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Optimized generation capacity expansion using a further improved screening curve method

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ABSTRACT

As more renewable resources are integrated into the grid, non-dispatchable renewable energy and more detailed considerations of short-term operation should be represented in generation planning models. In this paper, the screening curve method is utilized to model these details for generation capacity expansion. In addition to previous studies, we further develop the screening curve method with more detailed consideration of thermal cycling. Computational results performed on a real system case are compared and analyzed.

1. Introduction

Generation capacity expansion has always been an important part of power system planning. With detailed short-term operation issues considered and with renewable energy as well as micro-grid resources integrated into power grids [1], many new methods and improvements have been proposed [2]. Besides, commercially available software is able to deal with generation mix optimization. However, the huge amount of data input, long run time, and limited intuition in such "black boxes" are major drawbacks, particularly in the context of policy decision. Thus, we are interested in building up a simpler and faster model that can provide us with reliable results. Further, such a model gives us a way to conveniently analyze the sensitivity of different impacts on generation planning, including such issues as carbon policies.

This paper describes four types of models based on the screening curve method (SCM). The SCM is a simple way to use annual load shape information and costs of competing power plant technologies, such as capital costs and variable fuel costs, to find a least-cost generation mix solution for a given load shape. We classify the four models as type 1 through type 4 screening curve model for notational convenience. Each model has its own advantages and drawbacks regarding computational efforts, accuracy, and limitation.

Type 1 SCM was first proposed in [3]. In type 1 SCM, total annual costs of planning alternatives are computed against load duration curves, providing a least-cost generation mix solution. The Electric Generation Expansion Analysis System (EGEAS) software that was developed in the early 1980s uses the type 1 SCM as one of its options for generation planning.

However, with increasing penetration of wind energy, thermal generation has to cycle more frequently. Start-up costs are no longer negligible for thermal generators. Type 2 SCM was developed in [4], where a long-term analysis of evaluating start-up cost was implemented. A chronological net load curve was included for calculating annual start-up cost.

The wind integration impact on unit commitment (UC) issues for thermal units was further discussed in [5–7]. To incorporate the UC process, type 3 SCM was developed in [8], which was referred to as an enhanced screening curve method. This development considers how short-term cycling affects long-term decisions. Instead of just shutting down and starting up a generation unit when the electricity demand fluctuates, this model considers the operational alternative of running it at its minimum stable output (also known as low sustained limit).

In this paper, we further develop SCM to type 4 SCM. Type 4 SCM computes the opportunity cost for a generation unit when running at minimum stable output rather than at full output. This opportunity cost is then compared with the start-up cost and is used to determine the economic maximum time of running at minimum output for each generation technology. Moreover, iterative computations can be incorporated to converge to a more accurate

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Table 1
Parameters of generation costs.

	Nuclear	Coal	CC	CT
Annualized *CapC* (k$/MW/year)	224.00	174.72	60.12	38.52
NCFC (k$/MW/year)	89.88	30.04	14.58	14.88
INFC ($/MW/h)	2.05	4.31	3.45	7.07
Fuel price ($/mmBtu)	0.62	2.18	6.29	6.29
Full output VFC ($/MW h)	6.50	19.05	39.80	53.78
Start-up cost ($/MW/start)	N/A	150	50	15

result. Meanwhile, an alternative approximation approach is also proposed to facilitate the speed of computation.

This paper is structured as follows: Section 2 reviews fundamental definitions and the previous three screening curve methods; Section 3 focuses on the development and performance of type 4 SCM; Section 4 explores an Electric Reliability Council of Texas (ERCOT) 2030 case study.

2. Terminology and review of previous screening curve methods

The screening curve method (SCM) is a useful approach to compute the optimal generation capacity for a target year. In this section, three types of SCM are introduced. The SCMs were developed in [3,4,8], respectively, and are classified based on their accuracy and computational requirement. We draw from these references to briefly describe these three models in order to better illustrate our contribution to a new SCM. To enable clear discussion of the models, we first discuss a few fundamental cost definitions for the SCMs.

2.1. Cost definitions

In a generation planning study, costs are evaluated for activities such as building new capacity, generating energy, and maintenance. The values of these costs and the way we interpret them are crucial for determining the future generation mix.

Capital cost (CapC) is the total overnight cost of building a power plant. For a target year, it is annualized with the consideration of amortization and construction cost financing issues.

Variable fuel cost (VFC) is the fuel cost for producing energy assuming a start has already occurred. It depends on the fuel price, and on the production level, since efficiency varies with production.

Non-capital fixed cost (NCFC) is the fixed cost for a year other than capital cost, which includes the cost of maintenances, property taxes, facility fees, insurances and overheads that do not depend on operating level [7]. This is also known as fixed operation and maintenance (O&M) cost.

Incremental non-fuel cost (INFC) is the cost of activities (parts and labor) related to the incremental non-fuel O&M cost of a generator [9]. These costs are incurred once over several years but can be evaluated as an hourly cost adder. It includes major overhaul expenses, air filter replacements, water treatment expenses and catalyst replacements. This is sometimes referred to as variable O&M cost.[1]

Startup cost (SC) is defined as the cost for each restart. It is the cost to bring the boiler, turbine, and generator from shutdown conditions to a state ready to connect and be synchronized to the system.

We collect generation costs data from [8,10–12] and evaluate a set of generic data for each generating technology. These are listed in Table 1. Note that *CapC*, *NCFC*, *INFC*, and *SC* are averaged on megawatt (MW) capacity basis, and represent the costs for a 1-MW slice of capacity.

[1] The definition and calculation of what is referred to as "variable O&M cost" vary in different documents. Some interpret it as an energy adder, while some interpret it as an hourly cost. The way we understand it is that it behaves like a "quasi-fixed cost" [14], and should be allocated to the total equivalent service hour (ESH) [9]. Therefore, we deliberately avoid using the phrase of variable O&M cost to avoid confusion.

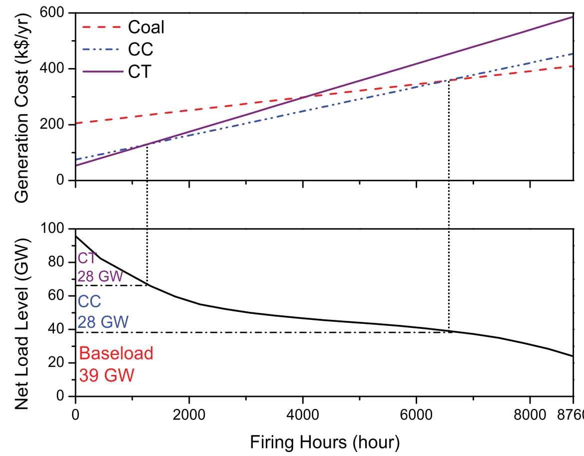

Fig. 1. Type 1 screening curve method.

2.2. Type 1 screening curve method

Type 1 SCM is the foundation of all other SCMs and was first introduced in [3]. On the generation side, the total annual cost for 1-MW of generation from a particular technology is represented as an affine function of firing hours. This is represented in (1).

$$\widetilde{TC}(T) = CapC + NCFC + (VFC + INFC) \cdot T, \quad (1)$$

where $\widetilde{TC}$ is the total cost as a function of T; *CapC* is the annualized capital cost per MW-yr; *NCFC* is the non-capital fixed cost per MW-yr; *VFC* is variable fuel cost at full output per MW h; *INFC* is incremental non-fuel cost per hour per MW; and T is the total annual firing hours of that MW.

Note that the *CapC*, *NCFC*, *INFC* and *VFC* vary for different generation technologies. Thus, for a given time duration T, the total cost would be different for each generation type. The top half of Fig. 1 illustrates the annual generation cost curve, showing the total generation cost curve per MW for three candidate technologies: base-load (such as coal and nuclear), combined-cycle gas turbine (CC) and simple-cycle combustion turbine (CT). The minimum cost is the overall lowest piece-wise linear function of firing hours. The horizontal axis coordinates of the points of intersection for the different technologies and the time intervals between these values determine the optimal annual firing duration for those technologies.

On the demand side, an annual cumulative distribution function (CDF) of load level can be built up, which is called a load-duration curve. At any particular demand level the annual load-duration curve evaluates the time duration (in hours) at that level. However, as more and more wind generation is integrated into the power grid, the renewable integration impact should be considered. This issue was modeled in [5] by representing renewables as must-run generation. We define net load to be the load level minus the wind generation, and the corresponding duration curve is consequently called the net load-duration curve, and is shown in the bottom half of Fig. 1. The net load-duration curve is the primary determinant of thermal generation planning. Thus, in this paper, we will only focus