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Impact of Wind Farms in Power Systems

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1. Introduction

Beyond any doubt, we can consider century 21st as the one devoted to renewable energy. According to the International Energy Agency (IEA) (IEA, 2009) renewable sources shall provide about 35% of the European Union's (EU) electricity by 2020, and within this context, wind energy is set to contribute the most - nearly 35% - of all the power coming from renewable sources. This evolution is based on sustainability scenarios, like the BLUE one (IEA, 2008) related to the reduction of greenhouse emissions. However, the appropriate integration of such renewable energy into power system grids still presents major challenges to Power Systems Operators (PSO) and planners.

Nowadays wind energy has widely proved to be one of the most competitive and efficient renewable energy sources and, as a result, its use is indeed continuously increasing. As an example, in June 2010 total installed wind energy capacity around the world was 175,000 MW. Incorporation of wind energy units into distribution networks not only modifies power flows but also, in some situations could also result in under or over-voltage on specific points of the network (Jenkins, 2000), as well as could increase the cases of power quality problems and produce any type of alterations regarding voltage stability (Abdullah et al., 2010, Baghaee et al., 2009).

The process of high wind energy penetration requires the impact analysis of this new technology in power systems. In these terms, some countries have developed grid codes in order to establish the requirements of wind farms (WF) into power networks. Moreover, power network planning with high wind energy penetration requires the definition of several factors, such as: the best technology to be used, the optimal number of units to be connected and the optimal size to be chosen.

Currently a connected variable speed wind turbine to power systems by means of power electronics has the ability to supply reactive power to power systems. This capability allows wind turbines to participate in ancillary services as synchronous generators (Bhattacharya & Zhong, 2001), however, there are little works focusing on the participation of variable speed wind turbines in reactive power ancillary services (Amaris & Alonso, 2011; Bhattacharya & Zhong, 2001).

In this chapter, a review of wind farms impact on power networks and on Grid codes requirements are analyzed. An optimal allocation of wind farms has been selected in order to maximize the system loadability as well as to reduce active any power losses of the whole network by using an optimization algorithm where reactive power capability of Double Fed Inductor Generator (DFIG) is already included in the formulation. Finally, conclusions and future researches are shown.

2. Impact of wind energy on power systems

Incorporation of great amount of distributed resources, such as wind energy, has a significant impact on power network, which are mainly related to environmental, economical and reliability aspects.
Low wind penetration levels are usually accommodated in power networks considering that the network is passively controlled and operated.
Although there are several available tools to be used for wind power forecasting (González et al., 2004), wind energy is still considered as a non dispatchable and not centrally planned technology.
Impact of wind energy on power systems is thus focused on several issues related to security, stability, power quality and operation of power systems.

- Wind energy has several impacts on power flow that could lead to reverse power flow and, as a result, power systems operation will become more complex (Vilar, 2002). Moreover, power injection by wind farms may cause power losses in the distribution systems.
- All the utilities have to keep stable and reliable the voltage supply to the customers within specific limits of frequency and magnitude. Connection of wind farms may result in voltage changes, consequently, some countries have defined a higher short-circuit level at the connection point, normally between 20 and 25 times the wind farm capacity. There are already some examples of successful operation of power networks with a lower short circuit level (Jenkins et al., 2000).
- Power quality is related to voltage variation and harmonic distortion in the network. However, the incorporation of wind energy in power networks could affect the quality of the supplied voltage to the customers. To reduce this impact, nowadays, variable speed wind turbines equipped with power electronics are widely used in wind energy conversion. Power electronics increase power quality because they raise the harmonic distortion.
- Protection system is also affected by wind farms since the incorporation of wind power injection alters power flows; so that conventional protection systems might fail under fault situations.
- In the past, power network was passive operated and kept up stable under most circumstances. However, this statement is no longer valid if considering an increase of wind energy penetration. Recently, new requirements for wind units have been designed in order to keep power networks stable under several disturbances, such as low voltage ride through capability.

2.1 Reactive power grid code requirements

Countries with high wind energy penetration have developed grid code requirements in order to increase wind energy penetration and to improve the reliability and security of the network (Tsili & Papathanassiou, 2009). The most important aspects are related to active and reactive power regulation, power quality and low voltage ride through capability (Martínez et al., 2007) .
Nowadays, transmission systems operators (TSO) are demanding wind turbines to behave as synchronous power plants. New advances in the field of wind technologies have shown that wind generators offer regulation capabilities as conventional plants.

Some grid codes require wind farms to offer reactive power capability in order to maintain reactive power balance in power network (reactive power compensation) and to improve voltage level even in a remote node (Singh, 2009). Fig. 1 and 2 show the requirements of common grid code for power factor in terms of voltage deviations.
From country to country, there are some differences to be observed. According to German grid code (E.On, 2006), wind farms will work with leading or lagging power factor under overvoltage situations. In the case of English grid code (National Grid Electricity Transmission, 2008), wind farm must be able to supply full reactive power capacity within ±5% of nominal voltage, for voltage levels of 400kV and 275kV. English code requires an automatic voltage control at the point of connection of grid farm. Nordic grid code (Nordel, 2007) demands wind farms to have a reactive power output control in order to regulate the voltage at the point of connection.

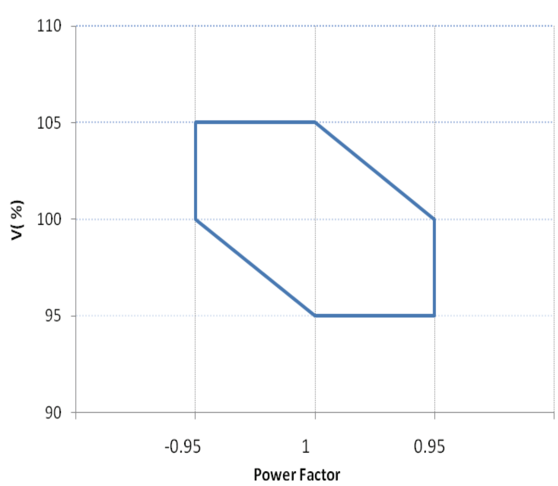

Fig. 1. Typical requirements for power factor in terms of voltage deviation

Fig. 2 shows the reactive power requirements in terms of power factor for different grid codes. According to ESB (ESB, 2007), Iris code requirements establish that wind farm must be able to work with a minimum power factor of 0.835 leading or lagging for active power outputs level around 50% of the rated one. Hydro-Quebec (Hydro Quebec, 2006) requires those wind farms with an upper rate form 10 MW to offer voltage regulation within the range of 0.95 leading or lagging power factor. Moreover, this grid code establishes that wind farms must contribute to voltage control under normal, abnormal or dynamic operation conditions. Canadian code, AESO (AESO, 2004), emphasis that voltage and reactive power regulation will be assessed at the low side of wind farm grid transformers. AESO grid code requirements are divided in two different operation conditions: for continuous operation the power factor range is set between 0.95 lagging and 0.9 leading; in the case of dynamic operation a range between 0.95 capacitive and 0.985 inductive is required. Both ranges are established in terms of power output. On the other hand, Danish grid code (Eltra, (Energinet, 2004a, 2004b)) requires wind farm to support limited reactive power by a band, which corresponds to orange line and dot-line of Fig. 2. These lines represent a power factor of 0.995. Furthermore, reactive power control can be implemented not only at each wind units but also centrally at wind farm level.
Some grid codes establish a minimum reactive power control; this requirement is related to the capability of wind units to work within a power factor range between 0.95 leading and

0.95 lagging. Modern wind units use variable speed generators connected to the grid by power electronics converters. This converters offer the possibility to control reactive power outputs of wind units by varying voltage magnitude and frequency. DFIG are the most popular employed generator in wind units, and could offer dynamic reactive power control due to the grid side converters. This converter capacity is within the range of 20% - 30% of the machine rate.

3. Voltage control and reactive power support as ancillary services

One of the main issues is the Reactive Power Management which entails the requested operation and planning actions to be implemented in order to improve the voltage profile and the voltage stability in power networks (Raoufi & Kalantar, 2009). An efficient reactive power planning could be obtained by choosing an optimum location of var sources during the planning stage, whereas efficient reactive power dispatch could be achieved by scheduling an optimum regulation of the voltage set point at the generators connection point and at the var settings during the reactive power dispatch (Hugang, 2008).
Current power systems are working close to this operational stability limit, so distribution and transmission system operators (DSO and TSO) are required to wind energy to work as a conventional power plant and contribute to ancillary service such as reactive power control. Actual wind units are considered such as a non-dispatchable energy so, in many cases, they act as a PV or PQ nodes for load flows and reactive power studies (Raoufi & Kalantar, 2009). Some wind farm technologies, such as DFIG, have the ability to supply reactive power, so it could be possible to offer this reactive power capability to TSO and DSO in order to improve voltage stability of power network.

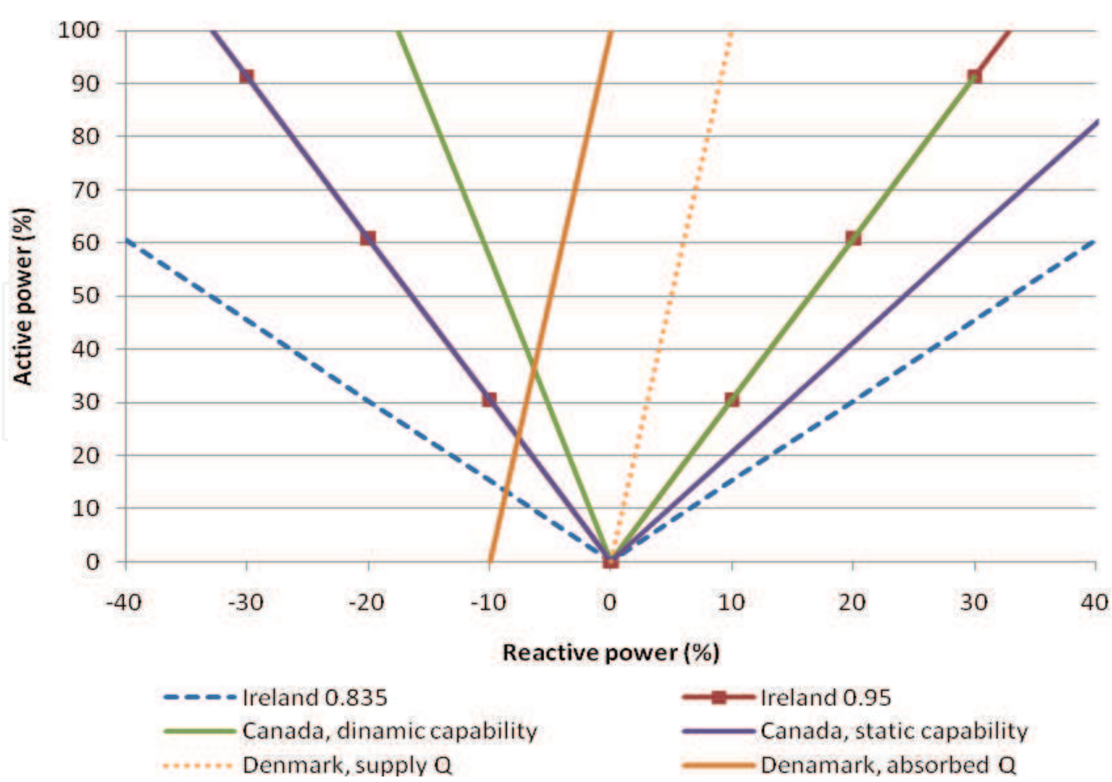

Fig. 2. Reactive power requirement for several grid codes.

3.1 Voltage stability

Voltage Stability is defined as the ability of a power system to maintain steady-state voltage at all buses in the system after being subjected to a disturbance from a given initial operating condition (Kundur, 1994). In the literature, two voltage stability problems are analysed:

- Estimation of the maximum loadability.
- Computation of the critical power system loading that could lead to voltage collapse.

Voltage stability is usually represented by P-V curve (Fig. 3). In this figure the noise point is called the point of voltage collapse (PoVC) or equilibrium point. At this point, voltage drops rapidly with an increase of the power load and subsequently, the power flow Jacobean matrix becomes singular. Classical power-flow methods fail to converge beyond this limit. This failure is considered as an indication of voltage instability and frequently associated with a saddle-node bifurcation point (Kundur, 1994).

Although voltage instability is a local phenomenon, the problem of voltage stability concerns to the whole power system, becoming essential for its operation and control. This aspect is more critical in power networks, which are heavily loaded, faulted, or with insufficient reactive power supply.

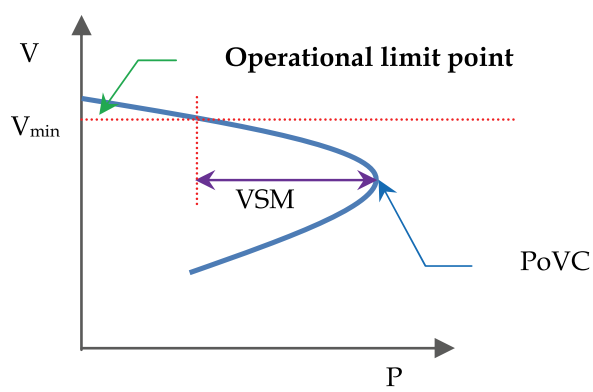

Fig. 3. P-V curve

In power networks with huge amount of wind penetration levels, the role of voltage stability is of great importance due to the lack of reactive power contribution of many wind generators as well as their integration into weak networks.

Wind farms equipped with variable speed are presented as a good alternative to alleviate problems related to voltage stability. Therefore reactive power planning in large power systems has become a particularly important point in recent years since it is necessary to develop new techniques to solve any problem that may arise.

3.2 Reactive power planning

Optimal allocation of Var sources happens to be one of the most challenging problems in power networks. The incorporation of shunt reactive power compensation devices in power networks provides voltage support, and reduces the danger of voltage instability or voltage collapse. In the past years, locations of Var sources were barely determined by estimation or by approach (Zhang et al., 2007); however, neither of both methodologies proved to be effective.

In this work, optimal locations of wind farms with reactive power capability are determined by using Genetic algorithms (GA). The methodology proposed could be successfully applied to any renewable energy resources inverted based unit offering reactive power capability (DFIG or PV).

3.3 Reactive power capability of wind units

Power systems with great amount of wind energy require a dynamic reactive power support to the network. Variable speed wind turbines, such as DFIG or full power converter technology, are connected to the grid by electronic power converters and, consequently, they have the capability to provide voltage support to the network as well as to fulfill the grid code requirements (Amaris & Alonso, 2011; Bhattacharya & Zhong, 2001).
The main drawback of this methodology is that the reactive power capability of DFIG's Power Converters is not being considered since it only incorporates reactive power capability limits of wind generators according to a maximum cos(φ) or a fixed regulation band (Vijayan, 2009)-(Sangsarawut, 2010), and so that this representation does not allow to take full advantage of the reactive power injection from the wind turbine.
In this work, a better wind turbine model is proposed that does take into account the actual available reactive power capability for each working operation point. The proposed formulation could be included indeed in any modified power flow analysis for optimum reactive power dispatch. At the same time, this methodology will enable to regulate the reactive power injection either locally, at the wind farm, or globally, in the whole network. As a result of the optimum and coordinated reactive power dispatch, the voltage stability in the power network will be significantly improved and enhanced.

3.3.1 Reactive power injection from DFIG

Double Fed Induction Generator is composed of a wound induction machine in which the stator is directly connected to the grid and the rotor is connected via slip rings to a two back-to-back converters as shown in Fig. 4. The electronic power converter allows controlling the active and the reactive power. Moreover, the Grid Side Converter (GSC) of these generators offers reactive power capability, so DFIG could work as a reactive power source injecting reactive power from the machine and from the GSC converter. According to this reactive power capacity, TSO and DSO could include in their voltage control strategies the extended reactive power capability of DFIG in order to improve the voltage stability of the whole power system.
DFIG power capability has been traditionally represented in a PQ diagram (B. Singh & S. N. Singh, 2009; Ullah & Thiringer, 2008) and it is well known that reactive power capability of DFIG is limited by:

- stator current (heating of stator coils),
- rotor current (heating of rotor coils), and
- rotor voltage (limiting the rotor speed).

The GSC could be used to control the reactive power and to improve the total reactive power capability of the wind turbine (B. Singh & S. N. Singh, 2009; Ullah & Thiringer, 2008) This potential usage represents a key aspect since it may be quite useful to system operators in order to perform a coordinated reactive power management in the whole power network.
The proposed methodology could be applied in the available converter designs not being necessary to perform any physical modification to the current DFIG commercial converters.

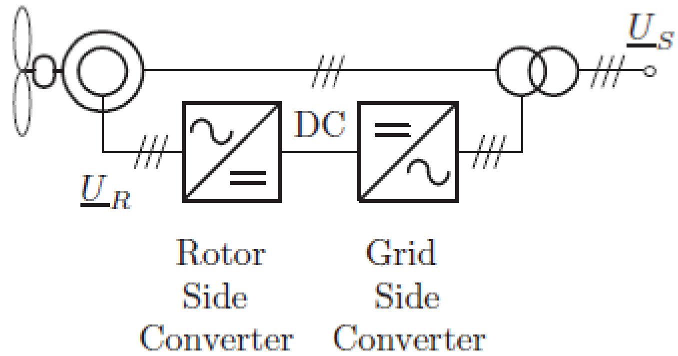

Fig. 4. DFIG Wind Turbine

Therefore, the grid side converter could be treated as a reactive power source dynamically controlled.
The total reactive power injected to the grid will be composed by the superposition of two components, the reactive power injected by the induction machine (stator) and the reactive power injection from the grid side converter (Amaris & Alonso, 2011).

$$Q = Q_S + Q_{GSC} \tag{1}$$

The reactive power capability of the GSC can be computed by:

$$Q_{GSC} = \pm\sqrt{(V_{GSC} I_{GSC})^2 - P_R^2} = \pm\sqrt{S_{GSC}^2 - P_R^2} \tag{2}$$

Where V_{GSC} and I_{GSC} are AC side voltage and current of GSC, and P_R is the active power.
The resulting PQ capability curve is shown in (Amaris & Alonso, 2011). This extended capability would be very useful to system operators not only by performing voltage stability or contingency analysis, but also in every situation where power reactive reserves are critical factors to keep the network stable.

4. Genetics algorithm

Metaheuristic techniques have come up to be a good alternative to face the question of optimal management of reactive power, which involves operation, location and optimal size of these units. The main reason is because of their ability to reach a satisfactory solution of the problem; furthermore they are very fast and they have low computation complexity. Among all these techniques genetic algorithms stand out because of their speed of calculation and simplicity, sum up to their robustness .and the fact that they can find a global optimal solution in complex multi-dimensional search spaces (Díaz & Glove, 1996).
Genetic algorithms are a family of computational optimization models invented by Holland (1975) (Holland, 1975) and firstly implemented by Goldberg (1989) and Hopgood (2001) (Goldberg, 1981) to solve both constrained and unconstrained optimization problems. GA are based on natural evolution process, as it could be deduced from the employed operators, which are clearly inspired by these natural sequences, and from the main driver of the GA, which would be defined as a biological selection. One of the main advantages of the GA is that they work with a set of possible solutions, called population, which will be modified on each step (generation) of the algorithm according to genetic operators.

The main advantages of GA to be stressed over conventional optimization methods are:

- They do not need any prior knowledge about issues such as space limitations or any other special properties of the objective function of the problem to be optimised.
- They do not deal directly with the parameters of the problem. They work only with codes, which represent the parameters and the evaluation of the fitness function to afterwards, be able to assign a quality value to every solution produced.
- They work with a set of solutions from one generation to the next making the process likely to converge into a global minimum.

The solutions obtained are randomly based on the probability rate of the genetic operators such as mutation and crossover.
This technique is very useful for solving optimization problems such as the one proposed in this paper. The optimisation problem would be formulated as:
Min F(x)
Subject to:

$Aeq(x) = Beq$

$A(x) \leq B$

$x \in S$

where:

- F(x) is the objective function to be optimised
- Aeq is equality constraint
- A is inequality constraint
- x is the vector of variables
- S is the search space.

4.1 Representation

A population is formed by a set of individuals that correspond with a possible solution of the problem. Each individual is represented by a set of variables to be optimized and they are usually represented in a string form called chromosome.
Indeed, the method of chromosome's representation has a major impact on the performance of the GA. There are two common representation methods for numerical optimization problems: binary string or vector of integers and real numbers. Each element (bit, integer or real number) in a chromosome is called gene.

4.2 Initial population

Instead of facing a single solution each time, GA works with a group of initial solutions to start the process of optimization. This initial population could be created in two ways. The first one consists in using randomly produced solutions which have been preciously created by a random generator; this method would be preferable in those cases in which no prior knowledge existed. The second method employs a set of known solutions able to satisfy the requirements of the problem. This method does require a previous knowledge about the optimization problem and converges to an optimal solution in less time than the first one.

4.3 Fitness evaluation function

The formulation of the Fitness Function (FF) is a major aspect of the optimization problem. FF assigns a quality value to each individual of the population depending on how well the solution performs the desired functions and satisfies the given constraints. Moreover, it allows to determinate which individuals of the population will survive for the next generation. The fitness values of individuals in a given population are employed to drive the evolution process. In the case of a GA, this calculation must be automatic and the problem lies in how to devise an effective procedure to compute the quality of the solution. These characteristics enable the GA to present excellent results even when optimizing complex, multimodal or discontinuous functions.

4.4 Genetic operators

After implementing the fitness function, three basic genetic operators are applied to the population, in order to create a new population: selection, crossover and mutation. All of these three generators are inspired by natural process, as we pointed out above; however, it is not necessary to employ all the operators in a GA simultaneously. The choice or design of the operators depends on the problem to be analyzed and the representation scheme to be employed.

4.4.1 Selection

The aim of the selection procedure is to copy individuals whose fitness values are higher than those whose fitness values are lower in the next generation. Besides this, the operator allows transmitting the best individual's genetic material in the next generations in order to drive the search towards a promising area and finding optimal solutions in a very short time.

4.4.2 Crossover

This operator is considered the most important one of GA method because it is responsible for the genetic recombination. It is used to create two new individuals (children) from two existing ones (parents), which are picked from the current population through the selection operator. There are several ways of doing this, but the most common crossover operations are: one point, two point, cycle and uniform crossovers.

4.4.3 Mutation

During this procedure all individuals of the population are checked, gene by gene, and this gene value is randomly reversed according to a specified rate. This operation introduces new information in the algorithm to force it to search new areas. Additionally, this operator helps GA to avoid premature convergence due to genetic material that has been lost during the selection operation. In addition to that already mentioned, it helps to find out a global optimal solution.

4.4.4 Control parameters

The most important control parameters of a simple GA are:

Population size: It allows a better exploration of the solution space during the search, so that the probability of convergence to the global optimal solution will be higher.

Crossover rate: It determines the frequency of the crossover operation. It is used to discover a promising area at the start of the simulation.

Mutation rate: It controls the mutation operation. In general, an increase in the mutation rate helps the GA to reach the global solution avoiding the local minimum. However, if this mutation rate parameter is too high, it could result in a wide diversity in the population and, so that the global solution will not be reached.

5. Improve management of power systems by optimal allocation of wind farms

Currently, grid code requirements of wind farms are demanding wind turbines to offer reactive power capabilities at the connection point (Energinet, 2004a; National Grid Electricity Transmission, 2008). Moreover, they must be able either to inject or to absorb reactive power according to the system operator's commands. Although there is no standard grid code yet, all national grid codes agree to include the reactive power injection from wind turbines in both normal and fault situations.

Optimal allocation and reactive power injection of wind farms equipped with DIFG unit is essential for optimal management of power systems with high wind penetration level.

In this section, a GA for optimal reactive power planning is developed. Optimal allocation and reactive power injection of wind units are determinate in order to maximize loadability of the power system and minimize real power losses of the whole network. Optimal allocation lets improve voltage stability of distribution network.

5.1 Optimization methodology for reactive power planning

5.1.1 Encoding

In the present work, value encoding of chromosomes has been used where the placement problem is modelled by using real numbers. The target is where to locate three wind farms and what is the reactive power injection of each wind farm. Each chromosome has seven genes that represent the variables of the system. The first one represents the loadability parameter of the system (λ); the other ones represent the bus number location in which wind farm could be connected and the var injection from each wind farm (Table 1).

Gen 1	Gen 2	Gen 3	Gen 4	Gen 5	Gen 6	Gen 7
λ (p.u.)	$\#WF_1$	Q_1 (Mvar)	$\#WF_2$	Q_2 (Mvar)	$\#WF_3$	Q_3 (Mvar)

Table 1. Chromosome structure

5.1.2 Fitness function

According to the objective of the work, the Fitness Function deals with the loadability of the system and the real power losses. For this purpose, a load change scenario is considered, in which P_d and Q_d can be represented as:

$$P_d = P_{d0}(1+\lambda) \tag{3}$$

$$Q_d = Q_{d0}(1+\lambda) \tag{4}$$

Where:

- P_{d0} and Q_{d0} are the original power load (base case).
- λ represents the load parameter.
  (λ =0 corresponds to the base case).

In this scenario of load change, λ_{max} corresponds to the maximum power transferred under voltage constraints.
To maximize the loadability of the system through the load parameter λ, and minimize real power losses, the FF function used is:

$$FF(x) = \tfrac{1}{2}(1-\lambda) + \tfrac{1}{2}LOSS \tag{5}$$

$$LOSS = \frac{P_{loss}}{P_{loss_{ini}}} \tag{6}$$

$$P_{loss} = \sum_{k \in N_e} g_k (V_i^2 + V_j^2 - 2V_i^2 V_j^2 \cos\theta_{ij}) \tag{7}$$

Where:
- x is a vector of variabl $Q_d = Q_{d0}(1+\lambda)$ es: load parameter, bus connection and var injection.
- λ value depends on voltage constraints violation.
- P_{loss} and $P_{lossini}$ are the real power losses for optimal allocation and var injection and for base case, respectively, calculated with eq. 7.

5.1.3 Constraints
The main constraints that are considered in the optimization process are the following:
- Voltage level at all buses should be held within established limits.
- Active and reactive power generation are limited by the generator capabilities.

5.1.4 Optimisation formulation
Tacking into account the FF objective and constraints equations, the optimization process flowchart is shown in Fig. 5 and the optimization problem can be formulated as:

$$MinF(y) = \tfrac{1}{2}(1-\lambda) + \tfrac{1}{2}LOSS \tag{8}$$

Load flow constraints:

$$\Delta P_i = P_{gi} - P_{di} - P_i \tag{9}$$

$$Q_i = V_i \sum_{i=1}^{N} V_k (G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) \quad \Delta Q_i = Q_{gi} - Q_{di} - Q_i \tag{10}$$

Where:

$$P_i = V_i \sum_{i=1}^{N} V_k (G_{ik}\cos\theta_{ik} + B_{ik}\sin\theta_{ik}) \tag{11}$$

$$Q_i = V_i \sum_{i=1}^{N} V_k (G_{ik}\sin\theta_{ik} - B_{ik}\cos\theta_{ik}) \tag{12}$$

Voltage constraints:

$$V_{i,\min} \le V_i \le V_{i,\max} \qquad i = 1, 2, \ldots, N_B \tag{13}$$

Active and reactive power generator:

$$P_{gi,\min} \le P_{gi} \le P_{gi,\max} \qquad i = 1, 2, \ldots, N_G \tag{14}$$

$$Q_{gi,\min} \le Q_{gi} \le Q_{gi,\max} \qquad i = 1, 2, \ldots, N_G \tag{15}$$

Point of connection:

$$PC_{gi,\min} \le PC_{gi} \le PC_{gi,\max} \qquad i = 1, 2, \ldots, N_G \tag{17}$$

Limits of power flow at each branch

$$S_l \le S_{l,\max} \tag{19}$$

Reactive power capabilities constraints:
Stator side constraints:

$$I_s \le I_{s,\max} \tag{20}$$

$$V_s \le V_{s,\max} \tag{21}$$

Rotor side constraints:

$$I_R \le I_{R,\max} \tag{22}$$

$$V_R \le V_{R,\max} \tag{23}$$

Grid side converter constraints

$$S_{GSC} \le S_{GSC,nominal} \tag{24}$$

5.2 Case study

The optimization strategy has been applied to a 34 buses distribution power system Fig. 6 (Salama & Chikhani, 1993). Three wind farms equipped with DFIG have been optimal allocate and var injection is optimal management in order to maximize loadability of the systems and minimize real power losses.

Four different scenarios have been studied, the first one represents the base case without WF, the second scenery incorporate 3 WF to the distribution networks without reactive power capability, the third one incorporate reactive power capability of WF corresponds to a cosφ=0.95 leading or lagging, finally the last scenery take into account the extended reactive power capability of DFIG incorporating reactive power capability of grid side converter.

Table 2 shows the results obtained by the algorithm: column 3 and 4 are the bus number where each WF should be located and the reactive power injected by each one. Column 5 to

8 represents voltage stability parameters: the maximum loadability (λcrit.) for low limit operational voltage (0.95 p.u.), percetange of loadability increase of the power system, maximum loadability in the point of voltage collapse and increase in voltage stability margin define as the distance between the operational point and the point of voltage collapse. Finally, column 9 and 10 show the real power losses and percentage decrease of real power due to optimal allocation of WF.

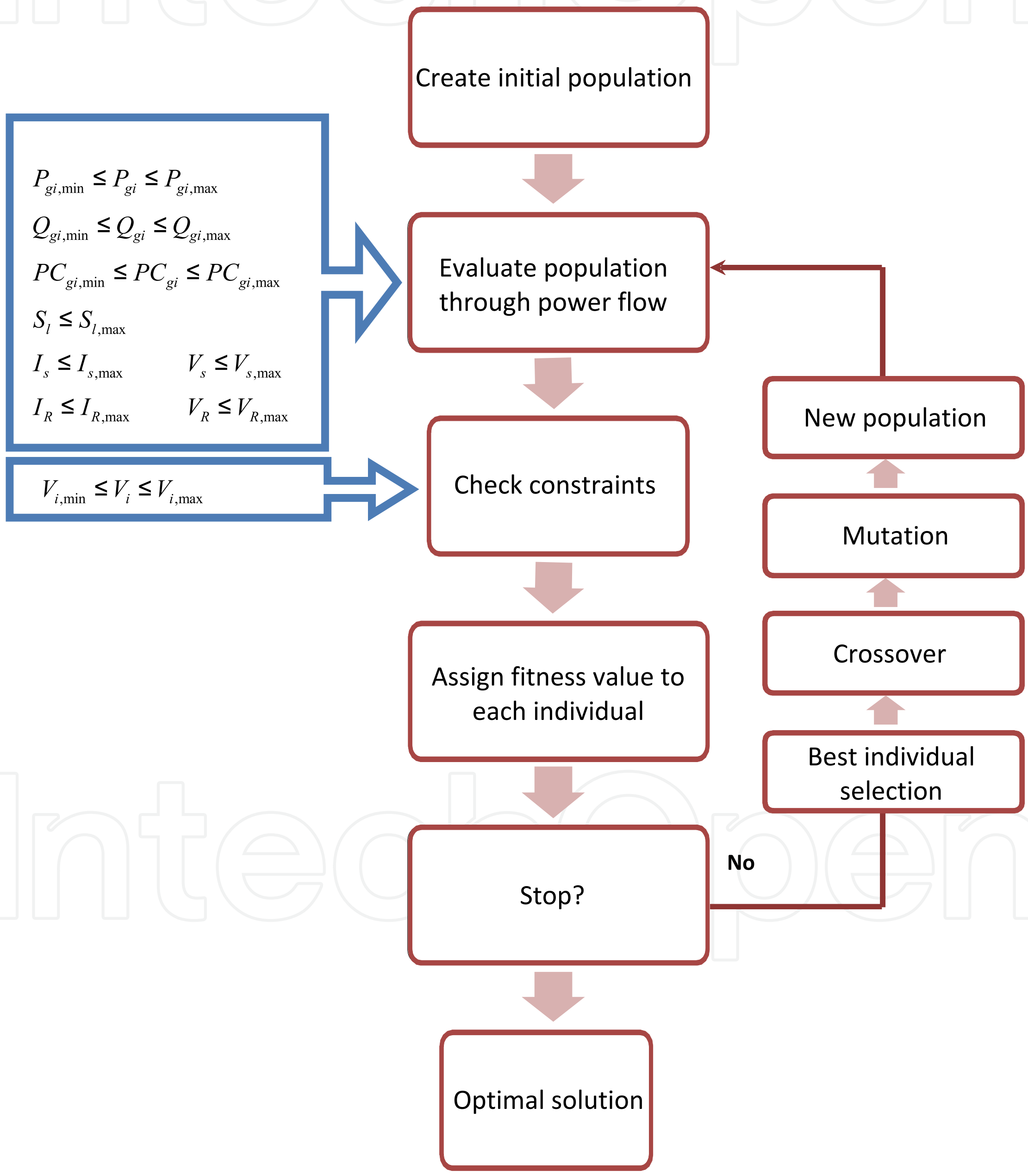

Fig. 5. Flowchart of optimization process

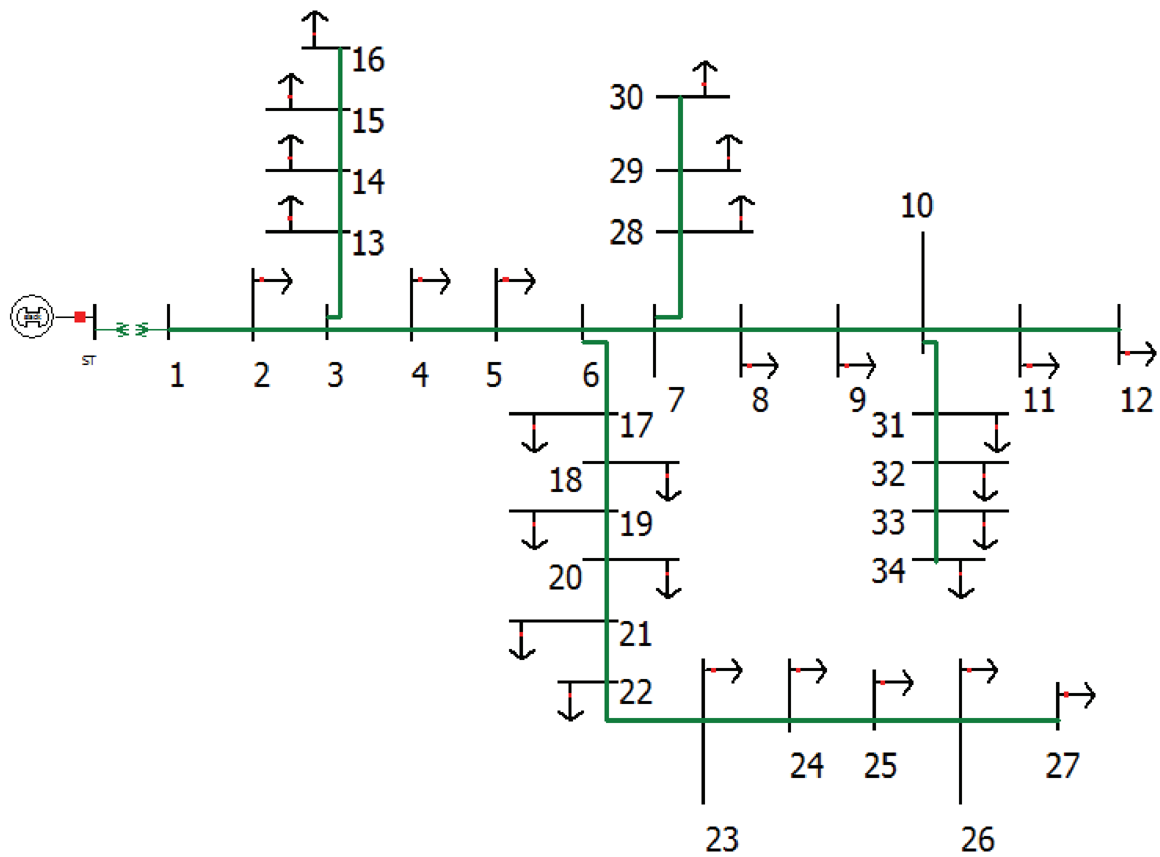

Fig. 6. Modified IEEE 34 bus system

		GA solution		Stability parameters				Losses	
		# Bus_{WF}	Q_{WFinj} (Mvar)	$\lambda_{crit.}$ (p.u.)	Δload-ability	$\lambda_{max.}$ (p.u.)	ΔVSM	P_{loss} (Mvar)	ΔP_{loss}
Scenery 0	No WF	-	-	0	-	2.8	-	0.64	-
Scenery 1	3 WF Q=0 MVar	9	0	0.26	26%	3.3	15.15%	0.44	31.25%
		25	0						
		26	0						
Scenery 2	3 WF $Q=Q_g$	24	0.059	0.285	28.5%	3.4	17.65%	0.37	42.19%
		26	0.33						
		33	0.243						
Scenery 3	3 WF $Q=Q_g+$ $+Q_{GSC}$	24	1.026	0.387	38.7%	3.5	20%	0.31	51.56%
		27	0.979						
		33	1.021						

Table 2. Results of GA

In Table 2 it must be noted that increasing in reactive power capability of WF leads to an increase in the loadability of the system, and reduce real power losses. Furthermore, as much as reactive power injection of wind farms longer the voltage collapse point.
Fig 7 shows the voltage profile at the base loadability of the case studied (λ=0), at the base case and after the application of the optimisation algorithm for the proposed scenarios. It is shown that the optimal management of wind farms in distribution networks with high wind energy enhances the voltage profile and increases the maximum loading of the system. Most specifically, if adding three wind farms with extended reactive power capability to power systems, the maximum loading of the system for operational voltage limit will increase by 38.7%, the real power losses decrease in a 51.56% and voltage stability margin is increased 20% (Fig. 8).

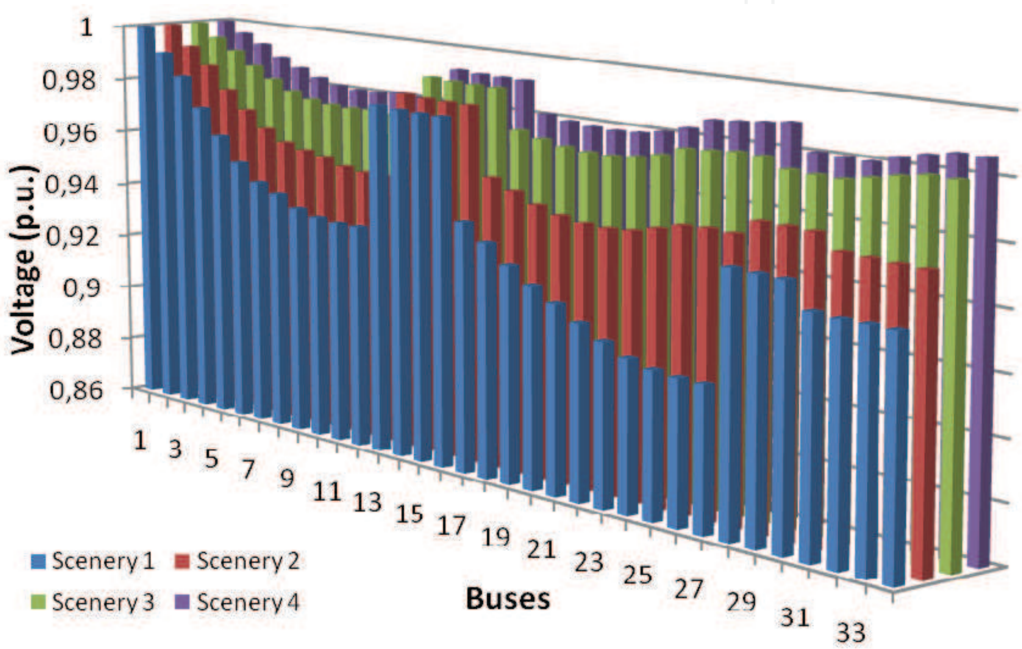

Fig. 7. Voltage profile of the modified IEEE 34 bus system

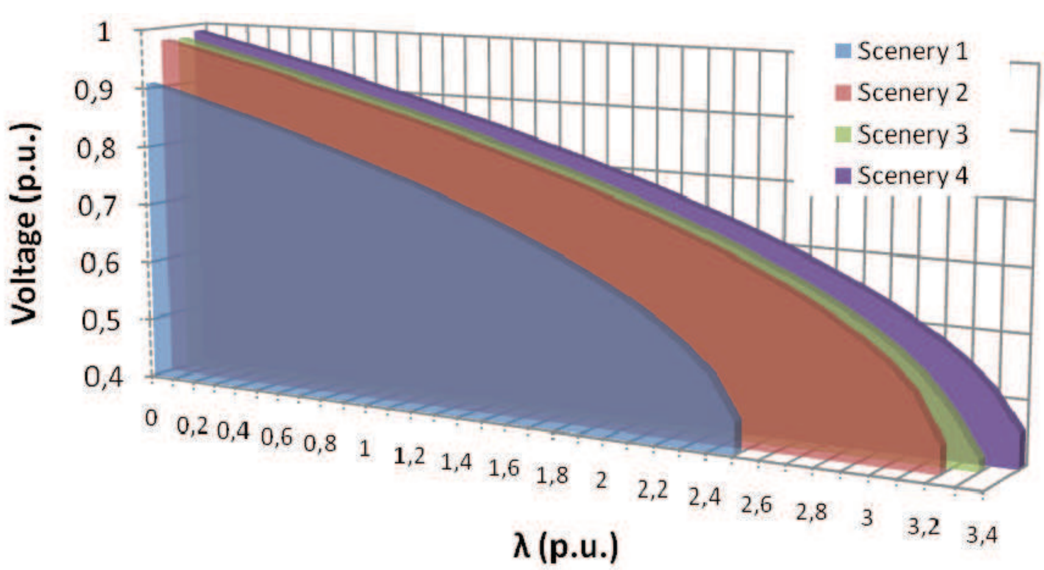

Fig. 8. Maximum loading parameter and Voltage Stability Margin

6. Conclusion

Nowadays, wind energy plays an important role in the generation mix of several countries. The major impacts resulting by the use of wind energy are related to reverse power flow, harmonics and voltage/reactive power control. At the same time, System Operator requires behaviour of wind generators similar to the conventional plant, and thus wind farms must be able to control active as well as reactive power according to the System Operator's commands. At this moment, variable speed wind turbines use electronics power converters that are capable to offer a regulation of both, active and reactive power. In this work, an optimization problem is shown in order to deal with the optimal reactive power planning of a power network with high wind energy penetration. The optimization process is based on Genetic Algorithm and is able to find out the optimal location of wind farms in order to maximize the voltage loadability and to minimize any active power losses of the whole network. The study results show that an optimal allocation of wind farms, sum up to an optimal reactive power dispatch of these ones, improve indeed voltage stability of power systems and minimize active power losses too.

7. Future researches

The methodology proposed could be extended to work with other types of wind generators, such as full power converter. Furthermore, incorporation of fixed speed wind units in power system, equipped with FACTS devices to control reactive power, could lead a very interesting work on optimal reactive power between conventional var sources and reactive power capabilities of variable speed wind turbines.
In this work stability and economic issues are only taking into account in the optimization process. By the way, it is important to notice that wind energy, as a renewable energy, lets decrease CO2 emissions. Therefore, an interesting future research is the incorporation of reduction of CO2 emissions in the optimization problem. The optimization problem lets distributed the generation between the conventional plants and the wind farms in order to improve technical, economic and environmental issues.

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9. References

Abdullah, N.R.H., Musirin, I. & Othman, M.M. (2010). Transmission loss minimization using evolutionary programming considering UPFC installation cost, International Review of Electrical Engineering, Vol. 5, No. 3 Part. B, (May.-Jun. 2010), pp. 1189-1203, ISSN 1827-6660.

AESO. Wind power facility technical requirements. Revision 0. Alberta Electric System Operator (AESO), Canada, November, 2004.

Amaris, H. & Alonso, M. (2011) Coordinated reactive power management in power networks with wind turbines and facts devices, Energy Conversion and Management, Vol. 52, No. 7, (Jul. 2011), pp. 2575-2586, ISSN 0196-8904.

Baghaee, H.R. , Mirsalim, M., Kashefi, A. & Gharehpetian, GB. (2009). Optimal allocation of multi-type FACTS devices to improve security and reduce the losses and fault level using multi-objective particle swarm optimization, International Review of Electrical Engineering, Vol. 4, No. 6 Part. B, (Nov.-Dec. 2009)¸pp. 1326-1335, ISSN 1827-6660.

Bhattacharya, K. & Zhong, J. (2001) Reactive power as an ancillary service, IEEE Transactions on Power Systems, Vol. 16, No. 2, (May. 2001), pp. 294–300, ISSN 0885-8950.

Díaz, A. & Glove, F. (1996). Optimización Heurística y Redes Neuronales en Dirección de Operaciones e Ingeniería, Paraninfo, ISBN 8428322694, Madrid. (in spanish).

E. On. Grid code-high and extra high voltage. E.On Netz Gmbh, Bayreuth, Germany, April 2006.

Energinet. Grid connection of wind turbines to networks with voltage above 100 kV, Regulation TF. 3.2.6. Energinet, Denmark, May 2004.

Energinet. Grid connection of wind turbines to networks with voltage above 100 kV, Regulation TF. 3.2.5. Energinet, Denmark, December 2004.

ESB. Grid code-version 3.0. ESB National Grid, Ireland, September 2007.

Goldberg, D.E. (1989) Genetic algorithms in search, optimization and machine learning, Adddison-Wesley, ISBN 0201157675, Massachusetts.

González, G. et al. (2004). Sipreólico, Wind power prediction tool for the spanish peninsular power system. Proceedings of the CIGRE 40th General Session & Exhibition, Paris, France.

Holland, J. (1975) Adaptation in Natural and Artificial Systems: An Introductory Analysis with Applications to Biology, Control, and Artificial Intelligence, Univ. of Michigan Press, ISBN 0262581116, Cambridge.

Hugang, X., Haozhong, C. & Haiyu, L. (2008) Optimal reactive power flow incorporating static voltage stability based on multi-objective adaptive immune algorithm, Energy Conversion and Management, Vol. 49, No. 5, (May. 2008), pp. 1175–1181, ISSN 0196-8904.

Hydro-Quebec. Transmission provider technical requirements for the connection of power plants to Hydro-Quebec transmission system. Hydro Quebec Transenergie, 2006.

IEA Energy Technologies Perspective 2008, OECD/IEA, March 2010, Available from: < www.iea.org/techno/etp/index.asp>

IEA Wind Energy. Annual Report 2009, March 2010, Available from: < www.ieawind.org/AnnualReports_PDF/2009.html>

Jenkins, N. et al. (2000). Embedded Generation, The Institution of Electrical Engineers, ISBN 085296 774 8, London, U.K.

Keung, P.-K., Kazachkov, Y. & Senthil, J. (2010). Generic models of wind turbines for power system stability studies, Proceedings of Conference on Advances in Power System Control, Operation and Management, London, UK, Nov. 2009.

Kundur, Prabha. (1994). Power System Stability and Control, MC-Graw-Hill, ISBN 007035958-X, California.

Martínez, I. et al. (2007). Connection requirements for wind farms: A survey on thecnical requirements and regulation. Renewable and Sustainability energy reviews, Vol. 11, No. 8, (Oct. 2007), pp. 1858-1872, ISSN 1364-0321.

National Grid Electricity Transmission. Grid code, issue 3, rev.24. National Grid Electricity Transmission plc, UK, October 2008.

Nordel. Nordic Grid Code. Nordel, January 2007.

Raoufi, H. & Kalantar, M. (2009). Reactive power rescheduling with generator ranking for voltage stability improvement, Energy Conversion and Management, Vol. 50, No. 4, (Apr. 2009), pp. 1129–1135, ISSN 0196-8904.

Salama, M.M.A. & Chikhani, A.Y. (1993). A simplified network approach to the VAR control problem for radial distribution systems. *IEEE Trans. On Power Delivery*, Vol. 8, No. 3, (Jul. 1993), pp 1529-1535, ISSN 0885-8977.

Sangsarawut, P., Oonsivila, A. & Kulworawanichpong, T. (2010). Optimal reactive power planning of doubly fed induction generators using genetic algorithms, Proceedings of the 5th IASME/WSEAS international conference on Energy; environment, ISBN 978-960-474-159-5 Cambridge, UK, Feb. 2010.

Singh, B. (2009). Wind Power interconnection into the Power System: A review of Grid Code Requirements. The electrical Journal, Vol. 22, No. 5, (Jun. 2009), pp. 54-63, ISSN 1040-6190.

Singh, B. & Singh, S. N. (2009). Reactive capability limitations of doubly-fed induction generators, Electric Power Components and Systems, Vol. 37, No. 4, (2009), pp. 427–440, ISSN 1532-5008.

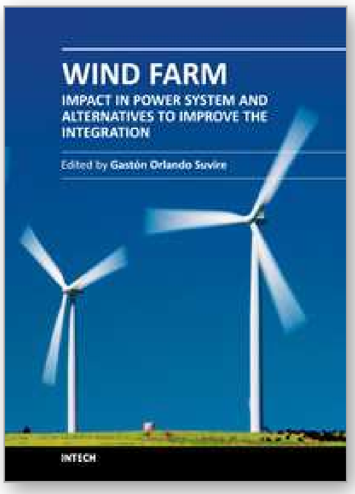
Tsili, M. & Papathanassiou, S. (2009). A review of grid code technical requirements for wind farms. IET Renewable Power Generation, Vol. 3, No. 3, (2009), pp. 308-332, ISSN 1752-1416.

Ullah, N. & Thiringer, T. (2008). Improving voltage stability by utilizing reactive power injection capability of variable speed wind turbines, International Journal of Power and Energy Systems, Vol. 28 , No. 3, (2008), pp. 289–297, ISSN 1078-3466.

Vijayan, P., Sarkar, S. & Ajjarapu, V. (2009). A novel voltage stability assessment tool to incorporate wind variability, Proceedings of Power Energy Society General Meeting, ISBN 978-1-4244-4240-9, Calgary, CANADA, Jul. 2009.

Vilar, C. (2002). Fluctuaciones de tensión producidas por los aerogeneradores de velocidad fija. Ph. D. Thesis. Universidad Carlos III de Madrid. Electrical Engineering Department. 2002.

Zhang, W., Li, F. & Tolbert, L.M. (2007). Review of Reactive Power Planning: Objectives, constraints and algorithms. IEEE Trans. On Power Systems, Vol. 22, No. 4, (Nov. 2007), pp.-2177-2186, ISSN 0885-8950.



Wind Farm - Impact in Power System and Alternatives to Improve the Integration
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During the last two decades, increase in electricity demand and environmental concern resulted in fast growth of power production from renewable sources. Wind power is one of the most efficient alternatives. Due to rapid development of wind turbine technology and increasing size of wind farms, wind power plays a significant part in the power production in some countries. However, fundamental differences exist between conventional thermal, hydro, and nuclear generation and wind power, such as different generation systems and the difficulty in controlling the primary movement of a wind turbine, due to the wind and its random fluctuations. These differences are reflected in the specific interaction of wind turbines with the power system. This book addresses a wide variety of issues regarding the integration of wind farms in power systems. The book contains 14 chapters divided into three parts. The first part outlines aspects related to the impact of the wind power generation on the electric system. In the second part, alternatives to mitigate problems of the wind farm integration are presented. Finally, the third part covers issues of modeling and simulation of wind power system.