Transient Stability Analysis and Enhancement of Industrial Power System with Cogeneration

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Abstract

It is widely accepted that transient stability is an important aspect in designing and upgrading electric power system. This paper presents detailed power studies, load flow 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. The industrial system with cogeneration is modelled using ETAP. Frequency stability analysis has performed for the worst operating scenario of the industrial system with cogeneration. Frequency excursion is determined for maximum mismatch between available generation and in-plant load. Three steps under frequency relay based load shedding has been designed to maintain the stability in the islanded industrial system.

Keywords **—** *Frequency stability analysis, load flow, transient stability analysis, ETAP, load shedding.*

I. INTRODUCTION

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. The CHP technologies make cost of power and steam economically quite attractive for the process industries due to relatively lower capital and operating cost [1-3]. In addition, with the high energy efficiency in producing the electricity and steam at the same time, a significant energy cost saving can be obtained by the cogeneration system for the industrial customers.

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 [4]. 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 [5]. Frequency is a reliable indicator of load-generation mismatch condition in the power system. Every change in this balance that disturbs the steady-state operation of the power system is referred to as a power imbalance. This power imbalance in the network leads frequency instability. To ensure system stability and availability during disturbances, generation trip, transmission and distribution equipment failure, generally utilize some type of load shedding scheme. With the under frequency relay the load is shed in predetermined blocks with some intentional time delay after the frequency has fallen below certain set points [6-7].

II. SYSTEM DESCRIPTION

The electrical distribution system of an industry having cogeneration has been considered for study and simulated using Electrical Transient Analyser Program (ETAP) software. To start power system analysis an up-to-date electrical single line diagram (SLD) is required with the following information:

- The short circuit capacity and X/R ratio of utility supply at interconnection point
- MW/MVAr rating, reactance and time constants, inertia constant, generation voltage, and grounding of in-plant generator
- Size, length and type of feeders
- kVA ratings, connections, impedance and X/R ratio, grounding method and tap changer of distribution transformer
- Size, voltage and X”d of rotating equipment
- Ratings of distribution equipment

In order to perform power system studies of industrial power distribution system, mathematical model of the generator, exciter and governor control systems of the cogeneration units and loads have been simulated using ETAP software. The simplified electrical Single Line Diagram (SLD) of the industrial distribution network with equipment rating is shown in Figure 1. To provide continuous power supply for critical loads and enhance overall efficiency of the plant, industrial facility has installed the four steam turbine generators based cogeneration units STG-1,

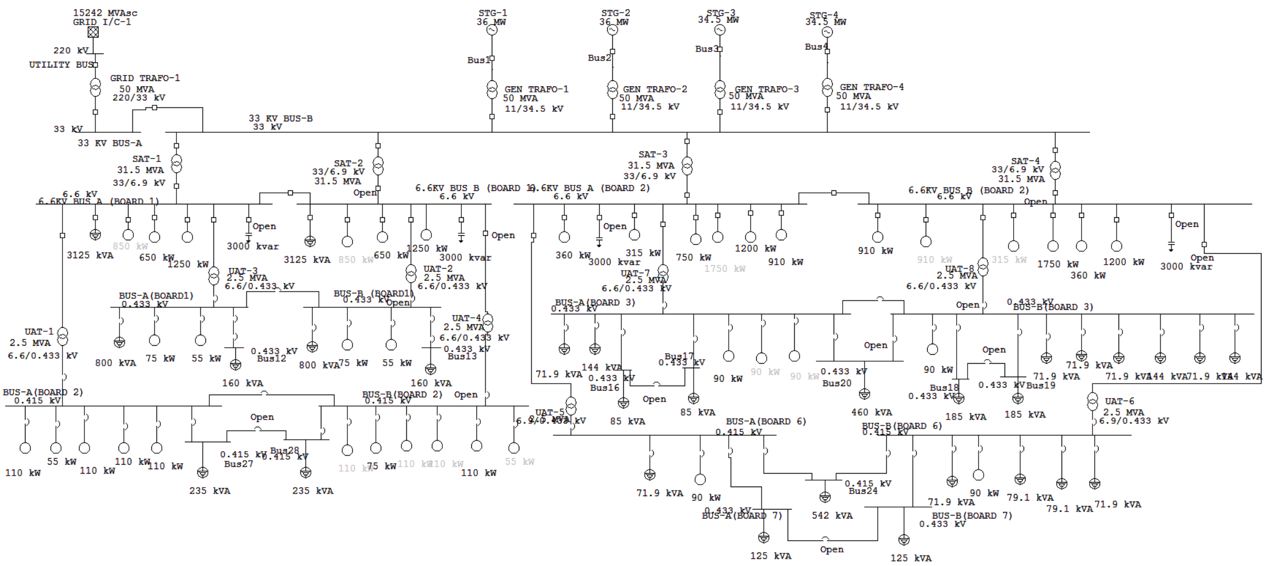

Figure. 1 Single Line Diagram (SLD) of the industrial system

STG-2, STG-3 and STG-4, 36 MW, 36 MW, 34.5 MW, and 34.5 MW respectively. PPC power is available at 220 kV voltage level through utility grid incomer GRID I/C-1 which is stepped down by grid transformer GRID TRAFO-1 from the 220 kV to the 33 KV level and connected to switchgear 33 KV BUS-A.

III. SYSTEM

The load flow analysis is one of the most common and important study used in power system analysis. Load flow study is generally performed to determine the voltage and voltage angle at buses, current, active and reactive power flow and voltage drop in all branches, power factor and total losses in the system. The results of the load flow study serve a base for other power system studies i.e. short-circuits, stability, motor starting, protection coordination, load shedding design and reactive power compensation. The scenario-1 is illustrating base operating condition of the industrial facility. Table I shows Operating scenarios of the industrial system.

TABLE I
COMBINATION OF RESOURCES

Scenarios	Sources in Line √ = source is present X= source is not present					Cap. Banks
	STG-1	STG-2	STG-3	STG-4	GRID I/C-1	
1	√	√	√	√	√	Off
2	√	X	√	X	√	Off
3	X	X	√	X	√	On
4	√	X	X	X	X	On

For the industrial facility load flow studies are required to determine the following important information of the system:

- Evaluation of all power system components rating, cables, buses, transformers etc.

TABLE II
LF RESULT FOR ALL LOAD-GENERATION SCENARIOS

		Scenario-1	Scenario-2	Scenario-3	Scenario-4
STG-1	MW	17.97	18	X	23.4
	MVAr	6.43	10		13.4
	Pf	0.94	0.89		0.86
STG-2	MW	17.97	X	X	X
	MVAr	6.43			X
	Pf	0.94			X
STG-3	MW	16.98	17	10	X
	MVAr	6.49	10	7.58	X
	Pf	0.94	0.88	0.8	X
STG-4	MW	16.98	X	X	X
	MVAr	4.21			X
	Pf	0.94			X
GRID I/C-1	MW	-46.5	-11.5	24	X
	MVAr	-12.8	-6.5	-0.7	
	pf	0.96	0.87	-1.0	
CAP Banks	MVar	Off	16.9	9.2	on
Total Demand	MW	23.4	23.4	23.37	23.4
	MVAr	16.3	16.5	16.3	16.3
Total Losses	kW	301	154	114.2	143
	kVAr	10775	4202	2424	3599

- Identification of best system operating configuration

- Component or circuit loadings
- Optimum transformer taps settings and range/step selection
- Optimum generator exciter/regulator voltage set points
- Reactive power compensation requirement.
- Load and in-plant generation imbalance for different operating scenarios.
- The available methods for load flow solution are Newton Rapson Method, Fast Decoupled Method and Gauss Seidal Method. The Newton Rapson method has been used for ac load flow analysis with the help of ETAP environment, which has following features.
- Less number of iterations and Less processing time.
- Suitable for large systems and Superior conversions.
- Accurate and precise.

Load flow results are summarised in Table II. The scenario-1 is illustrating base operating condition of the industrial facility. In scenario-1, bus sectionalizer between 33 kV and is closed, all 6.6 kV ties CBs are closed, all 0.433 kV bus ties CBs are closed. The capacitor banks are operated in such a manner that they can supply local reactive power demand of the load. The surplus power generated of the plant is being supplied to PPC. All transformers are being operating at tap positions as per required to maintain voltage level uniform in distribution system.

IV. TRANSIENT STABILITY ANALYSIS

Transient stability of industrial cogeneration system has been performed to improve the effectiveness of the protective relay settings as well as to enhance the power quality for the critical and voltage-sensitive loads in the plant. The dynamic behavior of the generators during three phase 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. Table III presents CCTs for all possible operating scenarios for three phase fault on different voltage level buses in the system.

For the severe operating scenario i.e. Scenario-4 and fault on the 33 kV systems results are presented. 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 2. Generator power angle is shown in Figure 3. If the fault is cleared at 0.4 sec after the fault then variation of generator electrical power is shown in Figure 4.

TABLE III
CCT 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
	Scenario-2		
	33 kV	0.4	Stable
		>0.4	Unstable
	6.6 kV	<1.5	Stable
	Scenario-3		
	33 kV	0.4	Stable
		>0.4	Unstable
	6.6 kV	0.5	Stable
Islanding Operation	Scenario-7		
	6.6 kV	0.2	Stable
		>0.2	Unstable

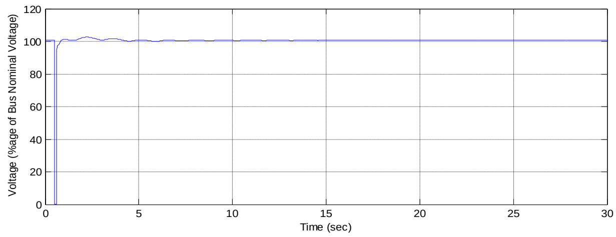

Figure 2 Voltage variation of industrial system for three phase fault on 33 kV Bus

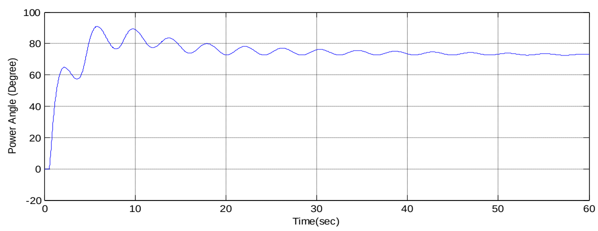

Figure 3 Generator power angle oscillations for three phase fault on 33 kV systems for scenario-4.

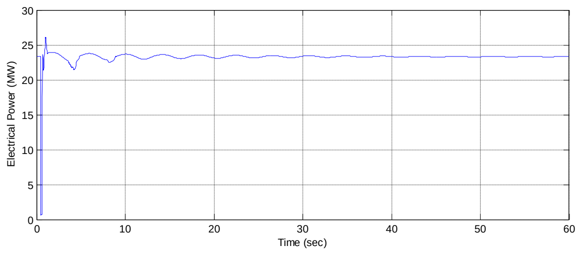

Figure 4 Electrical power output variation for scenario-4 for fault on 33 kV systems.

If the rotor angle converges less than 180º, system is stable. It is clear from the analysis that if the fault is within CCT the system will be stable.

V. ANALYSIS FREQUENCY STABILITY AND UNDER FREQUENCY LOAD SHEDDING

The frequency stability refers to the ability of a power system to preserve steady frequency following a severe system upset resulting in a significant imbalance between generation and load. The system frequency response has been determined including the effects of rotating load inertia, total spinning reserve of the generators and load damping characteristic by considering total tie-line power import as disturbance power. The UFLS is done on the above mentioned principle and carried out in steps. The system under study has one generators operating at capacity of 10 MW. The frequency stability analysis is carried out for this case as shown in Table IV.

When the tie line trips, generator operate to supply the total load and the excess load amounting to corresponding mismatch. The total mismatch during the operating scenario-3 is 13.4 MW. Hence the load shedding is required. The total amount of mismatch should be separated from the system to maintain frequency stability of islanded system. Assuming non-essential loads amounting to mismatch can be shed, the frequency settings of the frequency relays can be determined.

TABLE IV
TEST CASES FOR LOAD SHEDDING STUDY

Scenario	Total Generation (MW)	Total Load (MW)	Stages (%age load shed in each)
1	10	23.4	30
			30
			40

The stage of load shedding with frequency limit and percentage of load shedding amount is given in Table V. The time delay of 0.1 sec is incorporated to activate load shedding steps for self-cleared fault and relay error.

In the scenario-3, total in-plant generation 10 MW and load 23.5MW is considered. At t=0.5 sec three phase fault is occurred in utility grid which is cleared by opening tie-line Circuit Breaker (CB-3) at 0.6 sec. As the system frequency reaches below 49.5 Hz at 1.06 sec, underfrequency relay is activated and implement first stage load shedding at 1.1 sec. The system frequency still not recovered and it crosses 49 Hz (second step load shedding threshold) and second step load shedding is implemented at 1.8 sec. The frequency still not recovered upto safe limit and 3rd step load shedding is implemented at 3.08 sec. After 3rd step load shedding system frequency is improved upto 50 Hz. The frequency response of all the three step load shedding is shown in Figure 5.

TABLE V
LS STAGES WITH THEIR FREQUENCY LIMITS AND LOAD REDUCTION

Stage No.	Frequency Threshold	% Load to be shed	Amount in MW
1	49.5	30	4.02
2	49	30	4.02
3	48.5	40	5.36

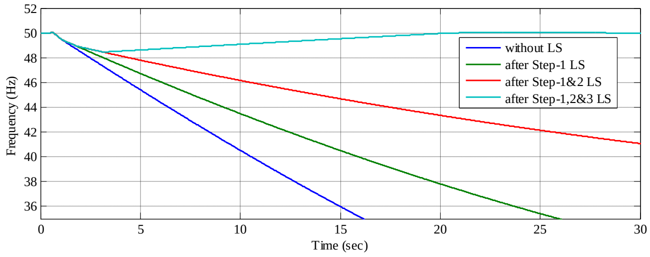

Figure 5. System Frequency Variation with and without Load Shedding

VI. CONCLUSION

The industrial distribution network with in-plant generators has been modeled using ETAP software. Load flow analysis has been performed for different operating of the industrial facility. For different operating scenario, total power in-plant generation, total power import from utility, total active reactive power losses in the distribution network, power factor of generators, total active and reactive power demand, etc. have been determine using power flow analysis. Critical Clearing Time for three phase fault on various locations of industrial distribution network is determined. Transient stability has been performed for calculated CCT and voltage and angle stability of industrial system is evaluated. It is determined that if the fault is cleared on or before CCT system is stable. Frequency stability analysis is also performed for islanded condition after fault in utility system. The under frequency relay based load shedding is designed and investigated. It is found that under frequency relay based load shedding is sufficient to maintain stability of the islanded industrial system.

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