Optimal size and location of PV based DG-unit in transmission system using GA method for loss reduction

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Abstract- ***This paper proposed the Optimal Power Flow (OPF) for power system in presence of DG-unit, considering the objective of minimal power losses using genetic algorithm method. This method determines the optimal DG-units location and size in a transmission system. The efficiency of the optimization method discussed in this work has been validated on standard test network IEEE 30_busand Algerian114_bus power system using MATLAB softwer.***

Keywords– Photovoltaic, distributed generation, location and size, Loss rduction, Transmission system, Optimal power flow, Genetic Algorithm.

I. INTRODUCTION

For many years, the development of electric power in the world has led to an extensive electrical system of generation, transmission, and distribution. This system has been very largely conditioned by very strong constraint: electrical energy is very difficult to store, it must be sent in real time from production plants, either, industrial or domestic consumers. The energy sector is vastly developed. Customers have increasingly electricity demand, economic conditions are needed to do more, and new competitors are emerging every day.

Distributors of electricity strive to ensure the quality of electricity supply. Early efforts focused on continuity of service to make always available access to energy for the user. The problem of placement distributed generation unit to optimal places and also their sizing is of higher priority amongst all issues [1]. However, with a non-optimal integration, the decentralized generation units can provoke negative impact in power system [2].

Many studies have focused about the problem of integration of DG-unit in transmission systemorin distribution system, the present methods of decision support enabling the company to make the appropriate choices that meet critical needs at management power system. Some are limited to the integration of distributed generation in transmission system [3]. For example, paper [4] suggested the Distributed Parallel Optimal Power Flow method to solve OPF problems in transmission system a smart grid considering renewable generation units, tested on a 26_bus network. Paper [5] shows a MINLP method to optimize placement and number of DG in hybrid electricity market. An effective method has been present in [6] to direct distribution companies to optimize size and locations of DG-units. The Parametric Performance Evaluation of diverse types of PSO-algorithmwas applied in DG-grid [7]. The OPF considering wind generation cost have been proposed in [8]. A.Panda, and M. Tripathy [9] suggested an OPF solution for 30_bus transmissionsystem modified substituting three conventional productions by wind power energy. In research [10], OPF was used to perform negative load to efficiently maximize capacity and identifies available headroom in UK. This last method is applied to a wide distribution and sub transmission power system.

While some workfocused on the insertion of DG-unit in distribution network [11, 12]. This is the last link in supply chain of global power system.R. Viral, D.K. Khatod [13] presented an analytical method to decide the optimal position and size of DG-units in balanced distribution network in order to reduce power losses. Suggested method was based on minimizing real and reactive component of line currents lossthrough DG-unit insertion at different locations. In reference [14] an analytical technique to obtain optimal placement of DG-unitwith objective minimizereal losses in power system. Others in [15] have presented PSO-technique to define the optimal location and size of the multi type desterilized generation units in a distribution power system. A multi-objective optimization (power losses and minimization number of DG-unit) has been presented, to deduce optimum placement and size of DG-unit using non-linear programming technique [16]. Paper [17] offered a comprehensive study on the application of artificial intelligence and various conventional optimization for assessing the impact of optimal placement of distributed generation consider the coordination of FACTS systems and DG-units to control the power system. The work in [18] proposed a technique to obtain the optimal configuration and optimal placement of dispersed generation in grid network for reduction real power loss and voltage stability enhancement using cuckoo search method. In [19], an artificial bee colony technique was presented for resolving optimal load flow in presence wind energy. This technique determines optimal values of control variables considering various limitations with wind energy. Analytical technique has been proposed to obtain optimal position of DG-unit and determine their optimal capacity considering two novel bus types *P* and *PQ* buses [20]. In research [21], a multi-objective method was proposed to determineoptimal size of multi types DG-units considering both economic and technical factors of distribution system, with objective, minimize power losses, line load, voltage profile improvement and economical cost. The planning and operations system cover all management issues of power system.

In this work, we explore OPF to determine optimal location and sizetheDG-units in transmission system, and see DG impact insertion on real power losses. Effectiveness of optimization approach discussed in this study has been validated on standard test IEEE 30_bus andAlgerian114_bus power system.

II. PROBLEM FORMULATION

Optimal location and size of DG-unit are defined by active power loss minimization in power networkwith system operating constraints.

A. Fitness function

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

$$F = P_{loss} = min \sum_{i=1}^{NB} r_i \left(\frac{(P_i^2+Q_i^2)}{V_i^2}\right) \quad (1)$$

Where$r_i$is resistance line, P_i,Q_i are active and reactive power flow transmission line, V_i is bus voltage.

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

B. 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:

$$\begin{cases} \sum_{i=1}^{NG} P_{Gi} + \sum_{i=1}^{ND} P_{DGi} = P_D + P_L & (2) \\ \sum_{i=1}^{NG} Q_{Gi} = Q_D + Q_L & (3) \end{cases}$$

Where(P_{Gi}, Q_{Gi}), areactive and reactive power of conventional generator, (P_{DGi})isactivepower of DG (DG unitmodeled as photovoltaic power), $(P_D, Q_D)$are total real and reactive power demandofload bus, (P_L, Q_L)aretotal active and reactive powerlosses, respectively.

C. Inequality constraints

$$S_{li} \le S_{limax}\ for\ i = 1 \dots\dots\dots\dots\dots\dots . N_B (4)$$
$$P_{Gimin} \le P_{Gi} \le P_{Gimax}\ for\ i = 1 \dots\dots . N_{BG} (5)$$
$$V_{imin} \le V_i \le V_{imax}\ for\ i = 1 \dots\dots\dots ... N \quad (6)$$
$$S_{min}^{DG} \le S_i^{DG} \le S_{max}^{DG}\ for\ i = 1 \dots\dots\dots ... N_D (7)$$
$$\Sigma P_{DGi} \le \Sigma P_D\ for\ i = 1 \dots\dots\dots . \dots ..... N_{DG} (8)$$

Where $S_{li}$is apparent power flow of the branch between bus $i$and$j$, $P_{Gimin}$and $P_{Gimax}$are minimum and maximum generation output thei^{th} conventional generator, S_{min}^{DG} and S_{max}^{DG} minimum and maximum generation output ofDG.N_L, N_G, N_BandN_{DG} are number of loads bus, number of generators, number of branches and number of DG, respectively.

D. Treatment of constraints

To optimizeDG-unit location, it's agreed upon to mention that the control variables are generated in their admissible limits using randomly strategy. In order to manipulate inequality constraints of stat variables, including load bus voltage, active power outputs generator at slack busand lines loading, the extended fitness function is mathematically formulated as [22, 23, 24]:

$$F_p = min \sum_{i=1}^{NB} r_i \left(\frac{(P_i^2+Q_i^2)}{V_i^2}\right) + P_c (9)$$

Where P_c is penalty coefficient introduced for each functional constraint violation, these coefficientsexpressed as:

$$P_c = \xi_p.\Delta P + \xi_v.\Delta V + \xi_g.\Delta Q_{Gi} + \xi_s.\Delta S_l \quad (10)$$

Where ξ_p, ξ_v, $\xi_g$and $\xi_s$are penalty coefficientand$\Delta X = (\psi^i - \psi^{lim})$, the$\psi^{lim}$ is limit value of dependent variableψ.
According to the formulation, we can see that using such a model for solving problems of real size is practically impossible using a classical approach. Therefore, to solve practical problems, we must have recourse to develop effective Meta-heuristic methods to solve this type of problem. Some of these methods attempt to determine an acceptable solution, while other methods show that there is no acceptable solution in some cases. So, in our case we chose to use the genetic method, because this technique is undoubtedly the most popular technique, and is widely used among the evolutionary algorithms

III. APPLIED METHOD

a. Geneticalgorithmmethod

The origins of these algorithms back to the early 1970 with the work of *J-Holland* [25]. Genetic algorithms is meta-heuristics method, based on stochastic optimization of afitness function. Their evolution towards the optimal solution trained by a set of operations inspired from biology, such as the generation of a population, selection, crossover, and mutation. The genetic algorithm aims to find the optimal location simultaneously gains and parameters of Boolean mode, while retaining the logical design of the supervision system.

b. Optimization of OPF withDG

Optimal Power Flow withDistribution Generation (OPF-DG) has already been raised by formulas of equation (1). The state variables vectorχconsisting of, slack busrealpower P_{G1}, load bus voltages V_{L1}, reactive power outputstheall conventional generator Q_{Gi} transmission line power flow S_{l1}. Hence,χcan be expressed as:

$$\chi^T = [\delta_1 \ldots . \delta_N , P_{G1}, V_{L1} \ldots V_{LNL}, Q_{G1} \ldots Q_{GNG}, S_{l1} \ldots S_{lNl}]$$

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

$$v^T = [L_{DG1} \ldots \ldots L_{DGn}, P_{DG1} \ldots . P_{DGn}]$$

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.1illustratechromosome structure applied in this study.

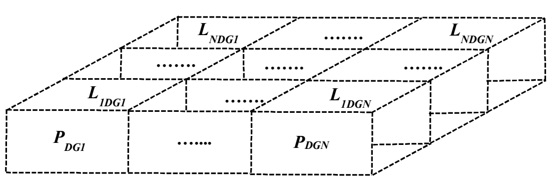


Fig.1. Chromosome structure

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 DG-unit. 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 DG. We should mention that, we have used OPF function implanted in MATPOWER software, and we added a new control variable (DG size, DG location). Fig. 2 presents combination strategy of classic OPF with DG-unit.

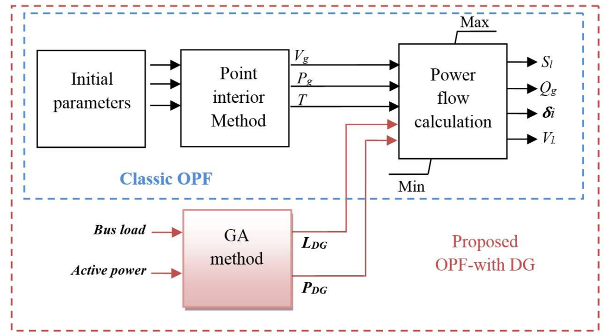


Fig.2. Proposed model based DG-unit integrated in classic OPF

In order to determine location and size of DG-unit, genetic algorithm method has been suggested, the main steps of this algorithm: Step 1 determining operating point of power system by a load flow calculation. Step 2 formulate the optimization problem and determine limits of controls settings, Step 3 solve optimal power flow considering DG-units using genetic algorithms method. Step 4 the retired of best chromosome, presents optimal result. Step 6 Show simulation results.

IV. CHARACTERISTIC OF TEST NETWORK

To validate the developed algorithm, we will perform tests on standard network IEEE 30_bus, and Algerian 114_bus power system.

- IEEE 30_bus power system: The test network IEEE 30_bus given in [26], consists of 6 generators, 41 transmission branches and 4 on load tap changing transformers.The total active and reactive power absorbed by load is 283.4 MW and 126.2 MVAr. Fig. 3illustrate the IEEE 30_bus power system topology in presenceDG-units.

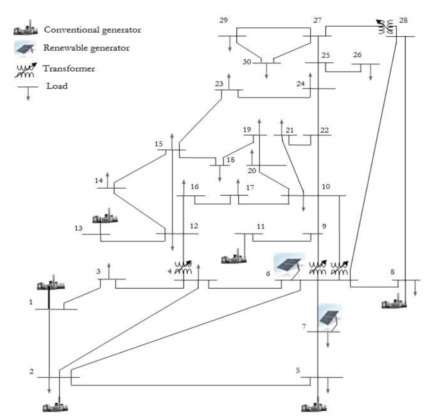


Fig. 3. IEEE 30_bus power system topology

-***Algerian 114_bus power system****:* Algerian energy strategy based on accelerating of solar energy development. The government plans to launch several photovoltaic projects have total capacity about 800 MWp in 2020. Other projects have a capacity of 200 MWp per year will be made in period 2021-2030 [27]. Many existing projects connected to Algerian power system in 2017, like, Souk-Ahras, Djelfa, Saida, Touggourt, Ghardaia, Sidi-Belabes, Laghouat, M'sila, El-Biedh and Naama, with total capacity of 266.1 MW [27].To determine location and optimal size of forecasts photovoltaic sources in Algerian power system, we applied genetic algorithms method. The Algerian 114_bus power system comprises 15 generators, 159 transmission lines, 16 on load tap changingtransformers. The total active and reactive power absorbed by load is 3146.18 MW and 1799.38 MVAr.Fig. 4illustrateAlgerian 114_bus power systemtopology.

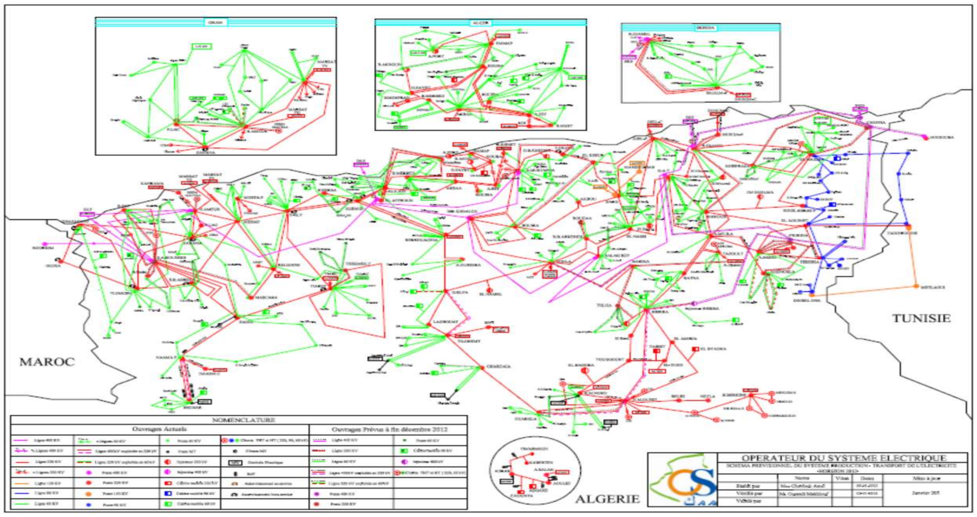


Fig. 4.Algerian 114_bus power system topology [28]

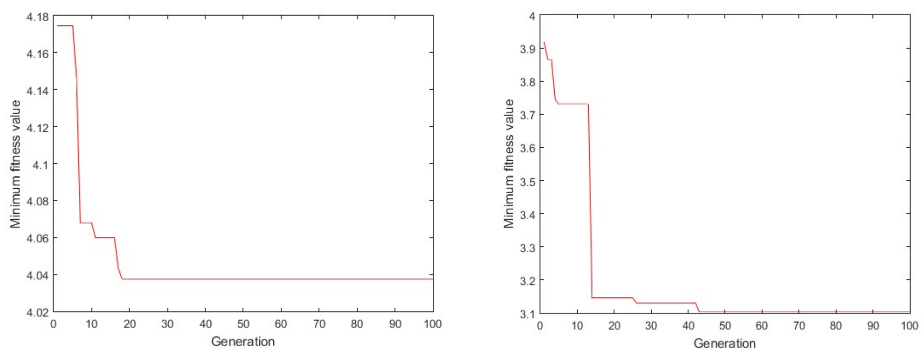
In this study, we made an application of optimal power flow considering renewable generationunits using genetic algorithm technique. The inferior andsuperiorvoltage magnitude limits for all generator buses (PV-bus) are 0.95pu-1.1pu, and voltage limits for load buses (PQ-bus) are 0.95pu-1.05pu. It is known that all load buses have been considered as candidate for DG-unitlocation. You have to know that the values of control variables are generated in their acceptable limits using randomlystrategy. This work, we had considered that the generation power by DG-units are negative loads, such as the DG active power for each load bus is limited by a minimum value 0 (no generation power by DG) and a maximum value corresponding tototal network load. The DG-units are modeled as photovoltaic power, the power factor is assumed as unity (capable injecting P only). The application of proposed technique to transmission power system has been examined on threecases:case 1 (OPF without DG), case 2 (OPF with single DG) and case 3 (OPF with two DG_s).

V. Results and Discussions

- ***IEEE 30_bus case****:*The number of iteration chosen for this case is 100, with 80 populations of GA algorithm. The probability of mutation is 0.01, and crossover probability is 0.8.The inferior and superior limits of active power DG are $P_{DG} \epsilon \, [0, \, \sum P_{Di}] \Rightarrow [0, \, 283.4]$ .After convergence algorithm, the results obtained by GAmethod are represented as following. Fig.5 illustrates convergence curve of GA method in case 2 and case 3. In case 2, characteristic converges at 19^{th} iteration, it converges to 42^{th} iteration in case 3. The comparison of power losses in various cases simulations is presented in Fig.6. Fig.7 shows output reactive power produced by conventional generators. Fig.8illustrate voltage magnitude profile with and without integration DG-units. Fig.9 shows apparent power flow transmission lines with and without integration of DG-units. Fig.10 illustrates active load bus, total loadfor different cases and negative loads in bus 6 and 7.According to simulation results presented in Fig.8, the voltage profile is affected by integration of DG-units, we note that increasing of voltage, for example the minimum voltage is 0.998pu in bus 30 when DG-unit is not installation, but the improved value of voltage is 1.049pu while the DG installed in optimal location (bus 6), with size is 170.21 MW. The voltage at bus 30 improved to 1.01pu,when installation of two DG_s in bus 6 and bus 7, for optimal sizes of 100.1 MW and 69.13 MW respectively, Table I illustrated parameters system for different cases. The comparison of losses in the various cases of simulations is presented in Fig.6. In the first case before integration of DG-unit, the active power losses is 9.423 MW and that reactive is 37.87 MVAR. After integration of one DG-unit, the total losses have become 4.038 MW and 20.48 MVAR when the discount rate is 57.14% and 45.92% respectively, compared to case 1. Same thing after integration two DG_s, total losses became 3.098 MW and 16.30 MVAR respectively, with reduction rates to 67.12% and 56.95% always compared to case 1. A significant reduction in power losses was recorded. This effect is due to physical proximity of the generation plants to loads, and thus reducing power flow in transmission line.

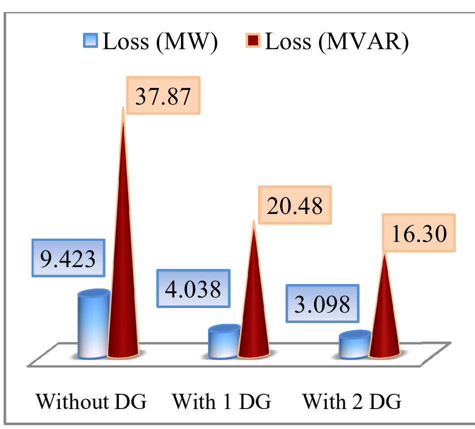
TABLE I. ACTIVE LOSSwith and without DG, PLACEMENT AND SIZE OF DG FOR IEEE 30_BUSPOWER SYSTEM

Parameters	**Limits**		**Case_1**	**Case_2**	**Case_3**	
	Inferior	**Superior**	**OPF without DG**	**OPF with 1 DG**	**OPF with 2 DG**	
P_{g1} (MW)	50	200	176.32	50.22	50.25	
P_{g2} (MW)	20	80	48.78	20.00	20.00	
P_{g3} (MW)	15	50	21.48	15.00	15.00	
P_{g4} (MW)	10	35	22.00	10.00	10.00	
P_{g5} (MW)	10	30	12.17	10.00	10.00	
P_{g6} (MW)	12	40	12.07	12.00	12.00	
V_1 (pu)	0.95	1.1	1.060	1.06	1.06	
V_2 (pu)	0.95	1.1	1.046	1.046	1.046	
V_3 (pu)	0.95	1.1	1.017	1.017	1.018	
V_4 (pu)	0.95	1.1	1.025	1.026	1.03	
V_5 (pu)	0.95	1.1	1.067	1.065	1.03	
V_6 (pu)	0.95	1.1	1.049	1.049	1.033	
DG location bus			**	**6**	**6**	**7**
DG size (MW)			**	**170.21**	**100.1**	**69.13**
Total real power loss (MW)			9.423	**4.038**	**3.098**	



Case 2 Case 3

Fig. 5.GA method convergence with one DG and two DG for IEEE 30_bus



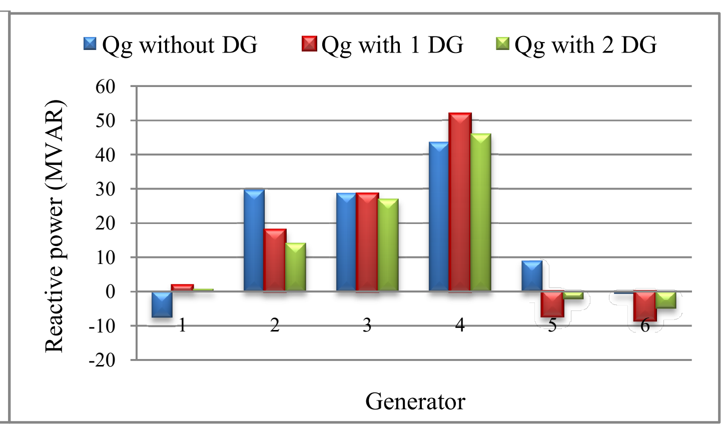


Fig. 6.Comparison between active and reactive losses for 30_bus

Fig. 7. Output reactive power produced by conventional generators for 30_bus

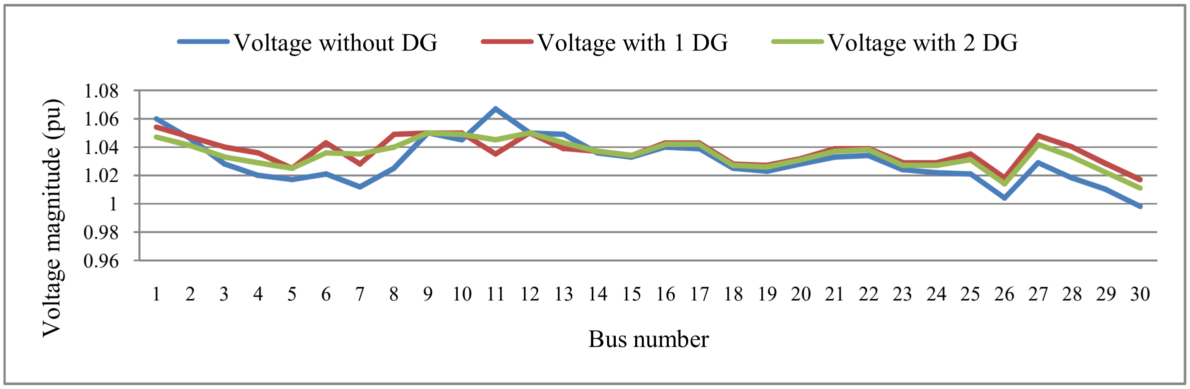


Fig. 8.Voltages profile with and without DGfor 30_bus system

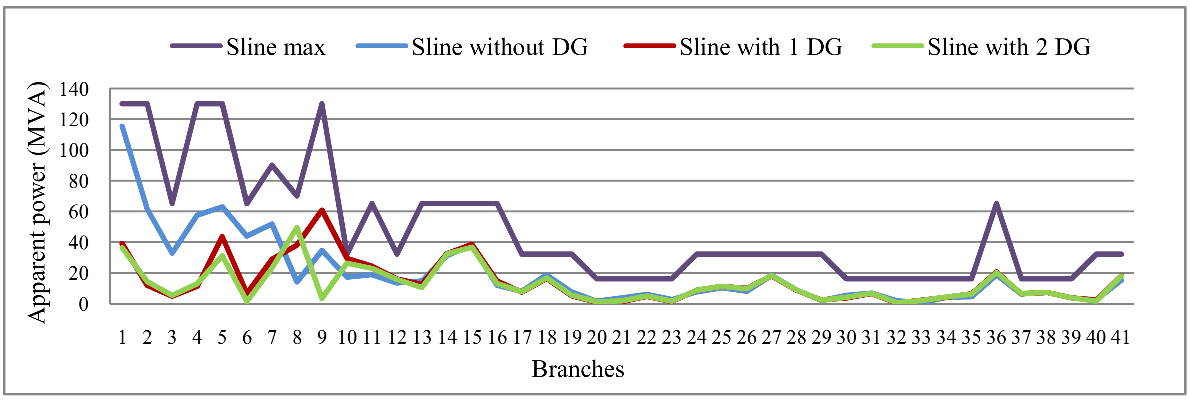


Fig. 9. Apparent power of transmission lines with and without integration of DG-unitsfor 30_bus system

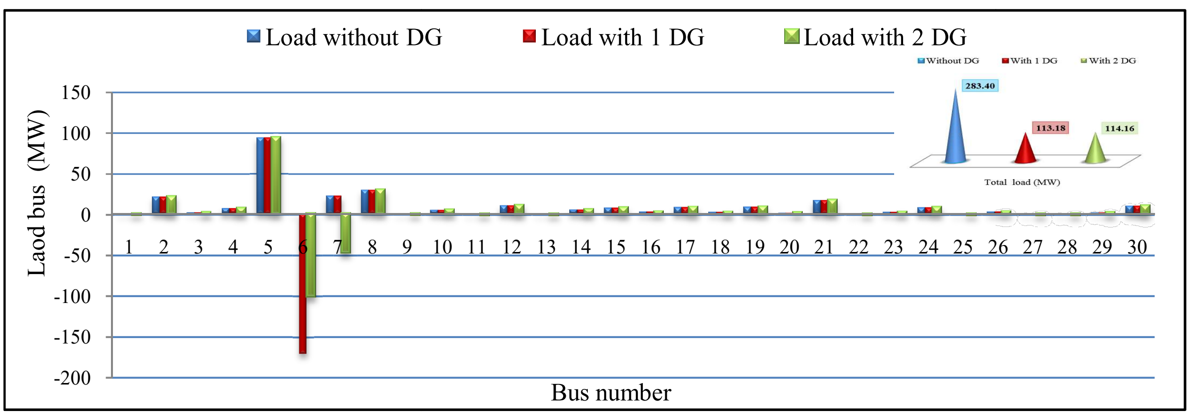


Fig. 10.Load actives buseswith and without DG-units for 30_bus system

- ***Algerian 114_bus case***: Number of iteration chosen for this case is 155, with 110 populations of GA algorithm. The probability of mutation is 0.01, and crossover probability is 0.8. The inferior and superior limits of active power DG are $P_{DG} \epsilon\ [0,\ \sum P_{Di}] \Rightarrow [0,\ 1799.38]$.After convergence algorithm, the results obtained by genetic algorithms method are represented as following. Fig.16 illustrates convergence curve of GA method for case 2 and 3. In case 2, characteristic converge at 70th iteration, it converges to 80th iteration in case 3.The comparison of power losses in various cases simulations is presented in Fig.14. Fig.15 shows output reactive power produced by conventionalgenerators. Fig.11illustrate voltage magnitude profile with and without integration of DG-units. Fig.12 shows apparent power flowin transmission line with and without integration of DG-units. Fig.13 illustrate active load bus, total loadfor different casesand negative loads in bus

44 and 66. According to simulation results presented in Fig.11, the voltage profile is affected by integration of DG, we note that increasing of voltage, for example, the minimum voltage is 0.955pu in bus 67 when DG is not installation, but the improved value of voltage is 0.971pu in bus 92 while the DG installed in optimal location (bus 66), with size is 59.36MW. The voltage at bus 67 improved to 0.974pu, when installation of two DG$_s$ in bus 44 and bus 66, for optimal sizes of 137.83 MW and 46.41 MW respectively, Table II illustrated parameters system for different cases. In the first case before integration of DG-unit, the active power losses is 33.45 MW and that reactive is 158.82 MVAR. After integration of one DG, the total losses have become 30.93 MW and 148.91 MVAR when the discount rate is 7.53% and 6.24% respectively, compared to case 1. Same thing after integration two DG$_s$, total losses became 29.44 MW and 146.5 MVAR respectively, with reduction rates to 13.61% and 8.41% always compared to case 1.

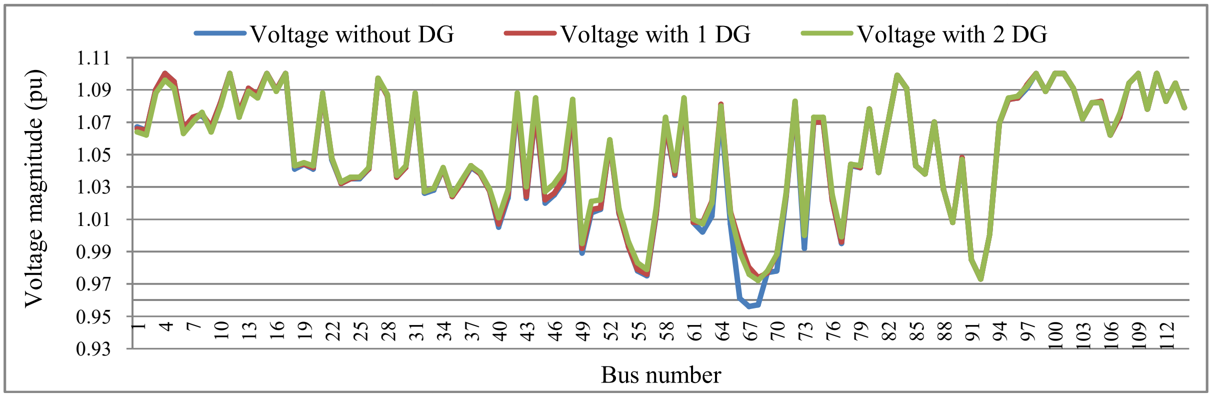


Fig. 11.The voltages profile with and without RG for Algerian 114_bus power system

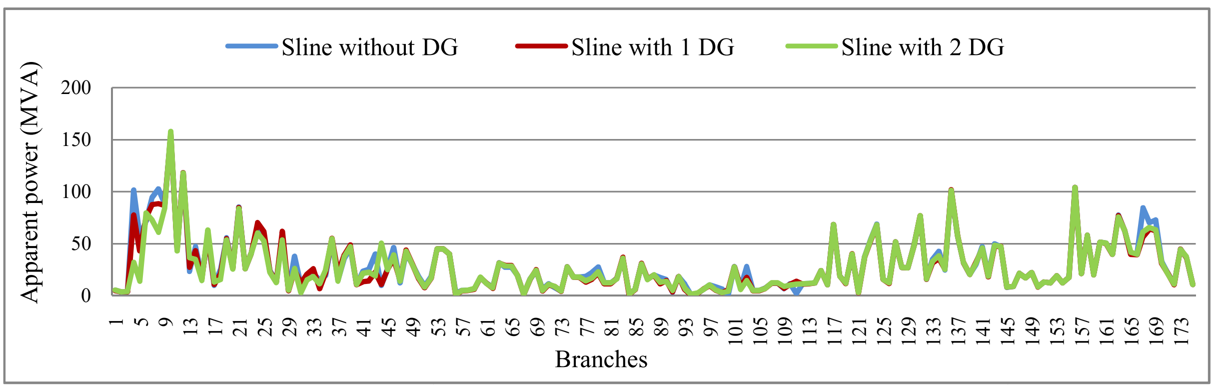


Fig. 12. Apparent power of transmission lines with and without integration of DG-unitsfor Algerian 114_bus power system

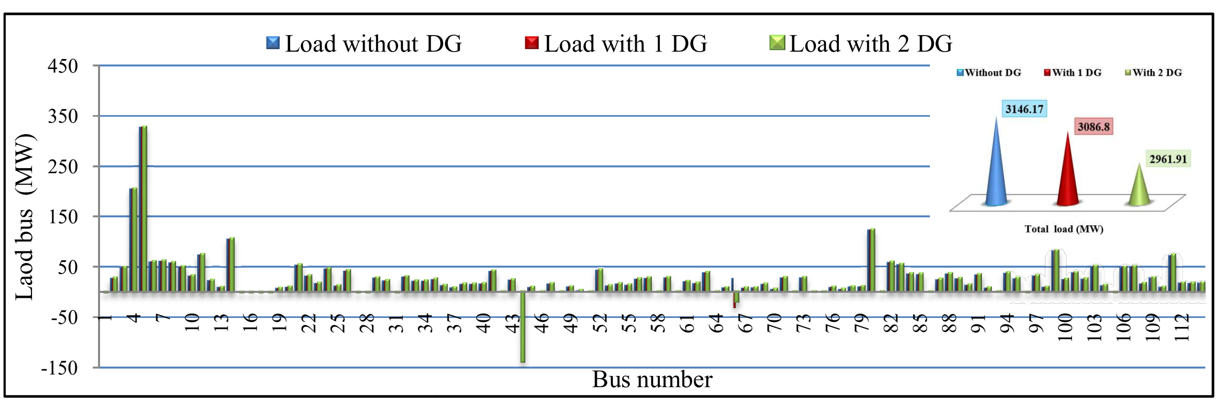
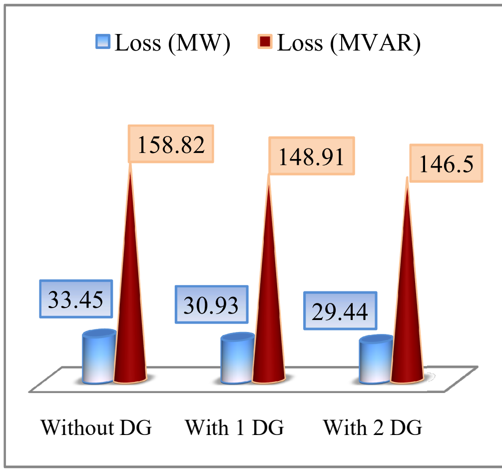


Fig. 13.Load actives buseswith and without DG for Algerian 114_bus power system



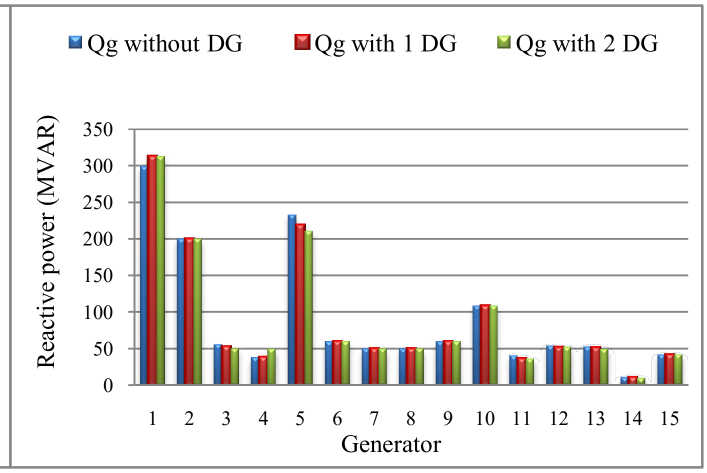
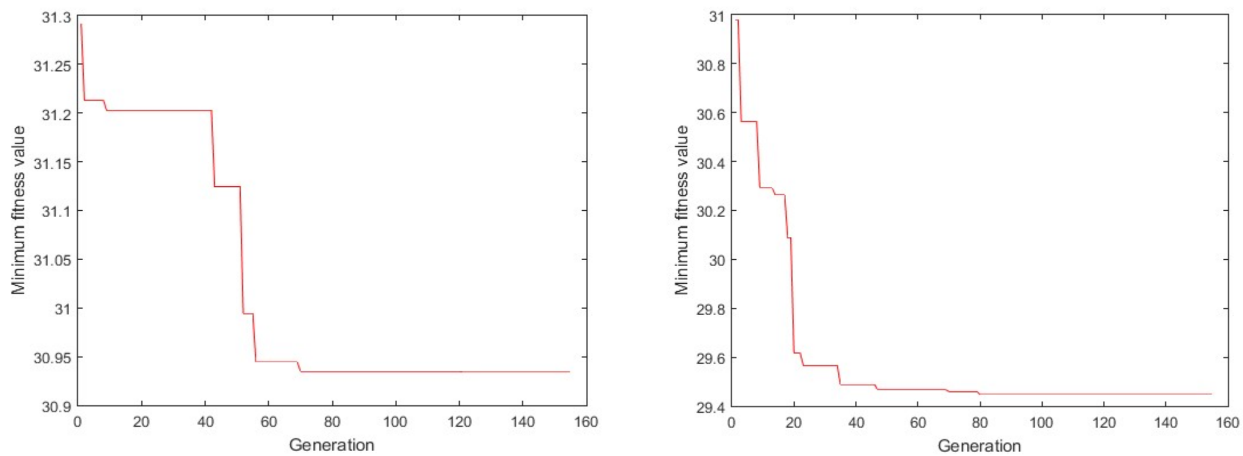


Fig. 14.Comparison between active and reactive losses, 114_bus

Fig. 15. Output reactive power produced by conventional generators, 114_bus



Case 2

Case 3

Fig. 16.GA method convergencewith one DG and two DG for 114_bus

TABLE II. ACTIVE LOSS with and without DG, PLACEMENT AND SIZE OF DG FOR ALGERIAN 114_BUS POWER SYSTEM

Variables	**Limits**		**Case_1**	**Case_2**	**Case_3**	
	Inferior	**Superior**	**OPF without DG**	**OPF with 1 DG**	**OPF with 2 DG**	
P_{g1} (MW)	0.00	1200	447.85	426.02	379.28	
P_{g2} (MW)	0.00	650	506.78	482.37	430.04	
P_{g3} (MW)	0.00	150	150.00	150.00	150.00	
P_{g4} (MW)	0.00	150	150.00	150.00	150.00	
P_{g5} (MW)	0.00	600	225.01	209.36	182.05	
P_{g6} (MW)	0.00	150	150.00	150.00	150.00	
P_{g7} (MW)	0.00	150	150.00	150.00	150.00	
P_{g8} (MW)	0.00	150	150.00	150.00	150.00	
P_{g9} (MW)	0.00	150	150.00	150.00	150.00	
P_{g10} (MW)	0.00	150	150.00	150.00	150.00	
P_{g11} (MW)	0.00	150	150.00	150.00	150.00	
P_{g12} (MW)	0.00	250	250.00	250.00	250.00	
P_{g13} (MW)	0.00	250	250.00	250.00	250.00	
P_{g14} (MW)	0.00	150	150.00	150.00	150.00	
P_{g15} (MW)	0.00	150	150.00	150.00	150.00	
V_1 (pu)	1.1	0.95	1.100	1.100	1.096	
V_2 (pu)	1.1	0.95	1.095	1.095	1.091	
V_3 (pu)	1.1	0.95	1.100	1.100	1.100	
V_4 (pu)	1.1	0.95	1.100	1.100	1.100	
V_5 (pu)	1.1	0.95	1.100	1.100	1.100	
V_6 (pu)	1.1	0.95	1.044	1.044	1.045	
V_7 (pu)	1.1	0.95	1.047	1.048	1.048	
V_8 (pu)	1.1	0.95	1.058	1.058	1.059	
V_9 (pu)	1.1	0.95	1.078	1.078	1.078	
V_{10} (pu)	1.1	0.95	1.099	1.099	1.099	
V_{11} (pu)	1.1	0.95	1.100	1.100	1.100	
V_{12} (pu)	1.1	0.95	1.100	1.100	1.100	
V_{13} (pu)	1.1	0.95	1.100	1.100	1.100	
V_{14} (pu)	1.1	0.95	1.100	1.100	1.100	
V_{15} (pu)	1.1	0.95	1.100	1.100	1.100	
DG location bus			**	**66**	**44**	**66**
DG size (MW)			**	**59.36**	**137.83**	**46.41**
Total real power loss (MW)			33.45	**30.93**	**29.44**	

VI. CONCLUSION

The optimization method based on genetic algorithm was used for insertion of one and two DG-units in term of optimal location and size in transmission system, with calculating of optimalpower flow, including the technical and security constraints. From this work, we have found that the integration of twoDG_s has proven its effectiveness better than one DG by minimizing of total power losses by ensuring acceptable voltage profile, and this integration provides relief overload transmission lines through the local production of DG-unit.The significant contribution in this paper is the application on a real network of Algerian power system.

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