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Security Evaluation of Power Systems in Various Conditions of Wind Energy Penetration Using MCS

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Abstract: *With the ever growing increase in power systems, demand of energy is increasing every day. Therefore, renewable energy is a hot topic these days. They are renewable, sustainable and environment friendly. The increase in renewable generation, on the other hand, can affect many power systems issues in different ways. One of these issues affected by renewables is power systems security. Since power systems are always subject to different contingencies, contingency ranking in power system is very important. This paper tries to evaluate the effects of wind power on power systems security in various conditions of wind generation penetration into the conventional power system. In addition to using fuzzy logic to get a flexible performance index (PI), the proposed method is dealing with Monte Carlo Simulation (MCS) to simulate the stochastic behaviour of wind Generation. Finally, the proposed method is simulated on IEEE-RTS with satisfactory results and the results are discussed.*

Keywords: *Power systems security, Monte Carlo methods, Fuzzy logic, Wind energy*

INTRODUCTION

Power systems have evolved over decades. Their primary emphasis has been on providing a reliable and economic supply of electrical energy to their customers [1]. A real power system is complex, highly integrated and almost very large.

Unfortunately, the environmental impact of the electricity industry has been diverse for decades. So, in recent years, there has been a trend towards the increased commercialization of various renewable energy resources. This incremental use of renewable energy leads to effects on various aspects of power systems. Because of stochastic behaviour of most renewable resources, one of the issues that could be affected due to renewable energy penetration, is power systems reliability which includes power systems' adequacy and security. This paper tries to evaluate the effects of wind generation on power systems' security.

There is no clear official definition of decentralized production. Generally, decentralized production is defined as the opposite of centralized production. Usually, decentralized generators are not planed in a centralized way, have a power which does not exceed 50 to 100 kW and are scattered over a territory. The development of this type of production can contribute to solving technical, economic and environmental problems [2].

Broadly, reliability indices of a system can be evaluated using one of two basic approaches [3]:

- Analytical techniques
- Stochastic simulation

Simulation techniques, estimate the indices by simulating the actual process and random behaviour of the system. Volatility is a common feature of almost all renewable energies. Since wind generation has stochastic behaviour, Monte Carlo Simulation (MCS) which is one of the most powerful methods for statistical analysis of stochastic problems is used to simulate the amount of power produced by wind generators.

Contingency ranking is one of the ways to evaluate the security level of power systems. Generally, to study this issue, two methods are used: direct and indirect. In direct method, changes in one performance index is the indication of contingency danger. In indirect method using fast evaluation methods such as fast load flows, first, post contingency situation is evaluated; then these amounts are placed in a function and ranking is performed. Conventionally, different tools have been used for contingency ranking such as Performance Index [4-5], neural networks [6-7] and fuzzy logic [8]. Indirect methods usually are calculated either in active or reactive domain. While active domain deals with active power flowing through the transmission lines, the magnitude of bus voltages is concerned in reactive domain. Many performance indexes have been suggested for contingency ranking so far. Unfortunately, many of them are rigid and inflexible. In other words, they either consider only the over loaded lines in the performance index, or they treat all the transmission lines in the performance index equally. In other words, in some of the proposed PIs, transmission lines change from totally risky to totally safe only due to a small difference in the power flowing through them during contingency conditions. On the other hand, some proposed PIs are treated all lines (overloaded and non-overloaded lines) equally without considering the incremental amount of power flowing through them during contingency conditions. Therefore, in this paper, a flexible, fuzzy PI is used to perform contingency ranking. This paper evaluates power system security due to contingencies that may happen in transmission lines in presence of wind generation using fuzzy logic and MCS. In section-2, fundamental of wind generation is briefly discussed. Section-3 presents the proposed method; and finally, in section-4, numerical studies are presented and discussed.

I. Wind generation: Basic concepts

Wind speed on a specific site varies with the seasons, months, days. After taking measurements on site for a year, the frequency of occurrence of a specific wind speed (i.e. its probability) can be simulated by a Weibull distribution curve. This Weibull distribution of a site enables us to determine the energy that could be produced by the wind turbine for each value of the wind speed. Therefore, unlike conventional power plants and because of random behaviour of wind speed, wind turbine often does not operate at its nominal power. In fact, its use is characterized by the Loading Factor (LF) which is defined by the ratio between the number of hours of operation at nominal power (full power) and the number of hours in a year [9]. Obviously, however LF is higher, the potential of generation by wind turbine is increasing. The value of LF could be very varied dependent on time scales and locations. In some windy countries, such as New Zealand, LF can reach above 50% [10].
The gross power in a wind turbine can be written as [11]:

$$P_v = \frac{1}{2}\rho \pi R^2 v^3 \qquad (1)$$

Where ρ is air density ($^{kg}/_{m^3}$), v as wind speed (m/s) and R as blade length (m). However, the turbine extracts a mechanical power P_m, which is lower than the aerodynamic power P_v. Then, C_p can be defined as the turbine power coefficient:

$$C_p = \frac{P_m}{P_v} \quad , \qquad C_p < 1 \qquad (2)$$

$$P_m = C_p \frac{1}{2}\rho \pi R^2 v^3 \qquad (3)$$

According to Betz limit, $C_{p\,max}$ cannot exceed the value of 0.5925 [12].

II. Presentation of the proposed method

In this paper, Equation (4) is proposed to calculate the PI in active domain for each contingency. The PI is flexible and fuzzy which includes all the transmission lines and treats them according to their over load amount in post-contingency conditions. Meanwhile, the probability of each contingency could be considered independently.

$$\mathrm{PI} = \left[\sum_{i=1}^{M} \mathrm{W}_i \left[\frac{PL_i}{Pn_i}\right]^{(MFL+1.5MFM+2MFH)}\right] \times P_{con} + \left[\sum_{i=1}^{M} \mathrm{W}_i\right] \times (1 - P_{con}) \tag{4}$$

$$W_i = \frac{Pn_i}{\sum_{i=1}^{m} Pn_i} \tag{5}$$

Where:

Pn_i: Pre-contingency (normal conditions) transmitted power through line i

PL_i: Post contingency transmitted power through line i

MFL: Low-load membership function in transmission lines

MFM: Medium-load membership function in transmission lines

MFH: High-load membership function in transmission lines

M: Number of lines in which their transmitted power in post-contingency conditions is more than their transmission power in pre-contingency conditions

m: Number of total transmission lines

W_i: Weight coefficient of line i

P_{con}: Probability of contingency

Where the amounts of Pn_i and PL_i are calculated by DC Load Flow (DCLF); and MFL, MFM and MFH are obtained from Fig.1.

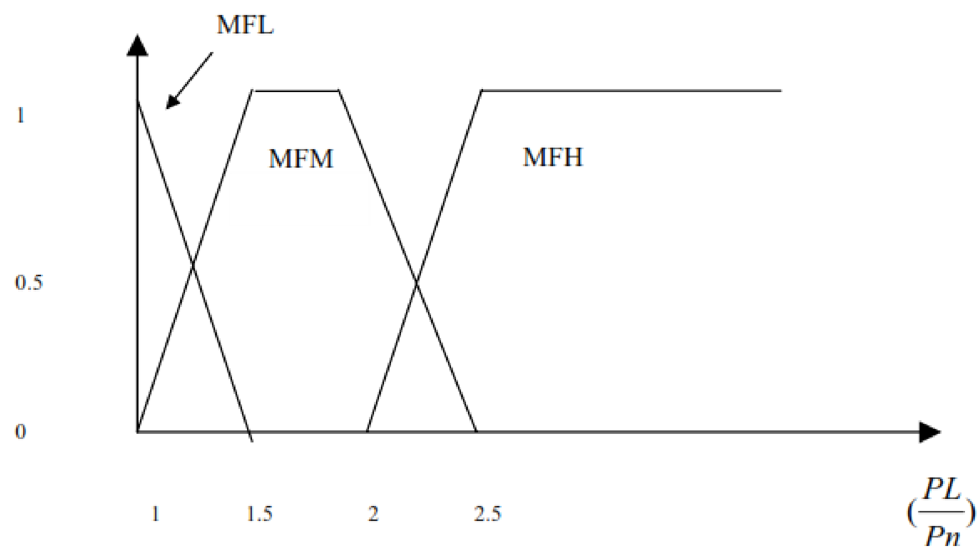

Fig. 1. Membership functions of low-load, medium-load and high-load fuzzy sets in transmission lines

III. Numerical studies

IEEE-RTS (Fig.2) is used as the case study in this paper [13]. Four scenarios are considered to evaluate the effects of wind generation on contingency analysis. It is assumed that the number of contingencies is 33 (including all the transmission lines and transformers, except L11).

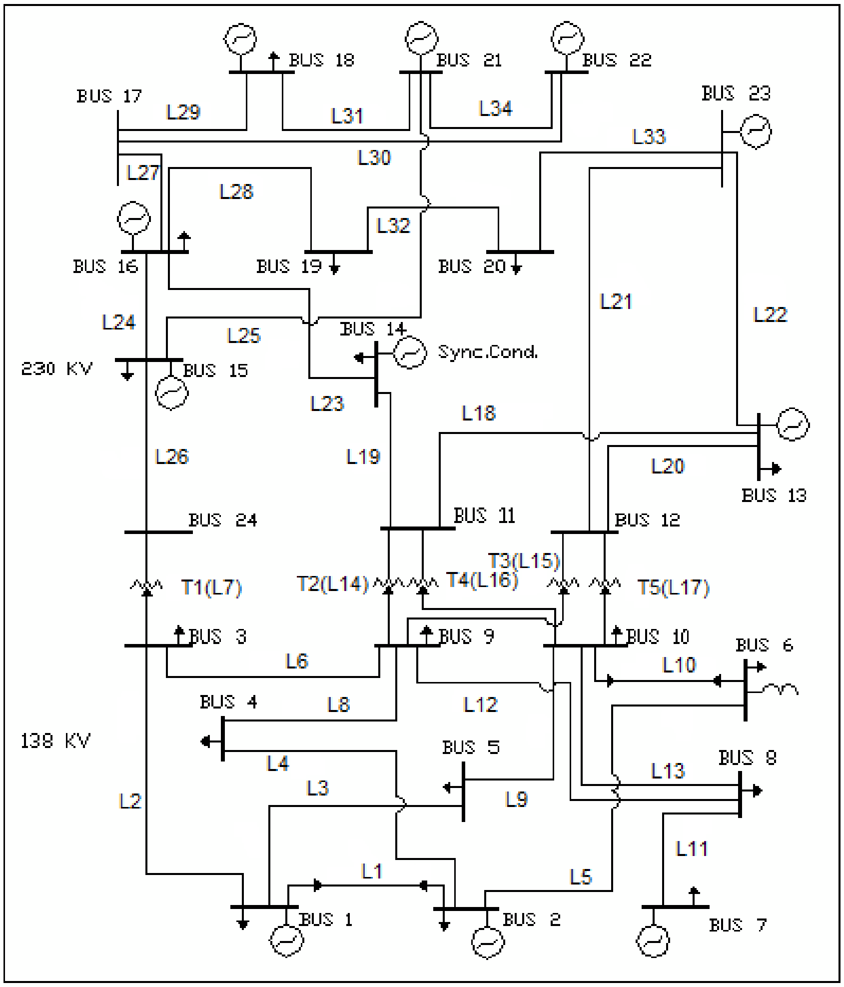

Fig. 2. IEEE Reliability Test System

Following assumptions are used in all the scenarios:

1- All the scenarios are run with 5000 iterations in MCS in Matlab R2014a.
2- To get clear perception and to provide equal condition for all contingencies, probability value for all the 33 contingencies is considered "1" (obviously, according to (4), the probability for each contingency could be chosen differently).
3- For more realistic simulations, load amount at each bus is simulated by a random number produced by a Normal distribution (given demand at each bus as Mean value; and "0.1*Mean value" as Standard Deviation (SD)).

Scenario 1: Basic scenario (Without any wind generation)

In this scenario, the power system without any wind generation is simulated. The amounts of active power flowing through each transmission lines are calculated by DCLF. Using (4) and MCS, PI values for contingencies are calculated as Table 1.

Table 1. PI values for scenario 1 (Basic Scenario)

Outage Line No.	PI	Outage Line No.	PI
25	**1.668244**	22	0.672735
26	1.632017	32	0.66955
7	1.632017	3	0.643624
27	1.280889	20	0.63068
23	1.084204	4	0.613589
33	0.973648	14	0.612216
21	0.85194	28	0.609825
17	0.848516	29	0.565087
2	0.792751	6	0.56095
18	0.784697	34	0.560664
9	0.73102	31	0.560169
1	0.727905	24	0.559004
15	0.718597	13	0.557017
10	0.717493	5	0.55595
8	0.714972	12	0.555716
16	0.700172	30	8.18E-05
19	0.699365	**Total PI**	**25.48**

According to Table 1, L25, L26 and Transformer 1 (L7) outages could lead to the worst post-contingency conditions in the power system. The most value for PI is 1.67, and sum of the PI values is equal to 25.48.

Scenario 2: Wind generators are installed in 8 buses

In this scenario, only 8 buses are considered to install wind generation. This scenario is divided into two sub-scenarios according to the quality of dispersion of wind generators:

- *Sub-scenario 2-1*: Centralizing wind generators in a small area
- *Sub-scenario 2-2*: Spreading wind generators over the whole power system

Also, each sub-scenario is simulated in two different conditions:

- *Condition A*: 10% of basic generation capacity in each bus is *added* into the conventional generation.
- *Condition B*: 10% of basic generation capacity in each bus is *replaced* with wind generation.

Sub-scenario 2-1: Wind generators are centralized in a small area

In this sub-scenario, 8 wind generators are considered to install in buses 1-8 which are centralized over a small area in the power system. LF is simulated by a Normal distribution with μ=0.4 and σ=0.05. Using (4) and MCS, PI values for contingencies are calculated as Table 2 for two conditions A and B.

Sub-scenario 2-2: Wind generators are spread over the whole power system

Contrary to sub-scenario 2-1, in this sub-scenario, 8 wind generators are spread randomly over the whole power system in each iteration of MCS. Since this sub-scenario considers a larger area, LF is simulated by a Normal distribution with μ=0.4 and σ=0.1. Now, using (4) and MCS, PI values for contingencies are calculated as Table 3 for two conditions A and B.

Table 2. PI values for sub-scenario 2-1

Condition A: Adding wind generation				**Condition B:** Replacing with wind generation			
Outage Line No.	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**
25	**1.700412**	22	0.704418	**25**	**1.62396**	22	0.631725
26	1.664675	32	0.700223	26	1.585149	32	0.627927
7	1.664675	3	0.67103	7	1.585149	3	0.606509
27	1.30896	20	0.662788	27	1.242298	20	0.588161
23	1.107447	28	0.640784	23	1.055872	4	0.583329
33	1.003798	4	0.63891	33	0.930669	14	0.576621
21	0.881606	14	0.63832	17	0.815756	28	0.568316
17	0.872947	29	0.59503	21	0.812289	5	0.526316
2	0.817731	6	0.59196	2	0.759013	29	0.524354
18	0.817628	13	0.590525	18	0.741834	6	0.521187
1	0.767039	34	0.590034	9	0.691841	34	0.519123
9	0.75766	31	0.589422	10	0.689671	24	0.518884
15	0.743988	24	0.589035	15	0.685136	31	0.518138
8	0.738832	12	0.586937	8	0.684754	13	0.516044
10	0.738216	5	0.579456	1	0.673079	12	0.514928
19	0.727986	30	0.000159	16	0.668422	30	0.000103
16	0.723863	**Total PI**	**26.41**	19	0.663346	**Total PI**	**24.25**

Table 3. PI values for sub-scenario 2-2

Condition A: Adding wind generation				**Condition B:** Replacing with wind generation			
Outage Line No.	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**
25	**1.851064**	16	0.774627	**26**	**1.434876**	1	0.549741
26	1.759855	32	0.765923	7	1.434876	22	0.519235
7	1.759855	3	0.764825	25	1.406775	20	0.501746
27	1.463843	29	0.736731	27	1.056722	14	0.499231
23	1.188234	28	0.734421	23	0.964064	3	0.469899
33	1.053543	4	0.733964	33	0.87103	28	0.451133
21	0.947388	20	0.732475	21	0.726159	4	0.43921
17	0.931176	34	0.718671	17	0.717904	5	0.377448
2	0.898598	31	0.718616	18	0.651957	6	0.36935
18	0.893682	24	0.7185	2	0.616556	13	0.364063
1	0.861563	6	0.714004	16	0.594405	12	0.36294
9	0.843241	12	0.709812	15	0.586472	34	0.359989
8	0.831682	13	0.709457	10	0.583563	24	0.358459
10	0.819385	14	0.699772	9	0.578396	31	0.356839

15	0.810732	5	0.694626	19	0.57047	29	0.352032
19	0.796798	30	0.000118	8	0.55507	30	9.26E-05
22	0.791479	**Total PI**	**29.43**	32	0.553358	**Total PI**	**20.23**

Scenario 3: Wind generators are installed in 16 buses

In this scenario, 16 buses are considered to add wind generation. Similar to scenario 2, added wind generation into each bus is assumed to be 10% of basic generation in each bus. This scenario is again divided into two sub-scenarios according to the quality of dispersion of wind generators. Also, similar to scenario 2, each sub-scenario is simulated in two different conditions A and B.

Sub-scenario 3-1: Wind generators are not spread over the whole power system

In this sub-scenario, 16 wind generators are considered to install in buses 1-16 which are not spread over the whole power system. Since according to Fig.1, buses1-16 cover a larger area than buses 1-8 (sub-scenario 2-1), SD is considered to be higher than that of sub-scenario 2-1. Therefore, LF is simulated by a Normal distribution with μ=0.4 and σ=0.075. Using (4) and MCS, PI values for contingencies are calculated as Table 4 for two conditions A and B.

Sub-scenario 3-2: Wind generators are spread over the whole power system

Similar to sub-scenario 2-2, in this sub-scenario, 16 wind generators are spread randomly over the whole power system in each iteration of MCS. LF is simulated by a Normal distribution with μ=0.4 and σ=0.1. Using (4) and MCS, PI values for contingencies are calculated as Table 5 for two conditions A and B.

Scenario 4: Wind generators are installed in all buses

In this scenario, all the buses are considered to add wind generation. LF is simulated by a Normal distribution with μ=0.4 and σ=0.1 (since all the generators are spread over the system, SD is increased into 0.1). Added wind generation into each bus is assumed to be 10% of basic generation in each bus. Like scenarios 2 and 3, this scenario is also simulated in conditions A and B. Using (4) and MCS, PI values for contingencies are calculated as Table 6 for two conditions A and B.

Table 4. PI values for sub-scenario 3-1

Condition A: Adding wind generation				**Condition B:** Replacing with wind generation			
Outage Line No.	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**
25	**1.814325**	32	0.783038	**25**	**1.458888**	1	0.518728
26	1.766187	16	0.775762	26	1.403137	22	0.511889
7	1.766187	3	0.767473	7	1.403137	14	0.492841
27	1.438565	28	0.746541	27	1.084221	20	0.484721
23	1.172957	20	0.73845	23	0.985464	3	0.449475
33	1.072011	4	0.735145	33	0.845248	28	0.433928
21	0.958452	29	0.730175	17	0.72041	4	0.424059
17	0.930977	34	0.726741	21	0.719481	5	0.36366
2	0.906787	31	0.725509	18	0.6289	12	0.349367
18	0.904799	24	0.724579	2	0.599081	6	0.347716
1	0.875473	6	0.719746	15	0.590408	29	0.347264
9	0.847552	12	0.719332	16	0.585821	13	0.345932
8	0.832239	13	0.716582	10	0.574537	24	0.342536

10	0.818544	14	0.702208	19	0.572264	34	0.342273
15	0.809299	5	0.696358	9	0.558883	31	0.341431
19	0.801192	30	0.000228	8	0.5432	30	6.74E-05
22	0.797511	**Total PI**	**29.52**	32	0.526737	**Total PI**	**19.9**

Table 5. PI values for sub-scenario 3-2

Condition A: Adding wind generation				**Condition B:** Replacing with wind generation			
Outage Line No.	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**
25	**2.019454**	29	0.88555	**26**	**1.221315**	20	0.403183
26	1.889814	3	0.881369	7	1.221315	8	0.401125
7	1.889814	32	0.86203	25	1.188777	1	0.392763
27	1.634009	34	0.857279	27	0.891805	14	0.385024
23	1.29708	24	0.857247	23	0.856727	28	0.328784
33	1.133254	31	0.856984	33	0.794168	3	0.310001
21	1.039399	16	0.850593	21	0.601697	4	0.287979
17	1.012136	28	0.848746	17	0.58352	5	0.245841
2	1.001117	6	0.847965	18	0.55748	6	0.236856
1	0.994212	12	0.847529	16	0.477498	12	0.234711
18	0.992963	13	0.843236	32	0.465393	13	0.233948
9	0.954819	4	0.841753	15	0.460382	34	0.230371
8	0.939373	20	0.825863	10	0.452473	24	0.229584
10	0.920352	5	0.821581	19	0.446336	31	0.224303
15	0.901115	14	0.785484	9	0.421361	29	0.212878
22	0.897073	30	0.00021	2	0.420841	30	7.13E-05
19	0.895286	**Total PI**	**33.12**	22	0.4038	**Total PI**	**15.82**

Table 6. PI values for scenario 4

Condition A: Adding wind generation				**Condition B:** Replacing with wind generation			
Outage Line No.	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**	**Outage Line No.**	**PI**
25	**2.148233**	22	0.977291	**25**	**1.05754**	14	0.301535
26	2.002299	15	0.976335	26	1.048829	1	0.290514
7	2.002299	24	0.957223	7	1.048829	8	0.28827
27	1.763794	34	0.956874	27	0.803079	2	0.270975
23	1.391651	31	0.955537	23	0.766114	28	0.260016
33	1.201542	12	0.949014	33	0.750463	3	0.211392
21	1.11569	6	0.948196	18	0.506832	4	0.201107

1	1.112657	32	0.943625	21	0.505493	5	0.180059
2	1.092371	13	0.941035	17	0.484043	6	0.178392
17	1.085212	28	0.936429	32	0.415308	12	0.175937
18	1.068316	4	0.92779	16	0.389086	13	0.175847
9	1.055071	16	0.922447	15	0.375778	24	0.174749
8	1.028253	5	0.920947	10	0.353493	34	0.174684
10	1.009617	20	0.900284	19	0.351662	31	0.167579
29	0.993204	14	0.860113	20	0.348033	29	0.150912
3	0.979018	30	0.000278	22	0.339081	30	4.95E-05
19	0.977355	**Total PI**	**36.1**	9	0.302474	**Total PI**	**13.05**

Comparison of conditions B in scenarios 2, 3 and 4 turns with basic scenario turns out that replacing conventional generation with wind generation improves power systems' security. On the contrary, comparison of conditions A in scenarios 2, 3 and 4 turns with basic scenario shows that adding wind generation into buses worsens power systems security. It is to be noted that however, the three worst contingencies in the system in all the scenarios are the same (L25, L26 and Transformer 1 (L7)). Also, comparison between sub-scenarios turns out that in condition A (adding wind generation), more centralization of wind generation improves power system security, while in condition B (replacing with wind generation), more spreading of wind generation improves power system security.

IV. Conclusion

This paper analysed the effect of wind generation penetration on power systems security. The research used a flexible fuzzy PI for contingency ranking. Also, MCS was used to model loads and wind generation power. Four scenarios were simulated on IEEE-RTS with the following results:

1- Replacing conventional generation with wind generation improves power systems' security.
2- Adding wind generation into power system without transmission lines development decreases power systems' security.
3- Wind generation penetration does not have major effect on the worst contingencies.

Also, these are some proposals for future work:

- Finding some sensitive transmission line(s) using an intelligent method such as PSO to add another parallel line(s) for security enhancement
- Security evaluation considering other common renewables such as PVs integrated with wind generation

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