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RELIABILITY OF WIND POWER PLANTS IN COOPERATION WITH POWER SYSTEM NETWORK

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ABSTRACT
In presented paper the results of investigations of reliability factors in MV networks connected with wind power plant are presented. The calculations were made for internal network with wind farm taking into consideration the different reasons of supply interruptions. Reliability model for network with wind farm is proposed and reliability factors of wind farm are determined. The conclusions of analysis are important for the cooperation of MV local system network with the national power system.

KEY WORDS
Reliability, power system, wind power plant, power quality, wind farm internal network

1. Introduction: Reliability representation of connection of wind power plant to network node

The proper integration of wind turbines into the power system by maintaining existing reliability and performance standards has become an issue of immense interest. Development of wind power plant caused the creation of big wind farms of 100 MW although consist of many the same wind units with power at most of few MW.
In such wind farm the important role play:

- internal medium voltage (MV) network for distribution of generated power and energy from individual wind units into main station of MV of whole farm (or number of farms),
- connection of MV station to external network with voltage level depending on power of farm – like distribution of supply from power system plant. Such connection is created by transformers MV/HV (MV/110 kV, MV/220 kV or MV/400 kV). Such voltage level of external network results from power and work conditions of wind farms, where the local conditions of temporary use of generated energy in different periods of work of plant are not enough for use of farm generation. Transmission of electrical energy for long distance is necessary in such situation.

The solutions result from wind plant work condition, energy losses in network, reliability and investment editions. Very important are:

- requirements of external networks,
- solutions of wind power plant (farm, complex of farms) and connection, taking into account among others power flow, voltage, current, energy losses etc.
- damages of system components of wind power plant, which cause decreasing of generated power and importance of economy losses in such situations.

2. Reliability data of wind units in Poland

Program TRELSS-PW for wind power plants requires the introduction of failure factors for each power unit taking into consideration the unit transformers. There are needed two reliability factors: probability of forced outage of generator - FOR (Forced Outage Rate) and, t_m - average duration of outages.
For turbines installed in Poland following values of factors are taking into account:

- failure frequency - 3 per year,
- average duration of interruption of work - 30 h/interruption,
- FOR = $2{,}5.10^{-2}$,
- average duration of maintenance outages - 120 h/interruption.

Reliability factors of wind farms decide about final value of index for whole farm because of their particular values.

The above mentioned values are depending on size and location (land or sea) of turbine. By comparison of failure frequency of components the enormous differences between particular statistical periods were detected. It is difficult to explain because in statistical distribution of quotas on individual parts of turbine the dominant are “remaining” exceeding even 50%.

The basic parameters are: age, size, type of turbine, reason as differences between network, weather, technical service, mechanical damages etc. Even in [3] was detected that enormous dispersion of disconnection time from few till over 100 hours. After modernization of devices making for reduction of frequency failure the indices were proposed:

- onshore 2,31 failure/year,

- offshore 1,55 failure/year.

In given statistical results it is not possible to get the dependence of failure frequency on data of wind supply, its solution and power age of turbine, type of data collection etc.

3. Electric system of wind farm

The power of wind farm decides about size in area. There are needed the size of spade of windmill as well distances between windmills. This determines size of MV network which is connected with individual wind unit. General but simplified solution for internal wind farm is shown in figure 1. Each unit is connected through transformer and connector to main line (route) of MV. To route can be connected from few 10 till wind units. Wind farm can get some such MV routes. The main MV switch station is connected to power system through transformer MV/HV and HV transmission line (i.e. 110 kV, 220 kV, 400 kV) - fig. 1. Network of wind farm with generation unit create equivalent „power unit" – like power plants. Therefore the common reliability evaluation for whole wind farm is recommended.

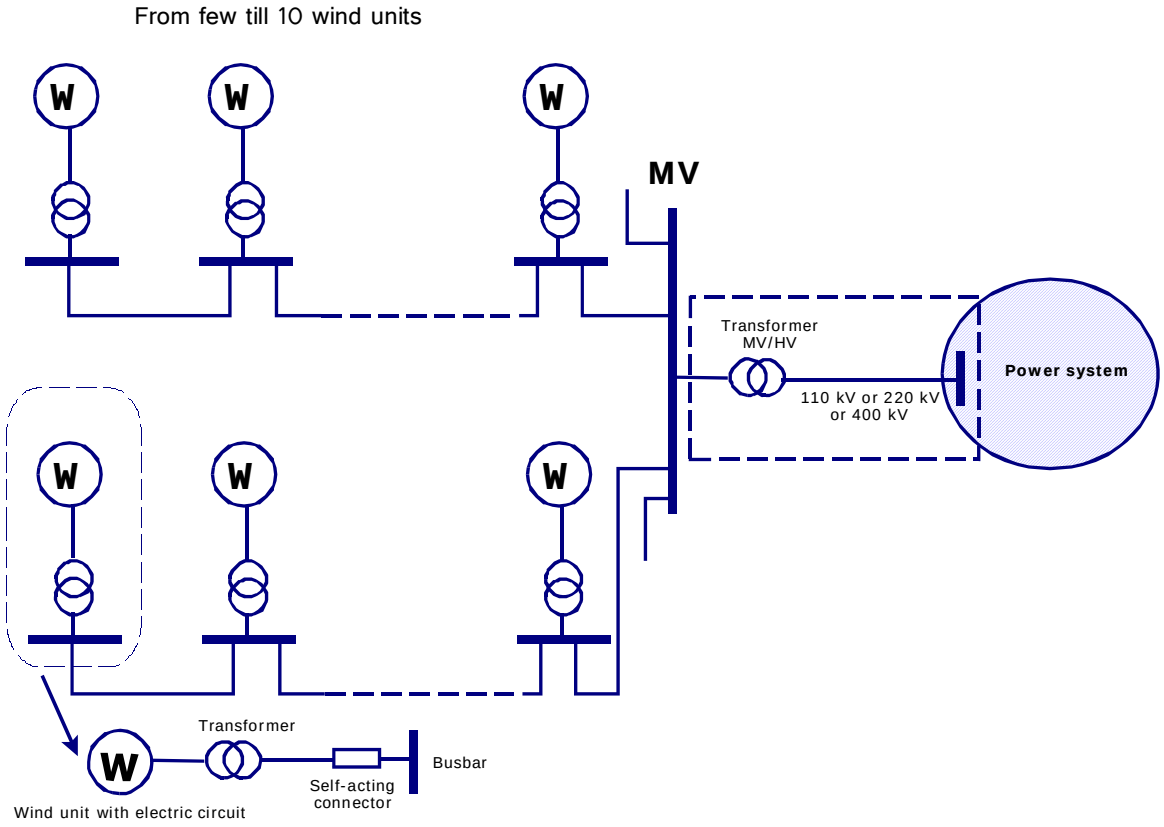

Figure 1 Representation of wind farm with connection to power system

Connection of wind farm to power system depend on many local factors i.e. parameters of generation units creating farm, structure and network parameters as well as power balance in different periods, criterion of local or system use of farm power, predicted mutual action between wind farm and power system. Therefore many solutions of connection to power system exist and the importance of problem is represented in legislation. In case of wind farm the investigation for each individual connection to power system is required. Expertise which are made in this area should show the connection possibility of predicted wind farm to power system and usually can impact to realize project faster and to avoid any problems and impediments. In figures 2, 3 and 4 some proposal of general solution for the wind farm, which are in neighbor the common output of power i.e. through three-winding transformer to transmission line 110 kV or MV are presented. Such examples show that wind farm could represent the specific generation power unit connected to power system and this way could make the summary reliability evaluation.

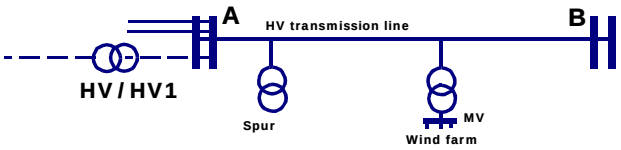

Figure 2 Simplified connection of wind farm to HV power system as spur between nodes A and B

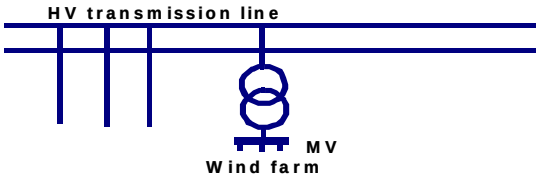

Figure 3 Simplified connection of wind farm to one-level HV station

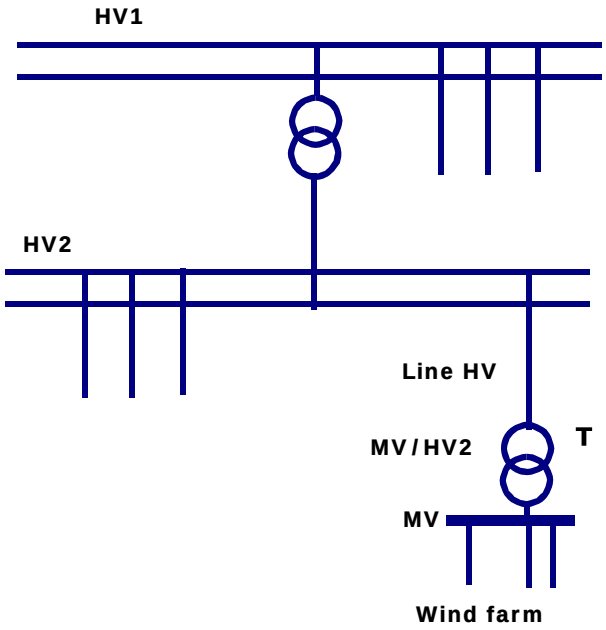

Figure 4 Simplified connection of wind farm to two-level HV station (HV1, HV2)

4. Reliability representation of network with wind farm

Internal network working with wind farm is subordinated to generation of electrical energy and supply to node with customer. The most important reliability factors for each network component are:

- probability of forced outage (equivalent of FOR), q_i;
- average time of forced outage (equivalent of MTTR), t_i.

In the Table 1 are given as example the above mentioned reliability data for MV network components [18] – as for new elements. In comparison with reliability factors of wind farm: $q_i = FOR_i = 2{,}5.10^{-3}$, $t_i = 30$ h/out., these value are much lower. The reliability factors for each component of wind farm Network are shown In Table 2.
The circuit presented in Figure 1 shown reliability cooperation for components of whole farm, and from the point of view of generated power it is parallel-series system. Starting from main MV switch station of wind farm it is series system consists of transformer MV/HV and HV transmission line connected into the network node of power system. The wind farm is supply for this node. Reliability of wind farm is determined as resultant value of wind unit and network structure.

Table 1 Proposed verified reliability factors of wind farm network

Component	q_i	t_i
	[-]	[h/out.fail.]
Transformer of generator of wind unit	$2{,}7\cdot10^{-5}$	24
Route MV	$27{,}4\cdot10^{-5}\cdot L$	20
Transformer MV/110 kV	$32{,}9\cdot10^{-5}$	24
Transformer MV/220 kV	$43{,}8\cdot10^{-5}$	24
Transformer MV/400 kV	$54{,}8\cdot10^{-5}$	24
Transmission line 110 kV – power output	$3{,}0\cdot10^{-5}\cdot L$	7
Transmission line 220 kV – power output	$2{,}9\cdot10^{-5}\cdot L$	20
Transmission line 400 kV – power output	$2{,}1\cdot10^{-5}\cdot L$	17
where L – line length in km		

Structural reliability of internal network connected with wind farm was evaluated under assumption:

- network structure is show in Figure 1,
- wind units working on route create change of loads, which are avoid during analysis, but it could be take into account as power of equivalent unit,
- for the network component creating with wind power plant (new situation) the reliability factors are presented in Table 2,
- during calculations was assumed that the connection point to power system is the customer for power plant (according to Fig. 2),
- the resultant estimation of reliability of network are:

- probability – reliability factor,
- time – average time of outage.

In addition the wind farm failure must be taking into consideration, which gives additional change of generated power.

Using data from table 1 and 2, the resultant factors for wind farm (fig. 2) were determined:

- for connection to 110 kV system (length 10 km), $q = 62{,}9\cdot10^{-5}$, t = 11 h/out;
- for connection to 110 kV system (length 50 km), $q = 183\cdot10^{-5}$, t = 8 h/out;
- for connection to 400 kV system (length 10 km), $q = 56\cdot10^{-5}$, t = 15 h/out;
- for connection to 400 kV system (length 50 km), $q = 160\cdot10^{-5}$, t = 14 h/out.

Table 2 Verified reliability factors of MV wind farm network components

Factor	Unit	Bar coupling		Transformer		Transmission line	
		MV	MV	Gen/MV	MV/HV	Air line MV	Cabl. MV
Average frequency of outage	out./100unit/a	5	5	1,2	15	5	10
Average time of outage	h/out.	6	6	48	48	10	24
During bad weather: – average frequency of outage, – average time of outage	out./100km/a h/out.					0,5 12	
Probability of planned disconnection	-	0,001	0,001	0,0011	0,0018	0,0011	
Average time of planned disconnection	h/out	4	4	8	8	7	

5. Conclusion

The obtained results show that the resultant failure depend mostly on failure of:

- MV farm main switching station,
- transformer MV/HV and HV transmission line.

Results could be given as factors of structural reliability of wind farm which represents equivalent wind farm. These values could be interpreted as equivalent value FOR and MTTR.

The results of calculations are important for the future planned increased role of middle voltage network taking into consideration wind farm network.
In the electric power network which will work with wind power plant a high degree of reliability is expected. In practice such requirement is not easy to fulfill, because the main role will make the MV network and the reliability factors for MV network are low.
The cooperation of local system network working at the MV with the national power system can improve the reliability conditions for this network. At the HV level the reliability factors are very high and based on the results of calculations it's evident that this high degree of reliability is assured.

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