Optimal Location and Size of Wind Source in Large Power System for Losses Minimization

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Abstract. This paper presents a Genetic Algorithm approach for optimal integration of Wind based on Distributed Generation (WDG) in smart grid taking in to count technical and security constraints. The optimal integration that is to say, look for the optimal location and size of the WDG to be integrated into the network. The objective function considered in this study is minimize active power losses. The proposed method is applied on IEEE 14 bus using MATLAB software.

Keywords: Wind · Distributed Generation · Location and size · Loss reduction · Power system · Optimal Power Flow · Genetic Algorithm

1 Introduction

The world electricity demand has permanently and quickly developed. This evolution has been contributed by population increasing, economic activity development, household equipment evolution, life modernization and comfort [1]. The fact to introduce other sources (e.g. Distributed Generation, DG) in bus load can cause an impact on the transmission system. The location and size of DG can play an important role in the power system exploitation and operation. The DG placement at non suitable location can provoke in transmission system negative impacts [2]. The efficient solution to avoid this impact passes throw optimal integration of DG. In literature, many different types of techniques varying from meta-heuristic approaches [3] have been used to determine the optimal location and size of DG, for example, the research [3] presented a technique based an Optimal Power Flow (OPF) calculation with DG unit, bat the location is predetermined on bus 7, 10 and 30, the bi-objective function is fuel cost and power losses minimization. The paper [4] used continuation power flow method

M. Hatti (Ed.): ICAIRES 2019, LNNS 102, pp. 566–574, 2020.
https://doi.org/10.1007/978-3-030-37207-1_60

and voltage stability index, in order to determine the location vulnerable to voltage, to decide which bus has to be targeted (candidate bus), and then DG location. Another study proposed in [5] to show the influence of DG on gas emission and fuel cost. In this study the used optimization technique is interior-point method, the DG location is chosen before. Zhu et al. [6] had formulated of Distribution Optimal Power Flow (DOPF) into consideration DG units, with an objective function to minimize total power losses. The quadratic programming method is used to resolve this problem. Harrison and Wallace [7] developed a method based on OPF in a distribution network and considered DG as a negative load. The DPOPF algorithm (Distributed and Parallel OPF) proposed to solve the OPF with DG units of renewable energy in the transmission system [8]. Authors of [9] also presented Particle Swarm Optimization technique for solving multi type DG unit sizing and placement problem in distribution networks. A multi-objective optimization (minimization power losses and number of DG) has been proposed, in order to deduce the adequate location and optimal size of DG, using Non-Linear Programming technique [10]. The work in [11] presented Mixed Integer Non-Linear Programming (MINLP) approach for determine optimal location and number of DG in hybrid electricity market. Reference [12] developed application of Multi-Objective Particle Swarm Optimization (MOPSO) with the aim of determine optimal location and size of DG and shunt capacitor simultaneously with considering load uncertainty in distribution network. The multi-objective optimization includes three objective functions: improving voltage, decreasing active power losses and voltage stability. Another study proposed a multi-objective index-based approach to optimally determine size and location of multi DG units in distribution system with non-unity power factor considering different load models [13]. In paper [14] presented a Genetic Algorithm method for optimal location and sizing of Photovoltaic based-DG unit. The objective function is minimize total power losses in transmission power system. In this work, a metaheuristic technique based on the genetic algorithm was applied to determine the optimal location and size of wind based on distributed generation, while minimizing active losses. The developed program is applied on the IEEE 14 node network under MATLAB language.

2 Problem Formulation

2.1 Objective Function

Optimal location and size of WDG are defined by active power loss minimization in power network with system operating constraints.

In order to avoid the negative effect of power losses, the location of delivered power should be optimal by even installed WDG-unit, to balance load with production at every moment. So our problems consist to optimize the size of WDG and their location in power system. The fitness function of active losses can be expressed as:

$$P_{loss}^{T} = I_{pq}^{2} R_{pq} \tag{1}$$

$$F = Min \sum_{i=1}^{NB} P_{loss(i)} \tag{2}$$

where V_p is voltage at bus p, R_{pq} is resistance of line connecting bus p and bus q, I_{pq} is current through the branch between bus p and bus q, NB is number of lines.

The objective function, subject to set of equality and inequality constraints that should be satisfied while achieving the minimization of active power loss.

2.2 Equality Constraints

This constraints represent active, reactive power balance equations. The power balance equation in transmission system in presence of distributed generation units with renewable and non-renewable energy units can be expressed as follows:

$$\begin{cases} P_G + P_{WDG} = P_D + P_L \\ Q_G + Q_{WDG} = Q_D + Q_L \end{cases}$$

where (P_G, Q_G), are the total active and reactive power of conventional generator, respectively, (P_D, Q_D) the total active and reactive power of load, respectively, (P_L, Q_L) is the total active and reactive power losses, respectively, P_{DG} is active power of DG (DG source modeled as photovoltaic power).

2.3 Inequality Constraints

Voltage limit:

$$V_{imin} \le V_i \le V_{imax} \quad for\ i = 1\ldots\ldots N \tag{5}$$

Line thermal limit:

$$S_k \le S_{kmax} \quad for\ k = 1\ldots\ldots NB \tag{6}$$

Real power generation limit:

$$P_{Gimin} \le P_{Gi} \le P_{Gimax} \quad for\ i = 1\ldots .NG \tag{7}$$

The DG source limit:

$$0 \le \sum_{i=1}^{NDG} P_{DGi} \le 0.3 * \sum_{i=1}^{Nbus} P_{Di} \quad for\ i = 1\ldots\ldots NDG \tag{8}$$

2.4 Preserving Solution Feasibility

Note that the control variables are generated in their permissible limits using strategist preservation feasibility (perform a random value between the minimum and maximum value), while for the state variables, including the voltages of load bus, the power flowing in distribution lines, it appealed to penalties functions that penalize solutions that violate these constraints. The introduction of penalty in the objective function, transforms the optimization problem with constraints in an optimization problem without constraints [14], so it is easier to deal, in this case the Eq. 2 shall be replaced by:

$$F_p = Min \sum_{i=1}^{NB} P_{loss(i)} + P_f \tag{9}$$

$$P_f = k_v.\Delta V + k_s.\Delta S \tag{10}$$

$$\Delta V = \sum_{i=1}^{NL} \left(V_{Li} - V_{Li}^{lim}\right)^2 \tag{11}$$

$$\Delta S = \sum_{i=1}^{NB} \left(S_{li} - S_{li}^{lim}\right)^2 \tag{12}$$

where k_v and k_s, are penalty factors, in this study, the values of penalty factors have been considered 10.000.

3 Applied Approach

3.1 Genetic Algorithm (GA)

GA are stochastic optimization algorithms found on the natural selection mechanism of a generation. Their operation is extremely simple. We start by an initial population of potential solutions (chromosomes) chosen randomly. We evaluate their relative performance (fitness). In the base of their performance we create a new population of potential solutions by using simple evolutionary operations: The selection, crossover and mutation. We repeat this cycle until we find a satisfied solution. GA have been initially developed by John Holland.

3.2 OPF with WDG

Optimal Power Flow Considering Wind Distribution Generation (OPF-WDG) has already been raised by formulas of Eq. (1). The state variables vector χ consisting of, slack bus real power P_{G1}, load bus voltages V_{L1}, reactive power outputs the all conventional generator Q_{Gi} transmission line power flow S_{l1}. Hence, χ can be expressed as:

$$\chi^T = \left[P_{G1}, V_{L1} \ldots V_{LNL}, \delta_2 \ldots \delta_{N,} Q_{G1} \ldots Q_{GNG}, S_{l1} \ldots S_{lNl}\right] \tag{13}$$

The vector v of control variables consisting, renewable generator active power outputs (size) P_{WDG} and distribution generation location (location)L_{WDG}. The other control variables (P_G,V_G, T) are considering in OPF function. Hence, v can be expressed as:

$$v^T = \left[L_{WDG1} \ldots \ldots L_{WDGn}, P_{f_{WDG1}} \ldots P_{f_{WDGn}}, P_{WDG1} \ldots P_{WDGn}\right] \tag{14}$$

The objective of optimal power flow in presence DG unit is minimize a selected fitness function via optimal settings of control variables vector. The Fig. 1 illustrate chromosome structure applied in this study.

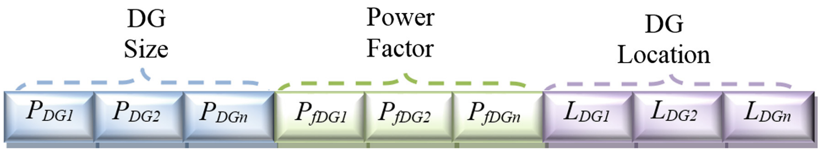

Fig. 1. Chromosome structure

OPF role is to provide different control variables values, namely, conventional generators active power, generators voltage, transformers tap settings, transforms angle control and FACTS devices, to minimize an objective function, considering technical, security, economic and environmental constraints. OPF challenge is able also to determine optimal size and location of WDG. For that, an algorithm based on OPF function and coupled with genetic algorithm method is proposed. The aim of GA method is to define optimal size and location of WDG. We should mention that, we have used OPF function implanted in MATPOWER software, and we added a new control variable (WDG size, WDG location). Figure 2 presents combination strategy of classic OPF with WDG-unit.

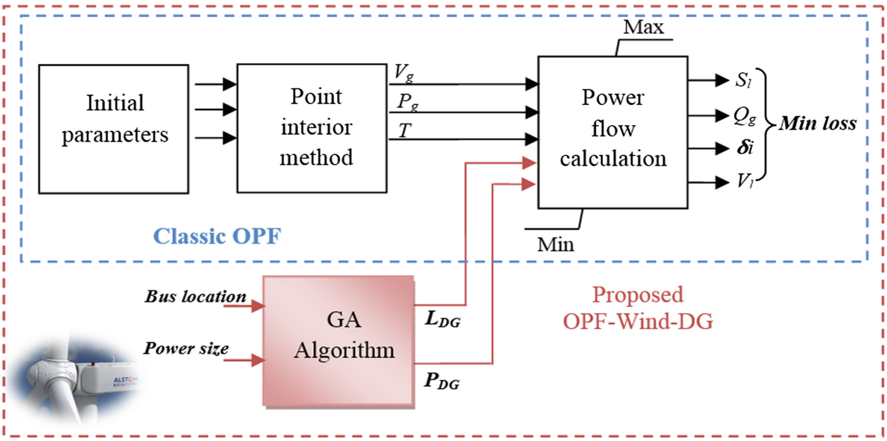

Fig. 2. Proposed model based WDG-unit integrated in classic OPF

4 Simulations and Results

The test network IEEE 14_bus, consists of 6 generators, 20 transmission lines and 4 on load tap changing transformers. The total active and reactive power absorbed by load is 259 MW and 73.5 MVAr. Figure 3 illustrate the IEEE 14_bus power system topology.

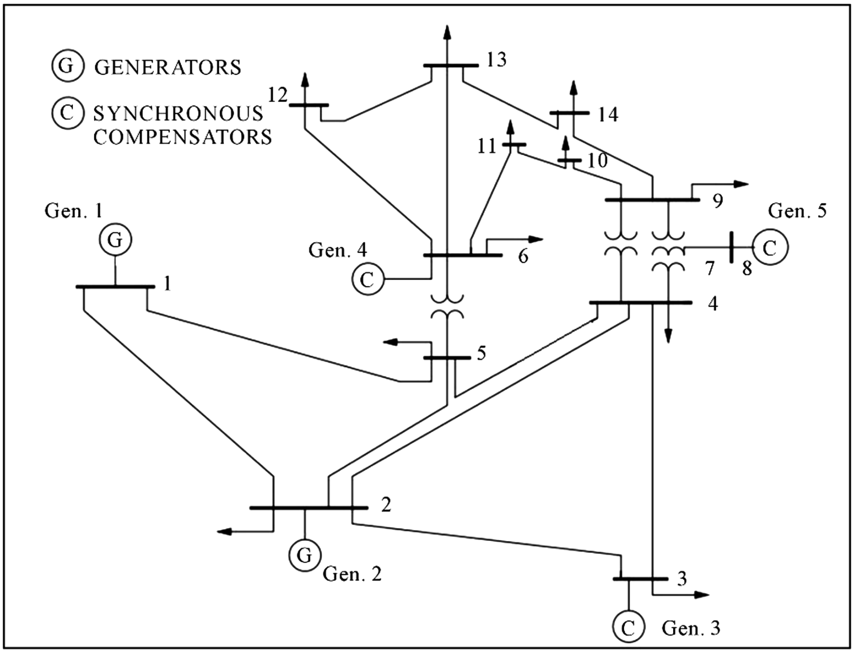

Fig. 3. IEEE 14_bus power system topology

In this study, we made an application of optimal power flow considering wind turbine based distributed generation using genetic algorithm technique. The inferior and superior voltage magnitude limits for all generator buses (PV-bus) are 0.9 pu–1.1 pu, and voltage limits for load buses (PQ-bus) are 0.95 pu–1.05 pu. It is known that all load buses have been considered as candidate for WDG location. You have to know that the values of control variables are generated in their acceptable limits using randomly strategy, in an interval of 0 to 50 MW. This work, we had considered that the generation power by WDG are negative loads, such as the WDG active power for each load bus is limited by a minimum value 0 (no generation power by WDG) and a maximum value. The distributed generation are modeled as wind source with power factor comprised between 0.8 and unity (capable injecting P and Q). The application of proposed technique to transmission power system has been examined on seven case studies: case 1 (OPF without WDG), case 2 (OPF with 1 WDGs), case 3 (OPF with 2 WDGs), case 4 (OPF with 3 WDGs), case 5 (OPF with 4 WDGs), case 6 (OPF with 5 WDGs) and case 7 (OPF with 6 WDGs).

Number of iteration chosen for this case is 50, with 100 populations of GA algorithm. The probability of mutation is 0.01, and crossover probability is 0.9. After convergence algorithm, the results obtained by genetic algorithms method are represented as following.

Table 1 shown the different parameters system for different cases. The comparison of voltage profile in various cases simulations is presented in Fig. 4. Figure 5 illustrate active load bus, total load for different cases and negative loads in bus 4, 9, 12 and 13.

Table 1. Active loss with and without WDG, location and size

Variables	Limits		Case 1	Case 2	Case 3		Case 4			Case 5				Case 6					Case 7					
	Inferior	Superior	OPF Without WDG	OPF With 1 WDG	OPF With 2 WDG		OPF With 3 WDG			OPF With 4 WDG				OPF With 5 WDG					OPF With 6 WDG					
P_{g1} (MW)	0	332.4	194.33	81.01	1.22		44.43			0.00				0.19					0.00					
P_{g2} (MW)	0	140	36.72	17.49	11.86		16.06			25.10				31.72					26.66					
P_{g3} (MW)	*	*	28.74	19.93	96.18		54.15			91.89				93.14					95.27					
P_{g6} (MW)	*	*	00.00	00.00	00.00		00.00			0.00				0.00					0.00					
P_{g8} (MW)	*	*	8.50	97.65	100.0		00.00			0.00				15.40					0.00					
Q_{g1} (MVAr)	-990	990	0.00	0.00	10.00		0.00			0.00				0.00					0.00					
Q_{g2} (MVAr)	-40	50	23.69	2.08	-0.83		-40.00			-34.02				-30.27					-24.65					
Q_{g3} (MVAr)	-6	24	24.13	40.00	22.25		13.27			0.54				3.61					5.33					
Q_{g6} (MVAr)	-6	40	11.55	-6.00	-6.00		-6.00			-6.00				-6.00					-6.00					
Q_{g8} (MVAr)	-6	24	8.27	8.24	8.32		-6.00			-6.00				-6.00					-6.00					
V_1 (pu)	0.9	1.1	1.060	0.959	0.950		0.954			0.947				0.946					0.946					
V_2 (pu)	0.9	1.1	1.041	0.946	0.943		0.940			0.940				0.940					0.940					
V_3 (pu)	0.9	1.1	1.016	0.940	0.948		0.940			0.940				0.940					0.940					
V_6 (pu)	0.9	1.1	1.060	0.990	0.989		1.033			1.026				1.034					1.021					
V_8 (pu)	0.9	1.1	1.060	0.940	0.940		1.007			1.036				1.032					1.005					
WDG location bus			**	12	9	12	4	9	13	4	7	10	13	7	9	11	13	14	4	5	9	10	12	14
WDG size (MW)			**	48.77	3.59	49,01	48.93	48.75	48.69	34.44	48.89	33.17	26.59	45.76	13.39	21.47	36.66	2.20	28.29	23.84	36.59	7.69	15.80	25.57
WDG size (MVAr)			**	34.08	1.61	34.6	21.19	30.14	26.54	13.02	32.10	22.45	16.42	34.13	10.04	16.10	17.16	1.65	1.51	4.58	26.55	5.571	11.12	17.90
Total real power loss (MW)			9.287	5.860	2.866		2.026			1.112				0.960					0.737					
Total load (MW)			259	210.22	206.39		112.62			115.88				139.48					121.19					

According to simulation results presented in Fig. 4, the voltage profile is affected by integration of WDG. In the first case before integration of DG-unit, the active power losses is 9.287 MW. After integration of WDG, in case 2 the total losses (TL) have become 5.86 MW, case 3 is 2.866 MW, case 4 is 2.026 MW, case 5 is 1.112 MW, case 6 is 0.96 MW and in case 7 have become 0.737 MW.

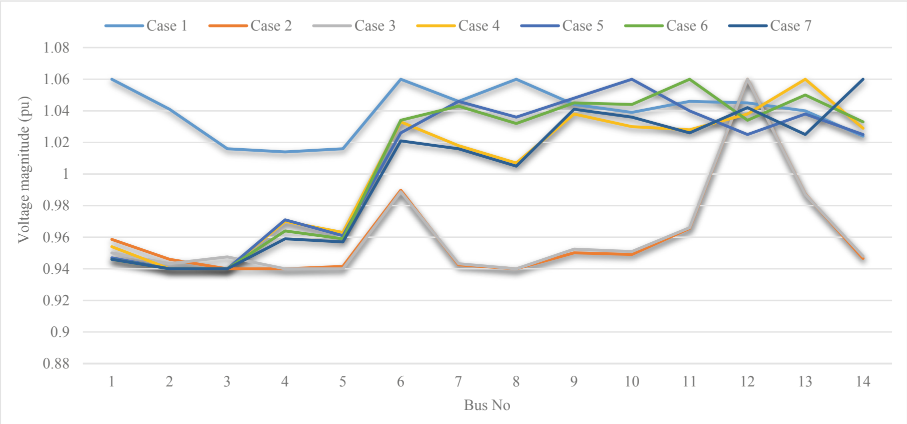

Fig. 4. The voltages profile with and without WDG

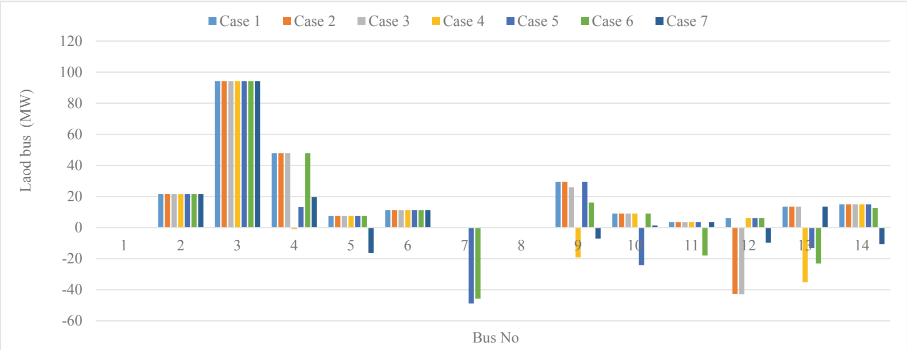

Fig. 5. Load actives buses with and without WDG

5 Conclusion

The optimization method based on genetic algorithm was used for integration of one and two wind based DG source in term of optimal location and size in power system, this is bay calculating the optimal power flow, including technical and security constraints. From this work, we have found that the integration of WDGs has proven its effectiveness better than without DG by minimizing of total power losses and acceptable voltage profile, and this integration provides relief overload transmission lines through the local production of wind source.

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