2014 IEEE PES T&D CONFERENCE & EXPOSITION
CHICAGO | APRIL 14-17

# A Probabilistic Approach to Solve Economic Dispatch Problem in Systems with Intermittent Power Sources

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# Outline

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- Introduction
- The Stochastic Economic Dispatch (ED) Problem
  - Stochastic ED Formulation
  - Proposed Methodology
- Case Study and Results
- Conclusions

# Introduction



- This presentation shows a new methodology for the ED problem in a probabilistic and discrete point-of-view, taking into account :
  - The intermittency of renewable power sources through the estimation of the probability density function (PDF) of output power of each generator;
  - The total generation cost;
  - The energy not supplied (ENS);
  - Avoiding the hard time consuming scenario generation/reduction techniques.

# The Stochastic Economic Dispatch Problem (1/3)

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- The solution of the ED problem helps the system operator (SO) adjust the output power of conventional generation units in an economic way.
- The problem can be modeled as:

$$C_i = \alpha_i + \beta_i P_i + \gamma_i P_i^2$$

- $C_i$ – operation cost;
- $\alpha_i$, $\beta_i$ and $\gamma_i$ – coefficients of the cost curve;
- $i$ – conventional generation unit of total $G$;
- $P_i$ – power production of generator $i$;

# The Stochastic Economic Dispatch Problem (2/3)

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- If the forecasting error is incorporated the optimization problem is presented as follow, which consists:
  - to reduce the expected value of the generation cost:
    - Subject to the operational restrictions of the generation units
  - the satisfaction of load demand in a particular way.

$$\min E\left\{\sum_{i=1}^{G} C_i\right\}$$

$$P_r\left\{\sum_{i=1}^{G} P_i = L\right\} \geq 1 - \varepsilon\varepsilon$$

$$P_{min}^{i} \leq P_i \leq P_{max}^{i}, \qquad i = 1,2,\ldots,G$$

- $E\{\bullet\}$ – expected value;
- $P_r\{\bullet\}$ – probability estimation of certain event;
- $L$ – load demand variable in a random way;
- $\varepsilon$ – significance level of the probabilistic analysis;

# The Stochastic Economic Dispatch Problem (3/3)

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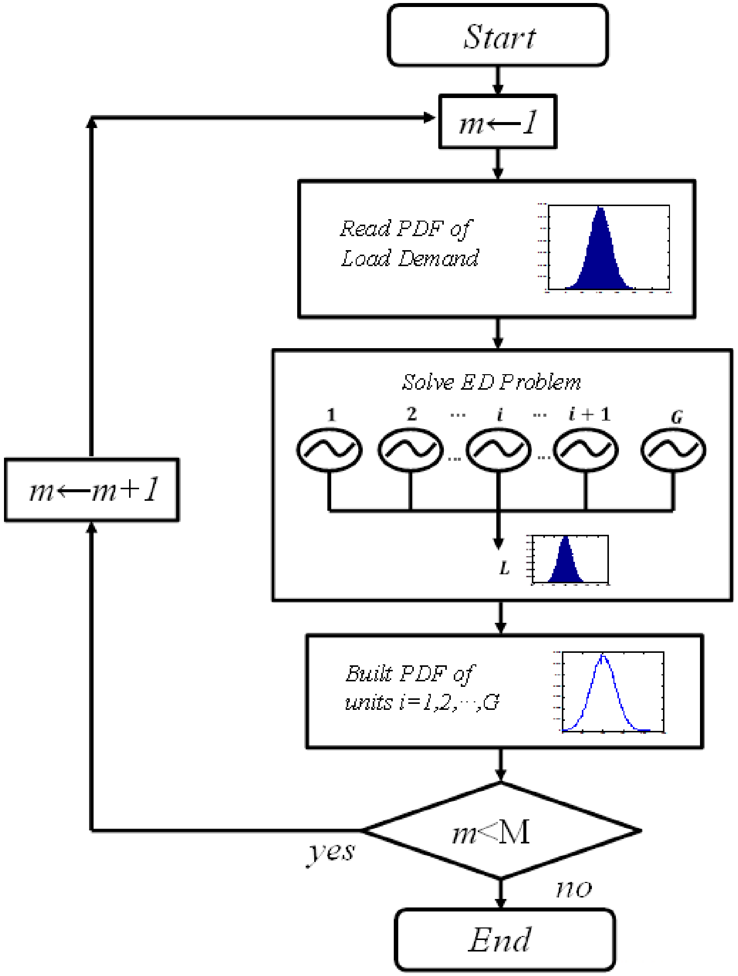
- The proposed methodology to solve the ED problem follows the structure:
  - It is considering the uncertainty related to the intermittent nature of wind power resources;
  - The algorithm permits to computes the probability density function (PDF) of all units and the energy not supplied (ENS);
  - Also, it is required the selection of pre-determined number of power classes (*M*) and for each power class chosen (*m*) the ED is solved using quadratic programming;
  - All the results obtained and their probabilities are saved and the PDFs are built.




Algorithm to solve the Stochastic ED problem.

# Case Study and Results (1/5)

- The proposed methodology was applied in a insular power system which is including wind power generation.
- Table 1 presents the minimum and maximum output of each generator.
- The parameters of the cost curve were fitted using data provided by manufacturers,.
- The diesel fuel price was assumed to be $ 3.903 per gallon.

Table 1, Generation units description.

| $i$ | $P_{min}^{i}$ (MW) | $P_{max}^{i}$ (MW) | $\alpha_i$ ($l$/h) | $\beta_i$ ($l$/MWh) | $\gamma_i$ ($l$/MW$^2$h) |
|---|---|---|---|---|---|
| 1 | 1 | 2 | 64.283 | 228.90 | 0 |
| 2 | 1.25 | 2.5 | 129.90 | 151.28 | 23.424 |
| 3 | 1.5 | 3 | 236.70 | 121.07 | 21.156 |

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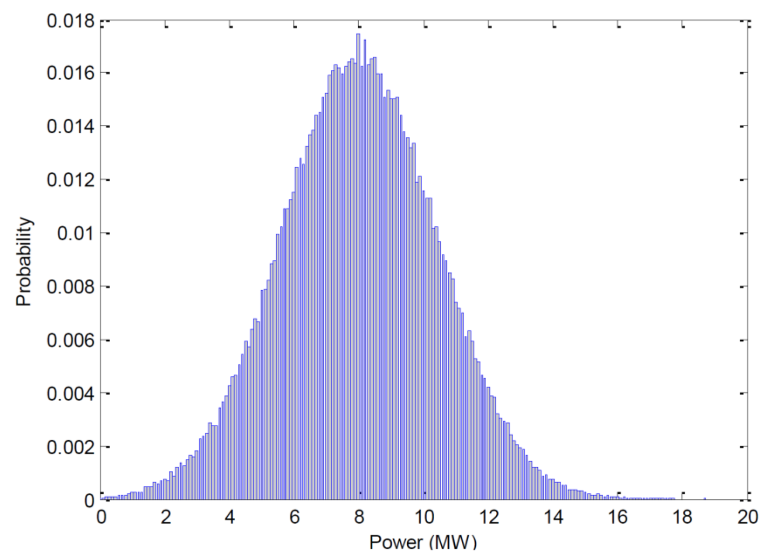
# Case Study and Results (2/5)

- The stochastic ED problem can be solved considering 30% of uncertainty in the net load.
- The case study considers a significance level $\varepsilon = 5\%$.
- The power classes are defined within an interval of 0.1 MW according to the PDF of net load.
- The following figure shows the PDF of net load




PDF of load demand.

# Case Study and Results (3/5)

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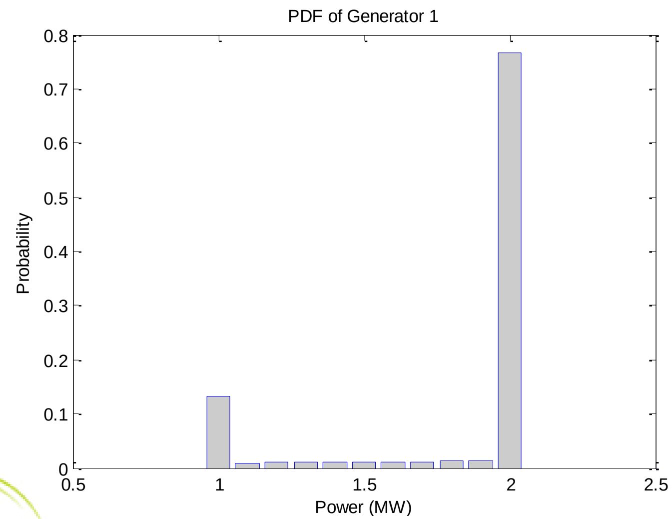
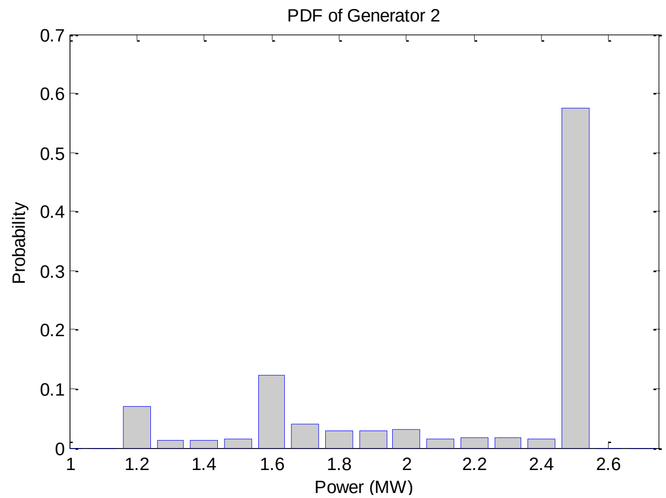
- The following results show the PDF of units 1, 2 and 3.
  - It is observed a high probability related with the maximum capacity requirement of each generator as result of forecasting errors in wind power generation.
  - The probability of each unit to be committed are 76.7%, 57.4% and 65.5% respectively, due to the aforementioned forecasting errors.
  - The bars observed in unit 1 and 3 between its boundary may be related to the PDF of load demand




PDF of generation unit 1.




PDF of generation unit 2.

# Case Study and Results (4/5)

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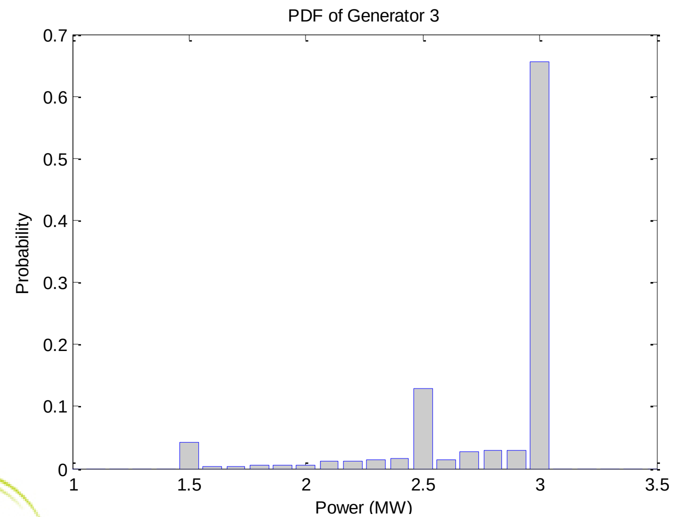
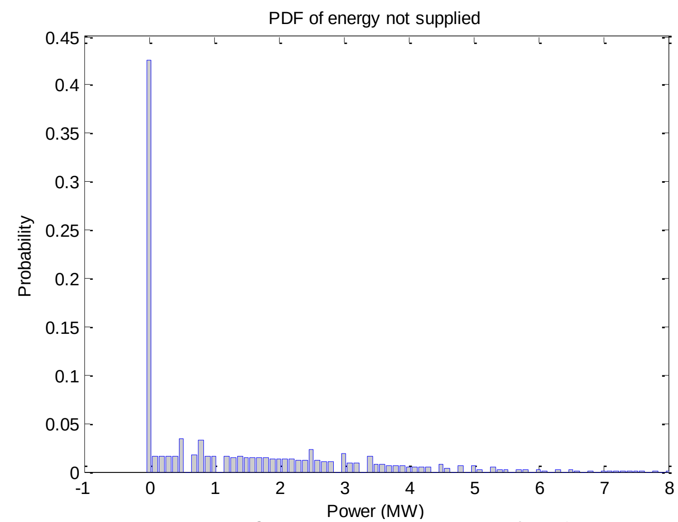
- The following results show the PDF of unit 3 and energy not supplied.
  - The total cost can be calculated as the addition between the operational costs and the product between ENS and VOLL..
  - The proposed methodology could be used to determine the PDF of the total generation cost, which is presented on the right (at button).
  - This PDF was obtained considering a VOLL of 12 $/MWh and an uncertainty of 30% in the net load.




PDF of generation unit 3.




PDF of energy not supplied.

# Case Study and Results (5/5)

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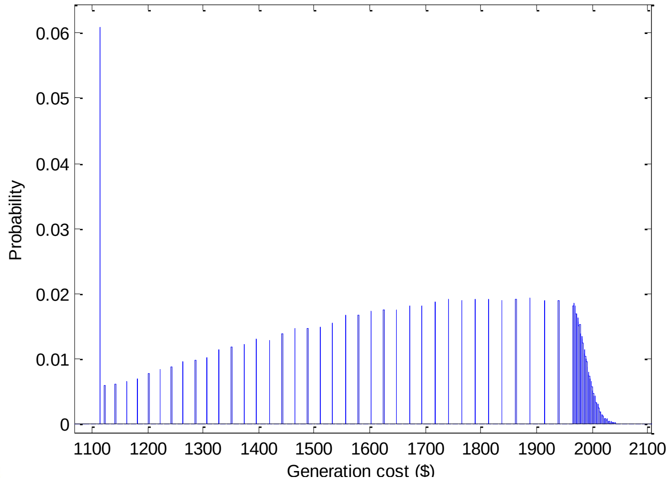
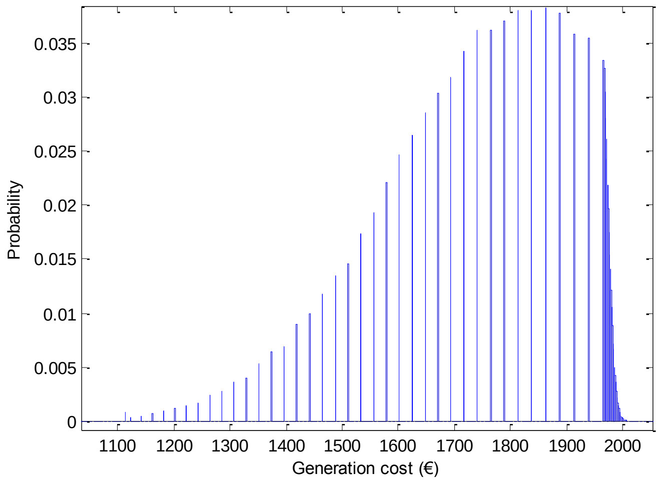
- The following results show the PDF with 30% and 15% of uncertainty.
  - A wide range of load demand values caused by high uncertainty produces a wide range of generation cost values..
  - An inferior and superior limit in the generation cost can be observed due to the operation of all generators at their minimum or maximum output power. (Left figure).
  - If the uncertainty is reduced to 15%, the effects on the PDF of total generation cost will be considerably reduced. (Right figure).




PDF of Gen. cost with 30% of uncertainty.




PDF of Gen. cost with 15% of uncertainty.

# Conclusions

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- A new probabilistic methodology to solve stochastic ED with a probabilistic point-of-view is presented.
- The proposed approach considers several power classes according to the PDF of load demand.
- The ED problem is solved using a quadratic programming and the results are used to build some different variables, i.e., ENS and total generation cost.
- The main features of the proposed methodology were illustrated in an insular power system.
- The PDF of all generation units and ENS were analyzed by observing the influence of the shape of PDF of load demand on the PDFs of generation units and ENS.
- The effects of load demand uncertainty on the total generation cost were studied, demonstrating the direct relationship between such variables.

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