Frequency Response for Next Decade Solar Power Development Plan in Thailand Part 1: Frequency Response Model of Thailand Power System

C. Sansilah, P. Bhasaputra and W. Pattaraprakorn

Abstract— *This paper proposes the appropriate frequency response model to analyze the frequency deviation of Thailand power system due to various sizes and location of solar power. Large installed capacity of uncertain solar power will affect power system stability in term of voltage stability and frequency deviation. Existing three types of power plants in Thailand with different automatic frequency control parameters are collected to develop real-time automatic individual power plant parameters tuning (RIPT) frequency response model that can represent frequency response of the whole Thailand power system in dynamic operating conditions. In addition, the RIPT frequency response model is simulated system responses at peaked load operating condition with instantaneous and ramp change in solar power generations. The simulation results show that frequency deviation of each case compare to standard control. Finally, the RIPT frequency response model can be applied to analyze effect of real power and load deviation to power system frequency response for protective planning.*

Keywords— **Load frequency control, power system of Thailand, renewable power, solar power plant.**

1. INTRODUCTION

Thailand's electricity demand grows about 4.0 percent per year and the estimated demand will become double within the next two decades [1,2] while the main energy source (as shown in Figure 1), natural gas in the gulf of Thailand, is running out of reserves[3]. One dependence source is leading country energy security problem hence use of renewable energy instead of conventional fossil fuel is the most promising solution. However, uncertain energy generation of renewable resource especially solar power significantly affect to power system reliability in term of voltage stability and frequency response. Frequency deviation is unwanted for consumer due that most of AC motors run at speed that are directly related to frequency as well microcontrollers are dependent on frequency for their timely operation. Normally, Thailand's power system frequency is controlled at 50 Hz as the result of controlling all synchronous generators which are performed by the automatic generation control (AGC) system. Nevertheless, instantaneous imbalance of load and generated power during AGC adjustment is to deviate the frequency. According to normal load profile of Thailand, the rapid increasing demand occurs at around 13.00, 15.00 and 20.00 which AGCs response to nominal frequency with a short period of oscillating under frequency not less than 300 MW per 0.1 Hz however at least one time a day the rapid decreasing demand causes the oscillating over frequency. The frequency response of the power system at a specific time of instantaneous changing demand depends on a combination of time constants and AGC's parameters for running individual power plants which are difficultly investigated the actual values and time dependent.

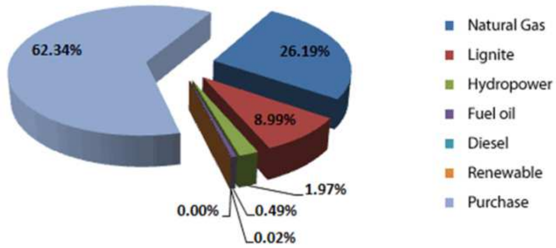

Fig.1. Electrical power generation resources in Thailand (EGAT, 2014)

The generalized load frequency response control (LFC) models are proposed by Kunpur P. [4] and Saadat H. [5] then the modified LFC model for specific power plant types is studied in [6] and renewable energy integration is studied in [6, 7]. Moreover, system inertial frequency response estimations are suggested in [8]. Many recent related researches in frequency respond are proposed and studied through test system [7, 9] or studying influence of solar and wind power integration on frequency dynamic for individual area through various cases with loss of large plant [10]. All of researchers proposed improved LFC model as well as control scheme for system reliability improvement. However, studies of real-world power systems are complicated because the system contains various different types of power plants therefore the appropriate frequency response model is necessary to simulate the effect of unexpected instantaneous deviation of load or

C. Sansilah (corresponding author) is with Department of Electrical Engineering, Faculty of Engineering, Thammasat University, 99 M18 Phaholyothin Road, Khlongluang, Pathumthani, 12120 Thailand. Phone: +66-89-1589-885; E-mail: Chokechais@gmail.com

P. Bhasaputra is with Department of Electrical Engineering, Faculty of Engineering, Thammasat University, 99 M18 Phaholyothin Road, Khlongluang, Pathumthani, 12120, Thailand. E-mail: bporr@engr.tu.ac.th.

W. Pattaraprakorn is with Department of Chemical Engineering, Faculty of Engineering, Thammasat University, 99 M18 Phaholyothin Road, Khlongluang, Pathumthani, 12120, Thailand. E-mail: pworarat@engr.tu.ac.th.

renewable generated power in the system which can support system operator to make prevention plan in order to maintain power system reliability and security.

The main purpose of this study is to investigate impact of large solar power integration on Thailand's power system through considering of frequency response. This paper is a first part to introduce the RIPT frequency response model formulation and another related second part to illustrate simulation result of a PDP 2010 case study. This paper consists of eight sections. Section 1 introduces the research of model LFC. Section 2 is to explain Thailand's power system then basics of power system stability and frequency control are described in section 3 and section 4. Developing frequency response model of Thailand's power system is explained in section 5 then various case studies of load and solar generated power deviation for model examination are described in section 6. Result and discussion of the simulation are presented in section 7. Finally, section 8 is conclusions of this study.

2. THAILAND POWER SYSTEM

Three state enterprise organizations are conducting electrical business in Thailand, the Electricity Generating Authority of Thailand (EGAT) generates and transmits the bulk electricity directly to two distribution authorities, the Metropolitan Electricity Authority (MEA) and the Provincial Electricity Authority (PEA).

Power Generation System

In 2014, EGAT's power plants has a total installed generating capacity of 15,474.13 MW accounting for 44.28 percent of the country's gross energy generation while the purchased power capacity included 13,541.69 MW from domestic independent power producers (IPPs) representing 38.75 percent of the country's total generating capacity 3,524.60 MW or 10.08 percent from small power producers (SPPs) and 2,404.60 MW or 6.88 percent imported from neighboring countries. Proportion of EGAT's power plants classified by types are 10.44 percent of thermal power plant, 23.99 percent of combined cycle power plant, 9.83 percent of hydropower power plant and 0.02 percent of diesel and others power plant as shown in Figure 2.

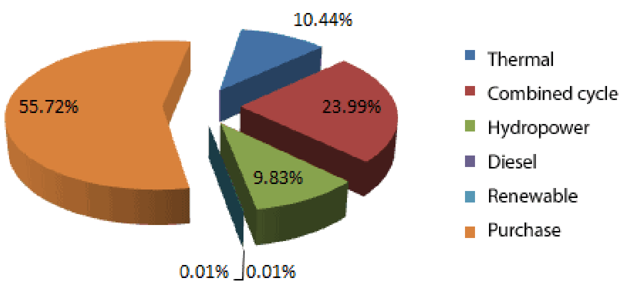

Fig.2. Proportion of EGAT's power plants classify by types (EGAT, 2014)

Transmission Systems

In 2014, Thailand's transmission system consists of 213 substations, 88,036 MVA of transformer capacity and 32,509 circuit-kilometers of transmission line with various voltage levels ranged from 115 kV, 230 kV and 500 kV. The generation and transmission system of Thailand are owned and operated by EGAT via The national control center and five regional control centers. Main power plans and 230/500 kV transmission line of Thailand are showed in Figure 3.

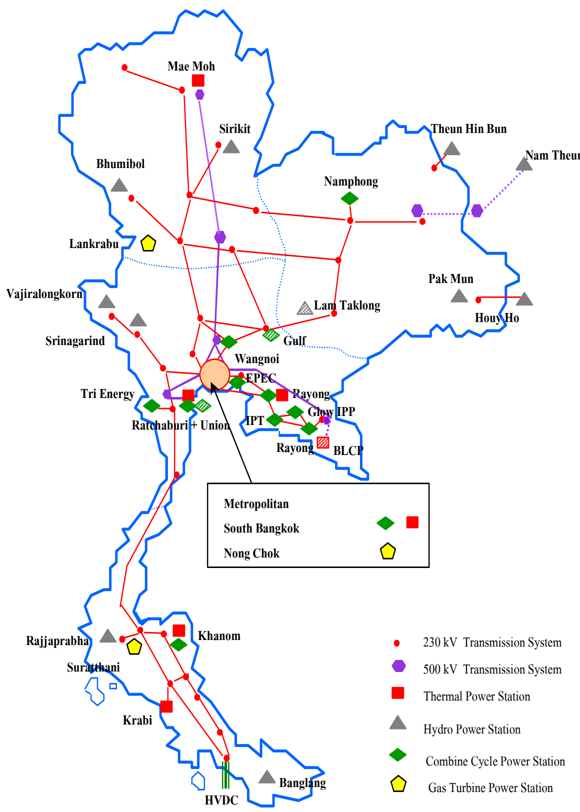

Fig. 3. Main power plans and 230/500 kV transmission line of Thailand.

Electricity Demand of Thailand

In 2014, the peak demand topped 26,942.10 MW on April 23, 2014 at 14.26 marking an increase of 343.96 MW or 1.29 percent from the previous year. In 2013, the net energy totaled 173,535.45 million kWh, 72,113.94 million kWh or 41.56 percent of the country's energy demand was generated by EGAT's power plants, and 101,421.51 million kWh or 58.44 percent were purchased from the private power producers and from neighboring countries.

3. POWER SYSTEM STABILITY

Power system stability is the ability of the power system to maintain the state of operating equilibrium under normal operating conditions and to regain an acceptable state of equilibrium after being subjected to disturbance [3]. The parameters to indicate system stability are system frequency and system voltage. Stability is generally divided into two major categories, steady state stability and transient state stability. Steady state stability is the ability of power system to regain synchronism after small and slow disturbances. Transient state stability studies deal with effect of large and sudden disturbance such as a fault, sudden outage of a line or sudden application or removal of load [4].This paper focuses on the frequency response of Thailand's power system due to large disturbance of solar power generation.

4. POWER SYSTEM FREQUENCY CONTROL

A power grid requires generation and load closely balance moment by moment therefore, frequent adjustments to the output of generators are necessary. The balance can be judged by measuring the system frequency; increasing of frequency, more power is being generated than used, and all the machines in the system are accelerating. Decreasing of frequency, more load is on the system than the instantaneous generation can provide, and all generators are slowing down. The operating principle of controlling system frequency is controls mechanical energy that applied to turbine of the generator which system frequency is directly related with revolution speed of the rotor. Thus, controlling frequency is controlling the revolution speed of the generator's rotor. Figure 4 insulates a block diagram of load frequency control system (LFC). Generally, large interconnected power system frequency is controlled by the Model energy control centers (MEC).

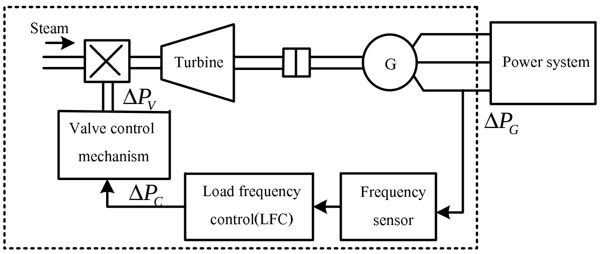

Fig. 4. Block diagram of load frequency control system for *N* generator in power system.

5. FREQUENCY RESPONSE MODEL OF THAILAND POWER SYSTEM

Mathematical modeling of frequency control system in this study is conducted by the transfer function method which is obtained for the following components.

Genorator and Load Model

The frequency deviation ($\Delta\Omega$) under influence of inertia of turbine and generator (inertia constant, H) caused by unbalance of electrical power (P_e) and the mechanical power (P_m) during a small disturbance is define as equation 1.

$$\Delta\Omega(s) = \frac{1}{2Hs}\left[\Delta P_m(s) - \Delta P_e(s)\right] \tag{1}$$

The overall frequency-dependent characteristic of composite load in the system may be expressed as;

$$\Delta P_e = \Delta P_L - D\Delta\omega \tag{2}$$

where ΔP_L is resistive load change, $D\Delta\omega$ is reactive load change and D is load-damping constant which is expressed as a percent change in load for one percent change in frequency.

Turbine Model

The model for nonreheat steam turbine relates change in mechanical power output (ΔP_m) to change in steam valve position (ΔP_V) can be approximated with a single time constant τ_T as;

$$\Delta P_m(s) = \frac{1}{1+\tau_T s}\Delta P_V(s) \tag{3}$$

Governor Model

In order to stable load division between two or more generators operating in parallel, the governors are provided with a characteristic so that speed drops as the load increase. The governor model can be defined as equation 4.

$$\Delta P_V(s) = \frac{1}{1+\tau_g}[\Delta P_{ref}(s) - \frac{1}{R}\Delta\Omega(s)] \tag{4}$$

where τ_g is time constant for the governor, ΔP_{ref} is the reference power change and R is speed regulation of the governor which is the ratio of frequency deviation to change in power output in percentage.

The Isolated Power System

Combining mathematic models from equation 1-4 results in the block diagram of frequency control model for isolated power system, as shows in Figure 5 and the close-loop transfer function relating the load change (ΔP_L) to the frequency deviation ($\Delta\Omega$) is shows in equation 5

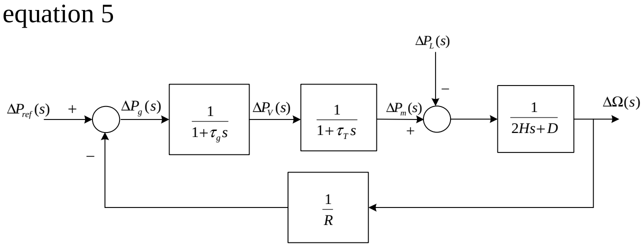

Fig. 5. Block diagram of frequency control model for isolated power system.

$$\frac{\Delta\Omega(s)}{-\Delta P_L(s)} = \frac{(1+\tau_g s)(1+\tau_T s)}{(2Hs+D)(1+\tau_g s)(1+\tau_T s)+\frac{1}{R}} \tag{5}$$

The Isolated Power System with AGC

In order to reduce frequency deviation to zero, the integral controller is added to the model as show in Figure 6 and the close-loop transfer function equation 6

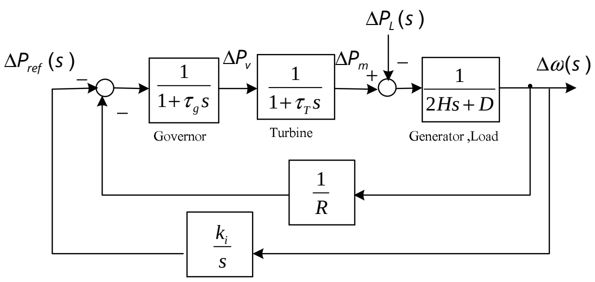

Fig. 6. Block diagram of frequency control model for isolated power system with integral controller.

$$\frac{\Delta\Omega(s)}{-\Delta P_L(s)} = \frac{s(1+\tau_g s)(1+\tau_T s)}{s(2Hs+D)(1+\tau_g s)(1+\tau_T s)+k_i+\dfrac{s}{R}} \tag{6}$$

The equivalent Isolated Power System for multi-generaters

The equivalent isolated power system for multi-generators model assumes that the coherent response of all generators to change in system load and represent them by an equivalent generator which an inertia constant (H_{sys}) equals to the sum of the inertia constants of all generators. Similarly, a single damping constant (D_{sys}) is represented the effect of system loads. The block diagram of the model shows in Figure 7 which parameters are defined as, $\tau_{g1}...\tau_{gN}$ are time constant of governors 1 to N, $\tau_{t1}...\tau_{tN}$ are time constant of turbines 1 to N, $k_{g1}...k_{gN}$ are gain constant of governors 1 to N, $k_{t1}...k_{tN}$ are gain constant of turbine 1 to N, $R_1...R_N$ are speed regulating of governors 1 to N and k_i is grain constant of integral control unit.

RIPT Frequency Response Model

The real-time automatic individual power plant parameters tuning (RIPT) frequency response model is the time-dependent model based on amounts, types and capacities of online-generators at a considered time. According to numerous unknown parameters in the system, all possible typical ranges of individual power plant parameters are used for running in model to find out reasonable model that can represent frequency response characteristic of the system.

RIPT model simulates the isolated power system which is parallel connection of 105 power generators with 4 groups of power plant types, 47 generators of hydro power plants, 17 generators of thermal power plants, 14 generators of combined cycle power plant and 27 generators of IPP's combined cycle power plant.

6. SIMULATION CASE STUDIES

Operating Condition

Frequency response of power system at a specific time depends on various combination types of power plants which are operating at that time. The system operators have to optimize operating cost with acceptable reliability. Thus, the most economical thermal power plants are base load power plants while combined cycle and IPPs power plant are supported for intermediate load level and Hydro power plants are reserving for peaked load etc.

In this study, RIPT frequency respond model of Thailand's power system is examined by peaked load operating condition which all generators are running as shows in Table 1.

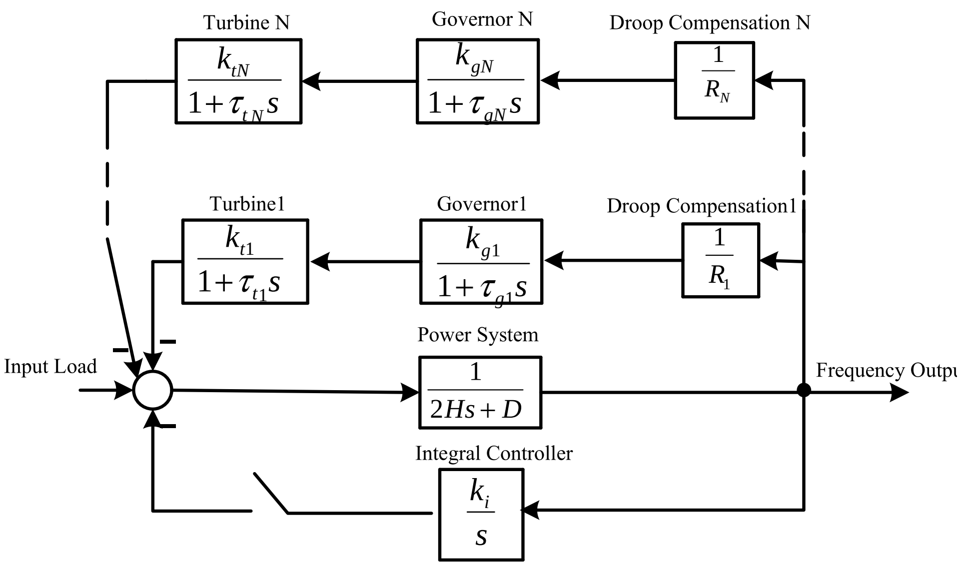

Fig.7. Block diagram of the isolated power system equivalent for multi-generator

Table 1. Number of online-generator of peaked load condition

Group of generator	Number of generators	Installed capacity (MW)	Percentage
Hydro	47	3,391	10.7
Thermal	17	5,615	17.7
Combined cycle	14	7,926	25.0
IPPs	27	14,760	46.6
Total	105	31,692	100.0

Model Parameter Tuning

According to discover an appropriate frequency response model, all possible values of unknown parameter sets such as the inertia constant (H_{sys}), damping constant (D_{sys}) and gain constants of turbine and governor etc., are used to run in the RIPT frequency response model. Over 43,923 cases of results are screened and classified into 3 models, the strong system model, the near actual system model and the weak system model.

Variation of Solar Power

Depending on the aggregation level and geographic diversity, solar plants output can decrease/increase within a range of 20%-80% of capacity at 1 min interval [11]. Therefore, the examination assumes that the solar power deviation at average rate, 40 % (300 MW) of the existing 780 MW capacity. The examination cases are divided into 3 cases;

1) Step decrease/increase of solar power by 300 MW
2) Ramp decrease/increase of solar power by 300 MW in 30 seconds
3) Step decrease of solar power by 300 MW with outage of the 700 MW of conventional power plant

7. SIMULATION RESULTS

The developed RIPT frequency response models consist of 3 different tuned parameter sets under assumption of the strong system model, the near actual system model and the weak system model. The results of simulation performed though multi-scenarios of solar power change are present as below.

Case1: Step decrease/increase of solar power by 300 MW

The effective step decrease of solar power by 300 MW shows in Figure 8. According to the graph, the upper line, the middle line and the lower line represent frequency response of the strong system model, the near actual system model and the weak system model, respectively. Considering on the strong system model, without AGC, the steady state system frequency is dropped from 50 Hz to 49.96 Hz at the different -0.04 Hz which in normal frequency control range (±0.1 Hz). Similarly, the steady state frequency of the near actual system model is dropped from 50 Hz to 49.90 which is on the normal control limit. However, the steady state frequency of the weak system model is dropped 0.21 Hz which is out of range for emergency control.

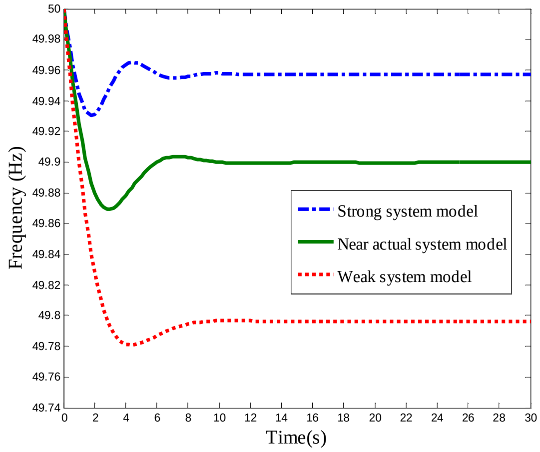

Fig. 8. Frequency response due to step decrease of solar power by 300 MW.

The effective step increase of solar power by 300 MW is shown in Figure 9. In contrast of frequency response of previous case, without AGC, the steady state system frequency of strong, near actual and weak system model are increased from 50 Hz to 50.04 Hz, 50.10 Hz and 50.21 Hz, respectively. A case of weak system model is out of range for normal control.

Case 2: Ramp decrease/increase of solar power by 300 MW in 30 seconds

The effective ramping decrease of solar power by 300 MW in 30 seconds shows in Figure 10. According to the graph, the lower line, the middle line and the upper line represent to the system frequency without AGC of strong, near actual and weak system model, respectively. The result shows that system frequency is slowly decreased from 50 Hz to steady state at 49.96 Hz, 49.90 Hz and 49.79 within about 35 seconds for strong, near actual and weak system model, respectively. A case of weak system model is out of range for normal control.

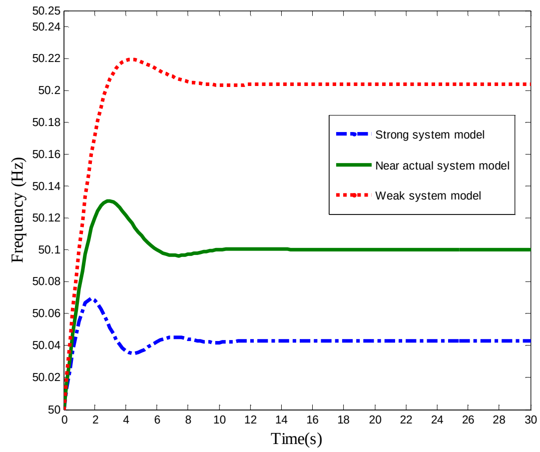

Fig. 9. Frequency response due to step increase of solar power by 300 MW.

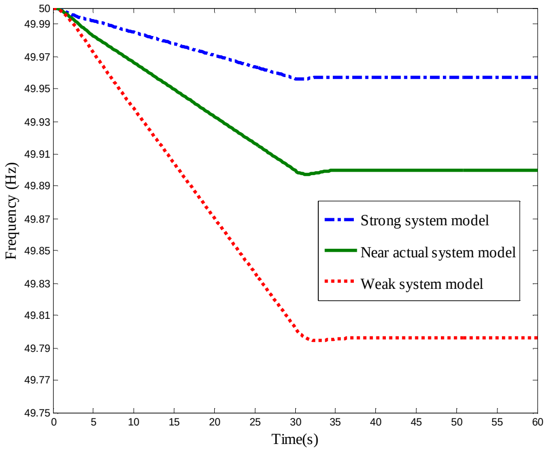

Fig. 10. Frequency response due to ramping down of solar power by 300 MW in 30 seconds.

The Figure 11 shows frequency responses due to step increase of solar power by 300MW in 30 seconds. The system frequency without AGC of the weak system model is out of range for normal control.

Case 3: Step decrease of solar power by 300 MW with outage of the 700 MW of conventional power plant

The results of frequency responses due to the worst case scenario, the step decrease of 300 MW solar power with outage of the largest online-generator (700 MW) are presented in Figure 12, without the AGC, the steady state frequency are dropped from 50 Hz to 49.85 Hz with 0.15 Hz of difference, 49.65 Hz with 0.35 Hz of difference, and 49.30 Hz with 0.70 Hz of difference for strong, near actual and weak system model, respectively. All of 3 models are out of range for normal control.

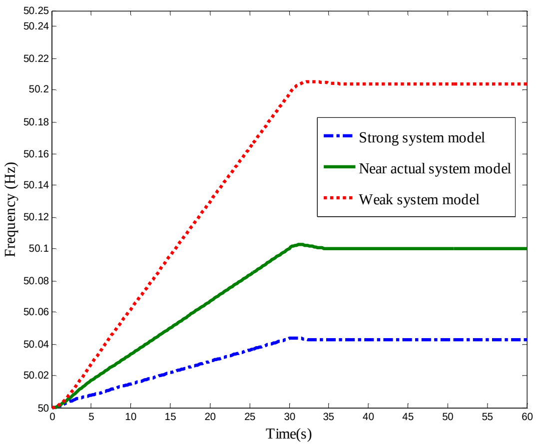

Fig. 11. Frequency response due to step increase of solar power by 300MW in 30 seconds.

From the simulation results, solar development plan in Thailand needs the dynamic model to evaluate frequency response; however the accurate real-time model is very complicated to develop under the actual conditions. In addition, most of frequency response researchers are not interested in the effect of solar power plant in long term planning.

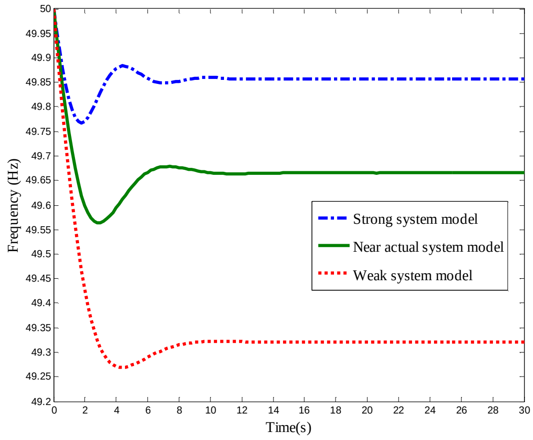

Fig. 12. Frequency responses due to step charge of solar power by 300 MW with outage of the largest generator 700 MW.

8. CONCLUSIONS

The enhancing sustainable energy development introduces large solar power plants to Thailand's power system therefore studying their impacts on system stability are important for regulator and system operator to make the regulation and prevention plan. This paper proposes the RIPT frequency response model to analyze the frequency deviation due to uncertain solar power. The model is simulated the load frequency control system for 105 generators divided into 4 groups which consist of 47 hydro power generators, 17 thermal generators, 14 EGAT's combined cycle generators and 27 IPP's combined cycle generators. The time dependent RIPT frequency response model is examined by a peaked load operating condition which is operated all of generators in the systems under multi-scenario of solar power changes with outage of a 700 MW of conventional generator.

The results show that in case of solar power change at 300 MW instantaneously, and slowly change at 300 MW in 30 seconds, the frequency deviation of the strong system model and the near actual model stay in normal frequency control. However, in case of the weak system model, frequency deviation is 0.2 Hz and out of range for the normal control. The near actual model can be handled the 300 MW of solar power step change however when the 700 MW biggest unit outages, normal frequency control is out of range. In the next part of the paper will present the frequency response for next decade solar power development plan in Thailand by using the proposed real-time automatic individual power plant parameters tuning frequency response model.

ACKNOWLEDGEMENT

This research was supported by Faculty of Engineering, Thammasat University.

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