# Adjustment of wind farms to new standards

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## Abstrac

Wind farms will have to adapt to new guidelines of Electrical System Operator, and current legislation and the one that will shortly be passed. These requirements are based on continuity of supply in case of voltage dips, reactive power control and power quality problems. The new generators, as well as the already existing wind farms, will have to adapt to these requirements.

In Spain, the installed wind power is more than 10.000 MW, and the PER (Renewable Energies Plan) aims to reach to 20.155MW between 2005-2010. The Autonomous Communities are planning to install a total amount of 40.000MW. From this information, the technical problems are derivate to evacuate and to handle this considerable amount of wind installed power, allowing the large-scale integration in the electrical network without producing destabilization of the electrical system.

To be able to do this feasible integration, have been established new standards more demanding. The fulfilment of the grid code requirements require to introduce new solutions and the development of new control strategies.

The challenge is to adapt older installations that cannot face the voltage dips and fulfil the new requirements. This problem extends to approximately 50% of the 20GW that will be working in 2010, supposing that all new installations will incorporate technology already brought up to date.

To settle this problem is proposed the use of DG-FACTS, these devices can help wind farms to solve problems such as:, reactive power capacity, frequency control, voltage control, active power curtailment and others.

## Key words

DGFACTS, Grid Code, Wind farm, Power Quality, Dips, DSTATCOM, DVR

## 1. Introduction

The European challenge of producing 12 % of primary energy consumption by means of renewable sources before 2010, would suppose an electrical production of 30,5 % of the whole one from renewable sources, being 10,6 % from wind. In Spain, the forecast to aim the goals established by the UE, in 2010 show in table 1.

| | 2010 | |
|---|---|---|
| Gross Electricity consume | 337.407 | |
| Total generation with Renewable | 102.259 | 30,3% |
| Wind Production | 45511 | 13,5% |

Table 1. PER prevision for 2010 (GWh)

The wind energy will be of 45.511 GWh, considering on average working period for all parks of 2258 hours per year (45511 GWh / 20155MW)

The current wind energy situation has permitted that wind energy production during 2006 has reached 22.198,67 GWh, 6,48% more than in 2005, covering the 8,8 % of total demand. The current wind energy situation has allowed the wind production to reach 8142 MW and cover the 31% of the demand. Because of these penetration levels, the system operator demands a higher security and reliability level in the wind farm installations.

Operation procedures have been established to guarantee the right performance of the electrical system, including the higher penetration of distributed generation, establish operation proceedings. These proceedings include the conditions that the wind farms have to fulfil in order avoid problems in the system operation. In general, wind farm installations affect frequency and voltage regulation, power system reserve, voltage dips, synchronous oscillations, etc.

Distribution and transmission networks of each zone show significant differences. These differences make the wind farms response to certain perturbations very different from each other. Thus, the way these perturbations affect the system stability varies strongly from zone to zone. Parameters such as grid and interconnection level, short-circuit power and power reserve of the electrical grids make necessary that requirements vary depending on the country.

In case of sudden voltage variations, the Transmission System Operators, TSO, have elaborated some general standards about the voltage dips that wind farms and especially wind generators have to fulfil. Organizations like the UCTE (Union for the Co-ordination of Transmission of Electricity) and FGW (Fördergesellschaft Windenergie e.V.) are working towards the standarization of the global requirements of wind installations that will give an answer to these problems manufacturers.

To accomplish these standards the producers of wind generators have to include new devices and develop new control strategies that mainly affect the electrical components, such as: generator, transformer, transformation centre and protections.

When wind installations accomplish the new standards, the system operator will see them as conventional generators. Thus, they will participate on the system stability, supplying a controlled energy with predetermined frequency and voltage levels, supplying a complementary voltage control service to the transmission grid and using correctly the reactive power generation and absorption resources.

## 2. Technical problems with wind farms

One of the most important serious problems of wind farms connected to distribution and transmission networks is the response to sudden voltage variations that are transmitted through the grid.

Electrical systems suffer perturbations due to the starting of big motors, coupling of transformers, capacitors switching, short-circuits due to fallen of trees or lightning. All these factors produce sudden variations that are transmitted all through the system with attenuation.

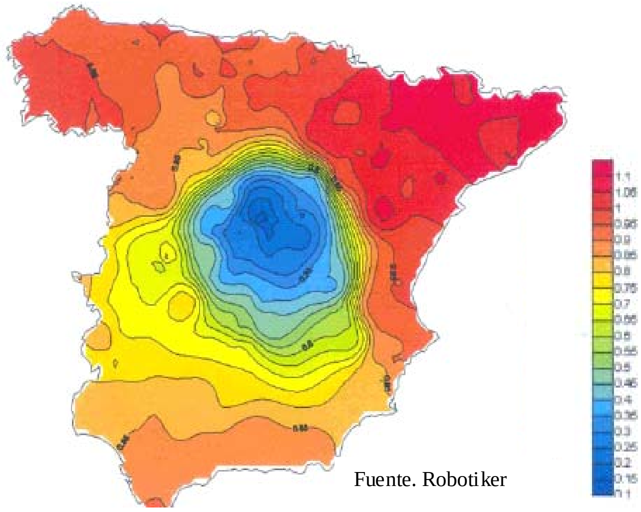


Fig.1 Short circuit incidence in SE Loeches

A good evaluation to know the stability degree of the transmission and distribution network is its response to voltage dips. Voltage dips are drops of voltage level due to a short-circuit located in another point of the grid. Depending on the impedance between the fault point and any other network point, a significant voltage drop may happen in this last point. The network faults can be classified into symmetrical faults (it happens in the three phases at the same time) and unsymmetrical faults (it happens in one or two phases).

Any of these fault type generates instabilities in the grid and in some cases, disconnections with lost of supply in big areas ( Figure 1).

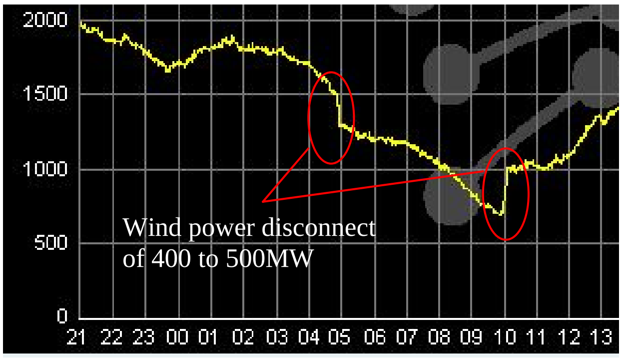


Fig.2. Wind power generation at 1/1/2004

These anomalies have produced a massive disconnection of the wind farms (Figure 2), because of the tripping of minimum voltage protections (Standard O.M of 1995). This situation can cause serious damages and collapse the system.

Recently, the 4$^{th}$ of November of 2006, a variation on the performance of the electrical power grid in Germany, meant the disconnection of 2.800 MW the operative wind power at that moment in Spain, due to a drop of frequency to 49,01 Hz ( Figure3).

The minimum frequency or under-frequency protection of the wind generators (Standard O.M. of 5th of September 1985) caused that disconnection. If the frequency had dropped to 49Hz, all wind farms would have gone out of service.

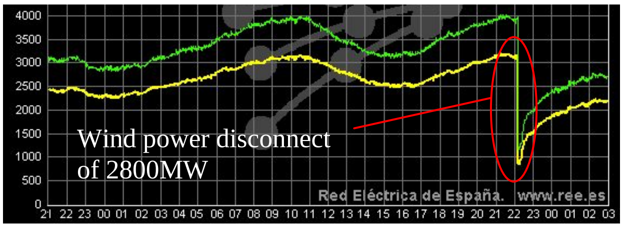

Fig.3. Wind power generation at 4/11/2006

## 3. New operability requirements for wind farms.

In the Standards already in use, it is compulsory for the generator to keep connected to the grid during any voltage dip measured in PCC the wind farm.

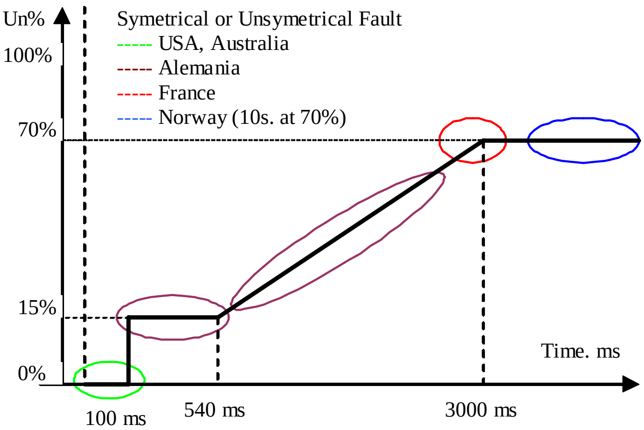

Fig.4. More restrictive requirements

To be able to compare the different standards, the sudden voltage drop in one phase and its recuperation in milliseconds (the voltage dip) can be simplified in a square waveform with a remanent voltage UR (percentage of the nominal). This voltage is maintained between 100 and 600 miliseconds and it recovers completely 1 or 3 seconds after. This way, we can compare the standards different countries, such as Spain, Germany and Denmark (Table 2).

| | Time | UR% |
|---|---|---|
| Germany | 540ms | 15 |
| Denmark | 100ms | 0 |
| Spain | 500ms | 20 |

Table 2. Grid Standards

These standards consider three-phase symmetrical faults, taking into account the voltage of each phase. In case of single-phase and two-phase faults to ground, voltage is not the same in the three phases, so the phase with the highest voltage has to meet the requirement for the biggest dip. In case of two-phase fault without ground, the lowest limit of the UR voltage can be of 60% of the UN being time equal to the one of the dip previously defined.

Graphically, the area where the disconnection of the wind generator cannot be made, is visualized. In Spain this is the brown area of the voltage-time curve, that defines the voltage dip area at the disconnection point.

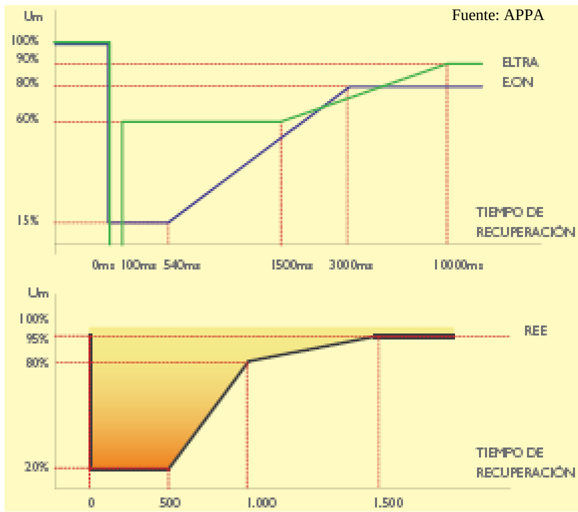

Fig. 5. Curves Voltage -Time of Dip's area

## 4. Standards in Spain.

The operation procedure P.O. 12.2 (minimum design, equipment, running and security requirements, BOE 1st March 2005) for the installations connected to the transmission network, obligate not to disconnect these generation installations when voltage dips happen due to short-circuits that have been correctly solved.

The operation procedure P.O.12.3 (Answer requirements for voltage dips in electrical wind installations) developed by REE (Red Eléctrica de España) about the continuity of supply, establishes the requirements that must be satisfied in order to guarantee the continuity and quality of supply when disturbances happens according to the fourth disposition by Royal Decree 436/2004.

Operation procedure P.O. 12.3 makes compulsory for the special regime generation installations, that use wind energy as the single source of primary energy (group b.2 of the Royal Decree 436/2004) to take the necessary design and/or control measures, so that all generation installations under its control that accomplish with the present procedure keep coupled to the electrical system without suffering disconnection due to correctly solved short-circuit that have caused voltage dips.

That means that these installations will have to hold on to three-phase, two-phase to earth or single-phase faults, in the Point of Common Coupling (PCC) to the transmission network, with profiles of indicated magnitude and duration. This means that in the brown part of the voltage/time curve, which describes the area of the voltage dips in the Point of Common Coupling, no disconnection should happen (Figure 5). In case of two-phase short-circuits isolated form earth, the level the residual voltage dips increases from 20% to 60% of the rated voltage.

The recuperation times are generally verified for a wind production lower than 5% of the short-circuit power at the connection point. In case the wind production overcomes this limit, the installations will have to be able to bear deeper voltage dips.

The P.O.12.3 demand that not disconnection happens when a disturbance without active or reactive power consumption occurs and also in fault and system recovering period, in the Point of Common Coupling.

Besides, wind farms should also help the system by giving reactive power, during fault period, recovering period as well as during the postfault period until the voltage recovers, so they should generated the biggest current possible (Itotal), never lower than the current there was before the fault. This is why active and reactive power are located on the shadowed area which defines the admissible operation during fault periods (150ms) and the recovering voltage, depending on the voltage of the Point of Common Coupling to the network (Figure 6).

However, punctual consumption is allowed when the conditions resumed in tables 3 and 4 are given.

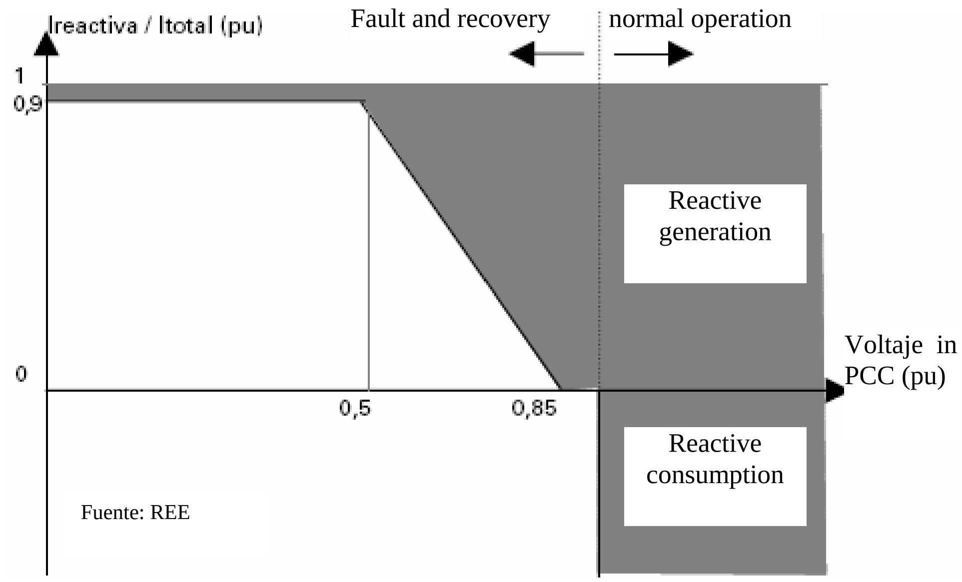


Fig.6. Admissible operation area during fault periods and the recovering voltage

| SYMMETRICAL FAULT (THREE-PHASE) | | | |
|---|---|---|---|
| | During fault period of 150 ms since the fault is produced | During the first 150 ms from post-fault. | Rest fault |
| Reactive Power per cycle (20 ms). | < 60% of the nominal power | < 60% of the nominal power | |
| Reactive Current per cycle (20 ms) | | Less to 1,5 times the corresponding current to registered nominal power | |
| Active Power | Punctual consumption | Punctual consumption | Additional consumption < 10% nominal power |

Table 3. Punctual consumption in Symmetrical Fault

| UNSYMMETRICAL FAULT (TWO-PHASE AND SINGLE-PHASE) | | |
|---|---|---|
| | During fault period of 150 ms since the fault is produced and during the first 150 ms from post-fault | Rest fault |
| Reactive Power. | Punctual consumptions | < to the reactive power equivalent to 40% of the nominal power registered during a period of 100 ms<br><br>< 40% of the nominal power registered per cycle (20ms) |
| Active Power | Punctual consumptions | < to the active power equivalent to 45% of the nominal power registered during a period of 100 ms<br><br>< 30% of the nominal power registered per cycle (20ms) |

Table 4. Punctual consumption in Unsymmetrical Fault

The P.O: 12.3 will apply to new wind farms connected to the electrical power system after the 1st of January of 2007. Older installations will have a transitory adaptation period established by the legislation in use.

*A. Incentive to fulfil the P.O. 12.3*

To enable wind farms to adapt their technologies, a bonus percentage for a four-year period has been established. Thus, the sector has a motivation to seek for solutions and so meet the requirements set by the P.O.123. The fourth additional disposition establishes a complement for supply continuity in case of voltage dips, for wind installations classified into b.2, that have the necessary technical equipment to guarantee the supply continuity, including the necessary coordination of protections. It also recognizes the right to receive a specific complement during four years that will be equivalent to the 5% of the medium or reference electrical tariff of each year defined by the Royal Decree 1432/2002.

The standard in Spain has recommended that, for installations after 1/1/2002, a three year period has to be given to adapt the installation to what the P.O. requires. For installations set before 1/1/2002 a five year period should be given. If after this period the adaptation has not been made the complement will not be received.

*B. Incentive by reactive power exchange*

The RD. 436/2004 establishes requirements for reactive power variable with the time of the day (peak, low and normal level). In each period, bonus and penalties are defined in percentage of the average price. This standard defines a transitory disposition that allows facilities to perceive a bonus of 4% of the average or reference price until January 2007, if they maintain a unity power factor at their point of connection.

| | COS PHI | PUNTA | LLANO | VALLE |
|---|---|---|---|---|
| INDUCTIVO | < 0.95 | -4 | -4 | 8 |
| | <0.96 y ≥0.95 | -3 | 0 | 6 |
| | <0.97 y ≥0.96 | -2 | 0 | 4 |
| | <0.98 y ≥0.97 | -1 | 0 | 2 |
| | <1.00 y≥0.98 | 0 | 2 | 0 |
| | 1.00 | 0 | 4 | 0 |
| CACPACITIVO | <1.00 y ≥0.98 | 0 | 2 | 0 |
| | <0.98 y ≥0.97 | 2 | 0 | -1 |
| | <0.97 y ≥0.96 | 4 | 0 | -2 |
| | <0.96 y ≥0.95 | 6 | 0 | -3 |
| | < 0.95 | 8 | -4 | -4 |

Tabla.5 Complement by reactive control

Currently, almost all installations receive a 4% complement for maintaining a unity power factor at the connection point. Just because wind generators have reactive power control or because static compensation systems with capacitor banks are used.

Besides, the way of considering reactive power is done per month. This is an advantage because statistically, positive deviations compensate the negative ones.

Starting from the 1st of January 2007, the payment for complement of reactive power can get to be superior to the previous one (until to 6%) but also inferior to 4%, since penalties will be applied if any means to the control the reactive power are not taken. The way to enter the reactive power will be based on 15 min period, which will force to make a dynamic control of the installation.

The requirements are stricter, because the periods in which the reactive exchange is accounted for are of a quarter of an hour and this make a dynamic control of the installation necessary. Thus, the following points have to be taken into account:

- The distance of the connection point to the grid, that makes necessary the consumption produced in the lines and transformers generally at full load, have to be compensated.

- The normal operating limits offered by the producers of wind generators has a power factor of 0,95 (inductive or capacitive) that does not compensate the total demanded reactive power.

## 5. Current situation

The new wind generators installed are capable of operating under the described requirements of PO. 12.3. Also a part of other existing ones, with some modifications, will be able to face voltages dips without needing to disconnect. The challenge is to adapt the older installations that cannot face the voltage dips and fulfil the new requirements.

Current wind farms have generators of three technologies. The distribution by technology, considering the installed power is the following:

- Asynchronous Generator of squirrel cage (34%)
- Doubly Feed Induction Machine (DFIM) (61%)
- Synchronous Generator + Full converter (5%)

Wind farms with asynchronous squirrel cage generators (Figure 7) are not able to fulfil the P.O. 12.3 standard and have to be disconnected in case of voltage dip. If they are not disconnected, the generator would be seriously damaged.

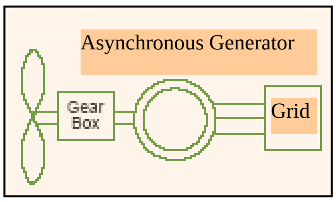


Fig.7 Asynchronous Generator

Doubly Feed Induction Machine (DFIM) type generators (Figure 8) previously installed must also be disconnected in case of voltage dips. However the ones that are being currently installed include a complete control system DFIM + Crowbar or an overdimensioned converter able to accomplish the requirements of the P.O. 12.3.

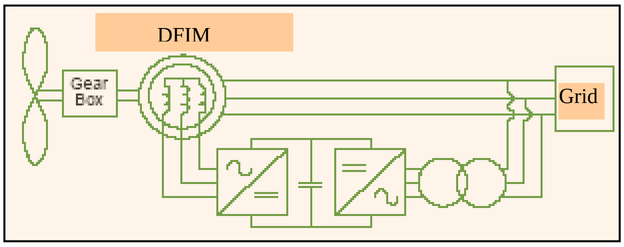


Fig.8 Doubly Feed Induction Machine (DFIM)

Finally, wind farms with synchronous generators of variable velocity and double converter between stator and the grid ( Figure 9), can handle voltage perturbations and short duration voltage dips without major problems.

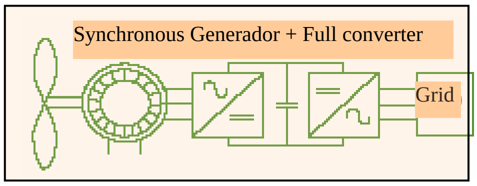


Fig. 9 Synchronous Generator + Full converter

Nowadays it is technically possible to reach capacities of more than 22000 MW from wind farms in Spain if the 75% of them are adapted to P.O. 12.3. and the 100% is managed by centralized buro. This problem extends to approximately 50% of the 20GW that will be working in 2010, supposing that all new installations will incorporate technology already brought up to date. Therefore retroactive modifications should need to be implemented

The possible solutions are multiple:

- Handle individually over the wind generators. It implies modifications in the old machines, control logic or incorporating power electronics or specify protections. In case of asynchronous generators whit squirrel cage, the technological updating is difficult and expensive.

- Handle over the wind installations. It implies to include DGFACTS devices connected in shunt to the wind farm substation (DSTATCOM) or dynamic voltage restorers (DVR) that make a serial compensation during voltage dips.

## 6. Application of DGFACTS devices

To solve the problems of the wind farms unable to fulfil the requirements of the O.P. 12.3, about bearing voltage dips without disconnecting of the system and co-operate with the system injecting reactive power after the fault is solved, a possible solution is the installation of DG FACTS systems at wind farms. This devices work co-ordinately with the generators, providing the reactive energy that the machines are unable to give (Asynchronous generators as well as DFIM).

The requirements of reactive power generation can cause that the currently installed generators and transformers designed to work with an unity power factor in generator terminals have to be redesigned and the heat energy evacuation systems increased. This last factor is some times impossible (dimension of the nacelle), or very difficult to achieve (too high environment temperature or farms far away of the connection point) or just too expensive.

The solution can be a DGFACTS device installation and in some cases it is the only possible solution.

From the possible alternatives of DGFACTS devices, shunt compensation (DSTATCOM) and a serial compensation (DVR) are described:

- **DSTATCOM.** (Distribution Static synchronous Compensator)

When the STATCOM device is applied in distribution systems it is called D-STATCOM (Figure 10). Its topology is the same one with small modifications and adaptations. So, it is oriented to a possible future extension of its possibilities in the distribution network at low and medium voltages, implementing functions as flicker damping, harmonic filtering, voltage dips and short interruption compensation.

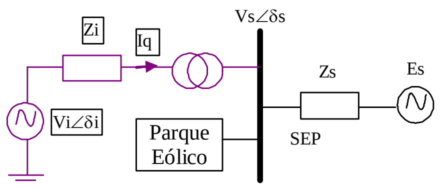


Fig. 10 DSTATCOM connection

- **DVR.** (Dynamic Voltage Regulator)

The SSSC version applied in distribution systems is the DVR (figure 11), that basically consists on a three-phase converter connected to the distribution line through a serial connected transformer, with a storage (or source) element in the DC side of the converter. A voltage to synchronize it with the line voltage can be injected of variable amplitude and phase. This allows active and reactive power exchange between the line and the storage device, compensates voltage dips in the network and improves the unbalances between phases.

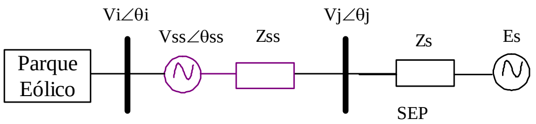


Fig.11. DVR connection

## 7. Conclusions

It is necessary to make the previsions of the PER 2005-2010 to guarantees the reliability and stability of the electrical system. This scenario should even allow the increase the prevision of wind farms installations in Spain and take into account the incorporation of Off-shore wind farms. Thus, the technological development and improvement of all existing installations, specially the old ones, is necessary. This should allow the installation to meet the present and future requirements and be economically feasible.

An option to keep the current structure of a wind farms and meet the new requirements is the installation, at farm level, of DGFACTS devices that work co-ordinately with the existing control systems and give solution to the current problems.

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