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Systematic tool to plan and evaluate demand side strategies during sustained energy crises in hydrothermal power systems

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ABSTRACT

HARE, a systematic tool to evaluate demand side measures to face sustained energy supply risk in hydrothermal power systems is presented in this paper. The main focus of the paper is to help centralized planners to systematically discuss, select, and plan the measures that better respond to the variety of critical situations that can arise due to expected energy shortage, integrate them into the usual medium-term scheduling tool and consequently keep the associated overall costs as low as possible. A medium-term definition of the system state is proposed as a decision-making aid, as well as a set of general energy saving measures that can be applied with their corresponding attributes (time delays, costs of implementation, and energy saving impact). The tool is demonstrated and applied to a simplified version of Chilean's medium-term hydrothermal scheduling model and to a specific risk scenario experienced during 2011. The results show that it is possible to define various sets of demand side measures that avoid the impacts on the system and subsequently to select among them those with least expected implementation costs. This tool seems mainly useful for hydro-electric systems, which are more vulnerable to sustained energy supply risk. Every power system will have to go through a detailed review and planning process to implement this type of tool.

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Introduction

International context

In the current privatization and deregulation environment, one of the main problems that electricity markets have to address is the adequate expansion of generation capacity and transmission networks so that demand can be met. Adequacy is a mid/long term problem that also involves the appropriate provision of resources to meet the demand, which is particularly critical in hydrothermal systems, due to the challenges related to the management of the hydro resources stored in the reservoirs. This problem resides within a broader set of challenges in every country related to energy security provision, which involves the development of policies to avoid and/or face potential crises. In all cases it will be clear that a reasonable adequacy policy takes into account some level of risk of deficit in which not all demand can be met.

When a power system threatens to become incapable of serving demand in a sustained way after applying all the actions available under its normal market organization, it becomes necessary to implement extraordinary preventative rationing measures (e.g. voltage reduction in distribution networks, quota systems, energy reduction campaigns) to avoid using rolling blackouts to keep the system balanced.[1] Usually the task of choosing those measures is done under extreme pressure because of the proximity of the expected shortage, which can lead to wrong decisions, hence yielding a suboptimal scenario with high social costs [10]. This short-term decision-making can also lead to unnecessary market distortions and 'gaming' in anticipation of such (political) intervention. Preferably, the design of such sets of measures should be conducted in an organized way, ahead of time, to efficiently minimize the negative impact of the imbalance and prepare the market. In particular, measures on the demand side are likely to help the situation in a very effective way because diminishing consumption directly reestablishes the balance between the demand and a limited energy/power supply. Therefore, measures associated to the demand side are the main focus of this work.

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[1] It is important to differentiate between preventive and mandatory rationing periods. The latter refers to periods in which extraordinary measures are taken along with rolling blackouts to overcome the effects of an energy constrained system, whereas a preventive rationing period describes a situation where extraordinary measures are taken in advance to explicitly avoid the need of rolling blackouts.

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Nomenclature

Functions

C_{TG_i}	cost function of thermal generator *i*
C_{UE_j}	unserved energy cost function for load *j*

Parameters

β_q	cost of unserved irrigation water
p_{L_j}	expected power consumption of load *j*
$\underline{x_{ij}}$	line reactance between bus *i*th and bus *j*
$\overline{f}_{ij}$	max transfer between bus *i* and bus *j*
f_{ij}	max reversed transfer between bus *i* and bus *j*
$\overline{N}_B$	number of buses
N_{TG}	number of thermal generators
N_L	number of loads
N_I	number of extractions for irrigation
ϑ_j	future cost function linear approximation *j*
$\alpha_{L_j}^{t,b}$	lower bound reduction factor of load *j*
$\beta_{L_j}^{t,b}$	upper bound reduction factor of load *j*
σ	global energy reduction factor
IM_{ij}	interaction factor of measure *j* on measure *i*
$\phi^{t,b}$	total costs of operation from stage *t* block *b*
$\underline{H}$	incidence matrix of hydro-related constraints
$\vec{b}$	right hand side vector of hydraulic constraints

Sets and indices

t	time index (stage)
b	demand block index
Ω_{G_i}	set of generators connected to bus *i*
Ω_{L_i}	set of loads connected to bus *i*
Ω_{BB_i}	set of buses connected to bus *i*
Ω_{BB}	set of buses in the system
Ω_{S_p}	set of measures associated to strategy *p*
φ	set of expected future cost function cuts

Variables

p_{G_j}	power output of unit *j*
p_{U_j}	unserved power of load *j*
$p_{T_{ij}}$	power transferred from bus *i* to bus *j*
θ_i	phase angle of bus *i*
q_{U_k}	unserved flow of irrigation *k*
δ_{L_j}	power consumption of load *j*
ϑ	future cost
$\vec{\theta}$	vector of phase angle variables
$\vec{p}$	vector of power output variables of all units
$\overrightarrow{p_H}$	vector of power output variables (hydro units)
$\vec{\delta}$	vector of demand variables
$\vec{q}$	vector of flow variables
$\vec{v}$	vector of volume variables

The analysis of the best measures to apply in a certain situation relies on two main factors. On the one hand, it is necessary to modify the usual models to study the systems' adequacy in order to be able to determine the degree of deficit risk being faced by a system, which in case of hydrothermal systems with large reservoirs is represented by mid-term (up to 24 months in the Chilean case) hydrothermal coordination. On the other hand, an overview of available measures, their potential (demand reduction) impact and costs (economic and political) is necessary.

Sustained deficits have been faced by several countries around the world despite of their market structure and generation mix as reported by [10,5,1], many of these are hydro-dominated electricity systems. Fig. 1 shows some of the major sustained energy crises around the world and the main sources of the problem: unexpected demand growth (*U*), extreme temperatures (*E*), droughts (*D*), lack of investment in new generation (*I*), financial problems/liquidity of generators (*L*), extended failure/maintenance of critical generators in the system (*M*), failed market reforms (*R*), and transmission constraints (*T*) among other causes.

The challenge of including the effects of scarcity periods in the long-term hydrothermal coordination has been studied only in a few cases, in particular for the energy crisis in Brazil in 2001. Marcato et al. [8] study the effects on the prices and the operation of the system by including the characteristics of a rationing period (recreating the situation experienced in Brazil) in the long-term optimization of the system. Carreno et al. [2] describe the influence of the rationing period on the consumer behavior during the Brazilian energy crisis in 2001. Galetovic and Muñoz [4] determine the impact on the index of deficit probability when the long-run price elasticity of the demand is taken into consideration. Kelman et al. [7] define an index of probability for the enforcement of a rationing period by the Brazilian government, considering the context in which the regulator has high incentives to impose such a regime.

The New Zealand electricity market – though not centrally planned – has also invested significant effort to come to a coordinated Emergency Response after droughts in 2001, 2003 and 2008, including staged response in what are called Watch, Alert and Emergency stages depending on the probability of future supply shortages under expected demand, supply and rainfall scenarios [15].

Chilean experience in rationing management

The Chilean Power System was liberalized in 1982, following a mandatory pool structure at generation level with bilateral financial contracts between generators and large customers. The initial structure remains, along with the liberal orientation of the reform, but is has been modified throughout the years to improve its weaknesses, yielding the organization described in [4]. The system has a large amount of hydropower, with important storage capacity (approx. 9 TW h, 22% of the energy generated in 2010), which is highly concentrated in the Lake Laja (approx. 7 TW h), the main reservoir of the system and a good reference for resource availability. The penetration of non-conventional renewable energy[2] remains low (around 2.8% total generated energy in 2011). As shown in Fig. 2, the system faced a major drought in 1998–1999, which had mayor impact on the Central Interconnected System (SIC), leading to the use of rolling blackouts (mandatory rationing) and to important changes in the structure of the law, regulating the force-majeure conditions and the associated compensations to the regulated end users. The law has given powers to the regulator to establish a special regime of operation if scarcity is foreseen. That power has been used three times since the system was liberalized (yellow circles in Fig. 2 shows the start of the rationing period, which usually lasts 6–12 months). Apart from the situation in 1999, when the system was actually close to a complete energy deficit (visible in Fig. 2 in terms of lake level and installed thermal capacity being much lower than

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[2] Non-conventional Renewable Energies are all the generation systems connected to the respective power system, and which energy source is nonconventional, as geothermal power, wind power, solar power, tidal power, hydro power under 20 MW of installed capacity, cogeneration and other similar determined fundamentally by the Chilean Energy Commission.

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