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석유화학공장의 전력계통 안정도 해석 - 멕시코 카데레이타 경우

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POWER SYSTEM STABILITY ANALYSIS ON PETROCHEMICAL PLANT - MEXICO CADEREYTA CASE

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Abstract - When electrical engineers get started with the design of main electrical system of a complex petrochemical plant along with chemical and mechanical engineers, they are usually confronted with lack of power system data. This paper presents a procedure how to perform power system stability analysis for the purpose of design studies within the limited system data given and to verify the given data to get reliable convergence in dynamic simulation as well as to apply the stability analysis result on practical system design. The power system stability analysis on the Cadereyta petrochemical plant in Mexico is provided as a study case.

1. INTRODUCTION

The advanced numerical techniques and customized power system modelling for industrial and commercial power systems have resulted in powerful software tools. With the aid of integrated database management tools, full featured programs can deal with every aspect of power system analysis.

Enhancement in capability of personal computer has changed the way how engineers perform power system design and analysis. No longer does the electrical engineer have to depend upon time consuming hand calculation or main frame computer software.[1]

When the electrical engineers get started with the design of main electrical system of a complex petro chemical plant along with chemical and mechanical engineers, they are usually confronted with lack of power system data, since the electrical system data can be confirmed after settlement of both chemical process and its associated mechanical design. Modern power system analysis software on the base of personal computer enables engineers to perform preliminary design studies utilizing default values provided by the software as well as reasonable assumption for system modelling such as generator and its prime mover, transformer, line, load, and etc. The assumed system parameters become basis to determine the key specification of major equipment in the objected plant.

This paper presents a procedure of power system stability analysis for the purpose of design studies on a large petrochemical complex plant and technical points born in mind during the studies.

2. MODELING OF POWER SYSTEM

2.1 Network system

The Cadereyta petrochemical plant is connected from the 230kV grid of CFE (utility company of Mexico) through two main transformers with a rating of 230-13.8kV, 75MVA each to two main receiving 13.8kV substation bus(no.10 and 20). Two steam turbine generators are connected to 13.8kV generating bus (no.40 and 50) respectively. The two generating bus and two substation bus are connected through a synchronizing bus (no.30), where a new gas turbine generator is connected. The four bus are the power supplying back bones to the existing and new petrochemical plant. The back bones are supplying with power in the manner of radial system through a number of 13.8-4.16kV and 4.16-0.48kV distribution transformers. Fault limiters and current limiting reactors are introduced to 13.8kV system to reduce its fault level to the possible equipment rating.[3]

The Cadereyta 230kV substation of CFE located in the neighborhood of the plant is considered as a swing bus and represented as a generator in classical model. The plant loads are mainly composed of induction motors and therefore represented as a constant kVA model, which impose the worst condition on simulation studies.

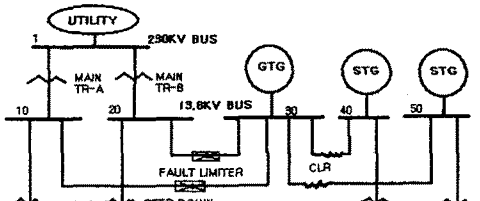

Figure 1. System configuration of Cadereyta Petrochemical complex

2.2 Modelling of prime movers, generator, and excitation systems[2]

2.2.1 Generators

Synchronous generator is modelled with an internal voltage source proportional to the field flux linkages behind the armature resistance and quadrature reactance as shown in the following equations (1) through (7).

$$\frac{dEq'}{dt} = \frac{1}{Tdo'}(Efd - Ei) \quad (1)$$

$$Ei = Et + RaIt + j(XdId + XqIq) + F(Eq') \quad (2)$$

$$Et = Eq - (Ra + jXq) \quad It \quad (3)$$

$$Eq = Eq' + j(Xq - Xd')Id \quad (4)$$

$$F(Eq') = \text{ Machine saturation} \quad (5)$$

$$\frac{d^2\delta}{dt^2} = \frac{120f}{H}(Pm - Pe) + D\omega \quad (6)$$

$$\frac{d\delta}{dt} = \omega - \omega_o \quad (7)$$

where,

Eq':quad. voltage of transient reactance
Eq :quad. axis synchronous reactance
Et :external bus voltage
Ei :voltage proportional to field current
Efd: field voltage across quad. axis
It : terminal current
Id :direct axis machine terminal current
Iq :quad. machine terminal current
Tdo' : d-axis trans. open circuit t.c., in sec.
δ :machine internal bus angle in degree
Pm :mechanical power in per unit megawatt
Pe : electrical power in per unit megawatt
ω : machine speed in radians per second
H : machine inertia in MW.s/MVA
f : system frequency in Hz
D : damping in MW/Hz

2.1.2. Excitation system

The excitation system of the existing turbine generator has been confirmed to be a static type through data survey on the existing plant, which can be fairly assumed as IEEE Type 1S model. The parameter of the excitation system model is not given during the data survey and should be obtained by a parameter identification study which entails much time and expense. However this study is not appropriate during the preliminary design stage. The parameters are determined by resonable assumption under expert's experience. The excitation system of the new gas turbine generator is a rotating field brushless type which is represented as IEEE Type 2 model. The parameters are obtained from its manufacturer.

The computer representation along with its parameters have been simulated by Matlab /Simulink in the time domain. The linear models are obtained as follows. [6], [7]

$$\frac{dX}{dt} = AX + BU \quad (8)$$

$$Y = C\,X \quad (9)$$

For IEEE type 1S, system matrices are :

$$A = \begin{bmatrix} -8367 & 200 & 1 \\ 0 & -200 & 0 \\ 8333 & 0 & -1 \end{bmatrix} B = \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} C = \begin{bmatrix} 8333 & 0 & 0 \end{bmatrix}$$

Eig(A) = -8368, -3.983 x10^{-3}, -200

For IEEE type 2, system matrices are:

$$A = \begin{bmatrix} -5.3 & 8333 & 0 & 0 & 0 \\ 0 & -33.3 & 200 & -0.1 & 0 \\ 0 & 0 & -200 & 0 & 0 \\ 0 & 8333 & 0 & -2.9 & -1.1 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix} B = \begin{bmatrix} 0 \\ 1 \\ 0 \\ 0 \\ 0 \end{bmatrix} C = \begin{bmatrix} 2.5 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Eig(A) =-5.28, -18.1+/-j14.33, -0.07, -200

The eigen values of the system matrix A have been confirmed to remain at the left half plane. The linear models are also tested applying a stepwise input and an impulse input. Frequency domain analysis have also been performed to confirm the stability margin in the model.

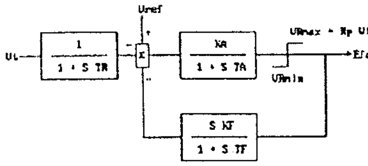

Figure 2. Potential source controlled rectifier exciter system IEEE Type 1S

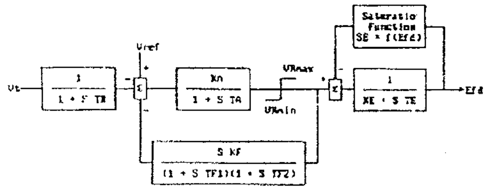

Figure 3. Brushless exciter system IEEE Type 2

2.1.3 Prime mover system

The model of the existing steam turbine is fairly assumed to be a IEEE type ST2 after careful review on the data and drawings of turbine mechanical configuration. The parameters for computer representation block diagram are adopted from the default data given by the commercial program with proper adjustment and test simulation on the model parameters.

A simple block diagram is assumed by design engineer for the gas turbine generator. Its parameters adoptable to the diagram are obtained from the manufacturer of gas turbine and used after test simulation on the diagram.

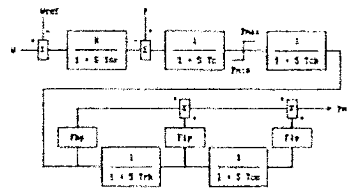

Figure 4. Steam turbine and governor system IEEE Type ST2

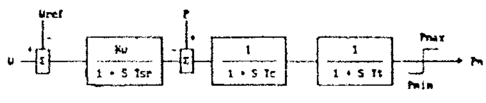

Figure 5. Gas turbine and governor system

3. CASE STUDIES

3.1 Study cases

More than 20 study cases are selected considering system configuration and relevant protection relaying as well as operational logics of circuit breakers. Study cases have been selected to simulate possible disturbances such as :

- short circuit applied and cleared with several time delays
- system isolation and subsequent load shedding
- loss of generators.

3.2 Check points

Check points are :

- stability by checking power angle difference between generators,
- frequency deviation,
- and voltage variation of each bus.

3.3 Dynamic simulation on a sample case

A dynamic simulation result is shown in the figure 6, 7, and 8. This is to simulate a disturbance , that is, at t=0 3-phase fault occurred at bus no. 40; at t=1.004 second two 13.8kV tie lines are isolated by blow-up of fault limiters; at t=1.4 second fault cleared; and t=2.2 second 10.1MW of existing loads are shed.

Result : Angles of three generators are close to each others after isolation from CFE grid. Frequencies of three generators drop to 58.6Hz, but increase to 60Hz after load shedding. Voltage at each generator bus initially drops to 0.24 pu at the lowest, and return to its steady state voltage soon.

4. CONCLUSION

The dynamic stability studies on the power system of Mexico Cadereyta Petrochemical Plant have been carried out. The followings are found and concluded through the studies.

1) Improper selection of parameters in dynamic models does not guarantee convergence in dynamic simulation. Model parameters shall be carefully chosen through verification test such as eigen value confirmation, frequency domain analysis and time domain simulation on the partial dynamic models before initiating case studies.

2) The prime purpose of stability analysis is to find the critical fault clearing time. It has been proved that the Cadereyta power system remain stable, when any short circuit faults are cleared by the primary or secondary protection. This is a guide for setting of fault protection relays.

3) The transient frequency fluctuation after clearing short circuit fault provides a guide for setting of frequency relays at generator terminals.

4) When in-house generators are isolated from CFE grid due to disturbances at the grid or in-house power system, the power system of in-house plant can become unstable. **Guides for load shedding strategy including setting of frequency relays are** provided to disconnect the plant from the grid as well as to initiate a proper amount of shedding of load in the plant.

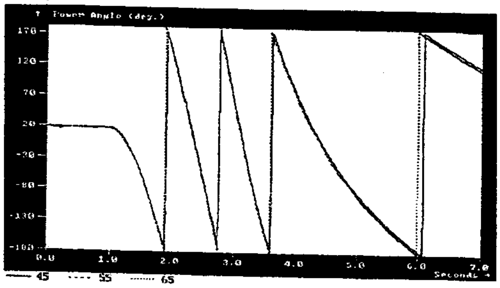

Figure 6. Angles of generators isolated from grid

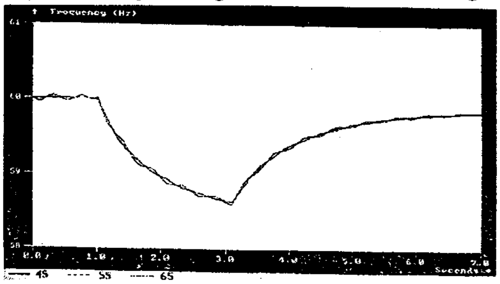

Figure 7. Frequencies of generators

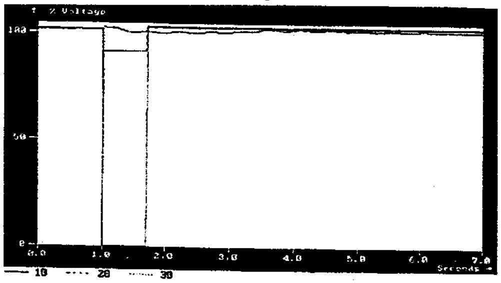

Figure 8. Voltage at each bus

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