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Optimal Sizing and Sitting of Distributed Generation for Power System Transient Stability Enhancement Using Genetic Algorithm

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***Abstract*— Distributed Generation (DG) is the use of small generating sets connected to the grid or feeding power islands, based on technologies such as internal combustion engines, small and micro turbines, fuel cell, photo voltaic and wind plants.**

Driven by increasing environmental concerns and increasing amount of new generation technologies, it is expected that many new generation technologies, including renewable generation, will be connected to electrical power system in the near future, therefore stability condition changes shall be studied to improve overall power system operation.

In this paper the impact of DG on power system transient stability is investigated by genetic algorithm method. It is observed that both size and location of DG technologies will influence network stability. The fitness evaluation function that drives the GA to the solution is an integral of rotor angle oscillations versus time.

***Index Terms*— Distributed Generation (DG), Power system stability, Genetic Algorithm (GA), Rotor angle oscillation.**

I. INTRODUCTION

Along with the increasing concerns on environmental issues, the impacts of electricity generation are being minimized and efforts are made to generate electricity from renewable sources [1-3].

These generating utilities can be found anywhere on the power system. Although they produce usable electrical sources but their impact on power system characteristics can not be neglected. Several studies have been conducted to model and investigate potential impacts of a considerable penetration level of DG. In [4] the impacts of several types of DG including squirrel cage induction generators, synchronous generators and uncontrolled power electronic converter have been studied. In the above mentioned paper, authors tried to investigate transient stability of the power system while the test system was subjected to a particular fault. In that case, the test system was investigated by applying a fault to a specific transmission line and afterwards it was assumed that the fault had been cleared by tripping the faulty line after certain fault duration. Therefore three fault durations were introduced. In each scenario, eleven penetration levels were surveyed. These penetration levels were proportional to load power changes. They used two indicators:

- The maximum rotor speed duration
- The oscillation duration.

They concluded that the impact of the DG on the transmission system transient stability depends on both the technology used and penetration level of DG. In [5] the impact of distributed gas turbine generators on the bulk transmission system was investigated.

In [6, 7] the modelling of wind turbines in power system dynamics simulations is addressed. In this paper a methodology is presented for allocation and sizing of distributed generation in power systems in order to improve network transient stability. The optimization process is conducted by Genetic Algorithm. In this case a stability index is introduced as the fitness function of GA. The stability index is integral of power angle oscillations. In each step a three phase short circuit is implemented on one predetermined line afterwards stability criterion is checked and when ever this criterion is optimized, GA shows the best answer.

II. TEST SYSTEM

A typical 6-bus test system is used in this paper. Table 1 lists characteristics of the system in detail. Fig. 1 shows the topology of the typical 6-bus system. DG model used here is as P+jQ which will be introduced in detail in section 3.

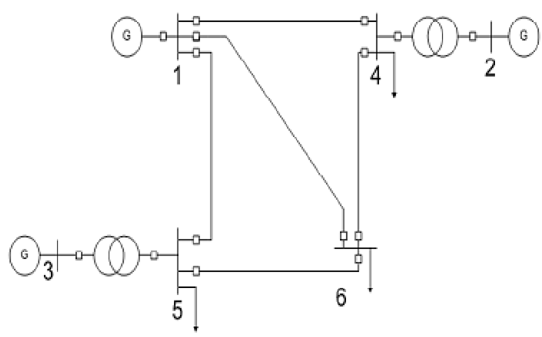

Fig.1 One line diagram of the test system

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Table1 Characteristics of the test system

System characteristic	Value
# of buses	*6*
# of generators	*3*
# of loads	*3*
# of transmission lines	*5*
Total generation	*350 MW/210 MVAr*
Total load	*355.3 MW/242.8 MVAr*

III. Research approach

As it can be seem from Fig. 1, typical 6-bus power system has 3 load bus namely bus no. 4, 5 and 6. In order to reach our goal in this study, we implement a balanced three phase fault near each load bus then the fault is cleared by tripping the faulty line. Since each load bus contain several connected transmission lines, in each step a certain transmission line is tripped for example while the three phase fault occurs near bus no. 6 in each stage one of transmission lines connected to this bus is tripped afterwards GA searches for allocation and sizing DGs in load buses in order to optimize the stability index. With regard to the fact that we have three generating buses, DGs would be allocated only on the 3 load bus remained. Generation bus no.1 is considered as slack and the two remaining generating buses are considered as PV buses.

After the implementation of three phase short circuit, one transmission line is tripped and rotor angle of generators no. 2 and 3 oscillates with respect to rotor angle of generator no. 1. Rotor angle differences of generators no. 2 and 3 are defined as $\Delta\omega_{21}$ and $\Delta\omega_{31}$ respectively. The stability index which will be used as a fitness function for Genetic Algorithm is the absolute value of integral of rotor angle oscillation of two generators with respect to slack bus, the fitness function is defined as:

$$Fitness = \left|\int_0^t (\Delta\omega_{21})dt\right| + \left|\int_0^t (\Delta\omega_{31})dt\right| \quad (1)$$

Since simulation time is considered as 1.5 seconds upper limit in Eq. (1) would be equals to 1.5.

The reason of taking into account of two generators rotor angles together in fitness function is that if one of them loses its stability so the fitness value increases dramatically, therefore GA searches for DG locations and sizes that best minimize this value. Following assumptions have been considered for this study:

- A DG is connected to every load bus directly
- DG is modeled as (P+jQ) and power factor for each DG is supposed to be 0.8
- Fault clearing time for all simulations is assumed as $t_c = 200ms$

When genetic algorithm is running it will randomly finds active power of DGs and locates them on each bus. Reactive power would be calculated by multiplying 0.75 to the corresponding active power i.e. $Q_i = 0.75 \times P_i$ then it will check the stability index and active powers which optimize this value would finally be shown as the result. It is worth noting that values of P and Q which GA finds are considered as a generation source on the load buses.

According to our system, we can run seven different cases which are summarized in table 2.

Transmitted powers of each line before tripping are summarized in table 3.

It is worth noting that MATLAB software is used for preparing simulation scenarios and results.

IV. GA Setup and Coding of the Solution

When applying Genetic Algorithms to optimize the DG allocation and sizing problem, an important aspect is the coding of the potential solutions. The coded variables are, therefore, the candidate locals for DG installation and the respective size of the units. In that sense, each chromosome is coded through a vector whose dimension is the number of candidate points and whose content is the size of the installed units. The chromosome coding in this study is defined as a six-vector chromosome which three of them are the number of buses that DG is assigned and the other three ones are respective sizes of those DGs. Lower and upper limits for distributed generations are identified as zero and 50 MW respectively.

Genetic Algorithm seeks for the optimum answer in a continuous way between these two boundary limits, consequently the optimal case is GA output.

Genetic Algorithm parameters used for all system were:

- Population size: 20
- Number of generation: 10
- Cross-over function: Scattered
- Mutation function: Gaussian
- Mutation scale setting: 8
- Mutation shrink setting: 1
- Selection type: Stochastic uniform

Table2 Possible Cases

Case No.	Short-circuit near bus No.	Tripped line
1	*4*	*4-6*
2	*4*	*1-4*
3	*6*	*4-6*
4	*6*	*1-6*
5	*6*	*5-6*
6	*5*	*1-5*
7	*5*	*5-6*

Table3 Transmitted Active Power of Lines

Transmission line	Power flow
1-4	*15.1 MW*
1-5	*35.4 MW*
1-6	*54.8 MW*
4-6	*64.9 MW*
5-6	*44.9 MW*

V. RESULTS

In order to thoroughly study the impact of adding DG to power system, we divide our survey to three sub-divisions that each of them contains short circuits near one specific bus.

A. Short circuit near bus No.4

If a fault is occurred near bus no.4, there would be two cases to study. These two cases would be tripping line (1-4) or tripping line (4-6) in order to clear the fault. Active power of slack bus generator before fault is 105.3 MW, this power changes after a line is tripped and that's because of change in power route. This change in power for all cases is listed in Table 4. Optimal DG sizes for case no. 1 and 2 and optimized fitness values are summarized in Table 5. By the way, base case represents initial fitness values with no DG penetration, i.e. integral of rotor angle oscillations for the primary 6-bus test system.

B. Short circuit near bus No.6

In this case because of 3 lines connected to bus no. 6, there would be 3 cases to study. Results of these cases are summarized in table 6.

C. Short circuit near bus No. 5

Here like bus No. 4, we have got only two cases to examine. Results of each case are shown in table 7.

At the first glance, one can see that the penetration level of DG sizes is related to power change of slack bus generator. It means that in order to minimize generators rotor angles, GA finds DG sizes which can best reduce power change of slack bus generator.

Fig. 2 shows a comparison of the summation of DG sizes for each case and power change of slack bus generator when a line is tripped and there is no DG.

As it can be seen from Fig. 2, in order to optimize rotor angle deviations DGs shall be located on specific bus numbers which best reduce power change of slack bus generator.

VI. CONCLUSIONS

This paper presents the results of simulations performed to investigate the impacts of distributed generations (DG) on the power system transient stability. A typical 6-bus power system is used in this study. Several scenarios are investigated by genetic algorithm for allocation and sizing of DGs. After occurrence of a fault and tripping faulty line, power of slack bus generator change in order to compensate for the losses of new power flow route. These changes of power in each case with no DG are calculated and compared with summation of DG sizes. It can be seen that in order to minimize the rotor angle oscillations and reducing power change of slack bus generator, DG penetration levels after tripping the line, are proportional to power change of slack bus generator before the DG is inserted.

Table4 Power Change of Slack Bus Generator

Case No.	Slack-bus generator power change
1	*5.5 (MW)*
2	*0 (MW)*
3	*5.5 (MW)*
4	*3.4 (MW)*
5	*3.6 (MW)*
6	*0.9 (MW)*
7	*3.6 (MW)*

Table5 Results for Fault near Bus No.4

Case No.	Tripped line	Base case / Optimized case	DG size on bus No. in [MW]		
			4	5	6
1	4-6	2884.592 / 1676.063	2.222	2.035	1.701
2	1-4	1926.1155 / 1926.1155	0	0	0

Table6 Results for Fault near Bus No.6

Case No.	Tripped line	Base case / Optimized case	DG size on bus No. in [MW]		
			4	5	6
3	4-6	551.6117 / 515.5109	0.758	0.001	0.265
4	1-6	165.0073 / 101.2129	0.371	1.683	1.794
5	5-6	515.7074 / 496.0883	0.177	0.127	2.4

Table7 Results for Fault near Bus No.5

Case No.	Tripped line	Base case / Optimized case	DG size on bus No. in [MW]		
			4	5	6
6	1-5	652.238 / 652.238	0	0	0
7	5-6	10.4768 / 6.44e-7	0.54	0.867	0.058

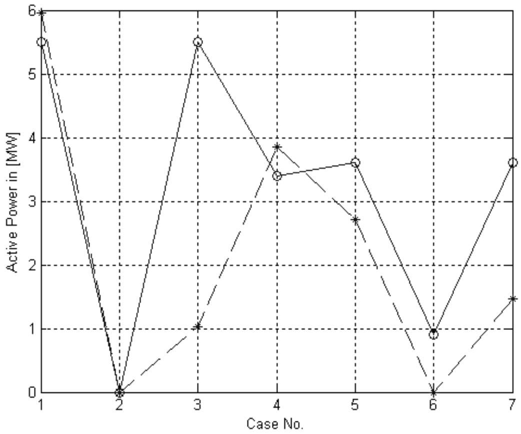

fig.2 comparison between power change of slack bus generator and summation of dg sizes for each case. broken line is for summation of dg sizes and solid line is for changed power of slack bus generator.

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