Voltage Sags Improvement for the High-Tech Industrial Customers by Using Cogeneration System

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***Abstract*- This paper presents the improvement of the voltage sags for the semiconductor fabrication facility by the installation of cogeneration systems. The critical equipment is evaluated against the SEMI F47 and ITIC power quality documents. The cogeneration system is installed to mitigate the voltage sags due to external system faults. Also, the under voltage relays to disconnect the cogeneration system from the utility are designed by considering the critical clearing times at the point of common coupling and voltage sags ride-through curves. The dynamic responses of different fault conditions are executed by using the transient stability analysis to calculate and define the voltage sags ride-through curves with and without considering the disconnection of the cogeneration system. It is concluded that the voltage sags ride-through capability can be improved greatly if the cogeneration systems are performed to trip accurately according to the under voltage relays design proposed by the paper.**

Keywords: Semiconductor Fabrication Plant, Cogeneration, Voltage Sag

I. INTRODUCTION

With so many semiconductor manufacturers in the Hsin-Chu science-based industrial park, the power quality and service reliability have always been the critical issue for the industrial customers. The power service outage due to Taiwan Power Company (Taipower) system fault has caused serious production loss for the high-tech customers. Furthermore, the problem of voltage sags also introduces the shutdown of IC production processes which are controlled by the power electronic equipment.

To enhance the power service quality, Taipower has installed the loop transmission network with automatic transfer switches (ATS) for the critical customers and replaced the overhead lines with underground systems. However, it is difficult to guarantee the perfect power service quality for the customers in the science-based industrial park. Although the diesel generators are considered to provide the backup power, the long start up time of the generators is not be able to resolve the problem of short time power outage. The uninterruptible power supply (UPS) and dynamic voltage restorer (DVR) may be used to solve the voltage sags problem. However, the constraints of service time and capacity have made them impossible to be applied to solve the long-term power interruption for the power service of large manufacturer equipment. To solve the above problem, a large cogeneration system has been designed and implemented in the Hsin-Chu Science-based Industrial Park to improve the power service quality for the high-tech industrial customers [1]. This paper presents the mitigation of voltage sags for the high-tech industrial customers with the support of the cogeneration facility.

II. VOLTAGE SAGS RIDE-THROUGH CAPABILITY CURVES

More and more industrial equipments become very sensitive to voltage sags[2]. Voltage sags are short duration reduction in root-mean square (rms) voltage mainly caused by the system faults and large motor starting. In general, equipment sensitivity to voltage sags can be presented in the form of ride-through capability curve (or voltage-tolerance curve). The voltage sags ride through capability curves proposed by the Information Technology Industry Council (ITIC) [3] and the semiconductor industry (SEMI-F47) [4] are widely adopted by the industrial customers. By integrating the ITIC and the SEMI F47 curves into a wider range of voltage tolerance curve as shown in Fig. 1, a voltage sags ride-through curve has been adopted in this paper to evaluate the effect of voltage sags. The voltage sag ride-through curve gives the limitation of voltage of 0.9, 0.8, 0.7 and 0.5pu. with corresponding duration 10, 0.5, 0.2 and 0.02 seconds respectively. Any voltage sag events have the magnitude and duration below the ride-through curve may result in the tripping of sensitive load.

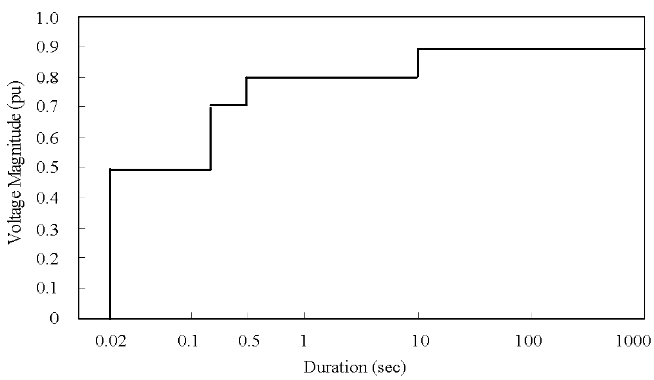

Fig. 1 The proposed voltage sag ride-through capability curve

III. DESCRIPTION OF THE COGENERATION SYSTEM

To provide the better power service to the industrial customers in the science park, a cogeneration system has been installed and commissioned since 1999. It consists of three units of 46MW gas turbine and one unit of 36.6MW steam turbine. Fig. 2 shows the network configuration of the study cogeneration system and Taipower substation with several nearby industrial customers. The dash line illustrates the scope of the cogeneration system with its service

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customers. One 161kV transmission line is connected to ACER customer and one is directly connected to Taipower Long-Song substation due to the loop circuit. Several high-tech customers served by the same substation with 161 kV and 22 kV service voltages respectively are also shown in the figure. The cogeneration system serves the 22.8kV customers by transformers TR5 and TR6 with rated capacity of 40MVA each and another four transformers (TR1-TR4) with rated capacity of 50MVA each are used to provide the power to the 161kV customers. There are another two large industrial customers, VIS and ACER, which are served by the same 161kV loop as the cogeneration system and several 161kV and 22.8kV customers are served by Long-Song substation. The steady operation condition is also shown in the figure. Four cogeneration units generate 154MW electric power to provide the total load demand of 151.9MW. The tie lines power flow with Taipower has only 1.6MW as shown in the figure.

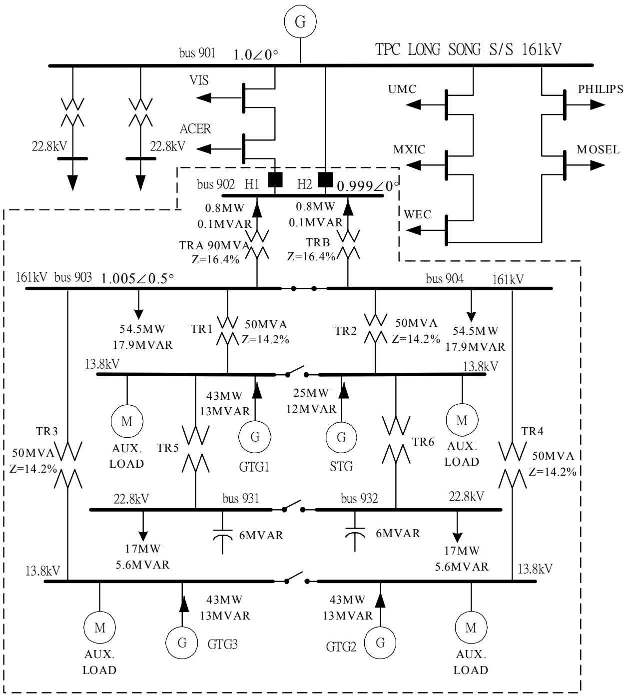

Fig. 2 One-line diagram of the study power system

IV. Voltage Sags Analysis without Considering the Tripping of Tie Lines

To investigate the effectiveness of cogeneration system on the voltage sags, transient stability analysis has been executed by considering the mathematical models of the cogeneration units, exciters, governors and load [1]. A three-phase fault is assumed to occur at Long-Song substation (bus 901) and the tie line between Taipower and cogeneration facility is still connected during the fault period. Four study cases with different fault impedances are simulated to examine the voltage variations at the 161kV buses of the cogeneration system.

Figs. 3-6 give the voltage variations at buses 902 and 903 of the study system when a three-phase fault is occurred at bus 901 with various fault impedances of 2.46, 6.14, 10.5 and 16.9 ohms, respectively. In the Fig. 3, the tie lines remain connected to Taipower system during the fault period. It is found that the residual voltages at bus 902 and bus 903 are dropped to the minimum values of 0.41pu. and 0.5pu. respectively after the fault occurrence 0.2 second. It means that the voltage can be boosted from 0.41pu. to 0.5pu. for the 161kV bus if the industrial customers have connected with the cogeneration system. In the Fig. 4, the residual voltages at bus 902 and bus 903 are dropped to the minimum values of 0.64pu. and 0.7pu. respectively after the fault occurrence 0.5 second. The residual voltages at bus 902 and bus 903 are dropped to the minimum values of 0.75pu. and 0.8pu. respectively in the Fig. 5. Also, the 161kV bus voltage can be improved from 0.83pu. to 0.86pu. when the fault has an impedance of 16.9 ohm as shown in Fig. 6.

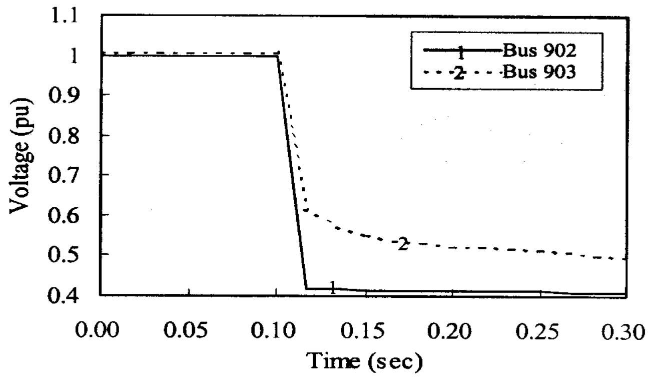

Fig. 3 Voltage responses at 161 kV buses of the cogeneration system with a fault impedance of 2.46 ohm.

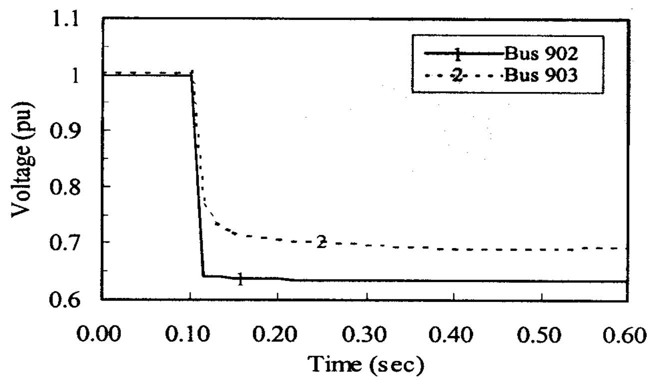

Fig. 4 Voltage responses at 161 kV buses of the cogeneration system with a fault impedance of 6.14 ohm.

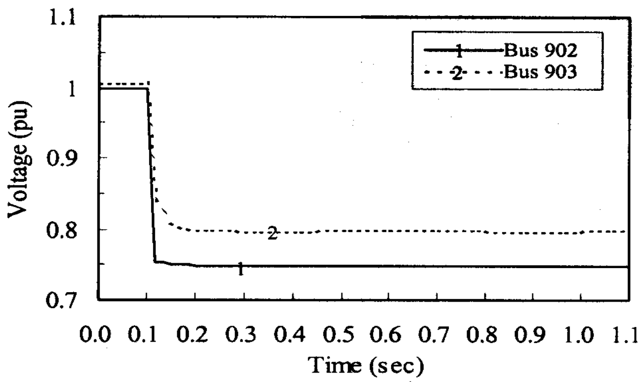

Fig. 5 Voltage responses at 161 kV buses of the cogeneration system with a fault impedance of 10.5 ohm.

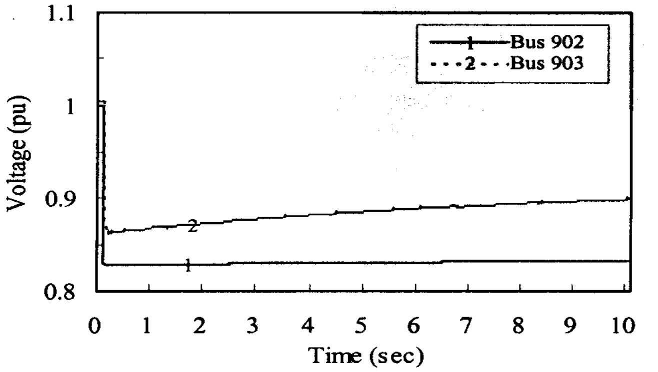

Fig. 6 Voltage responses at 161 kV buses of the cogeneration system with a fault impedance of 16.9 ohm.

Fig. 7 gives a new voltage sag ride-through capability curve when the industrial customers have connected to the cogeneration system without considering the tie line tripping. According to the previous simulation, it is found that the new curve give the limitation of voltage drops to the 0.83, 0.75, 0.64 and 0.41pu. with corresponding duration 10, 0.5, 0.2 and 0.02 seconds respectively. The sensitive loads will not be tripped due to voltage sags when they are located between the two curves in the Fig. 7 if the cogeneration has been installed.

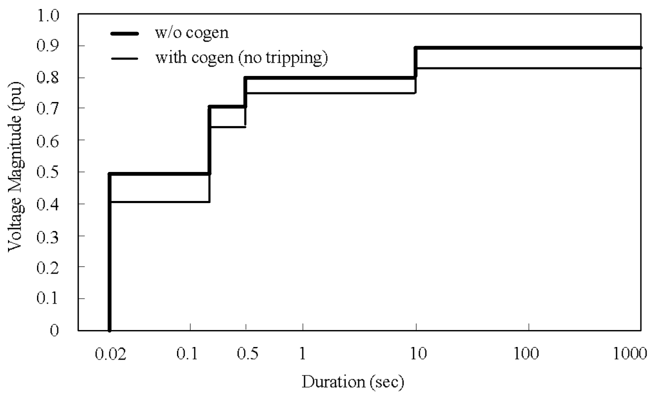

Fig. 7 Improvement of voltage sag ride-through capability curve without considering the tripping of cogeneration system.

V. Voltage Sags Analysis with Considering the Tripping of Tie Lines

When a fault occurs on the utility and is unable to be cleared in time, the cogeneration system has to be isolated from the Taipower network to maintain stable operation of the cogeneration units. To solve the voltage sag problem and to maintain the stable operation of the cogeneration units, the under voltage relay for tie line tripping must be designed according to the voltage ride-through curve and the critical clearing time (CCT).

5.1 Under Voltage Relay Setting for Tie Line

Fig. 8 shows the CCT for the three-phase short circuit fault with different fault impedances at bus 902. The CCT is 0.217 second for the most severe fault with residual voltage 0.17pu. at bus 902. When the residual voltage is 0.29pu., the CCT is 0.28 second. When the residual voltage is 0.38pu., the CCT is 0.43 second. If the residual voltage at bus 902 is higher than 0.45pu., there is no CCT problem and the cogeneration units can return to stable operation without even clearing the Taipower system fault. According to above discussion, it is therefore to design one instant operation of the under voltage relay with the setting of 0.3pu. and 0.1 second time delay, and another setting of 0.45pu. and 0.2 second time delay.

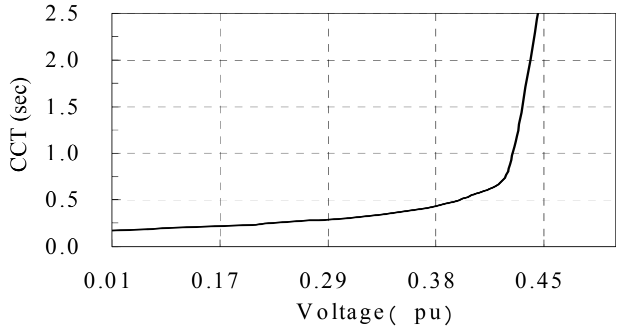

Fig. 8 The critical clearing time versus residual voltages at bus 902

On the other hand, under voltage relay is also designed to prevent the tripping of sensitive load due to voltage sags. Four steps voltage of 0.41, 0.64, 0.75 and 0.83pu. with corresponding time delay of 0.1, 0.2, 0.5 and 10 seconds are suitable for the under voltage relay settings. It is found that the relay setting due to voltage sags is much sensitive than the CCT consideration. It is therefore to adopt the four steps under voltage relay settings to trip the tie line connected between the Taipower and the cogeneration system.

5.2 Voltage Sags Analysis with Tie Line Tripping

Different scenarios of fault cases with proper design of under voltage relay settings to disconnect the tie line between Taipower and cogeneration network are simulated to find the voltage variation at the 161kV customer buses.

Case A assumes a three-phase bolted ground fault is occurred at bus 901 and the first step setting of under voltage relay is activated to trip the tie line in 0.1 second after the fault. Fig. 9 shows the voltage responses at bus 902 and bus 903. The voltage at bus 903 has ever dropped to the minimal value of 0.26pu. and restored to the nominal value after fault clear. From the simulation result, it is found that the voltage at bus 903 below the values of 0.5, 0.7, 0.8 and 0.9pu. has the duration of 0.1, 0.133, 0.2 and 0.917 seconds respectively. Most of the voltage variation can maintain above the proposed ride-through curve, except when the voltage drops below 0.5pu. with 0.1 second duration.

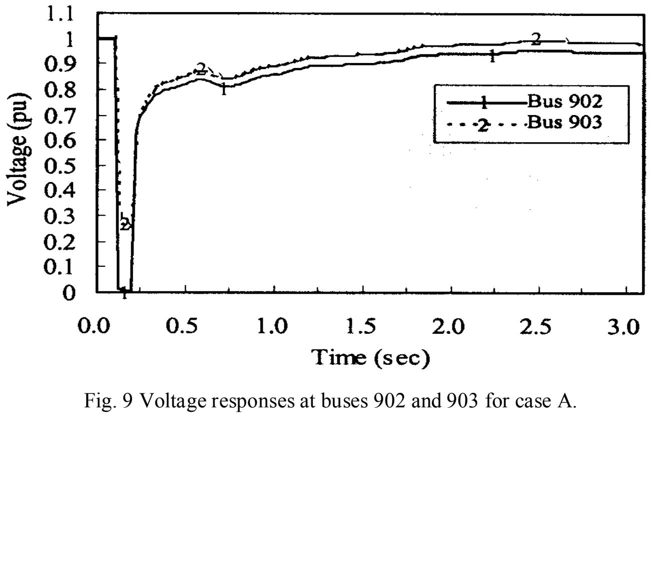

Fig. 9 Voltage responses at buses 902 and 903 for case A.

Case B assumes an impedance fault has been occurred at bus 901. It is found that the minimal voltage at bus 902 has dropped to the 0.42pu. to activate the second step setting of under voltage relay to trip the tie line in 0.2 second after the fault as shown in Fig. 10. The voltage at bus 903 has ever dropped to the minimal value of 0.50pu. during the fault and then restored slowly after fault clear. According to the statistic value from simulation result, the voltage at bus 903 below the values of 0.7, 0.8 and 0.9pu. has the duration of 0.2, 0.267 and 1.0 seconds respectively. Although the voltage variation phenomena have been observed, the sensitive load will not be tripped because the voltage still maintain above the proposed ride-through curve during the transient period.

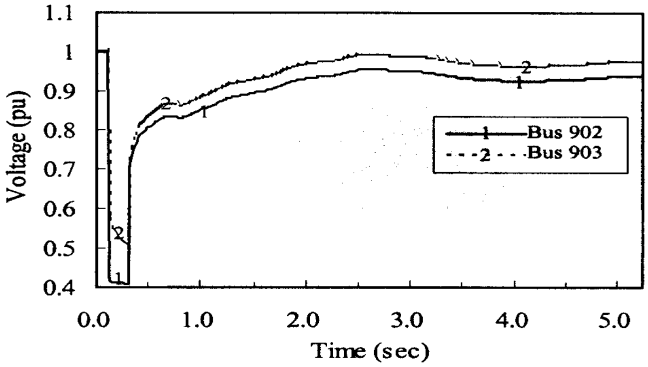

Fig. 10 Voltage responses at buses 902 and 903 for case B.

For case C, the minimal voltage at bus 902 has dropped to the 0.64pu. to activate the third step setting of under voltage relay to trip the tie line in 0.5 second after the fault. The voltage at bus 903 has ever dropped to the minimal value of 0.70pu. during the fault as shown in Fig. 11. The voltage at bus 903 below the values of 0.8 and 0.9pu. has the duration of 0.5 and 1.4 seconds respectively and it is kept above the proposed ride-through curve.

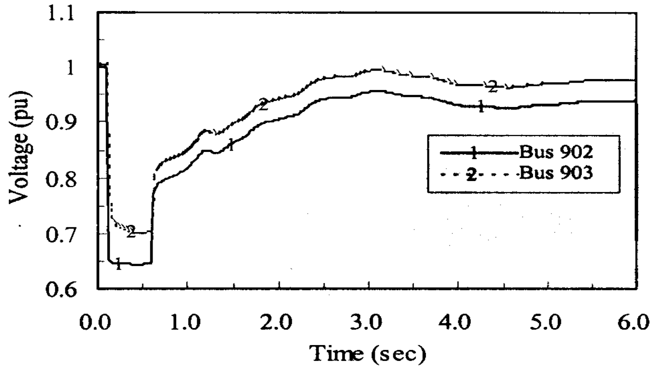

Fig. 11 Voltage responses at buses 902 and 903 for case C.

For case D, the minimal voltage at bus 902 has dropped to the 0.75pu. during the fault period. The fourth step setting of under voltage relay is activated to trip the tie line in 10 second after the fault. The voltage at bus 903 has ever dropped to the minimal value of 0.80pu. during the fault as shown in Fig. 12. It can be observed that the voltage at bus 903 below the value of 0.9pu. has the duration of 10 second.

According to the previous demonstration, it is found that most of the voltage sag event can be improved significantly to avoid the tripping of sensitive load if the cogeneration system with proposed relay settings is applied. However, it is uneasy to improve the sag with a magnitude below 0.41pu. and duration over than 0.02 second. Fig. 13 gives the voltage sag ride-through capability curve when the industrial customers have connected to the cogeneration system with considering the tripping of tie line.

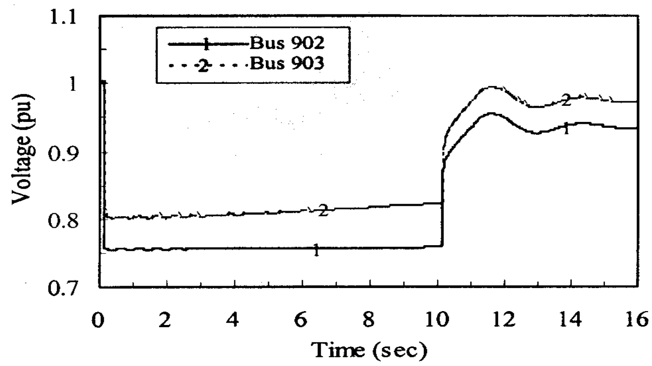

Fig. 12 Voltage responses at buses 902 and 903 for case D.

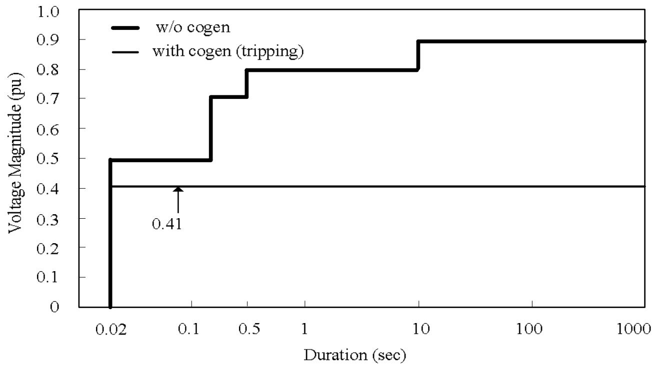

Fig. 13 Improvement of voltage sag ride-through capability curve with considering the tripping of cogeneration system.

VI. CONCLUSIONS

In this paper, a cogeneration system has been applied to improve the voltage sags for the semiconductor fabrication facility. The ITIC and SEMI F47 voltage sag ride-through capability curves have been integrated to evaluate the effect of voltage sags on sensitive equipment. It is found that the problem of voltage sags has been improved if the cogeneration system has not disconnected from the utility during fault period. By applying the designed under voltage relay for tie line tripping, the isolated cogeneration system will be eventually restored to stable operation and the voltage sags problem can be further improved. It is concluded that the power quality of the high-tech industrial customers can be enhanced significantly by the cogeneration system and the implementation of the protective relay setting.

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