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A new analytical technique for incorporating base loaded energy limited hydro units in reliability evaluation

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ABSTRACT

Energy limited hydro generation is one of the important sources for electricity. Hydro units, however, behave differently as compared to conventional fossil fueled units. The output of these facilities is largely dependent on the availability of the primary resource of water while the effect of unit forced unavailability is usually not significant in comparison. Energy limited hydro resource can, however, significantly affect electric power system reliability. It is therefore very important to accurately incorporate energy limited nature of hydro units in reliability assessment. This paper presents a new capacity modification technique to model energy limited characteristics of hydro generation serving as base load units. In this method the effect of unit's energy limitation is reflected by modifying the capacity and treating the energy limitation as reduced capacity. The method is illustrated using simple examples and applied to model hydro units in two reliability test systems. The results are compared with those obtained using the load modification approach proposed in other published work. The two methods produce exactly the same results. One of the salient advantages of the proposed method is that reliability indices can be calculated by convolving appropriate load model with system capacity outage probability table. It is, therefore, easier to incorporate energy limited hydro units in commercially available reliability evaluation softwares. The proposed technique also has the advantage of easily incorporating large number of hydro units in reliability evaluation as compared to other methods.

1. Introduction

Generating capacity adequacy assessment has been performed for decades and generating units including energy limited hydro units are mostly modeled as two-state or multi-state units without energy limitation. The energy limitation, however, does exist for generating units particularly for hydro units, which can significantly impact system reliability. It is therefore very important to correctly model energy limited hydro units in electric power system reliability evaluation.

A great deal of effort has been devoted to incorporate energy limited hydro units in reliability evaluation using different methods. A load modification method is proposed in [1]. The basic idea behind this technique lies in answering the question, "How does the load appear to the rest of the system when a generating unit is loaded to supply power to the system? [1]". Conceptually, it is based on the idea of determining the equivalent load model that appears to the rest of the system as one or more generating units, each having a capacity probability model, are loaded to supply power to the system. The load modification method is a sequential process to modify a given load model to produce an equivalent load model. If the generating system is energy limited, the process includes modification of the equivalent load model by energy distributions of the generating unit. The load modification method proposed in [1] is direct and efficient but the number of load steps or load points may become unmanageable with the increase in the number of energy limited units. A method to calculate frequency and duration indices for systems with energy limited hydro units is proposed by other researchers [2]. Different types of hydro systems are considered in this paper and techniques for unit addition and removal are also presented. An analytical approach is proposed for multi-area reliability evaluation incorporating limited energy availability using the concept of peak shaving [3]. A load modification method which modifies a load duration curve with a generating capacity distribution is proposed in [4]. Limited energy characteristics, load forecast uncertainty and system interconnection can be incorporated using this method. Comparative studies of modeling energy limited hydro

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units using forced outage rate modification technique, load modification approach and frequency and duration method are presented in [5]. Most of these published methods are focused on modeling energy limited hydro units as peak shaving resources.

A new stationary stochastic process with a multiple states Markov chain is proposed to represent the river inflow to capture the energy limitation of small hydro in [6]. Hydro unit forced unavailability is also considered and a capacity outage probability table is produced by utilizing clustering techniques to perform reliability assessment [6]. This method, however, requires a large number of data in order to develop the Markov model of the river inflow. Some recent publications present techniques used to incorporate energy limited hydro units in simulation [7–9].

Over the years, several computing tools for example the Multi-Area Reliability Simulation (MARS) [10] and Gridview [11] used for the calculation of the reliability indices have been developed by the vendors and used by utilities particularly in North America [12]. Most of the tools are, however, focusing on the reliability modeling and evaluation of large power systems containing mostly thermal and nuclear units that are usually considered as non-energy limited resources. No efficient models are, however, available for accurately modeling energy limited resources for example hydro units in these tools. Hydro units are typically treated either as deterministic load modifiers or thermal units in these tools. Incorporation of some of the existing hydro molding techniques for example the load modification method proposed in [1] in these tools needs a great deal of efforts in modifying and testing the source codes. This is not a trial task and hence the program developers may be reluctant to modify their tools.

This paper proposes a new capacity modification approach to incorporate energy limited hydro units serving as base load resources in generating capacity adequacy assessment. The technique is based on an analytical approach and treats energy limited hydro units as equivalent units with different capacity. Reliability indices can be evaluated by convolving appropriate load model with system capacity outage probability table using the proposed method. The capacity modification method, therefore, provides an efficient way of incorporating energy limited hydro units in most of the commercially available programs. The proposed technique is simple and easy to model a large number of hydro units in reliability evaluation as compared to other methods for example the load modification approach.

The results obtained from the proposed technique and load modification model are compared in this paper. It is shown that the reliability indices obtained using these two methods are identical. The proposed method is illustrated by modeling energy limited hydro units in both the RBTS [13] and the IEEE-RTS [14]. The concept may not, however, be restricted to hydro units. Investigations are under way to apply this method in reliability evaluation of generating systems with wind, solar and/or energy storage facilities.

2. Methodology

A new way of modeling hydro units is proposed in this paper. The proposed capacity modification technique is validated against the load modification approach presented in [1]. The methods of incorporating energy limited hydro units using capacity modification and load modification are described in this section.

2.1. Proposed capacity modification approach

The energy limited hydro units are first treated as peak-shaving units and then the concepts are extended to model these units as base load units. The expected period of need for an energy limited hydro unit k is:

$$T_k = P_{k-1}(0) * I \tag{1}$$

where $P_{k-1}(0)$ is the probability of capacity deficiency with $(k-1)$ units committed. This can be calculated by convolving the system capacity model containing the first $(k-1)$ units with the load model. I is the length of the study interval in hours. Further assume that an energy limited hydro unit has N states. The capacity in state i is C_i and the corresponding probability is p_i. Assume that the unit operates at its maximum output during the period of need, the expected energy output E_k, is given by:

$$E_k = T_k \sum_{i=1}^{N} C_i p_i \tag{2}$$

Compare the energy requirements, E_k, of the unit with the energy (output) available to the unit, Z_k. There are two possibilities:

1. If $E_k \le Z_k$, the unit is not energy limited for reliability purposes and the unit capacity model can be combined with the system capacity model reflecting the first (k) units without modification.
2. If $E_k > Z_k$, the unit is energy limited and the unit state capacities C_i must be adjusted to reflect the reduced proportion of energy the unit can produce at the required time period.

If the energy limited hydro units are serving as base load resources, the need time period is the total study period. The expected energy output of a unit in this study time period is:

$$\text{Expected Energy} = \sum_{i=1}^{N} C_i p_i T \tag{3}$$

The modified capacity of each state of the unit is calculated as follows considering energy limitation.

$$C_i' = \frac{C_i * \text{Available Energy}}{\text{Expected Energy}} \tag{4}$$

where C_i' is the modified capacity at state i. Available Energy is the total energy available for the unit in the study period, which is calculated as in Eq. (5):

$$\text{Available Energy} = \sum_{j=1}^{M} E_j P_{E_j} \tag{5}$$

where E_j is the energy level j (MWh/h) of the energy distribution of the energy limited unit. M is the total number of energy distribution levels. The probability of each state remains unchanged. After the modification of the capacity of the energy limited unit, the expected energy output is:

$$\begin{aligned}\text{Expected Energy} &= \sum_{i=1}^{N} C_i' p_i T = \sum_{i=1}^{N} \left(\frac{C_i * \text{Available Energy}}{\text{Expected Energy}} p_i \right) T \\ &= \frac{\text{Available Energy}}{\text{Expected Energy}} * \sum_{i=1}^{N} (C_i p_i) T = \text{Available Energy}\end{aligned} \tag{6}$$

Eq. (6) shows that after the capacity modification, the energy limited unit is able to produce energy equal to the available energy during the total study period. This calculation of the state capacity for an energy limited unit is illustrated using a simple numerical example. Table 1 shows the capacity probability and energy distribution of energy limited unit. These data are taken from examples provided in [1].