Frequency Response for Next Decade Solar Power Development Plan in Thailand Part 2: A Case Study of PDP 2010 Version 3

C. Sansilah, P. Bhasaputra and W. Pattaraprakorn

Abstract— *This paper studies the impacts of large solar power installations on frequency responses of Thailand's power system according to the power development plan (PDP 2010 version 3) by considering three levels of electrical demand; light load, partial peaked load and peaked load; during available solar power generation. In addition, the selected actual solar power generation patterns from large solar power plant are collected to analyze the average solar power output and maximum deviation. The frequency responses are simulated by using the proposed real-time automatic individual power plant parameters tuning (RIPT) frequency response model to indicate the effect of installed solar power plants from PDP with various cases in term of the maximum frequency deviations for the next fifteen years. Furthermore the system frequency deviations of each cases are the results of combination of different power plant types and parameter settings, which are compared to each other and the frequency standard control. Finally, the outcomes can be utilized to make prevention plans in order to maintain power system reliability and security for sustainable power development plan with solar power plants.*

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

1. INTRODUCTION

Thailand Power Development Plan 2010 - 2030 (PDP 2010 version 3) is targeted on increasing share of solar power by 3,940 MW at the end of 2030, in order to successfully develop sustainable energy production [1-2]. However, the new challenges for power system operators are to control and manage system reliability for both short-term and long-term, the system operators have to consider the influence of uncertain solar power generation which may significantly affect to power system reliability especially in term of frequency deviation. Generally, decreasing solar power generations due to weather conditions, will drop the system frequency because of the imbalance between generation and load. Normally, Thailand's power system is controlled frequency at 50 Hz by the automatic generation control (AGC). The ability to maintain frequency of the system depends on characteristics of the power system at considering time which concerned the combination of online-generator types and its parameter settings. Therefore, the frequency response simulation is necessary to investigate effective solar power deviation that the results can support system operator to make prevention plan in order to maintain power system reliability.

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 are 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.

The main purpose of this study is to investigate impact of large solar power integration on Thailand's power system through considering frequency deviation. This paper is a second part to illustrate simulation result of a PDP 2010 case study and another related part to introduce the RIPT frequency response model formulation. In this study, various cases of integrations of conventional power plants and solar power plants from the PDP 2010 version 3 will be simulated through the RIPT frequency response model.

This paper consists of six sections. Section 1 introduces the research of frequency control. Section 2 shows the collected data of the selected actual solar power generation patterns from large solar power plant and the analyzed data for frequency response simulation. Then PDP 2010 version 3 is described in section 3 and section 4 explains more details about three levels of electrical demand during available solar power generation and annual solar power deviation of PDP then the simulation results of the frequency response in term of the maximum frequency deviations for the next fifteen years are discussed in section 5. Finally, the conclusion

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of this study and recommend on power system reliability and security for sustainable power development plan with solar power plants will be presented in section 6.

2. IMPACTS OF SOLAR POWER PLANTS

Solar power plants convert the solar irradiance of the sun into electric power. Thus, any variations in the solar irradiance lead to fluctuations in the generated output power. The time period of fluctuations can range from few seconds to few hours depending on the wind speed, the type and size of passing clouds, and the area of the solar power plant. Therefore, the time period for collecting the solar power output should be accurate for frequency response simulation. Figure 1 shows the fluctuation of solar power output every minute during daytimes. The different lines represent solar irradiance for different weather and the sky conditions such as sunny, partly sun and cloud and fully cloud. Depending on the aggregation level and geographic diversity, solar plants output can decrease/increase within a range of 20%-80% of its capacity at 1 min interval [3].

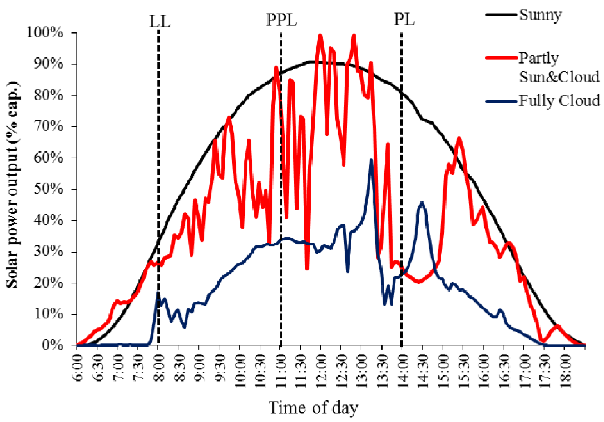

Fig.1. Variation of solar power output

Table 1. The average solar power output and the maximum deviation

Solar power output	LL (8:00) (% cap.)	PPL (11:00) (% cap.)	PL (12:00) (% cap.)
Average	22.92	62.09	48.15
Maximum deviation	16.71	45.28	35.12

There are several factors that dominate the severity of solar power impacts on the power system, some of these factors are type of clouds, location of the solar power plant, installed capacity of the solar power plant, characteristic of the solar power plant and characteristic of the power system. The purpose of this study is to investigate solar power impacts for the preventive planning and the worst case assumption of solar power generations. The maximum deviations of solar output at each considering time, light load at 8.00 (LL), partial peaked load at 11.00 (PPL) and peaked load at 14.00 (PL) as shown in Table 1, are used to calculate the step changes of solar powers, based on installed capacity of solar power from the PDP 2010 version 3.

3. POWER DEVELOPMENT PLAN OF THAILAND

Thailand's Power Development Plan (PDP), is the master investment plan for power system development. The themes of PDP 2010 substantially focused on security and adequacy of power system, environment concern, energy efficiency and renewable energy promotion. The PDP targeting on increasing share of renewable energy and alternative energy uses by 25 percent instead of fossil fuels within the next 10 years, new projects of renewable energy development are initiated into PDP2010 version 3. Hence, at the end of 2030, total capacity of solar power will be up to 3,940 MW or 5.6 percent of total generating capacity in the power system comprising total existing capacity amounting 138 MW, total added capacity of renewable energy of 3,802 MW [1] that is equal to 2,755 percent increasing as shown in Table 2 and Figure 2. According the PDP 2010 version 3, this study will investigate the impacts of increasing uncertain solar power.

Table 2. Capacity of renewable energy as PDP 2010

Type	As of 2011	Additional (2012-2030)	Grand Total
Solar	138	3,802	3,940
Wind	3	1,974	1,977
Hydro	5,323	5,804	11,127
Biomass	747	2,602	3,350
Biogas	106	46	152
MSW	21	352	374
Tides &Waves	2	-	2
Total	6,340	14,580	20,920

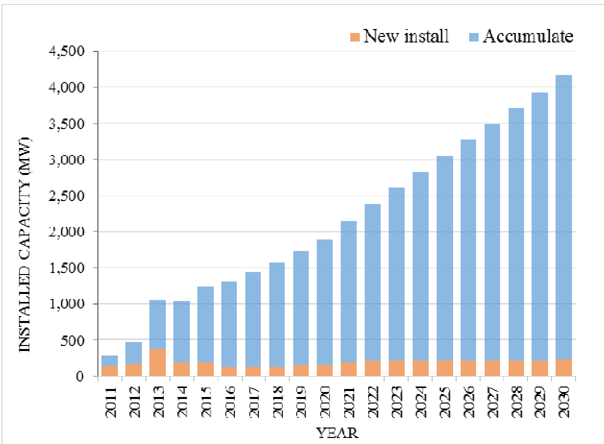

Fig.2. Capacity of solar power from PDP 2010 version 3

4. PDP 2012 CASE STUDY

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.

Generators 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 response model of Thailand's power system is used to simulate the frequency of 3 operating conditions as following.

1) Light load operating condition (LL)
2) Partial peaked load operating condition (PPL).
3) Peaked load operating condition(PL)

The summary number of operating generators of each case shows in Table 4.

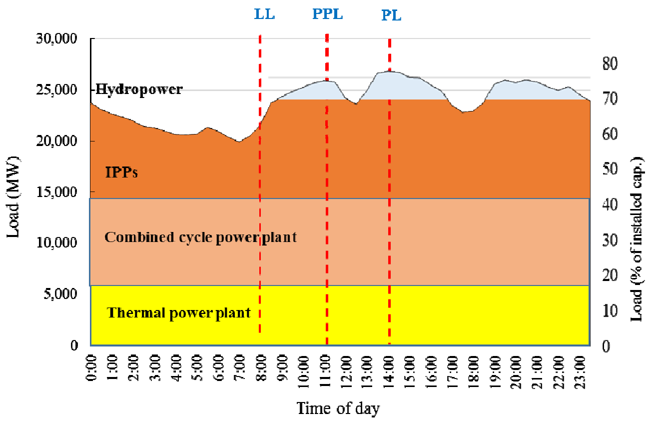

Fig. 3. Power plant operation base on electricity demand.

Table 3. Solar power deviation of each case study

Year	Total cap. (MW)	Solar cap. (MW)	Maximum step change of solar and load combination (MW)					
			LL		PPL		PL	
			Decrease	Increase	Decrease	Increase	Decrease	Increase
2014	39,542	860	179	113	347	427	292	310
2015	43,157	1,051	215	143	429	517	358	378
2016	45,530	1,181	239	163	485	578	403	424
2017	47,240	1,311	262	183	542	638	448	470
2018	48,329	1,441	285	205	600	697	493	515
2019	51,386	1,592	314	228	664	768	546	569
2020	50,389	1,743	338	254	733	835	599	622
2021	52,912	1,944	375	286	821	928	668	692
2022	56,135	2,164	415	321	917	1,031	745	770
2023	56,732	2,384	453	358	1,016	1,130	822	847
2024	59,509	2,604	492	393	1,112	1,232	898	925
2025	60,477	2,824	531	430	1,210	1,332	975	1,002
2026	64,007	3,045	571	464	1,306	1,435	1,051	1,080
2027	64,979	3,266	609	501	1,404	1,535	1,128	1,158
2028	67,012	3,487	649	537	1,501	1,637	1,205	1,236
2029	69,358	3,710	688	573	1,599	1,739	1,283	1,314
2030	70,686	3,940	729	611	1,701	1,844	1,363	1,395

Table 4. Number of on-line generators of each scenario

Group of generators	Number of on-line generators		
	LL (8:00)	PPL (11:00)	PL (14:00)
Hydropower	-	20	47
Thermal	17	17	17
Combined cycle	14	14	14
IPPs	15	27	27
Total	**46**	**78**	**105**

Solar Power Variation Based on PDP 2010

The assumption of solar power change for the simulation based on installed capacity of solar power plants according to the PDP 2010 version 3 is presented in Table 3. In case of LL, the average solar power output is 22.9 percent of installed capacity and the maximum deviation is 16.71 percent of install capacity. Similarly, in case of PPL and PL, average solar power outputs and maximum deviations are presented in Table.1

5. SIMULATION RESULTS

In normal conditions, the system frequency is controlled within $\pm$0.1 Hz either side of 50 Hz then out of this range are emergency control range. This section presents the maximum frequency deviations of the LL, PPL and PL operating conditions due to combination of solar power and load changes based on the solar power installed capacity of each year and the maximum solar power deviations as shown in Table 3.

Frequency Response of Light Load (LL)

The LL conditions occur at 8.00 o'clock that the solar power plants can produce the average power outputs 22.92 percent of their installed capacities then the power changes are less than in case of PPL and PL. Considering Figure 4, in case of solar power decrease, the steady state frequency of year 2020 and 2030 are out of normal control range. On the other hand, in case of solar power increase, only the frequency of year 2030 is out of normal control range while the frequency of year 2020 is stayed in normal control range because of load increase at this moment. Note that the AGC is needed in case of the frequency out of normal control range.

Frequency Response of Partial Peaked Load (PPL)

In PPL, steady state frequencies of all years are out of normal control range (as see in Figure 5) because there are large changes of solar power and load in this moment. In this study, the worst case of solar power fluctuation, 73 percent of its capacity is assumed although in real situation, the occurrence probability are less than 0.1 percent. However, the frequency of year 2014 will be in normal control range in case of the maximum fluctuation of solar power less than 30 percent of its install capacity.

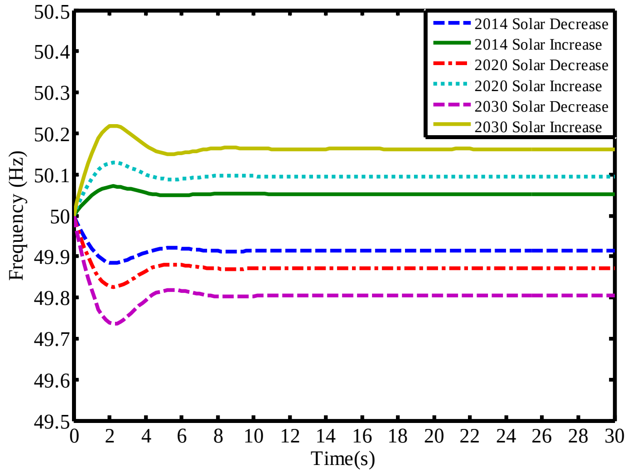

Fig. 4. Frequency response of LL for the years 2014, 2020 and 2030.

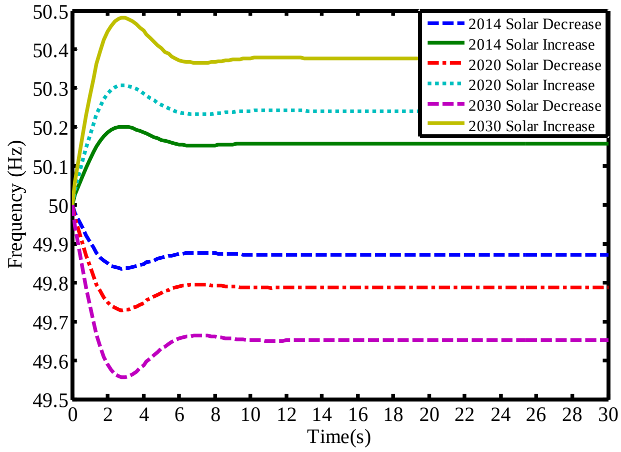

Fig. 5. Frequency response of PPL for the years 2014, 2020 and 2030.

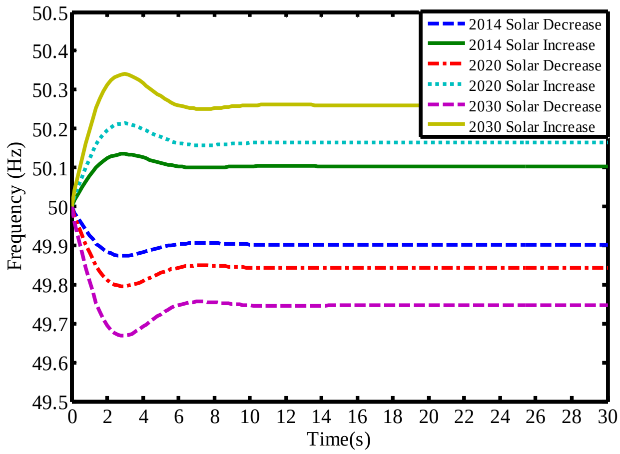

Fig. 6. Frequency response of PL for the years 2014, 2020 and 2030.

Frequency Response of Peaked Load (PL)

The PL operating condition represents for stronger power system because there are more numbers of online-generators can be handle power changes. In year 2004, the frequency deviations due to change of solar power and load are less than normal control allowance while the frequencies for year 2020 and 2030 are out of normal control as seen in Figure 6.

Frequency Response of the Worst Case in Year 2030

The frequency responses of worst cases the in year 2030 which is the highest installed capacity of solar, for LL, PPL and PL operating condition are represented in Figure 7, 8 and 9, respectively. In case of on AGC, the steady state frequencies of all condition are out of normal control range. With AGC control the frequencies are regaining to nominal frequency (50 Hz) with in 15, 13 and 18 seconds for LL, PPL and PL, respectively.

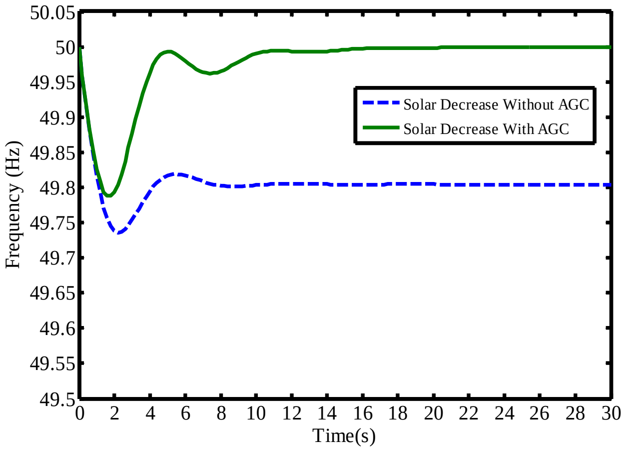

Fig. 7. Frequency response of LL with and without AGC.

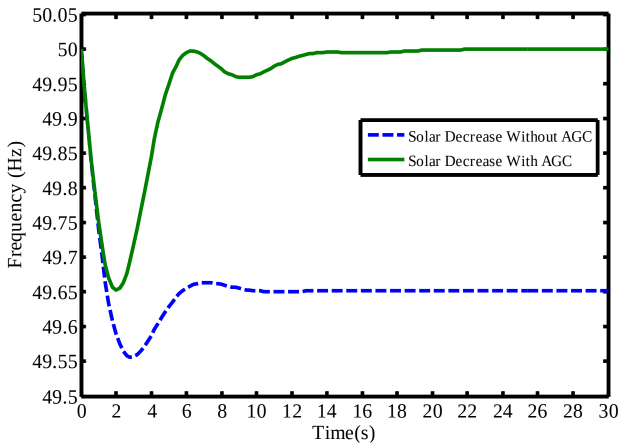

Fig. 8. Frequency response of PPL with and without AGC.

Considering on Figure 8 which represents for frequency response of PPL due to step decrease by 1,701 MW of solar power in the year 2030, the total 3940 MW of solar power plans are installed. The steady state frequency without AGC is dropped to 49.64 Hz which is out of normal control. To keep the frequency back in the control range, the AGC has to control all conventional online-generators and produce more power to compensate the decrease of solar power which requires 13 second for this response.

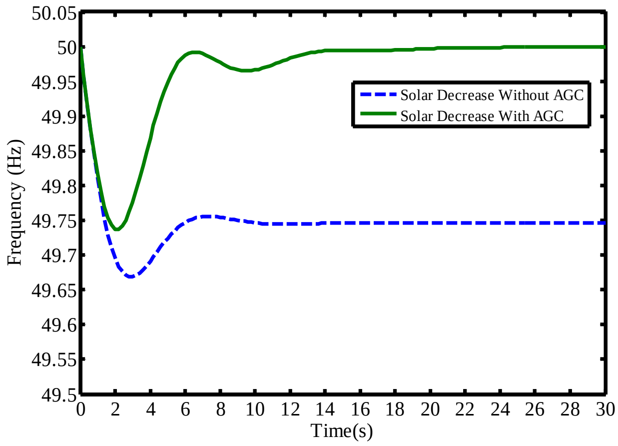

Fig. 9. Frequency response of PL with and without AGC.

Frequency Response for Next Two Decades

For the next two decades, the maximum frequency deviations of Thailand's power system have probably incremental trends due to influence of incremental solar power capacity as shows in Figure 10. In addition, the simulation results show that the highest frequency deviations can be observed at the PPL which presented larger step change of solar power and load while the number of online-generators for reserve power is less than PL condition. In case of LL condition, maximum frequency deviations are stayed in normal control range ($\pm$0.1 Hz) during years 2014-2022 after those similar maximum frequency deviations are out of normal control range. In cases of PPL and PL, all of the maximum frequency deviations of years 2014-2030 are out of normal control range. Moreover, comparison between year 2014 and year 2030, the maximum frequency deviation is increased 0.22 Hz as a results of increasing solar power capacity by 3,080 MW. However, this result is not considered the diversity of solar power outputs in the different locations.

The increasing of solar power plants will lead the frequency response of Thailand's power system to the weakest system because the total inertia of the system is reduced by the ratio of total solar power plants with total power plants. However the Thailand's power system can maintain system reliability and security for sustainable power development plan with solar power plants by realizing the ratio of total solar power plants with total power plants but impossible for realistic PDP. The further study of solar power plant controller especially modern inverter is needed to handle the fluctuation of solar radiation for frequency deviation. Finally, the additional regulation for solar power plants in term of energy storage requirement will be studied to optimize between incremental cost of energy storage and the system stability.

6. CONCLUSION

This paper presents frequency responses of Thailand's power system for the next two decades by considering influences of solar power integrations according to the PDP 2010 version 3. The developed RIPT frequency response model which is time dependent model based on characteristics of online-generators at specific time, is used to investigate impacts of solar power deviation. The simulations are performed through multi-scenarios of power plant operating condition, the light load (LL), the partial peaked load (PPL) and the peaked load (PL) with the assumptions of maximum solar power deviations. The results present the frequency responses of each operating conditions for 16 years of the PDP. In addition, the results show that maximum frequency deviations of Thailand's power system have probably incremental trends due to influence of incremental solar power capacities. The highest frequency deviation is 0.377 Hz which can be observed in PPL operating condition in the year 2030 with the 3,940 MW installed capacity of solar power plant.

Actually, these impacts of solar power deviation can be solved by application of various energy storages. Finally, the further studies in more details about long term planning of solar power plant for frequency response are very important to maintain reliability of the power system in critical period as well as PPL, system operators have to provide reserve power to ensure that there is enough governing and load response to keep the frequency in the normal control range. However, long term protective planning is needed as well as the regulation for solar power plants.

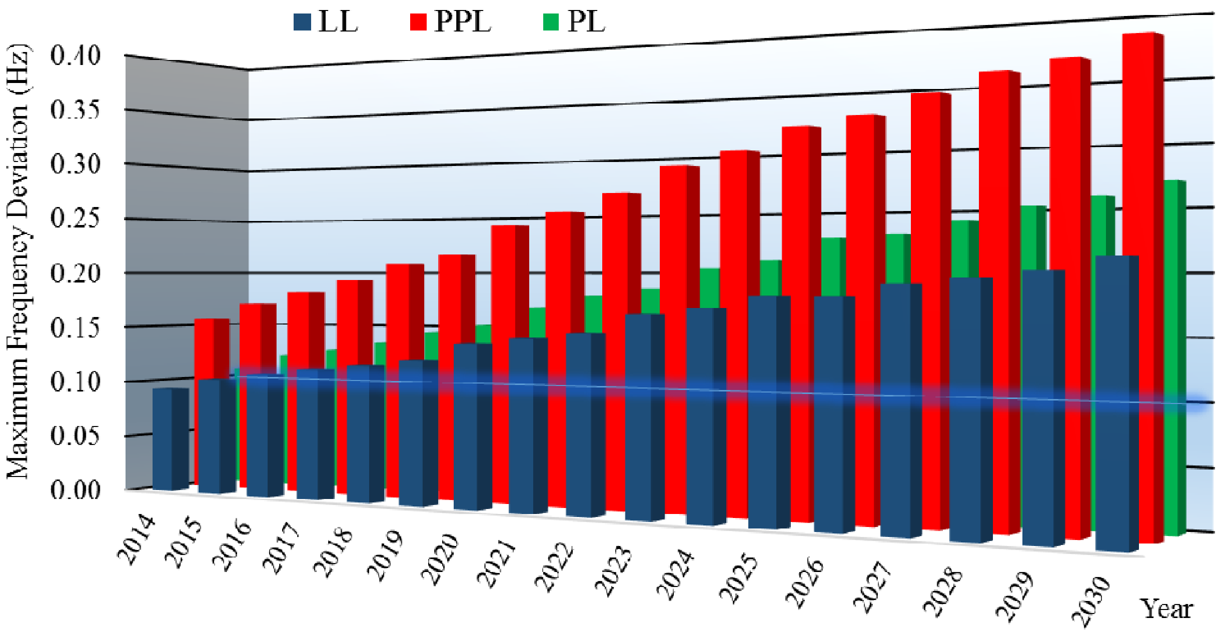

Fig. 10. Simulation results of maximum frequency deviations divided by operating condition through 20 years of PDP 2010.

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