Long Term Evaluation of Operating Reserve with High Penetration of Renewable Energy Sources

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***Abstract* – Due to the high penetration of renewable energy into the energy matrix of today's power networks, the design of generating systems based only on static reserve assessment does not seem to be enough to guarantee the security of power system operation. From the wind power integration perspective, this energy source imposes additional requirements, mainly due to the inherent unpredictable characteristic of the wind. Besides the uncertainties in load and generating unit availabilities, the operating reserve needs also to deal with the fluctuation characteristic of the wind power. Therefore, more flexibility of the conventional generators (hydro and thermal) is required to provide system support services. This paper discusses a new methodology based on chronological Monte Carlo simulation to evaluate the operating reserve requirements of generating systems with large amounts of renewable energy sources, in particular, wind power.**

***Index Terms*–Monte Carlo simulation, operating reserve, reliability assessment, wind power generation.**

I. Introduction

In order to comply with the set of measures of the United Nations Framework Convention on Climate Change established in 2007 [1], some countries have made strong investments in the expansion of their generating system using renewable energy sources. These kinds of sources can play a major role in tackling the double challenge of energy security and global warming because they are not depletable and produce less greenhouse-gas emission than fossil fuels. A recent example of this concern is an agreement made among Europe's Heads of State, in March 2007, when they agreed to raise the level of renewable energy to 20% by 2020 [2]-[3].

The increase in the amount of renewable energy expected for the next years sends a strong signal to system planners and operators about the necessity of developing new methodologies and tools for planning the expansion and operation of power systems. The main reasons are that the number of random variables and system complexities considerably increases, when renewable energy sources are added to the system, due to the fluctuating capacity of these sources.

As far as static reserve requirements are concerned, several methodologies have been recently proposed to deal with the fluctuating nature of renewable energy sources; see, for instance, [4]-[5]. When it comes to operating reserve requirements evaluation, the worldwide probabilistic approach used is the PJM method [6]. Approaches based on PJM are adequate to assess short-term risks for time intervals up to a few hours. In this case, the system risk obtained is conditioned to a short period, assuming that the operator knows *a priori* the generating units available to take up load. Conversely, in the medium- and long-term running, the operator does not know exactly the set of generating units that will be available for each period of time and, therefore, the risk assessment must account for the chronological evaluation of the generating capacity system.

Due to the growing penetration of renewable energy into the energy matrix of today's power networks, the design of generating system based only on static reserve assessment does not seem to be enough to ensure the security of power system operation. The inclusion of operating reserve in the medium- and long-term analysis [7]-[8] has been seen as a way of providing more information to planners about the system performance, assuring that investment options will result in more robust and flexible generating configurations.

The main idea of this paper is to investigate the operating reserve requirements of generating systems, when a significant portion of the energy matrix is composed of renewable sources. In this paper, renewable energy sources will comprise: hydro, wind, small-hydro, co-generation (e.g.: biomass), and solar thermal-photovoltaic generation. In order to achieve this goal, the sequential Monte Carlo method [8] will be used and models to represent the renewable generation will be discussed. Case studies with the Portuguese and Spanish generating systems are presented and discussed [9] under a planning perspective, where generation expansion flexibility concerns are highlighted. Moreover, a methodology to assess non-spinning reserve is presented through the use of a modified configuration of the Reliability Test System (RTS-96) [10].

II. Generating Capacity Reserve Evaluation

The assessment of capacity reserve requirements to ensure an adequate level of energy supply is an important aspect for both expansion and operation planning of generating systems. During the last decade, the massive use of renewable production in some countries, especially wind generation, brought with them several new challenges to the generating capacity reserve evaluation.

From the technological perspective, for instance, the design characteristics of conventional hydro and thermal generators enable the generating unit to contribute to the provision of system support services, such as voltage and frequency regulation [11]-[13]. Conversely, a wind turbine uses different technology and, at the moment, it is not capable of providing the same system support services. Moreover, from the integration perspective, wind generation imposes additional requirements, mainly due to the inherent unpredictable characteristic of the wind. Firstly, the reserve needs to deal with the uncertainty

This work was partially supported by the CNPq, Ministry of Science and Technology, Brazil.

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978-1-4577-1002-5/11/$26.00 ©2011 IEEE

that comes from the wind production and it may increase due to the fluctuation characteristic of this power source. Secondly, this fluctuation characteristic may also impose more flexibility of the conventional generators (hydro and thermal) in order to provide system support services [11]. In order to deliver both flexibility and system support services, large conventional plants usually require expensive investments [14].

The generating capacity reserve evaluation can be traditionally split into two conceptually different research areas: static reserve and operating reserve. With the massive usage of the wind power technology, the previous hydro and thermal flexibility requirements should be revisited bearing in mind the operating reserve evaluation. Therefore, the generating capacity reserve problem may be extended from short- to long-term generating capacity evaluation.

A. Flexibility Requirements of Generating Units

Traditionally, the balance function between consumption and generation is managed by flexible generating units, which are able to deal with fast variation in demand and generation. These generating units should be able to respond, when requested, to fast variations from a few seconds to a few minutes, and slow variations from several minutes to several hours. Wind power generation brings with them different levels of output variations, essentially, on short time interval. Figure 1 shows a wind power output observation of a real wind farm from the West Cost of the United States [15]. The observation consists of 15 hours collected up to 10 minutes of the same day. The values are presented in per unit (pu) of the maximum capacity of the wind farm. First, observe that within a 60 minutes interval the wind output can suddenly vary from 0.4 pu to 0.8 pu, requiring a fast downward reaction of the synchronized and non-synchronized reserve.

On the contrary, within 50 minutes interval, the wind output can vary from 0.5 pu to 0.2 pu, requiring a fast upward reaction of the synchronized reserve. All this movement happens within a 4 hour interval. Based on these requests, system operators around the world adopt several different classifications to the reserve problem [6]. As one can see, to the synchronized reserve, flexible generating units based on OCGT (open cycle gas turbine) and CCGT (combined cycle gas turbine) technologies for short-term variations are usually required.

B. Short Term Reserve Evaluation

Due to the inherent uncertainty of the operating reserve calculation, the consideration of probabilistic methods becomes indispensable. The first method that incorporated the idea of risk to calculate the reserve was the PJM [16]. Once an acceptable level of risk has been adopted, the objective is to strictly maintain it, for as long as possible, through the programming of appropriate operating reserve. Variations in relation to this method have been proposed; for several authors [6], [17]-[18].

The system risk index is the probability of the existing generation capacity not satisfying the expected load demand, during time period T, in which the operator may not replace any damaged unit nor initialize the operation of new ones. Thus, the index that appears represents a measurement of the loss of load associated with the scheduled generating reserve.

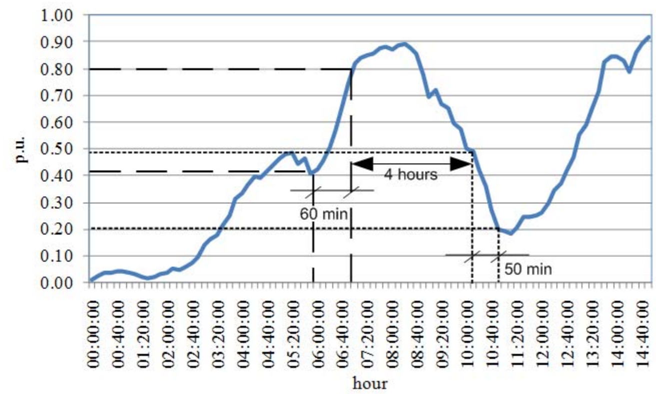

Fig. 1. USA Wind Power Fluctuation.

For a single unit, the probability of failure at interval [0, T], i.e. $P_{down}(T)$, can be determined by [6]:

$$P_{down}(T) \approx P(t_{up} \leq T) = 1 - e^{-\lambda T} \quad (1)$$

where λ represents the failure rate of the given generating unit. If $\lambda T << 1$, for short lead times of up to several hours, then (1) becomes $P_{down}(T) \approx \lambda T$ = ORR. The product λT is known as Outage Replacement Rate (ORR) and represents the probability that a unit fails and is not replaced during lead time T. The ORR parameter is similar to the Forced Outage Rate (FOR) [6] used in planning studies. The only difference is that the ORR is not simply a fixed characteristic of a unit but a time-dependent quantity affected by the value of the lead time being considered. Thus, it is also possible to build a generation model similar to the Capacity Outage Probability Table [6], whose techniques follow the same efficiency principles described in [19]. The difference is that the ORR of each unit is used instead of the FOR parameter.

The previous concepts are applied to one major and relevant component of the operating reserve named spinning reserve; a capacity that is spinning, synchronized, and ready to take up load. However, spinning is one among other reserve requirements that also include [18]: regulation, non-spinning, and replacement. This assessment has also to account for rapid start units such as gas turbines and hydro-plants, interruptible loads, assistance for interconnected systems, etc.

C. Long-Term Reserve Evaluation

Bearing in mind the long-term reserve requirements, the interest is to verify if a given generating configuration will be able to supply the forecasted load demand for a specific year in the future. This evaluation has to consider unscheduled (i.e. forced followed by corrective maintenance) and scheduled (i.e. preventive maintenance) outages, load forecasting uncertainties and, most essential in renewable-based systems, the unavailability of energy sources, e.g., wind power.

The PJM method calculates the system risk index conditioned to a short period of time (a few hours), where the operator knows *a priori* the generating units available to take up, for instance, the peak load. In fact, it can be used for any period of time and, if considered together with generating costs, an optimal scheduling of the spinning reserve can be assessed [20]. Conversely, in the medium- and long-term running, the system operator does not know the exact set of generating units that will be available for each period of time and, therefore, all risk evaluations must account for the chronological evolution of the generating system. This sort of evaluation is well known for static reserve assessment [6], [19], but rarely mentioned in operation reserve [5]. Particularly with the increasing of wind power generation, the assessment of both static and operating reserves has to be accurately evaluated for the long-term horizon. The design criteria have to be re-discussed as well as the tools and methodologies [7], [9], [21].

D. Transmission System Flexibility Requirements

Another major paradigm, the flexibility of transmission systems, has been discussed related with the massive usage of renewable power production. Transmission lines are the critical link between generation and load consumption. As demand grows and generation is built in areas away from the load centers, more capacity on the transmission system is needed to meet the demand. In this sense, when wind sites and/or other renewable sources are installed, for instance, far from the demand, it is necessary to pay attention to the flexibility of the transmission system, which must be expanded to enable management of both uncertainty and variability of wind and/or other resources. On the other hand, wind power, solar photovoltaic, biomass, and others can eventually be connected near from the demand. Therefore, the concept of distributed generation (DG) must be also evaluated.

III. Proposed Methodology

In order to deal with wind and hydro power uncertainties and their respective time-dependent behaviors, as well as to represent the flexibility needed to cope with the synchronized reserve evaluation considering the impact of ramping rates in thermal units, and complex correlated load models, the proposed methodology is based on chronological Monte Carlo simulation. Therefore, the problem of calculating reliability indices is equivalent to the evaluation of the following expression [5], [8]:

$$\tilde{E}[F] = \frac{1}{NY}\sum_{n=1}^{NY} F(y_n) \tag{2}$$

where NY is the number of simulated years and y_n is a sequence of system states in year n. Each performance index can be estimated using a suitable test-function F. For instance, the energy not supplied will be the summation of unsupplied energy associated with each interruption of a simulated year. The convergence of the simulation process is monitored by using the coefficient of variation β [5], [8].

A. Generating Units and Load Representation

The selection of an appropriate model to represent the stochastic behavior of power system units is a critical requirement in the adequacy evaluation of generating systems. Essentially, two aspects should be represented to each technology: firstly, the up and down cycle (failure/repair) of each unit or set of units; and secondly, the power availability of each unit or set of units, considering their natural resources, such as water inflows, wind speed, solar irradiations, and others. The two-state Markov model [6] and the multi-state Markov model [5] will be used to represent the conventional generation technology with large units, such as thermal and hydropower plants, as well as DG technology with small units concentrated in farms or aggregations, such as wind power, solar central receiver or photovoltaic, small hydro generators, and others [5],[7]-[8]. The standard chronological load model containing 8760 levels corresponding to each hour of a year is used. The chronological MCS will sequentially follow these load steps during the simulation process.

B. Static Reserve Perspective

Traditional reliability studies on generation adequacy generally focus on generation static analysis, where the risk of not having enough capacity to meet the load is evaluated through a number of indices, for instance:

- LOLP – loss of load probability;
- LOLE – loss of load expectation (h/y);
- EPNS – expected power not supplied (MW);
- EENS – expected energy not supplied (MWh/y);
- LOLF – loss of load frequency (occ./y);
- LOLD – loss of load duration (h).

All these indices are obtained from the statistics of the simulation, but it should be stressed that it is also possible to obtain the probability distributions of random variables that are behind the average values [8]-[22]. This is an important feature of the chronological MCS that cannot be found in analytical or non-chronological simulation approaches. Finally, well-being indices can also be evaluated [8].

C. Operational Reserve Perspective

All previous risk indices are based on the following power balance equation:

$$PG^{Static}(t) - L(t) < 0 \tag{3}$$

where $PG^{Static}(t)$ represents the system available generation at time t and $L(t)$ is total load at time t. The random variable $PG^{Static}(t)$ depends on equipment availabilities and capacity fluctuations due to, for instance, hydrology and wind variations, etc. The random variable $L(t)$ depends on the short- and long-term uncertainties.

Similarly, for the operating reserve, more specifically the spinning one, all previous traditional indices can be obtained from the power balance equation (1), adapted as follows:

$$PG^{Synch}(t) - L(t) < 0 \tag{4}$$

where $PG^{Synch}(t)$ represents the amount of synchronized generation at time instant t. This random variable depends not only on the parameters previously mentioned, but also on start-up times of the generating units, operation strategies (dispatching function, etc.) and also on the pre-specified reserve criterion. The reserve criterion can be: (i) a percentage of the hourly load; (ii) a fixed amount; (iii) the largest synchronized unit, (iv) a combination of (i)-(iii). In the long-term operational planning, it is interesting to observe that the traditional rule-of-thumb methods can be used but their consequences in terms of risk along the analyzed year will be evaluated by the proposed methodology. In relation to the system operation strategy, any set of rules, as close as possible to the system operation, can be used such as: merit order list based on costs, start-up times, etc.

D. *Flexible Operational Reserve Representation*

In order to better evaluate the non-spinning reserve, and, consequently, to have a better depiction of this type of reserve in the system, four generation classes are considered bearing in mind the corresponding start-up times:

- Class 1 – Generating units that can be synchronized up to 10 minutes;
- Class 2 – Generating units that can be synchronized between 10 and 30 minutes;
- Class 3 – Generating units that can be synchronized between 30 and 60 minutes;
- Class 4 – Generating units with start-up times greater than one hour.

The ranges of these classes will depend on the system utility and they have received different designations such as: e.g. rapid start units, hot/cold reserve, flexible standing reserve, etc. Moreover, in some European countries [7], [21], bearing in mind the long-term planning of the operating reserve, spinning and non-spinning up to one hour (i.e. Classes 1-3) are treated together. In addition to the previous set of indices, the following indicators are proposed to measure the performance of the non-spinning reserve:

- ETP – expected total power reserve (i.e. spinning/synchronized and non-spinning) (MW);
- EP_{NS} – expected power of non-spinning reserve, per class (MW);
- EH_{NS} – expected number of hours per year (h/y) that the non-spinning reserve (per class) is nil; the unit could be in a synchronized mode or under repair;
- EF_{NS} – expected frequency in a period of one year (occ./y) that the non-spinning reserve (per class) is nil;
- EPR_{NS} – expected power per class of non-spinning reserve that is used to restore system failures (MW/occ.);
- EFR_{NS} – expected frequency per class of non-spinning reserve that is used to restore system failures (occ./y).

Other performance indicators could be defined to accurately measure the needs of a specific class of system reserve.

The proposed methodology and corresponding algorithm will be firstly applied on two real case studies involving both Portuguese and Spanish generation systems. In these cases, the concept of spinning and non-spinning up to one hour is assumed. Additionally, a modified configuration of the IEEE RTS-96 [8] to cope with hydro and wind power fluctuations is evaluated. In this case, the full flexibility of the previously proposed methodology to deal with different criteria in terms of reserve requirements is discussed.

IV. Application Results – First Part: Portuguese and Spanish Systems

In 2010, the Portuguese Generation System (PGS) had about 18 GW of installed capacity in which more than 25% was hydro. The thermal generation is over 40% of the total capacity installed highlighting the natural gas technology (21%), which has been increasing significantly, mainly due to the flexibility needs to cope with wind variations.

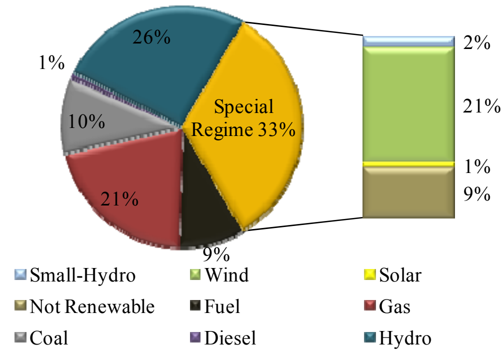

Fig. 2. Portuguese Generation System Share.

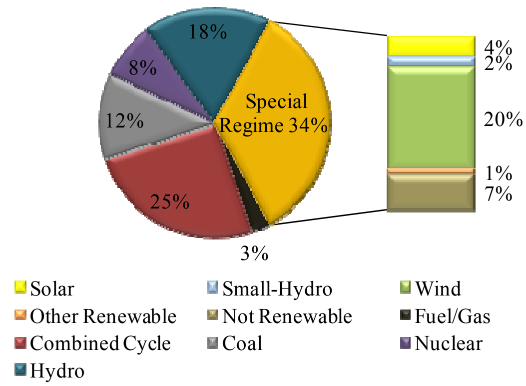

Fig. 3. Spanish Generation System Share.

Regarding “Special Regime”, it accounts for 33% of the total power capacity installed in Portugal, where wind power accounts for more than 20% of the total power capacity (see Fig. 2) [23]. Even in 2010, Portugal had already reached 9.229 MW of installed capacity for electricity generation from renewable energy sources. Hence, Portugal was, in 2008, the fifth country in the European Union (EU15) with the greatest incorporation of renewable production [24].

In 2010, the Spanish Generation System (SGS) increased about 3717 MW, resulting in 97447 MW of total installed capacity. This significant amount of generation capacity is strongly linked to the commitment of new renewable energy facilities, consisting of more than 1634 MW, where 1094 MW comes from wind generation and 540 MW comes from other renewable technologies (see Figure 3). However, in order to preserve the generating flexibility to deal with wind variations, an amount of 2154 MW of combined cycle power plants [25] was also installed. During this year, coal production decreased 13.6%, while fuel and gas production remained only 0.4% of the total energy production. Hydroelectricity increased 12.7% together with the share of renewable energies (12.6%), mainly due to solar thermal and photovoltaic sources, as well as wind production. Spain has 8 nuclear power plants placed over six different locations, which represent 8.1% of the total electric installed capacity.

Coal power plants produced 13.6% less than the previous year, due to the unusual diminishing of the expected demand and a restructuration of generating system with a large diffusion of renewable production [25].

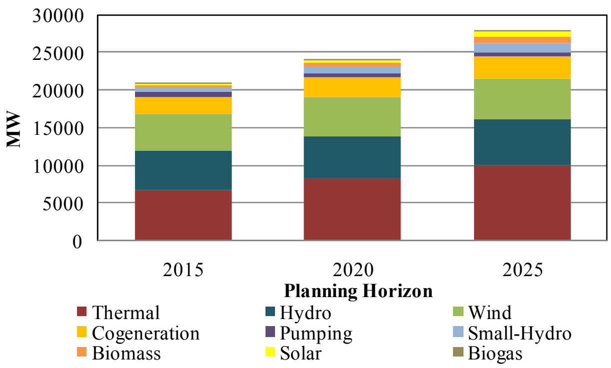

Fig. 4. Portuguese Generation System Evolution.

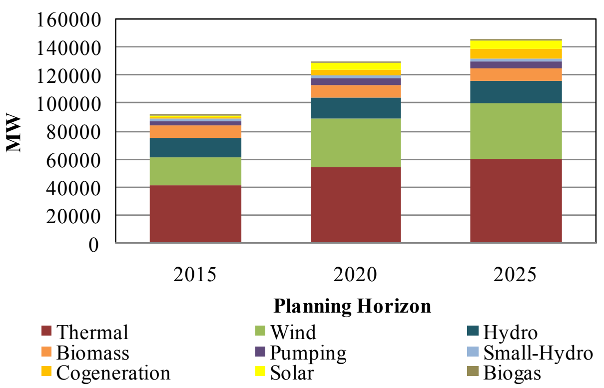

Fig. 5. Spanish Generation System Evolution.

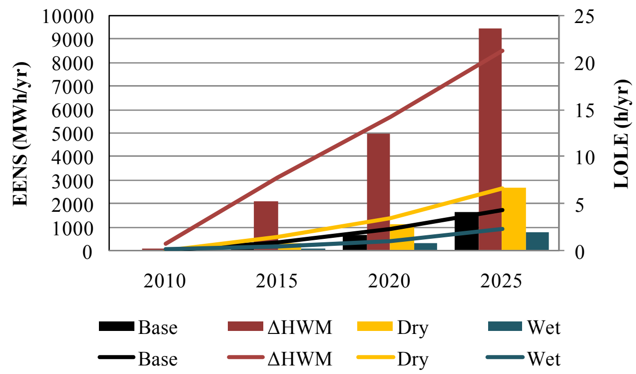

Fig. 6. Portuguese Generation System: Operating Reserve Performance.

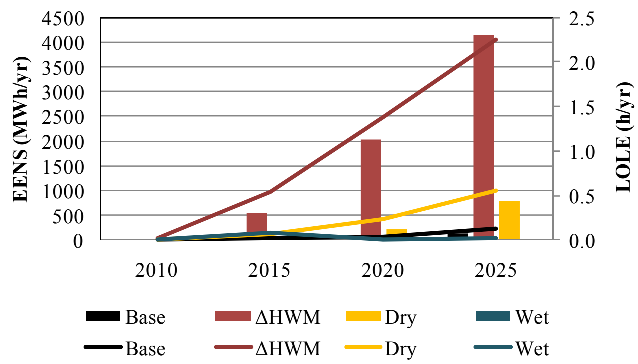

Fig. 7. Spanish Generation System: Operating Reserve Performance.

A. Evolution of Portuguese and Spanish Generating Systems

From 2015 to 2025, the PGS is expected to increase from 20592 MW to 27496 MW of installed capacity. The annual peak load is foreseen to increase from 12716 MW to 17962 MW. In 2015, the thermal installed capacity will represent 33% of the total PGS installed capacity, divided into coal-fired and natural gas, which will mainly replace oil-fired technology, and ensure flexibility to cope with wind variation. Hydropower is expected to represent 25% of the total installed capacity. Wind power is expected to have 24% of the installed capacity. Cogeneration share stays at 11% and pumping stations will increase 2%. Both hydro power and thermal power decrease slightly their share in the global mix. Figure 4 shows the evolution of the PGS up to 2025, where the 2015 trends remain the same.

From 2015 to 2025, the SGS is expected to increase from 106287 MW to 139257 MW of installed capacity. The annual peak load is foreseen to increase from 59100 MW to 75644 MW. In 2015, the thermal installed capacity will represent 46% of the total SGS installed capacity, divided into coal-fired and natural gas, which will mainly replace oil-fired technology, to ensure flexibility to cope with wind variation. The nuclear sub-system will remain with 8 stations. Hydroelectricity by the SGS is expected to represent 15% of the total capacity. Wind power represents 21% of the installed capacity. Cogeneration share stays at the same level and pumping stations will increase 3%. Figure 5 shows the evolution of the SGS up to 2025, where the 2015 trends remain the same, with the exception of solar technology, which will increase 3% in 2020, and nuclear technology that will also increase in 2025.

B. PGS and SGS - Results and Discussion

Different scenarios for the PGS and SGS were exploited. For the Base case, all historical hydrological and wind series were simulated. In the Wet case, the wettest hydrological year was considered, and in the Dry case, the driest hydrological year was simulated. The ΔHWM case considers that the driest hydrological condition occurs simultaneously with all observed wind series having their capacities reduced by 50%. Also, the usual amount of power on maintenance was increased by 20%. Certainly, this is a very severe scenario.

Figs. 6 and 7 show the evaluation of LOLE and EENS operating reserve indices for both systems, considering the planning horizon. As it could be expected, the worst condition occurs for the "ΔHWM" scenario, not only for LOLE indices, but also for the EENS indices on both systems.

It should be mentioned that the operating reserve performance for the PGS shows an interesting result in 2010: the LOLE of 0.2760 h/y for the ‘‘Wet” scenario is greater than the LOLE of 0.1107 h/y to the "Dry" scenario. This is due to the commitment of more hydro units to meet the load, with a negative influence on the tertiary reserve (Classes 1 to 3). Therefore, if all three classes are grouped into a tertiary reserve, it is hard to identify the lack of specific non-spinning reserve and also the corresponding effect on generation flexibility. This effect was not observed in other PGS future scenarios

In the case of the SGS, one can provide the following interpretation for the 2010 configuration: if everything goes wrong (ΔHWM case) in terms of operational reserve, the SGS will stay in a very good condition, where LOLE is 0.02577 h/y and EENS is 15.7 MWh/y.

V. Application Results – Second Part: Flexible Operational Reserve Approach

As previously stated in Section III, to evaluate the non-spinning reserve through the flexibility point of view, four generation classes are considered bearing in mind the corresponding start-up times of generating units. Hence, the discussed methodology, which considers an improvement on the assumption of one hour to the fast tertiary reserve, is used. For the purpose of this paper, a modified version of the IEEE-RTS 96 [8] is evaluated. The IEEE-RTS hourly load model is also used.

A. IEEE-RTS 96 HW Generating Systems

The original configuration of the IEEE-RTS 96 [10] consists of 96 generating units divided into five different technologies with a total installed capacity of 10215 MW and the annual peak load of 8850 MW. In this configuration, static reserve corresponds to 16.3% of the total installed capacity, a value that should be noted. Renewable energy consists of only 8.8%, held by 900 MW on hydro power plants. In order to deal with renewable variations, a modified version of this test system named "IEEE-RTS 96 HW" is used and can be found in [8]. The main changes consists of the inclusion of hydro power fluctuations over the year and the replacement of the 350MW unit of coal for 1526 MW of wind power, increasing the total installed capacity from 10215 MW to 11391 MW.

B. IEEE-RTS 96 HW – Results

For this configuration, where the renewable power accounts for 21% of the installed capacity, several tests were carried out with different merit orders and pre-specified reserve levels. In this case, two scenarios are analyzed: *normal*, where all hydro and wind series are considered, and *critical*, where only the worst hydrological series is considered simultaneously with the worst wind series.

Tables I shows the traditional reliability indices for the static reserve capacity of the IEEE RTS-96HW. Under the normal scenario, it can be observed that the substitution of the coal thermal unit (350 MW) by 763 wind units of 2 MW has slightly improved the reliability indices; the LOLE index is reduced from 0.5834 h/y to 0.3449 h/y. Although 1526 MW of wind installed capacity represent, on average, circa 350 MW, due to the capacity fluctuation, the system becomes slightly more reliable because there are several small generating units instead of only a big one. Clearly, capacity equivalent systems do not mean adequacy equivalent systems. In case the critical scenario occurs, there will be a slight deterioration of the static reserve indices due to the combined effect of both worst (hydro and wind) conditions.

Table II shows the conventional reliability indices now applied to the spinning reserve. Also, in this case, a minimum level of reserve of 400 MW (scheduled 24 hours ahead) is kept all over the year. Any pre-set schedule could be accomplished. In addition, a merit order based on the production costs is used, except for four hydro units that are shifted to the end of the list, in order to have more rapid start units available as Class 1 reserve. The effective amount of spinning reserve will vary from 599.6 up to 1119MWdue to several factors: discrete size of the units, start-up times, load shape, etc.

Table I
Conventional Reliability Indices – Static Reserve: IEEE RTS-96HW

Scenario	LOLE (h/y)	EENS (MWh/y)	LOLF (occ/y)	LOLD (h)
Normal	0.3449 (3.35%)	65.20 (5.00%)	0.1239 (2.64%)	2.783 (4.07%)
Critical	1.484 (3.54%)	294.7 (5.00%)	0.4937 (2.76%)	3.006 (4.30%)

Table II
Conventional Reliability Indices – Spinning Reserve: IEEE RTS-96HW

Scenario	LOLE (h/y)	EENS (MWh/y)	LOLF (occ/y)	LOLD (h)
Normal	8.295 (3.53%)	1743.0 (4.91%)	3.358 (2.04%)	2.470 (3.96%)
Critical	23.60 (3.08%)	5686.0 (4.68%)	7.584 (3.16%)	3.111 (4.32%)

Table III
Indices for Non-Spinning Reserve: IEEE RTS-96HW

Reserve Class	ETP (MW)	EP_{NS} (MW)	EH_{NS} (h/y)	EF_{NS} (occ/y)	EPR_{NS} (MW/ occ)	EFR_{NS} (occ/y)
Normal						
1	1025.	173.8	49.88	18.45	137.9	0.4321
2	0.0	0.0	8760.	1.0	0.0	0.0
3	2327.	215.5	79.49	26.56	40.0	0.0063
4	6047	2937	0.7139	0.1988	0.0	0.0
Critical						
1	775.8	171.6	108.6	32.64	135.4	0.4170
2	0.0	0.0	8760.	1.0	0.0	0.0
3	2327.	212.9	160.4	44.35	20.26	0.0090
4	6047.	2687.	1.669	0.4020	0.0	0.0

Under the critical scenario, the system presents an index LOLE associated with the spinning reserve of 23.60 h/y. On average, 5686 MWh will be lost per year due to lack of synchronized generation. Moreover, these interruptions will occur about 7 times per year and the corresponding duration will be of approximately 3 hours.

Table III presents the indicators for the non-spinning reserve. As it can be noted (see [8] for complete understanding), the performance of the non-spinning reserve indices is similar to those obtained before adding wind power. This behavior could be expected since all wind power units are used whenever the wind is sufficient to produce electrical energy.

The previous results demonstrated that the use of reliability indices, normally obtained from a conventional static capacity reliability assessment, can be tailored for evaluating the performance of the synchronized power in any generating system. The basic probabilistic concept is to balance the system power considering only the spinning capacity. Moreover, the non-spinning reserve capacity can also be evaluated by some measures of interest to assist system planners to take adequate decisions. The proposed analysis framework can better ensure capacity values of these renewable power sources. A complete discussion on innovative planning criteria can be found in [8].

VI. Conclusions

Renewable energy technologies will take a greater share of the electricity generation mix in order to minimize the dependence on oil and the emission of CO2. While contributions from renewable energy sources for electricity production are modest, with the exception of hydro, their market penetration is growing at a much faster rate than any conventional source. More renewable power sources cause, however, an increase in the number of random variables and operation complexities in the system, due to the intermittent nature of these sources.

Therefore, the determination of the required amount of system capacity and operating reserves to ensure an adequate supply becomes a very important aspect of generating capacity expansion analyses.

The dimensioning of operating reserve, spinning, and non-spinning, plays an important role in systems with high penetration levels of renewable sources, mainly those from wind power, due to its natural volatility. Although there are many reference values for LOLE indices related with static capacity analysis, there are no such standards for operating reserve, spinning and non-spinning, indices.

As dealing with medium- and long-term planning, it is not possible to ensure which generating units will be available (due to their failure/repair rates and start-up times) and also the capacity of these units, particularly those that depend on renewable power such as wind sources. Moreover, for a given pre-specified criterion, the assessment of reserve requirements has to cover wider ranges, (e.g. each year of the planning period) to provide planners with a better picture of their problem. Finally, the non-spinning reserve has also to receive the appropriate attention to cope with the complete set of decisions that have to be taken regarding generation flexibility.

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