THE ROLE OF DSM+C TO FACILITATE THE INTEGRATION OF RENEWABLE ENERGY AND LOW CARBON ENERGY TECHNOLOGIES WITHIN BUILDINGS

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ABSTRACT

Recent legislation and building regulations have aiming to reduce the energy demands of buildings and include renewable based micro-generation technologies. Due to the variations in energy delivery from these technologies, optimised control over building plant and loads is essential if we are to achieve a good demand-supply match and achieve a reduction in energy demands.

This paper reports on research being undertaken as part of the UK EPSRC SuperGen Future Networks programme, specifically relating to the development of algorithms for simulating dynamic demand side control strategies to identify demand-supply matching options when deploying building integrated renewable energy and low carbon technologies. The development of demand side management and control (DSM+c) is a means to improve the dynamic demand-supply match taking account of the available demand side management capacity and time of occurrence. The principle of the developed DSM+c algorithms is to maximise the available control capacity which will enable a better demand-supply match while minimising any impact on users. This paper will demonstrate the application of DSM+c to improve the energy efficiency of a building (e.g. reduced total capacity), restructure the demand pattern via load shifting and switching (e.g. on/off or proportional control) to one more favourable to building integrated renewables. The impact of different control strategies on demand profile restructuring will be demonstrated using simulation to alter the settings of the DSM+c parameters – such as priority, methods and periods – for a given demand profile.

The paper will conclude by presenting the outcomes from a case study using the decision support/ design tool, MERIT where the developed DSM+c algorithms have been implemented to better facilitate the match between demand and building integrated clean energy supply technologies at the individual multi-familiy building level.

KEYWORDS

demand side control, MERIT, building simulation

INTRODUCTION

To reduce the environmental impact associated with traditional energy supply systems and improve the efficiency of energy utilisation within the buildings, recent legislation and building regulations such as EPBD (Energy Performance of Buildings Directive) by European Union (2002), UK Energy Whitepaper by DTI (Department of Trade and Industry, 2003) and the Scottish building regulations by SBSA (Scottish Building Standards Agency, 2007) etc are bought forward to increasing the energy performance of buildings, reducing the energy demands of buildings and including the small-scale renewable-based micro-generation energy systems. Two possible approaches are adopted either through improving the efficiency of energy utilisation on the demand side or through adopting the green technologies into the energy supply system on the supply side. Due to the variations in energy delivery from these technologies such as intermittency for renewable and demand-profile sensitive for low carbon technologies, optimised control over building plant and loads is essential to reduce and reshape the demand profile for better performance of these new energy systems if we are to achieve a good demand-supply match and a reduction in energy demands.

The easiest, cleanest and safest way to improve the match between the demand and supply is to deploy the demand side management measures on the various loads, either reducing the demand or reshaping the demand profile (DTI, 2003). The DSM+c is one of the promising approaches among the demand side measures to manipulate the demand profiles significantly being capable of considering the users' impact (comfort) level. It could not only lead to the carbon dioxide savings and may help to facilitate the connection of greater amounts of intermittent renewable energy generation, such as solar and wind power. It could also improve the performance of building-integrated low carbon emission system operation to a certain level through creating a favorable demand profile.

DSM+c ALGORITHM

Concept & Objectives

The concept of DSM+c algorithm is to use control devices to manipulate the individual demand profile based on the availability of supply resources to achieve the favourable aggregated demand profile for better energy supply system operation over a certain time period. It can be regarded as a mean to improve the demand/supply matching rate and optimize the performance of energy supply system. The principle of DSM+c is to minimize the impact of users and at the same time maximize the match between demand and supply through identifying the best combinations of different demand side control options such as load shifting, load control (On/off control and proportional control) and load recover for the various demand loads. The available options of demand side measures will improve energy efficiency (e.g. reducing the total capacity), change the pattern of use (e.g. load shift), and apply the switching strategies (e.g. on/off or proportional control) etc.

The main objectives that the DSM+c algorithm is going to achieve are:

- To maximize the energy efficiency of energy use, even reduce energy;
- To facilitate power from building-integrated renewables and avoiding export from or import to the grid;
- To create optimal or favorable demand profiles for LCTs & RETs operation.

DSM+c algorithm is a new concept of demand side management, which not only does the management work but also has the control capability. In the following section, it describes this algorithm in detail.

DSM+c Algorithm

DSM+c algorithm is capable of managing both energy and load based on the comparison results between the demand and the supply resources available. Therefore it can be classified into two fields: energy management and load management plus control.

- **Energy Management**

Energy management refers to managing the demand over a certain period. Energy Efficiency (**EE**) and Load Shifting (**LS**) are the two main measures. **EE** measure can reduce the magnitude of demand profile by a certain amount of percentage and result in reducing the energy consumption over a period of both peak and off-peak time (if more appliances with higher energy efficiency are adopted). **LS** measure is another energy management strategy on the demand side. Traditionally, it is used to shift the load from on-peak to off-peak period (Clark W.Gellings, 1993). Due to the involvement of renewable based low carbon energy system, the **LS** strategy is different from the traditional one. Shifting the loads from the period with inadequate supply to the period with sufficient supply becomes important. Depending on the characteristics of the demand itself, it can be classified into shifting the whole load profile and shifting the part of load profile.

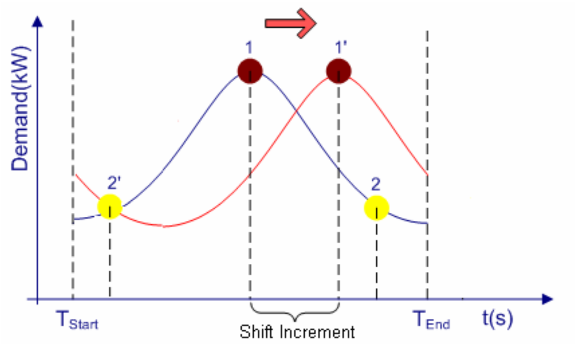

Figure 1 Diagram for whole load shifting

In **Figure 1**, it shows the mechanism of shifting the whole load. There are two lines in the graph, the left one representing the demand profiles before load shifting and the other one showing the demand after load shifting. The demand profile is made up of dispersed data points. Therefore the load shifting for the profile is all about offsetting the data points. Whole load shifting means that it moves the total profile according to the shift increment, direction and boundary specified. There are mainly two situations for the whole load shifting. One is that the data points after being shifted are still within the shifting boundary. This replaces the data point one shift increment ahead each time (such as the point 1 and 1' in the graph). The other situation is that the data points after being shifted will be outside the shifting boundary (such as point 2). In this case, the data points outside the boundary will replace the data points on the other side of the boundary subsequently (such as the point 2').

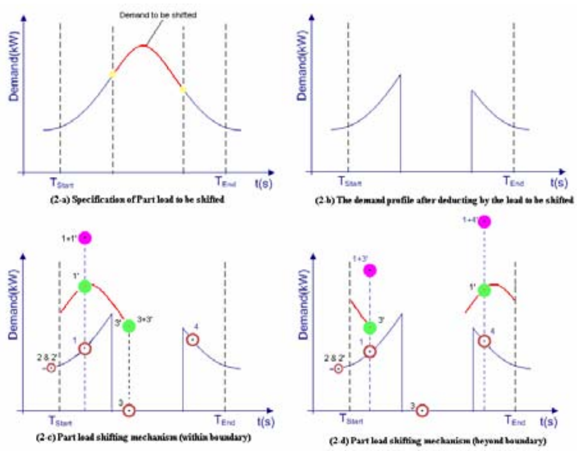

Figure 2 Procedure of part load shifting

For the load with part shift, it's more complex than the whole load shift. After defining the load to be shifted (see **Figure 2-a**), the original demand is deducted from this. The changes are shown in **Figure2-b**. **Figure 2-c** and **2-d** illustrate the mechanism of part load shifting in detail. Similar to the whole load shifting, 'part load' is also involved in offsetting the data points in two situations. **Figure 2-c** shows one situation, on the one hand, where the data point of part load to be shifted is within the shifting boundary. It simply adds the value point upon the relative data point on the deducted demand profile (such as 1, 1' and 1+1'). The other situation, shown in **Figure 2-d**, is that the data point of part load will be outside the boundary after it has shifted. It will add the relative data point upon the deducted load on the other side of boundary (such as point 1, 3' and 1+3').

- **Load Management and Control**

Load management and control is another principal strategy of DSM+c algorithm. It applies the switching strategies to the various loads in order to reshape the total demand profile and create the favorable load profile for the operation of the renewable based low carbon emission energy system. The demand profile can be obtained from two-level resources. One is high level that the data is mainly from monitoring or historical way. Another is low level through developing physically-based simplified or detailed demand models to simulate demand profiles.

Several DSM+c parameters are employed such as Control Priority (CP), Control Method (CM) and Control Duration (CD) etc. CP refers to the availability that the loads can be controlled, from high to low even no control at all. If the demand is defined as high CP, it means that it has got the high availability to be controlled. Therefore, if the total supply is less than the total demand at the time step, the demand with high **CP** can be controlled first to reduce the demand in order to meet the supply. **CM** refers to the switching strategy either on/off or proportional control, which depends on the features of the loads. For example, the domestic refrigerator is suitable for on/off control. And the lights can be controlled proportionally. **CD** means the maximum time that can be controlled for the load. Depending on the demand profiles obtained at high or low level domain, the control duration can be identified in different way. For demands at high level, the maximum control time for a specific load is set using the empirical data through the users' specification. For demands at low level, **CD** can be quantified by running the demand models to check the control variables at a previous time step and then decide whether keep holding or releasing the control.

Figure 3 describes the procedure of the DSM+c algorithm at each control time step in detail. It compares the total demand with the total supply at each time step. If the total demand is greater than the total supply, the algorithm of controlling loads (**Figure 4**) is activated. While the total demand is less than the total supply, the algorithm of recovering loads (**Figure 5**) is triggered. As the total demand is equal to the total supply, it dispatches and continues to the next time step.

Figure 4 illustrates the algorithm for controlling the loads in detail. The philosophy of this algorithm is to control various loads as less as possible to meet the total supply. Depending on the control priority parameters defined previously, the algorithm sorts the selected demands by the decreasing order of the control priorities from high to low automatically. After controlling one demand with a higher priority, the algorithm sums up all the demands to get the new total demand and compares it with the total supply. If the new total demand at this stage is still greater than the supply, the control for the demand with the priority next to the previous demand is required until the total demand is less than or equal to the total supply. If the total demand is less than or equal to the supply, it breaks the loop and continues to the next time step.

Figure 5 shows the algorithm for recovering the loads in detail. The principle for this algorithm is to recover the loads as much as possible to satisfy the supply with the order of the increasing control priority. Similar to the load control algorithm, the load recovering algorithm also starts with sorting the demands. The difference is that it sorts the demands in the increasing order from low to high priority. And it recovers the demand with low control priority at the first place, when there is surplus supply at the current time step. Depending on the total demand recalculated after recovering the load, it compares the new total demand with the total supply. If the total supply is still greater than the new total demand, it moves to the next demand to be recovered until the total supply is less than the total demand. If the total supply is less than the total demand, it stops the circulation and moves to the next time step.

Impact of DSM+c Algorithm

The impact of DSM+c algorithm upon the micro environment (mainly refers to the users' comfort level) is a vital issue. It relates to whether the control strategy is acceptable or not to the users. Similar to the nature of the demand profiles (either from statistical data or simulated data), two levels of way can be classified to examine the impact of the DSM+c algorithm: high level and low level.

- **High Level**

It's hard to quantify the impact for high level demand profile (such as historical or monitoring data etc.) after DSM+c algorithm. The only possible way to realize it is to build the actual control hardware systems into the real building. By measuring the parameters relevant to the micro environment, we know if the control strategy is good or bad. Otherwise we only can compliment the impacts through more intelligent control algorithm. The high level DSM+c algorithm described in this paper is capable of analyzing the match between supply and demand (include magnitude and phase) after specifying the DSM+c parameters. By specifying different values of the **CD** parameter, we are able to compare the match results and see how much the DSM+c algorithm can improve the match. Through this way, we can optimize the DSM+c parameters to achieve a better match while maintaining the minimum level of users' comfort.

- **Low Level**

The impact for low level demand profile (such as physically-based demand models) can be quantified through calculating the relevant micro-environmental parameters within the demand models. It can decide the control action by comparing the new values of control variables with the initial settings whether the customer minimum comfort levels are violated. Through this way, the **CD** parameter can be quantified automatically. Discrepancies between real effects on the load demand curve and preliminary results are mainly due to the incorrect modeling of loads involved in these control strategies (Molina et al, 2003). Therefore the more accuracy the demand model is, the more realistic load control strategy provides. At this stage for the SuperGen project, the physically-based demand model for cooling and heating system is developed for the purpose of low level load control algorithm application. Physically based load modeling methodologies have been widely used, because they are able to predict the individual load dynamic response and allow one to obtain the aggregated response of these loads efficiently.

IMPLEMENTATION

The DSM+c algorithm was successfully implemented into a demand-supply matching software tool, called MERIT (F.J.Born, 2001), which was developed by ESRU (Energy System Research Unit) in the Department of Mechanical Engineering at the University of Strathclyde.

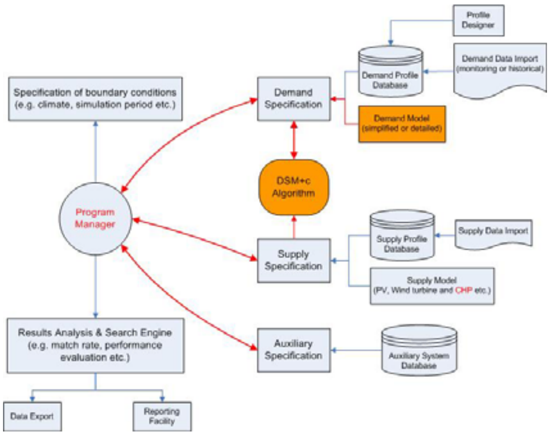

Figure 6 DSM+c module within Merit structure

Figure 6 describes the modular components of MERIT, whereby the users enter the program through the central program manager and continues through a series of modules typically followed in the clockwise order depicted (F.J.Born et al, 2001).

The modules of DSM+c algorithm and demand model are newly developed and implemented in MERIT. The DSM+c algorithm has functioned as a bridge connecting the supply module and the demand module, which compares the demand with the supply at each time step. Judging from the comparative results, the specific demand side measures are taken to manipulate the demand profile either reducing the demand or shifting the demand to another period. The new changed demand is passed to the program manager again and matches with the supply. The updated match results are stored in the file and shown in the graph displaying section.

The DSM+c parameters are set through the pop-up demand-side-control dialogue and load-shifting dialogue respectively, shown in **Figure 7**. For the demands with different DSM+c properties and the supplies, the algorithm will be activated when the total demand is not equal to the relating total supply. The impact of this DSM+c algorithm on the demand profiles also can be examined. For the high-level demand profiles, the impact can be identified by changing the value of control duration. For the low-level simulated demand profiles, the impact can be quantified by recalculating the control variables relevant to the users' comfort. By comparing with the initial setting value, it decides whether it holds the control for the next time step or not.

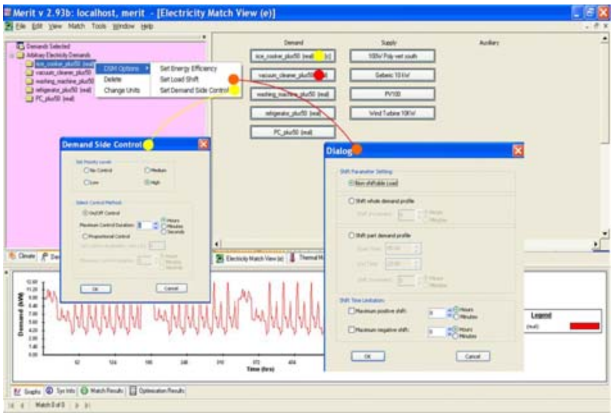

Figure 7 Interface of DSM+c algorithm in Merit

CASE STUDY

The case study focuses on the UK EPSRC SuperGen Future Networks program, specifically relating to the development of algorithms for simulating dynamic demand side control strategies to identify demand-supply matching options when deploying building integrated renewable energy and low carbon technologies. The challenge is to establish the levels of demand flexibility that can realistically be achieved without compromising user functionality and expectations. Currently the control flexibility of the demand profile within the residential sector is mainly examined.

Identify load types found in domestic and the control actions and time duration which can be implemented, as listed in **Table 1**.

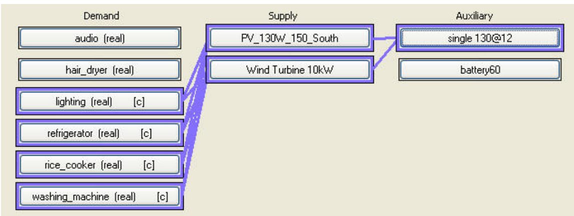

Figure 8 demands/supplies match combination

Take one multi-family building in residential sector as an example, the monitored profile from various appliances is obtained from the real monitoring project. Then specify the different DSM+c properties for each profile including the priority, control duration and control method. The RE supply options available for the building are PV and wind turbine. They are clearly defined in **Figure 8**. To establish demand-side management and control analysis, the individual electricity demand profiles representing home appliances are assigned control priorities and methods based on the information described in **Table 1**. As an example, the domestic loads of refrigerators, rice cookers, lighting and washing machines are selected for DSM+c analysis. The control duration for these loads without the notice by users is important for understanding how much energy can be saved after adopting the DSM+c algorithm. Unfortunately, this kind of information is difficult to find. For this paper, in order to show how the DSM+c algorithm work, the assumptions of the DSM+c parameters for each selected load (5 minutes maximum control duration for one refrigerator, 15 minutes maximum control duration for one rice cooker, 30% energy efficiency upgrade for lighting and load shifting strategy for washing machine) are made respectively.

Table 1 Identification of DSM+c parameters for domestic appliances

Load	Control Method		Time	Priority
	On/ Off	Partial		
Hot water	√	√	Hour/ Min	High
Washing machine	√	√	Hour/ Min	High
Tumble dryer	√	√	Hour/ Min	High
Dishwasher	√	√	Hour/ Min	High
Fridge/Freezer	√		Min	High
Towel rails	√	√	Min	High
Elec. Apps. (with chargers)	√	√	Min	High
Lighting	√	√	Min/Sec	High
Elec. Apps. (heating)	√	√	Sec	High
Electric oven/hob	√	√	Min	Medium
Slow cookers	√	√	Min	Medium
Elec. heating	√	√	Min	Medium
Air-conditioning	√	√	Min	Medium
Elec. blanket	√	√	Min	Medium
Microwaves	√		Sec	Medium
Extractor fans		√	Sec	Low
Hairdryers		√	Sec	Low
Elec. Apps. (instantaneous)	√			No control
Entertainment	√			No control

The results of the matching analysis with DSM+c are compared with the results which correspond to the original demand profiles as given in **Table 2**. As can be seen, the matching rate is increased by 6.3% after adopting DSM+c, from 57.6% (before DSM+c) to 63.9% (after DSM+c). It is also found that after DSM+c the match statistics (inequality coefficient and correlation coefficient) for the demand and the supply improve. From the above results, it indicates that the DSM+c algorithm can not only reduce the magnitude of the demand but also reshape the demand profile for better match with the supply. The match rate can be improved further by 6% after adopting the auxiliary supply system, such as battery etc, also shown in **Table 2**.

Table 2 Results comparison for various criteria

	Before DSM+c	After DSM+c	After DSM+c & battery
Demand (MWh)	74.08	60.86	60.86
RE Supply (MWh)	45.19	45.19	45.19
Aux Supply (MWh)	0	0	0.77
Match Rate	5/10	6/10	6/10
Percentage Match (%)	57.60	63.91	69.89
Inequality coefficient	0.42	0.36	0.30
Correlation coefficient	-0.03	0.41	0.46

CONCLUSION

This paper has described the concept and methodology of DSM+c algorithm in detail including the energy management and load management plus control measures. The DSM+c algorithm has been implemented into the demand-supply matching analysis tool, called MERIT, which was developed to assist with the quantification of the match between RE-based low carbon energy systems and the demand profiles. A case study of a multi-family building in residential sector has been studied. After having specified the DSM+c parameters on the selected demand profiles, more than 6% of the improvement in the match between the demand and the supply has been achieved. A further improvement was also obtained by adopting the auxiliary supply within the energy supply system. Further work will focus on the impact quantification of controlling the demand. The demand will be model-based. The more accurate and detailed the demand model is, the more realistic and better control strategy can be achieved. The advanced energy simulation software ESP-r will be used to simulate the demand profile, which is connected with the DSM+c module in MERIT to quantify the control impact such as thermal or visual comfort etc.

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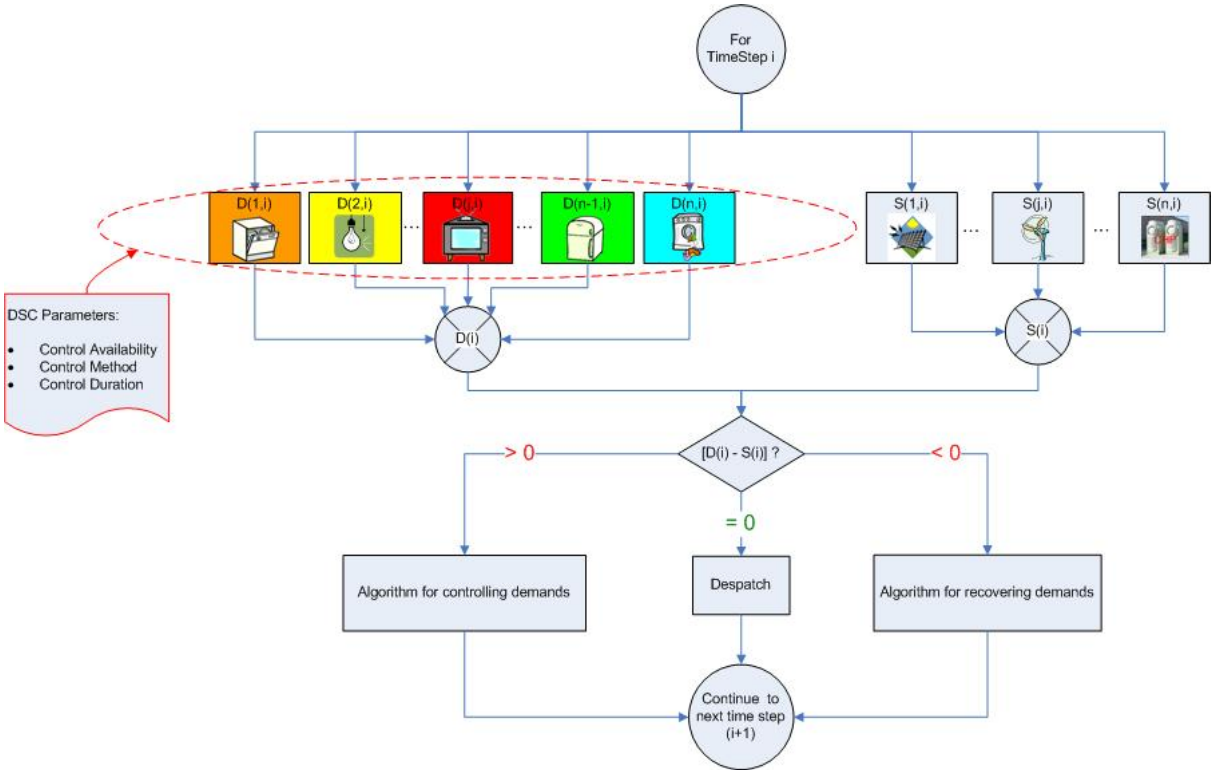

Figure 3 Procedure of DSM+c algorithm (load)

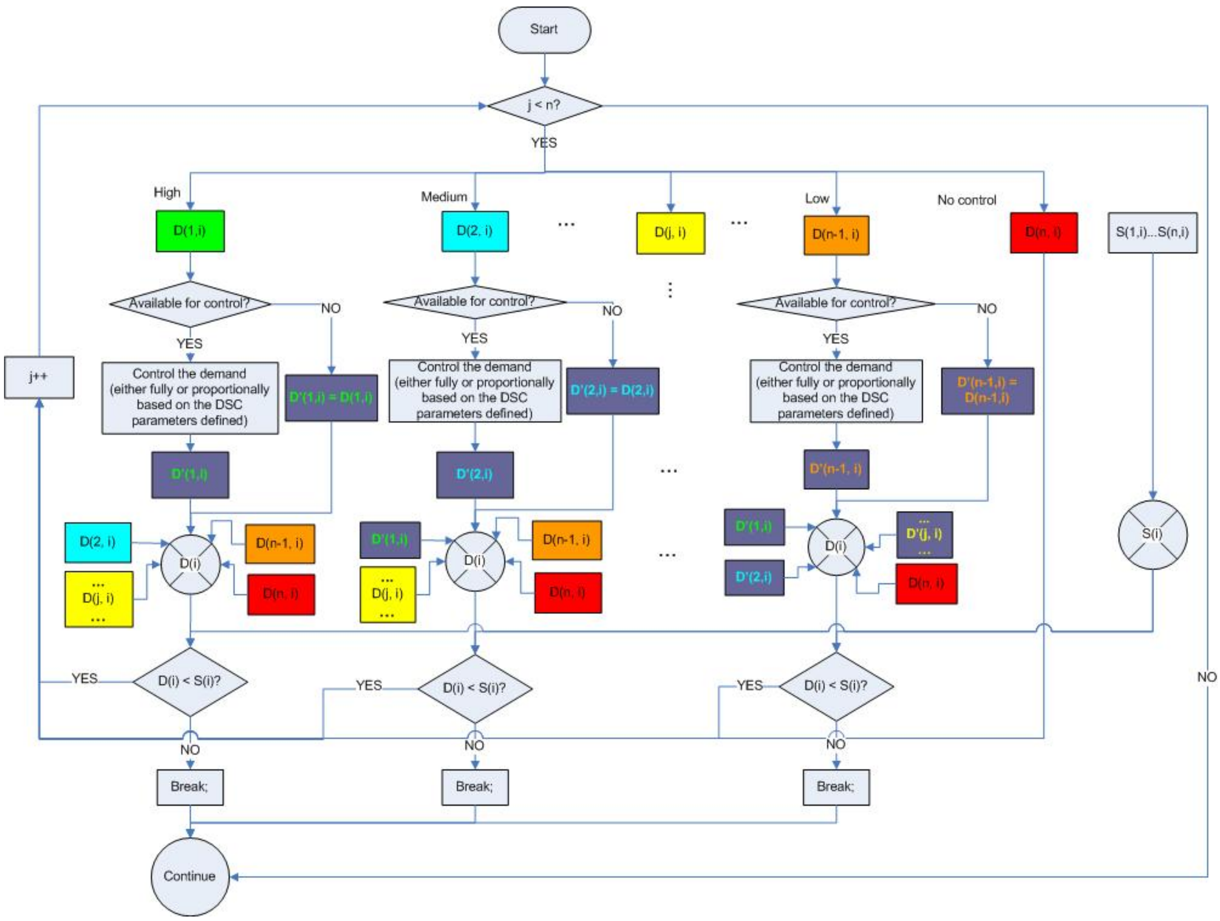

Figure 4 Flowchart for load control algorithm

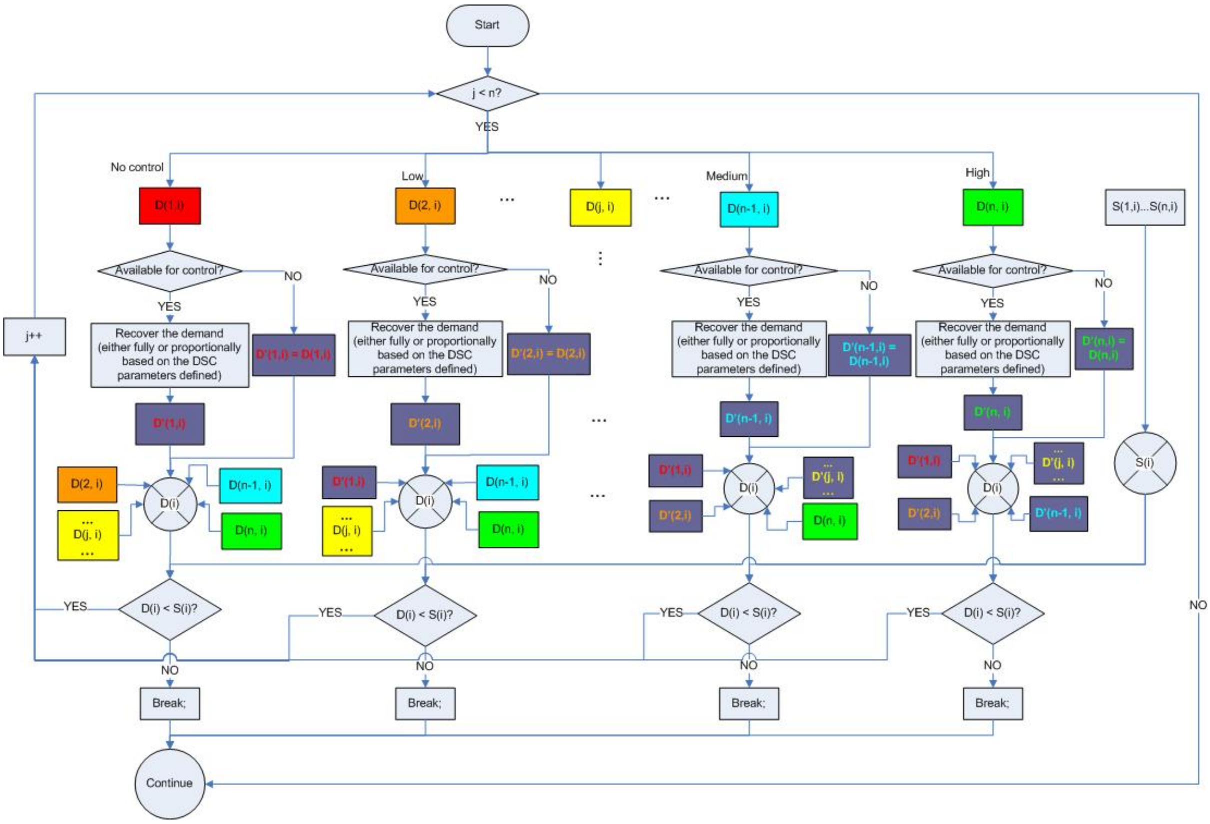

Figure 5 Flowchart for load recover algorithm