A Concept for Reliability Assessment for the Provision of Ancillary Services

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Abstract: In order to ensure the quality of supply in the electric energy system the ancillary services frequency and voltage control are necessary. With regard to the ongoing decentralization of power supply, approaches are being investigated to provide those ancillary services by decentralized units some of which are highly volatile in power generation. This leads to the question of the reliability with which ancillary services can be provided. In this paper a method is proposed that allows for the assessment of reliability of aggregations of distributed units with respect to their ability to provide ancillary services.

1 INTRODUCTION

The penetration of renewable electricity generating units in the electrical supply system steadily increases and with that large power plants are replaced. In addition, more flexible and controllable loads are connected to the grid. This leads to new challenges and increased demand for ancillary services. Ancillary services are services to support a stable and secure operation of the network and need to be constantly available. These services include frequency and voltage control.

To a great extend ancillary services have to be provided by distributed flexible consumers and producers since large power plants are no longer available to the extend as they are today. A variety of devices, e.g. small power plants, batteries, and house hold appliances being captured under the term unit can be controlled by intelligent agents. However, individual units usually can only provide a small contribution to ancillary services. Furthermore, from today's point of view units must be able to reliably provide ancillary services in the sense that they are 100 per cent available. The paradigm proposed in (Nieße et al., 2012) allows the pooling of units in order to provide ancillary services in a decentralized and distributed way. The resulting coalitions must be able to reliably provide ancillary services such that safe operations are guaranteed. For this reason, it will be necessary to evaluate the reliability of ancillary service provided by coalitions of distinct units.

In this paper a method is proposed for the probabilistic evaluation of reliability of unit coalitions with regard to the provision of ancillary services. Therefore, a new understanding of reliability is introduced. To this end, the ancillary services frequency and voltage control are discussed in section 2. Furthermore, a generic description of those services is given. In the following section 3, the term of reliability is discussed and a proper definition in this context is introduced. A concept for a method for the evaluation of a coalition's reliability is presented. The paper ends with conclusion and outlook in section 4.

2 ANCILLARY SERVICES

In order to maintain service quality in the electrical supply system, amongst others the aspects of frequency and voltage quality must be kept. This means that operation constraints must not be violated. To this end ancillary services are applied.

Section 2.1 discusses the system boundaries of frequency and voltage band. Furthermore, a definition of the ancillary services frequency and voltage control as well as their properties is given. Section 2.2 follows with a formal description of these two ancillary service types. In section 2.3 an outline is given of how ancillary services are provided by agent coalitions.

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2.1 Definition and Properties

In IEC 60050-617 (system) ancillary services are defined as "services necessary for the operation of an electric power system provided by the system operator and/or by power system users" (see (IEC, 2011)). In this paper, the ancillary services frequency and voltage control are considered. In the sequel, a brief overview of network frequency and voltage band are given, respectively, since they constitute margins for safe grid operations. Moreover, both ancillary services are described, reflecting the actual situation.

The network frequency is a global variable that has the same value in the whole system and should be close to the setpoint value of $50Hz$ in the European power grid. However, a deviation of the frequency from this target value cannot be avoided. Nevertheless, the frequency must stay within a certain range.

In order to keep the frequency at a stable level, it is necessary that the generated and consumed active power is in balance. To ensure this, frequency control reserves must be provided. This reserve is differentiated into primary, secondary and tertiary control that are triggered depending on a certain deviation from the set point and have to be delivered within different time intervals. For details see e.g. (Rebours et al., 2007)).

Another crucial variable is the voltage at each grid node. The target value to keep the voltage at is the nominal voltage of a voltage level. Due to changes in the power feed-in and consumption along a line the nodal voltages usually deviate from the nominal voltage. However, not more than a certain ration from the nominal value is allowed, e.g. in the distribution grid a deviation of not more than ten per cent is allowed.

Since voltages differ from node to node it is necessary to provide voltage control locally. This is done by injection or consumption of reactive power according to given (by e.g. the TSO) characteristic curves. Additionally, in the distribution grid a combination of active and reactive power for regulating the voltage can be applied.

2.2 Formal Description

The ancillary services described before have common attributes. This allows for a generic description of ancillary services of different types. The following specification covers the services types of frequency and voltage control, but it can be extended and added to describe other service types as well.

Agent coalitions provide a certain amount of ancillary services (see 2.3). In order to determine whether ancillary services and in which amount are necessary, the considered quality aspect (frequency or voltage level) must be investigated. To this end, there are three main properties of a quality aspect. First of all, a measure of the quality aspect must be available in order to evaluate if ancillary services must be activated, termed the measurable quantity. This variable has a set point. Furthermore, the value of the measurable quantity is allowed to vary within a feasible area. The deadband is the area within which the quantity is allowed to vary in without any reaction of the system.

As mentioned before, the measured value can be influenced by providing a certain quantity, here termed ancillary service quantity. In case of frequency this is active power, in case of voltage this is reactive power, or (as voltage control is becoming more important in the distribution grid) a combination of active and reactive power, i.e. it can be a real or a complex number.

In order to guarantee the provision of ancillary services with the necessary amount, in the presented concept ancillary service products are introduced that allow for the annotation of costs for the provision of ancillary services. An ancillary service product is defined as a triple of a time interval – the product horizon, ancillary service amount, and corresponding costs.

2.3 Provision of Ancillary Services

The system has certain demands on ancillary services regarding its amount and a minimum reliability (actual requirements depend on the ancillary service type). Hence, the system calls for bids for the provision of those services for a given time interval, the product horizon. The units or agents (see below for details) that want to contribute to a service provision determine what amount they can provide. If this contribution is not sufficient, agents must negotiate with other agents in order to form coalitions that fulfil system requirements. In case a coalition is chosen by the system to provide an ancillary service this coalition is responsible that the required amount is available with a required reliability throughout the whole product horizon. If an ancillary service is actually called by the system the responsible coalition must deliver the required amount automatically.

A unit is an electrical device or a set of electrical devices that produces or consumes electric power and is further equipped with an embedded system. A unit is associated with exactly one grid node. An agent is a software component exhibiting intelligent behaviour. Each agent represents a unit, hence there is a one to one relationship between units and agents. A coalition is an aggregation of units resp. agents.

Each agent must calculate the amount of ancillary service quantity its unit can contribute to an ancillary-service coalition. The contribution of agent and correspondingly its represented unit within a product horizon is defined as the set of pairs consisting of the amount of ancillary service quantity and costs for all product intervals (assuming that a product horizon is a union of product intervals). For conceptual clarity, in the following, the focus is laid on the ancillary service amount contributed rather than the costs it causes.

Many of the decentralized units are subject to a certain behaviour of users (e.g. controllable loads or combined heat and power plants), or depend on uncertain and volatile weather phenomena, such as photovoltaic or wind turbines. Consequently, planning of available amounts of an ancillary service quantity strongly depends on predictions which inherently bear errors. Thus, coalitions that provide ancillary services must be evaluated with regard to reliability.

3 CONCEPT OF RELIABILITY

As pointed out before, due to a decentralized provision of ancillary services, i.e. by agent coalitions, an assessment of reliability with which these coalitions are able to provide ancillary services is necessary. In section 3.1 a definition for reliability is discussed and a proper definition is given. In section 3.2 a concept for reliability evaluation is introduced.

3.1 Definition and Evaluation of Reliability

In (IEC, 2011) reliability of an electric power system is defined as "the probability that an electric power system can perform a required function under given conditions for a given time interval." It is stated that "reliability quantifies the ability of an electric power system to supply adequate electric service on a nearly continuous basis with few interruptions over an extended period of time". To this end it is necessary that ancillary services are available at a rate of 100 per cent. If ancillary services are being provided by coalitions consisting of distributed units this requirement can hardly be met since those units may be volatile in production or consumption.

A prerequisite of reliable system performance is the reliable functioning of its components. The reliability performance of an item according to (IEC, 1990) is defined as the ability to "perform a required function under given conditions for a given time interval". It is further stated that in some applications an appropriate measure for reliability performance is expressed by a probability. In order to guarantee a reliable supply of ancillary service by distributed units, a metric is necessary that allows the assessment of the performance of unit coalitions regarding their ability to provide ancillary services beforehand. To this end, the following definition is proposed:

> Reliability of a coalition with respect to the provision of an ancillary service product is the probability with which this product is available within a product horizon under certain conditions.

This definition of reliability can be used in the course of coalition formation as it can be integrated in the objective function of ancillary service coalitions given a minimum acceptable reliability value depending on the ancillary service type of interest. In the following, a corresponding concept is introduced which allows the calculation of reliability.

3.2 Hierarchy of Reliability Evaluation

In this section a concept for a method is introduced for the evaluation of agent coalitions with regard to their ability to provide an ancillary service product. The reliability of a coalition with regard to the provision of an ancillary service product depends on the reliability of all of the coalition's member units. The reliability of a unit again is influenced by several factors. This leads to a hierarchy for the evaluation of a coalition's reliability. In the following, the non influenceable and influenceable factors are introduced in detail. Based on these factors, the reliability of a unit can be calculated. Finally, the determination of a coalition's reliability is discussed.

Non influencable factors that have to be taken into account for reliability evaluation are for instance predictions of the operation behaviour that might depend e.g. on weather phenomena or user profiles. But also factors such as unplanned outages must be regarded.

In order to represent a unit, its agent must know the unit's behaviour given as an operation schedule. The operation schedule and with that the resulting operation flexibility depend on predictions of meteorological phenomena, user behaviour and so on. Predictions deal with uncertainties and thus usually are imprecise and prone to errors. Furthermore, errors may occur with growing considered time horizons. This is especially the case for generation units that depend on the availability of certain resources, e.g. wind or solar power plants. The probability that the predicted power amount is actually fed-in is assumed to decrease whereas the probability for both positive and negative deviations increases with time, i.e. the prediction error increases.

There are methods to integrate several influences in order to obtain a common model for prediction errors such as convolution. This is amongst e.g. a common procedure for the determination of power reserve dimension, as e.g. in (Kays et al., 2010). Given a distribution function from a (possibly convoluted) density function of the prediction error it is possible to derive an available amount of ancillary service quantity with a certain reliability. The other way around, given a reliability level the appropriate amount of ancillary service quantity can be determined.

Given the prediction of a unit's behaviour based on non influenceable factors, influenceable factors can be adjusted in order to achieve a certain goal, for instance satisfy a given reliability level. In this paper three factors of that kind are considered. Those are the accepted level of reliability, the provided amount of ancillary service quantity, and the considered prediction horizon.

As mentioned before, the contribution of a unit to an ancillary service product might in general be too small to satisfy system requirements. Moreover, the reliability of the contribution might not reach a required level. As a consequence, units form coalitions with the goal to provide a required amount of an ancillary service quantity with a minimum value of reliability. The reliability value for a coalition's contribution must be determined based on the reliability of each of its member units.

Here the three influenceable factors mentioned previously also apply, i.e. units can adjust their contribution, their individual reliability or the prediction horizon can be adjusted. Moreover a forth factor contributes to a coalition's reliability evaluation - the size and structure of a coalition. Often different units are subject to the same influences, e.g. photovoltaics installed on neighboured houses. Hence, simultaneous behaviour reflected by error distributions cannot be modelled using convolution since stochastic independence is required for its application. Suitable methods for estimating coalition reliability will be developed in future work. The estimation of a coalition's reliability can then be integrated into a coalition formation strategy as part of an objective function.

4 CONCLUSIONS AND OUTLOOK

In this paper a definition of reliability was introduced for the assessment of agent coalitions with regard to provision of ancillary services. Furthermore, a concept was proposed that allows an ex-ante evaluation of reliability. This method is applicable for different types of ancillary services since those types have common properties. In order to determine the reliability of a coalition, first the reliability of its member units must be calculated. This is based on different factors which were categorized into influenceable and non influenceable factors. Based on the reliability of its member units, the reliability of a coalition can be determined. A coalition's reliability depends on the size and structure of the coalition. This procedure can be applied in the course of coalition formation.

In future work the proposed techniques will be extended and further techniques will be evaluated. Especially methods from other domains such as finance and insurance will be investigated and if possible adjusted to the considered context. The developed method will then be checked for validity, e.g. using Monte Carlo Simulations. Further intended research will also include costs and extend the existing methods for the assessment of coalition reliability. In particular, it must be taken into account if the same influences on units and corresponding agents lead to stochastically dependent behaviour within a coalition.

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