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Distributed Generation Stability During Fault Conditions

A. S. El Safty[1], B. M. Abd El Geliel[1] and C. M. Ammar[1]

[1] Department of Electrical Power& Control Engineering
College of Engineering & Technology
Arab Academy for Science, Technology & Maritime Transport (Egypt)
Phone/Fax number:+002035614956, e-mail: drsamahsafty@yahoo.com, malgeliel@yahoo.com

Abstract. The difficulties facing electric utility companies to satisfy on-site customer power demand aroused an increasing interest in small distributed generators (DG). Also the environmental concerns, the technology evolution and the need to integrate renewable energy resources into distribution system gave way to the construction of (DG) using alternative energy sources. The presence of such new generators creates new operating conditions for the interconnected system. The aim of the paper is to study the impacts of faults on stability in systems with (DG) and their satiability during faults. In this paper, the impact of different types of faults at various locations on a distribution system with and without the presence of (DG) is studied. The IEEE 13 node distribution test feeder is used as a model for the study together with synchronous generator (DG). The simulation of the distribution system and the (DG) is performed using PSCAD software. A comparison between fault currents with and without the insertion of the DG is carried. The effect of such faults on the stability of the used DG is considered taking into account the control actions expected for the system to remain within the stability limit.

Key words

Distributed generator, Distribution system, fault analysis, IEEE node test feeder, synchronous generator.

1. Introduction

The economic and environmental impacts nowadays have altered the traditional construction of large generation stations. The arising concept of privatization of the electricity authorities gave way to the building of small dispersed generator units. The diminishing and high cost of fuel resources directed the researchers to alternative energy resources. Distributed generation encompasses a wide range of prime mover technologies, such as internal combustion engines (IC) engines, gas turbines, micro turbines, photovoltaic, fuel cells and wind-power. The variation of the load sharing between the distribution network and the distributed generator at different loading conditions has its impact on the stability of the distributed generator. Current researches concerning DG interconnection to utilities are showing that new Grid paradigm will help in mitigating distribution system capacity constraints. In addition to enhancing voltage profile, improving system stability and reducing transmission line losses which in turn will lead to deep penetration of DG in the field of power generation to share continuous increase of customer load demand without exceeding capacity of the existing networks [1].

On the other hand; insertion of DG into Distribution networks must be accomplished with protection schemes modifications since conventional networks were previously planned as passive networks, carrying the power unidirectional from the central generation downstream to the loads [2]. Also DG's contribution in fault current during transient faults must be strictly evaluated since it may have major impacts on the protection of feeders and could raise the short-circuit level enough to cause protective devices malfunction in addition to mechanical and thermal stresses on feeders circuit breakers that might exceed breaker permissible limits[3]-[5].

It is also important to understand the impact of transients in the distribution system on the proposed DG. Some researchers showed that the voltage control is the main factor in the quality of supply for distribution networks [6]. While in [7] it could be seen that the choice of type of DG and its control scheme depends mainly on the network and load characteristics.

It is worth to say that integration of DG sources to utility grids tends to make electric power system to be more reliable, secured, and stable and to reduce environmental releases. It is expected that distribution generation will have increasing importance for the independent production of electric energy to carry the full load or only the peak load [8]. In this paper IEEE 13 node test feeder is used as test system. PSCAD simulation

software is used for simulating our test system.
The paper could be divided into two parts. In the first part simulation of the supposed system is performed. In this part it is required to investigate the variation of the fault current due to the presence of the distributed generator.
In the second part the stability of the DG is tested, the PID controller of the governor is tuned first when stand alone using Ziegler-Nichols method [9], [10]-[11]. The DG is connected to the distribution system and its stability is checked out.

2. System Simulation

IEEE 13 Node test feeder in Fig. 1. was selected as benchmark test feeder to investigate DG stability and dynamics when interconnected to this test feeder.
For a small feeder IEEE 13 node provide a good test for the most common features of distribution analysis software and easy for implementation on various power system analysis software [12].

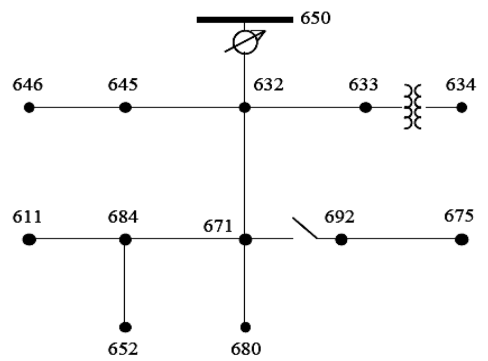


Fig. 1. IEEE 13 node test feeder

PSCAD software is used as a simulation platform for the proposed system which includes one synchronous distributed generator 2 MVA connected through distribution transformer 13.8 / 4.16 KV to bus # 632 of the 13 bus IEEE system shown in Fig.2.
Before DG insertion to the network IEEE 13 bus test feeder was implemented on PSCAD and in order to ensure the model validation it was verified and compared with the results and output data found in [13].
Upon system verification different types of faults are performed at different locations in the system with and without the presence of distributed generator. The value of the fault current corresponding to such scenarios could be seen in Table 1. It could be seen that as the fault is nearer to the DG the value of fault current increases compared to its value without the DG.

TABLE 1: Fault current due to varies types of faults at different locations

Fault location node	Without DG		With DG	
	Fault current (SLG)(kA)	Fault current (3 ph. To G)(kA)	Fault current (SLG)(kA)	Fault current (3 ph. To G)(kA)
645	3.8	4.1	4.3	4.4
684	4	4.7	4.2	5.4
692	3.2	8	4.3	8.8
633	5	7.5	5.6	8.2
632	6	9	7	10

3. System Stability

The single line diagram for the synchronous generator complete with its speed governor is shown in Fig. 3; block diagram for the speed governor is shown in Fig. 4. For varying loads it should be mentioned that the limit of the power supplied from the DG is kept constant giving way for the Grid to compensate for the different loading conditions. The stability of the connected DG is tested by applying symmetrical short circuit at bus 632. The load angle of the DG is seen in Fig. 5. It is noticed that load angle contains undesired oscillations during transient fault occurred at 10 sec and it is intended to mitigate this oscillations via suitable tuning method for the PID controller included in PSCAD governor model used for the speed loop control.

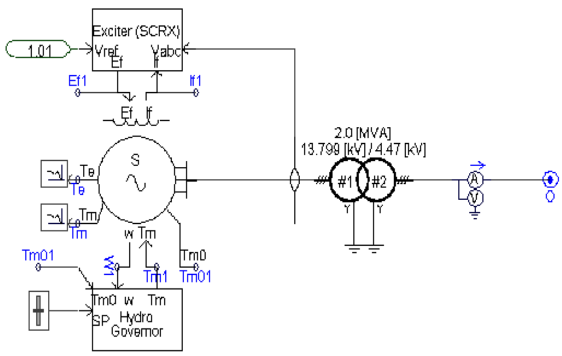


Fig. 3. Synchronous generator single line diagram

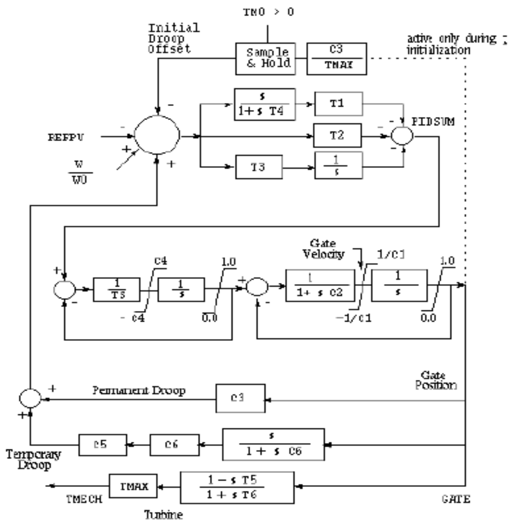


Fig. 4. PSCAD governor block diagram

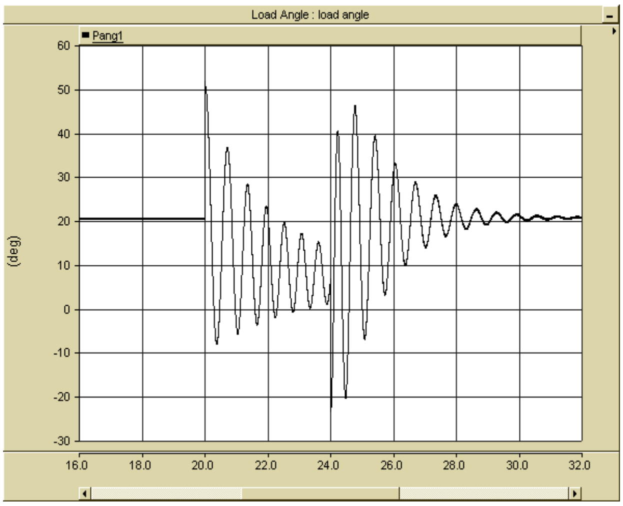


Fig. 5 Load angle of DG with symmetrical fault

4. Ziegler Nicholas method for tuning PID Controller

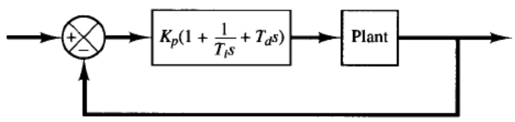
The PID controller is one of the most popular controllers used in more than 80% of industrial processes. It has dominated industrial control for half a century, and there has been a great deal of research interest into the implementation of the advanced controllers. The reason is that the PID control has a simple structure, which is easy to be understood by field engineers, and it is robust to disturbance and system uncertainty. In addition, many PID tuning techniques have been elaborated during recent decades [10], [11]. A tutorial given by Hang et al. [14] outlined the development in PID parameters adjustment based on relay feedback test. Some other techniques have also been used in developing auto-tuning PID controllers, Fuzzy controller [15], [16]; Advanced Ziegler-Nichols [11]. Many techniques are scattered in literature for auto-tuning of PID based specially on expert (neural network, fuzzy, etc.) system to tune the controller.

Since most of the real governor and voltage stabilizer of DG system employing PID controller, tuning of the PID of the DG governor is implemented here.

In order to improve the performance of the PSCAD model after DG interconnection to the test feeder it was tested as standalone generator without network effect then Ziegler-Nichols second method (closed loop) is applied for tuning governor PID controller [9].

The parameters of the used governor are calculated based on the summary of Ziegler-Nichols as follows:

1. Removing integral and derivative actions (K_I=K_d=0) then setting integral time (T_i) to infinity or its largest value and setting the derivative controller time constant (T_d) to zero.
2. Creating a small disturbance in the loop by changing proportional gain set point, increasing and/or decreasing, until the oscillations in the machine output torque reach constant amplitude.
3. Recording the gain value (K_{cr}) and period of oscillation (P_{cr}) in order to substitute their values into the Ziegler-Nichols closed loop equations and determine the necessary settings for the controller.
4. According to Ziegler Nicholas second method tuning PID controller rules the value for K_P=0.6K_{cr}, K_I=0.5P_{cr}, K_d=0.125 P_{cr}
5. PID parameters values are K_P=15, K_I= 4.1, K_d=13.745



PID controller transfer function:-

$$G_c(s) = K_p\left(1 + \frac{1}{T_i s} + T_d s\right)$$
$$= 0.6K_{cr}\left(1 + \frac{1}{0.5P_{cr} s} + 0.125\,P_{cr} s\right)$$
$$= 0.075K_{cr}P_{cr}\frac{\left(s + \frac{4}{P_{cr}}\right)^2}{s}$$

5. Simulation Results

The performance of the governor during different sudden loads increase at 10 sec was investigated before and after tuning the PID controller and results are shown in Fig. 6, 7, 8 and 9. It is obvious that before tuning the controller the time consumed by the governor to reach the steady state speed exceeds 20 sec for different loading 300 kw and 450 kw as shown in Fig. 6 and 7, while after tuning it only took around 10 seconds as shown in Fig 8 and 9. Moreover, the remarkable drop in the synchronous speed (frequency) was enhanced after tuning, specially in case of 450 kw sudden load increase; Fig. 7 shows the speed decreases 10% of its steady state value (before tuning the governor) at more than 5 sec leading protection devices to trip the synchronous generator to prevent loads operation under rated frequency; however, after tuning the PID the maximum speed drop at the same load increase only dropped 3% of its rated value for less than 5 sec, which represents a short time not allowing the protective relays to operate as shown in Fig. 9. The droop characteristic of the governor was decreased after tuning the controller in order to alleviate speed drop occurring when increasing the load as shown in Fig. 8 and 9; consequently steady state speed of the generator is almost the same before and after the transient load change.

The PID controller of governor was updated with the new obtained parameters settings and DG was connected to the IEEE test system in order to check the stability of the system under sudden load variation. Fig. 10, 11 and 12 show the load angle, speed and DG power variations, respectively, due to a sudden load variation occurring at 20 sec. The speed and load angle under symmetrical fault conditions, occurring at 20 sec, are shown in Fig. 13 and 14 respectively. The DG is synchronization with the network at 3 sec, before the connection to the network; the speed control loop was in a constant speed mode to maintain the synchronous speed of the generator. After the synchronization, the speed loop is adjusted to be operated at constant power mode to start sharing the load according to the reference power signal adjustment setting (1.2 MW) in the simulation.

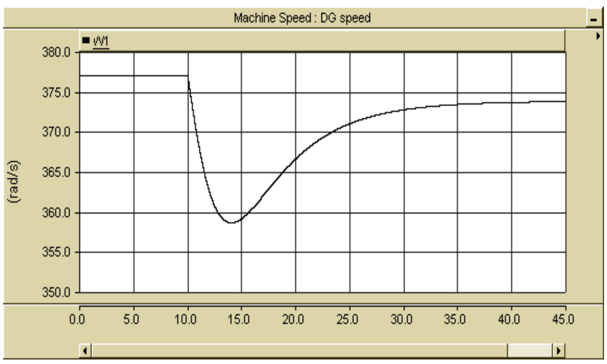


Fig. 6. DG time speed characteristic before tuning PID controller when applying 300 kw sudden load at 10 sec.

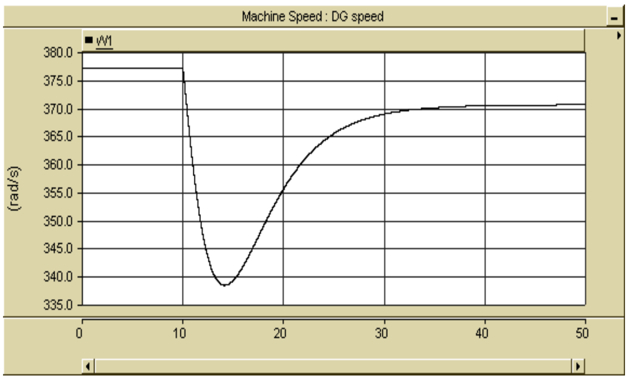


Fig. 7. DG time speed characteristic before tuning PID controller when applying 450 kw sudden load at 10 sec.

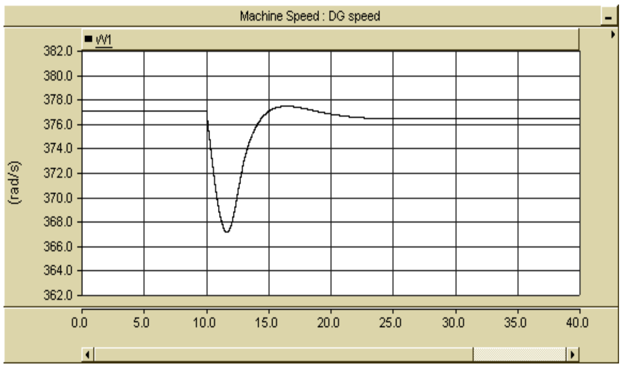


Fig. 8. DG time speed characteristic after tuning PID controller when applying 300 kw sudden load at 10 sec.

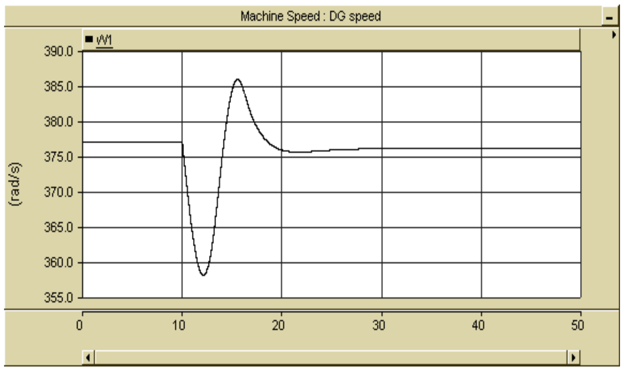


Fig.9. DG time speed characteristic after tuning PID controller when applying 450 kw sudden load at 10 sec.

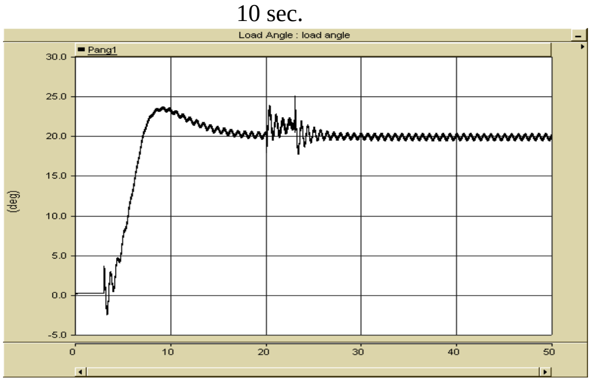


Fig. 10. DG load angle under variable sudden load.

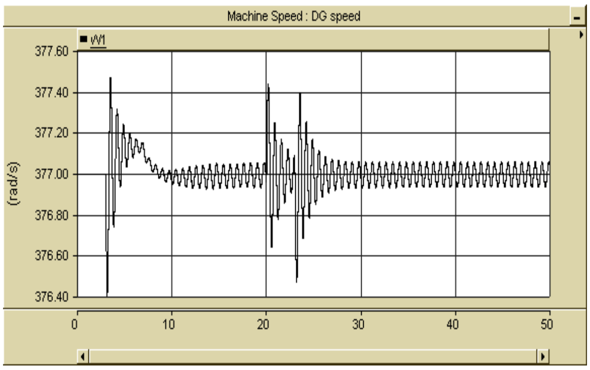


Fig.11. DG speed (rad/sec) under variable sudden load.

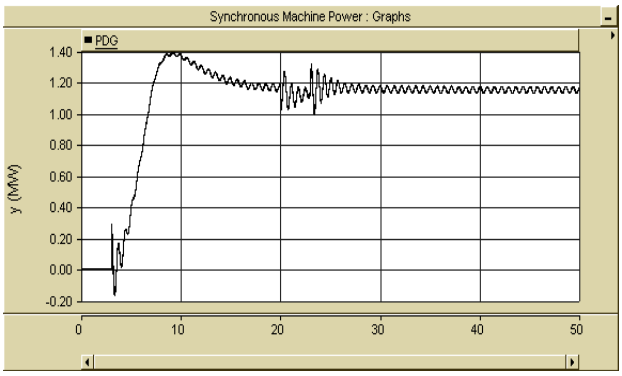


Fig. 12. DG Electrical power under variable sudden load.

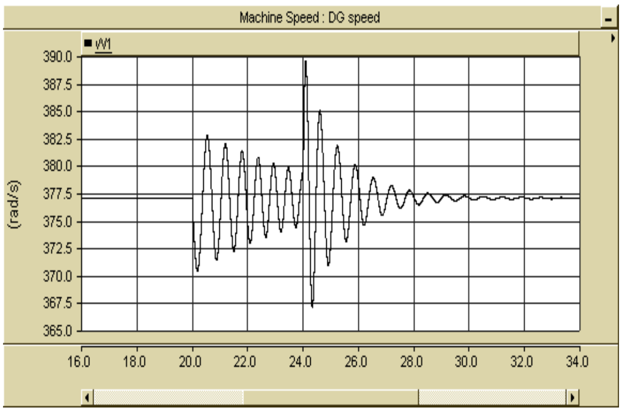


Fig.13. DG speed (rad/sec) under symmetrical fault

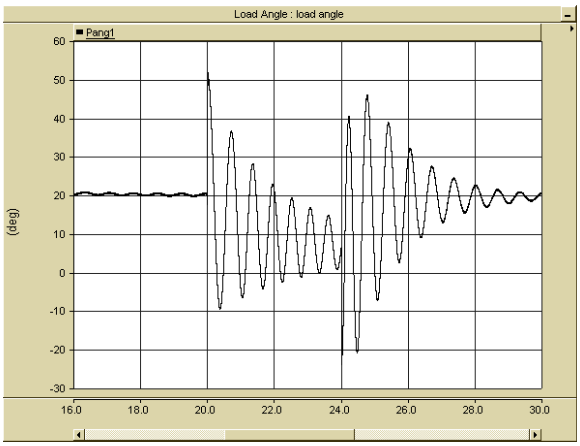


Fig.14. DG load angle under symmetrical fault.

Tuning PID controller enhances speed performance before and after connecting the DG to the networks at different loading and faults. Comparing load angle before and after tuning the PID controller there are no significant changes. That is because of tuning the DG parameters are done when the DG is stand alone. Moreover the operating points may change during the loading and fault effect so self-tuning on line for the DG is mandatory. Another important reason, which is neglected here, is the effect of voltage loop on the governor loop. These reasons shall be considered in the future work.

6. **Conclusion**

The modern civilization has made the demand for electric energy is exponentially increasing. Moreover, due the environmental concerns, alternative energy sources that integrate renewable energy resources into distribution system by using DG are employed. The paper is focusing on the impact of variable loading and faults on the stability and transient response of DG connected to distribution networks. The IEEE 13 node distribution test feeder is used as test system. PSCAD software is used to simulate the test system. Different fault scenarios are tested to illustrate the fault currents before and after using DG. In additions, the effect of faults and load variations on the DG stability and transients are tested. PID tuning based on Ziegler-Nichols method is carried out to enhance DG performance. Tuning PID improves the speed and load angle behaviour during variable loading and faults when the DG is stand alone. Connecting DG in the network after tuning enhance speed, while the load angle before and after tuning has no significant change due to different reasons: firstly, the limitations of Ziegler-Nichols tuning methods specially when the DG is connected to networks; second, the operating points may change during the loading and fault effect so self-tuning on line for the DG is necessary; third, the effect of AVR loop on the governor loop (coupling effect), which is not considered in this work; for the limitations of nonlinearities of the system, such as limiters, is not compensated. The handling of these limitations is the main scope of the extension of this work.

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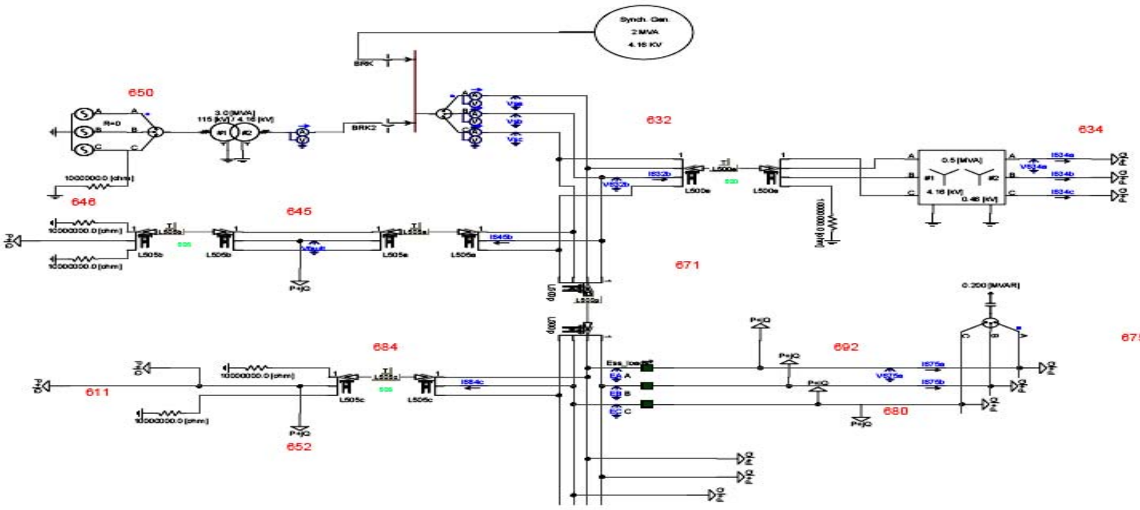

Fig. 2. Single line diagram of IEEE 13 node test feeder with DG