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Modelling and economic analysis of DSM programs in generation planning

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Abstract

This paper presents a technique to model demand-side management programs into production costing analyses within the framework of equivalent load duration curve and frequency and duration method. The technique allows a single simulation to study probabilistically the impact of DSM on loss-of-load probability, energy not served, energy consumption and cycling costs of power plants. Also the importance of incorporating the cycling costs of power plants in the cost-effectiveness analysis of DSM programs is presented. Comparable results are achieved when the technique is tested against the avoided cost method of two simulations by applying them to IEEE RTS data. The results also reveal that avoided start-up cost is a major benefit of DSM. The applicability of the paper is relevant to vertically integrated utilities.

Keywords: Integrated resource planning; Demand side management; Probabilistic production costing

1. Introduction

Integrated Resource Planning (IRP) is the process of optimising the energy savings and energy producing options to minimise the total costs [1]. IRP is a broader term that includes capacity planning (generation, transmission and distribution) while considering Demand Side Management (DSM) and social costs. As much of the world moves toward competitive electricity marketplaces by restructuring and unbundling, IRP fades quickly and the linkage between capacity-related issues and demand-side issues becomes much less direct. However, there are still many utilities in the world that are vertically integrated and can certainly reap the benefit of IRP.

DSM is actually planning, implementing, and evaluation of utility sponsored programs to influence the amount or timing of customers' energy use. DSM programs use a variety of different means to manage electricity demand such as peak clipping, valley filling, load shifting. Peak clipping reduces electricity demand during on-peak periods of the day, thereby lowering the peak demand that utilities must meet. Conversely, valley filling increases the electrical load during off-peak periods. While load shifting is the movement of loads from peak periods to off-peak periods without any shift in energy use pattern. The transfer of energy produced at times of low demand (and hence low marginal cost) to displace the more expensive energy at times of high demand (and hence high marginal cost) results in energy cost savings, i.e. (fuel and variable O&M). Such an operation also alleviates minimum-load conditions at night and over weekends. With load shifting and valley-filling objectives of DSM, the cyclic operation of thermal power plants can be reduced, not only in terms of the number of loading cycles but also as the number of start-ups and shut-downs. This in turns alleviates their maintenance costs. Such avoided cycling costs is an additional major benefit from DSM actions.

IRP studies based on energy production costs simulations and reliability analyses use load duration curve (LDC) technique. The LDC method has been extended to include the random forced outages of generating units known as the equivalent load duration curve (ELDC) method [2,3]. Production cost models based on the ELDC method, which include the probabilistic description of the customer demand and the failure of the generating units, are therefore widely known as probabilistic production costing (PPC) models.

Since PPC models are based on the LDC technique, which disregards the chronology of events, the time-dependent constraints, such as minimum up-time or down-time requirements, ramping rate restriction of thermal units, start-up and shut-down costs, cannot be taken into account. Therefore, the PPC can only assess the avoided energy cost

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of DSM, but the benefit of avoided cycling cost cannot be assessed.

The technique used for integrating the start-up costs of the units is the Frequency and Duration (FD) approach. The FD method can be considered as an extension of the ELDC based methods in that it retains some details of the time-dependent behaviour of system load and production units. The theory of the FD method for reliability studies can be found in literature in various formulations [4–6]. The method has been extended and employed to assess the start-up and banking costs of thermal units [7] and to estimate the load levelling benefits of pumped storage units [8].

In many IRP processes the resource contribution from DSM programs could be very large because of untapped resources that exists. To reduce the large number of DSM options in the resource planning process the individual DSM options are bundled together into larger resource blocks [9]. The economy of aggregated bundles of DSM options is tested by the avoided cost method. The avoided cost has two components of savings, the energy costs savings and capacity cost savings. The planning horizon is optimised twice; one with a base case set of loads and another with load shape changed by the expected load impact of DSM. Avoided cost is then calculated by the difference in energy and capacity costs of the two optimised cases.

The DSM impacts on system load generate new load shapes. This means that if we want to study the individual impact of different DSM resource blocks we have to change the original chronological load curve every time and then form a new LDC to do production costing simulation. Even a model that can change inverted LDC due to DSM load impact [10] needs a separate simulation for each DSM resource block to be studied. Moreover, these models do not give probabilistic treatment to DSM load impacts.

This paper presents an efficient method to estimate the expected aggregate load impact of the DSM resources in full probabilistic manner in ELDC and FD methodology. DSM resource blocks are modelled as equivalent DSM generating units [11], which thereupon can easily be simulated in the ELDC and FD framework. To include the effects of uncertainties of DSM resource blocks, the equivalent DSM generating units can be simulated with partial or full outage effects. The avoided energy and cycling costs estimation requires no two simulations. Instead, a base case production and start-up cost simulation is run and then few minor modifications due to DSM resource blocks, modelled as generating units, are incorporated. These modifications affect the energy generated by and start-ups of few thermal units while the energy generated by and start-ups of the majority of the units remain unchanged. As a result, the computations required by the proposed technique are only a fraction of those required by the avoided cost method. Also as the DSM resource blocks are modelled as generating units the DSM administrative costs, which consist of advertising, program management and handling costs, of any particular DSM resource block can be related to its corresponding DSM generating unit. This then will allow it to test the economy of any resource block within a single production and start-up costing run. The technique is applied to IEEE RTS data [12] and comparable results are achieved when the technique is tested against the avoided cost method of two simulations. The results also reveal that the avoided start-up cost is a major benefit of DSM and should not be neglected in DSM planning exercise.

2. DSM modelling in ELDC and FD framework

The DSM load shape objectives are realised in six generic load shape operations, i.e. peak clipping, valley filling, load shifting, strategic conservation, strategic load growth, and flexible load shape. With the exception of last all other operations can be modelled, within the framework of PPC by two basic operations, i.e. peak clipping and valley filling [11]. The flexible load shape objective cannot be realised within the framework of PPC methodology because PPC is based on LDC technique, which disregards the time chronology of events. The flexible load shape objective of DSM, however, is basically meant to give flexibility on system operation and is not much relevant in the case of system long-range planning. Although load-shifting objective is also chronological in nature it can be handled in LDC models without loss of rigor if the time-span of LDC is kept small.

2.1. Peak-clipping modelling

DSM peak clipping is very similar to peak-shaving operation of hydro plants. This is owing to the fact that in peak-shaving operation of hydro plants the peak energy of high marginal cost is replaced by the hydro plant operation, and; in DSM peak clipping, the peak energy is clipped by the DSM actions. Therefore, the DSM peak-clipping objective can be modelled as a hydro plant. For modelling of the DSM peak clipping two things have to be identified, i.e. the DSM resource block for peak clipping and the energy to be clipped. The resource block corresponds to the capacity of a hydro plant and the peak-clipping energy corresponds to the reservoir energy of the hydro plant.

In probabilistic production costing framework the hydro plants are termed as assigned-energy units [13] or limited-energy plants (LEP) [14]. Dispatching of an LEP or a peak-clipping resource block in probabilistic simulation is performed by finding the exact position for an LEP, under the effective LDC, where it can use the maximum energy assigned to it. The effective LDC, shown in Fig. 1, is formed by plotting only those portions of ELDCs, under which the units are loaded [8]. For finding the exact position of LEP the process of off-loading is performed which is equivalent to peak shaving [13,15]. In finding the exact position of the LEP, where it can discharge its full assigned energy it is possible that a thermal unit has to have its capacity split into two parts. However, in the algorithm the unit capacity is not