Dynamic Optimal Power Flow with Wind Penetration Using Differential Evolution Technique

N. Brik
University of Ferhat Abbas Sétif 1
n.brik@yahoo.fr

L.Slimani
University of Ferhat Abbas Sétif 1
slimaniblinda@gmail.com

T. Bouktir
University of Ferhat Abbas Sétif 1
tbouktir@univ-setif.dz

***Abstract*-- This paper describes the solution of the optimal power flow (OPF) problem with wind penetration using a Differential Evolution optimization technique. In order to make OPF become more reasonable, the cost of wind power generation is added into the objective function. This paper presents the enhancement of different performance parameters of power systems such as voltage profile, power flow of transmission lines , reduction of the active power losses , and a voltage stability index for identifying the most sensitive bus to the voltage collapse in the systems by optimally integrate the wind farm in power systems. The modified IEEE 30 system with six thermal generating units and one wind farm is used to analyze the effect of connected wind farm on the total generation cost, the voltage profile, to active losses and Fast voltage stability index (FVSI). Several scenarios according to the variation of the wind and the change in power demand (off peak and peak period) are performed in 24-h of a day. The numerical results provide valuable information for operators to determine the scheduling strategy for the power with system with wind farms that would increase performance parameters of power systems.**

***Index Terms*--Optimal Power Flow , wind Penetration, Dispersion of wind Generation, voltage Profile, weakest bus, voltage collapse, voltage stability, differential evolution.**

1. INTRODUCTION

Unlike the conventional energy sources, wind energy is characterized as free-fuel energy; free of air pollution, and it is the most competitive energy among all the renewable energies because of its high installed generation capability and also its advanced control technology. Therefore, the use of wind energy for electricity generation has been gaining popularity [1].

Wind generation system will not affect only the economic operation of a power system but also the bus voltage and transmission losses due to different locations of wind generation system. For the reason of maintaining the energy efficiency of power system operation, both the effects of wind generation on power system economic operations and the effects of wind generation on bus voltage and transmission losses should be studied. Optimal power flow (OPF) is one of the most important topics in power system operations that including economic operation and power flow analysis [2].

The aim of optimal power flow (OPF) is to minimize the total cost of generation while satisfying the system design and operational requirements. It is known that the conventional OPF problem involved only thermal energy power sources. With the introduction and development of renewable energy sources especially like wind energy there is a need to incorporate wind generation cost into the classical OPF problem [3]. Despite the interest in renewable energy and to incorporate renewable generation cost in the OPF, but that the problem of voltage stability in power systems always remain more important.

Voltage instability is considered as one of the major threats to the safe operation of many power systems due to the consequences of the kinds of incidents which have been reported worldwide in recent decades. One serious type of voltage instability is voltage collapse, which may leave large groups of people without electricity for extended periods of time. The blackouts that occurred in North America in 1996 and 2003 and in Europe in 2003 are examples of large-scale blackouts where voltage collapses played an important role [4],[5]. Such incidents have social impacts and caused huge economic losses. For this reason, the importance of implementing suitable and efficient techniques to monitor voltage stability have increased.

The identification of the weakest buses is an important task for the analysis of power system stability .To identify the weak buses several methods have been suggested in the literature, the most of these methods are based on Voltage Stability Indices [6].

In recent years evolutionary/meta-heuristic computing techniques like Genetic Algorithm (GA), Particle Swarm Optimization (PSO), evolutionary programming and others have emerged as very powerful general purpose solution tools. Basically these tools are search techniques capable of finding the optimum solution of a problem. The most remarkable feature of these tools is that they do not impose any restriction to the nature of the research space and type of the variables [6]. In this paper the optimization problem is solved using Differential Evolutionary (DE) technique.

We worked in previous articles on the optimal power flow (OPF) with wind penetration. We added the cost of wind power generation into the objective function [9] .and we used Lmn as the indicator for voltage stability margin and the weakest bus identification [6].

New in our article this, a Differential Evolution (DE) method is proposed to solve the optimal power flow problem. The objective function used is the minimization of the cost the thermal and the wind generators and The Fast voltage stability index (FVSI) is used as the indicator for voltage stability margin and the weakest bus identification In the presence of wind generators. Simulations are performed on IEEE 30, and several scenarios according to the variation of the wind and the change in power demand (off peak and peak period) are performed in 24-h of a day.

A. Modeling of Wind Turbine Generators

Wind model input assumptions vary from constant torque to constant power. The frequently make assumption of constant torque means any changes in shaft speed will result in a change in captured mechanical power, consequently change in power output of wind plant. A simple relationship exists relating the power generated by a wind turbine and the wind parameters [7],[3].

In this paper, the relationship between wind speed and mechanical power extracted from the wind is given as follows:

$$P_m = \begin{cases} 0 \quad V_\omega \le V_{cut-in} or V_\omega \ge V_{cut-off} \\ 0.5\rho A_{\omega t} C_P(\beta,\lambda) V_\omega^3 \quad V_{cut-in} < V_\omega < V_{rated} \\ P_{rated} \quad V_{rated} < V_\omega < V_{cut-off} \end{cases} \quad (1)$$

Where P_m is the power extracted from the wind, ρ is the air density, C_p is the performance coefficient, ƛ is the tip-speed ratio V_t/V_w the ratio between blade tip speed, V_t (m/s), and wind speed at hub height upstream of the rotor, V_ω(m/s) $A_{wt}=\pi R^2$ is the area covered by the wind turbine rotor, R is the radius of the rotor, V_ω denotes the wind speed, β is the blade pitch angle, V_{cut-in} and $V_{cut-off}$ are the cut-in and cut-off wind speed of wind turbine, and V_{rated} is the wind speed at which the mechanical power output will be the rated power. When Vω is higher than V_{rated} and lower than $V_{cut-off}$, with a pitch angle control system, the mechanical power output of wind turbine will keep constant as the rated power P_{rated}.

2. Voltage Stability Index

Recently, concerns over voltage instability phenomena have been growing as significant voltage drops and voltage collapse are regarded crucial in stable operations.

Thus, effective voltage control schemes using voltage stability indices have been brought to attention in a considerable number of studies [8].

There are many voltage stability indices such as: Voltage Margin Proximity Index (VMPI) [8], On-line Voltage Stability Index (L_{VSI}) [9][10], Line Stability Factor (LQP) [11], Line Stability Index(Lmn) [12], A Simplified Voltage Stability Index (SVSI) [5]…….i.e

In this paper the Fast Voltage Stability Index (FVSI) is used to determine the weakest bus. The Fast Voltage Stability Index (FVSI), proposed by Musirin and Rahman [16], Fast voltage stability index (FVSI) is capable in determining the point of voltage collapse, maximum permissible load, weak bus in the system and the most critical line in an inter-connected system. The trend of voltage and index profiles were studied by increasing the reactive power loading in stages until the load flow solution fails to give any results. FVSI was calculated for each line in the system as reactive load increased. The calculated FVSI could be used in determining the weakest bus, line criticalness and maximum loadability [10], [13].

The voltage stability index referred to a line was formulated from the 2-bus representation of a system. The value of line index that is closed to the unity indicates that the respective line is closed to its stability limit. The representation of a 2-bus model is illustrated in Fig. 1

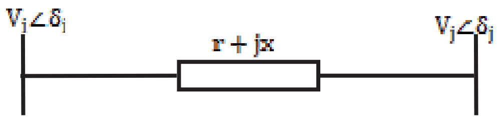

Fig.1. Model of simple branch for voltage stability research

The Fast voltage stability index is defined as follows:

$$FVSI = \frac{4Z^2 Q_j X}{V_i^2 X} \le 1 \quad (2)$$

Where:

Z, X, V_i,Qj = line impedance, line reactance , sending end voltage and reactive power at the receiving end.

The line that exhibits FVSI closed to 1.00 implies that it is approaching its instability point. If FVSI goes beyond 1.00, one of the buses to the connected to the line will experience a sudden voltage drop leading to system collapse

3. Formulation Of The OPF Problem

The OPF problem incorporating wind power is the problem to be studied in this paper and planned wind power combined with the power output of thermal power plant are as the variables to be optimized.

Also, the optimization of voltage stability index (FVST) is included in the objective function to improve system voltage stability.

The aim of this paper is to optimize a certain objective function such as cost, loss, the deviation of voltage and voltage stability index while satisfying all operational constraints. The general optimization problem can be written in the following form:

$$Min[f] = \sum_{i=1}^{Ng} f_i + P_{loss} + f_v + Max(FVSI) \quad (3)$$

Where:

f_i : is the fuel cost of the i^{th} generator.

$$f_i = \alpha_i + \beta_i P_{gi} + \gamma_i P_{gi}^2 \quad (4)$$

P_{gi}: is the actual power produced in the generator *i*;

α_i, β_i and γ_i *:* are the cost coefficients of generator at bus i;

N_g : is the number of generators in the system;

P_{loss} : are the active power losses.

$$P_{loss} = \sum_{i=1}^{Ng} P_{gi} - \sum_{j=1}^{Nl} P_{lj} \quad (5)$$

f_V : The deviation of voltage is given as follows:

$$f_v = \sum_{i=1}^{NPQ} \left(V_i - V_{rated}\right)^2 \quad (6)$$

FVSI: is the Fast voltage stability index

The equality and inequality constraints to be satisfied while searching for the optimal solution can be written as:

$$\begin{cases} P_i = P_{gi} - P_{di} = \sum_{j=1}^{nb} V_i V_j (g_{ij} \cos\theta_{ij} + b_{ij} \sin\theta_{ij}) \\ Q_i = Q_{gi} - Q_{di} = \sum_{j=1}^{nb} V_i V_j (g_{ij} \sin\theta_{ij} - b_{ij} \cos\theta_{ij}) \end{cases} \quad (7)$$

The system inequality operation constraints include:

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \quad (8)$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \quad (9)$$

Where:

P_{gi}, Q_{gi}: are the real and reactive power generations at bus i.

P_{di}, Q_{di}: are the real and reactive power demands at bus i

V_i, V_j: The voltage magnitude at bus i, j, respectively.

θ_{ij} : is the admittance angle.

b_{ij} and g_{ij}: are the real and imaginary part of the admittance.

nb: is the total number of buses.

4. Application Of Differential Evolution Algorithm On OPF Problem

Differential evolution is an optimization algorithm that solves real-valued problems based on the principles of natural evolution. DE uses a population of given size composed of floating point encoded individuals that evolve over generations to reach an optimal solution. It was introduced by Storm and Price in 1995 as heuristic optimization method which can be used to minimize nonlinear and non-differentiable continuous space functions with real valued parameters.

The advantage of DE can be summarized as follows: DE is an effective, fast, simple, robust, inherently parallel, and has few control parameters need little tuning. It can be used to minimize non-continuous, non-linear, non-differentiable space functions, also it can work with noisy, flat, multi-dimensional, and time dependent objective functions and constraint optimization in conjunction with penalty functions [6],[7],[14],[15].

The main steps of the DE algorithms are given below:

Initialization
Evaluation
Repeat
  Mutation
  Crossover
  Evaluation
  Selection
Until (termination criteria are met)

Step I: initialize power flow data, and DE related parameters such as the size of population (NP) , the maximum number of iteration , the number of variables to be optimized (D) , the crossover factor (CR) , and the mutation factor (F) .

Step II: randomly generate the initial population of *NP* individuals in the feasible space by:

$$X_{ij}(0) = X_j^{\min} + rand(0,1)(X_j^{\max} - X_j^{\min}) \quad (10)$$

Where

i=1,……., NP and j=1,……., D

X_j^{max} and X_j^{min} are the upper and the lower bounds of the jth decision parameter.

rand(0,1) is a uniformly distributed random number within [0,1] generated for each value of j.

$X_{ij}(0)$: is the j^{th} parameter of the i^{th} individual of the initial population.

Step III. Evaluate the fitness for each individual in the population according to the objective function in (3).

Step IV. Create a new population by:

1- Mutation: creates mutant vectors $(X_i^{'(G)})$ by perturbing a randomly selected vector Xa with difference of two other randomly selected vectors Xb and Xc

$$X_i^{'(G)} = X_a^{(G)} + F(X_b^{(G)} - X_c^{(G)}), i = 1......NP \quad (11)$$

Where Xa, Xb and Xc: are randomly chosen vectors among the NP Population, $a \neq b \neq c \neq i$.

The scaling constant F is an algorithm control parameter used to adjust the perturbation size in the mutation operator and to improve algorithm convergence. Typical value of F in the range of [0.4 - 1.0].

2- Crossover: In order to increase the diversity of the perturbed parameter vectors, crossover is introduced. To this end, the trial vector is formed, where:

$$X_i^{''(G)} = \begin{cases} X_{ij}^{'(G)}, if \quad rand(0,1) \le C_R \quad or \quad j = j_{rand} \\ X_{ij}^{(G)} \quad otherwise \end{cases} \quad (12)$$

Where:

j_{rand}: is a randomly chosen index ϵ {1…N_p} that guarantees that the trail vector gets at least one parameter from the mutant vector

CR is the crossover constant which has to be determined by the user in the range of [0 1]

3- Selection : The selection operation forms the population by choosing between the trail vectors and their predecessors (target vectors) those individuals that present a better fitness or are more optimal according to (13)

$$X_i^{(G+1)} = \begin{cases} X_i^{''(G)}, if \quad f(X_i^{''(G)}) \le f(X_i^{(G)}) \\ X_i^{(G)} \quad otherwise \end{cases} \quad (13)$$

Where

$X_i^{(G+1)}$ is the offspring of $X_i^{(G)}$ for the next generation.

Step V: stop the process and print the best individual if the stopping criterion is satisfied, else go back to step IV.

In this paper the following values are selected as: F=0.8, CR=0.8, NP= 20

5. Results And Discussion

The modified IEEE 30-bus test system consists of six generators at buses 1, 2, 5, 8, 11 and 13 and wind farms connected to bus 10. The wind turbine generators used are assumed to be Enercon, type E33 with the following specifications: diameter of 33.4 m and tower height of 49m (table 1) [16]. For a wind farm with 100*330kVA power output, is used to analyze the effect of connected wind farm on the total generation cost, the voltage profile, the active losses and the fast voltage stability index in 24 hours in the month of January. The system has 41 transmission lines and 24 loads. The system load curve (hourly load curve), where it is divided into two different periods, i.e. peak period and off-peak period fig .2.

The output from the wind is considered as "must-take" energy, all the output of the conventional generators will be reduced and optimized by DE to accommodate the wind output, and also DE optimization technique is used to define the best location to provide desired reactive power support under heavy load conditions.

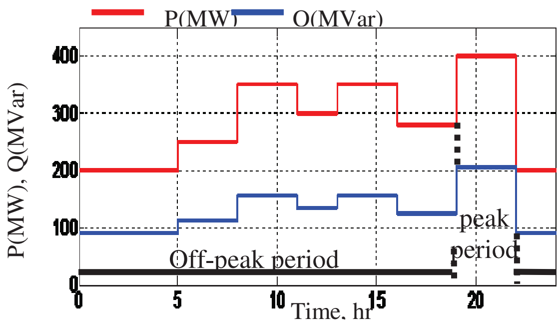

Fig. 2. IEEE 30-Bus System Load Curve.

TABLE I

The Parameters Of The Wind Turbine

Parameters	Value	Parameters	Value
ρ	1.225 kg/m^3	$V_{cut\text{-}in}$	2.5 m/s
D	33.4 m	$V_{cut\text{-}off}$	28m/s
Cp	0.59	V_{rated}	12 m/s

5.1. OPF Results Without The Insertion Of Wind Farms

The results including the generation cost, the minimum deviation and power losses in the case without the penetration of the farm wind generators for peak and off peak period are tabulated in table II, Figure 3, Figure 4 and Figure 5 show respectively the power generation system, voltage magnitudes and the Fast Voltage Stability Index (FVSI) for peak and off peak period. Figure 6 and 7respectively represented the voltage magnitudes and power generation according to the variation of the power required fig.2 in 24 hours.

TABLE II

Results of OPF without Wind Farm

Times (hr)	C0ST ($/h)	Ploss (MW)	Fv (P.U)	MAX(FVSI) (P.U)
1-5	519.547	-78.6088	0.00657505	0.0804
6-8	683.59	-25.6289	0.00704439	0.0955
9-11	1158.27	79.6769	0.0173837	0.0788
12-13	863.879	27.0823	0.0110733	0.0888
14-16	1158.27	79.6769	0.0173837	0.0788
17-19	790.212	5.98295	0.00895278	0.0937
20-22	1387.61	132.188	0.0354576	0.0837
23-24	519.547	-78.6088	0.00657505	0.0804

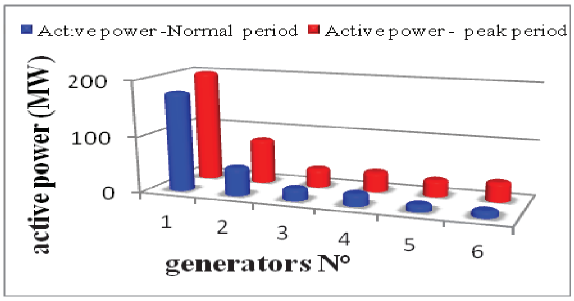

Fig. 3. The Active Power Generation.

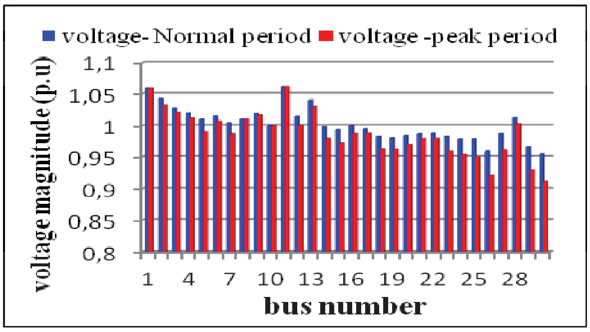

Fig. 4. Voltage Magnitudes.

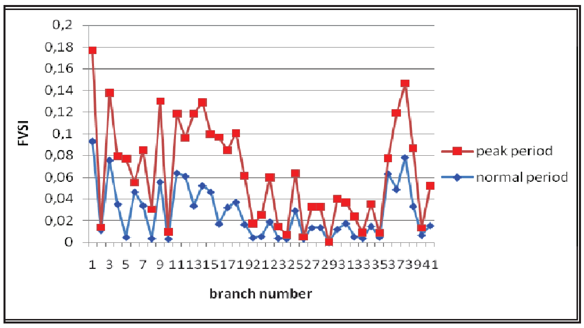

Fig. 5. FVSI Index in Normal and Peak Period.

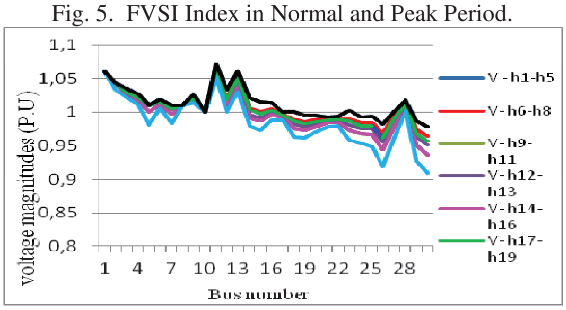

Fig. 6. Voltage Magnitudes in 24 Hours.

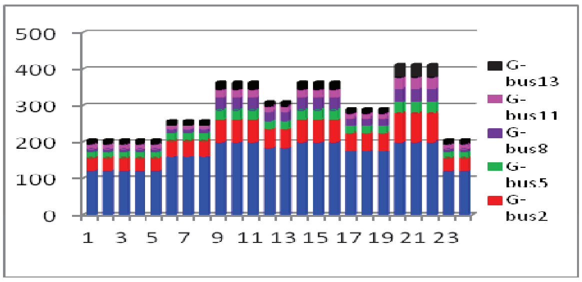

Fig. 7. The Active Power Generation in 24 Hour.

Figure 4 and 7 show that the voltages at the load bus are all within the system limits ranging from 0.95 to 1.05 P.U. But in the peak period (400MW) the voltage in the bus 26-29-30 exceeds the limit (0.95).

Ranking weak bus under heavy load conditions IEEE 30-bus system of Figure 6 is the bus 30-26-29-21-24.

5.2. OPF Results With The Insertion Of Wind Farms

The results including the generation cost, the minimum deviation and power losses in the case with the penetration of the farm wind generators are connected to bus 10 for peak and off peak period are tabulated in table 3; Figure 8 Figure 9-10 and Figure 11 show respectively the power generation system in 24 hours, voltage magnitudes, and the Fast Voltage Stability Index (FVSI) for peak and off peak period.

The results obtained from different values of the power requested show that wind generation can contribute towards improving the transmission system voltage profile for some case. Different values of the wind generation indeed change the system Operation.

The table 3 shows generation cost and power losses for different wind penetration levels for location of wind farm in the bus 10 are less, compared of the Table2 (without farm wind), where the cost of production and the power losses high.

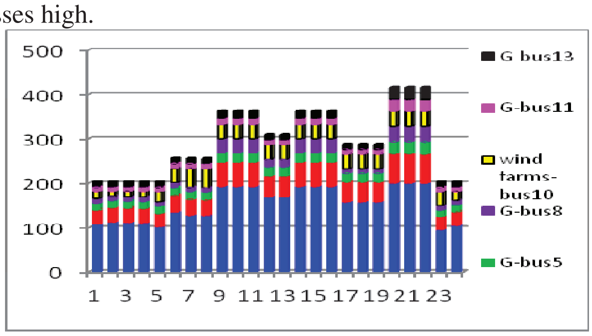

Fig. 8. The Active Power Generation in 24 Hour with Farm Wind.

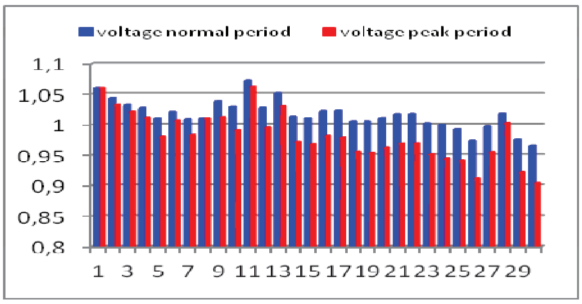

Fig. 9. Voltage Magnitudes with Farm Wind.

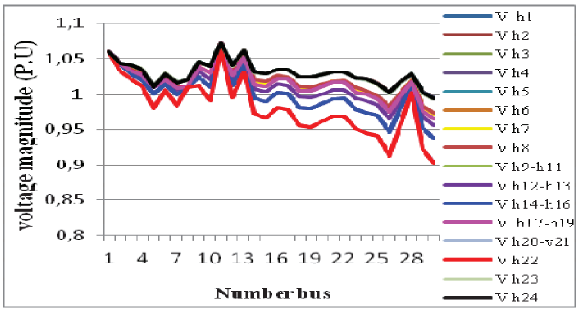

Fig. 10. Voltage Magnitudes in 24 Hours with Farm Wind.

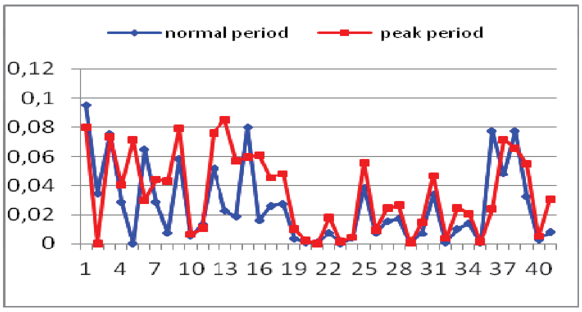

Fig. 11. FVSI Index in Normal and Peak Period with Farm Wind.

TABLE III

Results of OPF with Wind Farm

Times (hr)	Pw (MW)	C0ST ($/h)	Ploss (MW)	Fv (P.U)	MAX(FVSI) (PU)
1	16,211	478.444	-79.4884	0.018106	0.0826
2	10,8601	491.582	-79.2821	0.0181291	0.0810
3	12,0159	488.723	-79.3283	0.0181247	0.0812
4	12,6749	487.099	-79.3537	0.018122	0.0815
5	23,0817	461.921	-79.7244	0.0180674	0.0833
6	33	590.827	-27.2786	0.0101411	0.0886
7	42,1424	566.795	-27.6355	0.00934104	0.0852
8	43,3022	563.799	-27.676	0.00936066	0.0847
9-11	33	1047.26	78.8052	0.0149562	0.0802
12-13	33	761.763	25.8545	0.0089065	0.0946
14-16	33	1047.26	78.8052	0.0149562	0.0802
17-19	33	691.31	4.72543	0.00917546	0.0956
20-21	33	1252.86	131.552	0.0456602	0.0853
22	33,6002	1250.61	131.497	0.0456359	0.0838
23	31,6622	441.827	-79.9736	0.0180056	0.0817
24	20,1389	468.951	-79.6272	0.0180852	0.0832

The result of the weakest bus ranking under heavy load conditions obtained is presented in Table 4.

TABLE IV

Weakest Buses Ranking under Heavy Load Conditions in IEEE 30-bus System with Wind Farm

Ref [8]	30, 26, 29, 21, 24
Proposed method (DE)	30, 26, 29, 21, 24

6. CONCLUSION

This paper proposes the application of DE method to the optimal power flow for a system that incorporates thermal unit and wind farms during off peak period and peak period and is proposed to identify the weakest buses for IEEE30 bus systems.

Based on the technical result it has been concluded that the utilization of wind farms give significant benefit example like such as reduction in the real power loss, fuel cost and amelioration in the voltage profile in different periods (off peak and peak period).

According to the variation of the wind and the change in power demand, the cost is changed.

The weakest buses identification problem is modeled as optimization problem considering the voltage stability of power system. The scheme optimizes the cost, the power losses and the load voltage stability index to find the buses were the reactive power sources to be installed, and these buses (30-26-29) are considered as the weakest buses in the system.

REFERENCES

[1] kun yang, a. Garba, c.s. tan, k.l. lo, 'The Impact of the Wind Generation on Reactive Power Requirement and Voltage Profile'DRPT2008, Nanjing China 6-9 April 2008,p.p. 866-871.

[2] Yu-Cheng Chang,Tsung-Ying Lee , Chun-Lung Chen , Rong-Mow Jan, 'Optimal power flow of a wind-thermal generation system', Electrical Power and Energy Systems 55 (2014), p.p312–320.

[5] S. Pérez-Londoño L.F. Rodríguez, G.Olivar, "A Simplified Voltage Stability Index (SVSI)", Electrical Power and Energy Systems 63 (2014) 806–813.

[6] M. Amroune, A. Bourzami, T. Bouktir, "Weakest Buses Identification and Ranking in Large Power Transmission Network by Optimal Location of Reactive Power Supports", TELKOMNIKA Indonesian Journal of Electrical Engineering Vol. 12, No. 10, October 2014, pp. 7123-7130.

[7] Linda SLIMANI, Tarek BOUKTIR "Application of Differential Evolution Algorithm to Optimal Power Flow With high Wind Energy Penetration" , Mediamira Science Publisher. Vo53, N°1, 2012.

[8] Y. Kataoka, M. Watanabe, S. Iwamoto, "A New Voltage Stability Index Considering Voltage Limits", IEEE, 2006 .

[9] Hang Naishan, Xu Tao, Liao Qinghua, et al. "The analysis of abundance index of voltage stability based circuit theory," *Guangxi Electric Power*, pp: 12-14, Feb. 2006

[10] Liu Baozhu , Li Bolong, "A Novel Static Voltage Stability Index based on Equilibrium Solution Region of Branch Power Flow", DRPT2008 6-9 April 2008 Nanjing China

[11] Mohamed A, Jasmon GB. "A new clustering technique for power system voltage stability analysis", Int J Electr Mach Power Syst 1995;23(4):389–403

[13] Musirin I, Rahman TKA, "On-line voltage stability based contingency ranking using fast voltage stability index (FVSI)", In: Proc IEEE/PES transm distrib and exhibition conference; 2002. p. 1118–23.

[14] Leandro dos Santos Coelho ,Rodrigo Clemente Thom Souza, Viviana Cocco Mariani, "Improved differential evolution approach based on cultural algorithm and diversity measure applied to solve economic load dispatch problems", L.D.S. Coelho et al. / Mathematics and Computers in Simulation 79 (2009) 3136–3147.

[15] Ghamgeen I. Rashed1 and Yuanzhang SunH. I. Shaheen," Optimal Location and Parameter Setting of TCSC for Loss Minimization Based on Differential Evolution and Genetic Algorithm", Ghamgeen I. Rashed et al. / Physics Procedia 33 (2012) 1864 – 1878.

[3] Libao Shi, Yixin Ni," Optimal Power Flow Solution Incorporating Wind Power", IEEE Systems Journal , Vol. 6, N°2, June 2012.

[4] [G. Andersson, P. Donalek, R. Farmer, N. Hatziargyriou, I. Kamwa, P. Kundur, N. Martins, J. Paserba, P. Pourbeik, J. Sanchez-Gasca, R. Schulz, A. Stankovic, C. Taylor, and V. Vittal ,"Causes of the 2003 major grid blackouts in North America and Europe and recommended means to improve system dynamic performance", IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 20, NO. 4, NOVEMBER 2005.

[12] Moghavvemi M, Omar FM. "Technique for contingency monitoring and voltagecollapse prediction", IEE Proc Gen Transm Distrib 1998;145(6):634–40

[16] ENERCON wind energy converte