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Optimal Location and Control of Multi Hybrid Model Based Wind-Shunt FACTS to Enhance Power Quality

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1. Introduction

Modern power system becomes more complex and difficult to control with the wide integration of renewable energy and flexible ac transmission systems (FACTS). In recent years many types of renewable source (Wind, solar,) and FACTS devices (SVC, STATCOM, TCSC, UPFC) integrated widely in the electricity market. Wind power industry has been developing rapidly, and high penetration of wind power into grid is taking place, (Bent, 2006), (Mahdad.b et al., 2011). According to the Global Wind Energy Council, GWEC, 15.197 MW wind turbine has been installed in 2006 (Chen et al. 2008), in terms of economic value, the wind energy sector has now become one of the important players in the energy markets, with the total value of new generating equipment installed in 2006 reaching US 23 billion.

FACTS philosophy was first introduced by (Hingorani, N.G., 1990), (Hingorani, N.G., 1999) from the Electric power research institute (EPRI) in the USA, although the power electronic controlled devices had been used in the transmission network for many years before that. The objective of FACTS devices is to bring a system under control and to transmit power as ordered by the control centers, it also allows increasing the usable transmission capacity to its thermal limits. With FACTS devices we can control the phase angle, the voltage magnitude at chosen buses and/ or line impedances.

In practical installation and integration of renewable energy in power system with consideration of FACTS devices, there are five common requirements as follows (Mahdad. b et al., 2011):

1. What Kinds of renewable source and FACTS devices should be installed?
2. Where in the system should be placed?
3. How to estimate economically the number, optimal size of renewable source and FACTS to be installed in a practical network?
4. How to coordinate dynamically the interaction between multiple type renewable source, multi type of FACTS devices and the network to better exploit their performance to improve the reliability of the electrical power system?
5. How to review and adjust the system protection devices to assure service continuity and keep the indices power quality at the margin security limits?

Optimal placement and sizing of different type of renewable energy in coordination with FACTS devices is a well researched subject which in recent years interests many expert

engineers. Optimal placement and sizing of renewable source in practical networks can result in minimizing operational costs, environmental protection, improved voltage regulation, power factor correction, and power loss reduction (Munteau et al., 2008). In recent years many researches developed to exploit efficiently the advantages of these two technologies in power system operation and control (Adamczyk et al., 2010), (Munteau et al., 2008).
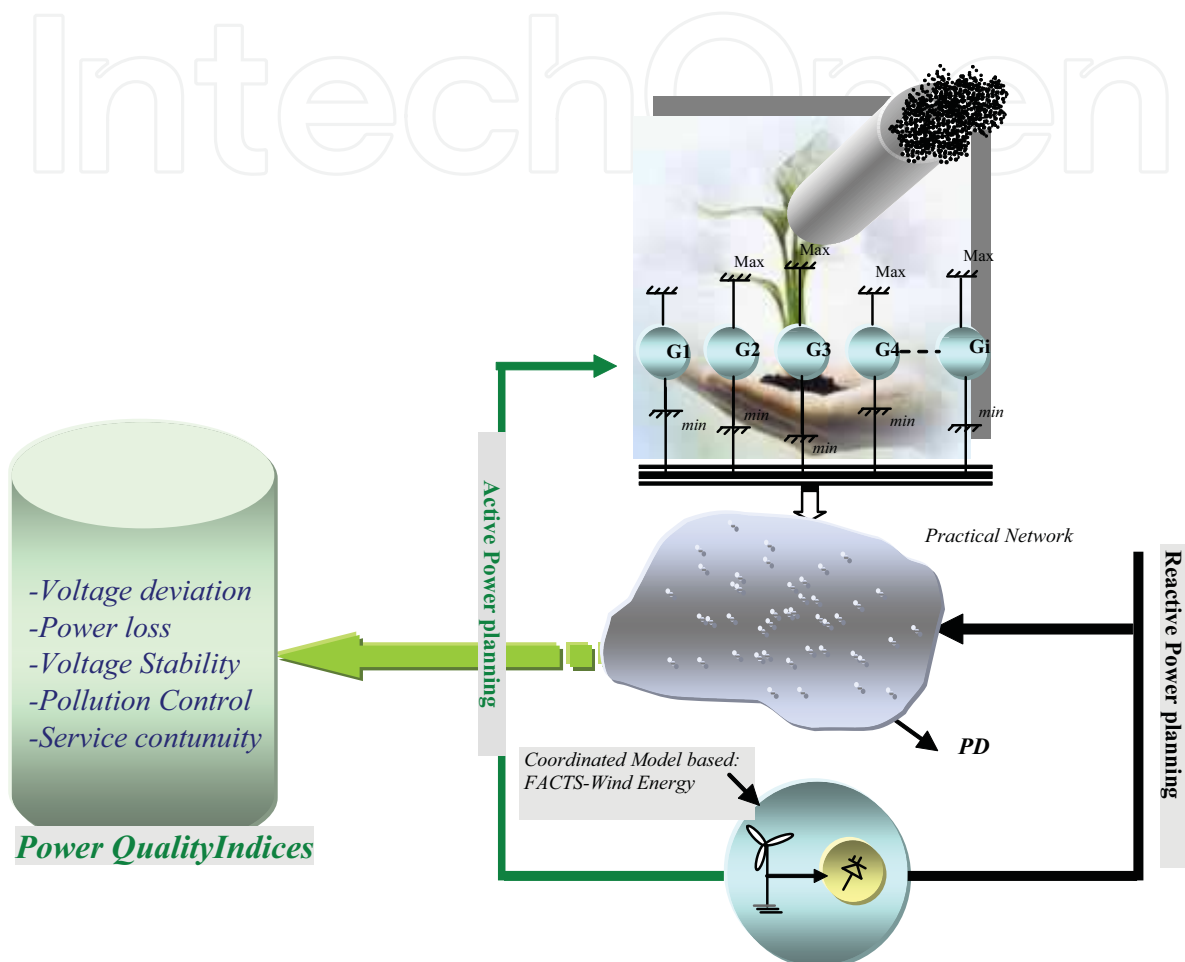

Fig. 1. Optimal power flow control strategy based hybrid model: wind and Shunt FACTS

In this study a combined flexible model based wind source and shunt FACTS devices proposed to adjust dynamically the active power delivered from wind source and the reactive power exchanged between the shunt FACTS and the network to enhance the power quality. Wind model has been considered as not having the capability to control voltages. Dynamic shunt compensators (STATCOM) modelled as a PV node used to control the voltage by a flexible adjustment of reactive power exchanged with the network.

2. Review of optimization methods

The optimal power flow (OPF) problem is one of the important problems in operation and control of large modern power systems. The main objective of a practical OPF strategy is to determine the optimal operating state of a power system by optimizing a particular objective while satisfying certain specified physical and security constraints. In its most

general formulation, the optimal power flow (OPF) is a nonlinear, non-convex, large-scale, static optimization problem with both continuous and discrete control variables. It becomes even more complex when various types of practical generators constraints are taken in consideration, and with the growth integration of new technologies known as Renewable source and FACTS Controllers. Fig. 2 sumuarizes the basic optimization categories used by researchers to analysis and enhance the optimal power flow solution.

In first category many conventional optimization techniques have been applied to solve the OPF problem, this category includes, linear programming (LP) (Sttot et al., 1979), nonlinear programming (NLP) (Wood et al., 1984), quadratic programming (Huneault et al., 1991), and interior point methods (Momoh et al., 1999).
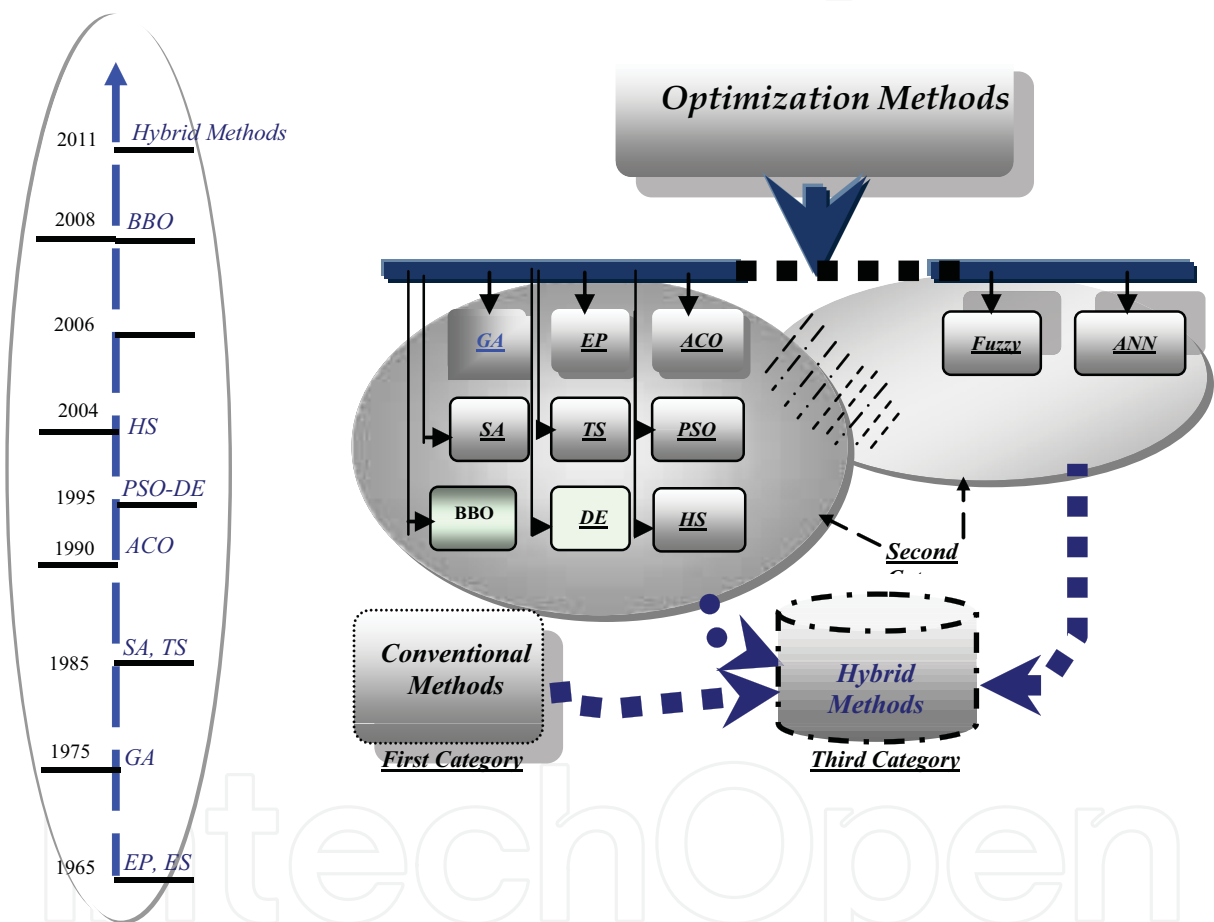

Fig. 2. Presentation of optimization methods: *Global, Conventional*, and *hybrids* methods

All these techniques rely on convexity to find the global optimum; the methods based on these assumptions do not guarantee to find the global optimum when taking in consideration the practical generators constraints (Prohibited zones, Valve point effect), (Huneault et al., 1991) present a review of the major contributions in this area. During the last two decades, the interest in applying global optimization methods in power system field has grown rapidly.

The second category includes many heuristique and stochastic optimization methods known as Global Optimization Techniques. (Bansal, 2005) represents the major

contributions in this area. (Chiang, 2005) presents an improved genetic algorithm for power economic dispatch of units with valve-point effects and multiple fuels. (Chien, 2008) present a novel string structure for solving the economic dispatch through genetic algorithm (GA). To accelerate the search process (Pothiya et al., 2008) proposed a multiple tabu search algorithm (MTS) to solve the dynamic economic dispatch (ED) problem with generator constraints, simulation results prove that this approach is able to reduce the computational time compared to the conventional approaches. (Gaing, 2003) present an efficient particle swarm optimization to solving the economic dispatch with consideration of practical generator constraints, the proposed algorithm applied with success to many standard networks. Based on experience and simulation results, these classes of methods do not always guarantee global best solutions. Differential evolution (DE) is one of the most prominent new generation EAs, proposed by Storn and Price (Storn et al., 1995), to exhibit consistent and reliable performance in nonlinear and multimodal environment (price et al., 2005) and proven effective for constrained optimization problems. The main advantages of DE are: simple to program, few control parameters, high convergence characteristics. In power system field DE has received great attention in solving economic power dispatch (EPD) problems with consideration of discontinuous fuel cost functions.

The third category includes, a variety of combined methods based conventional (mathematical methods) and global optimization techniques like (GA-QP), artificial techniques with metaheuristic mehtods, like 'Fuzzy-GA', 'ANN-GA', 'Fuzzy-PSO'. Many modified DE have been proposed to enhance the optimal solution, (Coelho et al., 2009) present a hybrid method which combines the differential evolution (DE) and Evolutionary algorithms (EAs), with cultural algorithm (CA) to solve the economic dispatch problems associated with the valve-point effect. Very recently, a new optimization concept, based on Biogeography, has been proposed by Dan Simon (Simon, D., 2008), Biogeography describes how species migrate from one island to another, how new species arise, and how species become extinct.

To overcome the drawbacks of the conventional methods related to the form of the cost function, and to reduce the computational time related to the large space search required by many methaheuristic methods, like GA, (Mahdad, B. et al., 2010) proposed an efficient decomposed GA for the solution of large-scale OPF with consideration of shunt FACTS devices under severe loading conditions, (Mahdad, B. et al., 2009) present a parallel PSO based decomposed network to solve the ED with consideration of practical generators constraints.

This chapter presents a hybrid controller model based wind source and dynamic shunt FACTS devices (STATCOM Controller) to improve the power system operation and control. Choosing the type of FACTS devices and deciding the installation location and control of multi shunt FACTS coordinated with multi wind source is a vital research area. A simple algorithm based differential evolution (DE) proposed to find the optimal reactive power exchanged between shunt FACTS devices and the network in the presence of multi wind source. The minimum fuel cost, system loadability and loss minimization are considered as a measure of power system quality. The proposed methodology is verified on many practical electrical network at normal and at critical situations (sever loading conditions, contingency). Simulation results show that the optimal coordination operating points of shunt FACTS (STATCOM) devices and wind source enhance the power system security.

2.1 Standard Optimal Power Flow formulation

The OPF problem is considered as a general minimization problem with constraints, and can be written in the following form:

$$\text{Min } f(x,u) \tag{1}$$

$$\text{Subject to: } g(x,u) = 0 \tag{2}$$

$$h(x,u) \le 0 \tag{3}$$

$$x_{\min} \le x \le x_{\max} \tag{4}$$

$$u_{\min} \le u \le u_{\max} \tag{5}$$

Where; $f(x,u)$ is the objective function, $g(x,u)$ and $h(x,u)$ are respectively the set of equality and inequality constraints. The vector of state and control variables are denoted by x and u respectively.
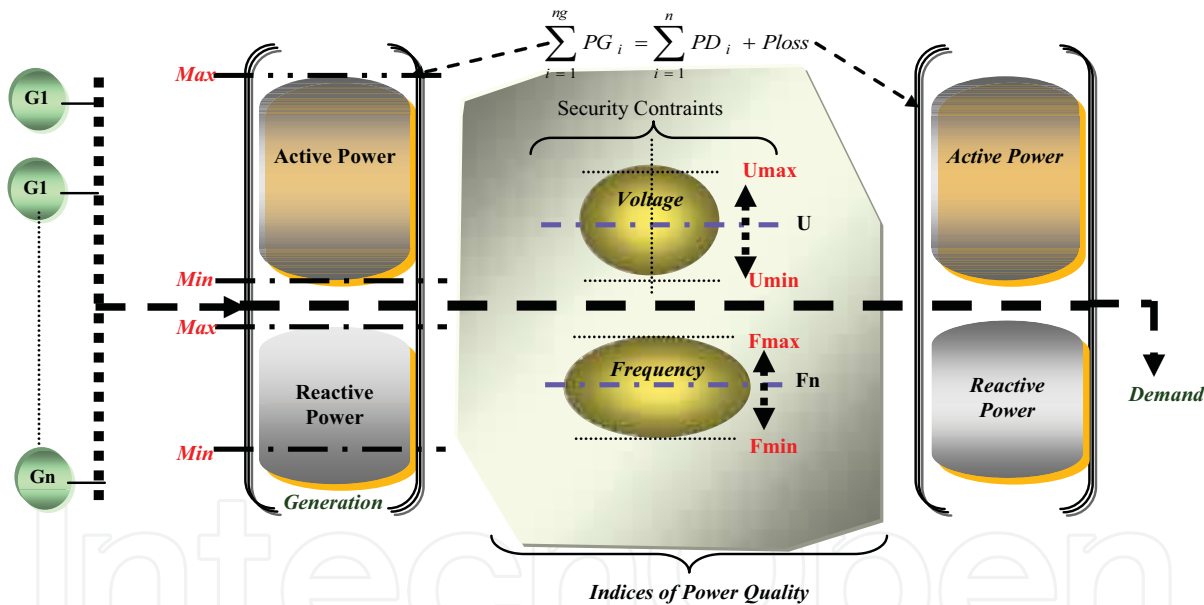

Fig. 3. Optimal power flow (OPF) strategy

In general, the state vector includes bus voltage angles δ, load bus voltage magnitudes V_L, slack bus real power generation $P_{g,slack}$ and generator reactive power Q_g. Fig. 3 shows the optimal power flow strategy. The problem of optimal power flow can be decomposed in two coordinated sub problems:

a. Active Power Planning

The main role of economic dispatch is to minimize the total generation cost of the power system but still satisfying specified constraints (generators constraints and security constraints).

$$\sum_{i=1}^{Ng} Pg_i = P_D + P_{loss} \qquad (6)$$

For optimal active power dispatch, the simple objective function f is the total generation cost expressed as follows:

$$Min \ f = \sum_{i=1}^{N_g} \left(a_i + b_i P_{gi} + c_i P_{gi}^2 \right) \qquad (7)$$

where N_g is the number of thermal units, P_{gi} is the active power generation at unit i and a_i, b_i and c_i are the cost coefficients of the ith generator.

In the power balance criterion, the equality constraint related to the active power balance with consideration of wind power should be satisfied expressed as follow:

$$\sum_{i=1}^{Ng} P_{gi} + \sum_{i=1}^{NW} P_{wi} - P_D - P_{loss} = 0 \qquad (8)$$

Where; Ng represents the total number of generators, NW the number of wind source integrated into the system, P_{wi} represents the active power of wind units, P_D is the total active power demand, P_{loss} represent the transmission losses.

The inequality constraints to be satisfied for this stage are given as follows:

- Upper and lower limits on the active power generations:

$$P_{gi}^{\min} \leq P_{gi} \leq P_{gi}^{\max} \qquad (9)$$

- Wind power availability: the total wind power generated, is limited by the available amount from the wind park P_w^{av},

$$P_{loss} + P_D - \sum_{i=1}^{Ng} P_{gi} \leq P_w^{av} \qquad (10)$$

b. Reactive Power Planning

The main role of reactive power planning is to adjust dynamically the control variables to minimize the total power loss, transit power, voltages profiles, and voltage stability, individually or simultaneously, but still satisfying specified constraints (generators constraints and security constraints). Fig. 4 shows the structure of the control variable to be optimized using DE.

- Upper and lower limits on the reactive power generations:

$$Q_{gi}^{\min} \leq Q_{gi} \leq Q_{gi}^{\max}, i = 1, 2, \ldots, NPV \qquad (11)$$

- Upper and lower limits on the generator bus voltage magnitude:

$$V_{gi}^{\min} \leq V_{gi} \leq V_{gi}^{\max}, i = 1, 2, \ldots, NPV \qquad (12)$$

- Upper and lower limits on the transformer tap ratio (t).

$$t_i^{\min} \leq t_i \leq t_i^{\max}, i = 1, 2, \ldots, NT \qquad (13)$$

- Upper transmission line loadings.

$$S_{li} \leq S_{li}^{\max}, \; i = 1, 2, \ldots, NPQ \qquad (14)$$

- Upper and lower limits on voltage magnitude at loading buses (PQ buses)

$$V_{Li}^{\min} \leq V_{Li} \leq V_{Li}^{\max}, \; i = 1, 2, \ldots, NPQ \qquad (15)$$

- Parameters of shunt FACTS Controllers must be restricted within their upper and lower limits.
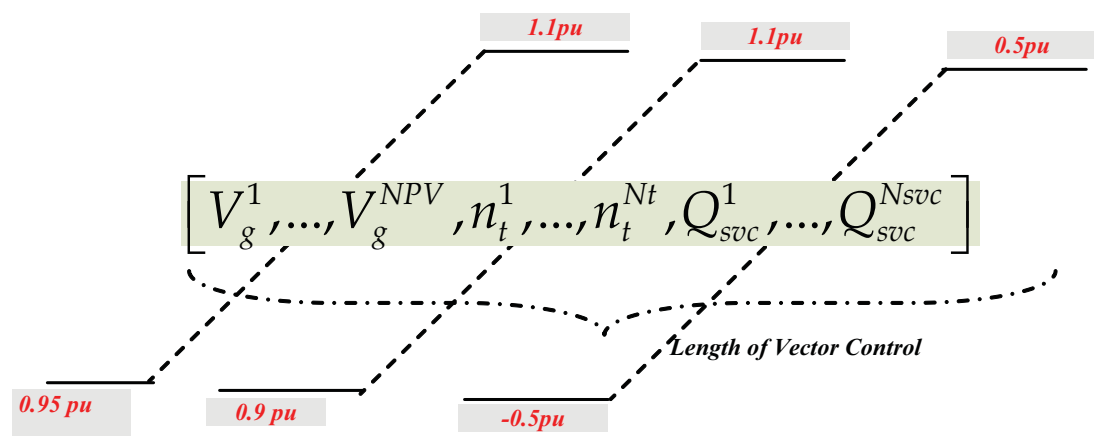
$$X^{\min} \leq X_{FACTS} \leq X^{\max} \qquad (16)$$

Fig. 4. Vector control structure based DE for reactive power planning

Fig. 5 shows the strategy of FACTS controllers integrated in power system to improve the power quality. In general these FACTS devices are classified in three large categories as follows (Mahdad et al, 2010):

1. Shunts FACTS Controllers (SVC, STATCOM): Principally designed and integrated to adjust dynamically the voltage at specified buses.

$$V^{des} - V_i = 0 \qquad (17)$$

2. Series FACTS Controllers (TCSC, SSSC): Principally designed and integrated to adjust dynamically the transit power at specified lines.

$$(18)$$

3. Hybrid FACTS Controllers (UPFC): Principally designed and integrated to adjust dynamically and simultaneously the voltage, the active power, and the reactive power at specified buses and lines.

$$\begin{cases} V^{des} - V_i = 0 \\ P_{ij}^{des} - P_{ij} = 0 \\ Q_{ij}^{des} - Q_{ij} = 0 \end{cases} \qquad (19)$$
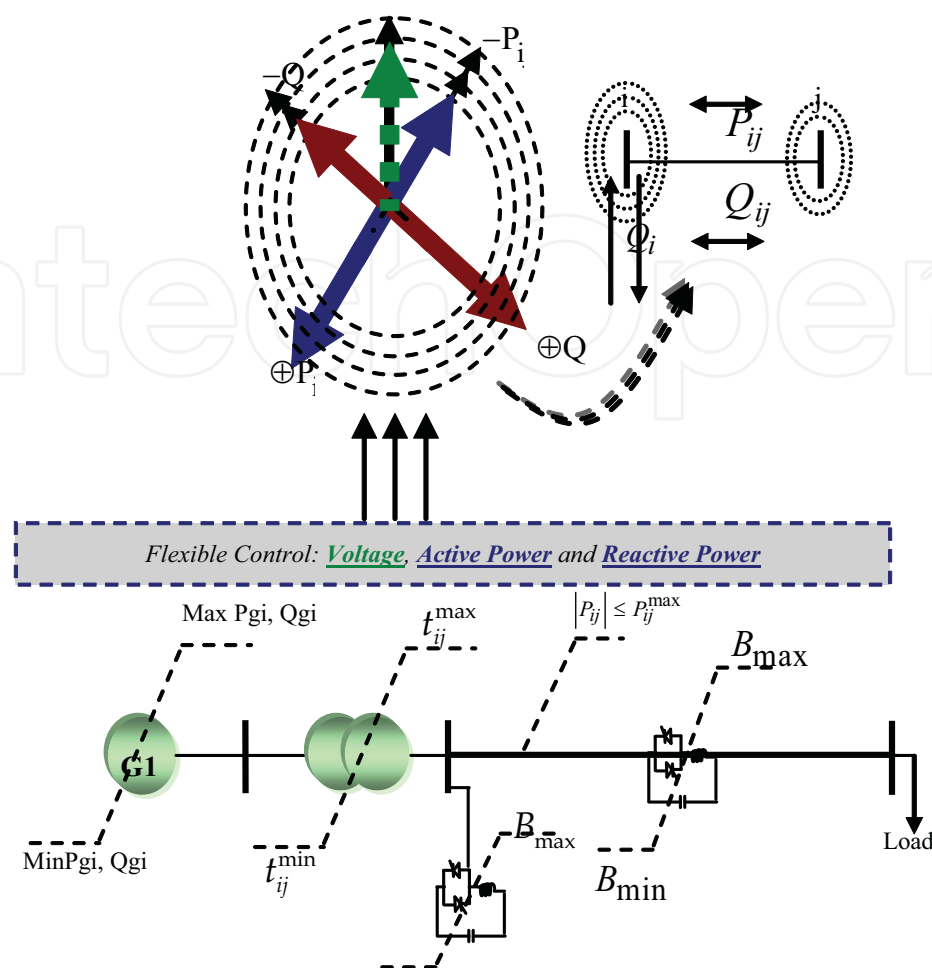
Fig. 5. Basic strategy of FACTS technology integrated in power system

In this study we are interested in the integration of hybrid model based shunt FACTS controller (STATCOM) and wind energy to enhance the indices of power quality at normal and at critical situations.

3. Hybrid model based wind energy and shunt FACTSController

The proposed approach requires the user to define the number of wind units to be installed, in this study voltage stability used as an index to choose the candidate buses. The differential evolution (DE) algorithm generates and optimizes combination of wind sources sizes. Minimum cost, and power losses, used as fitness functions. Wind units modelling depend on the constructive technology and their combined active and reactive power control scheme.

In this study wind has been considered as not having the capability to control voltages. Dynamic shunt compensators (STATCOM) modelled as a PV node used in coordination with wind to control the voltage by a flexible adjustment of reactive power exchanged with the network (Mahdad.b et al., 2011). Fig. 6 shows the proposed combined model based wind source and STATCOM Controller.
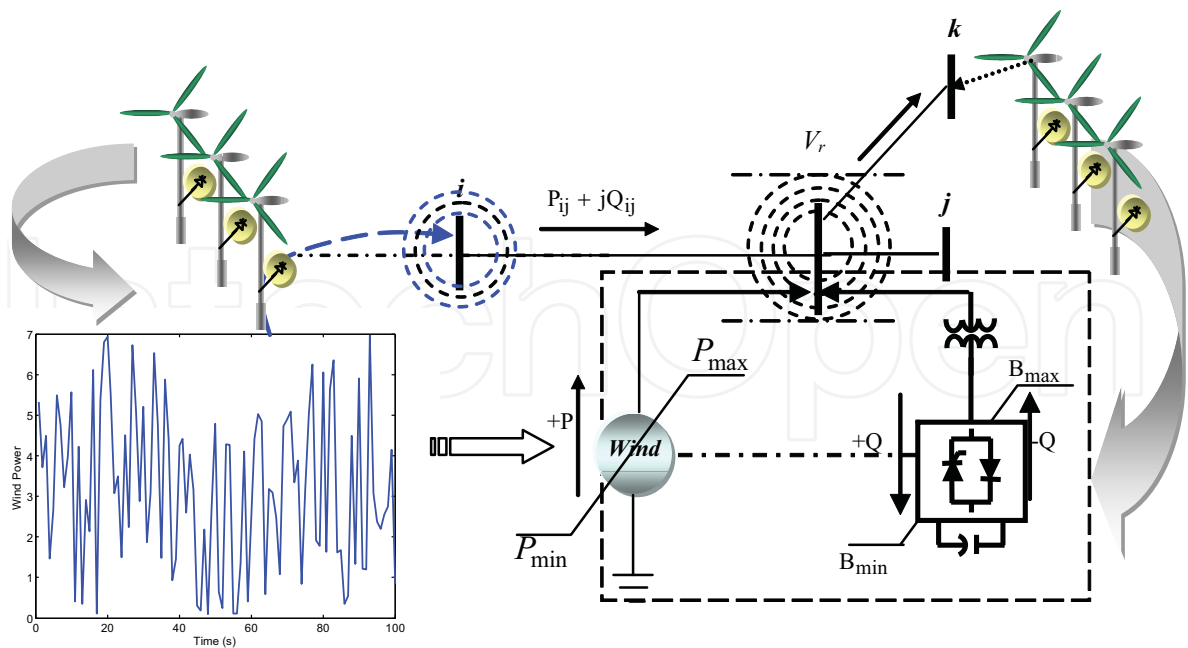
Fig. 6. The proposed combined model based wind/ STATCOM Compensators integrated in power flow algorithm

3.1 Wind energy

The principle of wind energy transformation based aerodynamic power can be formulated using the following equations:

$$P_w = \begin{cases} 0 & V < V_D \\ \dfrac{1}{2}.\rho.S.V^3.C_p(\lambda,\beta) & V_D \leq V < V_N \\ P_N & V_N \leq V < V_A \\ 0 & V \geq V_A \end{cases} \tag{20}$$

Where;

ρ : is the air density,

S : the surface swept by the turbine

V : Wind speed

V_D : Critical wind speed

V_A : Wind stopping speed

$$\lambda = \frac{Q_t.R_t}{V} \; ;$$

λ : tip speed ratio

R_t : is the blade length

Q_t : is the angular velocity of the turbine

Detailed descriptions about various types of aero-generators are well presented in many references (Bent, S., 2004), (Chen et al. 2008).

3.2 Steady state model of Static Compensator (STATCOM)

The first SVC with voltage source converter called STATCOM commissioned and installed in 1999 (Hingorani, N.G., 1999). STATCOM is build with Thyristors with turn-off capability like GTO or today IGCT or with more and more IGBTs. The steady state circuit for power flow is shown in Fig. 7, the V-I characteristic presented in Fig. 8.
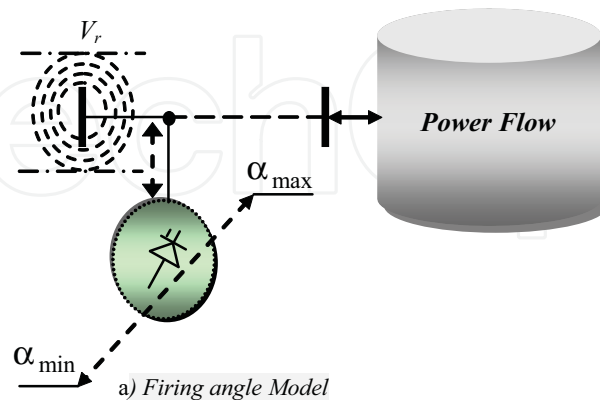

a) *Firing angle Model*

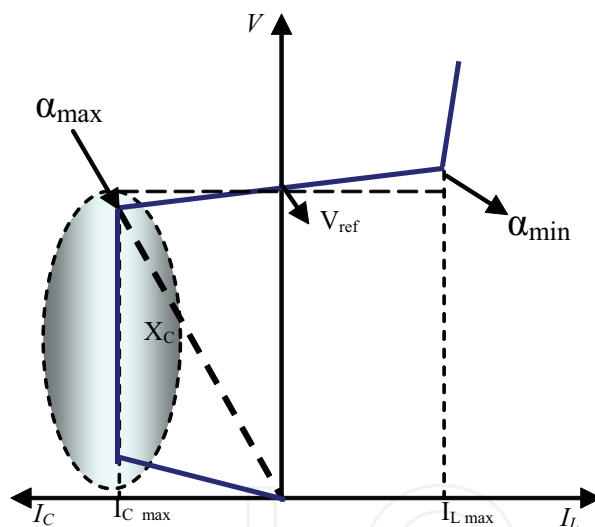Fig. 7. STATCOM steady state circuit representation

Fig. 8. V-I Characteristic of the STATCOM

3.2.1 Advantages of STATCOM

The advantages of a STATCOM compared to SVC Compensators summarized as follows (Hingorani, N.G., 1999):

- The reactive power to be exchanged is independent from the actual voltage on the connection point. This can be seen in the diagram (Fig. 9) for the maximum currents being independent of the voltage in comparison to the SVC. This means, that even during most severe loading conditions, the STATCOM keeps its full capability.
- Reduced size is another advantage of the STATCOM as compared to the SVC Controller, sometimes even to less than 50%, and also the potential cost reduction achieved from the elimination of many passive components required by SVC, like capacitor and reactor banks.

3.2.2 STATCOM modelling based power flow

In the literature many STATCOM models have been developed and integrated within the load flow program based modified Newton-Raphson, the model proposed by (Acha, et al, 2004), is one of the based and efficient models largely used by researchers. Fig. 9 shows the equivalent circuit of STATCOM, the STATCOM has the ability to exchange dynamically reactive power (absorbed or generated) with the network.
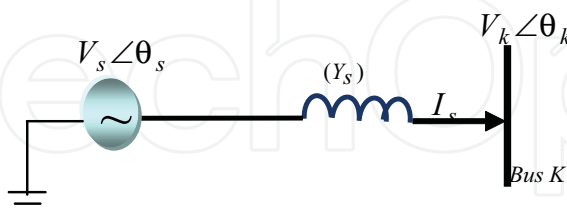

Fig. 9. STATCOM equivalent circuit

Based on the simplified equivalent circuit presented in Fig. 9, the following equation can be formulated as follows:

$$I_s = Y_s.(V_s - V_k) ; \tag{21}$$

Where,

$Y_s = G_s + jB_s$; is the equivalent admittance of the STATCOM;
The active and reactive power exchanged with the network at a specified bus expressed as follows:

$$S_s = V_s.I_s^* = V_s.Y_s^*.\left(V_s^* - V_k^*\right) ; \tag{22}$$

After performing complex transformations; the following equations are deduced:

$$P_s = |V_s|^2 G_s - |V_s||V_k|\{G_s\cos(\theta_s - \theta_k) + B_s\sin(\theta_s - \theta_k)\} \tag{23}$$

$$Q_s = -|V_s|^2 B_s - |V_s||V_k|\{G_s\sin(\theta_s - \theta_k) - B_s\sin(\theta_s - \theta_k)\} \tag{24}$$

The modified power flow equations with consideration of STATCOM at bus k are expressed as follows:

$$P_k = P_s + \sum_{i=1}^{N}|Y_{ki}|.|V_k|.|V_i|\cos(\theta_k - \theta_i - \theta_{ki}) \tag{25}$$

$$Q_k = Q_s + \sum_{i=1}^{N}|Y_{ki}|.|V_k|.|V_i|\sin(\theta_k - \theta_i - \theta_{ki}) \tag{26}$$

4. Overview of Differential Evolution technique

Differential Evolution (DE) is a new branch of EA proposed by (Storn and Price, 1995). DE has proven to be promising candidate to solve real and practical optimization problem. The strategy of DE is based on stochastic searches, in which function parameters are encoded as floating point variables. The key idea behind differential evolution approach is a new mechanism introduced for generating trial parameter vectors. In each step DE mutates

vectors by adding weighted, random vector differentials to them. If the fitness function of the trial vector is better than that of the target, the target vector is replaced by trial vector in the next generation.

4.1 Differential evolution mechanism search

The differential evolution mechanism search is presented based on the following steps (Gonzalez et al., 2008):

Step 1. Initialize the initial population of individuals: Initialize the generation's counter, *G=1*, and also initialize a population of individuals, *x(G)* with random values generated according to a uniform probability distribution in the n-dimensional space.

$$X_i^{(G)} = x_{ij}^{(L)} + rand[0,1] * \left(x_{ij}^{(U)} - x_{ij}^{(L)} \right) \tag{27}$$

Where:

G : is the generation or iteration

$rand[0,1]$: denotes a uniformly distributed random value within [0, 1].

$x_{ij}^{(L)}$ and $x_{ij}^{(U)}$ are lower and upper boundaries of the parameters x_{ij} respectively for $j = 1,2,...,n$.

Step 2. the main role of mutation operation (or differential operation) is to introduce new parameters into the population according to the following equation:

$$v_i^{(G+1)} = x_{r3}^{(G)} + f_m * \left(x_{r2}^{(G)} - x_{r1}^{(G)} \right) \tag{28}$$

Two vectors $x_{r2}^{(G)}$ and $x_{r1}^{(G)}$ are randomly selected from the population and the vector difference between them is established. $f_m \succ 0$ is a real parameter, called mutation factor, which the amplification of the difference between two individuals so as to avoid search stagnation and it is usually taken from the range [0,1].

Step 3. Evaluate the fitness function value: for each individual, evaluate its fitness (objective function) value.

Step 4. following the mutation operation, the crossover operator creates the trial vectors, which are used in the selection process. A trial vector is a combination of a mutant vector and a parent vector which is formed based on probability distributions.

For each mutate vector, $v_i^{(G+1)}$, an index $rnbr(i) \in \{1,2,...,n\}$ is randomly chosen using a uniform distribution, and a trail vector, $u_i^{(G+1)} = \left[u_{i1}^{(G+1)}, u_{i2}^{(G+1)}, ..., u_{i2}^{(G+1)} \right]^T$ is generated according to equation:

$$u_{ij}^{(G+1)} = \begin{cases} v_{ij}^{(G+1)} \; if \left(rand[0,1] \leq CR \right) or \left(j = rnbr(i) \right) \\ x_{ij}^{(G)} \; otherwise \end{cases} \tag{29}$$

Step 5. the selection operator chooses the vectors that are going to compose the population in the next generation. These vectors are selected from the current population and the trial population. Each individual of the trial population is compared with its counterpart in the current population.

Step 6. Verification of the stopping criterion: Loop to step 3 until a stopping criterion is satisfied, usually a maximum number of iterations, G_{max}.

4.2 Active power dispatch for conventional source

The main objective of this first stage is to optimize the active power generation for conventional units (>=80% of the total power demand) to minimize the total cost, Fig 9 shows the three phase strategy based deferential evolution (DE). Fig. 10 shows the structure of the control variables related to active power dispatch for conventional source. In this stage the fuel cost objective J_1 is considered as:

$$J_1 = \sum_{i=1}^{NG} f_i \tag{30}$$

$$Pd1 = \sum_{i=1}^{NG} Pg_i \tag{31}$$

Where;

f_i : is the fuel cost of the *ith* generating unit.

$Pd1$: the new active power associated to the conventional units;

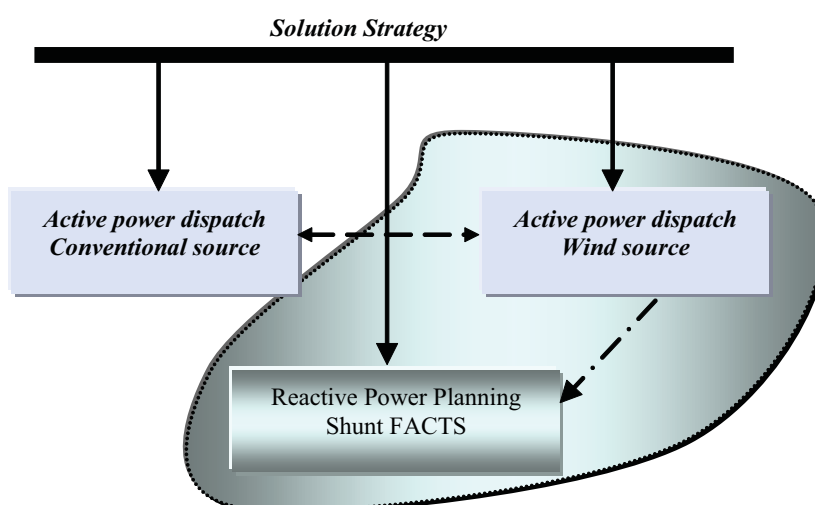$Pd2$: the new active power associated to the wind source;

Fig. 10. Three phase strategy based differential evolution (DE)

4.3 Combined active and reactive power planning based hybrid model

The main objective of this second stage is to optimize the active power generation for wind source (<=20% of the total power demand) in coordination with the STATCOM installed at the same specified buses, the objective function here is to minimize the active power loss (P_{loss}) in the transmission system. It is given as:

$$J_2 = Min\ P_{loss} \tag{32}$$

$$P_{loss} = \sum_{k=1}^{N_l} g_k \left[\left(t_k V_i \right)^2 + V_j^2 - 2t_k V_i V_j \cos\delta_{ij} \right] \tag{33}$$

The equality constraints to be satisfied are given as follows:

$$Pd_2 = \sum_{i=1}^{NW} Pw_i \tag{34}$$

$$Pd1 + Pd2 - \sum_{i=1}^{NG} Pg_i - \sum_{i=1}^{NW} Pw_i = P_{loss} \tag{35}$$

$$Pd1 + Pd2 = PD \tag{36}$$

Where, N_l is the number of transmission lines; g_k is the conductance of branch k between buses i and j; t_k the tap ration of transformer k; V_i is the voltage magnitude at bus i; δ_{ij} the voltage angle difference between buses i and j.
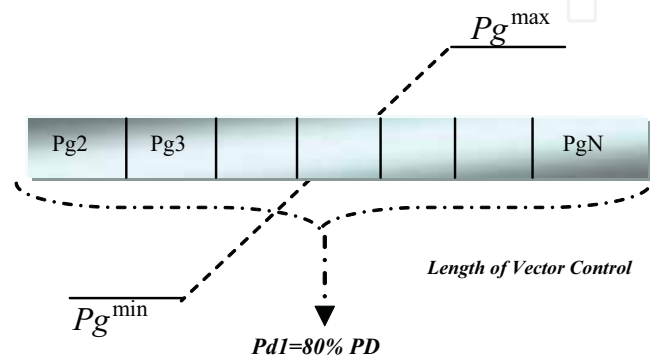

Fig. 11. Vector control structure: conventional source

The inequality constraints to be satisfied are all the security constraints related to the state varaibles and the control variables mentioned in section 2.1.
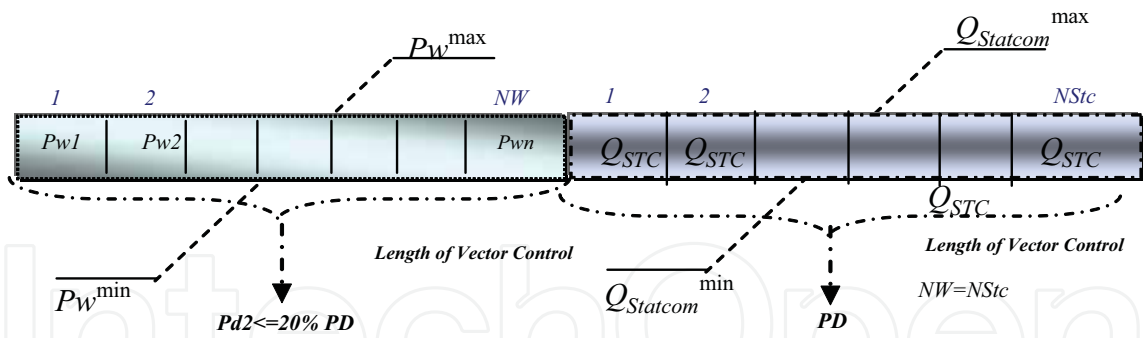

Fig. 12. Coordinated vector control

Fig. 12 shows the two coordinated vectors control structure related to this stage, the individual of the combined vector control denoted by $X_{pq} = [P_{w1},...,P_{wN}, Q_{STC1},...,Q_{STCN}]$
Where $[P_{w1},...,P_{wN}]$ indicate active power outputs of all units based wind source, $[Q_{STC1},...,Q_{STCN}]$ represent reactive power magnitude settings of all STATCOM controllers exchanged with the network.

5. Simulation results

The proposed algorithm is developed in the Matlab programming language using 6.5 version. The proposed approach has been tested on many practical electrical test systems (small size:

IEEE 14-Bus, IEEE 30-Bus, and to large power system size). After a number of careful experimentation, following optimum values of DE parameters have been settled for this test case: population size = 30, mutation factor =0.8, crossover rate = 0.7, maximum generation =100. Due to the limited chapter length, details results related to values of control variables (active power generation, voltage magnitudes, reactive power compensation ($Q_{STATCOM}$) for other practical network test will be given in the next contribution.

5.1 Test system 1
The first test system has 6 generating units; 41 branch system, the system data taken from (). It has a total of 24 control variables as follows: five units active power outputs, six generator-bus voltage magnitudes, four transformer-tap settings, nine bus shunt FACTS controllers (STATCOM). The modified IEEE 30-Bus electrical network is shown in Fig 13.
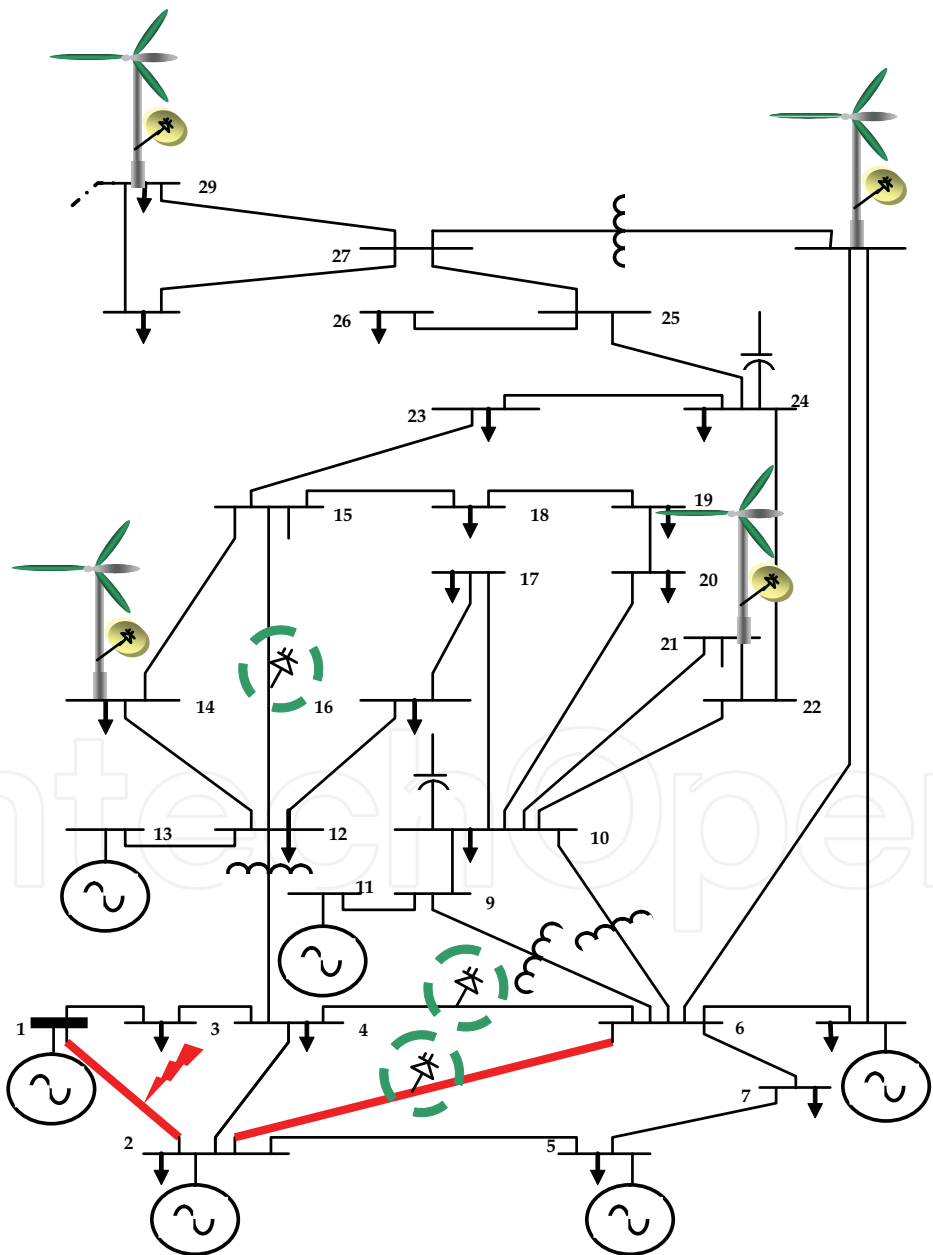

Fig. 13. Single line diagram for the modified IEEE 30-Bus test system (with FACTS devices)

Case1: Normal Condition

	Buses								
STATCOM	**10**	**12**	**15**	**17**	**20**	**21**	**23**	**24**	**29**
Q (MVAR)	35.92	-16.27	-9.82	-19.34	-1.96	-19.94	1.25	4.82	-4.25
Pw (MW)	3.9194	3.9202	4.0070	4.0615	4.1781	4.1956	3.9707	3.8700	3.8776
V (p u)	1.02	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\sum_{i=1}^{NW} P_w$ (MW)	**36** **(12.7%), PD =283.4 MW**								
Ploss (MW)	**7.554**								
Pg1 (MW)	149.92	**Case1** **Normal Condition**							
Pg2 (MW)	46.53								
Pg5 (MW)	20.64								
Pg8 (MW)	15.81								
Pg11(MW)	10.05								
Pg13(MW)	12								
Qg1	5.39								
Qg2	21.67								
Qg5	23.04								
Qg8	45.77								
Qg11	15.43								
Qg13	39.09								
$\sum_{i=1}^{NG} P_G$ (MW)	**254.95** **(89.96%)**								
Cost ($/ h)	**676.4485**								

Table 1. Power Quality Results based Hybrid Model: Wind Source: STATCOM: IEEE-30Bus: Normal Condition
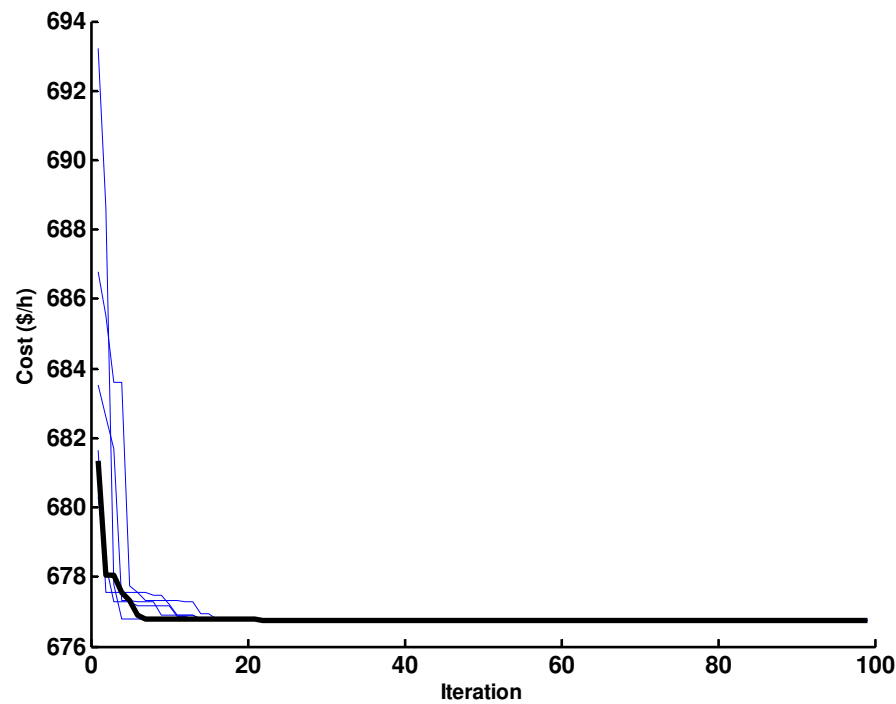
Fig. 14. Convergence characteristic of the 6 generating units with consideration of wind source and STATCOM
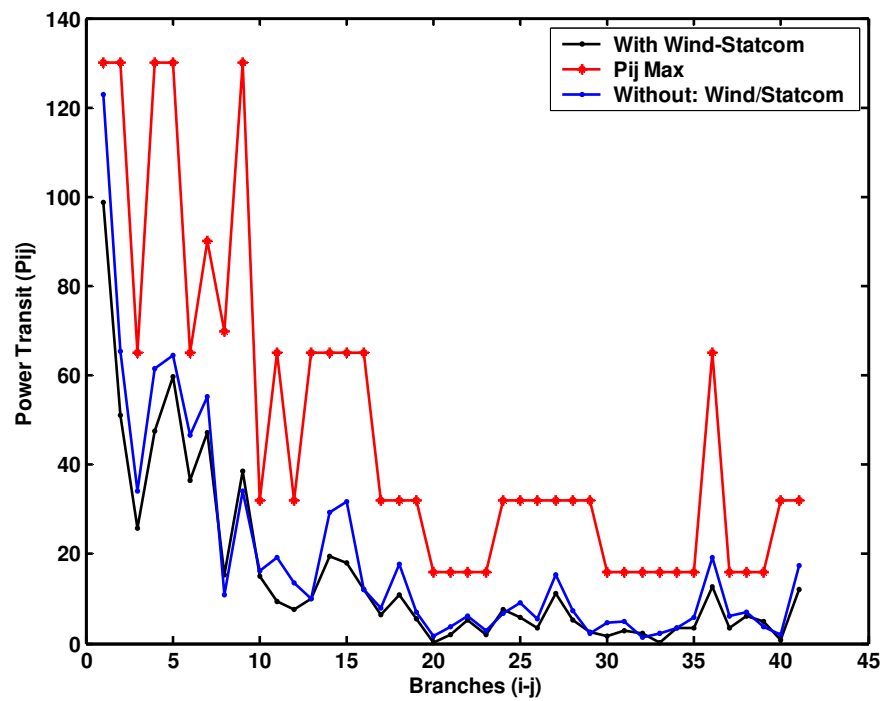

Fig. 15. Active power transit (Pij) with and without wind and STATCOM, Case1: Normal Condition: IEEE 30-Bus

Table 1 shows the results based on the flexible integration of the hybrid model, the goal is to have a stable voltage at the candidate buses by exchanging the reactive power with the network, the active power losses reduced to 7.554 MW compared to the base case: 10.05 MW, without integration of the hybrid controllers, the total cost also reduced to 676.4485 $/ h compared to the base case (802.2964 $/ h), Fig. 14 shows the convergence characteristic of fuel cost for the IEEE 30-Bus with consideration of the hybrid models, Fig. 15 shows the distribution of power transit in the different branches at normal condition, Fig. 17 shows the distribution of power transit in the different branches at contingency situation (without line 1-2).

The active power transit reduced clearly compared to the case without integration of wind source which enhance the system security. Fig. 16 shows the improvement of voltage profiles based hybrid model. Results at abnormal conditions (contingency) are also encouragement.
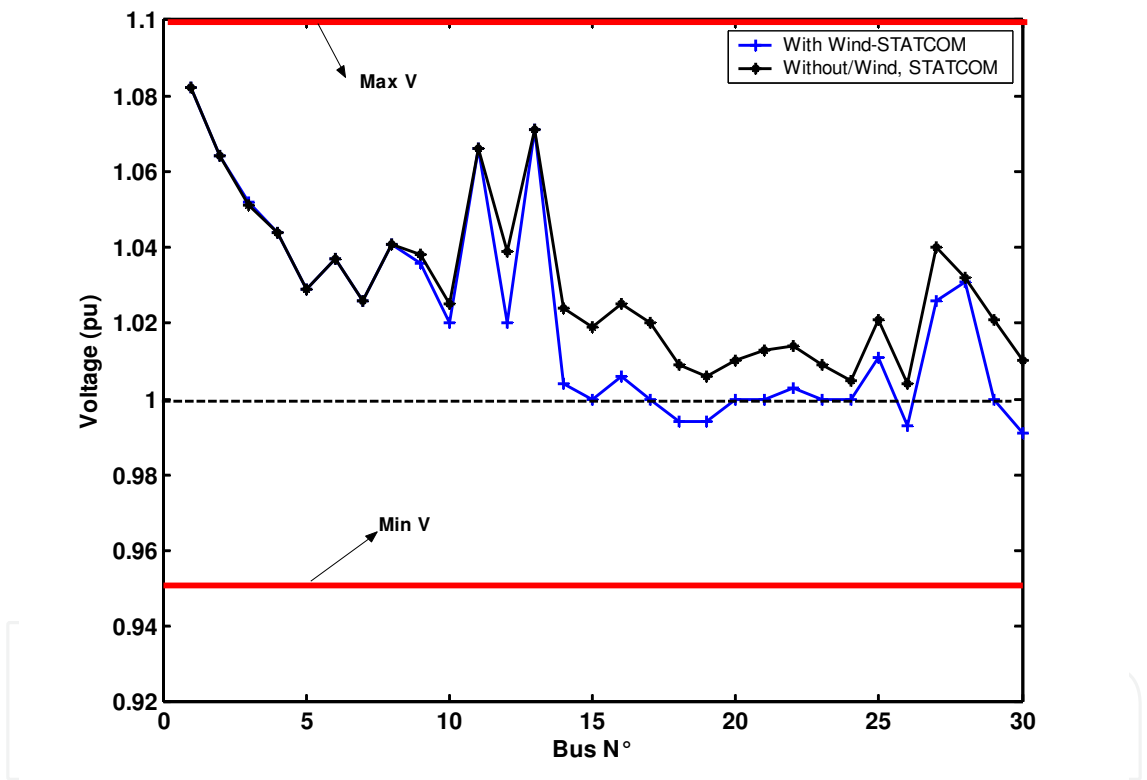

Fig. 16. Voltage profiles with and without hybrid model (wind and STATCOM): IEEE 30-Bus

Case2: Under Contingency Situation

The effeciency of the integrated hybrid model installed at different critical location is tested under contingency situation caused by fault in power system, so it is important to maintain the voltage magnitudes and power flow in branches within admissible values. In this case a contingency condition is simulated as outage at different candidate lines. Table 2 shows sample results related to the optimal power flow solution under contingency conditions (*Fault at line 1-2*).

	Buses								
STATCOM	10	12	15	17	20	21	23	24	29
Q (MVAR)	42.76	-15.65	-11.00	-20.10	-2.90	-20.83	0.28	4.09	-4.52
Pw (MW)	5.8791	5.8803	6.0105	6.092	6.2671	6.2934	5.9560	5.8050	5.8164
V (p u)	1.02	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
$\sum_{i=1}^{NW} P_w$ (MW)	**54 MW** **(19.05%), PD =283.4 MW**								
Ploss (MW)	**5.449**								
Pg1 (MW)	64.12								
Pg2 (MW)	67.98								
Pg5 (MW)	26.86								
Pg8 (MW)	34.65								
Pg11(MW)	21.00								
Pg13(MW)	20.24	**Abnormal Condition** **Without line 1-2**							
Qg1	1.76								
Qg2	41.3								
Qg5	20.98								
Qg8	35.55								
Qg11	8.08								
Qg13	39.26								
$\sum_{i=1}^{NG} P_G$ (MW)	**235.610MW** **(83.14%)**								
Cost (\$/ h)	**686.1220**								

Table 2. Power Quality Results based Hybrid Model: IEEE-30Bus: Abnormal Condition
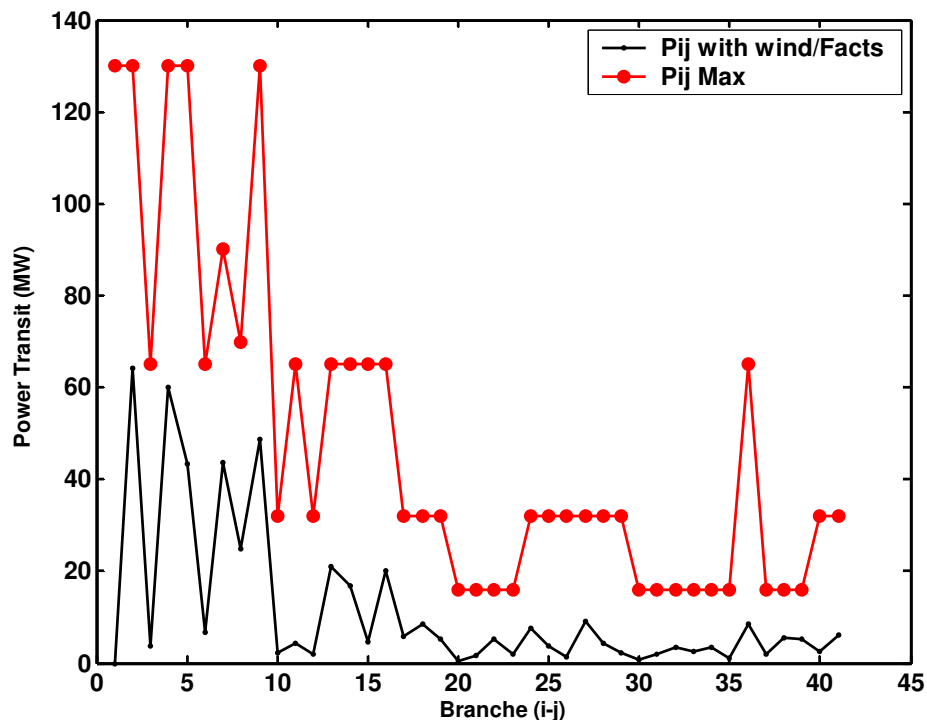
Fig. 17. Active power transit (Pij) with hybrid model: Case 2: Abnormal Condition: without line 1-2: IEEE 30-Bus

6. Conclusion

A three phase strategy based differential evolution (DE) method is proposed to enhance the power quality with consideration of multi hybrid model based shunt FACTS devices (STATCOM), and wind source. The performance of the proposed approach has been tested with the modified IEEE 30-Bus with smooth cost function, at normal condition and at critical loading conditions with consideration of contingency. The results of the proposed hybrid model integrated within the power flow algorithm compared with the base case with only conventional units (thermal generators units). It is observed that the proposed dynamic hybrid model is capable to improving the indices of power quality in term of reduction voltage deviation, and power losses.

Due to these efficient properties, in the future work, author will still to apply this algorithm to solve the practical optimal power flow of large power system with consideration of multi hybrid model under severe loading conditions and with consideration of practical constraints.

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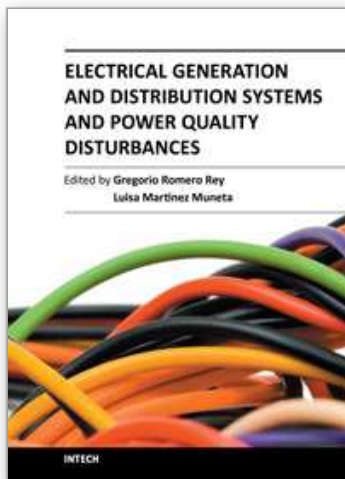
Electrical Generation and Distribution Systems and Power Quality Disturbances
Edited by Prof. Gregorio Romero

The utilization of renewable energy sources such as wind energy, or solar energy, among others, is currently of greater interest. Nevertheless, since their availability is arbitrary and unstable this can lead to frequency variation, to grid instability and to a total or partial loss of load power supply, being not appropriate sources to be directly connected to the main utility grid. Additionally, the presence of a static converter as output interface of the generating plants introduces voltage and current harmonics into the electrical system that negatively affect system power quality. By integrating distributed power generation systems closed to the loads in the electric grid, we can eliminate the need to transfer energy over long distances through the electric grid. In this book the reader will be introduced to different power generation and distribution systems with an analysis of some types of existing disturbances and a study of different industrial applications such as battery charges.

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