



HAL
open science

Maximal wind power penetration in radial MV networks

Wendy Carolina Briceño Vicente, Raphaël Caire, Nouredine Hadjsaid

► **To cite this version:**

Wendy Carolina Briceño Vicente, Raphaël Caire, Nouredine Hadjsaid. Maximal wind power penetration in radial MV networks. IFAC Proceedings Volumes, Sep 2012, Toulouse, France. pp.705 - 710, 10.3182/20120902-4-FR-2032.00123 . hal-01809942

HAL Id: hal-01809942

<https://hal.science/hal-01809942>

Submitted on 7 Jun 2018

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Maximal wind power penetration in radial MV networks

Wendy Carolina Briceno Vicente, Raphael Caire, Nouredine Hadjsaid

Grenoble Electrical Engineering laboratory, St Martin d'Herès, 38402
FRANCE (Tel: 047-682-6443; e-mail: Wendy.BRICENO-VICENTE@g2elab.inpg.fr)

Abstract: The increment of Distributed Generation (DG), especially wind power, in distribution networks has motivated the development of methodologies to evaluate their limits and effect in the power system. The distribution network is already characterized by variable parameters such as: loads, line parameters; the interconnection of renewable energy sources adds more uncertainties in planning studies. In this paper, a new approach is applied in Load Flow (LF) and Short-Circuit studies based on Monte-Carlo simulation (MCS) which takes into account network uncertainties to determine the maximal wind power penetration and its dispersion in the network.

Keywords: Monte-Carlo Simulation, Distributed Generation, Wind power, Probabilistic Power Flow, Probabilistic Short Circuit, Wind power penetration.

1. INTRODUCTION

The incorporation of Distributed generation (DG) in distribution networks, that allows supplying the growing demand, implies a big challenge; moving from the traditional vertical utility to a horizontally-operated power system. The installation of DG must guarantee that: voltage regulation, power quality and fault levels are in between the limits of distribution network. In addition, the random behaviour certain types of DG energy sources such as wind power adds a new constraint to their connection to power grid as result of the highly unpredictable behaviour of wind (because of the changeable nature of weather conditions).

The connection of DG sources affects preliminary studies, such as Load flow (LF) and Short-circuit currents, which must respect operating limitations of distribution networks. Planning studies are classically based on deterministic analysis, and assume that electrical parameters and topology do not change during the computation [Vorsic (1991)] and [Boutsika (2008)]. To establish the penetration of DG in medium voltage (MV) and low voltage (LV) networks is necessary the incorporation randomness in planning studies given the considerable benefits in the analysis of flexible expansion alternatives. Moreover, load varies continuously depending on customer power requirements.

The first proposal of Probabilistic Load Flow (PLF) was made in the 70s by [Borkowska (1974)], and has been further developed and applied on power systems under normal operation, short-term, and long-term planning [Chen (2008)]. PLF can be solved numerically, e.g. Monte Carlo Simulation (MCS); analytically, e.g. convolution method, or even with a combination of both methods [Hatziaargyriou (1993), Jorgensen (1998), Leite da Silva (1990)].

It is well known that, short-circuit currents are influenced by several factors that may vary randomly, such as: fault type,

period, and location. In consequence a first proposal of probabilistic short-circuits was made in the 70s. This work used MCS to deal with the difficulties of increasing fault currents, which cause restrictions in the power grid. Nevertheless, since at that time MCS was computationally expensive, another important line of research based on analytical was developed, see the works of [Havard (1988), Vainberg (1986) and Germani (1986)], and the references therein to determine the probability distributions of short-circuit currents.

The MCS models the uncertainty variables as Random Variables (RVs) by probabilistic density function (PDF), and resolves the probabilistic problem making a big number of random trials of PDFs. The MCS constitutes reference values for probabilistic problems, their results allow a wide analysis of all the possible states of power system state variables and their probability of occurrence, instead of a unique state obtained from deterministic analysis.

This work aims to contribute for integration of renewable energy in radial distribution networks. It proposes a methodology using MCS to evaluate the maximum penetration of DG considering the random behaviour of different variables such as: wind power generation, electrical network parameters and localisation of generation using Load Flow and Short-Circuit studies.

2. MONTE CARLO SIMULATION

The Monte Carlo method is a general probabilistic algorithm for estimating the probability of an event based on a number of random trials. MCS is one of the most common randomized algorithms. Being a randomized algorithm that makes at least one decision based upon a random choice, rather than a fixed rule; generally depends upon the laws of probability.

Moreover, a MCS is a numerical method for estimating the value of an unknown quantity by making use of the principles of inferential statistics. The two main features about MCS are: random number generation and random sampling [Chen (2008)]. This method uses the exact equations of the problem; hence results of this technique can be used as reference values for other approaches [Leite da Silva (1990)].

In order to get a high degree of accuracy, the MCS requires large amount of computations, which can be very time consuming. Being, hence unpractical for real-time simulations; nevertheless for short term analysis such as one day ahead and depending on the size of the power system, MCS can be appropriate.

3. PROBABILISTIC MODELLING

In this section, probabilistic models of electrical parameters are described. The probabilistic analysis by MCS substitutes a chosen number of the system parameters and handles them as RVs and performs a big number of deterministic analysis with their random trials.

3.1 Load model

The load is highly dependent on human activities, and temporal factors such as time of the day, day of the week or season of the year. Therefore, several PDFs have been used to model the load behaviour, for instance: uniform, Weibull, normal [Seppälä (1996)], log-normal and beta PDF.

In this work the load consumption (P_L and Q_L) and network parameters (R_L and X_L) are modelled as a normally distributed PDF [Chen (2008)] given by the following expression:

$$f_{P_L}(P_L) = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{(P_L - \mu)^2}{2\sigma^2}} \quad (1)$$

where each load is characterized by two parameters: mean value (μ) and standard deviation (σ).

Line parameters depend on line lengths and temperature changes [Debs (1988)] which varies with weather conditions and power flows. Variations of resistance and reactance can be modelled by a normal PDF.

3.2 Wind speed and power generation

Wind speed varies every minute, hour, day and season of the year, which highlights the importance of a probability model. In this way, wind speed variation is best described by a Weibull PDF as follows:

$$f_v(v) = \frac{\beta}{\alpha} \left[\frac{v}{\beta} \right]^{\beta-1} e^{-\left(\frac{v}{\alpha}\right)^\beta} \quad \text{if } v \geq 0 \quad (2)$$

where v is the wind speed, $\alpha > 0$ is the shape parameter and $\beta > 0$ is the scale parameter of the PDF.

Wind turbine (WT) power was assumed linear for wind speeds between V_C and V_R ; equal to its rated power (P_R) between V_R and V_F ; and equal to zero over V_F where WT must be shut down for safety reasons.

$$P_v(v) = \begin{cases} \left(\frac{P_R}{V_R - V_C} \right) (v - V_C) & \text{if } V_C \leq v \leq V_R \\ P_R & \text{if } V_R \leq v \leq V_F \end{cases} \quad (3)$$

where V_C is the cut-in wind speed, V_R is the rated wind speed, V_F the cut-out wind speed, and P_R is the rated power.

3.3 Wind power location

The wind power location is modelled as a discrete uniform distribution (also known as the "equally likely outcomes" distribution) among the network buses N .

$$P(E_i) = \frac{1}{N} \quad (4)$$

where N is the number of elements of the set $S = \{E_1, E_2, \dots, E_N\}$ such that $P(S)=1$, each element of S has the same probability.

4. WIND POWER PENETRATION AND DISPERSION

The wind power capacity penetration describes how the total installed wind power capacity in a certain region is related to the peak load in this region over a certain time period.

$$\tau_{C_{wind}} (\%) = \frac{P_{rated, wind} (MW)}{P_{peak, demand} (MW)} \quad (5)$$

where $\tau_{C_{wind}}$ is the wind capacity penetration (%), $P_{rated, wind}$ is the installed wind power capacity (MW) and $P_{peak, demand}$ is the peak load (MW). The level of dispersion of DG is the ratio of the number of DG buses and the number of load buses.

$$Dispersion_{DG} (\%) = \frac{\# Bus_{DG}}{\# Bus_{LOAD}} \quad (6)$$

In order to integrate wind power in the distribution network, it is essential to respect electrical limitations for which the system has been designed. The following constraints must be accomplished for wind power connection into the network:

- Current must not pass transformers and cables maximal intensity in charge.
- Voltage constraint must be respected during peak and low load periods, taking into account that DG power injections can change at any time between 0 and maximum power production depending on the weather conditions.
- The voltage drop in MV network does not exceed $\pm 5\%$ of network dimensioning.
- The short-circuit capacity of MV network must be respected.

5. DISTRIBUTION NETWORK LOAD FLOW

The distribution systems usually fall into the category of ill-conditioned power systems for generic Gauss-Seidel and Newton-Raphson methods, and its special features being radial or weakly meshed topology, high R/X ratio of the distribution lines, unbalanced operation, static load models, non-linear loads (such as rectifiers) and distributed generation [Iwamoto (1981)]. Traditional load flow methods

fail to meet the requirements, in both performance and robustness. Hence, a load flow algorithm specially designed for distribution systems and was used based on topology of radial distribution systems to resolve load flow [Jen-Hao (2003)]. This algorithm is based on the formulation of two matrices: branch current injections to (BIBC) and branch currents bus voltage (BCBV) composed by network impedances.

6. DISTRIBUTION NETWORKS SHORT CIRCUIT

Short circuit calculations are performed according to IEC Standard 60909 recommendations of network short-circuit impedances (Z) and correction factors (K). According to the type of generator or power converter considered, four main types of DG stations are distinguished in short-circuit current contributions. The following models are extension of the IEC 60909 methodology made by [Boutsika (2008)] for different types of DG units used in the calculus of short-circuit. Those models are not included in the Standard.

6.1 Type I: synchronous generators directly coupled to the grid (e.g. Small Hydroelectric Plant, Combined Heat Plant)

If synchronous generators are connected directly to the grid, apply the generator impedance (Z_G) and the correction factor (K_G). If the generator is connected via a unit transformer, apply impedance (Z_S) and correction factor (K_{SO}).

6.2 Type II: asynchronous generators directly coupled to the grid (e.g. constant speed Wind Turbine, Small Hydroelectric Plant)

Standard IEC 60909 treats only asynchronous motors, the calculation principle to asynchronous motors is identical and applies as well. The generator impedance (Z_M) is essentially the locked-rotor impedance of the machine.

6.3 Type III: doubly fed asynchronous generators, with power converters in the rotor circuit (variable speed Wind Turbine)

The DFIG can be roughly approximated as a conventional asynchronous generator (Type II) when calculating their maximum fault current contribution, since the behaviour of the machine until its disconnection from the grid is identical to a conventional asynchronous generator.

6.4 Type IV: power converter interfaced units, with or without a rotating generator (e.g. variable speed Wind Turbine, Photovoltaic, microturbines)

The fast current controllers are employed to limit overcurrent capability, resulting in fault current contributions generally under 200% of the rated current, without aperiodic or time-decaying components. Hence, a departure from the IEC Standard might be appropriate for Type IV units, applying the following relation for their fault current contribution:

$$I_k'' = kI_{rG} \quad \text{over interval } \Delta t \quad (7)$$

where I_{rG} is the rated current of power interface, $k = 1.5-2.0$, I_k'' is the contribution of short-circuit current contribution and Δt is the duration of the contribution (100 ms may be adopted here as well)

7. PROPOSED METHOD

This work proposes a planning procedure for the expansion of distribution networks. In order to reflect the impact of DG uncertainties, particularly of wind power generation MCS is used. This algorithm considers uncertainties such as: line parameters, wind power generation and location. The algorithm aims to find the maximum wind power penetration of the network, without any consideration on the location of wind farms. Wind farm location was modelled with a discrete uniform distribution, among all network buses. Then, a random trial of uncertainty variables was done increasing wind power penetration and the number of wind farms until voltage or current are out their limits in any study: Power Flow or Short-Circuit. The algorithm can be summarized in the following char-flow:

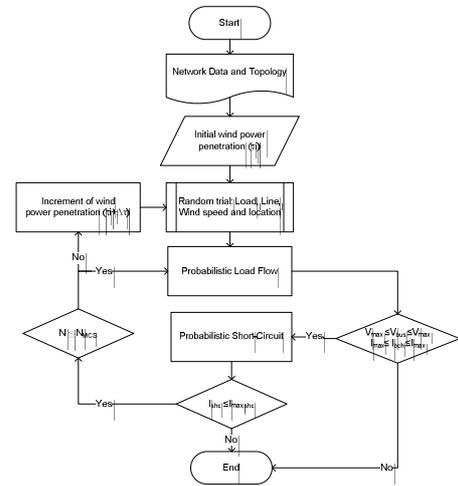


Fig 1. MCS load flow and short circuit algorithm procedure

where N_{MCS} is the number of random trials. In Fig. 1, one can see that for every value of wind power penetration MCS must be done. If results of Probabilistic Load Flow or Short Circuit overcome electrical limits, wind power must be reduced to allow its interconnection. The algorithm was developed in the software MatLab R2011b.

8. STUDY CASE

The test system chosen is a typical distribution network in 15.75kV of 7 lines, composed by a transformer 121/15.75kV, 31.5 MVA, connection YY with impedance to earth of 40Ω. The study case diagram is shown in Fig 2., data is given in table 2 of appendix I. The preliminary studies of load flow and short-circuit studies without DG is given in tables 5 and 6 of appendix II. The analysis of flexible expansion alternatives with wind power are presented in this section.

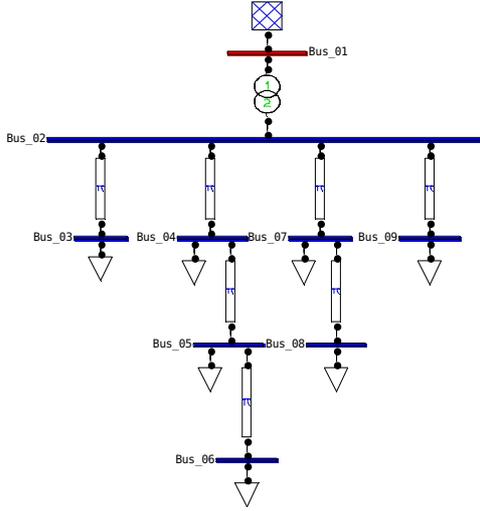


Fig. 2. Radial distribution network of 9 buses in 38kV.

All buses are constant PQ loads except Bus 01 which is the slack bus with a fixed voltage of 1.05 p.u. The load standard deviation and wind speed parameters were obtained from the analysis of ESB National data. All loads were considered non-correlated variables. In order to determine maximum wind power penetration, regardless any specific location on the network, load and wind generation was simulated for a year. Uncertainty of line parameters due to temperature variations was also considered, it was modelled as a normal distribution with a small standard deviation. The models of uncertainty parameters considered in the study are the following:

Table 1. Uncertainty parameters

Parameter	Distribution	Characteristic
Active power (P)	Normal	$\sigma_P = P * 8.5\%$
Reactive power (Q)	Normal	$\sigma_Q = Q * 8.5\%$
Resistances (R)	Normal	$\sigma_R = R * 5\%$
Reactances (X)	Normal	$\sigma_X = X * 5\%$
Wind speed (v)	Weibull	$\alpha=8.49, \beta=1.49$
Wind farm location (L)	Discrete uniform	$N=3, \dots, 9$

The WT has the following parameters: rated power of $P_r=4$ p.u., power factor of 0.9 and typical wind speeds of $V_C=5\text{m/s}$, $V_R=12.5\text{m/s}$, $V_F=25\text{m/s}$. Given that wind generation supplies power to the network; wind bus is considered as a power injection bus (PQ). In short-circuit studies, all wind farms were modelled as voltage sources which contribute to the fault current.

9. RESULTS AND DISCUSSION

Probabilistic Load Flow and Short-Circuit were tested in the study case considering one and several wind farms. For being

the most severe condition of fault current levels three-phase to ground probabilistic short-circuit was simulated. The electrical limitations of network components had to be respected under normal and faulted conditions, those values are shown in table 3 of appendix I. Finally, MCS were repeated for number of random trial of 1250.

The results of deterministic studies without DG are shown in appendix B. Deterministic load flow results in Table 5, shows networks minimum voltages of 1.0 p.u. in buses 6 and 8. Furthermore, Table 6 contains the results of deterministic short-circuit fault currents for the worst case of three-phase ground fault. Electrical components limits are shown in Table 3 of appendix I.

The results of voltage profile and branch currents obtained from probabilistic load flow under normal and faulted conditions are shown in Fig. 3. Load flow bus voltage in 8 varies the most from 0.99 to 1.03 p.u. When voltage drop decreases, branch currents also do, see Fig. 3, also when voltage drop increases, branch currents do. In general the voltage drop was improved which is a favourable factor in the insertion of one wind farm.

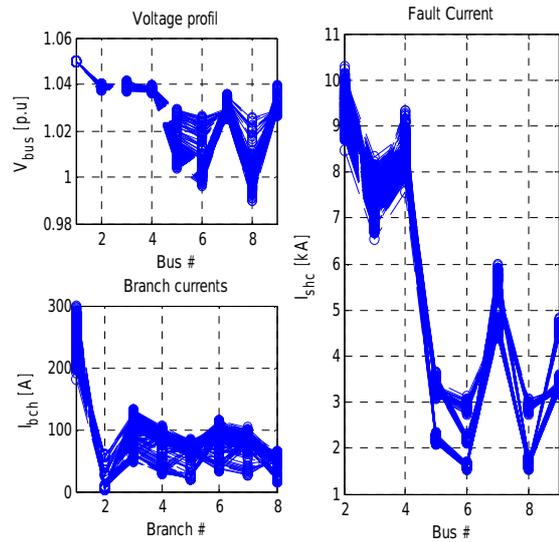


Fig. 3. One farm maximal wind power penetration of 25.5%

The results of fault currents for three-phase ground fault obtained by probabilistic short-circuit limited the wind power insertion. As it was mentioned, electrical limits must be preserved in order to allow wind farm insertion. From Fig. 3, one can see that fault current in bus 7 is near to the maximal current limit of 6kA. For this reason, the limit of penetration for one wind farm is reached to 25.5% of load, which means a dispersion of 14.29%. This wind farm corresponds to asynchronous generator type II with an active power injection of $3 \times 850\text{kW}$, see Table 4 of appendix. The simulation time was of 77.76 sec. The same analysis was made for two wind farms obtaining a maximal wind power penetration of 28.5%.

The Fig. 4 shows the results of probabilistic load flow for three wind farms. It can be seen that voltage drop was improved for bus 9 and branch currents changed lightly comparing to the case of one wind farm. The fault current in

bus 7 became a limitation for increasing wind power penetration. The maximal penetration was limited to 34.9%, which means a dispersion of 42.85%. Wind farm corresponds to one asynchronous generator type II with an active power injection of 1x850kW, and two others composed by two DFIG type III with an active power injection of 2x660kW each one.

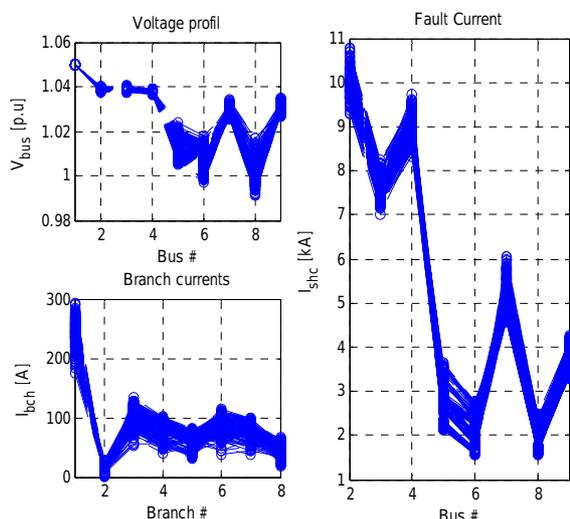


Fig. 4. Three farm maximal wind power penetration of 34.9%

The same analysis was made for four wind farms. In this case, the maximal wind power penetration was 32.3% inferior to the one obtained for three wind farms.

10. CONCLUSIONS

To guarantee a safe interconnection for the insertion of DG is necessary to study their impact in system behaviour. The integration of DG can reduce favourable losses and costs, especially when renewable energy sources (RES), as wind power are used. Since power generation are uncertain and vary according to the whether conditions, RES sources add a new constraint in planning studies.

The algorithm proposed for static planning studies, takes into account the uncertainties associated to wind power and its location, to find the maximal global wind power penetration of the network. The main issue for DG interconnection is keeping up electrical limits of network components. The variable uncertainties were evaluated through MCS.

The MCS is an iterative method used to solve probabilistic problems with random variables. Those variables can be modelled by probabilistic density functions (PDFs). The method lies on big number of random trials of the PDFs, in order to obtain a high degree of precision for the results. This method was used to evaluate the overall capacity of the network for admit wind power regardless the bus location.

From the study case, load flow studies did not limit wind power penetration in terms of voltage profile. After certain limit, DG may cause over voltages out of the range permit by the network components which may damage them. The maximum wind power penetration was determined by short-

circuit currents study. As the fault current in bus 7 was the highest current, in the case of one and three wind farms, it limited the wind power insertion. The maximal penetration was 34.9% after dispersing wind power with three wind farms, which corresponds to a dispersion of 42.85%. While for one wind farm the maximum wind power penetration was of 25.5%. Hence, in order to maximize the power penetration is necessary dispersing it with several DG units.

The next step to guarantee a safe connection of that level of wind power in the network is by effectuating stability studies. These studies include dynamic time domain simulations and static stability. It must be considered the same sources of uncertainty, such as: load, line parameters, and wind speed. The dynamic models of machines and controllers must be included, also the machine equivalent of the 110kV network. Furthermore the stability studies must consider several perturbations (load variations, short circuit events, line switching, etc.) in order to verify that electrical limits (frequency, machine powers, line currents, bus voltages) are maintain during the time domain simulations. While in the static stability studies eigenvalues must be negative to verify the network stability for small perturbations.

REFERENCES

- Borkowska, B. (1974). Probabilistic load flow. *IEEE Transaction. on Power Apparatus and Systems*, vol. PAS-93, no. 3, pp. 752-755.
- Boutsika, T. N., Papathanassiou, S.A. (2008). Short-circuit calculations in networks with distributed generation. *Elsevier, Electric Power Systems Research*, Volume 78, Issue 7, pp. 1181-1191.
- Chen, P.; Chen, Z.; Bak-Jensen, B. (2008). Probabilistic load flow: A review. *Electric Utility Deregulation and Restructuring and Power Technologies. Third International Conference on DRPT*, pp.1586-1591.
- ESB National Grid system information. [Online]. Available: <http://www.eirgrid.com/>
- Ford, G.L., Srivastava, K.D (1981a). The probabilistic approach to substation bus short-circuit design. *Electric Power System Research*, vol.4, no.3, pp. 191-200.
- Ford, G.L., Sengupta, S.S. (1982b). Analytical methods for probabilistic short-circuit studies. *Electric Power System Research*, vol.5, pp.13-20.
- Germani, M. D; Ford, G. L; Neudorf, E. G.; Valnberg, M.; El-Kady, M. A.; Ganton, R. W. D.(1986). Probabilistic Short-Circuit Uprating of Station Strain Bus System- Overview and Application. *IEEE Transactions on Power Delivery*, vol.1, no.3, pp.111-117.
- Hatziaargyriou, N.D.; Karakatsanis, T.S. Papadopoulos, M. (1993) Probabilistic load flow in distribution systems containing dispersed wind power generation. *IEEE Transactions on Power Systems*, vol.8, no.1, pp.159-165.
- Havard, D. G.; Pon, C. J.; Ewing, H. A.; Dumol, G. D.; Wong, A. C. (1986) , Probabilistic Short-Circuit Uprating of Station Strain Bus System - Mechanical Aspects, *IEEE Transactions on Power Delivery*, vol.1, no.3, pp.104-110.

Jen-Hao, T. (2003). A direct approach for distribution system load flow solutions. *IEEE Transactions on Power Delivery*, vol.18, no.3, pp. 882- 887.

Jorgensen, P.; Christensen, J.S.; Tande, J.O. (1998). Probabilistic load flow calculation using Monte Carlo techniques for distribution network with wind turbines. *Proceedings 8th International Conference on Harmonics And Quality of Power*, vol.2, pp.1146-1151.

Leite da Silva, A.M.; Arienti, V.L. (1990). Probabilistic load flow by a multilinear simulation algorithm. *IEEE Proceedings on Generation Transmission and Distribution*, vol.137, no.4, pp.276-282.

Seppälä, A (1996). Load research and load estimation in electricity distribution, PhD dissertation, *Technical Research Centre of Finland*.

Vainberg, M.; El-Kady, M. A.; Ford, G. L.; Ganton, R. W. D.; Germani, M. D.; Neudorf, E. G. (1986). Probabilistic Short-Circuit Uprating of Station Strain Bus System - Probabilistic Formulation. *IEEE Transactions on Power Delivery*, vol.1, no.4, pp.129-136.

Vorsic, J.; Muzek, V.; Skerbinek, G. (1991). Stochastic load flow analysis. Electrotechnical Conference. Proceedings, *6th Mediterranean IEEE*, vol.2, no., pp.1445-1448 .

Iwamoto, S.; Tamura, Y. (1981). A load flow calculation method for ill-conditioned power system. *IEEE Trans. Power App. Syst.*, vol. 100, pp. 1736-1743.

Appendix A. 38 KV DISTRIBUTION NETWORK DATA

Network feeder: $U_{nQ}=121$ kV, $S''_{kQ}=3000$ MVA, $R_Q/Z_Q=0.1$

Table 2. Network parameters

Branch	Busi	Busj	R _{ij} (Ω)	X _{ij} (Ω)	Y _{ij} /2 (Ω)
1	1	2	0.00	1.27	0
2	2	3	0.33	0.33	0
3	2	4	0.05	0.15	0
4	4	5	2.58	2.71	0
5	5	6	0.57	1.68	0
6	2	7	0.93	0.98	0
7	7	8	2.89	3.04	0
8	2	9	1.55	1.62	0

Table 3. Electrical limitations

Element	V _{rated} (kV)	V _{max} (kV)	I _{rated} (A)	I _{sh,c} (kA)
Lines (1-2)	15.75	20.5	511	12
Lines (3-8)	15.75	20.5	385	6
Switchgear-Bus 2	15.75	40	1250	16

Table 4. Wind farm models

DG sources	Wind farm 1	Wind farm 2
Machine	DFIG	Asynchronous
Type	III	II
P _{rG} (kW)	660	850
U _{rG} (V)	690	690
R _G (mΩ)	8.848	7.207
X _G (mΩ)	88.480	72.072
Transformer	Unit	Unit
S _{rT} (kVA)	700	1000
t _{rT} (kV)	15.75 / 0.69	15.75 / 0.69
R _T (Ω)@15.75kV	6.86	4.4
X _T (Ω)@15.75kV	27.74	23.59
K _T (Ω)	1.015	1.009
Line	Overhead	Overhead
R _L (Ω)@15.75kV	2.2	2.2
X _L (Ω)@15.75kV	3.3	3.3

Appendix B. DETERMINISTIC STUDIES WITHOUT DG

Table 5. Load flow results without DG

Busi	Type	V _i (p.u.)	θ _i (o)	P _g - P _d (MW)	Q _g - Q _d (MVar)
1	Slack	1.05	0.00	10.21	3.29
2	PQ	1.04	-1.70	0.00	0.00
3	PQ	1.04	-1.71	-0.25	-0.08
4	PQ	1.04	-1.78	-1.00	-0.33
5	PQ	1.01	-2.60	-0.75	-0.25
6	PQ	1.00	-3.13	-2.50	-0.82
7	PQ	1.03	-2.02	-0.50	-0.16
8	PQ	1.00	-2.89	-3.00	-0.99
9	PQ	1.03	-2.00	-2.00	-0.66

Table 6. Load flow and Short circuit results without DG

Bus	I _{Branch} (A)	I _{sc,1Ø-G} (kA)	I _{sc,2Ø-G} (kA)	I _{sc,3Ø-G} (kA)	I _{sc,2Ø} (kA)
2	273.6	4.421	5.895	10.610	9.189
3	6.67	3.254	4.339	7.810	6.764
4	116.36	4.010	5.466	9.839	8.520
5	89.67	0.985	1.314	2.366	2.049
6	69.09	0.720	0.960	1.727	1.496
7	96.71	2.056	2.741	4.934	4.273
8	83.24	0.722	0.963	1.734	1.501
9	53.86	1.482	1.975	3.556	3.08