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Optimal Size and Location of Distributed Generators using Intelligent Techniques

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Abstract

One of the modern and important techniques in electrical distribution systems is to solve the networks problem of service availability, high loss and low voltage stability by accommodating small scaled de-centralized generating units in these networks, which is known as distributed generation (DG). The Genetic Algorithm (GA) technique is dedicated in this work to find the optimal DG locations, and then optimally allocate units in order to maximize the penetration level, minimize loss, and improve voltage stability.

Keywords:. Distributed Generation, Distribution Systems Optimization, Genetic Algorithm.

ألموقع والحجم ألامثلين للمولدات الموزعة بأستخدام التقنيات الذكية

الخلاصة

يعتبر اضافة الوحدات التوليدية الصغيره غير المركزيه في انظمة توزيع الطاقة الكهربائيه من أهم وأحدث الستراتيجيات الحديثه لحل مشاكل تلك الانظمه من نقص التوليد وزيادة الخسائر وضعف استقرارية الفولتيه , وتعرف تلك الستراتيجيه بالمولدات الموزعه.
نتيجة للتطور والنمو في شبكات التوزيع فأن دراسة عملية أضافة المولدات الموزعة هي دراسة معقده من الناحيتين التقنيه والرياضيه , ونتيجة لذلك تم استخدام تقنية الخوارزمية الجينية لتحديد أمثل المواقع للاضافة ثم اختيار افضل الاحجام لتلك المولدات لامداد الشبكة باقصى قدرة توليدية ممكنه وتقليل الخسائر لاقل مايمكن و تحسين استقرارية الفولتية.

I. Introduction

Distributed generators (DG) are small de-centralized units embedded in distribution networks. Several types of units can be used as distributed generators, in this work "fossil-fuelled" unit such as diesel, mini-gas turbine with synchronous generators is studied. Some of the main advantages of accommodating DG units in distribution level are [1]:

1. Decreasing the dependency on central generation, and insures the continuity of service by serving the load demand during the central generation failure periods.
2. Peak load shaving.
3. The generation can be available as *spinning reserve*.
4. Improve system security and reliability.
5. Improve quality of service (*voltage*, *frequency*, *wave shape* and *harmonics*).
6. Improve voltage stability
7. Reduce transmission costs by connecting DG units near load centers.
8. Reduce network loss
9. Have a short lead time for procurement and installation
10. Be available in small modular fast replacing units

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11. Can be used as combined heat and power plant (CHP)

Several strategies can be adopted to accommodate a DG plant in distribution networks like

- *Central*
- *Terminal*
- *Feeder*

Under central strategy the sub-stations, bus-bars and switching stations is used as an accommodation location to reduce instillation cost , to maximize the penetration level and to connect the DG protection devices directly to the existing SCADA system, while when accommodating DG units at the end of feeder the strategy may called as *Terminal.* Finally, when accommodating them in any point of a ring feeder the strategy may call as *Feeder.*

II. Optimal Single Location For One Dg Unit/Plant

The optimal single location study is to find optimal single location for one DG unit/plant among many locations. This study starts with Connecting the DG unit/plant to each possible location and discovers its' effects on load serving contribution, voltage improvement, and loss minimization. The optimal location to accommodate that unit is the location that can provide more benefits from the three effects' point of view, a set of programs are developed in this work performing power injection test that returns the maximum power that could be injected generated at specific location when an infinite capacity DG unit is accommodated in that location. The objective function is:

$$\psi_S = P_i \; ; \; i = 1,2, \dots, n \qquad (1)$$

Where P_i is the generator capacity in MW at bus i, and n is the number of network buses.

The objective function ψ_s is maximized subjected to three technical constraints; these constraints are assigned as *Violation Rules* as described below:

1. *Voltage Stability Violation Rule (VSVR)*

The *Voltage Stability Violation Matrix* $VSVM^k$ is illustrated as:

$$VSVM^k = \begin{bmatrix} b1 \\ b2 \\ \vdots \\ bi \end{bmatrix}; i = 1,2, \dots, n \quad (2)$$

Where:

$$bi = \begin{cases} 0 \text{ if } 0.95\, p.u < V_i^k < 1.05\, p.u \\ 1 \qquad \text{elsewere} \end{cases}$$

The *Number of Voltage Stability Violations* NVV^k is estimated from:

$$NVV^k = \sum_{i=1}^{n} bi \qquad (3)$$

Where V_i^k is the voltage of bus i at iteration k and can be found from modified power flow (PF) program [1].

2. *Loss Violation Rule (LVR)*

$$LVR = \begin{cases} 0 \text{ if } L^k \leq L^o \\ 1 \;\; \text{elseware} \end{cases} \qquad (4)$$

3. *Voltage Gain Rule (VGR)*

$$VGR = \begin{cases} 0 \text{ if } \; V_g^{k+1} > 0 \\ 1 \qquad \text{elseware} \end{cases} \qquad (5)$$

Collecting all violation rules in one matrix, this will bring another matrix under the name of *violation matrix (Vm)*:

$$Vm = \begin{bmatrix} NVV \\ LVR \\ VGR \end{bmatrix} \qquad (6)$$

In order to do a violation test, an initial violation matrix Vm^0 is recorded, comparing it with the step violation matrix Vm^k to indicate any violation as follows:

Violation Test

Not Passed
If
$NVV^k > NVV^0$
or $LVR^k > 0$
or $VGR^k > 0$

Passed
If
$NVV^k \leq NVV^0$
and $LVR^k = 0$
and $VGR^k = 0$

The *violation factor (Vf)* gives a clear indication whether there is a violation at any rule through the injection test or not. It can be formulated as:

$$Vf = \begin{cases} 0 \text{ if violation test is passes} \\ 1 \text{ if there is a violation} \end{cases}$$

At each increment step, one bus in chosen and then the injection starts until any violation is recorded, Next an elimination criterion is implemented to eliminate un-wanted buses, at any bus, and after running the BITv1, if an adverse impacts are recorded, the bus is highlighted as *un-wonted bus*, and should be eliminated from the bus list. The adverse impacts are:

a) *There is no voltage gain*
b) *The loss reduction is small*

The next step is to organize all the buses in order based on the maximum power injected for each bus, and illustrate the ordered data in the *Maximum Power Injection Matrix* (MPIM) as shown in Figure 1.

III. Optimal Sizing of Dg Plant

In many distribution networks, multi DG accommodation is more practical and may reflect better impacts to the system. For this reason, a multi bus injection test (MBIT) is implemented and a multi injection process test is performed in different locations at the same time and returns the optimal size of each plant. Therefore, a very huge complex optimization problem arises, and the motivation to use intelligent techniques becomes more essential. The objective function of the MBIT is:

$$\psi_m = \sum_{i=1}^{bn} P_i \qquad (7)$$

Subjected to the constraint $V_f = 0$.

Where P_i is the DG capacity at bus *i*, and *bn* is the bus number. The objective function ψ_m is maximized in such a way that there is no violation of the violation rules illustrates as constraints.

IV. Genetic Algorithm

Genetic algorithm will populate solutions to the MBIT problem, test these solutions by measuring their fitness, then genetic operators will produce a new modified generation, the strongest individuals (solutions) that survive during the optimization. The MBIT steps may be listed as follows:

1. *Decision Preparation*

As a first step, we should decide which buses have to be chosen to inject power through them simultaneously. The sum of all elements' weights formulates the Fitness as shown in Figure 2.

2. *Initial Population*

The first step in the GA is to randomly generate a set of individuals ***X*** (chromosomes) in parallel, which means randomly selected amount of power for each DG unit, decided by the previous step.

3. *Fitness Evaluation and Probability*

Fitness evaluation of each individual

may evaluated from:

$$fitness = f\left(X_i^j\right) = P_{en}L \times 0.5 + ALR \times 0.25 + Vg \times 0.25 \qquad (6)$$

4. *Elitism*

The best-valued parent individual is selected from the existing generation *j*, then adding it to the newer generation *j+1* to form an $\boldsymbol{n_c}$ individual new population, which wholly replaces the old parents. This particular technique is called *the elitism mechanism*, i.e. preserving the best individual and moving it intact to the next generation. This technique guarantees that good solutions cannot be lost through some of the genetic operators Selection .In this step, two individuals are *selected* randomly from the parent population with a probability proportional to their fitness. This is known as *Roulette-Wheel parent selection*

5. *Crossover*

If a probability test is passed, the two individuals are combined (exchange values) in random points to form a new individual.

6. *Mutation*

With a small probability, random values of the produced individuals flip to give characteristics that don't exist in the parent population as shown in Figure 3.

V. Optimal Locations For Dg Unit/Plant

All the programs described in the previous sections are implemented in the Distributed Generators Optimal Locations (DGOL) study, BIT and MBIT with additional constraint of geographical fashion. The *Geographic Constraint* (GIO) provides the forbidden buses in order to exclude them from the study, and must be provided by utility. Furthermore, the utility may search for a defined number of optimal locations and not random one regarding their investment budget, capability of instillation, operation and maintenance.

VI. Test System And Results

IEEE 30 bus American system [2] is tested, under optimal single location study results it is found that bus number 6 is the optimal single location, the accommodation of a 270MW DG plant at this bus reflects many benefits without any violation with 40% load growth, these benefits like 63.4 % loss reduction, 1.47%

improvements in voltage gain and serving 68% of load As shown in Table (1).

Searching for optimal multi location shows that the best solution is to accommodate DG plants in these central bus locations (4, 2, 21 and 28) as shown in Table (2).

If these locations are user to accommodate DG plant the optimal size of these plants can be found by MBIT program as shown in Table (3).

Accommodating these units in the optimal locations with the optimal size can alter the power flow as shown in Table (4).

Comparing load flow data and bus voltage curves with and without accommodating DG plants and after implementing 40% load growth brings few important points, listed below:

A. The load demand and loss after 40% load growth is 100% covered since the DG penetration level is more than the demand.

B. If the penetration level exceeds both load demand and loss, the system can export the remaining power to the neighboring systems as shown by the negative signed active power of the slack bus in table 4

C. The accommodation reduces the system active loss by 70%

D. The accommodation reduces the system reactive loss by 91%

E. The system voltage stability is improved.

F. The accommodation improves system voltage, especially at the optimal buses and the buses connected to them even when the system undergoes 40% load growth as shown in Curve (1) and Curve (2).

VII. Conclusions

- The DG optimal accommodation study is found to be as large dimension complex problem
- The GA success in finding solutions to DG problem
- The DG accommodation reflect good impacts to distribution networks such as :

  (1) Improve Service Availability
  (2) Improve Voltage Stability
  (3) Reduce System Loss
- Multi DG accommodation is more practical in loaded networks.

References

[1] Azhar M. Al-Rawi, "*Optimal Location and Allocation of Distributed Generators with Their Transient Stability Study*", *Ph.D.* thesis, university of technology, electrical engineering department, Iraq, Baghdad, 2009

[2] P. K. Modi, S. P. Singh, J. D. Sharma and P. K. Pradhan," *Stability Improvement of Power System by Decentralized Energy*" , Department of Electrical Engineering, University College of Engineering, Burla, Orissa.

Table (1) BIT results

Bus No	Max.Po.Inj		Percent Loss reduction		Vavg Gain		Weight %
6	270		63.406		1.471		**100%**
28	195		48.895		1.1975		**76%**
3	207.2		33.135		0.71722		**64%**
4	142.8		56.476		0.76041		**62%**
2	228.6		30.137		0.40959		**61%**

Table (2)DGOL output

```
Elapsed time is 101.328000 seconds.
INPUT NUMBER OF LOCATIONS TO TEST (BET 2 & 6)=4
 GENETIC ALGORITHM FOR OPTIMUM LOCATION START........>>

 MANY SOLUTIONS FOUND,  Elapsed time is 424.406000 seconds.
 INPUT NUMBER OF OPTIMAL SOLUTIONS TO DISPLAY (BET 1 & 5)= 4
Bestfit =

    4.       21.        2.       28.      402.5400    8.0231   62.4759    2.1575
    2.       30.       28.        4.      349.9743   31.5649   97.8346    1.4010
    2.        3.        6.       14.      291.8007   59.7248  165.3306    1.0426
   17.        2.       28.       21.      290.7479   39.8798  147.5649    1.5373
```

Table 3

Optimal Size of DG plants

```
  OPTIMAL ALLOCATION OF DG
 Bus Number    MaxInjPower     Shared Power
      2         228.600         140.600
     28         195.000         156.955
      4         142.800          99.740
     21          50.000           5.245

  Sum of All Injected Power =  402.540  MW
  Sum of Losses Befor Injection =  17.765 MW +j 23.325 MVAR
  Sum of Losses After Injection =  16.339 MW +j 8.752 MVAR
  Percent of Losses Reduction    =  8.023 for MW  62.476 for MVAR
  Average Voltage Befor Injection =  1.01753  P.U
  Average Voltage After Injection =  1.03948  P.U
  Percent Voltage Gain After Injection =  2.1575
```

Table 4

Accommodation of DG plant

27	L	1.028	-3.992	0.000	0.000	0.000	0.000	0.000	0	0
28	G	1.030	2.773	0.000	0.000	156.000	1.886	0.000	0	0
29	L	1.000	-5.712	3.360	1.260	0.000	0.000	0.000	0	0
30	L	0.983	-6.963	14.840	2.660	0.000	0.000	0.000	0	0
Total				396.760	176.680	408.485	162.714	23.300	0	1

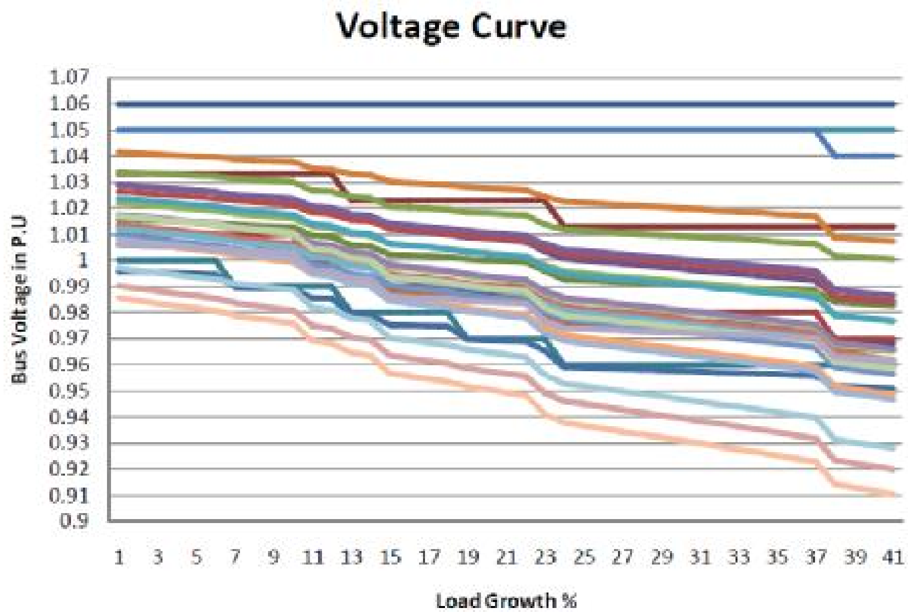
load grouth factor for active power = 1.4
load grouth factor for reactive power = 1.4
Voltage Magnitude (AVG) = 1.0166
Total no. of Violated Buses = 1

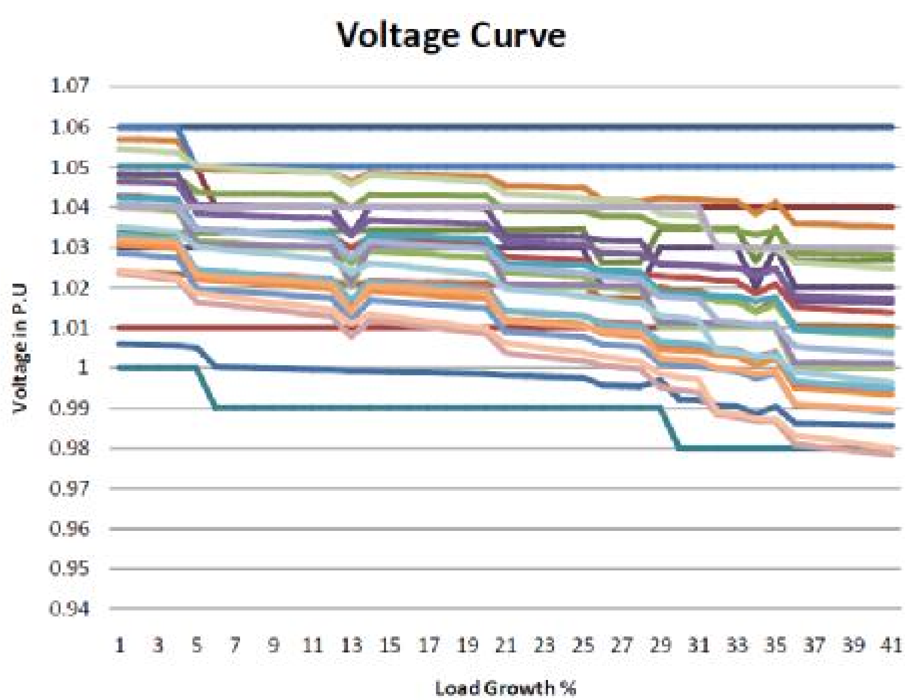
no. of Under Voltage Violated Buses (Vm < 0.95) = 0
Minimum Voltage = 0.980 At Bus No. = 5

no. of Over Voltage Violated Buses (Vm > 1.05) = 1
Maximum Voltage = 1.060 At Bus No. = 1

LGF	Vavg	V<	Vmin	AtBus	V>	Vmax	AtBus
1.40	1.017	0	0.980	5	1	1.060	1

Total loss					11.725	9.334				
18	L	1.000	-8.142	4.480	1.260	0.000	0.000	0.000	0	0
19	L	0.997	-8.272	13.300	4.760	0.000	0.000	0.000	0	0
20	L	1.002	-7.914	3.080	0.980	0.000	0.000	0.000	0	0
21	G	1.010	-6.972	24.500	15.680	5.200	2.624	0.000	0	0
22	L	1.011	-6.944	0.000	0.000	0.000	0.000	0.000	0	0
23	L	1.002	-7.554	4.480	2.240	0.000	0.000	0.000	0	0
24	L	0.997	-7.177	12.180	9.380	0.000	0.000	4.300	0	0
25	L	1.009	-5.431	0.000	0.000	0.000	0.000	0.000	0	0
26	L	0.983	-6.034	4.900	3.220	0.000	0.000	0.000	0	0


Voltage Curve
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
0.93
0.92
0.91
0.9
Bus Voltage in P.U
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
Load Growth %


Voltage Curve
1.07
1.06
1.05
1.04
1.03
1.02
1.01
1
0.99
0.98
0.97
0.96
0.95
0.94
Voltage in P.U
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41
Load Growth %

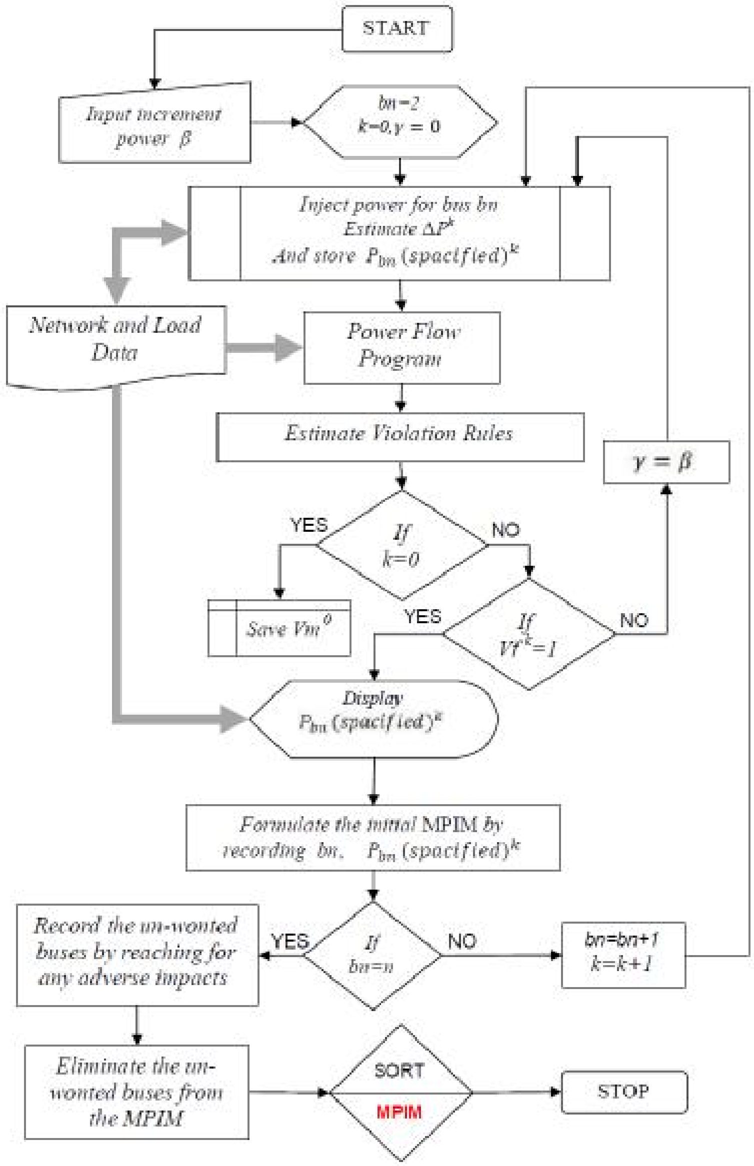


Figure 1
BIT flow chart

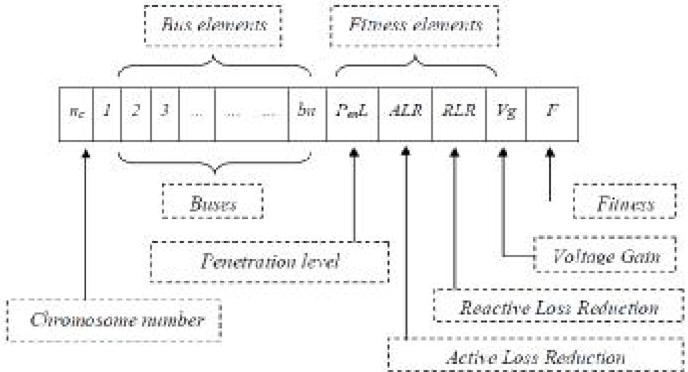


Figure 2

First population of single chromosome

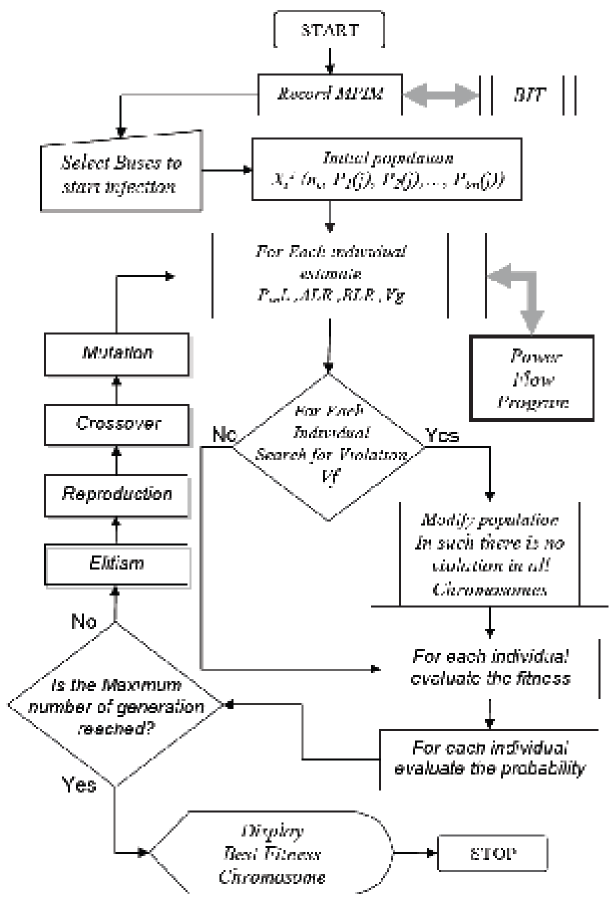


Figure 3
MBIT

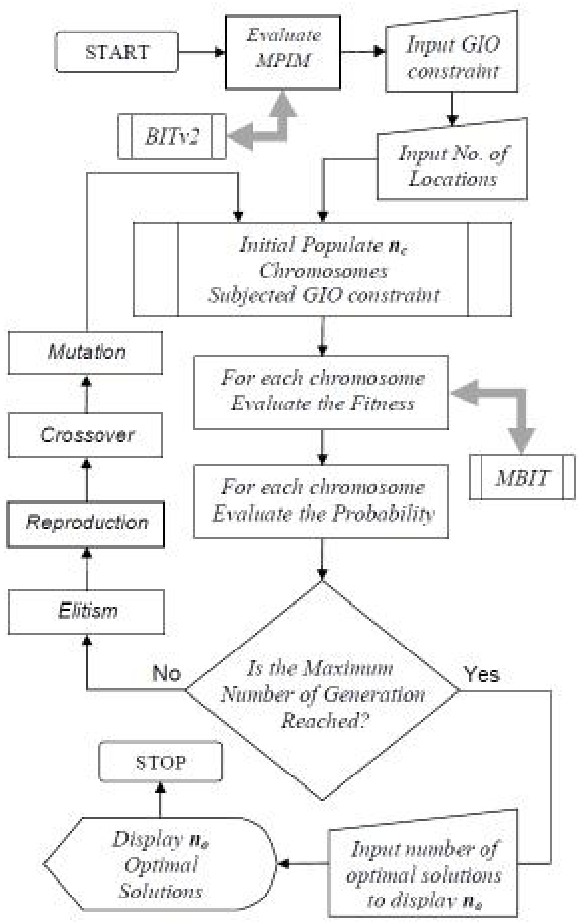


Figure 4
DGOL