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Research Article

Stability analysis of medium sized power plants subjected to grid events

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ABSTRACT

Connection of small generating units in the medium voltage distribution system is increasing substantially. Such units, called distributed generation, can have a significant impact on, load flow, shortcircuit, voltage, frequency, power quality, stability, islanding and synchronized running, protection and reliability. In this study, the stability impact of a private sector power plant in Thrace region having synchronous generators driven by gas engine and gas turbine has been investigated in terms of fault ride through capability. Critical clearing time has been determined, once the criteria of fault ride through capability were explored. Grid operators do limit penetration levels of such plants and can also disconnect available units when grid fails. Stability is affected by voltage dip much worsely than penetration levels. It has been seen that the disconnection of power plants is not necessary, when the voltage dip restricted to 0,5 pu. Also that the stability is positively affected when the power factor is decreased to 0,8 from 1,0. The results also show that even 100% penetrated synchronous generator based power plants in distribution system do not affect stability badly in steady state operation.

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Introduction

Today’s power systems are undergoing major changes. The penetration of generating units at the medium voltage grids are increasing in numbers. Such generation units (also called distributed generation, DG) can have a significant impact on some parameters such as voltage profile, power quality, reliability, frequency, etc. Because of their increasing penetration, the effect of these units cannot be neglected anymore. Some studies are also available for renewables on this subject.

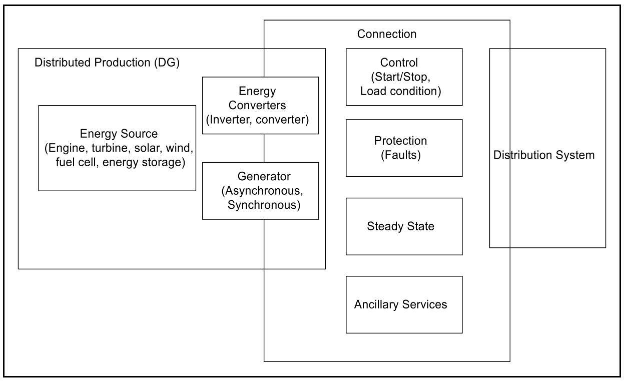


Fig. 1. Sources and events at the connection point

The increase of the power plants, together with new opportunities for power systems, also causes some problems to occur. Simulation studies on the grid voltage profile and short circuit effects of the DG stations connected to different locations of the radial distribution system have been carried out. DG will be a positive contribution to the voltage profile of the power plants connection, it will cause short circuit currents in the busbar that it is connected to, it can cause the healthy line to be disabled before opening the fault condition, DG will be not in one direction system with the power plants. It is stated that protection situations should be revised accordingly [1-7].

Recently, it has been stated that renewable energy and high efficiency systems are spurring efforts to generate electricity, that generators are connected to the system at the distribution level and are called distributed production, and that various researches carried out by the industry and the academy show that DGs will adversely affect the main distribution system in some ways. One of them is the determination of transient stability. Transient stability is generally not a problem because of the passive nature of the distribution grids, but it seems to have become more important recently with the increasing participation of the DG. The critical clearing time (CCT) for DG have been determined for the existing Denmark 10 kV distribution grid [8]. Three phase faults at different grid points have been analyzed. Such critical opening time is determined by the DG becoming unstable. The results obtained from the situation scenario are presented and evaluated. The overall conclusion is that DG can create transient stability problems at the distribution grid level. Therefore, this situation must be taken into account when connecting new DG to the grid. The lower voltage protection settings can also be determined based on the transient stability analysis. This is important to ensure that some types of DG units can remain connected to the grid during and after a fault.

Another issue that investigated the effects of generator parameters on the stability of the power system. Simulation studies on generator system model, excitation system, and power system stabilizer parameters on power system transients and dynamic stability have been carried out [9]. The degree of stability of the power system depends on the accuracy and suitability of the values of the components making up the system. It is the most important task to check and test the correctness of the generator parameters before starting the power system stability studies. If only one of the parameters is faulty, the result will not reflect the actual condition. However, it is not possible and economically feasible to test all the parameters of all generators very tightly. A model proposed to overcome this problem is proposed.

Traditional distribution grid protection systems are fast enough to clean the fault in the passive distribution grid. However, when a synchronous generator DG is connected, the time required for the protection system to detect and open the fault can exceed the DG's stability limits, so the DG has to leave without exceeding the limits of stability. According to some technical standards, for instant [10], the DG should be automatically disconnected in the event of an error or an abnormal condition. This prevents damage to the DG and prevents it from interfering with the protection system [11]. Due to the increasing prevalence of DG, it is no longer desirable to leave DG without unnecessary. This situation should be avoided as it reduces the expected benefits of DG [12].

Stability of DG units: When applied to failure criteria, DG units connected to the distribution grid must be able to withstand the voltage drops occurring after the failure without losing their stability within the specified limits. The existing protection systems are relatively inexpensive and simple, and they are designed according to the structure of the non-DG distribution grid. The fault clearance time may exceed the stability limits of locally connected DG units, especially for faults close to the transformer center. Thus, keeping DG units connected to the distribution grid protected by the traditional protection system can lead to instability of the DG units that are connected when the post-failure criterion is applied.

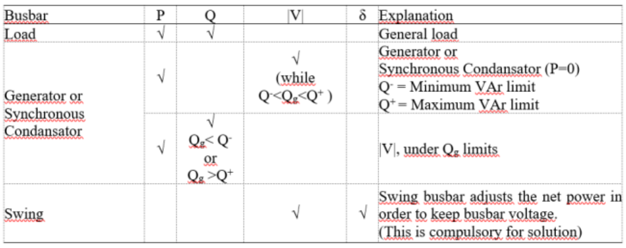
In this study, the answers to the following questions will be tried to be answered via the actual field / circuit parameters and DigSilent program.

- What would be the effect of the DG being connected during or after a distribution grid fault?
- Can a DG depend on the distribution system, either during or after a distribution grid fault, adhered to without losing its stability?
- What kind of fault leads to the disconnection of the DG depending on the distribution grid?
- What is the criterion to remain active after minimum breakdown to prevent DG from being disabled?
- How does the situation change at various DG participation rates?

Investigation of the grid events

The load flow is used to detect the state of the system for a given load and production [Table 1]. This corresponds to a decisive situation. In reality, however, this will vary with opening and closing, loading and unloading of loads and production resources, and sequential or random cascade situations.

Table 1. Load parameters at busbar



Busbar	P	Q	|V|	δ	Explanation
Load	√	√			General load
Generator or Synchronous Condansator	√		√ (while $Q^{-}<Q_{g}<Q^{+}$)		Generator or Synchronous Condansator (P=0) Q^{-} = Minimum VAr limit Q^{+} = Maximum VAr limit
	√	√ $Q_{g}< Q^{-}$ or $Q_{g} >Q^{+}$			|V|, under Q_g limits
Swing			√	√	Swing busbar adjusts the net power in order to keep busbar voltage. (This is compulsory for solution)

Load flow, short circuit, stability, motor starts, harmonic operations are the basis of the work. Initial conditions for such studies are provided through the system data. [13]. Short-circuit tests are conducted to determine the magnitude of the current that flows through the power system when a fault occurs. The size of the current changes over time until it reaches a stable state. In order to analyze the stability of the distribution grid, it is necessary to examine the behavior of sudden load changes in the event of failure or the disengagement or entry of some system elements. The stability of the system is defined by its stability, against normal and defective conditions. For this reason, the distribution grid is subject to possible harmful transient events, such as load loss, loss of synchronization, etc. Figure 2. Stability, small signs (static) and short circuits from small changes around the equilibrium point, transient state or angular stability with large amplitude faults such as sudden loss of production, dynamic stability such as voltage collapses, and so on. conceivable. It is expected that DG will be able to withstand and support the voltage and frequency in the distribution grid under normal conditions and for a certain period of deterioration.

Steady state stability is that, after a minor failure or change of a system, it can return to its beginning or near state even if this change continues. Normal steady state stability is used in the technical and economic design of the system. Failure steady state stability is used in the analysis of the system response to the new situation and steady state stability after failure is used to examine the weaker system that will occur in case of the disconnection of one or more system elements.

Transient state stability is the ability to recover to the initial state of the system after major failures [8,14]. Knowing the nature of transient behavior will allow the identification of the correct responses and equipment. The transient steady state simulating function takes into account the dynamics of electromechanical and control elements. The symmetrical, steady state of the passive mains is used, only the basic components of the voltages and currents are taken for.

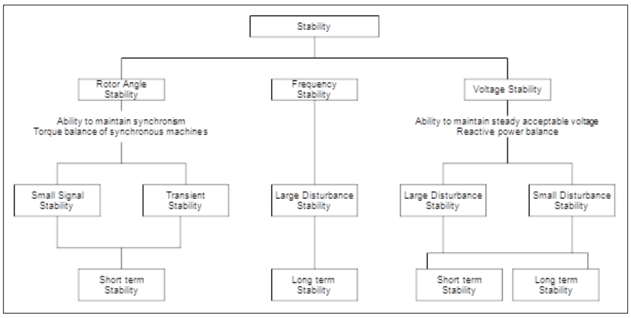


Fig. 2. Stability characterization

Transient states can be divided into three times domains, as seen in Figure 3 [15,16,17,18]:

- Short cycling or electromagnetic transient conditions
- Intermittent or electromechanical transients
- Long circulating transient situations

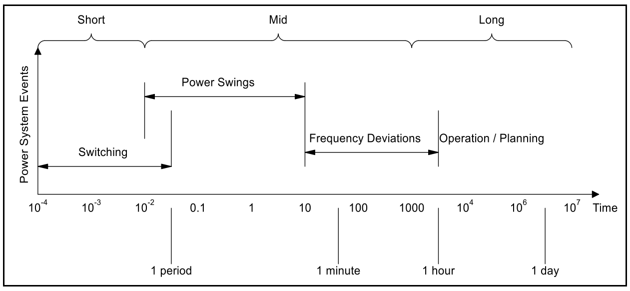


Fig. 3. Power system events and time characterization

In the event of a severe failure, the system values will deviate from their steady state values and will move to the new state. The stability in this new situation will be achieved by the acceptable of the busbar voltage and degree of rotation of generator rotor before openings of the failure. The generator rotor angle is usually used as a stability indicator. In the event of a fault, the bus voltages will decrease. The power given by the connected generators at the near point will also decrease. In this case, the mechanical power supplied by the engine may not be the same as the electrical power change. This constitutes the well-known oscillation equation given in Eq. (1) [19]:

$$\frac{2H}{w_s}\frac{d^2\delta}{dt^2} = P_m - P_e \qquad (1)$$

Here;

P_m : *Mechanical power [pu]*

P_e : *Electrical power [pu]*

H : Rotor inertia constant [MW.s/MVA]

δ : Rotor angle [rad]

ω_s : Angular frequency [rad/s]

t : Time [s]

Equation 4 is obtained when the rotor angular velocity is defined as in Equation 2 and the generator electrical power is defined as in Equation 3.

$$w_r = \frac{d\delta}{dt} = w - w_s \qquad (2)$$

$$P_e = P_{max}\sin\delta \qquad (3)$$

$$\frac{2H}{w_s}\frac{dw_r}{dt} = P_m - P_{max}\sin\delta \qquad (4)$$

After a number of mathematical operations applied to Equation 4, Equation 5 is obtained with the help of the power angle diagram [19].

$$\int_{\delta 0}^{\delta cr}(P_m - P_{max} sin\delta)d\delta = \int_{\delta cr}^{\delta max}(P_m - P_{max} sin\delta)\, d\delta \qquad (5)$$

The left part of the equation corresponds to the failure period and the right part corresponds to the post-failure situation. Where δ0 represents the angle of the steady state, and δcr represents the critical clearance angle. With the solution of Eq. (5), the critical clearing angle can be calculated.

$$\delta_{cr} = \cos^{-1}[(\pi - 2\delta_0)\sin\delta_0 - \cos\delta_0] \qquad (6)$$

The fault clearing time specifies the recovery of the kinetic energy of the generator. If this time is too long, the stability limits of the generator will be exceeded and the generator will be in an unstable state. For the generator's transient state stability, the fault clearance time is an important quantity and the stability limit can be expressed as the critical clean-up time. In [18], the critical clearing time is defined as the time between the occurrence of the fault and the cleaning. The critical cleaning time is expressed in Equation (7):

$$t_{cr} = \sqrt{\frac{4H(\delta_{cr}-\delta_0)}{w_s\, P_m}} \qquad (7)$$

DG behaviour against faults

The distribution grid may be suitable for expansion. It is important to examine the system according to various possible operating modes. Simplified single line diagrams are used for this. Single line diagram, grid, busbar, transformer, generator, load, capacitor, reactor, line, etc. Figure 4 shows an expanded single line diagram of the actual system of the distribution grid to be operated.

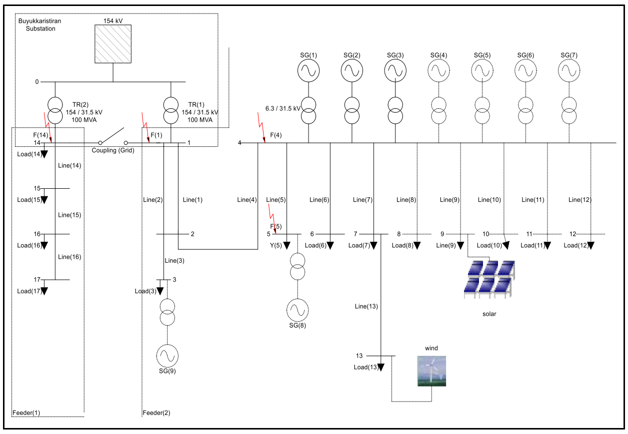


Fig. 4. Real grid and its model (data is available from [20])

In order to examine the effect of grid events on critical clearing time, a series of situation analysis was performed, such as the creation of a short circuit in any busbar in the system and the failure to terminate the other component. All working cases are summarized systematically in Table 2. Under these circumstances, various parameters such as rotor angle and generator active power were observed.

Table 2. Summary of study

Shortcircuit Point	Case Number	Feeder 2 Load [MW]	Detail	Subcase
Busbar 5	1	50	Generator nominal powers are changing	b
Busbar 14	2	50	cosφ = 0,98 for all SGs	b
	3	50	For SG1,2: cosφ =0,8; for SG3: cosφ= 0,98	b
Busbar 4	4	100	Generator power are fixed, feeder loads are changing	b
	5	50		a,b,c
	6	10		b
Busbar 5	7	50	Busbar voltage is 0 pu at the shortcircuit time	b
	8	50	Busbar voltage is 0,5 pu at the shortcircuit time	b
	9	50	Busbar voltage is 0,6 pu at the shortcircuit time	b
	10	50	Busbar voltage is 0,7 pu at the shortcircuit time	b
	11	50	Busbar voltage is 0,8 pu at the shortcircuit time	b
	12	50	Busbar voltage is 0,9 pu at the shortcircuit time	b
Busbar 5	13	50	Generator cosφ = 0,98	b
	14	50	Generator cosφ = 0,8	b
	15	50	Generator cosφ= 0,7	b
	16	50	Generator cosφ = 0,6	b
	17	50	Generator cosφ = 0,5	b
Busbar 5	18	10	Line 4 is opened	b
	19	10	Line 4 is opened	b + wind
	20	10	Line 4 is closed	b + wind
Busbar 2	21	50	Busbar changing	b
	22	50	Busbar changing	b + wind
Busbar 14	23	50	Busbar changing, Transformer disconnection	b
	24	50	Busbar changing, Transformer disconnection	b + wind
Busbar 5	25	10	Line 4 is opened	b + solar
	26	10	Line 4 is opened	b + solar + wind
	27	10	Line 4 is closed	b + solar
	28	10	Line 4 is closed	b + solar + wind
Busbar 5	29	100	Generator power are fixed, feeder loads are changing	a,b,c
	30	50		
	31	10		
Busbar 5	32	50	Busbar voltage is 0,5 pu at the shortcircuit time	c
Busbar 5	33	10	Line 4 is opened	c + wind
Busbar 5	34	10	Line 4 is closed	c + wind
Busbar 5	35	10	Line 4 is opened, and Line 7 is closed	c + wind + solar

Cases 1 and 2 analyse

In case 1, it will be given in detail in order to see the system being watched. The results obtained in other studies are given [20]. In this case, the load-2 has a load of 50 MW. Loads and synchronous generators are identical and SG1, SG2 and SG3 are active. Short circuits were made in busbar 5 and the situation analyzes were repeated for different opening times. Critical clearing times and states are realized and the generator active power and rotor angle changes for each case are achieved. If the fault is terminated within 240 ms, the rotor angle does not reach 90 degrees, it can go back to stable state even at 90 degrees at 360 ms, and if it is terminated after 360 ms, the steady state seems to have deteriorated.

In this case, shortcircuited busbar 14 was selected as busbar, and the fault was created in second. As in Case 1, the loader and synchronous generators are identical and have three generators (SG1, SG2 and SG3) with a cosφ of 0.98. The analyzes were repeated for different clearing times.

Cases 3-35

The results of examining all cases in Table 3. In addition, the generator angle change versus different trip times for selected conditions is given in Figures 5-10.

Table 3. Critical clearing times for cases of 7-12

			CCT [ms]	
Case	Busbar voltage [pu] at the shortcircuit time	Shortcircuit Resistance [Ω]	Case for 90^0 Angle	Unstable
Case 7	0	0	240	355
Case 8	0,5	0,65	1340	1600
Case 9	0,6	0,90	2600	3200
Case 10	0,7	1,20	4700	5900
Case 11	0,8	1,65	13000	14900
Case 12	0,9	3,00	53500	55000

Table 4. Critical clearing times for cases of 13-35

	CCT [ms]	
Case	Case for 90^0 Angle	Unstable
Case 13	240	355
Case 14	320	380
Case 15	320	390
Case 16	320	401
Case 17	320	412
Case 18	215	260
Case 19	80	83
Case 21	300	342
Case 22	300	341
Case 23	300	344
Case 24	300	343
Case 25	120	168
Case 26	50	60
Case 27	300	355
Case 28	300	353
Case 29 b	244	358
Case 30 b	238	354
Case 31 b	232	354
Case 32	300	600
Case 33	80	83
Case 34	300	351
Case 35	300	352

It is seen that limiting the voltage level above 0.5 pu is the most important parameter in stability evaluation. As the value of pu increases, the effect on stability becomes exponential. Short circuit resistors represent short circuit states at certain points in the lines.

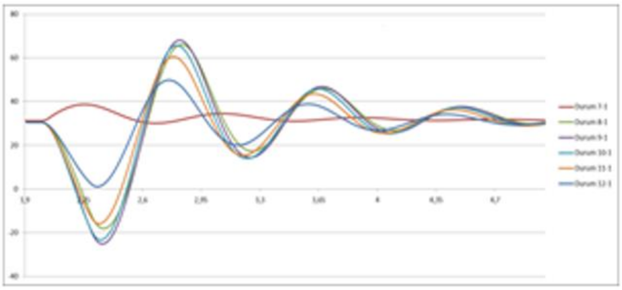


Fig. 5. Generator rotor angles for cases 7-12

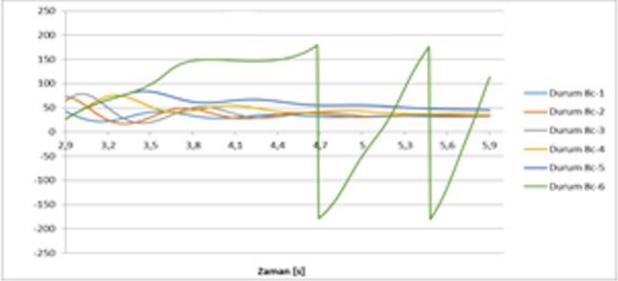


Fig. 6. Generator rotor angles for case 8

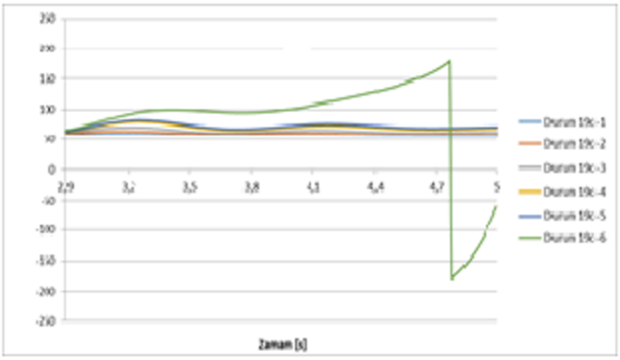


Fig. 7. Generator rotor angles for case 19c

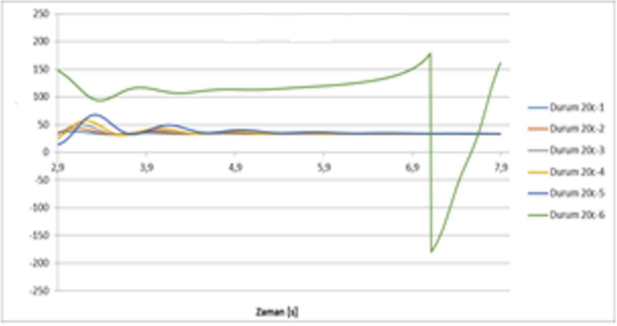


Fig. 8. Generator rotor angles for case 20c

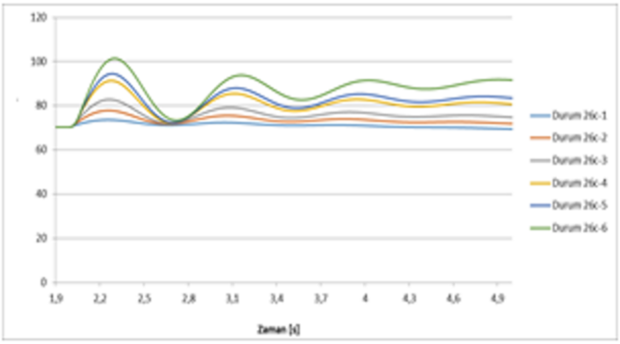


Fig. 9. Generator rotor angles for case 26c

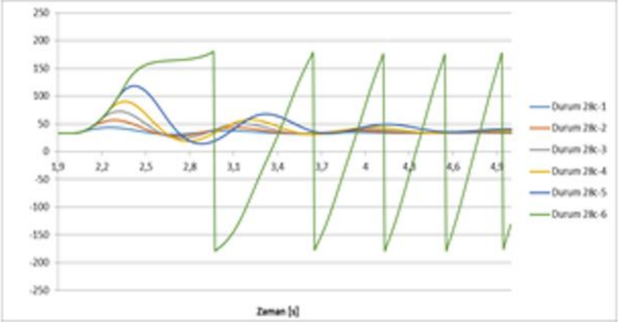


Fig. 10. Generator rotor angles for case 28c

The results from the simulations are summarized below:

- It is determined that the critical clearing time (CCT) of the DG connected to the conventional grid structure is low (230 ms). This situation is important for protection systems. If relay coordination is done considering this period, synchronous generators can be kept in operation.

- If the power factor is pulled from 1.0 to 0.8, then the CCT is increased to 320 ms and if the power factor is lowered, the CCT is not changed.
- At some points of failure in the distribution grid and at the power plants' side, the fault clearing time can exceed the critical clearing time of the DG's itself and this causes the DG engines to work erratically.
- In the case of severe transients, it is observed that the transient state stability of the critical systems is impaired when the DG are synchronized.
- The criterion for remaining in the distribution grid after a fault depends on the balance between the load and the production for a stable power system. To avoid the unbalance between the load and the production, the DG power plant has to remain connected to the grid during and after a grid failure. This can be achieved by voltage and frequency support. Due to the different sensitivities of the systems to the failure, it is seen that after the critical clearing time, the DG engines cannot meet this. Since the enable is directly related to the voltage drop, the greater the voltage drop can be held at 0.5 pu, the better the prevention of power plants deactivation.
- It is determined that when the voltage drop after short circuit is limited to 0,5 pu, the CCT reaches to 1340 ms and in this case the synchronous generators maintain their stability after failure.
- It has been observed that engine / turbine time in the same characteristics connection and load condition have no significant effect on critical clearing.
- Under normal operating conditions, SG participation in the distribution system has been observed to increase by up to 100%.
- One or more units in the distribution grid structure and the wind power plant and solar power plant conditions integrated into them have been examined for different load conditions for normal operation, island mode operation and fault conditions.
- It has been observed that wind and solar power plants do not have any adverse effects on the engine/turbine DG when connected to the grid and that wind and solar connections have no significant short circuit effect in the grid, but that these connections deteriorate in the case of island mode operation.
- At 10% - 50% - 100% DG participation rates, CCT was found to be 242 - 240 - 234 ms respectively. The effect of participation rate on CCT is very small.
- It has been determined that in the transient state the rotor angle is released to the unstable zone in the elapsed time of the trip.

Conclusions

In this study, various failures, different operating situations and transient state behaviors under different production-consumption conditions and their effects on stability were examined at certain points of the distribution grid to which a special SG-based power plant rated as DG was connected.

First, the grid events to dismantle the DG stations have been compared with other countries. Subsequently, distributed production systems have been evaluated for stability, frequency control and reliability, and the current standards for this issue have been summarized.

The production units of the exchanged plant and the grid to which it was connected were modeled with DigSilent software and related analyzes were carried out. One or more units in the distribution grid structure and the wind and solar conditions integrated into them have been investigated by comparing them for normal operation, island mode operation and fault conditions for different load conditions. The results obtained are as follows.

- The critical clearing time of synchronous generators at large amplitude voltage drops has been proven by simulations. Since the time required for the synchronous generators to remain in the circuit after the fault is low, the relay coordination at the exchange side and also at the grid connection point is important. The line voltage statistics and classification will allow to determine the appropriate setting values.
- It has been seen that the time exceeding the critical clearing time causes the uncertainty of the synchronous generators left on the circuit itself and the grid to which it is connected.
- It has been determined that increasing the participation rate of synchronous generators to be connected to the grid in normal working conditions will contribute positively to voltage and frequency control and reliability.
- It is not necessary to deactivate the synchronous generators in case of short term occurrence at the far points.
- It has been observed that engine / turbine connection and load condition have no significant effect on critical clearing time in the same characteristics.

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