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Evaluation of a payments proposal for blackstart services in the Colombian electricity system: A system dynamics approach

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A B S T R A C T

All electrical power systems require some contingency arrangements to enable a restart in the unlikely event that all or a key part of the system shuts down. The process of restoring the power system is commonly referred to as blackstart. Not all power generators have, or are required to have blackstart capability. We propose a market-based scheme for blackstart services in the Colombian electricity sector where it has been an unregulated ancillary service. In this study, a system dynamics model is developed to better understand and analyze the behaviour of such a market in the long term. The developed simulation model uses a 20-year planning horizon and the analysis covers most elements of the proposed market for provision of blackstart services, including price behaviour, investment, installed capacity, and potential shortfalls. The simulation results show that the proposal for a dynamic market for blackstart services is stable and viable over the time period investigated.

1. Introduction

In April 2007, the Colombian National Interconnected System (SIN) experienced a major power system disturbance that caused a 95% loss of the whole system load [1]. The outage lasted for over 4 h, bringing transport to a standstill, shutting down industrial production, and causing a general panic among the population. The impact of this blackout was so severe that the National Regulatory Commission imposed a fine of approximately $US 500,000 (considered very large in Colombia) on the Electrical Interconnection Utility (ISA), since the company had caused the interruptions during the maintenance of one of its substations [2]. In the last decade, similar disturbances have occurred in the US, Italy, Germany and the UK [3] that have caused multi-billion dollar damages to utilities companies and their customers [4]. Experience has shown that the cost of a blackout increases exponentially with duration, and that duration is exponentially reduced with the availability of what is known as blackstart service (BSS) [5]. Following a power system blackout, large generating units need external power for quick restart. In the absence of power from the network, blackstart generators provide such a service, either locally within the plant or remotely from outside [6]. In this paper we are concerned with local blackstart services, provided using a small prime mover powered by combustion turbines or, if available, small hydro units or pumped storage plants. The service is usually based on a contract with the system operator, and a generator must meet certain performance criteria to be considered as a blackstart plant.

Although the system operator recognizes the need for blackstart, it is not currently regulated in Colombia and utilities companies are not compensated for this service. This paper argues the need for remunerating blackstart in general, using Colombia as an example. The paper also evaluates a payment proposal, by developing and using a model to simulate the potential behaviour of a market in blackstart services. The results show that elements of the market, such as timing of investments, the time taken to install the plants, and the duration of the awarded contracts for blackstart are all fundamental to ensuring participation of the generators over a 20-year time horizon.

2. Payment proposal for blackstart services in the Colombian SIN

As blackstart helps to promote the fast, safe and reliable restoration of power after a blackout, we propose that the service is remunerated in Colombia to encourage its implementation. In general terms, the proposal considers that the system operator should establish the number of blackstart installations needed for each operational area, before carrying out an auction that awards contracts to those plants who can offer the service at the lowest price

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in order to reach the required number of installations. These auctions would be conducted according to a planning window, thereby creating a dynamic market.

We will now describe the different elements involved in our remunerative proposal, taking into account both the technical and commercial aspects necessary to regulate blackstart in the SIN.

2.1. Technical requirements

Blackstart requirements, as specified in the Network Code (CREG 025/95) [6] based on studies by the National Operational Council (CNO), include the ability to be started within 30 min of a blackout and without network support and to start three times in 24 h, to have sufficient fuel to operate continuously for 24 h, the ability to maintain system frequency within ± 0.2 Hz (59.8 & 60.2 Hz) [7] and to meet the required over- and under-excitation values.

In addition to these requirements it is important to identify each blackstart installation by name, location, capacity (real and reactive power), and type of unit as well as to identify the cranking path and the initial switching between each blackstart unit and the generating unit to be started. Loads and their location must be identified in order to control the frequency and voltage profiles [8] of the cranking path and it must be verified that units with blackstart are synchronized with the interconnected power system when the system operator gives the order.

2.2. Settlement of the procurement contract amount

In general, when establishing blackstart outside of Colombia, both the costs involved and the availability [9] required to render the service are considered. We propose that a similar procedure should be used in Colombia which recognizes that the service should be available continuously and, as such, requires sufficient financial planning and investment in equipment. In order to calculate and present a fair and accurate auction proposal, generating agents should take into account the following four economic factors: capital expenditure, depreciation of investment in blackstart equipment, an internal rate of return (IRR) permitted in Colombia (14%) [10] and the administration, operation, and maintenance (AOM) expenses, estimated at 5% of the original investment given the low blackstart usage rate (on average once every 10 years) [8].

The proposed remuneration methodology is based on the use of bilateral contracts for each operative area, since international experience has shown that such a market structure fits best with the characteristics of blackstart [4,11–13]. It is not economically efficient to pay all plants to have blackstart capabilities, as blackstart generators, when running, can be used to restart the other generators in the region.

The contracted amount for each area would be calculated by the (national) system administrator and be distributed among the appropriate number of generation plants in the area after a competitive bidding process. Determining the contracted number of plants requires a study of the characteristics of each operative to be carried out in order to value the auxiliary services according to their power, the amount of existing demand, and the percentages of residential, commercial and industrial use, as economic losses caused by a blackout are greater for the industrial user than the residential user and grow exponentially with restoration time delays [4,14].

In summary, the procurement amount can be estimated as follows:

$$Amount_{ijt}(\$) = [(AVABST_{ijt} * PAVABS_{ijt})] * (1 + Fm) \quad (1)$$

where $AVABST_{ijt}$ is blackstart availability delivered for generator i, required by the operative area j, in the contracted period t. $PAVABS_{ijt}$ is payment for the costs incurred in maintaining in-house restart capability, plus the training and availability of staff to restart functions if and when required. Finally, Fm relates to the section of the SIN that each plant with blackstart can help re-establish, as there are generating plants which, given their size, reliability, and location, could be faster and more effective in the restoration process. This factor must be evaluated by the system operator.

2.2.1. Power supplied in the event of a blackout

The bilateral procurement contract would only remunerate generators for making blackstart available. In the event of a shutdown, the power supplied would be paid at a reconciliation price. Eq. (2) shows how this price is calculated:

$$PR(\$/\text{MW h}) = \text{MAX}(P_e, P_b) \quad (2)$$

in which $PR(\$/\text{MW h})$ is the reconciliation price applied to the generator unit that supplies power during the outage, $P_e(\$/\text{MW h})$ is the exchange price established by the wholesale power market in the normal operational conditions of the SIN and $P_b(\$/\text{MW h})$ is the last bid price proposed by the generator agent to the electricity wholesale market.

2.2.2. Penalties

A penalty system for non-compliance of the blackstart service is proposed. Generators with blackstart contracts would be subject to periodic evaluations and inspections by the system operator to confirm the correct functioning of the blackstart plants. If any irregularity were found, the generator agent would receive no payment until its satisfactory conditions were met and verified in another evaluation. A fine would also be imposed depending on the severity of the failure.

2.2.3. Dynamic auctions

The proposal considers that once the amount and price of blackstart capabilities are settled by auction, a planning window for repeat auctions should be defined. Such auctions should be held at regular intervals to establish a dynamic and competitive blackstart market. Market conditions will be a determining factor in encouraging blackstart investment, where delays play an important role along with the contract length. The long-term behaviour of a blackstart market will also require analysis since it may be different to that of a power market. The next section provides a framework for evaluating such potential behavioural patterns using a simulation model.

3. Modelling the remuneration proposal

3.1. System dynamics

The standard system dynamics approach to modelling starts by establishing the feedbacks and delays in the system to be investigated, followed by a stock and flow diagram, and finally the formal equations, which are differential equations. This formalisation allows for the simulation of the system. For a detailed description and discussion of system dynamics modelling, formalization, and verification see Sterman [15].

3.2. Causal diagram of the blackstart ancillary service market

The causal or feedback diagram in Fig. 1 shows the main variables of the blackstart service market and their relationships, allowing the generators' behaviour in a remunerative blackstart scheme to be monitored. Generators will generally be willing to offer blackstart if the payment amount and length of contract reach their minimum required return (hurdle rate) on the investment.