ERACS Transient Stability Analysis of the Goodwyn "A" Power System

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Abstract

Analysing the transient stability of the Goodwyn "A" platform power system using the power systems analysis tool, ERACS, allows the impact of disturbances to be evaluated and facilitates the implementation of a load shedding system which will protect the system sufficiently. The benefits of utilising the ERACS software to achieve this objective are that further calculations may be run on the same power system model as required; for example, to test the effects of new installations or modifications to the power system network. ERACS also provides the capability to test the limitations of the power system network without risk, cost or disruption to operations.

1.0 Introduction

The objective of this project is to analyse the transient stability of the Goodwyn "A" (GWA) power system using ERA Technology's dedicated power system analysis software package, ERACS. The GWA power system is modelled in ERACS using standardised methods previously employed to model the North Rankin "A" (NRA) power system and parts of the GWA power system. This is a step towards standardisation of power system analysis methods across various individual projects within Transfield Worley Woodside Alliance (TWWA) and Woodside Energy Limited (WEL).

This thesis outlines the tasks completed, the inputs and assumptions and scope of elements used to model the GWA power system using ERACS. Various transient stability studies were run on the GWA ERACS model to investigate the effects of disturbances caused in the case of voltage excursions of high voltage (HV) motors, busbar faults, and loss of generation.

The outcomes of these tests were then applied to examine the effectiveness of the GWA power system's existing load-shedding system and the efficiency of the generation system.

2.0 Background

The previous ERACS model of the GWA platform power system was constructed as an approximation tool for load flow analyses of the system. However, this previous model was not constructed for the purpose of performing transient stability studies. The following are some aspects of the previous ERACS GWA model which required modification:

- Motor elements were created to approximate the load flow of all motor elements on each busbar; individual motors had not been modelled.
- A number of HV motors have since been upgraded.

- Protection devices.
- Transient components of synchronous generators and HV motors.
- Cables.
- Recent and future project installations.

The purpose of these modifications was to:

- Increase the overall accuracy of all studies run on the GWA power system model in ERACS; and
- Enable a transient stability analysis to be conducted on the GWA power system using the ERACS model.

3.0 Project Drivers

The effects of large disturbances on a power system are varied, unpredictable and potentially wide-ranging. Analysing the transient stability of a power system using an analysis tool such as ERACS allows the impact of disturbances to be evaluated and facilitates the use of a load shedding system which will protect the system sufficiently (Humpage 1974).

3.1 Transient Stability

Figure 1 shows that a power system impacted by an abnormal disturbance may be propelled from an initial steady state condition into one of two final states.

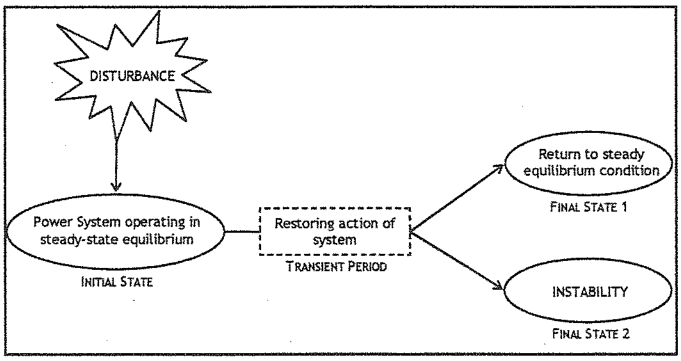

Figure 1 Power system dynamic operation flow diagram

Final State 1 – The restoring action of the system, which occurs in the transient period directly following the disturbance, is sufficient to return the system to a final steady equilibrium state.

Final State 2 – The disturbance has exceeded the transient stability limit of the system and the restoring action of the system is not sufficient to prevent the system from instability.

3.1.1 Types of Instability

Instability may arise through either of the following:

- Small operational transients
- Severe impact of a large disturbance

Small Signal Instability

The case of system instability resulting from small operational transients is not explored in this thesis. System instability of this type cannot be simulated using the ERACS model. Additionally, instability is only provoked at very high levels of power loading close to the systems load limit and does not occur at normal operational power load levels (Humpage 1974).

Transient Instability

System instability that is caused by a large abnormal disturbance in the power system has a far greater impact on the continued stability and safe operation of the system than the aforementioned "small signal instability". Significant disturbances to the system are most commonly in the form of a short-circuit in one or more elements of the power system. The most severe disturbances to the power system would occur with the loss of a synchronous generator or a high voltage (HV) induction motor through a three-phase short-circuit fault (Humpage 1974).

The two types of transient instability, "Transient Synchronous Instability" and "Transient Voltage Instability", are summarised in Table 1:

	Cause of Instability	**Type of Power Imbalance**	**Location of disturbance**	**Effect on power system**
Transient Synchronous Instability	Large disturbance	Active power	Synchronous elements e.g. synchronous generator	Loss of synchronism
Transient Voltage Instability	Large disturbance	Reactive power	Asynchronous elements e.g. induction motor	Voltage excursions

Table 1 Overview of transient instability types

3.2 Woodside Applications

By analysing the transient behaviour of the GWA power system it will be possible to highlight possible problem areas of the system in the event of a large disturbance. Possible disturbances may include:

- Loss of a synchronous generator due to fault;
- HV motor starting;
- Loss of a HV induction motor due to fault; and/or
- Faults occurring on the HV busbar.

In an event where the load demand becomes greater than the supply, the power system's load shedding scheme will be initiated. In light of the results obtained from transient stability analysis of the GWA power system, the suitability and effectiveness of the existing load shedding system can be examined.

An N+1 generator system is one where the number of generators required to feed the average system load is increased by one, in other words the system is running with one spare generator; this is also known as the "N-1 Contingency Criterion" (Milano, Cañizares & Invernizzi 2004). Considering the potential advantages of the N generator system, another benefit of analysing the loading of the GWA power system is that it may be examined whether it is possible to implement an N generator system in place of the existing N+1 generator system.

4.0 Objectives

The objectives of analysing the Goodwyn "A" (GWA) power system's transient stability using the power system analysis software, ERACS, are:

- To determine the effects of voltage excursions due to **starting or loss** of one or more **high voltage** (HV) **induction motors**;
- To determine the transient effects of **losing a synchronous generator** through fault;
- To determine the transient effects of a fault occurring on a **HV busbar** within the power network through **fault simulation** in ERACS;
- To determine the suitability of the existing GWA **load shedding** system; and
- To determine whether the GWA power system can move from an N+1 generator system to an **N generator system**.

The newly updated GWA ERACS power systems model also provides load flow study results for the GWA power system, inclusive of both recent and future installations resulting from ongoing projects.

To achieve the above objectives it was necessary to update and extend the existing GWA ERACS power systems model, tasks included:

- Completing the GWA **static power system** model in ERACS; and
- Extending the GWA ERACS model to include **dynamic analysis** capabilities:
    - Modelling of **dynamic HV motor components** into ERACS;
    - Determining an accurate algorithm for the action of the **Automatic Voltage Regulators** (AVRs) of the synchronous generators; and
    - Determining an accurate algorithm for the generator **speed governors**.

5.0 Methodology

To provide the most accurate representation of the GWA power system, each individual element would ideally be modelled in ERACS network. However, for visual appeal, efficiency and workability of the model, it is necessary to introduce design constraints.

The majority of element data was obtainable from various GWA electrical documents and drawings, and supplier equipment catalogues (e.g. Vendor Equipment Manuals (VEMs), load lists, cable schedules etc.). However, where data was unavailable or proved to be incorrect, theoretical electrical engineering models were used to calculate valid approximations for the required data entries. Approximation methods used include per-unit (PU) and equivalent circuit model analysis, and extrapolation of trend curves.

Only the dynamic capabilities (in the form of torque, speed and interia characteristics) of the synchronous generators and HV motors were modelled since these elements would have the most significant effects on transient stability.

The action of the generators' AVRs and speed governors act to improve system stability and thus impact significantly on transient analysis outcomes. In a multi-machine power system the AVR acts to regulate the power factor of the system, which dictates the reactive power flow. The governor controls the active power flow and maintains synchronism by ensuring even loading across the parallel generators feeding the power system. The actions of these controllers during transient analysis are simulated in ERACS using the "block diagram approach" (ERA Technology 2005, p. 5.108). The parameters used to model the GWA AVRs and governors were obtained from a combination of the transfer function block diagrams of similar AVRs and governors and IEEE standard values.

6.0 Results

6.1 Load Flow

An estimate of the future GWA loads made in a separate study postulates an additional load value of **2.453 MW** and. **0.629 MVAr** to be added to the GWA power system primarily through one of TWWA's ongoing major projects. Load flow data obtained from running the ERACS "Load Flow" study was comparable within **13%** to previously obtained load flow data from load lists with the inclusion of the estimated additional loads.

6.1.1 Normal Operation

	Load List	With Additional Loads	ERACS Load Flow	Discrepancy
Active Power Load Demand, P_L	7.079 MW	9.532 MW	10.411 MW	8%
Reactive Power Load Demand, Q_L	2.96 MVAr	3.589 MVAr	4.135 MVAr	13%

Table 2 Load flow summary data – Normal operation

6.1.2 Drilling Operation

	Load List	With Additional Loads	ERACS Load Flow	Discrepancy
Active Power Load Demand, P_L	11.948 MW	14.401 MW	14.711 MW	2%
Reactive Power Load Demand, Q_L	6.827 MVAr	7.456 MVAr	7.839 MVAr	5%

Table 3 Load flow summary data – Drilling operation

6.2 Transient Stability

The power system's transient response is analysed by determining the effects (severity and length) of different disturbance scenarios. Tables 4 – 6 summarise the effects of the different events on various elements within the GWA power system in normal operation. The effects on both an N+1 (= 4) and an N (= 3) generation system are examined for each case.

6.2.1 Loss of a Generator (3-phase fault)

From protection settings, the fault on the generator (applied at 0.1 s) causes the circuit breaker to trip after ~1.5 s. Note: DNR = does not recover.

		N+1 Generation			N Generation		
Element Affected	**Parameter**	[1] **Peak Deviation (%)**	[2] **Final Value (pu)**	[3] **Settling Time (s)**	[1] **Peak Deviation (%)**	[2] **Final Value (pu)**	[3] **Settling Time (s)**
HV Busbar	Voltage	+35.2	0.999	4.3	+25.1	0.995	5.9
	Frequency	-5.65	0.991	7.1	DNR: Complete failure at 5 s		
Generators	Shaft Speed	-5.6	0.991	6.2	DNR: Complete failure > 7.4 s		
HV Motors	Shaft Speed	-6	0.986	6.4	DNR: Complete failure > 7.4 s		

Table 4 Effects of losing a generator

6.2.2 3-phase Fault on HV Busbar

A 3-phase fault is applied to the main (HV) busbar at 0.1 s and then removed after 0.7 s.

		N+1 Generation			N Generation		
Element Affected	**Parameter**	[1] **Peak Deviation (%)**	[2] **Final Value (pu)**	[3] **Settling Time (s)**	[1] **Peak Deviation (%)**	[2] **Final Value (pu)**	[3] **Settling Time (s)**
HV Busbar	Voltage	+33.5	1	6.7	+32.4	1	4.1
	Frequency	-0.832	1	3.7	-4.158	1	7
Generators	Shaft Speed	-0.8	1	3.2	-4.1	1	6.3
HV Motors	Shaft Speed	-2.2	0.995	3.9	-4.5	0.995	7

Table 5 Effects of an HV busbar fault

6.2.3 HV Motor Starting

A large HV motor (1.65 MW) was started direct on-line at 0.1 s.

		N+1 Generation			N Generation		
Element Affected	**Parameter**	[1] **Peak Deviation (%)**	[2] **Final Value (pu)**	[3] **Settling Time (s)**	[1] **Peak Deviation (%)**	[2] **Final Value (pu)**	[3] **Settling Time (s)**
HV Busbar	Voltage	-9.3	1	4.3	-12	0.999	3.6
	Frequency	-0.576	0.9995	4.5	-2.132	0.9994	5.4
Generators	Shaft Speed	-0.6	1	3.1	-2.1	0.999	4.4
HV Motors	Shaft Speed	-1.1	0.994	2.4	-2.6	0.994	4.8

Table 6 Effects of HV motor starting

7.0 Conclusions

The results of transient stability studies involving various disturbances and events in the system provide the following information:

1. The model provides load flow estimates within 13% of expected values. Differences are expected due to approximations used in either of the two sources and required assumptions made during modelling. In addition, the number and type of running loads between the two estimates are similar but not identical.
2. During normal operation, in an N+1 generation scenario, there is a 3.6 MW spinning reserve. This margin is reduced to 0.09 MW when only N (number of generators required to supply the system load) generators are running. Under normal operation, N = 3.
3. The loss of a generator presents substantial dips in frequency as well as significant voltage excursions as predicted by theory. The effects are resolved within a suitable time period in the N+1 case.
4. The GWA power system can withstand large disturbances caused by 3-phase fault on the HV busbar and HV motor starting even in N generation. However, it is obvious that if a generator were to be lost for any reason this system would fail. This is the primary reason why most power systems are run with N+1 generation.
5. In real life, the system frequency would return to 1 pu (50 Hz) after the loss of a generator since isochronous load sharing is used. The reduced final value of the frequency (0.991 pu) is due to the fact that the closest governor representation was achieved with a droop control model.

8.0 References

ERA Technology Ltd. 2005, *ERACS Power Systems Analysis Software – Technical Manual*, ERA Technology, Surrey, UK.

F. Milano, C. A. Cañizares and M. Invernizzi. 2004, 'Voltage Stability Constrained OPF Market Models Considering N-1 Contingency Criteria', *Electric Power Systems Research*.

W. D. Humpage. 1974, *System Dynamics*, Energy Systems Centre, The University of Western Australia, Perth, Australia.

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[1] Peak Deviation (%) = the largest percentage deviation from the original value

[2] Final Value (pu) = the final resting value, given that the original value is 1 pu

[3] Settling Time (s) = the time difference between the event and when the final value is reached