WIND FARMS' GRID CONNECTION AND PROTECTION REQUIREMENTS FOR SUSTAINABLE DEVELOPMENT

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Abstract –*The present paper focuses on highlighting most important grid connection requirements for wind farms, in the context of sustainable development, in order to ensure best integration, compatibility, protection and stability of power system. Therefore it is working on drafting grid codes or for change them, where the codes already exist, to keep up with technology. This work is an overview on existing grid codes in countries with tradition in wind sources management like Germany and Denmark, and by reference, in Romania, a novice in the field, despite its huge wind potential and suitable areas for wind farm sitting.*
Keywords –*grid connection requirements, protection, grid code, point of common coupling*

CERINTE PRIVIND PROTECTIA SI CONECTAREA PARCURILOR EOLIENE LA SISTEMUL ENERGETIC IN CONTEXTUL DEZVOLTARII DURABILE

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Rezumat – *Lucrarea de fata are ca scop evidentierea celor mai importante cerinte de conectare la retea a parcurilor eoliene, in contextul dezvoltarii durabile, pentru asigurarea integrarii, compatibilitatii, protectiei si stabilitatii sistemului energetic. Pentru aceasta, se lucreaza in mod continuu la elaborarea codurilor de retea si la modificarea celor existente, in vederea adaptarii lor la tehnologiile existente. In lucrare este facuta o prezentare generala a codurilor de retea din tarile cu traditie in managementul energiei eoliene precum Germania si Danemarca, si prin raportare la acestea, este prezentat codul de retea din Romania, o tara novice in domeniu, in ciuda potentialului imens de vant si a muliplelor suprafete adecvate amplasarii parcurilor eoliene.*
Cuvinte cheie – *cerinte de conectare la retea, protectie, cod retea, punct comun de conectare*

ТРЕБОВАНИЯ К ОХРАНЕ И СИСТЕМЫ ПИТАНИЯ ПОДКЛЮЧЕНИЕ К ВЕТРОПАРКИ В КОНТЕКСТЕ УСТОЙЧИВОГО РАЗВИТИЯ

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Реферат –*В настоящем документе основное внимание уделяется выделяя наиболее важные требования присоединения к электрическим сетям ветровых электростанций, в контексте устойчивого развития, с тем чтобы обеспечить наилучшую интеграцию, совместимость, защиту и стабильность энергосистемы. Поэтому он работает на кодах сетки редакционных или изменить их, где уже существуют коды, чтобы идти в ногу с технологиями. Данная работа представляет собой обзор существующих сетевых кодексов в странах с традицией в управлении источниками ветра, как Германия и Дания, и по ссылке, в Румынии, новичок в этой области, несмотря на его огромный потенциал ветра и подходящих площадок для размещения ветропарка*
Ключевые слова – *Требования к технологическому присоединению, защита, код сетки, точка общего присоединения*

1. GRID CONNECTION REQUIREMENTS

The wind is a natural and renewable resource, despite its unpredictable and incontrollable variation. This requires infrastructure development for energy transport to high demand areas. Unfortunately, in some countries, the infrastructure does not comply with the increased potential of wind power installation. Some countries do not have specific codes for wind turbines grid integration, while other countries must review their codes, in order to follow wind turbines technology [1].
Most wind turbines manufactured are faced with standard grid requirements.

1.1 Reactive and active power control requirements

Reactive power requirements are dependent on the network's characteristics and appropriate voltage level. Variations of the generated power lead to variations of the voltage at point of common coupling (PCC), being related on the short circuit capacity and impedance at the PCC of the wind farm [2]. A small impedance results in small voltage variation, while large impedance results in a large voltage variation. Having this relationship between voltage and reactive power, it can be noticed that wind turbines, which has the ability to control reactive power, can regulate the voltage in PCC. In Fig 1 are presented the power requirements specified by grid codes. Active power control requirement allows systems frequency stabilization and is focused on automatic global adjustment of power to frequency.

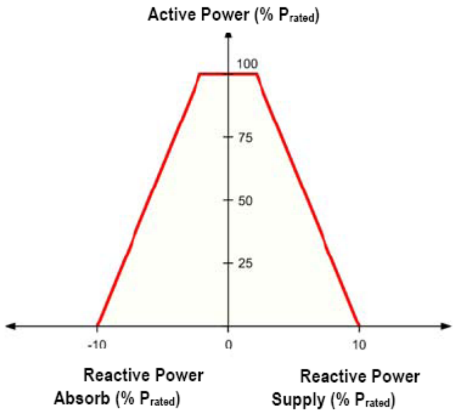

Figure 1 Wind generator's reactive power limiting curve

1.2 Protection requirement

Dynamic behaviour of wind farms imposes protection systems able to disconnect the wind farm from the grid in case of a fault in the network. Wind turbines and additional equipments may suffer damages caused by high short-circuit currents, voltage or frequency variations. The protection system of a wind farm must be designed to ensure protection of wind farms against damages resulted from grid faults.

1.3 Voltage requirement

To avoid critical situations, must be specified a voltage operation range, taking into account the maximum variation of wind turbine system without disconnection and the way the disconnection from the grid occurs. Rapid voltage changes are sudden, but relatively weak voltage variations over the range of values defined for steady state operation. Many times, rapid voltage change result from load changes on consumer installations or from switching operations on the supply system.

The magnitude of rapid voltage variations (*d*) caused by a wind turbine in connection point must be smaller than 4% for 10-20 kV grid's voltage and less than 3% for 110 kV grid's voltage. Those variations can be estimated using *Equation (1)*

$$d(\%) = 100 \cdot K_u(\psi_k) \cdot \frac{S_n}{S_k} \tag{1}$$

where, $K_u(\psi k)$ is the voltage variation factor, ψ_k represents the short circuit angle in the connection point, S_n is the wind turbine apparent rated power and S_k is the short circuit capacity in the point of common coupling (PCC).

Operating voltage ranges are different in various countries and highly dependent on local conditions. Low values, up to 90% of nominal voltage in transmission level, are reached during disturbances, while high values occur in reestablishment of supply after major disturbances.

1.4. Fault ride through capability

The fault ride through (FRT) or low voltage ride through requirement (LVRT) is established in order to avoid losses in generated wind power during short circuit faults or other grid faults and helps to system's stabilization. Modern wind turbines are capable to stay connected during and after the faults because its power electronics. In Table 1 are presented certain grid codes requirements for different countries.

Country	Voltage level	Fault ride through capability			
		Fault duration [ms]	Voltage drop level [%U$_r$]	Recovery time [s]	Reactive current injection
Denmark	DS/TS	100	25	1	No
Ireland	DS/TS	625	15	3	No
Germany	TS	150	0	1.5	Up to 100%
Spain	TS	500	20	1	Up to 100%
Italy	>35 kV	500	20	0.3	No
USA	TS	625	15	2.3	No
Romania	TS	625	15	3	Up to 100%

Table 1 Fault ride through requirements in some countries

2. GRID CODE FOR WIND FARMS

An overview of the national grid requirements in countries as Germany, Denmark and Romania is provided in next section.

2.1 Germany

Germany transmission power system operates at 220 kV and 380 kV levels and distribution system operates at 150 kV. Germany is divided in four energetic sectors, one Transmission System Operator (TSO) being responsible for each sector: RWE Transportnetz Strom GmbH, E.ON Netz GmbH, Vattenfall Europe Transmission (VE-T) GmbH and EnBW Transportnetze AG.

Together, they issued grid codes for wind turbines connection and operation in power system.

According to German code, the requirements for wind turbines behavior in transient periods are separated for generators with high contribution at short circuit current, and for generators with smaller contribution than that. Onshore wind farms must be considered like conventional power plants and connection should be performed at 380 kV transmission level [3].

Onshore wind farms must be considered like conventional power plants and connection should be performed at 380 kV transmission level. Concerning FRT or LVRT, German code specifies that wind farms have to remain connected in voltage dips up to 0% in PCC, typically for high voltage. Frequency range that wind turbines have to tolerate is 47.5 Hz up to 51.5 Hz.

There must be possible to limit the active power generated from each operating point as percent of rated power with at least 10% of rated power per minute. Wind farms with a rated power smaller than 100 MW have to be able to operate with a power factor between 0.95 lagging and 0.95 leading, PCC considered. Wind farms with 100 MW rated power or higher, should operate at power factor between 0.925 lagging and 0.95 leading [6], [7].

2.2 Denmark

In Denmark, transmission system is composed by 132 kV, 150 kV, 400 kV voltage levels, and was managed until 2005 by two TSOs: Eltra in west and Elkraft System in east, electrically separated, but interconnected with neighboring countries. In 2005, these merged in one single TSO, called Energinet Denmark. Despite high transfer capacity, are imposed operational limits as 800 MW to the north and 130 MW to the south, so that neighboring countries networks congestions are avoided. No reference about any operating voltage range or trip times, in transient conditions, can be found in Danish grid code. During any 3-phase or 2-phase, on any arbitrary line, wind farms must stay connected and stable.

At fault occurrence, the voltage may drop to 70% of initial voltage, for maximum 10 seconds, which should not lead to the wind farm instability. Wind farm control should be maintained up to 3 faults in 2 minutes or up to 6 faults, if the delay between the faults is 5 minutes. This requirement implies that all wind farms should have enough power reserve. Fault ride through requirements are almost the same with German's requirements, e.g. wind generators must remain connected during voltage dips up to 0% in PCC to the high voltage grid, which signifies about 15% at wind turbine terminals. This specification can vary according to the wind farms voltage level or power.

After fault occurrence, to limit wind farm's reactive power demand, must be possible active power reduction to maximum 20% of rated power in less than 2 seconds, so results a decreasing rate about 40% of rated power per second. Wind farms are required to have enough reactive power compensation to be neutral in any operating point.

2.3 Romania

Romania is one of the 148 countries that ratified on February 16, 2005, Kyoto protocol, initially signed on 1997, concerning drastically reduction of greenhouse gases until 2012. A possibility to perform this task is to product energy from renewable sources, like wind. Until the end of 2008, not much was done due to lack of legislation, Romania having only 7 MW installed power from wind.

In 2009, Romania was situated on 55th place in the world in installed power, reaching to 14 MW from wind, so a 100% increase rate. According to World Wind Energy Report 2010, Romania occupied the 23rd place in the world in total installed capacity (591 MW from wind) and first place for increase rate in 2010 (an increase rate of 4124.4% compared to 2009, as illustrated in Fig.2.

Romania's wind potential is estimated at 14,000 MW (Fig.3) taking into consideration that the 2 nuclear reactors from Cernavodă produce 1,400 MW installed power (20% of energy produced in Romania).

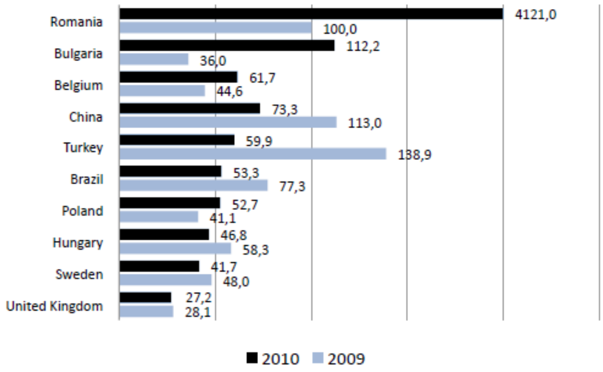

Figure 2 **Top ten countries by growth rate (%)**

In Dobrogea, population density is very low, so large and compact areas can be used for installation of at least 50 MW wind farms. The main problem in this area is represented by the low industrial and domestic demand, the producers being forced to transport energy to other areas using 400 kV TSO's transmission lines.

In Romania is only one TSO, called CNTEE Transelectrica that operates at 110 kV, 220 kV, 400 kV voltage level. Following other more developed countries, Romania, through CNTEE Transelectrica faced with problems regarding wind energy integration in existing network and emitted grid connection requirements for wind farms.

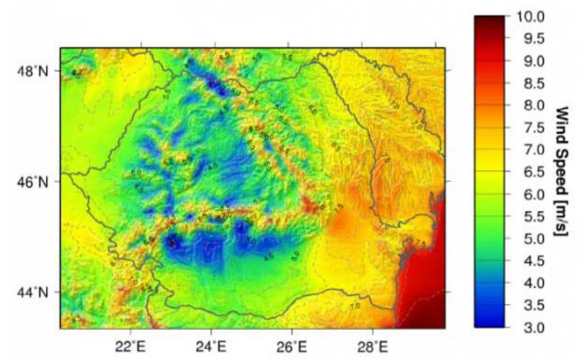

Figure 3 Romania wind speed map

Main requirements for wind farms bigger than 10 MW are [4]:

- to operate continuously for frequencies between 47.5 Hz ÷ 52 Hz;
- during voltage dips wind farm have to produce active power according to the remanent voltage level and to generate maximum reactive current for at least 3 seconds;
- active power adjustment will be performed, as possible, by proportional adjustment of each wind turbine's active power and not by cutting off or starting-up each turbine. Response speed in power regulation of each wind turbine must be at least 60% of rated power per minute;
- to remain connected on grid for frequencies between 47 Hz ÷ 47.5 Hz for minimum 20 s or when frequency varies with speeds up to 0.5 Hz/s;
- to operate continuously for voltage range 0.9 ÷ 1.1 of rated voltage in PCC;

- to remain operative in dips voltage occurrence on 1-phase or all phases, in PCC
- if frequency exceeds 52 Hz, the disconnection of wind farms is allowed;
- at voltage values in PCC in the allowed interval, reactive power produced / absorbed by wind farm must be continuously regulated, according to a power factor between 0.95 lagging and 0.95 leading;

3. CONCLUSIONS

The requirements depend on the specific characteristics of each power system and the protection employed and they deviate significantly from each other.
Can notice that the Danish grid code have specific fault ride through requirements for distribution network as well as for transmission one, while German grid code and Romanian grid code have focus only on the transmission level.
The Romanian grid code is very demanding regarding the fault duration, with 625 ms, Germany has 150 ms fault duration and Denmark has the lowest fault duration with 100 ms only. Concerning the voltage drop level, it varies between 25% of rated voltage in Denmark to even 0% of rated voltage in Germany in PCC. In Romania it is 15% of rated voltage. Also, in Germany and Romania is required an injection with reactive current up to 100%, while in Denmark it is not required [5].
Therefore an important step is advanced research of wind turbine behavior in extreme situations like voltage dips and short circuits. Since the production and testing of physical models is very complicated, the best solution for grid code drafting and for wind turbine designing is the development of virtual models.

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