Study and Analysis of Reactive Power in Wind Farm for Reducing Distribution Losses Using Genetic Algorithm

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Abstract— This paper presents the optimization of reactive power in wind form for reducing distribution losses. For this purpose a Wind Farm comprising Doubly Fed Induction Generation (DFIG) wind turbines is purposed as a continuous reactive power source to support system voltage control due to reactive power control capability of doubly fed induction generator. The genetic algorithm is utilized to find the optimize value of reactive power in wind farm for reducing the losses. The objective function is to minimize the real power losses of the system and minimize the deviation of the bus voltage is achieved.

Keyword- Doubly fed Induction Generator, Grid connected wind farm, Genetic Algorithm.

I. INTRODUCTION

CURRENTLY, there is an increasing concern over the environmental impact and sustainability of traditional fossil-fueled power plants. Because wind energy is one of the most important and promising renewable energy resources in the world, leading to a growing penetration of the wind energy in electrical system, in [1] proposed a wind farm made up with DFIG as a continuous reactive power source to support system voltage control due to the reactive power control capability of DFIG. The particle swarm optimization algorithm (PSO) is utilized to find the optimal reactive power output of wind farm. The main objective of the optimization is to minimize the real power losses of the system and the deviation of the bus voltage in the proposed optimization algorithm, reactive power output of wind farm is utilized as the control variable for loss minimization and voltage profile improvement, in [2] studies the reactive power output optimization of wind farm, and the variability and intermittency of wind speed is considered. The multi-objective reactive power optimization model including network loss, average deviation of voltage [3] the use of genetic algorithms for the resolution of the optimization. Problem of the voltages plan and the active losses in a power system including a wind power station by acting on the reactive productions of inductances and capacitors benches connected to the consuming nodes, In [4] an improved Genetic algorithm (GA) for reactive power optimization in wind farm. Traditional GA has some drawbacks, such as slow convergence. The coding method, genetic operators, crossover and mutation probability, stopping criterion in iteration has been improved. The reactive power optimization method with improved GA is tested in a MATLAB based simulation model, in [5] developed a wind farm model and concluded that wind farms made up of double fed induction generators constitute an important tool from the voltage regulation point of view. Furthermore, the designed proportional distribution algorithm makes all the generators work under similar conditions and quite far from saturation, which means far from the reactive power generation limits in [6] power capability limits of doubly fed asynchronous generators. These limits have been obtained by taking into account the maximum stator and rotor currents and the steady state stability limit of the generator in [7] describe the development of a new algorithm for the solution of a multi-objective problem in power systems with wind farm using Particle Swarm Optimization. Basically, the purpose is to search an optimal operation point of system which allows simultaneous power factor remote control and loss minimization. In [8] described the reactive power capabilities of wind power generator and then discuss reactive power ancillary services issues related to the wind farms in the electricity market. Presently, the (DFIG) system is popular and widely used for wind power generation due to its several advantages in [9]. A detailed view of wind turbine power, energy and torque is given. Different types of generators used in wind farm are also discussed. In the end, an overview of wind power plants is also provided.

In present work, a test system is taken and a Wind farm with Doubly fed induction generator is connected to one of its nodes. The active power output of the wind farm is used to find the maximum of reactive power capability limits. Then using Reactive power as a control variable, the optimum value of reactive power, for which the losses and voltage deviation are minimized, is determined by Genetic algorithm.

II. SYSTEM MODEL AND CONTROL

The model of DFIG consisting of a pitch controlled wind turbine and an induction generator [1]. The stator of the DFIG is directly connected to the grid, while the rotor is connected to a converter consisting of two back-to-back PWM inverters, which allows direct control of the rotor currents. Direct control of the rotor currents allows for variable speed operation and reactive power control thus DFIG can operate at a higher efficiency over a wide range of wind speeds and help provide voltage support for the grid. These characteristics make the DFIG ideal for use as a wind generator.Fig.1 shows the DFIG Configuration.

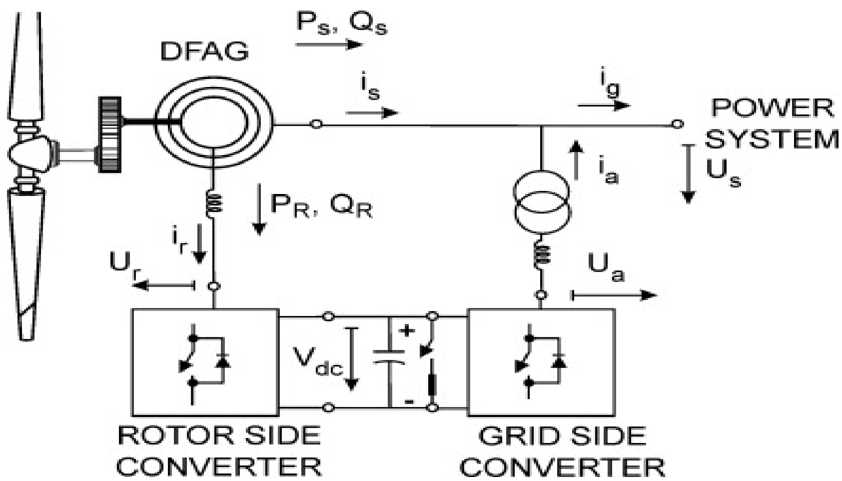


Fig.1 Configuration of DFIG

A. DFIG Capability Limits Curve

The stator active and reactive power can be expressed as a function of stator current and rotor current [1]

$$P_S^2 + Q_S^2 = (3U_S I_S)^2$$
$$P_S^2 + \left(Q_S + 3\frac{U_S^2}{X_S}\right)^2 = \left(3\frac{X_M}{X_S}U_S I_R\right)^2$$

In the PQ plane, (1) represents a circumference centered at the origin with radius equal to the stator rated apparent power. Equation (2) represents a circumference centered at $[-3U^2$s/Xs, 0] and radius equal to 3 $X_M U_S I_R / X_S$. Therefore, given the stator and rotor maximum allowable currents I*S* max and I*R*max , the DFIG capability limits are obtained. Fig.1 shows the composed curve for the DFIG capability limits. Additionally, the steady state stability limit of the DFIG is taken into account, which represented as vertical line at the [-3 U_s^2 /Xs, 0], coordinate. It's obvious that the DFIG reactive power capability mainly depend on the rotor maximum allowable current I*R* max

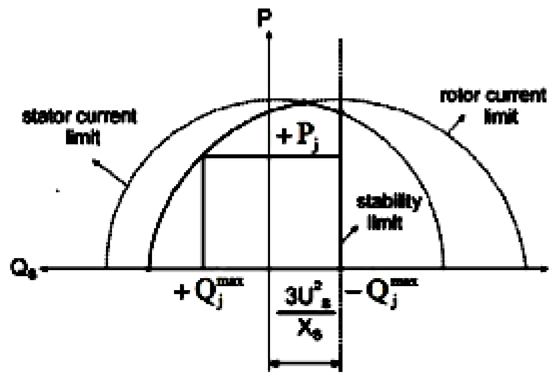


Fig.2. DFIG capability limits curve

In Fig.2, The DFIG can be able to operate at any point in the intersecting area within the given limits. From this figure, one can observe that when the available active power is far from its maximum, the amount of available reactive power is high. The large reactive power control capability of the DFIG making it possible to use DFIG as the continuous reactive power source to support system voltage control.

B. Wind Farm Model

In this paper, a wind farm model is developed with n DFIG wind turbines connected in parallel. As a result, the total active and reactive power output of the wind farm equal to the sum of the active and reactive power generated by each of the DFIG wind turbine in the wind farm:

$$P_{WF} = \sum_{i=1}^{N} P_{gi}$$

$$Q_{WF} = \sum_{i=1}^{N} Q_{gi}$$

Where *PWF* represents the active power output of the wind farm, *QWF* represents the reactive power output of the wind farm, *Pgi* represents the generated active power of each DFIG and *Qgi* represents the generated or absorbed reactive power of each DFIG.

In this paper, it's assumed that the wind speed at each DFIG is the same and all of the available active power in wind farm is fed into the distribution network.

III. PROBLEM FORMULATION

In this section, wind farm reactive power output optimization has been modeled as a multi objective, non differentiable optimization problem. In the proposed optimization algorithm, the objective function consists of two terms: 1) the real power losses of the system, 2) the deviation of the bus voltage.

$$\min f_1(\bar{X}) = \lambda_1 \sum_{i=1}^{Nl} R_i \frac{P_i^2+Q_i^2}{|V_i|^2} + \lambda_2 \; max|V_i - V_{rat}|$$

Due to the DFIG operational requirements, the minimization of the objective function is subjected to the following constraints:

1) Distribution power flow equations:

$$P_i + P_{WFi} = P_{Di} + V_i \sum_{j=1}^{Nb} V_j (G_{ij} \sin \delta_{ij} + B_{ij} \sin \square_{ij})$$

$$Q_i + Q_{WFi} = Q_{Di} + V_i \sum_{j=1}^{Nb} V_j \left(G_{ij} \sin \delta_{ij} - B_{ij} \sin \square_{ij} \right)$$

2) DFIG active capability limits:

$$P_{gi,min} \le P_{gi} \le P_{gi,max}$$

3) DFIG reactive capability limits:

$$Q_{gi} \le \left| \sqrt{\left(3 \frac{X_M}{X_S} U_S I_R\right)^2 - (P_{gi})^2} \right| - 3 \frac{U_S^2}{X_S} - Q_{gi} \le \left| \sqrt{\left(3 \frac{X_M}{X_S} U_S I_R\right)^2 - (P_{gi})^2} \right| + 3 \frac{U_S^2}{X_S}$$

4) Node voltage magnitude limits:

$$V_{min} \le V_i \le V_{max}$$

5) Distribution line limits:

$$\left| P_{ij}^{line} \right| < P_{ij,max}^{line}$$

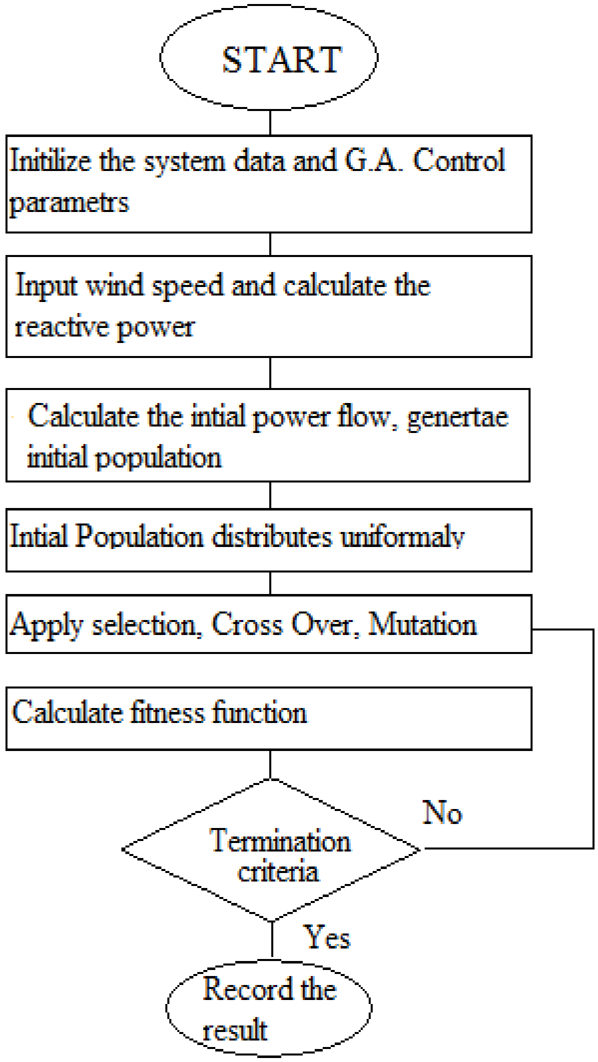
6) Radial structure of the network.

IV. GENETIC ALGORITHIM BASED REACTIVE POWER OUTPUT OPTIMISATION

Genetic Algorithm is a family of computational models inspired by evolution. These algorithms encode a potential solution to a specific problem on a simple chromosome. And apply recombination operators to these structures so as to preserve critical information. Genetic algorithms are often viewed as function optimizers although the range of problems to which genetic algorithms have been applied is quite broad an implementation of a genetic algorithm begins with a population of typically random chromosomes. One then evaluates these structures and allocates reproductive opportunities in such a way that those chromosomes which represent a better solution to the target problem are given more chances to reproduce than those chromosomes which are poorer solutions the goodness of a solution is typically defined with respect to the current population. Then GA operators are performed to obtain the new child offspring; the operators are:

1. Selection
2. Crossover,
3. Mutation,

The algorithm is amalgamation of Genetic algorithm. In Genetic algorithm population is initialized and when it satisfied the constraints by means of mutation and crossover, it assign a new generation which set the value for Reactive power for the given iteration and load flow is run by means of selection. By following this process of crossover, mutation and generation several times the objective function will reach at its minimum value. The Algorithm is explained by flow chart:



V. SIMULATION RESULTS

For modeling of a dynamic system, the system should be fully defined. After building each component, integrate them into a complete model of the system. A three feeder distribution system is used as shown in the Fig. 3 with a base voltage of 0.69 KV. Total system load is 28.7MW and 17.3MVAR. A small wind farm comprising 10 DFIG wind turbines of 900kW, with a power installed of 9MW is connected at node 12 through a rated 23/0.69 kV transformer.

The performance parameters of the studied DFIG wind turbine are given in Table 1
The electric parameters of the studied DFIG wind turbine are given in Table 2

Table 1
DFIG performance parameters

Parameter	Value
Rated capacity	900KW
Cut in wind speed	4m/s
Cut out wind speed	25m/s
Rated wind speed	12.5m/s
Rated voltage	.69KV

Table 2
DFIG electric parameters

Parameter	Value
Stator resistance per phase	.0067Ω
Stator leakage reactance per phase	.0300 Ω
General turns ratio	.3806
Mutual reactance	2.3161 Ω
Rotor resistance per phase	.0399 Ω
Rotor leakage reactance per phase	.3490 Ω

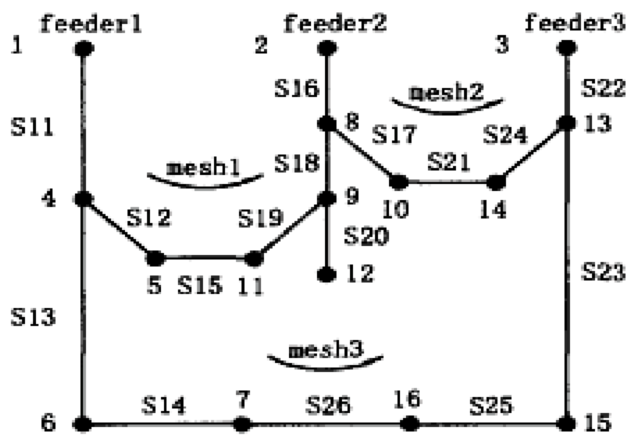


Fig. 3 Single line diagram of three feeder system

A. *Available Active and Reactive Power in Wind Farm*

A three feeder distribution system is modelled in MATLAB with a Wind farm connected at the 12th node and its simulation results are presented. The active power and reactive power output are in MW Shown in Fig. 4 & 5

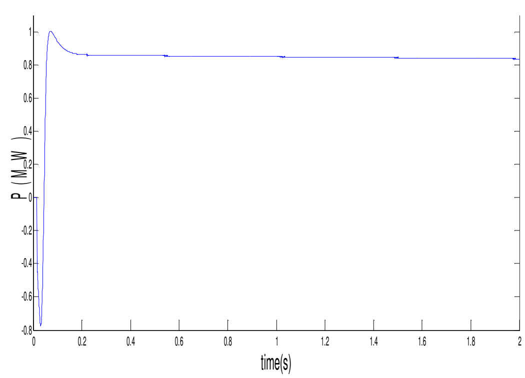


Fig.4 Active power output of Wind farm

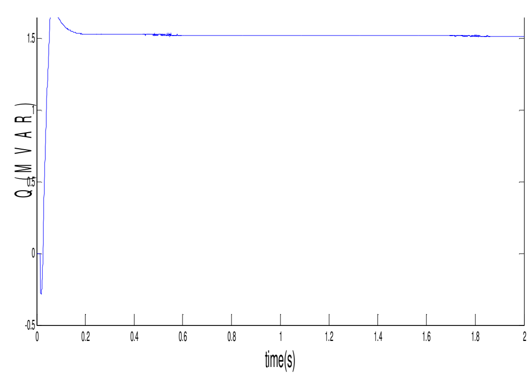


Fig 5 Reactive power output of Wind farm

B. *Results of Optimization*

The Reactive power output of the DFIG is used as control variable in Genetic algorithm. The objective function which includes minimization of losses and improvement of voltage profile is calculated by means of Genetic algorithm. The Table 3 shows the input values for the optimization toolbox in MATLAB while Table shows the results after optimization through genetic algorithm. Whereas the plot of Best Fitness, Best Individual, Max Constraint and Range are drawn by MATLAB Optimization toolbox.

Table 3: Input Values for GA Tool used in MATLAB

Number of variables	1
Lower Bounds	[0.58]
Upper Bounds	[9]
Mutation	uniform with rate 0.05
Current iteration	51
Generations	100
Crossover	0.5
Selection function	stochastic function
Elite count	2
Initial range	[0;1]

Table 4: Results from GA

DFIG at node	Losses (MW)	Optimum reactive power (MVAR)	Objective function
12	0.42768	5.6658	0.2238

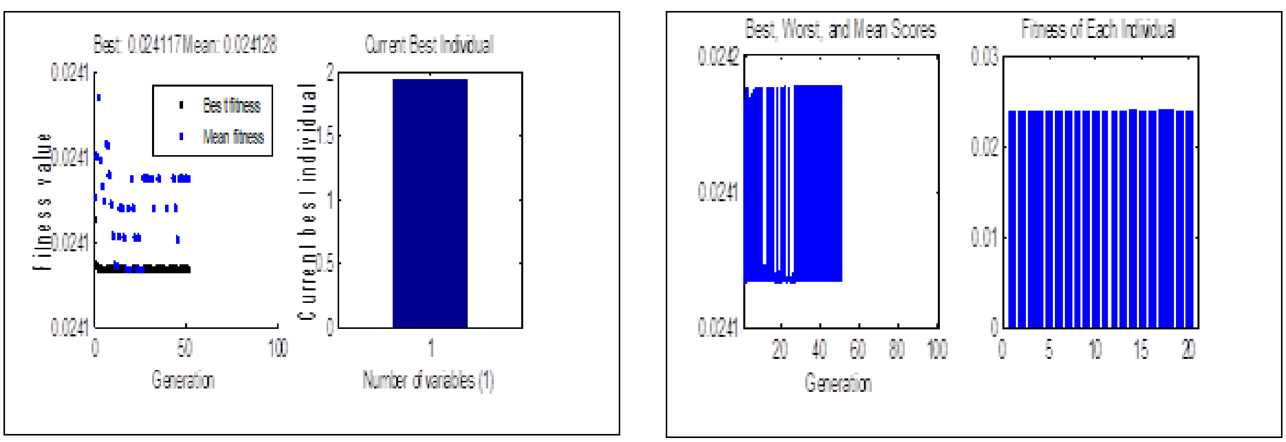


Fig 6 Best Fitness, Best Individual, Max Constraint and Range drawn for test system

Comparison between the power losses of the system when the power factor of the wind farm is kept constant at .98 and power losses of the system after optimization are shown in Fig. 7.

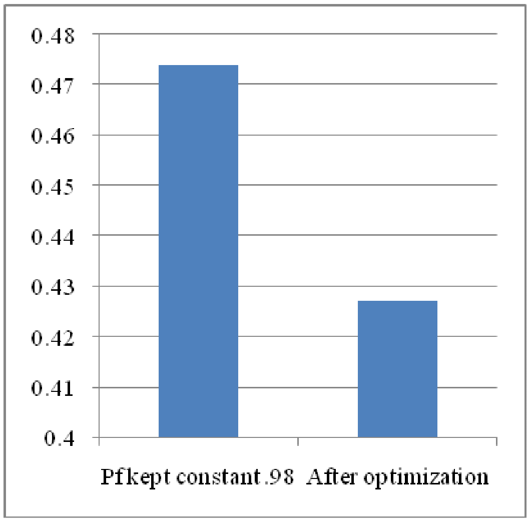


Fig.7: Power losses of the distribution system

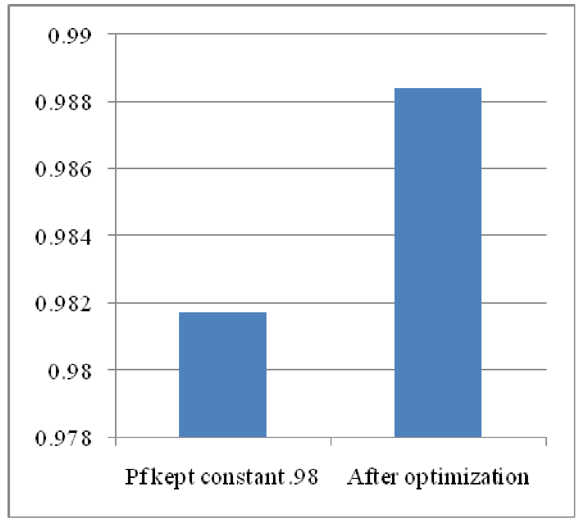


Fig. 8: Minimum nodal voltage of the distribution system

Comparison between the minimum nodal voltage of the system when the power factor of the wind farm is kept constant at .98 and nodal voltage of the system after optimization is shown in Fig. 8.

VI. CONCLUSIONS

In this paper the losses and nodal voltage of the system after optimization were compared with the losses and nodal voltage of the system when power factor of wind farm is kept constant. The losses in the system were 0.43368 MW when the power factor of wind farm is kept constant at 0.98. Comparing the two losses, it can be concluded that losses in the system were reduced after optimization. Minimum nodal voltage of the system after optimization was 0.9884 p.u. and Minimum nodal voltage of the system when power factor of wind farm is kept constant at 0.98 was 0.9817 p.u. Comparing the two voltages, it can be concluded that voltage deviation in the system was reduced after optimization. From the results obtained for the test system, it can be concluded that Wind farm made up of DFIG can act as a continuous reactive power source to support system voltage and reduce the losses of the system.

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