ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Website: www.ijareeie.com

Vol. 6, Issue 12, December 2017

Fault Analysis of Industrial System with Cogeneration

Anurag Upadhyay#[1], Rekha Agarwal*[2]

Student, Dept. of Electrical and Electronics Engineering & Sagar Institute of Science Technology and Engineering Sikandrabad, Near Ratibad, Bhadbhada Road, Bhopal, India #[1]

Asst. Professor, Dept. of Electrical and Electronics Engineering & Sagar Institute of Science Technology and Engineering Sikandrabad, Near Ratibad, Bhadbhada Road, Bhopal, India*[2]

ABSTRACT: Power system studies are required to explore the performance of electrical network, its elements, its control, protection, stability and reliability under normal and contingency conditions, under various expected operation scenarios. In this dissertation presents detailed power studies, load flow, short circuit and transient stability analysis of an Industrial Cogeneration plant (ICP). The transient stability analysis of the ICP has been performed, by considering different operation conditions, as the faults transpire at different locations in the system. Transient stability analysis has been performed for calculated critical clearing time to analyse variations in industrial system voltage and frequency. The industrial system with cogeneration is modelled using ETAP.

KEYWORDS: Fault analysis, Critical clearing angle, ETAP, Transient Stability.

I.INTRODUCTION

In recent years, power shortage particularly during the summer, has come up as a very serious issue for industrial customers in India [1]. In any industrial utility system with cogeneration, there is often a flexibility of buying electricity from the grid or selling excess electricity to the grid or for an isolated operation from the grid. Power system studies are required during the planning and conceptual design stages of the project as well as periodically throughout the operating life of the plant to ensure that a cogeneration plant will operate safely, reliably, and economically [2-5]. It is essential to update power system studies every five to eight years when industrial system is expanding or major plant modifications are planned [7]. The results of each and every electrical study serve specific purposes in the planning, design, and operation of electrical power systems. Objectives of electrical system studies are:

- To select adequate equipment ratings
- To evaluate performance of system
- To develop system operation strategies
- To determine effectiveness of alternatives
- To select cost effective solution

The transient stability study for an industrial facility with in-plant generation connected to PPC is required to investigate and implement necessary and cost-effective changes so that the plant generators can ride through disturbances [6]. In industrial system stability analysis is generally performed to evaluate system performance during islanding and load shedding events. Power system stability can be classified as frequency stability, angle stability and voltage stability [8].

II.SYSTEM DESCRIPTION

The simplified electrical Single Line Diagram (SLD) of the industrial distribution network with equipment rating is shown in Figure 1. Utility grid is modeled as swing source of power supply i.e. the voltage magnitude and angle of the

DOI:10.15662/IJAREEIE.2017.0612006

grid terminal remains at the specified values. The fault level of the grid at the point of interconnection is considered as 40 kA at 3-phase. The majority of the loads in the process industries are induction motor loads. Load modeling is a crucial factor that can greatly affect the outcome of the dynamic simulations, especially for the induction motor loads. It is important to point out that the behavior of induction motors may play a crucial role during low-voltage conditions. Load of the refinery is connected at 6.6 kV level and 0.415 kV level. The 6.6 kV motors are considered as Medium Voltage (MV) load. The motor load greater than 160 kW is connected to 6.6 kV voltage level. All the three in-plant generators in the system have been modeled as cylindrical rotor turbo generator with voltage control mode of operation, which means that the generator adjusts its reactive power output to control the voltage. The generator terminal voltage magnitude, operating real power (MW) and minimum and maximum allowable reactive power supply (QMax and QMin) are required to define for voltage control generators. A voltage control generator means that the generator is base loaded (droop mode with fixed MW) with an Automatic Voltage Regulator (AVR) controlling the field excitation for a constant voltage operation.

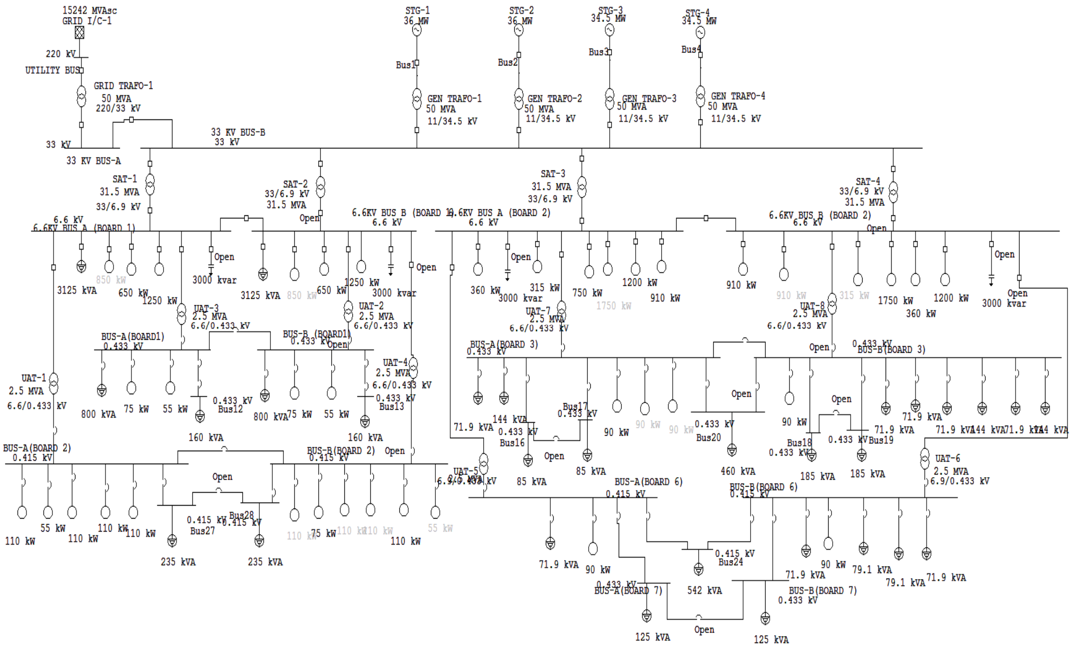

Figure. 1 Single Line Diagram (SLD) of the industrial system

III. MODELING OF EXCITATION AND GOVERNOR SYSTEM

The excitation system control of a synchronous machine has a very strong influence on its performance, voltage regulation and stability. The block diagram of the IEEE type 1 excitation model has been considered for the all generators is as shown in Figure 2.

The speed of prime mover and number of poles of synchronous generator are used to determine the frequency of the ac voltage produced by the generator. Frequency of the system is controlled by controlling the speed of the prime mover. To achieve the quick response of the cogeneration unit output to the disturbance, the single reheat steam governor-turbine system model as shown in Figure 3 has been considered.

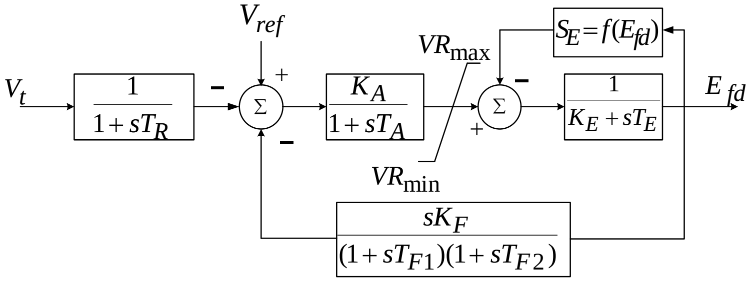

Figure 2 Block diagram of excitation system for STG-1, STG-2, STG-3 and STG-4

The speed of prime mover and number of poles of synchronous generator are used to determine the frequency of the ac voltage produced by the generator. Frequency of the system is controlled by controlling the speed of the prime mover. To achieve the quick response of the cogeneration unit output to the disturbance, the single reheat steam governor-turbine system model as shown in Figure 3 has been considered.

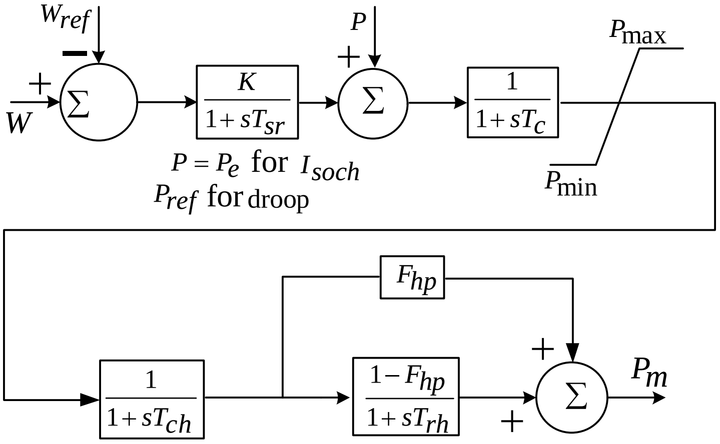

Figure 3 Governor system for STG-1, STG-2, STG-3 and STG-4

IV. OPERATION PHILOSOPHY

There are total five source circuit breakers (CBs) out of which CB-1 to CB-3 are in-plant generators CBs and CB-4 and CB-5 are tie-line CBs. The medium voltage (6.6 kV) and low voltage (0.433 kV) bus couplers circuit breakers are the network configuration determination circuit breakers. Table 4.1 depicts different combinations of available active and reactive power sources.

Scenario-1: In this scenario total refinery load is being fed by all in-plant sources i.e. STG-1, STG-2, STG-3, STG-4 and grid incomers GRID I/C-1. All the sources have been considered to be operated in parallel. All the capacitor banks were kept off.

Scenario-2: In this scenario total industrial load is being fed by the sources STG-1, STG-2 and grid incomers GRID I/C-1. The sources have been considered to be operated in parallel. All the capacitor banks were kept off.

Scenario-3: In this scenario total industrial load is being fed by the sources STG-3 and grid incomers GRID I/C-1. The sources have been considered to be operated in parallel. All the capacitor banks were kept On.

Scenario-4: In this scenario only STG-1 is in service supply to the industrial load. The OLTC for station transformer and grid transformer was ‘On’. All the capacitor banks are on.

V. SHORT CIRCUIT STUDY

The short circuit current of the system changes with change in network configuration, number of generation sources and rotating loads (i.e. induction and synchronous motor). Short circuit currents can create massive destruction to the power system. The maximum short circuit current condition has occurred for operating scenario-1 and the minimum SC current for islanding operating scenario-4. According to IEC standard (IEC 60909) for short circuit calculations, an equivalent voltage source at the fault location replaces all voltage sources. As per the IEC 60909, a voltage factor c has been applied to adjust the value of the equivalent voltage source for minimum and maximum current calculations. All machines were represented by their internal impedances and system impedances have been assumed to be balanced three phase and the method of symmetrical component is used for unbalanced fault calculations.

The power system components (i.e. transformers, buses, circuit breakers, cables, ground grid, etc.) should be designed to have a fault withstand capability defined in terms of current. The IEC 60909 and the associated standards classify short circuit current according to their magnitude (maximum and minimum) and fault distance from generator (far and near). The maximum short-circuit current determine capacity or rating of electrical equipment while the minimum short-circuit current which can be a basis for the selection of fuses and setting of protective devices [2]. Near-to-generator and far-from-generator determine whether or not to model the a.c. component decay in the calculation, respectively. In the case of a far-from-generator short circuit, the fault current is the sum of the a.c. component with constant magnitude during the whole short circuit and decaying aperiodic d.c. component. In this case r.m.s. value of symmetrical a.c. currents Ik", Ib and Ik are nearly equal in magnitude. If the short circuit is near-to-generator then short-circuit current can be considered as the sum of the a.c. component with decaying amplitude and the aperiodic d.c. component decaying to zero.

Short-circuit studies have been performed to calculate three phase bolted fault currents by creating fault in 33 kV, 6.6 kV and 0.433 kV systems. The synchronous and asynchronous rotating machines have been represented by their positive sequence subtransient reactance with suitable multiplying factor as per IEC60909 to calculate fault current contribution. The short-circuit analysis has been performed for two conditions i.e. maximum fault current condition and minimum fault current condition. Maximum fault current condition was occurred when all the generators and motors were running, all tie CBs of 6.6 kV buses are closed and maximum power was purchased from the PPC. The result of maximum fault current is shown in Table. 1. Minimum fault condition occurs when utility tie-line CBs are open, minimum plant load with only in-plant generators running, some motors running, tie breakers are open.

Table 1. Results of fault analysis for maximum fault current condition

Bus	Voltage	3-Phase Fault			Line-to-Ground Fault				Line-to-Line				Line-to-Line-to-Ground			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
6.6KV BUS A (BOARD 1)	6.6	26.5	69.2	19.7	0.0	0.0	0.0	0.0	23.2	60.5	23.2	23.2	23.2	60.5	23.2	23.2
6.6KV BUS A (BOARD 2)	6.6	24.3	63.2	18.7	0.0	0.0	0.0	0.0	21.6	56.2	21.6	21.6	21.6	56.2	21.6	21.6
6.6KV BUS B (BOARD 1)	6.6	26.5	69.2	19.7	0.0	0.0	0.0	0.0	23.2	60.5	23.2	23.2	23.2	60.5	23.2	23.2
6.6KV BUS B (BOARD 2)	6.6	24.3	63.2	18.7	0.0	0.0	0.0	0.0	21.6	56.2	21.6	21.6	21.6	56.2	21.6	21.6
33 KV BUS-A	33.0	19.7	52.2	12.6	23.5	62.5	23.5	23.5	17.3	45.8	17.3	17.3	22.5	59.8	22.5	22.5
33 KV BUS-B	33.0	19.7	52.2	12.6	23.5	62.5	23.5	23.5	17.3	45.8	17.3	17.3	22.5	59.8	22.5	22.5
BUS-A (BOARD1)	0.4	61.0	135.0	44.0	57.8	128.1	57.8	57.8	52.6	116.5	52.6	52.6	60.2	133.4	60.2	60.2
BUS-A (BOARD 2)	0.4	41.5	92.2	30.3	38.2	84.8	38.2	38.2	35.3	78.3	35.3	35.3	40.2	89.2	40.2	40.2
BUS-A (BOARD 3)	0.4	42.8	93.2	28.5	38.5	83.9	38.5	38.5	36.9	80.4	36.9	36.9	41.7	90.7	41.7	41.7
BUS-A (BOARD 6)	0.4	55.8	125.5	44.5	66.5	149.7	66.5	66.5	48.2	108.5	48.2	48.2	64.0	143.9	64.0	64.0
BUS-A (BOARD 7)	0.4	58.2	130.9	46.4	69.4	156.2	69.4	69.4	50.3	113.3	50.3	50.3	66.7	150.2	66.7	66.7
BUS-B (BOARD1)	0.4	61.0	135.0	44.0	57.8	128.1	57.8	57.8	52.6	116.5	52.6	52.6	60.2	133.4	60.2	60.2
BUS-B (BOARD 2)	0.4	41.5	92.2	30.3	38.2	84.8	38.2	38.2	35.3	78.3	35.3	35.3	40.2	89.2	40.2	40.2
BUS-B (BOARD 3)	0.4	42.8	93.2	28.5	38.5	83.9	38.5	38.5	36.9	80.4	36.9	36.9	41.7	90.7	41.7	41.7
BUS-B (BOARD 6)	0.4	55.8	125.5	44.5	66.5	149.7	66.5	66.5	48.2	108.5	48.2	48.2	64.0	143.9	64.0	64.0
BUS-B (BOARD 7)	0.4	58.2	130.9	46.4	69.4	156.2	69.4	69.4	50.3	113.3	50.3	50.3	66.7	150.2	66.7	66.7
UTILITY BUS	220.0	40.7	104.4	40.7	40.5	103.8	40.5	40.5	35.3	90.4	35.3	35.3	40.6	104.1	40.6	40.6

The actual short circuits current at different buses in the system for three phase bolted fault are shown in Table 1 and Table 2. Three phase fault is created at all the buses when all the sources are connected in the system including grid

Bus	**voltage**	**3-Phase Fault**			**Line-to-Ground Fault**				**Line-to-Line Fault**				**Line-to-Line-to-Ground**			
ID	kV	I"k	ip	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik	I"k	ip	Ib	Ik
6.6 KV BUS A (BOARD 1)	6.6	16.9	42.1	5.7	0.0	0.0	0.0	0.0	15.0	37.4	15.0	15.0	15	37.4	15.0	15.0
6.6 KV BUS A (BOARD 2)	6.6	15.3	38.1	5.5	0.0	0.0	0.0	0.0	13.9	34.5	13.9	13.9	13	34.5	13.9	13.9
6.6 KV BUS B (BOARD 1)	6.6	16.9	42.1	5.7	0.0	0.0	0.0	0.0	15.0	37.4	15.0	15.0	15.0	37.4	15.0	15.0
6.6 KV BUS B (BOARD 2)	6.6	15.3	38.1	5.5	0.0	0.0	0.0	0.0	13.9	34.5	13.9	13.9	13.9	34.5	13.9	13.9
33 KV BUS-A	33.0	4.5	11.3	1.2	5.3	13.2	5.3	5.3	4.0	10.1	4.0	4.0	5.1	12.7	5.1	5.1
33 KV BUS-B	33.0	4.5	11.3	1.2	5.3	13.2	5.3	5.3	4.0	10.1	4.0	4.0	5.1	12.7	5.1	5.1
BUS-A (BOARD1)	0.4	57.5	127.2	36.0	55.8	123.4	55.8	55.8	49.8	110.0	49.8	49.8	57.5	127	57.5	57.5
BUS-A (BOARD 2)	0.4	40.0	88.8	26.5	37.4	82.9	37.4	37.4	34.0	75.5	34.0	34.0	39.0	86.5	39.0	39.0
BUS-A (BOARD 3)	0.4	41.2	89.6	24.8	37.7	81.9	37.7	37.7	35.7	77.5	35.7	35.7	40.4	87.9	40.4	40.4
BUS-A (BOARD 6)	0.4	52.3	117.5	36.7	63.5	142	63.5	63.5	45.5	102	45.5	45.5	60.9	136.8	60.9	60.9
BUS-A (BOARD 7)	0.4	54.6	122	38.2	66.2	148.7	66.2	66.2	47.4	106.5	47.4	47.4	63.6	142	63.6	63.6
BUS-B (BOARD1)	0.4	57.5	127	36.0	55.8	123	55.8	55.8	49.8	110.0	49.8	49.8	57.5	127	57.5	57.5
BUS-B (BOARD 2)	0.4	40.0	88.8	26.5	37.4	82.9	37.4	37.4	34.0	75.5	34.0	34.0	39.0	86.5	39.0	39.0
BUS-B(BOARD 3)	0.4	41.2	89.6	24.8	37.7	81.9	37.7	37.7	35.7	77.5	35.7	35.7	40.4	87.9	40.4	40.4
BUS-B (BOARD 6)	0.4	52.3	117	36.7	63.5	142	63.5	63.5	45.5	102	45.5	45.5	60.9	136	60.9	60.9
BUS-B (BOARD 7)	0.4	54.6	122	38.2	66.2	148	66.2	66.2	47.4	106	47.4	47.4	63.6	142	63.6	63.6
UTILITY BUS	220.0	40.0	102	40.0	40.0	102	40.0	40.0	34.6	88.7	34.6	34.6	40.0	102	40.0	40.0

Table 2. Results of fault analysis for minimum fault current condition

Table 2 shows the results for the minimum fault current condition. The minimum fault current condition occurred when only one generator is connected and grid supply is out of service i.e. scenario-4.

VI. STABILITY ANALYSIS FOR FAULTS AT VARIOUS LOCATIONS

The dynamic behavior of the generators during three faults at different locations in distribution system has been analyzed. The stability of a synchronous generator may be defined in general terms as its ability to remain in synchronism with the power system to which it is connected. Extensive stability studies have been carried out for different system conditions from normal operation to disturbance inception until system stabilization.

The cogeneration and industrial load schedule used in transient stability studies are same as that used for load flow study. Table 5.1 presents CCTs for all possible operating scenarios for three phase fault on different voltage level buses in the system.

In case of a fault on the 33 kV systems: A three phase fault has been created on 33 kV bus at 0.5 sec during parallel operation with grid. The fault on 33 kV systems is the most severe fault location in the whole industrial distribution system. During this event, voltage in the industry at all busses collapsed near to zero value as shown in Figure 5.2. The CCT for all scenarios have been same apart from scenario-4 (islanding operation) for fault on 33 kV systems as shown in Table 3.

Table 3 Results of stability analysis for fault at different buses

	Fault Location	F.C.T in Sec	Remarks
Parallel Operation with Grid	Scenario-1		
	33 kV plant side	0.4	Stable
		>0.4	Unstable
	6.6 kV	<1.5	Stable
	6.6 kV	0.5	Stable

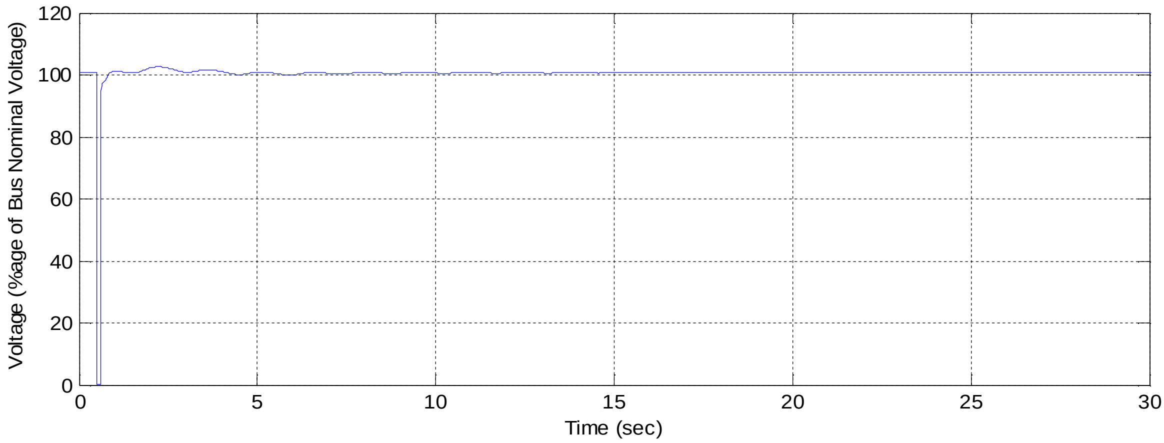

Figure 4 Voltage variation of industrial system for three phase fault on 33 kV Bus

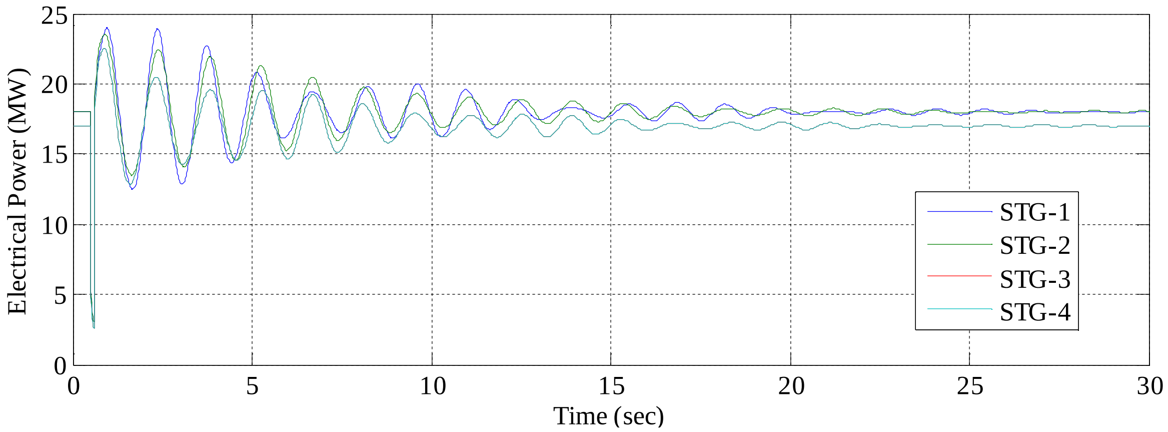

Figure 5 Electrical power output variation for scenario-1 for fault on 33 kV systems.

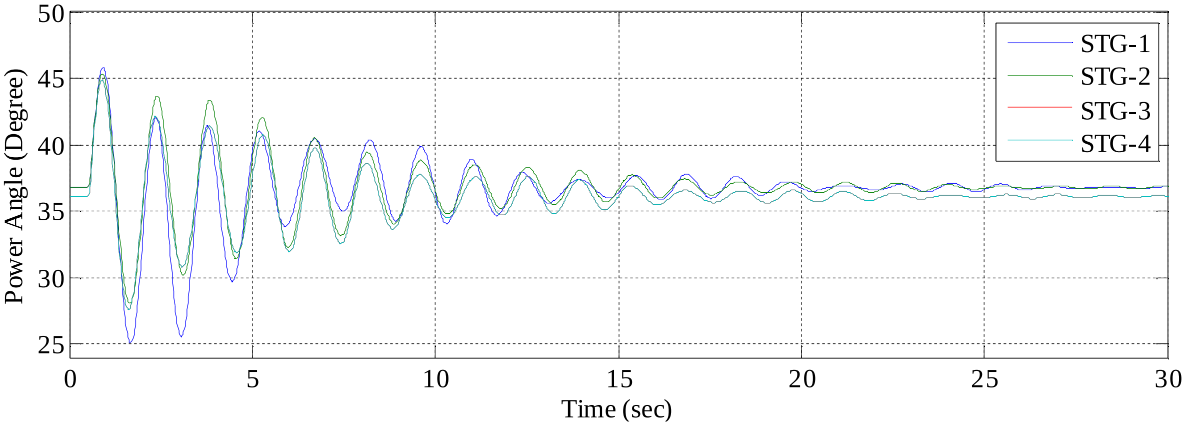

Figure 6 Generator power angle oscillations for three phase fault on 33 kV systems for scenario-1.

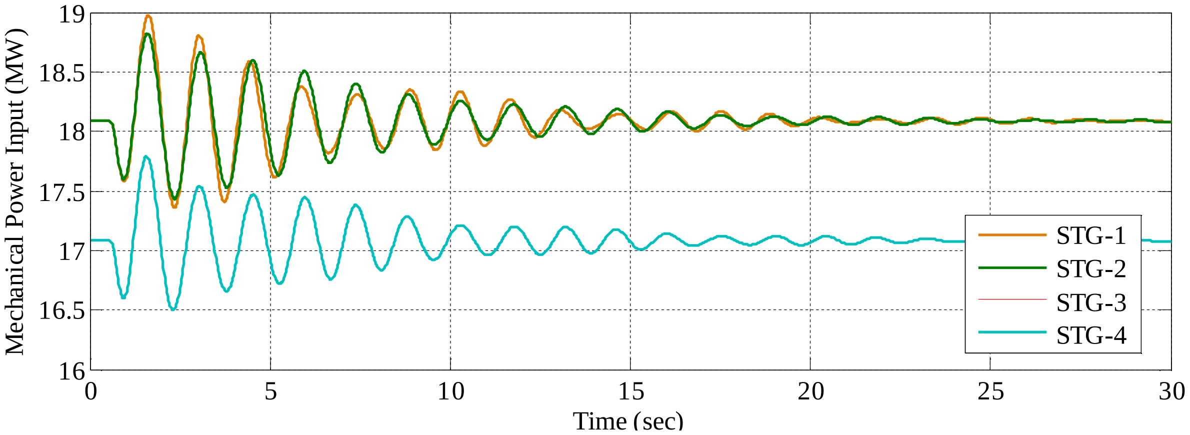

Figure 7 Mechanical power input variation for scenario-1 for fault on 33 kV systems.

Generator power angle is shown in Figure 6. As the all STGs have similar characteristics, they tend to swing together. If the rotor angle converges less than 180º, system is stable. The generator input mechanical variation is shown in Figure 7.

VII. CONCLUSION

The industrial distribution network with in-plant generators has been modeled using ETAP software. Power system studies enable the designing of the utility isolation and load-shed system. Fault analysis is performed to determine maximum and minimum fault current of the industrial system with cogeneration. Stability analysis of the industrial system is performed for different fault condition. It concluded that if fault is cleared within CCT system will be stable.

REFERENCES

[1] M.H.A. Costa and J.A.P. Balestieri, "Comparative study of cogeneration systems in a chemical Industry," Applied Thermal Engineering, Vol. 21, pp. 523-533, 2001.

[2] IEEE Recommended Practice for Protection and Coordination of Industrial and Commercial Power Systems (IEEE Buff Book)," IEEE Std 242-2001 (Revision of IEEE Std 242-1986) [IEEE Buff Book] , pp.1-710, Dec. 17 2001.

[3] C.J. Mozina, "Interconnection protection of IPP generators at commercial/industrial facilities," IEEE Transactions on Industry Applications, Vol. 37, No. 3, pp.681-688, May-Jun 2001.

[4] P. Mahat , Zhe Chen and B. Bak-Jensen, “Review of islanding detection methods for distributed generation,” Third international conference on electric utility deregulation and restructuring and power technologies 2008, DRPT 2008, pp.2743–8, 6–9 April, 2008.
[5] V. Menon, MH. Nehrir, “A hybrid islanding detection technique using voltage unbalance and frequency set point,” IEEE Transactions on Power Systems, Vol. 22, pp. 442–8, 2007.
[6] Y. Jun, C. Liuchen, C. Diduch, “Recent developments in islanding detection for distributed power generation,” In 2004 Large Engineering systems Conference on Power Engineering, LESCOPE-04, pp. 124–8, 2004.
[7] J.C. Das, "Transient stability of small plant generators connected to a weak utility system-a case study," IEEE Transactions on Industry Applications, Vol. 41, No. 1, pp.155-162, Jan-Feb 2005.
[8] IEEE Std 399 (1997) “IEEE Recommended Practice for Industrial and Commercial Power Systems Analysis” (IEEE Brown Book).
[9] P. Kundur, (2010) “Power System Stability and Control” New Delhi, Tata McGraw Hill.