. CPP rates are typically combined with either TOU or normal flat rate tariffs. CPP is called during system contingencies or higher wholesale market prices for a limited number of hours or days during a year. The rate may be 3-10 times higher than the normal rate.

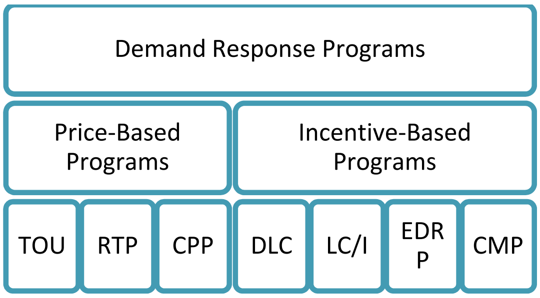
In addition to load responsive and price responsive programs, demand profiles can be changed by purely voluntary DR methods. Although it is difficult to quantify, its affects on load management cannot be ruled out completely. In the modern world, individuals as well as organizations are willing to alter their behaviour for the sake of environmental and/or financial interests. Promoting voluntary DR will bring benefits to utilities and customers as well. However, information has to be disseminated for the success of this method [10]. Figure 3 summarizes the demand response programs described above.

The benefits of demand response of electricity markets include improved economic efficiency, improved security of supply, reduced price volatility and the incentive for the exercise of market power, and reduced investment in peak generation.

These benefits can be categorized under two main groups: benefits that accrue directly to customers and benefits on electricity market operation [12].

As such, Demand-Response Management solutions can be applied to DCP for sustainable operation. A large DR potential has been identified in district cooling systems but hardly any research has been carried out to ascertain its technical and the economical feasibility.

Figure 03 - Classification of Price Based and Incentive Based Demand Response Programs



Electrical Analogy of District Cooling Model
Operation and control of a district cooling model can be explained using an electrical power system analogy. Technically, central plants of DCP can be compared with power generation plants. Distribution networks of DCP can be compared with transmission and distribution networks. Similarly, customer side of both the networks is similar in nature. Both have consumer substations and functions of them are analogues to each other.

DRM for Load Management of DCP
Direct Load Control (DCL) and Time of Use (TOU) methods can be used for reducing peak demand. Thermally heavy buildings can be used for improving load factors. The following actions will ensure implementation of the DR goals.

In DCP, thermal energy storage is widely used for peak load management. This technique enables plant capacity utilization during to off-peak. However it will not reduce the magnitude of peak load of the system. This scheme works well when the time of use pricing scheme is applicable to DCP operation.

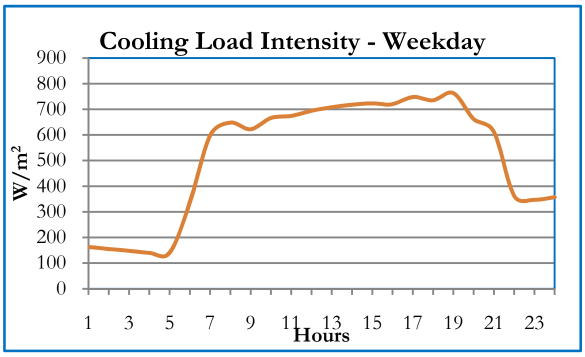
To examine technical feasibility of DR of DCP, the cooling load profile of a mixed-use city was examined. Total cooling load intensity for 5 hypothetical building types with different load profiles in Hong Kong during a summer month is shown in Figure 4. From the figure, we can observe that the peak load and troughs appear alternately and create a valley. Traditional practices demand a plant capacity greater than or equal to the maximum demand. However, application of DR objectives will effectively reduce the peak demand for capacity; clipping the peak and load shifting can be achieved through DR objectives. DCL, LC and TOU methods can be used for these purposes. These two schemes are very effective when compared with other DR programs. Voltage and frequency are very critical operating parameters in electrical networks, but in the case of DCP, there is no such constraints. Therefore, program like ELR and CPP are not suitable for DCP operation.

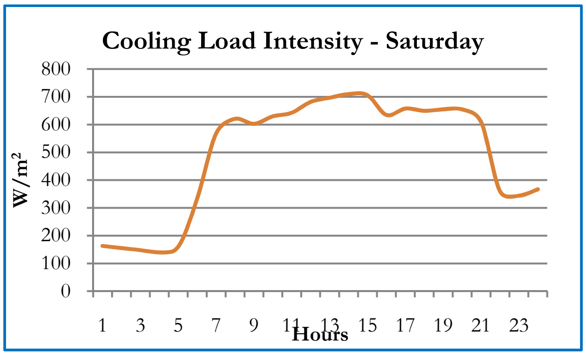
DLC can be used to clip the peak and storage mechanisms for shifting the load from off-peak to peak hours. Similarly, LC can be applicable to large commercial consumers where the thermal capacity of the building can be used for storing energy during off-peak hours and released during peak hours.

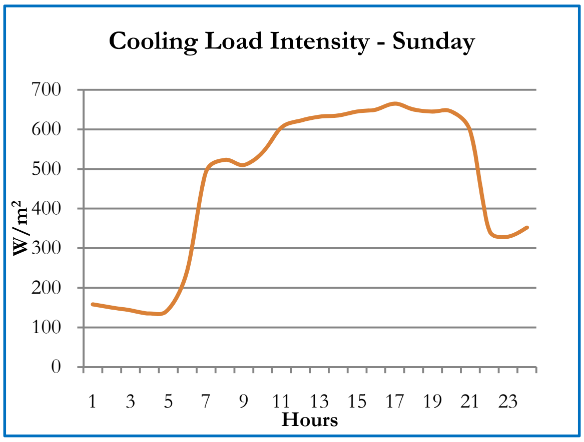
TOU methods can help in reduction of energy usage during peak hours as observed in electrical networks. Studies on electrical networks show that people are willing to sacrifice their comfort for the sake of financial and environmental benefits [5].

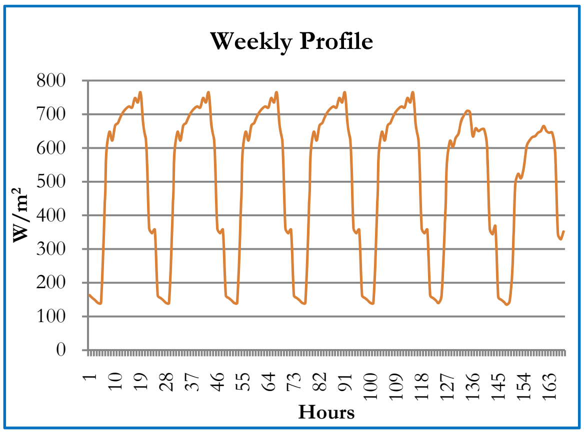
From these analyses we can conclude that load control can be achieved by applying DRM techniques. Therefore, DRM is technically feasible for DCP operation. Application of DRM for load control will results in reduced installed capacity and reduction of operating cost.

Figure 4 - Cooling-Load Profiles for Three Day-Types during a Summer Month [7]









DRM works well for new plants as capital investment required for its implementation would be readily available, and total investment required would be less than the actual amount without DRM. However, for an operating plant, it is a challenging task as additional capital investment will increase the payback period. Nevertheless, potential savings in operational costs and environmental costs would offset the investment required.

Although DR is a promising technology for district cooling operation, many challenges limit its practical implementation in a mixed use environment.

1. Technology Challenges

DRM needs a secure and reliable information and communication infrastructure for its operation. The technology should be customer oriented and future proof to handle future advancements in technology. Information security is another concerned area as energy systems are increasingly becoming vulnerable to information threats. Advanced meter management is needed for developing strategies and decision making.

2. Economic and Business Challenges

Socio-economic and business challenges need to be addressed before implementing DRM. It is really tough to answer what would be the cost and benefits to the market players. It is impossible to estimate potential savings. Unlike the electrical grid, district cooling business is dealt with relatively small market revenue schemes and hence, return on investment may be longer.

3. Regulation Challenges

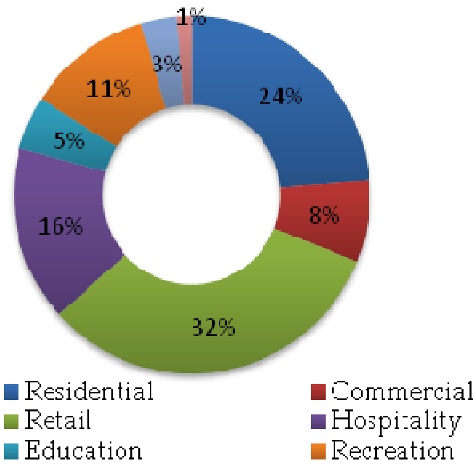
Interoperability ensures successful operation and control of energy system. This is possible or sustained through seamless integration of system devices. In reality, this is not the case; devices are built with different application interfaces. Resolving this issue is not an easy task unless all the vendors agree to integrate their systems on a common interface. Lack of industrial standards or regulations make implementation difficult.

Case Study

A specific case study was carried out in a mixed use development in Dubai. The objective of this study was to validate the applicability of DR programs. The total connected cooling capacity on the DCP is 200 MW and maximum demand about 123 MW (35,000 TR/hr). Eight customer categories are connected on the district cooling through 32 delivery stations and the distribution is as shown in figure 5 below. The cooling is being generated using all electrical chillers.

The case study initiated with a walk through to identify the need for DRM and potential opportunities available for its implementation. The following operational problems were identified during the inspection.

Figure 5 - Cooling-Load Distribution on Customer Categories.



Utilization: insufficient capacity during summer and under utilization during the rest of the year.

Water and electricity consumption: despite being 40% energy efficient than conventional systems, the consumption of a large amount of fresh water from desalination plants off-set the saving at national level. Cost of electricity is very high due to recently introduced time of use tariffs and non-availability of Thermal Energy Storage (TES). Regulations were enacted to reduce the water and electricity consumptions.

Low energy efficiency: part load operation, higher summer temperature and fouling of Heat Exchangers (HEX) at Energy Transfer Stations (ETS) and Air Handling Units (AHU). Non-availability of remote control and monitoring systems, and ineffective maintenance aggravate the problem. Wastage in the form of leaks is left undetected.

User behavior: Tariff structure and lack of awareness encourage the customers to over-consume chilled water.

Assessment of all the challenges shows that the DCP needs a set of operation and control strategies in terms of market, legislative, sustainability and command and control aspects, to migrate from its present operating conditions. Demand Response provides an opportunity to DCP operator to reduce water and electricity consumption according to their business and legal needs. On the other hand, it provides an opportunity to customers to reduce their bills through a commitment to reduce load in response to system requirements. Implementation of DRM will benefit to people, businesses and the environment. Additionally, it would enable the use of absorption systems with electrical chillers to optimize the operation. Load reductions during peak demand conditions also will help electrical and water utilities to cut down their peak-load. This would reduce emissions and environmental impacts associated with operation.

It is concerned with how cooling energy is commonly used across the various consumer classes in the city and providing information to influence the customers to reduce the load. Sufficient data is not available to generate load profiles hence user behaviors and performance of the DCP. Further study is needed to establish load profiles; this can be done either by simulation or by measurements. This is a pre-requisite for implementation of DRM.

Discussion

From the comparative study, it is observed that the DR objectives concept is going to influence future district cooling energy systems as it is very much successful in the electrical system. The literature review revealed that DCP has great potential to become a candidate for DRM. Moreover, the interesting finding was that DR in DCP is an un-tapped and promising component of demand management. It will be a future technology for achieving sustainability. At the enterprise point of view, sustainability has to be built on three major pillars or 3P. The Profit, Planet and People are those three pillars representing economic, environment and the social dimensions of a business environment respectively. DRM reduces the cost of operation with the active participation of customers which lead to environmental protection.

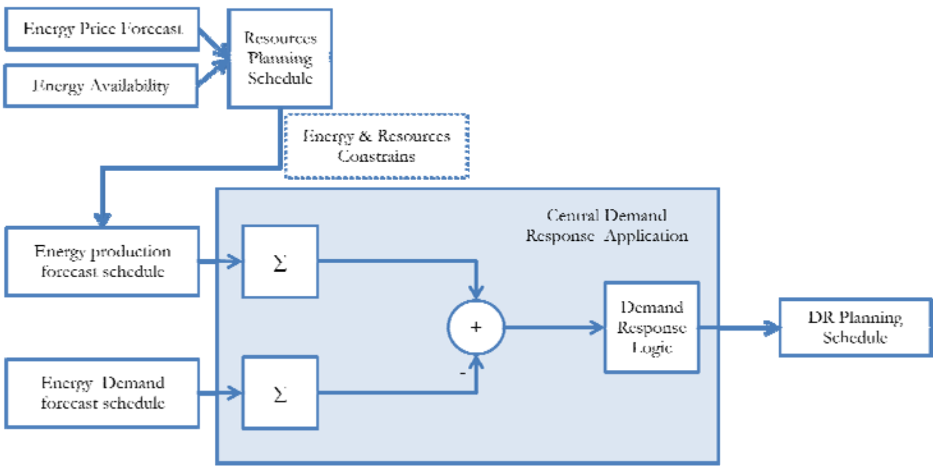
The technical feasibility and effectiveness of DRM were demonstrated using a case study. Investigation of customer behavior was the first step towards understanding the applicability of DRM. However, non-availability of data prevented validation of its applicability. It was strongly recommended to adopt DRM for demand management. Considering the practical difficulties, the implementation was not immediately possible but possible in the long-run. The following implementation strategies were proposed for implementation of DR objectives in demand management. It can be done in three steps as shown below.

In step one, energy use behavior needs to be determined by integrating DCP to a central command centre built for city operation and management. Based on this information, the production, distribution and end-user systems should be optimized and sustained for a longer period, and baselines of different customer classes should be established. This is very critical and important for the rest of the strategies. In other words, we can call it as optimizing the system locally.

In step two, all the communication and information requirement should be completed and a link from City Management System (CMS) to all the customers and DCP should be established. The link established can be used to collect and manage the large amount of information generated in the energy system.

In step three, DRM can be implemented using the model proposed in this paper. The proposed demand response model is a generic one not mathematic. The model is shown in figure 6.

Figure 6 - Generic Physical Model for Central DRM



The DR model proposed in this paper has limitations. A detail mathematical model is required to access the true economical feasibility of the DR objectives of a DCP. Technical and economical feasibility of the recommendations has to be done before implementing any recommendation. Also these recommendations are applicable to all electrical chillers plants. Detailed studies are required for different cooling technologies.

Information and communication technologies are the key enabling technologies needed for successful implementation of DR programs that heavily depend on technology. First part of this technology involves making linkages between utility systems to its customers (Communication). Second part of the technology involves utilizing the connectivity established to collect and manage large amounts of performance and consumption data (Information Management). Moreover, these are necessary to promote demand response or to remove barriers to demand response participation. Advanced Metering Infrastructure (AMI) and Smart meters appear as enabling technologies for effective use of demand response strategies. Two-way communications, intelligent networks, and multifunctional technologies will allow for demand response programs that are both more extensive and more efficient. Further work needs to be done in these areas to substantiate the requirements.

Conclusion

This paper is a preliminary investigation of the possibility of extending the DRM concept from electrical grid to another energy network; in this case district cooling network. From this study, it is obvious that Demand Response provides an opportunity to DCP operator to reduce water and electricity consumption according to their business and legal needs. Load reductions during peak demand conditions will help electrical and water utilities to cut down their peak-load. This would reduce emissions and environmental impacts associated with operation.

The implementation of demand response for non-electrical grids will simplify implementation of DRM in electrical grids. Electrical grid operators can deal with other non-electrical utilities (single entity) directly rather than targeting large numbers of customers and their equipment within industrial, commercial, and residential sectors. On the other hand, it will create a common view of economical resource utilization and energy pricing. It can be concluded that the research objectives are contributed to advance the knowledge of DRM in district energy networks and its implementation is highly achievable one. This study proves that Demand Response objectives are technically feasible for district cooling operation.

Reference

[1] *Susanne Lindmark, 2005. The Role of Absorption Cooling for Reaching Sustainable Energy Systems, Licentiate Thesis (KET R209), Dept. of Chemical Engineering and Technology Energy.*

[2] *The summary report of workshop on The Pathway to urban sustainability, 2010. National Academies Press, Washington, D.C. ISBN-13:978-0-309-15895-4.*

[3] *Charles Y.J. Cheah, Kok Sang Tan, Mixed-Use Project Development Process: Features, Pitfalls and Comparisons with Single-Use Projects. Conference Paper, The Fourth International Conference on Construction Engineering and Project Management (ICCEPM-2011).*

[4] *Power Saving on Peak hours, 2012. An article on load campaign by DEWA. Available at: http://www.dewa.gov.ae/community/conservation/ydc/savepower.aspx, Accessed on: 08 January 2012; Updated on: 08 January 2012.*

[5] *International Institute of Refrigeration, www.iifiir.org, accessed February-2010 (Statement given at COP-16 and CMP-6, United Nations Framework Convention on Climate Change, November 29 - December 10, 2010).*

[6] *Roelof Potter, 2004. European Energy Forum, www.europeanenergyforum.eu, accessed on February 2011. District Cooling: A Sustainable Response to Europe's Rising Cooling Demands, Dinner-Debate, 2004/11/2.*

[7] *T.T. Chow et. al., 2004. Energy modeling of district cooling system for new urban development. Energy and Buildings 36 (2004) 1153–1162.*

[8] *IndEco Strategic Consulting and Fraser and Company, 2003. How to Reward and Encourage Milton Hydro Customers to Conserve Power: Milton Hydro's 2003 DSM Plan.*

[9] *Jun Hong, 2009. The Development, Implementation, and Application of Demand Side Management and control (DSM + c) Algorithm for Integrating Microgeneration System within Built Environment, PhD thesis, Energy Systems Research Unit, Department of Mechanical Engineering, University of Strathclyde.*

[10] *Andrew Roscoe, 2004. Demand Response and Embedded Storage to Facilitate Diverse and Renewable Power Generation portfolios in UK, M. Sc. Thesis, Energy System Research Unit, University of Strathclyde.*

[11] *Benefits of Demand Response in Electricity Markets and Recommendations for achieving them. Report to the United State Congress Pursuant to the Section 1252 of the Energy Policy Act of 2005, United State Department of Energy (USDOE).*

[12] *Samuel Gyamfi, Demand response assessment and modeling of peak electricity demand in the residential sector: information and communication requirements, PhD thesis, Department of Mechanical Engineering, University of Canterbury, 2010.*

[13] *Bo He, 2004. High-Capacity Cool Thermal Energy Storage for Peak Shaving - A Solution for Energy Challenges in the 21st Century, Doctoral Thesis, Department of Chemical Engineering and Technology, Energy Processes, KTH, Stockholm, Sweden.*

[14] *Sustainable Energy Regulation and Policymaking for Africa, Training manual, Module 14. Published by: United Nation Industrial Development Organization,Available at: http://www.unido.org/fileadmin/import/83266 Module14.pdf.*

[15] *Primer on Demand-Side Management with an emphasis on price-responsive programs, 2005. Prepared for: The World Bank, 1818 H Street N.W. Washington, DC 20433. Prepared by: Charles River Associates, 5335 College Avenue, Suite 26, Oakland, California 94618.*
Published on: Feb 2005.