PRODUCTION COSTING IN ELECTRICITY GENERATION PLANNING WITH GENERATION COST UNCERTAINTY AND PLANT DERATING

by

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Abstract

Production costing is an important part of generation planning process where the expected cost of generation from various generating units already existing or those to be installed is determined for a specified period of time. Due to the probabilistic nature of certain inputs to this process such as the load and the generation unit availability, a probabilistic approach to the calculation of the production costs came into being. But these traditional techniques lack the ability to accommodate important uncertainties such as those in generation costs and plant derating which is a common occurrence in power system operation.

This paper discusses mathematical techniques to include plant derating and generation cost uncertainty in probabilistic production costing with a sound theoretical basis and a simple case study involving four generating units. It is concluded that these techniques which would enhance the accuracy of the final output relating to the expected production costs, can be implemented within traditional production costing routines without difficulty.

1. Introduction

Electricity generation system planning requires minimisation of the total cost of supplying the demand during a specified period of time. This period varies depending on the planning objectives; short term, medium term or long term. Long and medium term planning objectives will require the inclusion of both the initial investment costs as well as the production cost of electricity generation while short term planning requires only production costs. Therefore production costing is an important component of electricity generation planning where it can be the major cost component in the objective function [1].

Traditionally probabilistic production costing has been limited to using the generation unit models, consisting of uncertainties in generation availability only. Also in all practical cases the these models are only confined to two state models where either the units are available at their full generation capacity or they are not available. But in certain circumstances units are operated deliberately on derated capacities, which are not captured properly in these traditional production-costing models. Further, in production costing the usual pattern of generator loading is based on merit order dispatch where the units are considered to be loaded on to the system in the order of incremental cost of generation. Therefore the loading order varies with varying incremental costs and thus the production cost also varies accordingly. This uncertainty in generation incremental cost is also not captured in traditional probabilistic production costing techniques, which can be considered as a major drawback [2,3,4]. This uncertainty in generation incremental cost is an important aspect to be considered particularly in generation systems where fuel prices are likely change substantially within short periods.

2. Production Costing

In almost all present day planning models, production costing includes probabilistic treatment of the system load and the generation unit availability. The chronological load profile during a specified time period is converted to a load duration curve (LDC) as given in Figure 1.1 where F(x) is the percentage time that the system load exceeds a chosen load level x. The generation unit availability is represented by a two-state model given in Figure 1.2 where either the generating unit is available at its full capacity at a probability of pi or the unit is not available at a probability of qi which is called forced outage rate (FOR).

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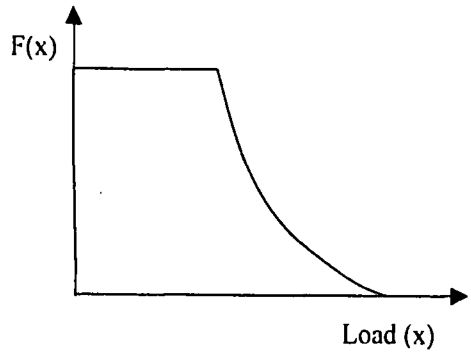

Figure 1.1: Load Duration Curve

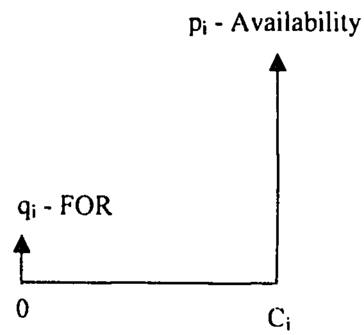

Figure 1.2: Generator Model (Ci - Capacity)

The generating units are gradually dispatched in merit order and the effective load duration curve (ELDC) given by Fi, is determined after loading each unit as given in equation 1.

$$F^i(x) = q_i F^{i-1}(x) + p_i F^{i-1}(x + C_i) \qquad (1)$$

Unserved energy (UEi) after loading generator i is given by

$$UE_i = T \int_0^{L_{max}} F^i(x)\, dx \qquad (2)$$

where T is the total duratio

Energy production by generator I, Ei is given by

$$E_i = UE_{i-1} - UE_i \qquad (3)$$

Corresponding production cost, Costi is given by

$$E_i = UE_{i-1} - UE_i$$

where IC_i is the incremental cost of generator i (4)

Total production cost, TC is given by

$$TC = \sum_{i=1}^{ng} Cost_i$$

where ng is the number of generating units (5)

The value TC is used as the expected total production cost associated with a given generation system considering the uncertainties in generating unit availability [1].

2. Generating Unit Derating

In most practical circumstances some of the generation units are likely to be deliberately operated part loaded as a technical requirement during operations. Such operations are not recognised in the above calculation process. Figure 3.1 shows a generating unit model with one part loading condition recognised

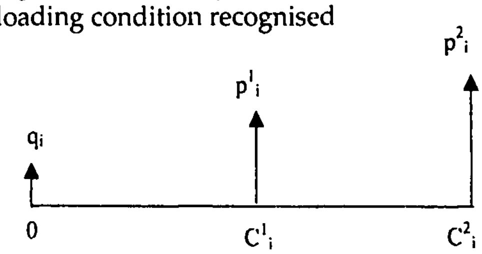

Figure 3.1: Generating Unit Model with a part loaded state

This will lead to the convolution equation in (1) being modified to

$$F^i(x) = q_i F^{i-1}(x) + p_i^1 F^{i-1}(x + C_i^1) + p_i^2 F^{i-1}(x + C_i^2) \qquad (6)$$

This approach to the determination of the ELDC and thus the calculation of production cost can be further generalised to accommodate a multilevel part loading scenario where the ELDC can be determined as given in equation 7.

$$F^i(x) = q_i F^{i-1}(x) + \sum_{k=1}^{n} p_i^k F^{i-1}(x + C_i^k);$$

; n - no of availability levels (7)

Other calculations can be carried out in the same manner as in section 2.

3. Generation Cost Uncertainty

The loading order of generating units during production costing is generally dependent on incremental generation cost. But these costs can vary from time to time affecting the loading order. Particularly this is true in case of power plants firing petroleum fuels where price variations are relatively very high. Therefore the uncertainties in generation costs are an important aspect which needs to be seriously considered in production costing. Traditional probabilistic models are incapable of accommodating such generation cost variations.

If the generation cost probability density function of generator 'i' is defined by h(y) and the probability density function of the generator availability is defined by g(x) then the generating unit availability at different costs, r(x,y) will be given by

$$r(x,y) = h(y) * g(x) \qquad (8)$$

Now the generating unit defined above in equation 8 can assume different positions in the loading order depending on the cost, y. The convolution process with the LDC (or ELDC) during loading of generating units should now use r(x, y(Y0) instead of g(x) as done in the traditional calculations. Also it is important to note that the if a given unit has been loaded at a different cost already, that function requires deconvolution before convolving the new r(x, y(Y0) with the ELDC to avoid double counting of the generation capability at the lower cost states. This process can be explained by considering discrete probabilities for generation availability and generation costs. The generating unit model can be viewed as in figure 4.1 [4].

pji - Probability that the generator cost does not exceed Y0 while being available at its full capacity, Ci

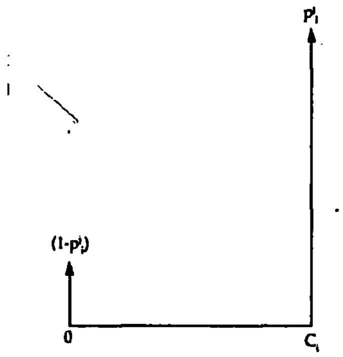

Figure 4.1: Generator Availability with cost uncertainty

This approach to inclusion of generation cost uncertainty is a little computationally cumbersome, particularly when using numerical convolution, since every cost state of each generating unit will require both convolution and deconvolution.

4. Case Study

Table 5.1 shows the details of four generators to be loaded on the load duration curve given in Table 5.2

Figure 5.1 and Figure 5.2 show the output of the production costing process considering a period of one month (720 hours) with and without generation cost uncertainty considered in the calculations.

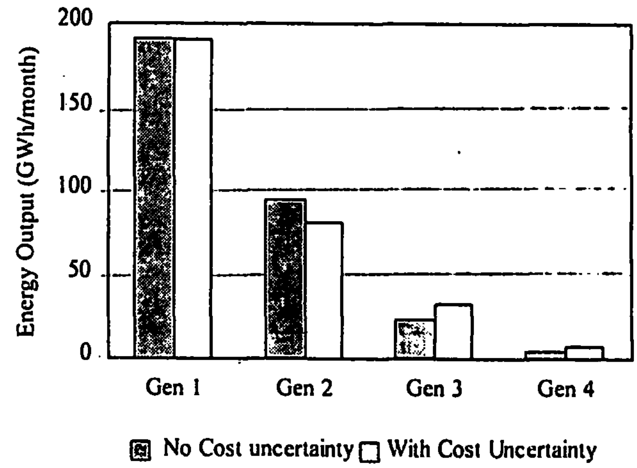

Figure 5.1: Comparison of Energy Output

Table 5.1: Generator Availability and Cost Details

Generator	Capacity (MW)	Availability	Incremental Cost (Rs/MWh)	Probability
Generator 1	0	0.05		
	200	0.20	1500	
	300	0.75	1.0	
Generator 2	0	0.05	1750	0.5
	250	0.95	2250	0.5
Generator 3	0	0.1	2300	0.5
	200	0.9	2800	0.5
Generator 4	0	0.1	2750	0.5
	100	0.9	3750	0.5

Table 5.2: Load Duration Curve

Load (MW)	0	50	100	150	200	250	300	350	400	450	500	550	600
Probability	1	1	1	1	1	1	0.625	0.625	0.375	0.375	0.375	0.375	0

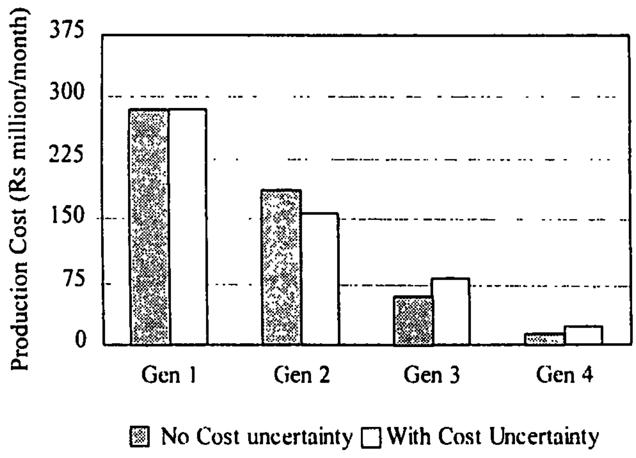

Figure 5.2: Comparison of Production Costs

It can be seen from these results that the individual output of each generator and hence the production cost has been modified when the generation cost uncertainty is considered in the calculations, apart from generator 1 of which the loading order has not changed. These modifications are mainly due to the change in loading order of generators when different blocks of generation costs are considered. The total energy served has not changed from one to the other because the overall generation capability of the units are not affected by the generation cost uncertainties.

5. Conclusions

A methodology for the inclusion of plant derating and generation cost uncertainty has been developed in the paper. The usefulness of the inclusion of these uncertainties has been demonstrated in the case study. Therefore it is concluded that the methodologies discussed in the paper will be relevant and useful in obtaining accurate simulation of power system operation in production costing calculations, particularly during long term planning studies where cost uncertainties can be significant and plant derating is a common phenomenon. These techniques which would undoubtedly enhance the accuracy of the final output, can be incorporated in the traditional production costing routines without difficulty.

6. References

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