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Models for HLI analysis of power systems with offshore wind farms and distributed generation

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***Abstract* - This paper focuses on reliability assessment of power systems with large wind installations. Due to the variability of the wind and the availability of components, reliability of wind farms is relevant both to its design and to investigate its influence on the energy balance of the whole system. Furthermore, a power system must keep a high level of reliability in order to meet the demand satisfactorily. A model for generation adequacy analysis is therefore presented, including components such as conventional power plants, distributed generation and offshore wind farms. Particular attention is paid to the latter aspect, since many factors affect it. The assessment is performed by a sequential Monte Carlo simulation, and results for different power systems are presented in the form of indices and probability distributions. These results can be used for preliminary assessment of power system reliability and as reference for more detailed analyses with the inclusion of transmission facilities.**

***Index Terms* - Monte Carlo methods, power generation reliability, power system simulation, wind power generation.**

I. INTRODUCTION

DUE to the increasing influence of offshore wind generation on power system operation and planning, a growing interest is paid to new models and techniques to analyse the behaviour of power systems when large wind installations are connected. One of the fields of interest refers to reliability: a power system must be able to supply the demand at any time with the required amount of power, but failure of components and availability of generation (e.g. renewable sources) may prevent the power system from performing this task satisfactorily.

This paper deals with this issue considering models and techniques to assess the generation adequacy of a power system, including renewable sources in the form of both onshore and offshore wind generation. In available literature, different models have been developed for performing this evaluation [1]-[4], but there is a lack of models of offshore wind farms, which introduce new issues for their representation, due to some new aspects such as the environment and the size of the wind farms.

In this paper, a sequential Monte Carlo simulation is described in order to perform the mentioned analysis, considering models for representing different components that are part of the system (e.g. conventional power plants, CHP generation, onshore and offshore wind farms). In section II, the used method is described, whereas in section III, models developed for different components are presented. In particular, a detailed representation of offshore wind farms is provided. Section IV shows some applications of the approach: in order to verify the model, the Roy Billinton Test System (RBTS) and the IEEE-Reliability Test System (IEEE-RTS) are analysed and results compared to available references. Moreover, the approach is applied to the West Denmark Power System (WDKPS) in order to assess its reliability and to show how models of distributed generation and offshore wind farms can be efficiently included in this type of studies. In section V, some conclusions are made.

II. APPROACH DESCRIPTION

In this paper, Hierarchical Level I (HLI) reliability evaluations of different power systems are performed. This type of analysis is also called “Generation adequacy assessment” [1] and it mainly consists of investigating if the installed generation is sufficient to satisfy the system demand, neglecting both transmission and distribution facilities. Generation is represented considering the aspects which may cause its unavailability, such as outages and lack of its “fuel” (e.g. renewable sources).

Regarding usable techniques, in available literature (e.g. [1]) probabilistic approaches are more considered today for this kind of analysis, due to the many stochastic aspects that influence operation and planning of power systems. It is possible to distinguish two types of probabilistic solutions: one based on analytical methods and one on Monte Carlo simulations. Both approaches present advantages and drawbacks and they can be very powerful with proper application. In this paper, all analyses are performed with a sequential Monte Carlo simulation. On the one hand, this technique is more flexible, especially when wind generation is included, and distribution functions of reliability indices might be obtained as well [5]. On the other hand, long computation

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time is usually required.

A general procedure of a sequential Monte Carlo simulation is used in this paper as the one described in [5]. Results are presented in the form of probability distribution functions and reliability indices [1] such as Loss Of Load Frequency (LOLF, [occ/y]), Loss Of Load Expectation (LOLE, [h/y]), Loss Of Energy Expectation (LOEE, [MWh/y]) and Duration Of Interruption (DOI, [h/occ]).

III. Models of System Elements

In order to perform a sequential Monte Carlo simulation, it is necessary to represent all different components that are part of the power system under analysis. In this paper, particular attention is paid to conventional power plants, onshore and offshore wind parks, CHP distributed generation and the load. Transmission and distribution facilities are neglected as normally done in HLI analysis. In case of WDKPS, also interconnections to neighbouring countries are not included in order to investigate the ability of the power system to operate as a stand-alone system.

A. Conventional Power Plant

Conventional power plants are represented as a two- or a multi-state model, depending on the ability of the considered power plants to operate in derated states and on the available information. In case of the IEEE power systems, two-state models are used, with the representation shown in Fig. 1.a): each plant might be either in full operation (state 1) or out of service (state 2) [1].

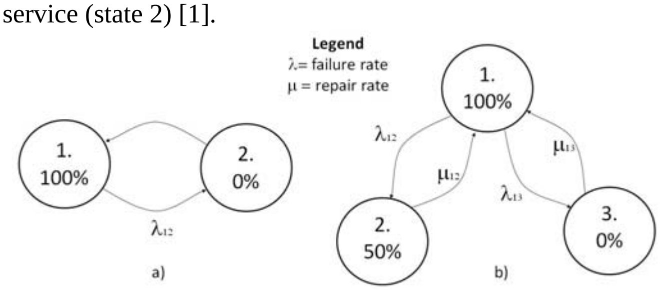

Fig. 1. Two- and three-states model for reliability representation.

In case of the WDKPS, some power plants are modelled as a three-states element (Fig. 1.b)): the generation can be fully available (state 1), 50% available (state 2) or out of service (state 3). In the present model it is assumed that states 2 and 3 are not connected, which means that a power plant operating at 50% rated capacity can only be repaired and not become completely unavailable. This is chosen due to the lack of information about possible connections between states 2 and 3.

B. Offshore Wind Farms

The model for offshore wind farms presented in this section has been discussed in [6], and a few comments are repeated here. In this reference, some factors that influence the output of offshore wind generation are presented, such as

1. Wind speed's randomness and variability
2. Wind turbine technology
3. Power collection grid in the wind farm
4. Grid connection configuration
5. Offshore environment
6. Different wind speeds at the installation site
7. Hub height variations
8. Wake effects and power losses.
9. Correlation of output power for different wind farms

These factors influence the model in different ways, since they are applied to different elements of the wind farm. Factors 1 and 7 play a relevant role in the definition of wind speed. Factors 2 to 4 depend on the choice of the components (wind turbine and cables). Finally, the other aspects either influence both wind speed and components definition (e.g. factors 5, 6 and 8) or they become necessary when several installations are connected to the power system (factor 9).

These factors have to be included in the model in order to assess the wind generation in a complete way. In general, a model for wind generation consists of four blocks (**Fejl! Henvisningskilde ikke fundet.**): inputs to the model are wind speed data (block a.) and component availability figures (block b.). The wind farm layout (block c.) collects the inputs, and the output results are calculated by sequential Monte Carlo simulation (block d.).

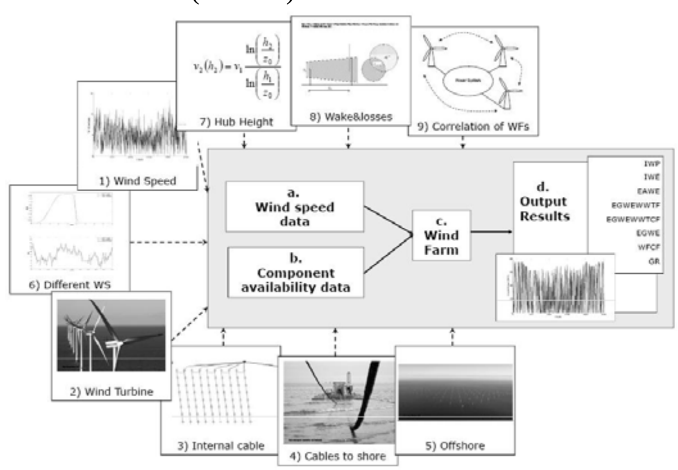

Fig. 2. Offshore wind farm model with influencing factors for reliability studies [6].

Outputs of the model can be in the form of both reliability indices and chronological output power: the latter is useful to evaluate the wind generation in each hour of the year, and it may be used as input for power system reliability analysis. The former provides a quantification of the yearly production of the wind farm: some commonly-used indices are [5], [6]

- Installed Wind Power (IWP, [MW]) is the sum of the rated power of all the installed wind turbines
- Installed Wind Energy (IWE, [MWh]) is the product of the installed wind power and the number of hours in the period
- Expected Available Wind Energy (EAWE, [MWh]) is the generated energy without accounting for wind turbine, cable and connector outages
- Expected Generated Wind Energy (EGWE, [MWh]) is the sum of the energies that all the available wind turbines can produce in the period, including wind turbine, cable and connector failures

- Wind Farm Capacity Factor (WFCF, [-]) is the ratio of EGWE to IWE
- Wind Farm Generation Ratio (WFGR, [-]) is the ratio of EGWE to EAWE.

In **Fejl! Henvisningskilde ikke fundet.**, the nine discussed factors are graphically shown together with the four blocks. In order to include each of the nine factors into the model, different approaches and assumptions have to be considered as discussed in the rest of this section. Further details are available in [6].

- Wind speed data (factor 1) present variability and randomness, which must be preserved when the generation of a wind farm is assessed. A solution for this may consider the use of available wind speed measurements: in this way it is not necessary to further manipulate the data, but the measurements must be long enough (i.e. several years) in order to correctly represent the wind conditions in the site of analysis. Another approach may consider the use of a synthetic wind speed generator. Different models are available in literature for creating synthetic wind speed generators: some based on ARMA models (e.g. [4]) and others on Markov chains (e.g. [7]). The main difficulty using these models is preserving the correlation between wind speeds of different locations. For this reason, the approach followed in this paper is to use the wind time series from the regional climate model REMO, provided by Max Planck Institute for Meteorology, Hamburg, Germany [8]. Data used here are hourly values from 1979 to 2003, at the resolution of approximately 50 km, covering the entire Europe continent: for a complete description see [8], [9]. For the work presented here, a 13x13 grid points, located over and around Denmark are used: a representation of it, with wind speed average for year 2000 and some offshore wind farm locations used as reference (Horns Rev, Middelgrunden and Nysted) are shown in Fig. 3.a). In this figure, it is possible to note how the wind speed average varies on shore and off shore: the shape of Denmark can be recognized in the middle-bottom part of Fig. 3.a), which represents low average wind speed locations. Average wind speeds increase moving away from shore and the highest average values are reached on the left side of the figure (light areas i.e. the North Sea).
- Regarding components' availability figures (factors 2, 3, 4), it must be highlighted that only few data are currently available for offshore wind farm components due to their recent development. In order to overcome this problem, several available works [10]-[12] have presented offshore figures, which are "guessed" from onshore reliability data. Reference [10]-[12] agree on expecting an improvement of offshore components' availability in order to compensate the negative effect of additional aspects, which are an issue off shore, but which do not affect onshore installations. Some of the reliability figures used in this paper are shown in Table II. Furthermore, the choice of a certain wind turbine causes its availability to be lower or higher, depending on the type of technology, and its power curve to be more or less efficient for different wind speeds. Considering the modelling of wind farm components, a two-states representation is used for both wind turbines and cables (see Fig. 1.a)): this approach is normally followed in available literature (e.g. [2], [3]) and it can be assumed to be suitable for the purpose of the analysis.

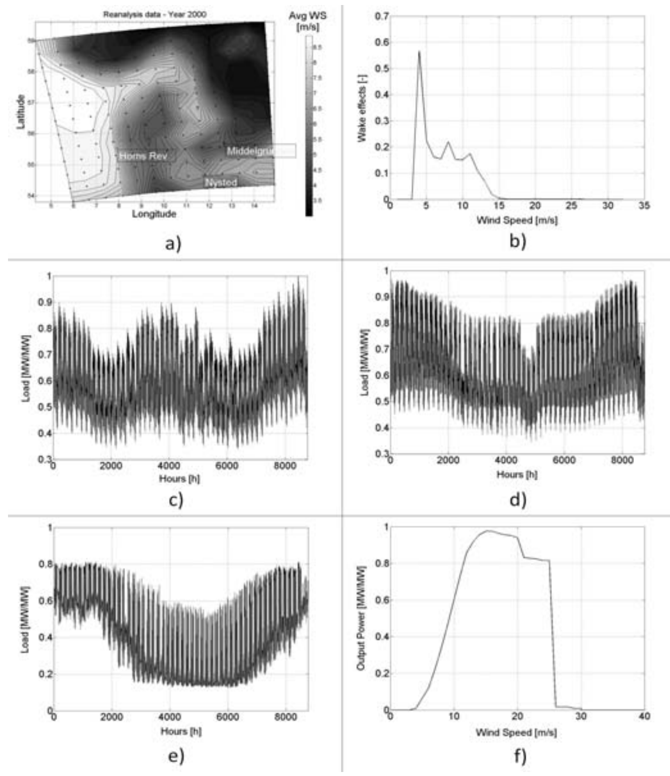

Fig. 3. a) Reanalysis data for year 2000 (13x13 grid points) [8]; b) Horns Rev's wake effects as a function of the wind speed [13]; c) Aggregated normalised load curve for IEEE test systems [1]; d) Aggregated normalised load curve for WDKPS; e) Aggregated normalised curve for CHP distributed generation; f) Aggregated normalised power curve for the wind distributed generation in west Denmark [14].

Due to the large dimensions of offshore wind farms (factor 6), it might be possible that the wind speed does not have the same instantaneous value at each wind turbine. This aspect is negligible for small wind farms, but it can assume a large influence otherwise. In this paper, since the wind speed of the Reanalysis database are defined over an area, it is assumed that they can represent an average wind speed input for the entire set of wind turbines.

- Values of wind speed are usually measured at a certain altitude, where the measurement equipment is installed (factor 7). If the mast height is close to the hub height, data can be directly used for further calculations, but if the difference between the two heights is large, measured wind speed should be scaled [3]. There are different formulae that can be used for this purpose, but the most common one is based on a logarithmic scaling, as presented in [14]. A roughness length equal to 0.0001m (open sea) is used [16].
- Wake effects and electrical losses reduce the total output of a wind farm. An efficiency coefficient that includes both aspects and depends on wind direction, number of wind turbines, their spatial arrangement and wind farm layout is

usually defined [2], [3] with a value equal to 90-95%. However, the use of a single value is a limitation since both aspects depend on the current wind speed that blows through the wind farm. For this reason, in this paper, both wake effects and power losses are considered as a function of the wind speed. The latter is obtained from information on Horns Rev, whereas the former is obtained from [13] and displayed in Fig. 3.b).

- If the wind power is generated in different locations, correlation among different outputs must be taken into account in order to avoid mismatch in the total generation of the system. The correlation is always lower than 1 and it decreases with the distance between locations: its definition depends on several factors such as local climatic and topographical characteristics, and it is difficult to fully represent. There are many works referring to this issue and different methods have been followed. In this paper, the correlation of wind speeds in different locations is preserved in the Reanalysis database.

For the calculations presented in this report, the model of offshore wind farms has been built according to the discussed factors: further considerations and implementations are provided in section IV.

C. Aggregated Load

An aggregated load is modelled as a yearly time series based on hourly steps. The same curve is used in each sample of the simulation since it can be assumed that the load has the same behaviour in different years, as stated in [1].

In cases of IEEE power systems, the load curve is defined according to daily, weekly and seasonal peaks, as provided in [1]. The normalised load curve is shown in Fig. 3.c).

For the WDKPS, an aggregated load curve is extracted from the yearly load curve available in [17], where the yearly load time series of the power system is available between years 2000 and 2006. From these data, each hour of the year is defined as an average of available information, depending on the date on which it occurs (holidays, working days, weekends, night and day). The obtained normalised curve is presented in Fig. 3.d).

D. Distributed CHP generation

CHP generation is distributed around the country in the Danish power system, it is connected to medium voltage (60kV) busbars, and it has nearly similar variations in different years, as shows in [17]. For this reason, the same approach used for the load in section III.C is utilized here. An aggregated normalised yearly time series with hourly steps (Fig. 3.e.)) is obtained from available measurements for years 2000-2006 [17].

E. Wind Distributed Generation

Onshore wind distributed generation (WDG) is arranged in the Danish power system as CHP installations, even if each wind generation is dependent on the wind blowing at each site, and it is therefore not possible to extract an average aggregated curve valid for all years, as in the previous section. A different approach is therefore considered, using the Reanalysis database and an average wind power curve (Fig. 3.f)), which can be considered a proper representation for WDG of the western part of Denmark [14]. The power curve is used for each busbar of the network (the installed capacity is known in each busbar [18]), whereas different input wind speed time series are applied to each site, depending on the available information from Reanalysis. The normalised curve for each year is obtained summing up the hourly generation at each busbar. In this way, the correlation among outputs of different locations is preserved in the total curve.

IV. Applications

In this section, the discussed method is applied to different power systems. In section IV.A, the two IEEE power systems are analysed in order to show how the method operates and to verify its validity with some results available in literature. In section IV.B, the reliability of WDKPS is assessed in order to show how the full model of the power system can be implemented and analysed. Some sensitivity studies are considered as well for this case in order to investigate the reliability response of the power system when some of its parameters are changed.

A. IEEE power systems

The purpose of this section is to show how some of the described methods are applied to a power system and to compare some obtained results with the ones available in literature. Two power systems are considered for testing the method: the RBTS [1] and the IEEE-RTS [19]. Both power systems have been defined in order to provide base cases for reliability analyses and for results comparison. Power systems data are available in [1], [19] and further details are not provided here. In both power systems, several power plants are considered, some with thermal nature, other using gas turbines and other based on hydro sources. However, for the purpose of the presented work and to help along the verification, no energy limitations are considered for any type of plant, which means that hydro power plants are considered to be conventional power plants and therefore able to generate at any time, if available. For the same reason, maintenance issues are not included in the presented results. Furthermore, both power systems do not have WDG and CHP generation.

The results are shown in Table I for both power systems with the indices defined in section II. In each case, results both available in literature and computed with the described approach are presented. Besides, time for the simulation, number of samples and reached coefficient of variation (row “C. Var.”) are included as well.

Observing the table, it can be noted that computed results are similar to the ones available in literature. Due to the nature of the approach considered, it is not possible to calculate exactly the same values: Monte Carlo simulations never provide exact results due to the different sequences of random numbers used in different simulations.

Due to the lack of information about the accuracy reached in literature, it is not possible to provide a complete comparison of the results, but closeness of results may suggest similar behaviour. Instead differences between coefficients of variation in the two computed cases can be justified considering that RBTS shows several years without any loss of load, which makes the convergence of the simulation more unstable and therefore more samples are needed.

TABLE I
MODEL VERIFICATION WITH THE TWO IEEE TEST SYSTEMS

Indices	Unit	RBTS		IEEE-RTS	
		Ref [1]	Sim.	Ref [4]	Sim.
LOLE	h/y	1.1282	1.1487	9.3716	9.4879
LOEE	MWh/y	10.311	10.126	1197.445	1186.281
LOLF	occ/y	0.2194	0.2307	1.9192	1.9253
DOI	h/occ	5.1414	4.9788	-	4.9280
Sample	-	-	20000	-	20000
Sim. time	s	-	11611	-	21689
C. Var.	%	-	3.97	-	1.69

According to the presented results and the given considerations, the model is assumed verified and it is further used in the next section for the analysis of WDKPS.

B. West Denmark Power System

The power system in West Denmark consists of 11 conventional power plants (3579MW of installed capacity), CHP and wind distributed generation (1600MW and 2200MW respectively), one offshore wind farm, Horns Rev (160MW), and a yearly peak load equal to 3737MW (2007). Availability data for conventional power plants are extracted from the real history of the plants as measured for the interval 2000-2007 by DONG Energy, whereas data for offshore wind farm components are obtained from [10]-[12] and shown in Table II.

TABLE II
WIND FARM COMPONENTS' DATA [10]-[12]

	Length	Failure rate	MTTR	Availability
Wind turbine	-	1.10-1.55 1/y	310–490 h/y	92-96 %
Int. cable	(0.7 km)	0.015 1/y/km	1440 h/y	99.83 %
Connector	(21 km)	0.015 1/y/km	1440 h/y	99.75 %

Since wind speed data of the Reanalysis database are available at 10m, the logarithmic transformation of [15] is used in order to scale the wind speed of Horns Rev to 100m and the wind speed of each onshore wind distributed generation to 39m with a roughness length equal to 0.01m. This last value is obtained empirically in order to have the total yearly wind energy similar to the real one measured for years 2000-2006 in [17].

The calculation is performed by using a sequential Monte Carlo simulation with a fixed number of samples equal to 10000. Three different cases are analysed (Table III)

1. A basic case, as described at the beginning of this section
2. A case with more reliable wind turbines
3. A case with higher WDG capacity.

The purpose of analysing different cases is to investigate how the variation of some parameters in the power system influences its reliability.

Results are presented in Table IV and Table V: in the latter, the reliability assessment of WDKPS is shown, whereas in the former, the generation of Horns Rev can be seen. Computation time of each simulation is approximately equal to 48100s, and the accuracy reached after 10000 samples is equal to 6.3%.

TABLE III
CASE DEFINITION

		Case 1	Case 2	Case 3
WT Failure rate	1/y	1.55	1.10	1.55
WT MTTR	h	490.83	310.00	490.83
WDG variation	%	100	100	110

TABLE IV
HORNS REV GENERATION ASSESSMENT

Indices	Unit	Case 1	Case 2	Case 3
IWP	MW	160	160	160
IWE	GWh	1401.6	1401.6	1401.6
EAWE	GWh	664.187	664.188	664.187
EGWE	GWh	585.669	609.665	585.669
WFCF	-	0.421	0.435	0.421
WFGR	-	0.883	0.917	0.883

TABLE V
FINAL RESULTS FOR THE WDKPS' RELIABILITY ANALYSIS

Indices	Unit	Case 1	Case 2	Case 3
LOLF	occ/y	0.1531	0.1544	0.1484
LOLE	h/y	0.3929	0.3951	0.3779
LOEE	MWh/y	48.0421	48.2990	46.1598
DOI	h/occ	2.5663	2.5589	2.5465

Comparing results in Table IV, it can be noted that the offshore wind farm included in the model behaves as expected. When availabilities of the components are improved (case 2), the wind farm increases its generation (i.e. EGWE) in a way which is proportional to the improvements of the component's availability (e.g. wind turbine availability improves by 4%, so does index EGWE). An opposite behaviour can be expected when the availability of the wind turbines is decreased.

Case 2 also shows that the increase of wind farm generation does not affect the total reliability of the power system (Table V). This can be expected considering that the installed capacity of Horn Rev represents a small portion of the total installed generation capacity in the system (approximately 2%). In order to observe the influence of these small variations in the wind farm on the total reliability, it is necessary to have a larger offshore generation. It must be finally highlighted that the differences of indices between case 1 and case 2 in Table V are due to the fact that a Monte Carlo simulation is performed and, as mentioned before, exact results can never be obtained.

When the total amount of WDG is changed in the system (case 3), it is possible to note a different behaviour in comparison to the other cases. Variations in WDG do not influence the offshore production, whereas power system reliability is affected. This is reasonable, considering that the original installed WDG capacity is equal to 2200MW, which represents almost 31% of the total installed capacity, and its variation may very well influence the response of the system to failures. An increase of WDG equal to 10% shows an improvement of the total reliability indices between 3% for LOLE and 4% for LOEE. An opposite behaviour can be expected if WDG capacity is decreased.

Finally, probability distribution functions of different indices can be observed in Fig. 4. For the three cases in Table III, the probability distribution function for index EGWE is shown for the wind farm (a), whereas plots for Energy Not Supplied (ENS), Frequency Of Interruption (FOI) and Duration Of Interruption (DOI) in each sample are presented in b), c) and d) respectively. It can be seen that when varying some parameters of the system, its response varies accordingly, e.g. EGWE distribution is shifted to higher values (left) comparing cases 1 and 2. In the other three plots, the same probability distribution can be observed in all cases: this is reasonable, considering that the same random sequence is used in all three simulations. Whereas cases 1 and 2 have the same values, values in case 3 are smaller: this cannot be seen in Fig. 4, but it is clear observing Table V.

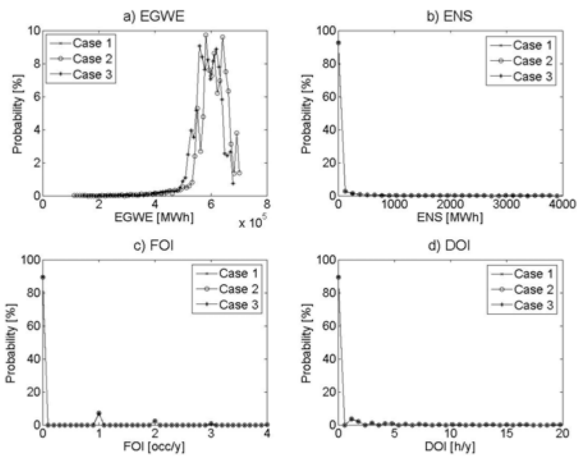

Fig. 4. Probability distribution functions of different reliability indices.

The presented analyses show how the described model can be used to assess the reliability of a power system with different kinds of generation. Different aspects have been included and the influence that different parameters have on the analysis is shown as well.

V. Conclusion

Wind generation has assumed an increasing relevance in power system operation and planning. Variability of wind and component availability may influence operation and planning of the system, and an important correlated issue is system reliability. This paper focuses on this aspect: models of different components (conventional power plants, offshore and onshore wind generation and CHP plants) for reliability analysis are presented, and a sequential Monte Carlo simulation is applied to them in order to assess power system reliability for an HLI analysis. The approach is applied to different test systems from IEEE for verification purposes, and a complete assessment is performed on WDKPS where all the described models are included. Presented results show that the choice of certain components (i.e. their availability) influences the reliability of a power system: besides, if the installed wind capacity is relatively small compared to the rest of the generation, its influence on the power system reliability is marginal. However, it is expected that its influence might increase if wind installation increases in size and penetration. Results of this analysis can be interesting in order to investigate the reliability of the power system from the HLI point of view and as input values for more detailed analysis, including transmission facilities (e.g. HLII analysis).

VI. References

[1] R. Billinton, and R.N. Allan, *Reliability Evaluation of Power Systems*, 2nd ed., Plenum Publishing Corporation, New York, USA, July 1996.

[2] F. Castro Sayas, and R.N. Allan, "Generation availability assessment of wind farms", *IEE Proceedings – Generation, Transmission and Distribution*, Vol. 143, No. 5, pp 507-518, Sept. 1996.

[3] J.R. Ubeda, and M.A.R. Rodriguez Garcia, "Reliability and production assessment of wind energy production connected to the electric network supply", *IEE Proceedings – Generation, Transmission and Distribution*, Vol. 146, No. 2, pp 169-175, Mar. 1999.

[4] Hua Chen, "Generating System Reliability Optimization", Ph.D. dissertation, Dept. Elect. Eng., University of Saskatchewan, Saskatoon, Canada, Fall 2000.

[5] N. Barberis Negra, O. Holmstrøm, B. Bak-Jensen, and P. Sørensen, "Comparison of different techniques for offshore wind farm reliability assessment", *in Proc. Sixth International Workshop on Large-Scale Integration of Wind Power and Transmission Networks for Offshore Wind farms*, Delft, The Netherlands, Oct. 2006.

[6] N. Barberis Negra, O. Holmstrøm, B. Bak-Jensen, and P. Sørensen, "Wind farm Generation Assessment for Reliability Analysis of Power Systems", *Wind Engineering*, Volume 31, No.6, pp 383-400, Dec. 2007.

[7] N. Barberis Negra, O. Holmstrøm, B. Bak-Jensen, and P. Sørensen, "Model of a synthetic wind speed time series generator", *Wind Energy*, Volume 11, Issue 2, pp 193-209, Mar./Apr. 2008.

[8] D. Jacob, and R. Podzun, "Sensitivity studies with regional climate model REMO", *Meteorology and Atmospheric Physics*, 63, pp 119-129, 1997.

[9] X. Larsen, J. Mann, H. Goettel, and D. Jacob, 'Wind climate and extreme winds from the regional climate model REMO', in *Proc. of EWEC 2008*, Brussels, Belgium, Mar./Apr. 2008.

[10] G.J.W. van Bussel and M.B. Zaarijer, "Reliability, Availability and Maintenance aspects of large-scale offshore wind farms, a concepts study", *in Proc. MAREC 2001*, Newcastle, England, 2001. Available: http://www.ecn.nl/wind/other/dowec.html (last visit Apr. 2008).

[11] A. Sannino, H. Breder, and E. K. Nielsen, "Reliability of collection grids for large offshore wind parks", in *Proc. 9th International Conference on Probabilistic Methods Applied to Power Systems*, Stockholm, Sweden, June 2006.

[12] Dowec Team, "Estimation of turbine maintenance figure within the DOWEC project", DOWEC project, Nr 10086, Issue 1, Oct. 2003, Available: www.ecn.nl/wind/other/dowec.html (last visit Apr. 2008).

[13] L. Jensen, "Array efficiency at Horns Rev and the effect of atmospheric stability", in *Proc. European Wind Energy Conference 2007*, Milan, Italy, May 2007.

[14] H.S. Christensen, "General introduction to wind power in the ELTRA area", *Presentation at Nordic Wind Power Conference*, Billund, Oct. 2003.

[15] R. Gasch and J Twele, *Wind Power Plants – Fundamentals, Design, Construction and Operation*, Solarpraxis AG, Germany, 2002, pp 114-115.

[16] T. Ackermann (Editor), *Wind Power in Power Systems*, John Wiley & Sons, Chichester, England, 2005.

[17] http://www.energinet.dk/da/menu/Marked/Udtr%c3%a6k+af+markedsdata/Udtr%c3%a6k+af+markedsdata.htm (last visit Apr. 2008).

[18] "Anlægsplan 2004 for transmissionssystemet", Eltra, Nov. 2004.

[19] Reliability Test System Task Force on Bulk Power System Reliability of

the Application of Probability Methods Subcommittee, "The IEEE Reliability Test System - 1996", *IEEE Transactions on Power Systems*, Vol. 14, NO. 3, pp 1010-1020, Aug. 1999.