Inertia estimation of diesel generators based on modified loading rejection tests

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Abstract
An inertia identification approach has been proposed for diesel generators by using the modified load rejection procedures. Large frequency deviation problems often occur in the Kinmen island power system where many diesel generators are used. In order to avoid erroneous evaluation of frequency deviation caused by generator tripping, one of the critical issues in system planning is to accurately estimate the maximum frequency deviation during system outage events. The main factors that influence the frequency deviation include the generator inertia (H), damping constant (D), and governor controller parameters. In order to improve the accuracy of the transient stability analysis to obtain more actual frequency deviation, it is critical to have more accurate inertia values of these diesel generators. This paper proposes a useful approach to evaluate reasonable inertia values. With the identified inertia values of diesel generators, the frequency responses of the Kinmen power system obtained from PSS/E simulation are more consistent with the field measurement results.

1 | INTRODUCTION

The inertia constant of a generator is an important part of analysing the stability of an island power network with high penetration of renewables. The awareness of the importance of verifying the generator model parameters was addressed in the final report of investigation of the many large-scale blackouts around the world [1]. In the 10 August 1996 event in North America, the field recorded data showed that the dynamic responses of power systems differed greatly from those from computer simulations.

The accuracy of computer simulations depends on the correct system models and generator control parameters used. Some regulations require that the generator sets model verification and parameter identification should be performed [2, 3]. NERC has established reliability related standards for North America and proposed technical guides for synchronous generator model verification and measurement methods [4]. The retardation methods in the IEEE Standard 115 [5] were used in Romania in 2010 to test hydropower unit efficiency [6]. This method is based on the electrical coupling of two generators which operate separately in motor and generator modes.

The main factors that influence the frequency excursion include the generator inertia (H), load damping constant (D), and governor response. The mathematical basis of dynamic system analysis was given in [7] to estimate the frequency and damping ratio from simulations. It shows that the frequency and damping characteristics of generator units are highly dependent on the inertia values. The contribution of the system inertia could be affected by the demand side in the GB power system discussed in [8]. Paper [9] indicated a procedure for estimating the inertia constant of a power system and the relationship of total system inertia with the on-line capacity of spinning-reserve generators. It also compared the simulated results with transients of the frequency measured at an event such as a generator load rejection test. The phasor measurement unit (PMU) has been used to the online identification of power system inertia constant [10] based on the simulation power imbalance waveforms and the second time derivative of rotor angles. The results of on-line identification of the synchronous generator inertia from the speed of generator rotor have also been given in [11].

During the lifetime of a unit, exciter or governor equipment replacement, turbine rotor or other related equipment
replacements could impact or change overall machine inertia. To calculate the inertia constant $H$ from test, machine speed or output frequency while subjecting the unit to a partial load rejection (10 and 20% of rated load) is measured. The initial frequency slope is the unit change in frequency versus time with no governor operation, or with the input shaft power remaining constant. Using the frequency change ($df/dt$), the unit MVA rating, initial power $P_0$ before the rejection test and an equation that relates these, the machine inertia constant can be calculated.

The load rejection test can be used to check the $H$ values used in the stability analyses. However, there are inherent errors in using test data including [4]:

- Errors in the measured power and speed calculation
- Fast-acting fuel/steam valve actions following unit-trip
- Governor response
- Drivetrain damping
- Inaccurate use of slope of acceleration curve at $t = 0$
- Friction and windage

It is difficult to identify each individual error; in order to achieve better estimate of diesel generator inertia response after power network disturbances, an inertia identification approach is proposed by utilizing load rejection test results in conjunction with simulation results.

This study takes the power system in the Kinmen island as the research object. The main power sources of this system are diesel generator sets in the Tashan power plant. The information of these units has not been updated for a long time, and some parameters should have been changed after more than 20 years of operation. Some maintenances included diesel generating set engines, cylinder blocks, pistons, piston rings, crankshafts, intake and exhaust valves, calibration connecting rods, crankshafts, dust removal of stators, and rewinding coils of rotors. These may affect the inertia of the unit, so it is necessary to develop a method for evaluating the inertia of the diesel generators.

This paper presents a suitable method for calculating the generator inertia values, and the main contributions are listed under diserption.

1. The system inertia could be divided into two parts: the generator’s inertia and residual inertia. If the utility cannot clearly understand the inertia of the generators, the residual inertia estimation cannot be accurate.
2. The inertia estimation method of a single generator is used to obtain inertia from the mass of the shaft or to calculate the relationship between frequency and power through the load rejection. The former method does not consider other components of the entire generator system, while the latter does not consider the simulation accuracy of generator dynamic parameters.
3. This paper proposes a hybrid analysis method through simulation and load rejection tests to obtain the inertia ($H$) of the diesel generators. The simulation result of frequency deviations is then used to compare with measurement data.

2 | GENERATOR LOAD REJECTION TEST AND PROBLEM DESCRIPTION

2.1 | The Kinmen power system

There are two power plants in the Kinmen power system, as shown in Figure 1. The overall installed capacity is 84.948 MW. The 22.8 kV power lines are used as the grid network. The Tashan power plant has eight diesel generators, and the Xiaxing power plant has six diesel generators, respectively. There are four substations, that is, Tashan, Juguang, Xiaxing and Queshan.

In the Tashan power plant, the capacity of G1 to G4 is 10.181 MVA, respectively, while that of G5 to G8 is 9.71 MVA, respectively. G1 to G4 are droop-controlled diesel generators, while G5 to G8 are frequency-adjustable diesel generators. There are six diesel generators in the Xiaxing power plant, and the total installed capacity is 20.312 MW. Since generators in the Xiaxing power plant are relatively old, they are not going to deliver power to the system during other generator events. There are also two 2 MW wind generators, which are connected to the Xiaxing power plant.

2.2 | Tashan power plant load rejection tests

Load rejection tests are carried out for two different units G4 and G5 in the Tashan power plant. The generator under test is first switched to the manual control mode and increases output power to 2 MW. Then, the generator circuit breaker is opened. The procedure of 4 and 6 MW load rejection tests is the same. Please note that during the 6 MW load rejection test, since the unit has reached more than half of the total system load, the power system dispatcher will put another unit online to balance the demand.

2.3 | Generator inertia and computer simulation

The inertia constant ($H$) can be recognized as the ratio of energy stored in rotating parts of the diesel generator to the rated
apparent power. Sometimes the moment of inertia of a diesel-generator is given in units of weight, and it can convert weight units to joules [12]. Therefore, the inertia constant is highly related to the physical specifications of the generator.

The most accurate method to measure the H is to calculate it from the dimensions of the diesel engine and the generator mechanical shafts. Therefore, it could be affected by manufacture tolerances, maintenance, and wear. On the other way, the value of H of a generator can also be obtained by load rejection test, that is, tripping an on-load generator. However, there are still many factors that affect the accuracy of the test results, such as valve action, governor response, damping, friction, and wind resistance.

There are many software programs can be used to evaluate the transient stability of a power system. Since the penetration of renewable energy in the Kinmen power system is increasing, it is important to set reasonable values of H in the program. In this paper, the diesel generator model in PSS/E is based on the torque swing equation and the model “GENSAL”.

2.4 Acceleration characteristics of inertia

In the speed control mode of a diesel-generator, in which the engine is operated in a speed control mode through the governor, the generator regulates the system frequency, as shown in Figure 2 [13]. A 0.05 pu step response test is given to the swing equation model as shown in Figure 3, with two cases H = 0.5 and 1 s, respectively, are compared, and the damping constant D is neglected. Within a short period, from t = 1 to 1.23 s, the curve reveals linear characteristics, but after a longer time, the curves will be non-linear.

2.5 Electrical frequency/mechanical frequency

Figure 4 shows the governor control diagram of the diesel-engine generator. The electrical frequency is measured from the generator terminal voltage waveform. The mechanical frequency is measured by using the triangular waveforms in the speed controller. Although both electrical frequency and mechanical frequency have been used in the load rejection tests, the different characteristics should be compared.

A. Electrical frequency:

The generator electrical frequency is usually expressed as ω in radian/s, or f in hertz (Hz). Here, the generator terminal voltage waveforms were measured by the phasor measurement unit (PMU) with a sampling rate of 6000 samples per second. The electrical speed deviation is obtained from

\[
\Delta \omega = \frac{\Delta \psi}{\Delta t} = \frac{\Psi_L - \Psi_{L-1}}{\Delta t},
\]

where \(\Psi_L\) represents the phasor angle of the positive sequence voltage at time \(L\), \(\Psi_{L-1}\) represents that at time \(L-1\). Then the electrical frequency deviation is obtained from

\[
\Delta f_e = \frac{\Delta \omega}{2\pi} = \frac{\Psi_L - \Psi_{L-1}}{2\pi \Delta t}.
\]

B. Mechanical frequency:

The mechanical frequency is measured by position signal of the rotor which is the triangular waveform signal as shown in Figure 5. It could produce pulse signals at the zero-crossing points. Each cycle of the triangular waveform gives two pulse signals. Therefore, the mechanical frequency can be described as

\[
f_m = \frac{N}{2\pi \Delta T_r},
\]
FIGURE 5  Triangular signals and pulse signals for measurement of mechanical frequency

FIGURE 6  Measurement of electrical and mechanical frequency in two generator load rejection tests: (a) G4, (b) G5

where

\[ N: \text{number of pulse signals in measurement window} \]
\[ S: \text{number of position sensors on the rotor} \]
\[ \Delta T_r \approx 0.0167 \text{ sec}: \text{time of the measurement window} \]

Calculation of the inertia must use the slope of the frequency response curve. The slope will be obtained during the acceleration period after the generator tripping. The measurements of electrical frequency and mechanical frequency of two load rejection cases are given Figure 6. It can be found that there is instant overshoot in the electrical frequency just after the moment of load rejection. The overshoot causes difficulty in the calculation of slope of frequency excursion for inertia estimation. Figure 7 shows terminal voltage waveform obtained from the PMU and the calculation results of electrical frequency. It is observed that the overshoot of electrical frequency comes from an instantaneous change in the terminal voltage waveform when the generator is tripped. This will cause an instantaneous change in the phase angle, and the electrical frequency overshoot.

2.6  Differences between field test and computer simulation results

Computer simulations are important at the system planning stage. Accurate models are the major factors to obtain reasonable results. In this paper, PSS/E is used to analyse the Kinmen power system, where the GENSAL model is used for the diesel-generator. In addition, it also considers the H and D parameters of the rotating components. The original H value for Tashan G1 ∼ G4 units provided by manufacture is 1.67 s, and that of G5 ∼ G8 is 1.54 s. As shown in Figure 8, using the original H values in the simulations, the frequency deviations are different from the actual generator frequency after the tripping of a generator.

In these simulations, damping(D) is set to 0 in PSS/E. To reduce the interference of non-linear factors in the swing equation diagram such as Figure 2. This leads to the decision that the value of H of the diesel-generator should be re-identified.

3  INERTIA IDENTIFICATION METHODS

3.1  Method 1-Load rejection method

A. Test procedure and frequency slope calculation

In a load rejection test of the diesel-generator, it is necessary to set the AVR to manual control, open the circuit breaker of the generator, and record mechanical frequency responses. Moreover, the suitable interval to draw the tangent line is usually within the first several hundred milliseconds. Observing Figure 9, the mechanical frequency response of the diesel generator after load rejection, the frequency acceleration will change with time. Then, using linear regression to get the slope of the
mechanical frequency. With the slope of mechanical frequency, the inertia can be calculated by Equation (4).

$$ H = \frac{\Delta P}{2 \times S_{base} \times \left( \frac{\Delta f_m}{\Delta t} \right)} $$

where

- $\Delta f_m$: change of mechanical frequency
- $\Delta t$: deviation of time
- $\Delta P$: loss of active power

In this study, the slope should be obtained just after the generator tripped, usually within the first several hundred milliseconds, to keep the measured results from interference of nonlinear components.

B. Free running in speed acceleration

The speed-time curve of diesel generators after the load rejection test is similar to that in the electric traction system, as shown in Figure 10. It usually includes accelerating, free running, coasting, and braking.

a. Accelerating: During 0a, the rotor speed of a generator after load rejection increases from the rated speed to the maximum. When the situation is detected that the rotor speed is too high, it would shut down the fuel valve. The input mechanical power $P_m$ is removed.

b. Free running: When the mechanical power $P_m$ is zero and the generator also does not deliver electric power, it means that the rotor speed remains relatively constant as shown by ab of the curve.

c. Coasting: With a deceleration due to the friction and wind resistance, the momentum of the generator gradually reduces, then the rotor slows down during the coasting period, that is, bc of the curve.

d. Braking: The generator is retarded to shut down because of low speed during cd.

C. Data processing and inertia calculation

The data processing flow chart is shown in Figure 11. It is described as follows.

**Step 1:**

The triangle waveforms are obtained from the measurement tachometer. Then pulse signals are obtained from the triangle waveforms. It uses the rising edge triggering method to obtain the pulse signals.

**Step 2:**

The time interval between adjacent pulse signals is then transformed into mechanical frequency. Refer to the mechanical frequency as that described in (3).

**Step 3:**

The mechanical frequency curves, which are obtained from the pulse signals, contain high frequency carrier noises. It is
important to extract the correct numerical data from these disturbed mechanical frequency measurement data. This is helpful for calculating relevant mechanical frequency slopes afterwards. Two filtering methods are compared. In Figure 12, the curves of mechanical frequency raw data, output of Butterworth filters [15] (filter data), and output of moving average [16] (m-avg data) are compared. Although it is not described in detail here, the output data of Butterworth filters are more suitable for inertia identification.

**Step 4 and 5:**

Calculate the slope of the mechanical frequency just after the load rejection accelerating interval. The slopes of mechanical frequency are used to calculate inertia values by using (4).

**D. Disadvantage of load rejection method**

The load rejection tests on Tashan units G4 and G5 under loading of 2, 4, and 6 MW, respectively, are performed. Taking G4 as an example, it can be found from Figure 13 that the mechanical frequency responses of the tripped generator under loading of 4 and 2 MW, respectively, have an overlap region. This means that if the output power of generator before the load rejection test is too light, it will affect the evaluation of the inertia value. For the generator under loading of 6 MW, the acceleration interval is large. Therefore, observing Figure 13, the linear acceleration interval is about 0.1 s after the tripping at \( t = 0.5 \) s.

In addition, according to Table 1, it can be found that the inertia values obtained with and without a filter are different. The unfiltered data obtains a wider Inertia value, and other values relatively converge under different load conditions. So, it can be observed that the mechanical frequency data must be numerically processed or filtered to obtain a useful slope value.

### Method 2—Modified load rejection method

This paper proposes a reasonable linear acceleration interval sampling method and combines the actual mechanical frequency measurement and filtering processing in method 1. The data processing flow chart is shown in Figure 14.
Step 1: Mechanical frequency data processing by using Method 1

It is the same with step 1 to step 4 of the data processing flow chart in method 1. The purpose is to obtain the measured mechanical frequency slope values.

Step 2: Obtaining H-m curve from simulations

Through the assumed inertia values, the slopes obtained based on adequate time interval from simulation results are determined, and the H-m curves are established for different generator loading conditions.

Step 2-1: Using different inertia assumptions to simulate frequency variation after load rejection

The load rejection simulations of G4 by using the PSS/E under $H = 1, 2, \text{ and } 4$ s, respectively, are shown in Figure 15. Let $D = 0$, it reveals that the simulation results of mechanical frequency response curves overlap for 0.03 s just after tripping of the generator. The simulated mechanical frequency slopes with different $H$ are calculated by using the data after the tripping at $t = 0.03$ s.

Step 2-2: Determine a reasonable sampled acceleration interval by checking the slope ratios

The duration of the acceleration period of the generator after tripping will affect the calculation of the mechanical frequency slopes. The longer the duration the influence due to closed-loop control of the generator is greater. The frequency data in Figure 15 from $t = 0.83$ to 0.89 s after tripping ($t = 0.06$ s) with $H = 1, 2, \text{ and } 4$ are given in Table 2. According to the simulated frequency shown in Table 2, it can be seen that the frequency slope decrease as time goes by.

Referring to Figure 13, it can be found that there is a broad non-linear acceleration period of the mechanical frequency response when time interval used to calculate the slope is high. We also find that there is an overlapping region starting from 0.03 s after tripping, as in Figure 15. In Figure 3, it displays that slopes in acceleration period are linear and inversely proportional to their corresponding inertia values. Thus, In the proposed generator inertia estimation process, we use a slope ratio (S.R.) to assist in verifying whether the time period used to calculate slope value is adequate. In the proposed approach, an adequate acceleration period for frequency slope calculation is determined by approximating the slope ratio (S.R.) defined Equation (5) to the inverse of inertia values under same loading condition.

$$S.R. \cong \frac{m_{H_1}}{m_{H_2}} \cong \frac{H_2}{H_1}, \quad (5)$$

where

$m_{H_1}$: the corresponding frequency slope to the inertia $H_1$

$m_{H_2}$: the corresponding frequency slope to the inertia $H_2$

Some sampled data of Figure 15 are revealed in Table 2, the simulation results with $H = 1, 2, \text{ and } 4$, respectively, are given. The data from $t = 0.83$ to 0.89 s after tripping ($t = 0.06$ s) the generator is given. And then the slope ratios of the mechanical frequency are calculated from their slopes. It can be observed that in the reasonable sampled interval, the
slopes ratio value $m(H = 1\text{ s})/m(H = 2\text{ s}) = 1.99$, and the slopes ratio value $m(H = 1\text{ s})/m(H = 4\text{ s}) = 3.93$, approximately equal to the reciprocals of their inertia ratio $H = 1\text{ s}/H = 2\text{ s}$ and $H = 1\text{ s}/H = 4\text{ s}$.

**Step 2-3: Obtaining the H-m curve**

After frequency slopes under different H values and loading conditions assumptions in simulations are calculated, the H-m curve illustrated in Figure 16 can be obtained. In Figure 16, the simulation results include two generator MW loading conditions $P_i$ and $P_j$, respectively. Slope values of three different H values are calculated and the general curve fitting method is used to obtain the two H-m curves.

**Step 3: Obtain inertia values by H-m curve**

As shown in Figure 17, the mechanical frequency slope values of field tests are obtained for two generator MW loading conditions $P_i$ and $P_j$, respectively. Then the corresponding H values can be obtained from the H-m curves.

**Step 4: Recommendation of inertia values**

In this method, different H values, $H_i(MW)$, and $H_j(MW)$, are obtained from the H-m curves under different load conditions.

### Table 3

| $P(MW)$ | Simulation | Field test |
|---------|------------|------------|
|        | $H = 1\text{ s}$ | $H = 2\text{ s}$ | $H = 4\text{ s}$ |
| 2      | 5.03       | 2.53       | 1.28           | 4.95       |
| 4      | 9.89       | 4.90       | 2.39           | 8.20       |
| 6      | 15.02      | 7.44       | 3.62           | 12.26      |

### Table 4

| $H = 1\text{ s}$ | $H = 2\text{ s}$ | $H = 4\text{ s}$ | Field test |
|-------------------|-------------------|-------------------|------------|
| $m(P = 4\text{ MW})/m(P = 2\text{ MW})$ | 1.97               | 1.97               | 1.97       | 1.66       |
| $m(P = 6\text{ MW})/m(P = 2\text{ MW})$ | 2.99               | 2.99               | 2.99       | 2.48       |
| $m(P = 6\text{ MW})/m(P = 4\text{ MW})$ | 1.52               | 1.52               | 1.51       | 1.50       |

The final inertia value will be determined by the median of the inertia set, $\{H_i(MW), H_j(MW) \ldots\}$.

### 4 | Identification Results

#### 4.1 | Slope of mechanical frequency and slope ratios

The slopes of mechanical frequency and slope ratios from simulation and field test are given in Tables 3–5 and Tables 6–8 for generators G4 and G5, respectively. In Table 3 and 6, it can be found that a linear relationship exists between slopes, loading conditions, and inertia values in the simulation, and in Table 6,

**Table 5**

| $P = 2\text{ MW}$ | $P = 4\text{ MW}$ | $P = 6\text{ MW}$ |
|-------------------|-------------------|-------------------|
| $m(H = 1\text{ s})/m(H = 2\text{ s})$ | 1.99               | 2.02               | 2.02       |
| $m(H = 1\text{ s})/m(H = 4\text{ s})$ | 3.93               | 4.14               | 4.15       |

**Table 6**

| $P(MW)$ | Simulation | Field test |
|---------|------------|------------|
|        | $H = 1\text{ s}$ | $H = 2\text{ s}$ | $H = 4\text{ s}$ |
| 2.1    | 5.60       | 2.80       | 1.39           | 2.84       |
| 4.1    | 10.69      | 5.37       | 2.69           | 5.9        |
| 5.88   | 15.29      | 7.68       | 3.85           | 8.74       |
the slopes of G5 are almost linear with loading ratios in field test.

In Table 4 for G4, there is only a case of 6 MW/4 MW that the slope ratio approximately equal to the loading ratio. In Table 7, it displays that the slope ratios of G5 in field test are close to the loading ratios.

### 4.2 Identification results of H by Method 1 and Method 2

As shown in Figure 18, the H-m curves for the generator G4 under three loading conditions, 2, 4, and 6 MW, are obtained from simulation with H = 1, 2, and 4 s, respectively, and the curve fitting method.

The identification results of H by method 1 and method 2 are given Table 9 for G4 and G5, respectively. The values obtained by using method 2 are smaller than that by method 1. The difference is about 10%. According to Table 9, it is found that during lower loading conditions, H of G4 differs more from that obtained in heavy loading condition. But for G5, it is more convergent. The recommendation values are from the median.

### 4.3 Comparison of Method 1 and Method 2

In Table 9, the recommendations of inertia for G4 are 1.44 and 1.2 s, respectively, by method 1 and method 2. The frequency response results of simulation and field test of G4 after load rejection are shown in Figure 19(a,b). It can be observed that the simulation result of frequency response with H = 1.2 s obtained by method 2 is closer to the field test results in the linear acceleration interval (≈ 1–1.2 s).

In Table 9, the recommendations of inertia for G5 are 2.15 and 1.8 s, respectively, by method 1 and method 2.

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**Table 7** Slope ratios of mechanical frequency under different loading condition and different inertia (G5)

| Simulation | H = 1 s | H = 2 s | H = 4 s | Field test |
|------------|---------|---------|---------|------------|
| m(P = 4.1 MW)/m(P = 2.1 MW) | 1.91 | 1.92 | 1.93 | 2.08 |
| m(P = 5.88 MW)/m(P = 2.1 MW) | 2.73 | 2.75 | 2.76 | 3.08 |
| m(P = 5.88 MW)/m(P = 4.1 MW) | 1.43 | 1.43 | 1.43 | 1.48 |

**Table 8** Slope ratio of mechanical frequency under different inertia and different loading condition (G5)

| P = 2.1 MW | P = 4.1 MW | P = 5.88 MW |
|------------|------------|------------|
| m(H = 1 s)/m(H = 2 s) | 2.00 | 1.99 | 1.99 |
| m(H = 1 s)/m(H = 4 s) | 4.02 | 3.97 | 3.97 |

**Table 9** Identification results of H (sec) under different loading conditions

| Generator | P (MW) | Method 1 | Method 2 |
|-----------|--------|----------|----------|
| G4        | 2      | 1.19     | 1.03     |
|           | 4      | 1.44     | 1.20     |
|           | 6      | 1.44     | 1.21     |
|           |        | Recommendation 1.44 | 1.2 |
| G5        | 2.1    | 2.28     | 1.99     |
|           | 4.1    | 2.15     | 1.8      |
|           | 5.88   | 2.08     | 1.77     |
|           |        | Recommendation 2.15 | 1.8 |

**Figure 18** H-m curves of G4 and to obtain H values with m from field tests

**Figure 19** Frequency response after load rejection of G4 in simulation and field test: (a) P = 2 MW, (b) P = 6 MW
FIGURE 20  Frequency response after load rejection of G5 in simulation and field test: (a) $P = 2.1 \text{ MW}$, (b) $P = 5.88 \text{ MW}$

TABLE 10  Slopes of mechanical frequency, $m$ (Hz/s), under different loading condition and different inertia (Guguan)

| Simulation | $H = 1 \text{ s}$ | $H = 2 \text{ s}$ | $H = 4 \text{ s}$ | Field test |
|------------|------------------|------------------|------------------|-------------|
| P (MW)     |                  |                  |                  |             |
| 11.4       | 5.24             | 2.67             | 1.32             | 1.76        |
| 40.2       | 17.93            | 9.17             | 4.46             | 6.25        |

The frequency response results of simulation and field test of G5 after load rejection are shown in Figure 20(a,b). It can be observed that the simulation result of frequency response with $H = 1.8 \text{ s}$ obtained by method 2 is also closer to the field test results.

4.4  Validation of another hydro generator based on Method 2

The purposed method 2 in this paper is also used to identify the inertia of a hydro generator in the Guguan power plant of the Taiwan Power Company. As shown in Table 10, the slopes of mechanical frequency are based on the data obtained from the G1 hydro generator (60.5 MVA) load rejection test under 11.42 and 40.2 MW. As shown in Figure 21, the $H$-m curves from simulation are used to determine the inertia with $m$ from field test. The identification results of $H$ are given in Table 11. The values obtained by using method 2 are 7 to 10 % smaller than that by method 1, and the values obtained by Method 2 is closer to the manufacturer’s data.

FIGURE 21  H-m curves of the hydro generator in Guguan power plant and to obtain $H$ values with $m$ from field test

TABLE 11  Identification results of $H$ (s) of the hydro generator in Guguan power plant under different loading conditions

| P (MW) | Method 1 | Method 2 | Manufacturer |
|--------|----------|----------|--------------|
| 11.426 | 3.22     | 3.19     | 2.9          |
| 40.2   | 3.19     | 2.88     |              |

5  CONCLUSIONS

In this study, the determination of equivalent unit inertia is based on a load rejection method and PSS/E simulator. A “modified load rejection method” is proposed to find inertia parameters that meet the measurement results and stability assessment requirements such that the simulated acceleration of the tripped generator could be consistent with that from tests. Instead of modeling individual components in the drivetrain and control system parameters, an equivalent inertia constant based on load rejection test and $H$ variant simulations is adopted in this study to include parameter variation effects in the stability assessment study.

Different from traditional inertia identification methods, this paper adopts numerical analysis through several times generator tripping records. Simulation results show that the proposed method has given reasonable generator inertia values for the Kinmen power system and has been verified with the measured data. In addition, the analysis procedure proposed in this paper also has been verified to be applied to other units.

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