Automatic Load Shedding Protection at A Coal-Chemical Plant

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Abstract -- This paper reports a dynamic modeling of a coal-chemical plant and studies for automatic load shedding protection. The plant had on-site generation to support partial plant loads. In the past, disconnecting from the grid had caused frequency and voltage decay in the plant electrical system to drop out some critical loads. A complete system computer model is constructed including generator dynamics and excitation and prime mover/governor control characteristics. Transient stability simulations to various loading and generation conditions were carried out to understand and study system frequency and voltage behaviors and patterns of change under a sudden islanding case by analyzing frequency vs. time and frequency change rate vs. time curves. Further, through carefully evaluating plant load priorities as well as load dependencies, several feasible load shedding control strategies were proposed and simulated by computer modeling and study. Simulation results verified that proposed load shedding schemes can correctly predicate the frequency drop thus automatically shed non-critical and independent loads to prevent system frequency drop to exceed the allowable deviation. The solution is automatic and feasible which has been successfully implemented at the plant.

***Index Terms*— Industrial power systems, Frequency stability, Computer modeling and Simulation, Generator control, Spinning reserve, Generation-load balance, Low frequency back up protection, Load shedding**

I. INTRODUCTION

A stable power system must operate at a constant frequency in order to perform designed and expected operations. Frequency stability refers to the ability of a power system to maintain steady frequency following a severe system upset resulting in a significant imbalance between generation and load. If system frequency decline is excessive, generating units can be automatically tripped off causing an additional decline of frequency, and possible collapse of the system.

Frequency stability study concentrates on studying the overall system stability for sudden changes in the generation-load balance, particularly the frequency variations during and after the disturbances. Frequency stability is a result of generation and load balance as directed in Fig. 1 in which a nominal frequency is obtained if demand (load) and supply (generation) are in balance; otherwise, system frequency will divert depending on the degree of imbalance.

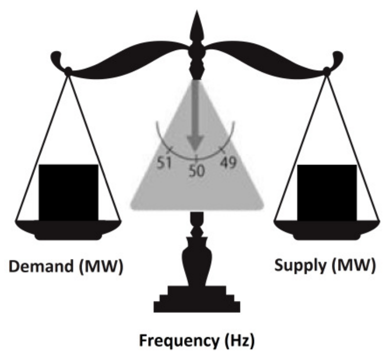


Fig. 1 Frequency stability is a result of generation and load balance

Generator speed (frequency) dynamics play an important role in frequency stability. Generator has certain capabilities to adjust generation output to rebalance generation-load equilibrium. This depends on generator speed recovery capability which is a matter of how much spin power reserve the generator has and speed-governor control system dynamics. Fig. 2 (a) and (b) are from IEEE Std C37.117-2007 Guide for the Application of Protective Relays Used for Abnormal Frequency Load Shedding and Restoration [1]. Fig. 2 (a) represents a situation in which the generator has sufficient spinning power in reserve; therefore after the initial frequency dip, the generation can pull in the reserved power quickly to compensate a gap in generation and rebalance the load. As a result, the frequency is recovered to the nominal value after a time constant that is determined by generator inertia and dynamics of speed-governor control. In contrast, Fig. 2 (b) shows a case where the generator does not have sufficient spinning reserve. It can be seen from the plot that a disturbance caused an initial frequency to dip sharply. The generator spinning power reserve kicked in trying to recover the frequency. However, it must be due to insufficient spinning reserve by the generator, the final generation-load gap cannot be filled up thus the final frequency is below the nominal value.

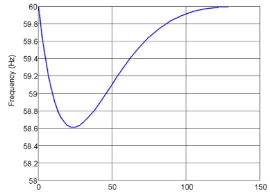


Fig. 2 Frequency changes with sufficient spinning reserve

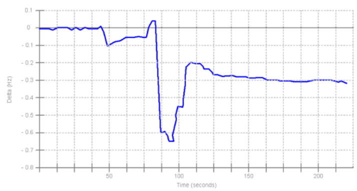


Fig. 3 Frequency oscillation with insufficient spinning reserve

II. Conventional and Proposed Low Frequency Protections

When the frequency decline cannot be recovered by generator spinning reserve, load shedding is another option to reduce load and bring the generation-load balance back. The conventional low frequency load shedding schemes are based on three operating principles [2]:

a) Based on fixed frequency

b) Based on rate of change of frequency $\frac{df}{dt}$

c) Based on average change of frequency $\frac{\Delta f}{\Delta t}$

In practice, low frequency load shedding back up protections are configured using one of the following configurations [3]: Fig. 4 Breaker interlock load shedding scheme, or Fig. 5 Underfrequency relay (81) load shedding scheme.

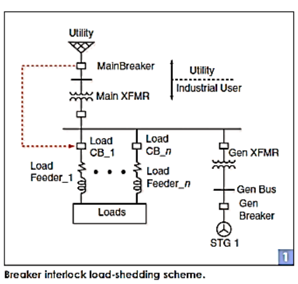


Fig. 4 Breaker interlock load shedding scheme

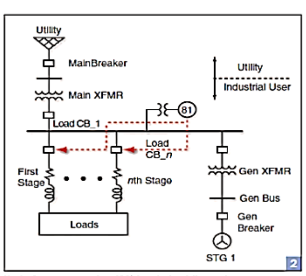


Fig. 5 Underfrequency relay (81) load shedding scheme

Breaker interlock scheme basically relays on status of main breaker (MainBreaker) that interties the plant with the grid. A pre-calculated load and controlled breaker (Load CB_1) is interlocked with the main breaker. The load is supposed to carry the amount of power equal or greater to the importing power from the grid. Upon disconnecting with the grid by opening the main breaker, Load CB_1 will automatically open to shed Load Feeder_1 load. Hopefully the system frequency can be recovered. This configuration is simple and easy to implement; however, it has a drawback as it cannot accurately balanced generation-load due to its preselected and configured lock breakers to control. Underfrequency relay scheme measures system dynamic frequency and/or change rate of frequency, and based on setting points to these quantities, certain loads will be shed if logics based comparisons of measurements from 81 relay with setting are met. 81 underfrequency relay can have several levels of settings, to allow additional load shedding if frequency continues to decline after a load shedding is done. Still, this configuration is purely depending on frequency and change rate of frequency values, without any knowledge of the system operating conditions, for example, importing power from the grid, local generation, and plant loads before the disturbance, etc. It does not reorganize actual loads connected to load control breakers either. The scheme therefore has limitations to correctly and quickly identify amount of loads to shed.

A more systematical approach to develop a load shedding protection is to study and analyze system dynamics and frequency responses under various conditions by constructing electrical system and dynamically modeling generators and other important components in the system using computer software. Generator loading, importing power from the grid, and plant loads shall all be carefully considered to generate study scenarios representing potential operation conditions. Sudden islanding condition then is simulated to investigate behavior of frequency change and produce frequency variation curves for understanding the relationships and dependencies between different parameters. Typical curves to be produced through studies are frequency change vs. time, and loss of generation vs. $\frac{df}{dt}$. Fig. 6 shows sample system frequency responses for different load generation scenarios [4], and Fig. 7 illustrates the theoretical relationship between percentage of loss of generation and the resulting rate of change of frequency [1].

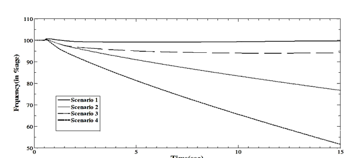


Fig. 6 Frequency (%) vs. time (s)

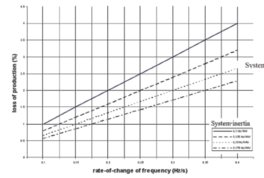


Fig. 7 Loss of generation (%) vs. $\frac{df}{dt}$ (Hz/s)

This paper is based on power system dynamic modeling to a chemical plant which has both on-site power generation and grid importing power, to perform a systematical study of frequency response under islanding condition to cover different combinations of generator initial loading, importing power from the utility, and other factors. By analyzing frequency and frequency change rate under different study scenarios, load shedding demands corresponding to each scenario are determined and put into a load shedding demand table to rebalance generation-load and recover system frequency. Load priority table obtained from plant electrical and process engineers are then applied to generate a load shedding schedule according to the load shedding demand table. A computer model is again used to validate the load shedding schedule and make needed adjustment to ensure the system frequency recovery. The developed load shedding schedule has been fully implemented at the plant.

III. System Description

An industrial system has a normal load of 29 MW. Out of that, 25 MW is supplied from the in plant generator, and 4 MW is imported from the utility grid. The plant is double fed through two 110kV transmission lines, connecting to 110kV Bus I and Bus II respectively as depicted in Fig. 8. Under normal operating conditions, one of the 110kV lines is feeding power to the plant, and the other is for spare.

The generator size is 30 MW, driven by a steam turbine. The generator is connected to 110kV Bus II through a unit transformer. Two 110kV buses are configured in Main-Tie-Main, and stepped down to 10kV substations via two 110kV/10kV main transformers.

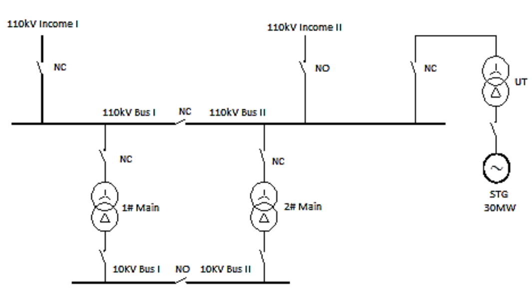


Fig. 8 System main connections

The existing electrical system has exhibited several issues and concerns:

1) In case of loss of normal power supply, backup power cannot be promptly kicked in thus low voltage contacts for motor protection will be drop off to shut down a large quantity of motors. Production lines are severely affected.
2) Due to restrictions from the utility, automatic transition switching of the spare 110kV line is not engaged. 110kV Bus I and Bus II are normally in parallel connection (110kV tie breaker normally closed).
3) The plant in fact has only one incoming line connection to the grid, thus it suffers a low reliability in power supply.
4) Under the situation the grid is lost, the plant is transited into islanding operation. All loads are to be supported by the in-plant generator. Power supply deficiency between before and after the islanding will be 29MW – 25MW = 4MW. Due to the deficiency in active power supply, system frequency is reduced significantly.

IV. Scope of Load Shedding Study

Based on customer feedback to the issues and concerns of the existing electrical system, a complete system modeling and study are proposed to include following tasks:

1) Understand system frequency and voltage variations, and voltage and frequency protection responses following a condition of a sudden loss of the grid connection.
2) Is there a possibility to switch to the spare incoming line to avoid system voltage drop that will trip motor low voltage contacts?
3) Will spinning reserve of the generator compensate the import power loss and keep the generator-load balance during the islanding?
4) If the spinning reserve is not sufficient to compensate the import power loss, how much load needs to be shed in order to maintain generation-load balance during the islanding from system frequency stability point of view?
5) For items 3 and 4 above, what will be the lowest system frequency during the transients?
6) Investigate whether generator governor speed control and valve control can pick up frequency deviation and quickly stabilize the system frequency.
7) Study the generator rotor angle stability under plant internal and external faults. Identify critical fault clearing times for major fault conditions.
8) Study generator voltage regulator and excitation system controllability for voltage regulation and reactive power support under islanding operation condition.
9) Study and identify system minimum voltage at various buses under different fault conditions.
10) Study and analyze other electrical system issues for

electrical network security, stability and power quality concerns.

Studies and results of tasks 1, 3, 4, 5, 6, and 10 are reported in this paper.

V. SYSTEM MODELING

Per system single-line diagram provided by the client, computer model is constructed for the entire plant electrical system using a industrially accepted software tool, shown in Fig. 9.

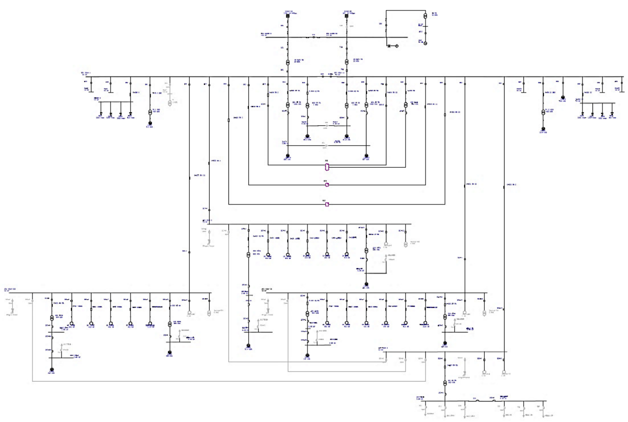


Fig. 9 Plant electrical system computer model in single-line diagram

System model is validated for both steady state and dynamic state simulations purpose before being used in the study.

A. *Steady state model validation*

Before being engaged for studies, the system computer model needs to be validated and verified for its parameters and configurations. It is selected to use measured and stored system SCADA data as validation benchmarks. The validated model data include motor name plate data (Fig. 10), and loading for general loads (Fig. 11).

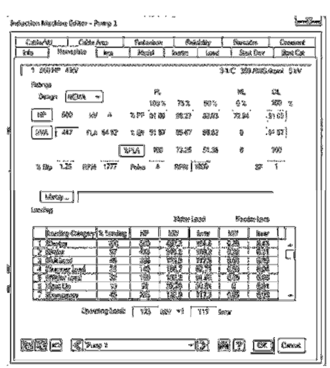


Fig. 10 Motor model and parameters in computer model

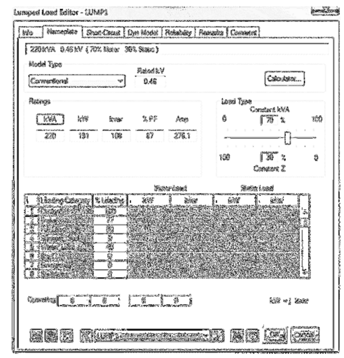


Fig. 11 model and parameters for general loads

Using the validated model and data, system steady state performance can be replicated and studied for load flow analysis. Load flow analysis is very important as it will set the system steady state and initial operating condition for transient study which is required for system frequency behavior investigation. Example of system load flow study results are demonstrated in Fig.12.

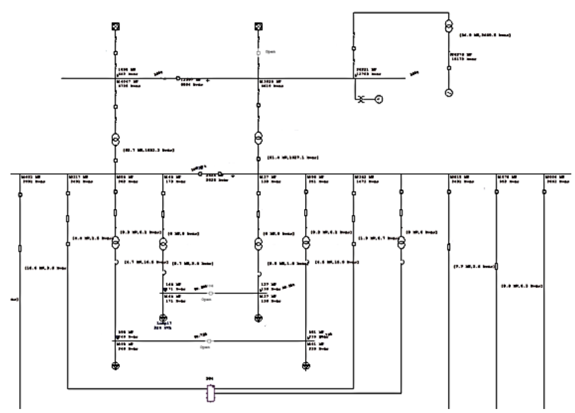


Fig. 12 Load flow simulation results using validate steady state model

B. *Dynamic model validation*

System dynamic models that will dominate voltage and frequency responses are generator rotor-stator interaction and generator associated controls, including automatic voltage regulator (AVR), excitation system, prime mover, and speed governor.

Generator ratings are obtained from the generator nameplate and entered into the software tool under Generator Rating data input page in Fig. 13.

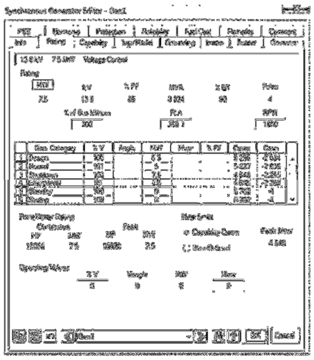


Fig. 13 Generator rating data input

Generator stator and rotor impedance model can be found from the generator datasheet. Data then are entered into the software tool under Generator Impedance Model page in Fig. 14. The complete subtransient model is selected for the plant generator per the datasheet.

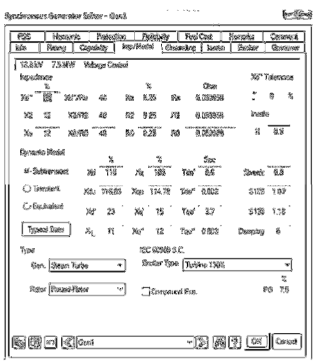


Fig. 14 Generator stator and rotor model and data input

Generator excitation and speed governor system models are provided by the plant engineers together with vendor applied parameters.

The excitation system model transfer function block diagram is shown in Fig. 15 and its parameters are entered in the software tool generator Exciter model page in Fig. 16.

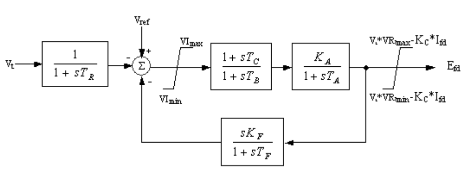


Fig. 15 Generator excitation system transfer function block diagram

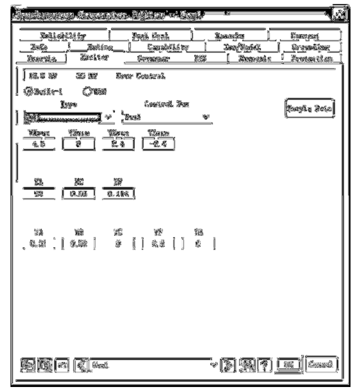


Fig. 16 Generator excitation system model and data input

The generator speed governor system model transfer function block diagram is shown in Fig. 17 and its parameters are entered in the software tool generator governor model page Fig. 18.

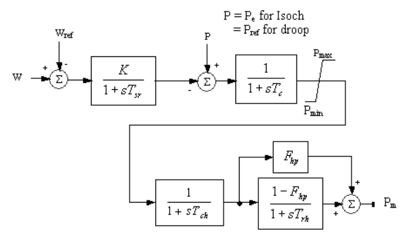


Fig. 17 Generator speed governor system transfer function block diagram

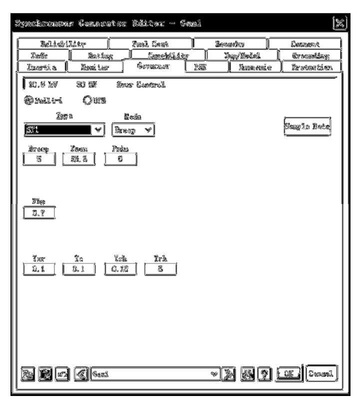


Fig. 18 Generator speed governor system model and data input

The plant engineers have validated the excitation system and governor system model structure along with their parameters with vendors.

VI. Simulation of the System from Parallel to Islanding Operations

The objective of dynamic simulation is to study generator behavior, system frequency and voltage responses when the system is transitioning from a parallel with the grid operation to an islanding operation. Under such conditions, generator speed will start to vary following acceleration power on the shaft based on Eq. (1):

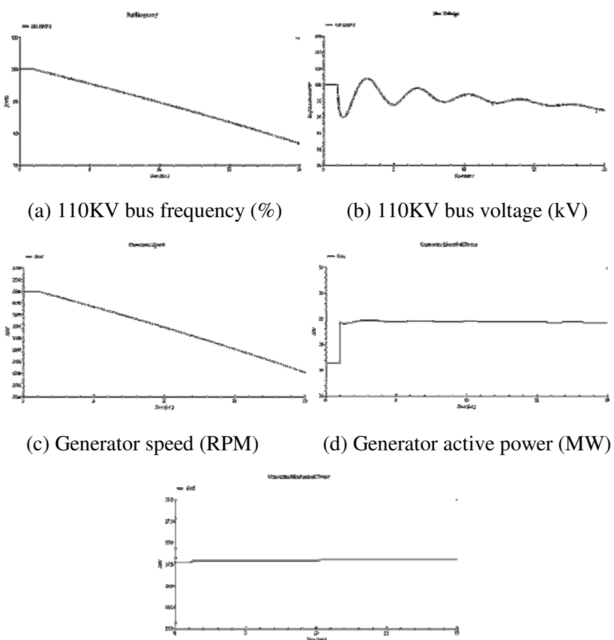
$$\frac{df}{dt} = \frac{P_a f_0}{2GH} \tag{1}$$

where

G = nominal MVA of machine
H = MW*sec. / MVA
f_0 = nominal frequency
P_a = net accelerating/decelerating power

Under the situation the generator mechanical power is less than the electrical power demand after the islanding, acceleration power becomes negative which will result in a frequency decay.

Assume under a normal loading condition the grid connection is suddenly tripped at a reference time of 1 sec., the system starts a transition from the initial steady state to an islanding state as plotted in Fig. 19.



(a) 110KV bus frequency (%) (b) 110KV bus voltage (kV)

(c) Generator speed (RPM) (d) Generator active power (MW)

(e) Generator mechanical power (MW)

Fig. 19 Responses of generator and network main quantities

Fig. 19 (a) and (c) look the similar this is because under an islanding operation mode with only one generator in the system, system frequency is equivalent to the generator speed. System voltage changes in Fig. 19 (b) reflect the combined effect of system load-voltage characteristics and generator AVR system control actions. Fig. 19 (d) is generator active power demand which jumps from pre-islanding generation to the entire plant load after the islanding. Fig. 19 (e) shows generator mechanical power input to the generator shaft which is raised to the maximum after the islanding, depending on the generator spin reserve available.

In this case, the steam turbine generator basically is converting excessive steam into electrical power. (The generator in fact does not have active power adjustment or control capability therefore it is seen the generator mechanical power has little change.) After the grid is lost, load demand to the generator suddenly increases. Without any extra energy provided to the generator, the generator has to release its stored kinetic energy in the rotating mass in order to support the load, resulting in the generator speed and the system frequency to decay. Continuation in this condition of operation without any mitigation of the loads will eventually exhaust all stored kinetic energy in the generator rotor and shaft to drive the generator to complete stop. This concept is simulated and validated through plots in Fig. 19. Simulation curves really helped to explain and understand nature of system frequency decay.

VII. Load Shedding Protection for Islanding Operation with Frequency Decay

Low frequency issue under islanding operating condition can be mitigated through properly arranged load shedding schemes.

A practical and feasible load shedding scheme has to be based on a load priority table which defines the priority of each load, from Low (Order 1) to High. Load shedding will start from shedding the low priority load, then increase the priority in the table, until sufficient amount of loads has been shed thus the system reaches a new generation and load balance.

Table I shows a typical load priority table. Each row is a load group that contains a number of loads defined with a unique load priority order. Column 1 is the priority order (1 is the lowest), Column 2 is the load group name, Column 3 is the number of pieces of loading equipment in the group, Column 4 and up (except the last Column) list name and loading in kW for all loading equipment in the group, and the last Column is the total load expressed in kW within the group.

TABLE I
LOAD PRIORITY TABLE

Order	Equip Name	No. of Equip	Equip 1 Name	(kW)	Equip 2 Name	(kW)	…	Total (kW)
1	Load Grp 1	x	xxxx	xxx	xxxx	xxx	…	xxx
2	Load Grp 2	x	xxxx	xxx	xxxx	xxx	…	xxx
3	Load Grp 3	x	xxxx	xxx	xxxx	xxx	…	xxx
4	Load Grp 4	x	xxxx	xxx	xxxx	xxx	…	xxx
5	Load Grp 5	x	xxxx	xxx	xxxx	xxx	…	xxx
6	Load Grp 6	x	xxxx	xxx	xxxx	xxx	…	xxx
…	…	…	…	…	…	…	…	…

To understand the system frequency decay characteristics, serious simulations were performed at different initial generation conditions. Fig. 20 show frequency (Hz) decays vs. time (sec.) at initial generation of 87% of the generator 30MW rating (solid line), 64% (dot line) of rating, and 45% of rating (dashed line), while the plant loading remains unchanged at its nominal values. It is clear that frequency decay after the system islanding closely relates to initial generation, or deficiency in active power supply by the generator to the remaining system. The higher the deficiency is, the deeper the frequency decay will be.

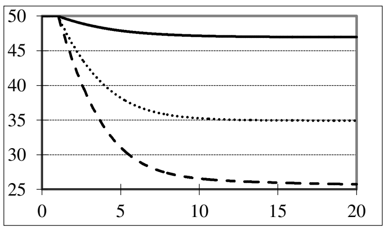
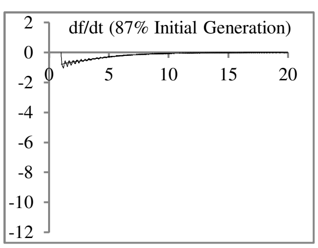
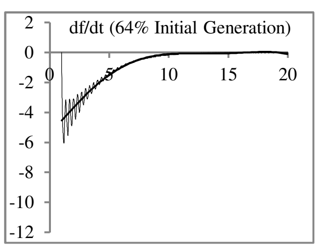


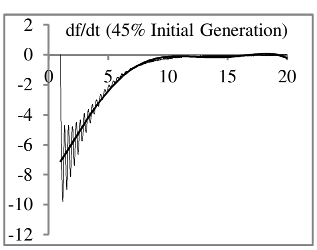
Fig. 20 Frequency (Hz) vs. time (sec.) curve after disconnecting from the grid at different initial generation

Not only the final frequency is important information, but also the frequency change rate $\frac{df}{dt}$ is an informative indicator for system frequency response and it plays an important role in providing a fast load shedding mitigation action. Frequency change rate (Hz/sec.) vs. time (sec.) curves in Fig. 21 (a), (b), and (c) can be derived from Fig. 20 for three initial generation conditions.





(a) Initial generation = 87% (b) Initial generation = 64%



(c) Initial generation = 45%

Fig. 21 Frequency change rate (Hz/sec.) vs. time (sec.) corresponding to Fig. 20

The combined information from frequency vs. time and frequency change rate vs. time obtained from system modeling and simulation provide needed data to derive proper load shedding schedules which are described next.

Three low frequency load shedding schedules are proposed. They are coordinated together to provide a robust islanding protection to the system.

A. *Load shedding protection based on frequency and frequency change rate*

The primary load shedding protection Schedule I is defined in Table II. This schedule provides computed load shedding amount and maximum execution time based on frequency decay and frequency change rate at a given point in time. For instance, if it is detected that at 0.32 sec. after the islanding, the system frequency has reached to 48.5 Hz and frequency change rate reached to negative 4.23 (row #5), then a load shedding of 9 MW must be initiated; or if for the same frequency decay of 48.5 Hz but the frequency change rate reached to negative 7.43 at 0.2 sec. (row #7) which indicates a faster frequency decay in the system, then more loads must be shed to recover the frequency. In this case, to shed a load of 14 MW will be required.

TABLE II
LOAD SHEDDING BACK UP SCHEDULE 1

#	Frequency (Hz)	Freq Change Rate *df/dt* (Hz/sec.)	Time (Sec.)	Load Shed MW
1	49	-7.6	0.14	14
2	49	-4.4	0.20	9
3	49	-5.4	1.42	2
4	48.5	-7.43	0.20	14
5	48.5	-4.23	0.32	9
6	48.5	-4.2	2.38	2
7	48	-7.4	0.26	14
8	48	-4.2	0.44	9
9	48	-3.8	3.63	2

B. *Load shedding back up protection by considering frequency change and grid importing power*

Considering in practical applications, data sampling and collection for frequency change rate could be difficult, a back up plan for load shedding is proposed below. This plan consists of two layers with the first layer being considered first, and the second layer as a backup for the first layer.

1) The first layer of low frequency protection is based on the strategy given in Table II.
2) The second layer of low frequency protection will follow the backup schedules 1, 2, 3, and 4 listed in Table III-1 through Table III-4. The backup schedules essentially will skip any computation and directly shed off the amount of load equivalent to grid importing power before islanding to balance the generation and load.
3) In order to ensure coordination between the first layer protection and the second layer protection, an interlock mechanism must be implemented. The function of the interlock is to block the second layer protection once the first layer protection is initiated and in process. The two layers must be carefully coordinated to avoid the overlap and at the same time to ensure proper back up protection is in place. Actual

time for the interlock depends on the execution time for the first layer protection to complete the scheduled load shed, normally a few hundreds of milliseconds.

4) To cover a full load range, it is suggested to use load shedding recommendations in Table III-1 to Table III-4 when load is in between maximum load, average load, and minimum load.

Table III-1 LOAD SHEDDING BACK UP SCHEDULE 2
(IMPORTING POWER FROM THE GRID ≤ 2MW)

Criteria		Load Shed
Frequency（Hz）	Time （Sec.）	
49	T ≧ 1.42	Importing power from grid
48.5	T ≧ 2.38	Importing power from grid
48	T ≧ 3.63	Importing power from grid

TABLE III-2 LOAD SHEDDING BACK UP SCHEDULE 2
(2MW < IMPORTING POWER FROM GRID ≦ 9MW)

Criteria		Load Shed
Frequency（Hz）	Time （Sec.）	
49	1.42 > T ≧ 0.2	Importing power from grid
48.5	2.38 > T ≧ 0.32	Importing power from grid
48	3.63 > T ≧ 0.44	Importing power from grid

TABLE III-3 LOAD SHEDDING BACK UP SCHEDULE 2
(9MW ≤ IMPORTING POWER FROM GRID ≦ 14MW)

Criteria		Load Shed
Frequency（Hz）	Time (Sec.)	
49	0.2 > T ≧ 0.14	Importing power from grid
48.5	0.32 > T ≧ 0.2	Importing power from grid
48	0.44 > T ≧ 0.26	Importing power from grid

TABLE III-4 LOAD SHEDDING BACK UP SCHEDULE 2
(14MW < IMPORTING POWER FROM GRID)

Criteria		Load Shed
Frequency（Hz）	Time (Sec.)	
49	T < 0.14	Importing power from grid
48.5	T < 0.2	Importing power from grid
48	T < 0.26	Importing power from grid

C. *Load shedding back up by considering frequency decay time and grid importing power*

The second load shedding back up schedule is based on frequency responses at various loading and generation conditions, time elapses from nominal 50Hz to 49.5Hz, 49Hz, 48.5Hz, 48Hz, 47.5Hz, 47Hz, 46.5Hz, and 46Hz (Table IV), as well as from 49Hz to 48.5Hz, 48Hz, 47.5Hz, 47Hz, 46.5Hz, and 46Hz (Table V). An identification algorithm is developed and implemented to program the data from Table IV and Table V and identify the proper time to shed grid importing power once frequency and decay time conditions are met. This plan is used as another back up with careful coordination with both the primary plan and the first back up plan.

TABLE IV TIME ELAPSE FOR FREQUENCY DECAY FROM 50HZ

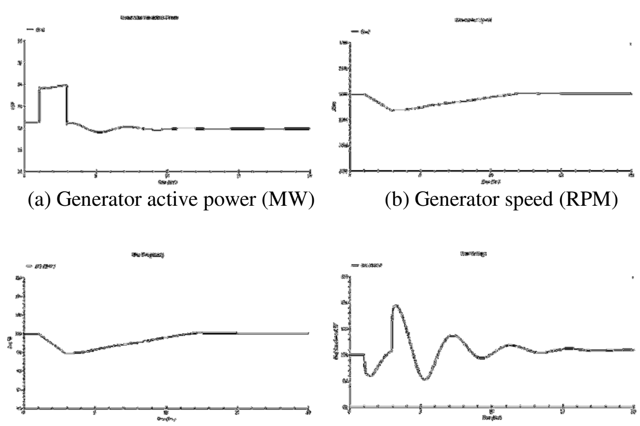
System Frequency (Hz)	Frequency Decay (%)	Generator Speed (R/min)	Time Elapsed for Frequency Decay from 50Hz to System Frequency (Sec.) Initial Generation		
			87%	64%	45%
49.5	1%	2970.0	0.6402	0.1162	0.0882
49.0	2%	2940.0	1.4242	0.2042	0.1442
48.5	3%	2910.0	2.3602	0.3202	0.1962
48.0	4%	2880.0	3.6202	0.4442	0.2642
47.5	5%	2850.0	5.7122	0.5442	0.3602
47.0	6%	2820.0	13.3402	0.6762	0.4362
46.5	7%	2790.0	-	0.8002	0.4962
46.0	8%	2760.0	-	0.9082	0.5562

TABLE V TIME ELAPSE FOR FREQUENCY DECAY FROM 49HZ

System Frequency (Hz)	Frequency Decay (%)	Generator Speed (R/min)	Time Elapsed for Frequency Decay from 50Hz to System Frequency (Sec.) Initial Generation		
			87%	64%	45%
49.5	1%	2970.0	-	-	-
49.0	2%	2940.0	-	-	-
48.5	3%	2910.0	0.936	0.116	0.052
48.0	4%	2880.0	2.196	0.240	0.120
47.5	5%	2850.0	4.288	0.340	0.216
47.0	6%	2820.0	11.916	0.472	0.292
46.5	7%	2790.0	-	0.596	0.352
46.0	8%	2760.0	-	0.704	0.412

By implementing the above described low frequency protection strategies, upon islanding from the grid, by monitoring and measuring generator speed, *i.e.* the system frequency, and the frequency change rate, duration of incident, accounting for importing power from the grid prior to the islanding, and initial generation from the generator, the proposed protection scheme can correctly identify system operating conditions and initiate proper load shedding commenced through the hardware system.

Proposed load shedding protection control scheme is simulated and validated through computer simulation using the system model that was constructed for dynamic modeling and frequency response studies. Some simulation result are shown in Fig. 22. It can be seen after the islanding at 1 sec., a load shedding is initiated at approximately 3 sec., followed by a full recovery of system frequency.



(a) Generator active power (MW) (b) Generator speed (RPM)

(c) System frequency (%) (d) System voltage (kV)

Fig. 22 Load shedding simulation and validation

VIII. SUMMARY OF LOAD SHEDDING STUDY AND DEVELOPMENT PROCEDURE

Procedures to develop a load shedding schedule for low frequency back up protection essentially involves two steps: System Dynamic Study, and Load Shedding Simulation. They are illustrated in Table V and Table VI.

TABLE V STEP 1: SYSTEM DYNAMIC STUDY

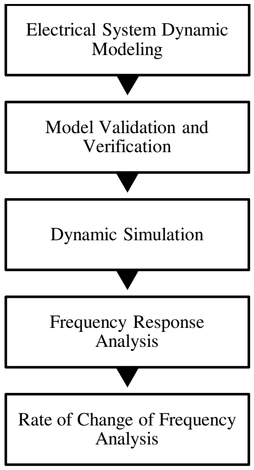
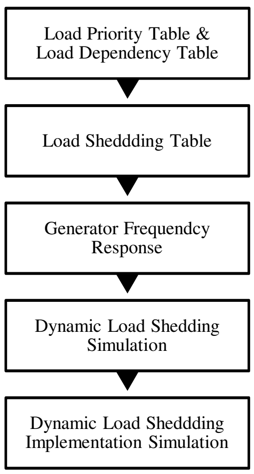


TABLE VI STEP 2: LOAD SHEDDING SIMULATION



IX. CONCLUSIONS

This paper addresses frequency stability issue in an industrial power system with on-site generation. Under system islanding condition, depending on initial importing power from the grid and the on-site generator spinning reserve, system frequency may drop significantly if the net power supply is less than the load demand. Conventional low frequency back up protection methods are discussed. An approach based on computer modeling and dynamic studies is proposed to provide a load shedding solution for rebalancing generation-load to recover the system frequency. A real system application case is presented to illustrate steps and procedures to develop a low frequency back up protection schedule using the proposed approach. Comprehensive computer simulation results are reported comparing system responses with and without the load shedding protection for the given system. Data and results clearly demonstrate the effectiveness of the proposed method.

REFERENCES

[1] *IEEE Guide for the Application of Protective Relays Used for Abnormal Frequency Load Shedding and Restoration*, IEEE Standard C37.117, 2007.

[2] GE: Load Shedding, Load Restoration and Generator Protection Using Solid-state and Electromechanical Underfrequency Relays. GET-6449.

[3] F. Shokooh, J.J. Dai, et al, "Intelligent Load Shedding," *IEEE IAS Magazine*, vol. 40, pp. 44-53, Mar.-Apr. 2011.

[4] M.K. Kirar, "LOAD SHEDDING DESIGN FOR AN INDUSTRIAL COGENERATION SYSTEM," Electrical and Electronics Engineering: An International Journal (ELELIJ) Vol 2, No 2, pp. 35-46, May 2013.

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