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Assessing power system security. A framework and a multi model approach

J.P. Deane [a,b,1,*], Francesco Gracceva [c,d,1], Alessandro Chiodi [a,b], Maurizio Gargiulo [e], Brian P.Ó. Gallachóir [a,b]

[a] Energy Policy and Modelling Group, Environmental Research Institute, University College Cork, Cork, Ireland
[b] School of Engineering, University College Cork, Cork, Ireland
[c] European Commission, Joint Research Centre, Petten, Netherlands
[d] ENEA, Italy
[e] Energy Engineering Economic Environment Systems Modelling and Analysis (E4SMA s.r.l.), Turin, Italy

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ABSTRACT

This paper presents a methodological framework using a multi model approach to assess power system security. System security is viewed here as a multidimensional systemic property of the entire energy system. The paper shows that the different dimensions of a secure energy system are correlated, and hence their behaviour cannot be explained solely by an understanding of the individual dimensions or by system elements in isolation. The implication of this is that a proper assessment of the security of a power system requires a combination of different techno-economic models. The paper develops a comprehensive multi-model approach for investigating energy security issues within power systems, and applies it to a case study focussing on the Italian power sector. The core research activity involves using an energy systems model of Italy (MONET) to build a dedicated power systems model (PLEXOS_IT) and then undertaking a soft-linking exercise between the two models. The purpose is to use PLEXOS_IT to investigate the system adequacy of the power system results produced by MONET for future possible energy system scenarios.

Introduction

The Europe Union has put in place legislation to underpin the transition towards a low-carbon, competitive and secure energy system. Security of supply, sustainability and competitiveness are the three established complementary pillars of European energy policy [1] and form the basis of a coherent strategy, [2]. In recent years, increasing attention has been paid to the need to adopt integrated approaches to energy policy. This becomes more apparent with the introduction of a wide range of policies that pave the way towards a low carbon energy system, due to the challenges that these may pose to the security of the EU energy system. The recent EU Green Paper on a 2030 framework for EU climate change and energy policies [3] states that "the 2030 framework must identify how best to maximise synergies and deal with trade-offs between the objectives of competitiveness, security of energy supply and sustainability" ([3], p. 3). The risk is that, if not properly designed, policies targeting the reduction of GHG emissions may affect the resilience of the energy system and its ability to tolerate disturbances and deliver stable and affordable energy services to consumers. By supporting technological and market solutions designed to mitigate climate change, there may be unforeseen impacts on energy security and unforeseen additional costs.

The current 2020 EU climate and energy targets were designed to be mutually supporting and while there are indeed obvious synergies between the different targets, there are also potential trade-offs. The EC Green Paper on 2030 policy framework stresses how some challenges were not addressed at the time of the 2009 climate and energy package and highlighted three issues: first, the necessary additional transmission and distribution infrastructure was not defined; second, the management challenges linked to the introduction of renewables were also not fully considered and third, the impact of many national support schemes for renewables on market integration was underestimated. Moreover, the Green Paper stresses that the while the Third Energy package addressed the issue of how to stimulate competition in the market but did not address the issue of whether the market offered the necessary incentives to invest in generation, distribution and

* Corresponding author at: Energy Policy and Modelling Group, Environmental Research Institute, University College Cork, Cork, Ireland. Tel.: +353 21 4901959.
E-mail address: jp.deane@ucc.ie (J.P. Deane).

[1] These authors contributed equally to this work.

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transmission, and storage capacity in a system with greater shares of renewables.

These considerations point clearly to the need for appropriate modelling tools, which are able to assess the complex interactions between climate change and energy security, in order to inform the development of cost-effective, evidence based strategies that ensure the future EU energy system is both a low carbon and a secure energy system.

This paper develops and presents a methodological framework that can be used to undertake rigorous quantitative analyses of the security of current and future possible power systems, based on a comprehensive theoretical approach. A key outcome of this methodology is the possibility to select economically rational energy security strategies, i.e. strategies based on a careful consideration of their costs and potential benefits, while at the same time taking into account the potential synergies and trade-offs between energy security and the other main energy policy goals. In short, this work addresses the increasingly urgent need for a framework within which to analyse the following three issues; (1) the impact of specific security events, (2) the level of risk attached to such events, and (3) the cost of measures which would provide insurance against them. This is vitally important because in the absence of these issues being addressed any statement about energy security is meaningless [4].

Section 'Security of power systems' provides an overview of the main issues related to the security of power systems. Section 'Met hodology' details the methodology used in this paper, a multi-model approach to power system security. Section 'Model description' applies the methodology to a specific case study, building a soft-link between an energy systems model (MONET) and a detailed power system model (PLEXOS-IT). Section 'Results' presents the results, which assess the potential impact of a climate change policy on the security of the Italian power system.

Security of power systems

An overview of the main issues

The main issues related to power system security can be categorised according to distinct time frames.

Very short-term

A primary power system security concern is the ability of the system to operate such that sudden perturbations, such as short circuits in lines, loss of critical system components, grid congestion etc, do not give rise to loss of load or cause stress of system components beyond their ratings [5].

Security of transmission infrastructure also has a crucial role as electricity supply and demand must be balanced in real time across the whole interconnected network. The outage of a single line can result in critical overloads on other lines due to redistribution of power flows and cascading effects within interconnected power systems. This challenge is magnified by the dynamic nature of flows on the current large-scale and highly complex interconnected transmission systems. Furthermore the dynamic system operating environment of transmission systems in liberalised markets add further elements of complexity to the issue [6].

Short-term

On a slightly longer-time scale, a critical issue is the ability of the power systems to cope with rapid and large imbalances, due to differences between forecast and actual real time generation or demand, which is primarily due to three key reasons. Firstly; power plants or/and transmission lines are subject to planned and unplanned outages of system components [6]. Secondly; fluctuating demand (from hour to hour, day to day, season to season) is a fundamental characteristic of power systems. Under normal operating conditions these fluctuations are relatively regular and predictable over daily and seasonal time periods. Day-ahead load forecast errors are typically below 1% mean average error of production [7]. Thirdly, variable energy resources (VER) , i.e. resources that fluctuate over the course of the day and from season to season are less predictable and more difficult to forecast, especially over longer time frames. For example, an average prediction error of 13% of installed wind capacity has been calculated for 24 sites in Finland for 36 h ahead [8], while on a day-ahead scale, system level errors of under 6% of production (root mean square error) have been demonstrated over the course of a year in Germany [7]. Moreover, the increased penetration of VER adds a set of specific operating challenges for the power system, e.g. the issues of peak load adequacy, minimum load balancing, ramp rates of residual demand and predictability of VER. At high levels of deployment, the level of uncertainty introduced into the system can make it difficult to meet the moment-by-moment challenge of balancing supply and demand for electricity across a power system [9].

Medium-term

The medium-term threats are those threats which can affect the energy system within its investment cycle, i.e. the time interval over which a complete change of the system is not feasible. Therefore, a key issue is if the development projects in the pipeline provide adequate extension to the existing infrastructure. A wide range of literature describes the potential reasons for market failures with respect to incentives for investment in generation and transmission, due to the specific characteristics of electricity[2], which introduce systematic biases in market behaviour [10] and imply that there are public good aspects in generation adequacy as well as in transmission investments [11,12]. A potential risk of market failure is related to the capacity of locational marginal prices (and even more of zonal prices) to recover all costs, together with the economies of scale and the lumpiness of investments [13,14]. Indeed, the strategic benefits of transmission and distribution systems are not generally valued. The grid is not seen as an easy profit making opportunity but rather a challenge, strongly influenced by the historical incumbent. Therefore, there is a risk of lack of maintenance and grid reinforcements, and of delays in new lines and connections, with the consequence of bottlenecks, i.e. inadequate capacity/location of network components with respect to the location and magnitude of future injections of electricity/gas.

Another risk of market failure is related to the fact that the power market is particularly prone to market power, due to some of its fundamental characteristics like the lack of price elasticity, the role of network and power flow constraints [15,16,17].

A new challenge is that the investments in flexibility required by a low carbon power system can be difficult to achieve if the market does not properly value the benefits of flexible resources. The problem here is if the market design benefits technologies that would help realize a system in line with political goals. A key characteristic of a market with large shares of RES is its new market rationale, where the merit order is replaced by net demand (and the profile of the price curve is different from the demand curve) and the role of thermal plants changes substantially. There are many more periods of (temporarily) very low market prices, when there is a surplus of renewables and nuclear output, so that RES electricity shifts the supply curve of conventional electricity

[2] i.e. the variability of demand, the non-storability, the network constraints requiring the physical balance of supply and demand on each point of the network at all times, the inability to control power flows to a large part of consumers, the limited use of real time pricing and the non-price rationing in some instances such as blackouts.