Transient Stability Analysis of an Industrial Cogeneration System

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Abstract

The purpose of the paper is to analyze the transient stability of an industrial cogeneration system in Hsin-Chu Science-Based Industrial Park using ETAP software. The cogeneration system is installed two 161kV/161kV high-impendence transformers with tap-changer to connect with TPC for decreasing the short-circuit fault current and increasing the fault critical clearing time. The transient stability of three types of operation modes in cogeneration units, 3G1S, 2G1S, and 1G1S, is analyzed. Under the 3G1S operation mode, the system frequency immediately restores to 60Hz after tie line tripping with the TPC. Under the 1G1S and 2G1S operation modes, the system frequency will continuously decrease after tie line tripping with the TPC. The system frequency must perform the load shedding to put back to 60Hz.

Keywords: cogeneration, protection relays, transient stability

1. Introduction

The cogeneration system in Hsin-Chu Science-Based Industrial Park is selected for case study in this paper. Because the Science Park is one of the most important high-tech semiconductor industries in Taiwan, the needs of power service quality and reliability are much higher than those of general customers. When suffering from the abnormal power failure and voltage dips, the high-tech manufacturers not only cause a loss, but even the high-precision processing equipments lead to the serious damages. Therefore, keeping the reliability and stability of power service quality for the Science Park become a quite important issue. To solve the power quality problems for the Science Park, Taiwan Power Company (TPC) has additional set the power substation to the Science Park and changed the catenary's power wire into underground distribution system with loop scheme. Power system in the Science Park keeping a duty of high power quality is the joint duty for the TPC and Science Park customers. Especially, many manufacturers in Science Park installing the cogeneration equipments will lead to one of the important factors about the effects of power service quality. Therefore, if we can properly plan cogeneration units in high-tech Science Park, it not only effectively copes with insufficient power supply for Power Company, but solving the problems of unstable power quality in power system.

The results of this study can make a reference to the cogeneration facility constructed by high-tech factory and help the high-tech manufacturers to face the dilemma of the current electricity problems. Finally, the TPC and manufacturers in the Science Park can create the aspect of twin win.

2. System Structure

The cogeneration system for this study is built in Hsin-Chu Science–Based Industrial Park. Hsin-Yu cogeneration factory has built three 45 MW gas turbine generators and one 36.6 MW steam turbine unit. Single line diagram of the system is shown in figure 1 [1], [2]. The cogeneration units are parallel connected with TPC mainly by two three-winding isolation transformers: TRAA and TRBB. The primary and secondary windings of the transformers all adopt 161 kV with Y-connection, their capacities are 90MVA and 60MVA, respectively. The third winding adopts 11kV with Δ−connection, its capacity is 30MVA. There is a parallel connection between transformers and TPC. In addition to improving the power supply reliability, it also achieves the goal of the fault current restriction.

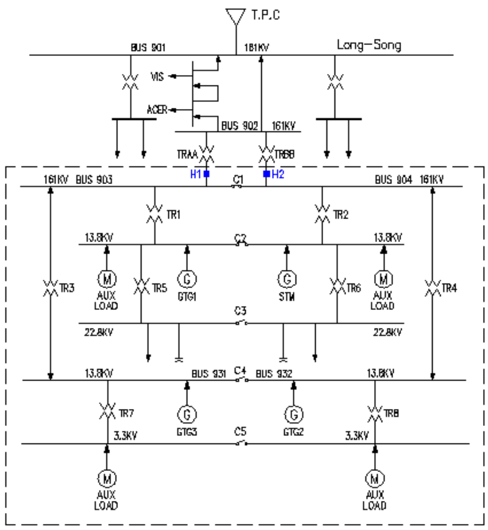

Figure 1. One-Line Diagram of the cogeneration System

2.1 Short-Circuit Fault Analysis

The breaker capacity is 40kA usually used at 161kV power supply loop. The TPC limits the maximum short-circuit current not exceeding 2kA for the cogeneration units because the TPC provides a maximum fault current 38.06kA. To deal with this problem, the cogeneration system has set two 161kV/161kV high-impendence transformers with tap-changer, which restricts the breaking fault current provided by the cogeneration units. According to ANSI standard, the breaking speed of the breaker and the parting time of the contact are set as 3 and 2 cycles, respectively. Having been installed the 161kV/161kV transformers, the instantaneous fault current provided by the cogeneration units is 1.54kA, which will satisfy the demands of TPC. The originally total instantaneous symmetric short-circuit current is 38.06kA at the TPC Long-Song substation. If the 161kV/161kV transformers are not installed, then the instantaneous fault current increases 2.64kA provide by the cogeneration units. Unfortunately, the total instantaneous symmetric short-circuit current is increased to 40.7kA at the Long-Song substation. From the short-circuit fault analysis, if the industrial cogeneration system is directly connected to the TPC system, the short-circuit capacity of the Long-Song substation will be greater than 40kA when a fault occurs. Therefore, we should adopt the 161kV/161kV transformers to connect with TPC system and then the short-circuit capacity is less than 40kA to meet the requirement of the TPC.

2.2 System Modeling

The cogeneration system consists of generators, exciters, governors, load and other equipments. In this study we would like to establish the mathematical models of these components first. We will now illustrate the equivalent models of the important components for this system below.

2.2.1 Generator Model

In this paper, the generator sets of the industrial cogeneration system will take into account the detailed effects of transient and sub-transient on the generator. It is assumed that the d-axis and q-axis all have damping coils. We will perform the simulation of the operation of generator under the saturation and un-saturation to obtain the more precise transient stability [3].

2.2.2 Exciter Model

The excitation systems of gas turbine units from GTG1 to GTG3 in the cogeneration system are all IEEE TYPE3, but the excitation system of steam turbine unit STG is IEEE TYPE2 [4]. Their control block diagrams are shown in Figures 2 and Figures 3, respectively.

2.2.3 Governor Model

The rotor speed of the generator in the governor control system serves as a main feedback signal. The comparison between the signal and reference speed gets the speed error, again by the error, it will serve as the change in the position of the steam valve to regulate the amount of steam entering the turbine. At last, the change in the output of mechanical power for turbine is performed so that the generators after the system disturbance occurred can restore to synchronous operation. The governors of gas turbine from GTG1 to GTG3 in the industrial cogeneration system are all GAST TYPE, but the governor of steam turbine STG is IEEE TYPE1. Their control block diagrams are shown in Figures 4 and Figures 5, respectively.

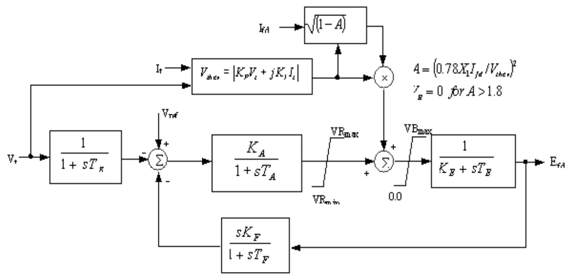

Figure 2. Block Diagram of Exciter Control System for the Gas Turbines

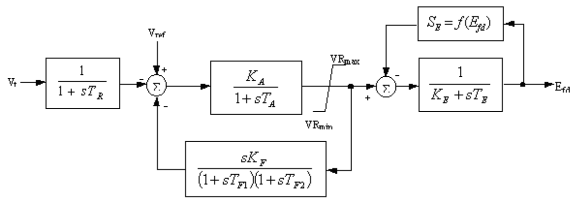

Figure 3. Block Diagram of Exciter Control System for the Steam Turbine

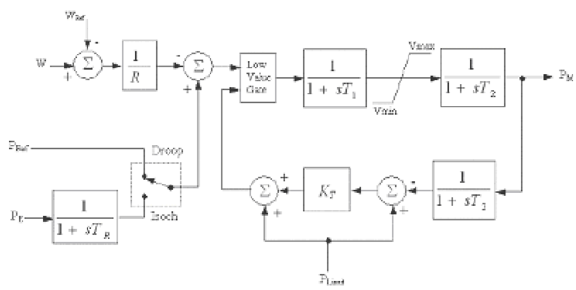

Figure 4. Block Diagram of Governor Control System for the Gas Turbines

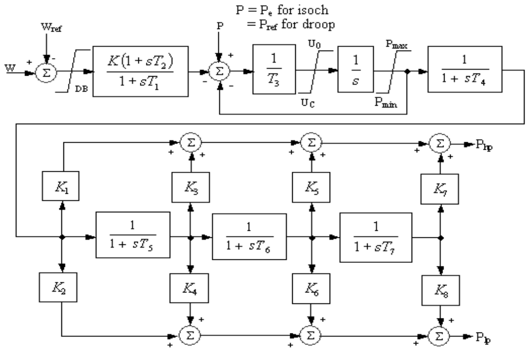

Figure 5. Block Diagram of Governor Control System for the Steam Turbine

3. Relay Setting for Tie Line Tripping

To make sure the power quality, power supply reliability, and utility safety operation of cogeneration plant after connecting to the TPC system, the cogeneration plant must install some different types of protection relays at TPC duty point. When the TPC system occurs fault disturbance resulting in cogeneration generator units or significant loads tripping inside the plant, it is necessary to trigger the protection relays action to trip the main breaker in TPC system tie line. The cogeneration plant can then be kept at an independent stable operation [5], [6].

The severest fault in power system is the ground faults. The customer's equipments should ensure keeping continuously stable operation when a ground fault occurred. Therefore, the relay for tie line tripping connected to the TPC system must trip within 0.1 sec. Because bus 903 is more close to the fault point than bus 931 and 932, the voltage drop at bus 903 is deeper than others. The voltage drops to 0.2456pu during the fault period with 161kV/161kV transformers and 0.0037pu without 161kV/161kV transformers, respectively. The bus 931 voltage drops to 0.4543pu and 0.3029pu, and the bus 932 voltage drops to 0.4223pu and 0.251pu. From these results, we observe that the voltage drop at bus 903 is greater than those at bus 931 and 932, as shown in Figures 6 and 7 [7].

In this paper, we will analyze the following three different types of operation modes for the industrial cogeneration system. The power generation for each gas turbine is 56.25MW with a power factor of 0.8 and for steam turbine is 36.6MW with a power factor of 0.8. The total load of the customers in cogeneration system is 153.97MW. Table 1 shows all the output power of each cogeneration unit and total load for three different types of operation modes.

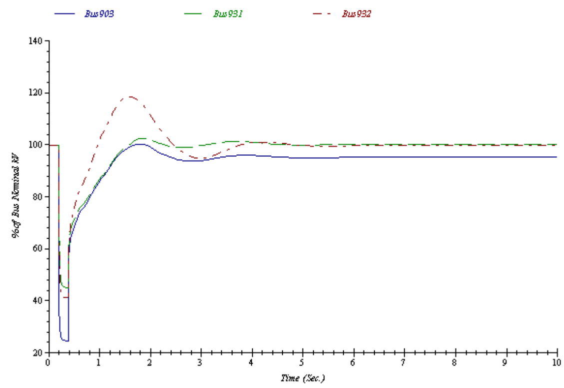

Figure 6. Voltage variations at Bus 903, 931, and 932 with 161kV/161kV Transformers

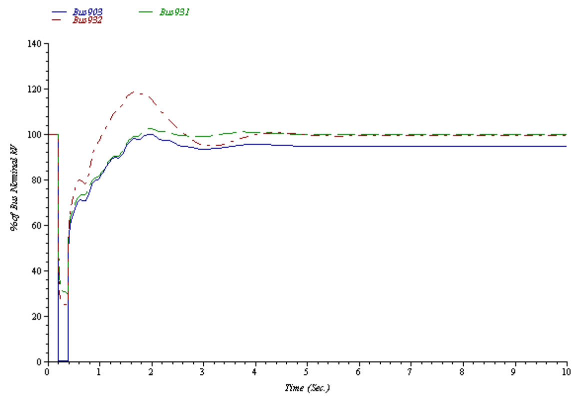

Figure 7. Voltage variations at Bus 903, 931, and 932 without 161kV/161kV Transformers

Table 1. Operation Modes of Cogeneration Units

Operation Modes	GTG1 (MW)	GTG2 (MW)	GTG3 (MW)	STG (MW)	Total Gen(MW)	Total Load(MW)
3G1S	45	45	45	36.6	171.6	153.97
2G1S	45	45	OFF	36.6	126.6	153.97
1G1S	45	OFF	OFF	36.6	81.6	153.97

3.1 3G1S Operation Mode

Under the 3G1S operation mode, we suppose that a fault is occurred at bus 901 in TPC system at 0.2 sec. The tie line between the cogeneration plant and the TPC system must be tripped after fault occurrence. At the moment, the power generation capacity is greater than the load demand, which the electrical powers of the gas and steam turbines are at their maximum ratings of 45MW and 36.6MW, respectively. After the tie line tripping, all the cogeneration units will settle to a new stable operation point at which the electrical power outputs will achieve to the 42.114MW, 35.839MW, 39.018MW, and 39.103MW, respectively. The cogeneration system frequency can fast restore to 60Hz. Figures 8 and 9 show the curves of the electrical power outputs and speeds.

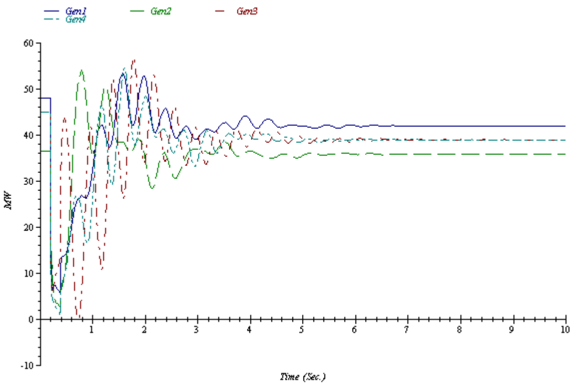

Figure 8. Electrical Power Outputs for 3G1S Operation Mode

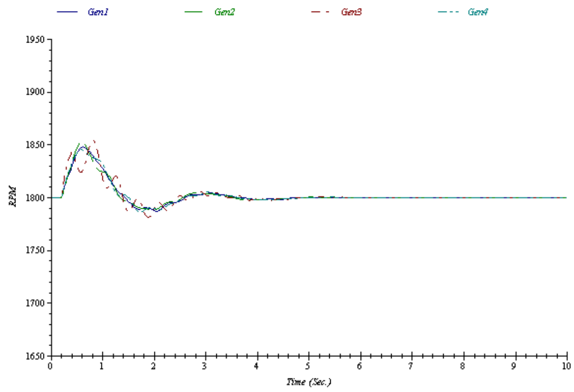

Figure 9. Generator Speeds for 3G1S Operation Mode

3.2 2G1S Operation Mode

Under the 2G1S operation mode, the cogeneration plant has been isolated from the TPC system after the tie line tripping at 23th cycles (0.384 sec.). The electrical power outputs of the generators have reached their maximum values of 56.25MW, 39.914 MW, and 56.25MW. At the moment, the total power generation capacity is less than the load demands. Hence, the generator frequencies will drop slowly so that these generator units can not keep operating for a long time, as shown in Figures 10 and 11.

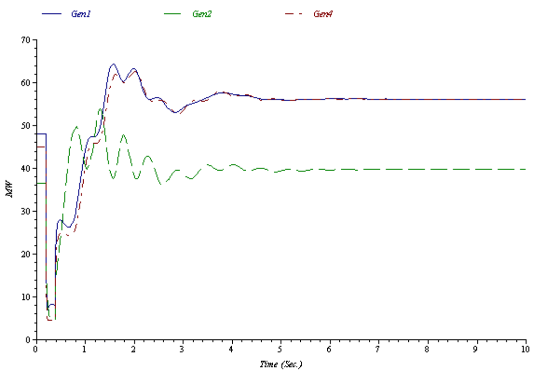

Figure 10. Electrical Power Outputs for 2G1S Operation Mode

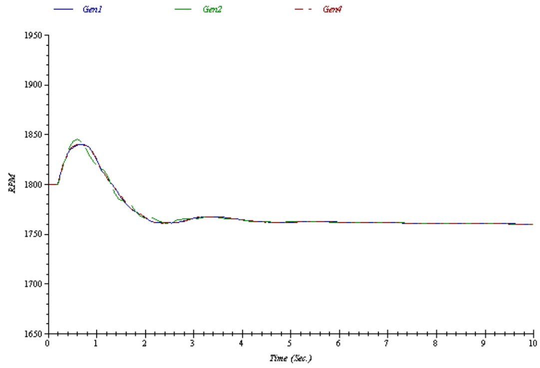

Figure 11. Generator Speeds for 2G1S Operation Mode

3.3 1G1S Operation Mode

Under the 1G1S operation mode, after the cogeneration plant has been isolated from the TPC system, the frequency will continuously drop and eventually collapse, as shown in Figures 12 and 13.

From the preceding results, if the system frequency wants to restore to the 60Hz and keep stable operation for both 1G1S and 2G2S operation modes, then it must perform the load shedding. The foregoing cases can be simulated using electrical transient analysis program (ETAP) software [8].

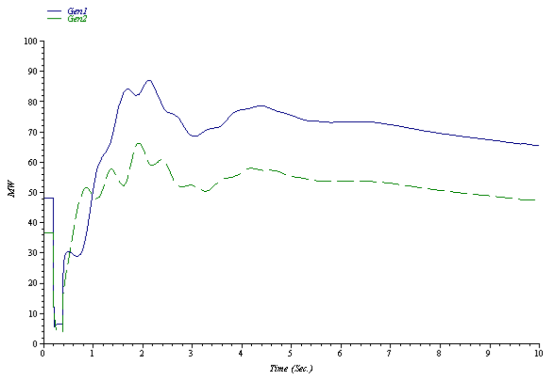

Figure 12. Electrical Power Outputs for 1G1S Operation Mode

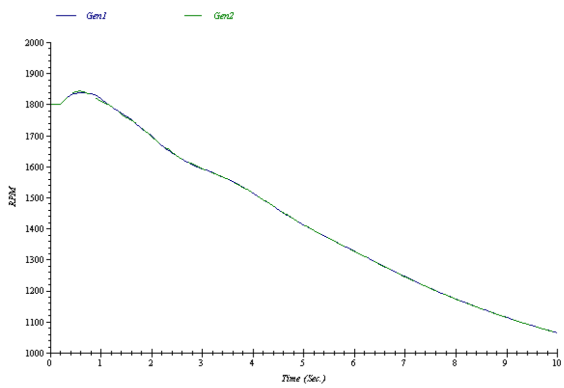

Figure 13. Generator Speeds for 1G1S Mode Operation Mode

4. Study on Load Shedding

The cogeneration plant performs the parallel operation with the TPC in order to supply power with reliability and safety. When the system operates at a stable equilibrium status, the cogeneration plant is not necessary to carry out any load shedding. However, when the fault is occurred and the tie line is tripped to isolate from the TPC system, the electric power generation may be insufficient to supply to the demand inside the cogeneration system. The system frequency will continuously drop. Consequently, it causes the industrial cogeneration units to trip and factory to power off. Therefore, after the cogeneration system has isolated from the TPC system, performing the load shedding based on the change in frequency becomes an extremely important thing. Through shedding some unimportant load, generator units can maintain and restore the stable operation.

After performing the tie line tripping, we can compute the initial frequency decay rate of the industrial cogeneration system. From equation (1), the amount of load to be unloaded can be determined [9] to avoid the occurrence of a misjudged thing due to the rapid load changes. The incorrect unloading in the cogeneration units results in the collapse of the power system. From equation (1), the initial frequency decay rate can be solved to determine the amount of unloading which can reduce the drawbacks of both excess in unloading and insufficient unloading. Moreover, the computation of equation (1) spends less time.

$$P_{step} = \frac{2H_{sys}}{w_0}\frac{d\Delta w}{dt} = \frac{2H_{sys}}{60}m_0 \quad (1)$$

where P_{step} is the total amount of load to be shed. m_o is the initial frequency decay rate at the moment of tie line tripping.

$$H_{sys} = \frac{H_1 MVA_1 + H_2 MVA_2 + \ldots\ldots + H_n MVA_n}{MVA_{sys}} \quad (2)$$

where H_{sys} is the equivalent system inertia constant of the cogeneration system and n is the number of the cogeneration units.

This study finds that the cogeneration system encountered the short-circuit fault in the 1G1S and 2G2S operation modes and performed the tie line tripping from the TPC system, it was necessary to execute load shedding to prevent frequency continuously drop and had an opportunity of recovering to 60Hz. We adopted the load shedding of a detective frequency drop manner to perform the unloading. For 1G1S operation mode, we obtained the inertia constant ***H*** and m_o as 2.065 and 11.84 based on equations (1) and (2). For 2G1S operation mode, the ***H*** and m_o can be computed as 3.101 and 2.69. Again, substituting the foregoing values into equation (1), we can obtain the P_{step} as 81.5MW and 27.8 MW, respectively. Under the 2G1S operation mode, the electrical power outputs after the tie line tripping from the TPC system and load shedding are shown in Figure 14. At this moment, the amount of power generation and the amount of load demand inside the cogeneration plant has reached the balanced condition. Namely, the output power of the gas and steam turbines are 48.004MW, 36.578MW and 44.988MW, respectively. Figure 15 shows the frequency curve after the tie line tripping from the TPC system for the 2G1S operation mode. This figure shows that the system performs the load shedding after 3.86sec., the frequency of the cogeneration plant has restored to the stable state of 60 Hz. Under the 1G1S operation mode and after the tie line tripping from the TPC system, the amount of power generation and the amount of load demand inside the cogeneration plant have reached the balanced condition. The power outputs of the gas and steam turbines are 48.247MW and 36.62MW, as shown in Figure 16. The frequency curve before and after load shedding is given in Figure 17. This figure shows that the frequency of the cogeneration system has restored to the stable state of 60Hz after performing the load shedding and through 6.645 sec.

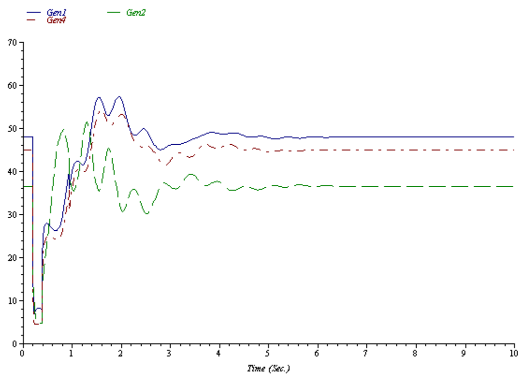

Figure 14. Electrical Power Outputs for 2G1S Operation Mode with Load Shedding

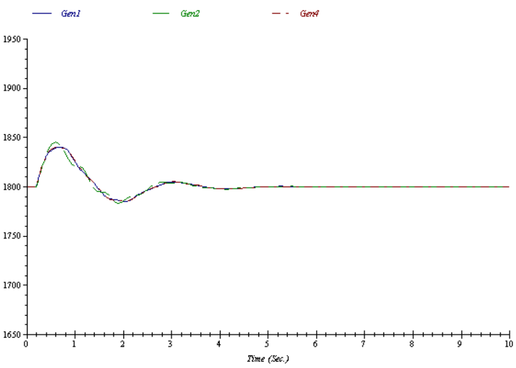

Figure 15. Generator Speeds for 2G1S Operation Mode with Load shedding

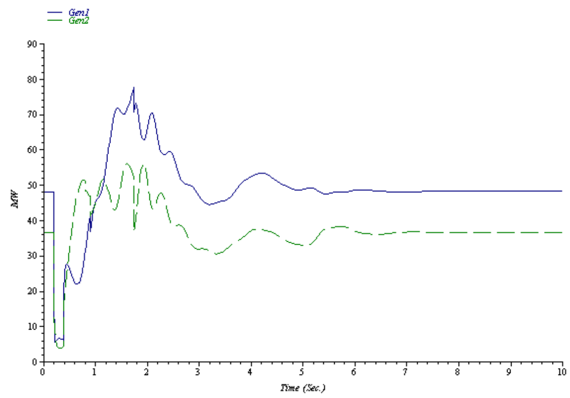

Figure 16. Electrical Power Outputs for 1G1S Operation Mode with Load Shedding

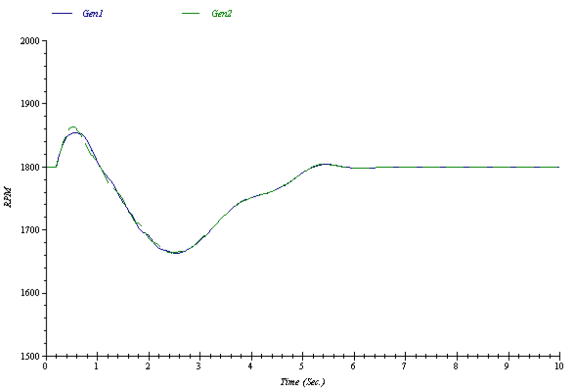

Figure 17. Generator Speeds for 1G1S Operation Mode with Load Shedding

6. Conclusions

This paper mainly investigates the power system transient stability for the high-tech Science Park with cogeneration facility. The load shedding has been applied to the industrial cogeneration system under the different tie line tripping opportunities and operation modes. If the system adopts 161kV/161kV transformers to connect to the TPC system in parallel, this study finds that the industrial customer's system voltage sags can be improved during fault contingency. The manufacturers can avoid a serious loss caused by the power failure, which contributes the coordination between the protective relays [10]. In addition, the mechanism of tie line tripping is very important between cogeneration plant and the TPC system. Except that we can select the frequency relays to activity we can also utilize the under voltage relays to perform a proper load shedding. In this way, the improper tie line tripping can be avoided due to the internal fault of cogeneration system, and the both power systems of the TPC and cogeneration plant can keep a normal independent operation after the tie line tripping.

Acknowledgements

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