Renewable Energy 99 (2016) 379–389

Contents lists available at ScienceDirect

Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Climate change impacts in the energy supply of the Brazilian hydro-dominant power system

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ARTICLE INFO

Article history:
Received 11 September 2015
Received in revised form
6 June 2016
Accepted 11 July 2016

Keywords:
Renewable generation
Multi-stage stochastic optimization
Climate change effects
Hydro-thermal scheduling
Water inflows

ABSTRACT

Over the past few years, there has been a growing global consensus related to the importance of renewable energy to minimize the emission of greenhouse gases. The solution is an increase in the number of renewable power plants but unfortunately, this leads to a high dependence on climate variables which are already affected by climate change. Brazil is one of the largest producers of electricity by renewables through its hydro-dominant power generation system. However, hydro-generation depends on water inflows that are directly affected by climate change that consequently affect the electricity production. Therefore, these changes need to be considered in the operation and planning of a hydro-dominant power system. In this paper, we present the effects of different climate scenarios in the water inflows produced by the regional Eta climate model. Normally, studies use an optimization model to make decisions in case of a hydro-thermal scheduling problem and use the assured energy to evaluate the hydro-production. In this analysis, water inflows used in the optimization process consider different trends according to its associated climate scenario. Our paper shows that climate change may drastically impact the system assured energy and consequently, the system's capability to supply load.

1. Introduction

Renewable energy sources are helping countries around the world to reduce oil supply dependence and move towards a more environmentally friendly society. There are compelling reasons associated with sustainability and public health, and also good perspectives for investments in renewable energy technologies such as wind, solar, and biomass. New investments in renewables are essential to match future electricity demands without contributing to the threat of global warming. For example [1], examines the threshold effect of the proportion of the renewable energy supply needed to reduce CO_2 emissions, which is one of the main actions towards minimizing global warming. Fortunately, many countries utilize access to clean energy in their energy programs [2,3].

Strong evidence related to climate change [4,5] as well as the understanding of the importance to consider this information in different spheres [6] has emerged over the years. However, it is important to take into account the current, and potential future, climate changes due to global warming when analyzing renewables' penetration and planning a power system's generation capacity. Climate conditions directly affect renewables and consequently affect their electricity production. For example, hydro is a type of renewable energy source that has gained a steady success attracting investments over the years. Hydro energy production highly depends on the amount of water inflows, the "fuel" responsible for powering hydro turbines, available at each hydro power plant during a particular period of time. Furthermore, these water inflows depend on precipitation (climate variable) which is often represented in rainfall-runoff models [7,8]. In several places, precipitation analysis has presented a contrasting behavior over the years [9,11] when compared with historical data, which climate change could intensify even more in the future. Another related example can be seen in a system with a large share of wind

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http://dx.doi.org/10.1016/j.renene.2016.07.022

Nomenclature

Abbreviations
IPCC Intergovernmental Panel on Climate Change
GCM Global climate model
HadCM3 Hadley Centre coupled model from United Kingdom
A1B Global climate change scenario from IPCC
INPE Brazilian national institute for space research
Eta-CPTEC Regional climate model developed by INPE in Brazil
Eta-X Eta regional climate model with resolution of X km
MGB large basin rainfall-runoff hydrological model
HTSP Hydro-thermal scheduling problem
EGS Existing generation system
FGS Future generation system
ISO Power system independent system operator
EPE Brazilian federal energy planning company
CO_2 Carbon dioxide
GHG Greenhouse gases
HIGH, MED, LOW, CTL Members from HadCM3 constructed from A1B climate scenario with different increases in global temperature
HRU hydrological response units
FUT_X 30-year periods starting in 2011 and going up to 2100, X = 01 (2011–2040), X = 02 (2041–2070), X = 03(2071–2100)
GDP Gross domestic product
SLP-T Stochastic linear program with T time stages
PAR-*n* periodic autoregressive model of order *n*
RE, PS, DM, FD Other water use scenarios, in order: country's economy in recession, country's economy in a process of stagnation, development of country's economy in a moderate proportion and country in a state of full social development

Indices and Sets
$t \in T$ set of time periods and its associated index

Parameters
c_t operational cost vector associated with power generation and curtailment costs at stage t
b_t represents deterministic electricity demand and a specific realization of the stochastic water (or energy) inflows at stage t
A_t model's structural constraint matrix at stage t that captures mass-balance, demand satisfaction, maximum hydro generation constraints and energy transfer constraints
$B_t x_{t-1}$ represents the storage in the system that is carried forward from stage $t-1$ and is available at stage t

Decision Variables
x_t decision vector to represent hydro generation, thermal generation, storage at reservoirs, and spills at stage t

Functions
$h_{t+1}(\cdot)$ recursive function that represents a model like (4)–(6) where t is shifted by one unit. It depends on decisions made at stage t, and random parameters that are revealed at the beginning of stage $t+1$
$\mathbb{E}_{b_{t+1}|b_t} h_{t+1}(x_t, b_{t+1})$ expected cost function of stage $t+1$ given decisions x_t, that were made in stage t, and the realization of the random parameter b_{t+1}

generation where changes in wind speed and wind direction impose vulnerability problems.

Therefore, in order to design a robust power system for the future, it is necessary to take into account different climate scenarios in the evaluation of renewable energy sources. For example, in [12] authors present a study of the impacts of global climate changes on the availability and the reliability of wind power in long-term energy planning for the Brazilian system. Impacts of global climate changes in terms of wind power density for selected sites can be found [13] and in terms of hydropower generation and liquid biofuels in [14]. In [15], climate change impacts in energy production of photovoltaic, wind and hydro power plants are evaluated in Croatia using climate data regionalized from a global climate model (GCM). Other studies present analysis of renewables as an alternative to mitigate climate change by reducing greenhouse gas emissions [16,17] from fossil fuel used by thermal power plants.

This paper presents significant advances from [18] in the assessment of climate change impacts in generation assured energy in Brazil. The available information from global climate change scenario A1B is downscaled by the regional Eta-CPTEC climate model [19]. Also, we have transformed climate variables, such as precipitation, that are outputs from this climate model into water inflows by using the large basin rainfall-runoff hydrological model (MGB) [7] for each hydro power plant site. The water inflows are then used as input in a mathematical optimization model to determine the generation assured energy for the whole power system, i.e. the system assured energy that can be defined as the total energy available in the system at a risk of 5% of not supplying the demand (the process to compute the system assured energy is further explained in Section 4.2). Based on the Brazilian regulation, individual values of generation assured energy can be obtained for each hydro power plant using the firm energy rights [38]. Such individual generation assured energy represents the maximum amount in which a hydro power plant can trade in the Brazilian electricity market. Finally, the sum of individual generation assured energy is equal to the system assured energy.

Given that the precipitation regime in some river basins may change, results from this work are crucial for the generation plan in terms of the placement of new power plants in the country. Additionally, this paper evaluates possible effects of different water use scenarios on energy production. Fig. 1 depicts the aforementioned steps of the procedure to assess the system assured energy. In this work, we consider the correct representation of the Brazilian power generation system described in Section 2.

A mathematical model that optimizes water resources and thermal plants generation is used to determine the system assured energy. This model aims to represent the hydro-thermal coordination, or hydro-thermal scheduling problem (HTSP) [21–24]. The HTSP is modeled over a planning horizon with a finite number of time stages, which are discretized on a weekly or monthly basis. One of the most important information related to HTSPs is the natural water inflow that is available at each hydro power plant at the beginning of each time stage of the planning horizon. Water