Modelling Power Adaption Flexibility of Data Centres for Demand-Response Management

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Abstract. Demand-response management is an approach that includes the power demand side into the power management process to reshape power demand of consumers to the current availability of power. Data centres are major energy consumers that are highly interesting for demand-response management. However, in contrast to many other energy consumers, data centres have a highly dynamic flexibility in terms of power adaption, depending on the current situation, which makes their integration into demand-response management difficult. This paper suggests a model for the dynamic power adaption flexibility of data centres, to foster their integration into demand-response management.

1 Introduction

The current power distribution grid was originally not designed to handle growing energy demand [1], reduce CO_2 emissions, be energy efficient, or integrate decentralised power generation based on highly volatile renewable energy sources. In spite of these challenges, power supply needs to match power demand as closely as possible, to keep power quality (e.g., in terms of current, frequency, and voltage) on a high level. *Demand-response (DR)* management establishes a communication flow between energy provider and energy consumer to enable the reshaping of power demand. *Open Automated Demand Response (OpenADR)* [2], e.g, provides a widely known DR solution.

Data centres provide great opportunities in being integrated into DR management, due to their high power demand[1]. Also, according to a study that has been performed for the Californian Energy Commission [3], data centres have a significant potential for DR that is not yet exploited. Various *power adaption strategies* [3][4] to exploit the flexibility in power demand are available within the data centre: the virtualisation and consolidation of services, shifting of services in time, migration of services across data centres, management of hardware energy-saving features, storage of energy in Uninterruptible Power Supplies (UPS), or the management of air-conditioning. It is important to see, however, that the power adaption flexibility depends on the current situation within the data centre. The degree of consolidation depends on the number of running services and the current usage of these services, for instance. The flexibility achieved by the cooling system depends of the heat within the data centre and probably outside

[1] http://www.guardian.co.uk/sustainable-business/data-centres-energy-efficient

weather conditions, and the shifting of jobs in time depends on the current mix of jobs in the data centre. Most of the resources that are used for the described strategies need to recover after a power adaption, e.g., the UPS batteries need to be recharged as fast as possible to have full reaction capacities to possible black-outs, or, in the cooling approach, the temperature needs to be brought back to normal operation temperature to prevent hardware damage. In other cases a recovery is not necessary, e.g., if services have been consolidated or hardware features have been used to fulfil a request of the energy provider. Instead, the services are de-consolidated again and the hardware performance is turned back to normal. In these cases, power adaption is achieved by reducing the Quality-of-Service (QoS) provided to data centre customers. This lost QoS can not be recovered afterwards and has to be covered by special service level agreements with the customers. In contrast to other approaches (e.g., the OpenADR temporal model for DR Events [5]), this paper suggests a flexibility model that is is able to cope with dynamic power adaption flexibility.

2 Power adaption flexibility model

A DR approach that includes data centres needs to consider their dynamically changing power adaption flexibilities. This means that the energy provider should not request a predetermined power adaption with a specified height and duration, but cope with the currently available flexibility within the data centre. To achieve this, the data centre's current flexibility needs to be communicated to the energy provider in a formal way. The flexibility of the data centre can be expressed by modelling available strategies in terms of the power adaption they are currently able to achieve. Each of these models expresses the current power adaption flexibility of the data centre for a selected strategy. The data centre can send a set of models to the energy provider, who is able to chose the most suitable model from this set for DR management.

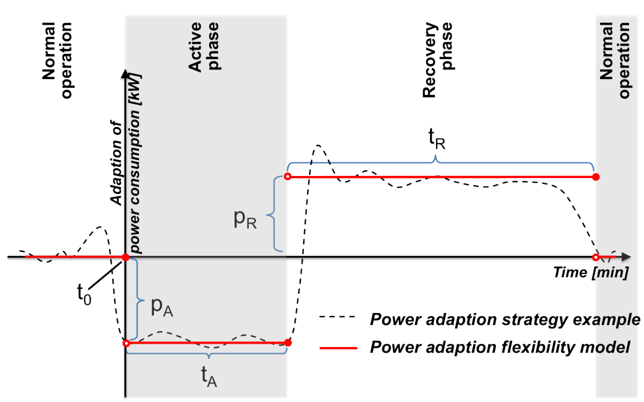

Fig. 1. Power adaption flexibility model

Figure 1 illustrates an example of a power adaption strategy as dashed line. The x-axis shows the time in minutes and illustrates different adaption phases, the y-axis shows the adaption of power consumption in kW. It can be observed that the power adaption during normal operation is around 0 – no adaption is performed. During the active phase, the power consumption is significantly reduced. During the recovery phase, the power consumption is higher than during normal operation of the data centre (e.g., due to the recharging of UPS batteries).

In the suggested model, the active and recovery phase are approximated by a step function $f(t)$. This has the advantage that the model can be easily determined and described by only using a few parameters. Although this simplification does not reflect all fluctuations in the power adaption of the data centre, it is assumed that the accuracy is sufficient to achieve DR management. This assumption is based on the fact that there are also fluctuations during the normal operation of the data centre that can not be controlled by the energy provider. These kind of fluctuations are put into perspective by fluctuations caused by all other energy consumers that are connected to the grid. Six main parameters determine the characteristics of the step function $f(t)$:

- t_0 represents the starting time of the adaption specified in the adaption request which is sent by the energy provider.
- p_A is the decreased/increased power consumption during the active phase (compared to normal operation) , measured in kW. p_A is positive if the power consumption is required to be increased, and p_A is negative if the power consumption is required to be decreased.
- t_A is the length of the active phase in minutes.
- t_{gap} is the length of the gap between active and recovery phase in minutes.
- p_R is the decreased/increased power consumption during the recovery phase , transition phase, and exit phase (compared to normal operation), measured in kW. $p_R = 0$ if no recovery phase is required, p_R is positive if p_A is negative, and p_R is negative if p_A is positive.
- t_R is the overall length of recovery phase, transition phase, and exit phase in minutes. $t_R = 0$ if no recovery phase is required.

With these parameters, the step function $f(t)$ can be defined as:

$$f(t) = \begin{cases} p_A & \text{if } t_0 < t \leq t_0 + t_A \\ p_R & \text{if } t_0 + t_A + t_{gap} < t \leq t_0 + t_A + t_{gap} + t_R \\ 0 & \text{otherwise} \end{cases}$$

The power adaption flexibility model is also illustrated in Figure 1 (step function). In this example it is assumed that $t_{gap} = 0$. During the active phase, the data centre reduces its consumption on average by p_A kW, while during the transition phase, recovery phase, and exit phase it has on average an increased power consumption of p_R kW. The step function based model describes the power adaption flexibility of a power adaption strategy with only 6 parameters. The model enables data centres to easily communicate the flexibility that is achieved by different power adaption strategies to the energy provider. The energy provider has to chose an appropriate set of power adaption strategies and to aggregate strategies of different data centres to solve the DR management.

3 Discussion

The suggested flexibility model for data centres is able to provide an approximation of the flexibility that is achieved by different power adaption strategies within the data centre. This model can be used to compute the current flexibility within the data centre as well as to communicate the flexibility to the energy provider. The energy provider is able to select and aggregate a suitable subset of strategies across different data centres. On request, a data centre offers one or more appropriate power adaption strategies to the energy provider. A possibility to further regulate such offers would be to send two strategies with maximised properties: the strategy with the longest duration and the strategy with the highest power adaption. However, both of the strategies would need to fulfil the minimum power reduction that has been agreed on by contract between energy provider and data centre. Additionally, the suggested model allows for the negotiation of strategies with the energy provider. In a case where the data centre is not able to fulfil a concrete request of the energy provider due to its current situation, it may still be able to offer an alternative strategy, lower or shorter than the original request.

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