Determination of PV and Wind Power Plant Penetration into a Power System: a Case of Java-Bali System

Musthafa Abdur Rosyied[1], Sarjiya[2], Lesnanto Multa Putranto[3*], Izzuddin Fathin Azhar[4], and Eko Yudo Pramono[5]
PT. Hutama Karya, Indonesia1
Department of Electrical and Information Engineering at Universitas Gadjah Mada, Indonesia2,3,4
PT. PLN, Indonesia5
**Corresponding Author Email: lesnanto@ugm.ac.id*

Abstract -- PT. PLN (Persero) has planned to develop a new renewable energy system which has a minimum energy mix of 23% in 2025 and 31% in 2030. An intermittent renewable energy plant, which is uncontrollable and unpredictable, will begin to be massively used. Being associated to the intermittent nature of the of intermittent renewable energy source (IRES), adequate system flexibility is necessary. This study determined the penetration level of IRES generating unit using the systems load and existing generating unit ramping rate characteristic, IRES generating unit ramping rate and system technical minimum load (TML) on the Java-Bali System based on the 2017 operation condition. The results showed that the TML value of the operating plant was 12164,69 MW. The ramping up and down capabilities of the conventional power plants were 945.04 MW / 30 min and 4006.08 MW / 30 min where ± 5% of penetration of IRES was still applicable for the Java-Bali System.

Keywords:
Intermittent Renewable Energy Source
Ramp rate
System Flexibility
Technical Minimum Load

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I. Introduction

In 2017 the peak load of Java-Bali system reached 25.325 MW. It happened at 6 pm on September 15, 2017. The peak load increases each year following the increase in electricity demand [1]. The customers number of Java-Bali system is predicted to increase by 2.031% per year during 2017-2026. The direct consequences of the customer increase are the peak load increase and the required additional generating units. It was planned to build around 39.1 GW during 2017-2026 [2].

The generation expansion planning (GEP) does not rely on the thermal generating units. It considers the environmentally friendly technology, which is the renewable energy source (RES) generating units. The consideration of RES generating unit technology is in accordance with the Law Number 16 Year 2016 concerning the ratification of the Paris Agreement by the Indonesian government, expressing the commitment to decrease greenhouse gas emission by 29% in the Year 2030. This commitment is realized by increasing the proportion of the RES generation. In addition, Government Regulation Number 79 Year 2014 concerning the National Energy Policy became the base for the establishment of the PT. PLN (Persero) plans to achieve the RES generation composition in the energy mixed by 23% in 2025 and 31% in 2030 [2].

RES generation technology comprises dispatchable and non-dispatchable generating units. Dispatchable generating unit includes the hydro, geothermal, biomass, biogas, and biodiesel units, while the non-dispatchable units cover the solar, wind and tidal generating units. The non-dispatchable units may also be called as intermittent renewable energy resources (IRES) [1]. In 2016, the hydro and geothermal power plants contributed by 8.48% and 4.15% of the total of generation in Java-Bali System [3]. These numbers were still much lower than the targeted 23% of RES generation in the energy mixed by 2025. Consequently, it is very important to consider the IRES generation to achieve the targets.

It is inevitable that the development of IRES generating units is continuously increasing. However, its integration into the power system must consider the supply-demand balance and the existing system flexibility. The existing electric power system must be able to respond to load change and the IRES generation variation. The IRES generation units are greatly influenced by their intermittent characteristics.

Massive penetration of IRES units into a system increases the load and generation variations, and consequently needs to be properly studied before implementation [4].

Some studies have been conducted to measure the impact of IRES integration planning to the existing power system. Reference [5] explained a strategy to plan the power system using 100% RES in Europe. The storage technology was also installed to support the system flexibility. Another integration planning in California electricity grid has been investigated in [6]. Load following analysis, ramping requirement analysis, day ahead error forecast and supporting technology option were described on that study. A new planning criterion for including the intermittency risk has been proposed in [7]. RES generation Levelized Cost and Levelized Avoided Cost of New Generation Resources were presented in [8]. Energy cost should be calculated and evaluated annually, especially for the IRES generation where the technology cost was still relatively high, as presented in [9].

Load and generation variations become more sensitive when there is a penetration of IRES generation, therefore it needs a meticulous planning to anticipate any undesirable impact of the IRES penetration into a specific power system. This paper proposes a method to measure the penetration level using the data of system operation condition. The penetration level of each power system is unique depending the power system flexibility, which covering the load and IRES generation variations, the existing generation system ramping up and down capability, and the system technical minimum load (TML).The Java-Bali system, which is the largest power system in Indonesia, was taken as the case study. The related operation condition and system infrastructure were based on the data in October 2017. The results showed that after a certain penetration level, the load and IRES generation variations were increasing and the system load profile was very close to the system TML. In this study, the load and IRES generation variations were observed within 30 minutes resolution. As a result, the IRES penetration level of 5% and 20% could be applied into the system if the automatic generator control was upgraded.

II. Intermittent Renewable Energy Source Penetration Impact

There have been some previous studies on IRES penetration with a large capacity in several countries. For example, California Independent System Operator (CAISO) in the USA conducted a study on the penetration of wind and solar generation as the IRES generation case in 2007. The total penetration of wind and solar generation were respectively 6700 and 4100 MW, contributing around 20% of the total capacity. The researcher in [10] was focusing on IRES generation penetration impact on load ramping rate and overgeneration problem. The result shows that the morning load ramping rate increased from 926 MW/3 hours to 1529 MW/3 hours and the evening ramping rate increased from 427 MW/3 hours to 984 MW MW/3hours. The load ramping rate increase affected the system ramping rate requirement from ±15 to ±25 MW/minutes, and furthermore affected the existing generation system operation, as described in [10]. To evaluate the impact of the IRES penetration to the system, some affecting variables need to be considered as follows.

A. Net Load Profile

Net Load profile is defined as the aggregation between the original load profile and the IRES generation profile. Since the IRES generation profile is uncontrollable, the net load approach needs to be considered to provide the new load profile, which should be supplied by the existing dispatchable generators. The output power of IRES generation is calculated as the negative load, so it will reduce the power consumption from the conventional generator, as given in Fig. 1.

As seen in Fig. 1, the net load is obtained by subtracting the power resulted by the wind generation and the solar generation from the load, as explained in [11].

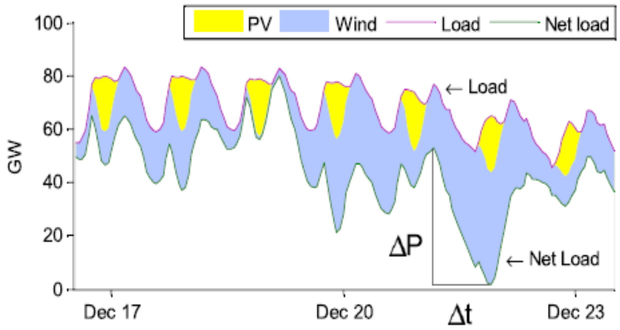

FIGURE. 1.
Net Load System Illustration [4]

Based on the net load profile illustration in Fig.1, the IRES generation will increase the load ramping rate so that system ramping requirement also increases. IRES generation will affect the generation profile of the existing dispatchable generation system for specific time slot. However, the base load generation cannot be flexibly changed. For that reason, the capacity of IRES generation should be limited in order not to reach the operation limit of the base load generation system [12]. Net load system value is represented in the equation (1).

$$NL(t)=L(t)-W(t)-S(t) \quad (1)$$

where,
t = time,
NL = net load system,
W = wind generation power output,
S = solar generation power output.

B. Ramp Rate

Ramp rate is defined as the rate of power changes in a specific time slot [4]. Ramp rate can be a variable for representing the load or generator characteristic. In a generator, ramp rate from a generator unit is defined as the capability of this generating unit to increase or decrease the output power to response the load variation [13]. The ramp rate for each generator varies depending on the size and technology. Equation to represent the ramp rate is given the equation (2).

$$\Delta P(t)=P(t)-P(t-1) \quad (2)$$

where,
t = time,
h = certain time interval,
ΔP(t) = ramp rate time,
P = certain power generation.

The ramp rate characteristics for each type of generator are presented in Table I. Based on the existing generation unit, the hydro and gas units have the greater capability to follow load variation. The ramp rate control can be set automatic or manual depending on the control design. For manual control, the command to change the generator power is the power system operator responsibility. On the other hand, the automatic control will let the generators change their output based on the load variation behavior. The automatic control can be realized using the automatic generation control (AGC) or local frequency control mechanism (LFC) as presented in [14].

Currently, the Java-Bali system uses LFC to perform the automatic control. The hydro and combined cycled units are assigned for LFC mechanism to deal with the power mismatch calculation. The hydro units in Cirata, in Saguling, the combined-cycle unit in Grati, and the combined-cycle unit in Gresik Baru are the units for LFC mechanism in this systems [3]. In this LCF operation, the unit ramping rate capability is needed. The other existing generating units are manually controlled by the power system operator (dispatcher) in PT. PLN P2B Gandul.

TABLE I.
Ramp Rate of Conventional Generator Characteristic in Java-Bali System [1]

Generator Types	Ramp Rate Value
Coal	1-5 MW/minute
Combined Cycled	5-8 MW/minute
Gas	5-8 MW/minute
Hydro	20 MW/minute

C. Technical Minimum Load

Technical Minimum Load (TML) is the minimum power output of generating unit when operating. Normally, a generator will produce the output power between the rated capacity and the TML. Since the system is operated by combining the generating units power output, the system will also have the TML. The system TML is the aggregation of all the individual TML of the generating units. For example, in the Java-Bali system, it consists of base load generation such as coal generation units, as presented in [13]. Being associated to the IRES unit characteristic, there must be operational reserves of conventional generating units which are ready to operate and to compensate for the frequency change and generation power loss. Reserve of conventional generating units should be ready if the IRES generating unit power output is less than the prediction. For that purposes, some generators are not operated at the rated capacity, 5-10% reserve are provided. On the other hand, when the IRES unit is over generating the power output, the conventional generator should reduce the power output. In reducing the output current of the generation power, the TML should be considered as an operational constraint. If the output power of a conventional generator is below the TML value, then the generator unit will shut down [1].

D. Duck Curve

Duck curve represents the net load from systems which are getting lower and lower over the course of a specific time-slot. Usually it will happen during the daytime when the system is integrated to the large-scale solar unit, as described in [12]. From the duck curve phenomena, the IRES integration would cause the operation problem, as described using Fig. 2. It indicates that the load decreases during a specific time slot from 2012 until 2020, then it has the potential to cause overgeneration when it touches the TML value.

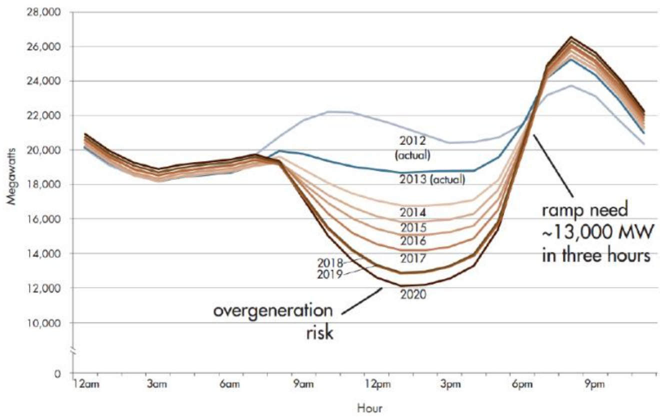

FIGURE 2.
CAISO Duck Curve [12]

E. Automatic Generation Control Needs

According to the Western Electricity Coordinating Council (WECC), the Automatic Generation Control is a tools/technology which automatically adjusts/controls the generation of each region from the control center to maintain the system frequency within permissible range. Based on the CAISO experience, the AGC can be set to response load changes and to change a generator dispatch every 5 minutes [10]. AGC can support the IRES penetration in a power system [15]. However, not every power system in the world has activated the automatic control.

III. METHODOLOGY

The primary data of this research were directly obtained from PT. PLN (Persero) Load Control Center (P2B) Java-Bali. The primary data include the IRES penetration planning location, the existing generator unit's TML, the generating unit's maximum power output, the generating unit's ramp rate, the substation load profile in 30 minutes resolution, and the generation unit's scheduling. Furthermore, the weather data were obtained from the national weather data center, called BMKG [16]. The evaluation document of Java-Bali system in 2016 [3][17] and the production data of the existing 1 MWp solar power in Cirata were used for validation purposes. The test system to be used was the modified 500kV Java-Bali test system having 26 stations. The planning of IRES penetration point in the Java-Bali system is presented in Table II, the substation location as connection point in Java-Bali system is shown in Fig. 3, whereas the flowchart of this research is presented in Fig. 4.

TABLE II.
IRES Generation Penetration Planning in Java-Bali System

No.	IRES penetration's Location	IRES Generating Unit Types	Installed Capacity
1	North Bekasi	Solar Power	600 MWp
2	Cirata	Solar Power	200 MWp
3	Sukabumi and South Banten	Wind Power	500 MWp
4	Tegal	Hybrid Wind and Solar Power	220 MWp
5	Samas	Wind Power	70 MWp
6	Tuban	Hybrid Wind and Solar Power	140 MWp
7	Negara	Solar Power	100 MWp
8	Amlapura	Solar Power	100 MWp

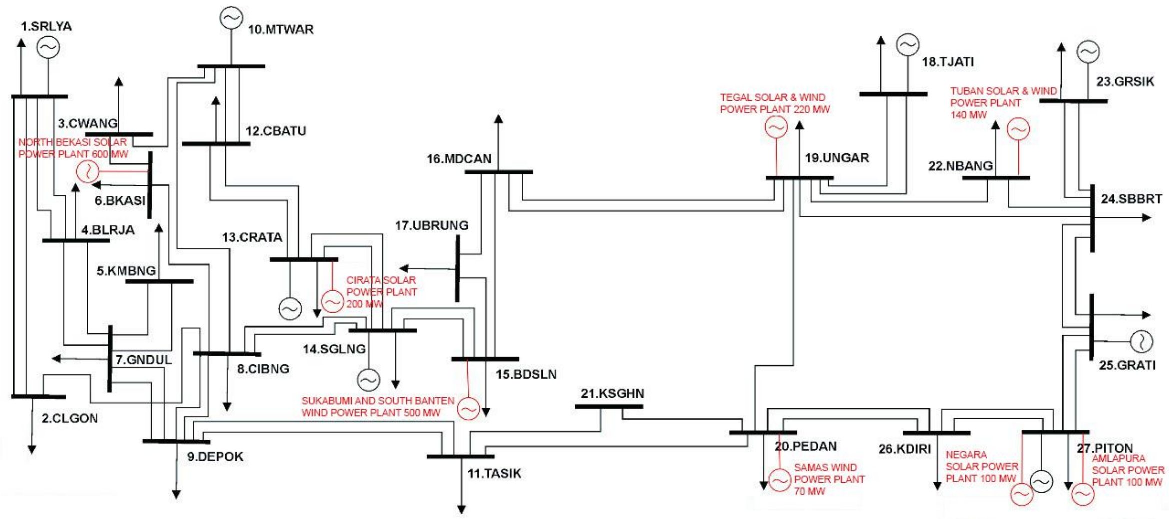

FIGURE 3.
Illustration of IRES Penetration on Java-Bali System

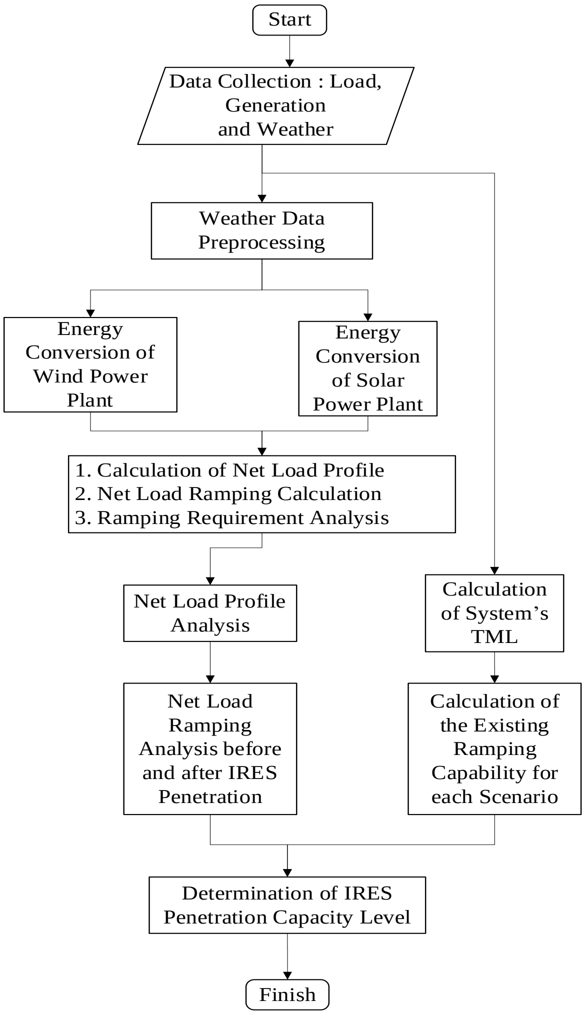

FIGURE 3.
Research Flow Diagram

As can be observed in Fig. 4, to get the maximum penetration, the data of load, generation, and historical weather were needed. The existing load profile, the existing generation operation data and the historical weather forecast data would be at least for 30 minutes resolution. The smaller the resolution, the better the accuracy that could be get. The following step was the generation of the IRES unit output. The simulation method to obtain the results has been conducted by considering the weather data in every IRES planning location [15]. By calculating the net load profile, the ramping load requirement for every penetration level scenario was obtained. After calculating the systems technical minimum load and calculating the generation system ramping up/down capability for every timeslot, the adequacy of the ramping requirement could be known by comparing the ramping load requirement and the system ramping capability. Moreover, the net load profile for every penetration level should be checked with respect to the corresponding TML of the system.

The maximum penetration was achieved before the generation system's ramping became smaller than the net load's ramping or the bottom point of net load profile became smaller than that corresponding system's TML. To demonstrate the effectiveness of the proposed method, three scenarios were simulated in this work. Since only the LFC being working for the automatic control, the full potential of IRES generation could not be penetrated into the system due to the inadequate system's ramping rate capability. For that purposed, the scenarios were developed to have different automatic control scheme. Those scenarios were presented as follows.

A. *Full Potential*

Full potential scenario considered all generating units to participate in the automatic control scheme. In this version, the AGC infrastructures should be installed in all generating units. Using this option, the full potential system ramping rate can be utilized.

B. *Fast Response*

In this scenario, only the fast unit generating could participate in the automatic control. Those generators types are combined-cycle, gas and hydro power plants. Those generators have high ramping capability.

C. *Existing LFC*

Existing LFC scenarios only considered the hydro units in Cirata and Saguling. The hydro units have not only high ramping rate but also high inertia.

IV. Result And Discussion

A. *System's TML Calculation*

The existing generation in Java-Bali System includes the hydro, gas, combined-cycle, and coal power plants with different performances based on the generator age, contract condition of Independent Power Producer (IPP) and other factors. It is essential to know the capability of the generator and system's TML.

The system's ramping calculation was based on the generation operation on October 15, 2017. Calculation of ramping down generation using the data of generation at 11.00 and 18.00 based on the gap between the committed generation and the load profile. The largest gap occurred on 11.00 while the smallest was on 18.00, as presented in Fig. 5.

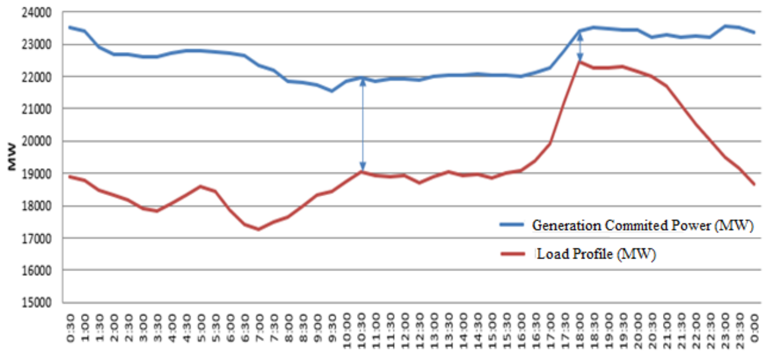

FIGURE 4.
Power Supply vs Total System Load

The number of generators on each time-slot were different because the number of operating generators were different between time-slots. For economic purpose, some generators should be shut down following the load profile variation. The result of TML calculation was presented in Table III. Based on the calculation, it can be known that the system's TML occurred at 11.00 when the number of generators off was the largest. The calculated system's TML was 12164.69 MW. The value of the TML was different for each day of operation.

TABLE III.
Off Generation Status and Technical Minimum Load Result

Entities	At 11.00	At 18.00
Number of Generator *Off*	56 Units	48 Units
TML	12164.69 MW	-

The system ramping capability was calculated in every scenario. The results of calculation on the existing generation maximum ramping capability in every scenario can be seen in Table IV, Table V and Table VI respectively.

TABLE IV.
Ramping Capability of Full Potential Scenario

Ramping Generation	Resolution		
	1 Minute	30 Minutes	1 Hour
Ramping down	308.2 MW/minute	2419.46 MW/30minutes	2846.26 MW/hour
Ramping up	551.51 MW/minute	945.04 MW/30minutes	978.24 MW/hour

TABLE V.
Ramping Capability of Fast Response Scenario

Ramping Generation	Resolution		
	1 Minute	30 Minutes	1 Hour
Ramping down	273.92 MW/minute	1248.94 MW/30minutes	1308.94 MW/hour
Ramping up	475.6 MW/minute	620.5 MW/30minutes	620.5 MW/hour

TABLE VI.
Ramping Capability of Existing LFC Scenario

Ramping Generation	Resolution		
	1 Minute	30 Minutes	1 Hour
Ramping down	4.92 MW/minute	4.92 MW/30minutes	4.92 MW/hour
Ramping up	314 MW/minute	314 MW/30minutes	314 MW/hour

B. Determination of IRES Penetration Level

Being based on the penetration planning into the system, the Java-Bali load profile after penetration would change. As seen in Fig. 6, the load level in the afternoon become very low. Penetration planning would be ±5% of the Java-Bali System peak load. The maximum system ramping up, ramping down were increased after the penetration of IRES, as shown in Table VII. Moreover, the average ramping up and ramping down for every time-slot were also increased.

Comparing the system ramping capability and the load ramping in Table IV-Table VII, it is shown that for 5% penetration the system operation was still safe under the full potential scenario but not under the other two scenarios. After checking the ramping up and ramping down for 30 minutes resolution, the generation system could still follow the net load variation. The ramping up required 732 MW/30 minutes while the available ramping up resource was 945.04 MW/30minutes. On the other hand, the ramping down required 768.5 MW/30 minutes while the available ramping down resource was 2419.46 MW/30minutes. However, the AGC infrastructures were required.

In this current situation, Java-Bali system did not have AGC technology, but LFC. The existing generation ramping up and down capability with generation calculating scenario only by LFC obtained values of 314 MW/30minutes and 4.92 MW/30minutes then existing generation lean capability still not be able to follow existing load ramping requirement. However, there were some Java-Bali generators which were still off (around 48 units), 6 units of them were hydro power in Cirata with the capacity of each was around 119 MW. If the generator was rescheduled, for penetration rates of ± 5% IRES generation was still able to be fulfilled.

TABLE VII
Ramping Load Requirement at 5% IRES Penetration

Ramping Load	Before Penetration	After Penetration
Ramp up/30minutes	320 (MW/30minutes)	732 (MW/30minutes)
Ramp up/hour	1483 (MW/hour)	1581.212 (MW/hour)

Ramping Load	Before Penetration	After Penetration
Ramp down/30minutes	660 (MW/30minutes)	768.5 (MW/30minutes)
Ramp down/hour	1537 (MW/hour)	1537 (MW/hour)
Ramp up average/hour	355.76 (MW/hour)	464.15 (MW/hour)
Ramp down average/hour	1272.85 (MW/hour)	1324.06 (MW/hour)

FIGURE. 5.
IRES Generation Penetration Result in ±5% from Peak

To see the effect of more significant penetration, an analysis was carried out with the projection of IRES penetration around ± 20% of peak load. The net load profile of ± 20% penetration can be seen in Fig.7. Ramping load result from IRES penetration ±, 20% of peak load can be seen in Table VIII.

TABLE VIII
Ramping Load Requirement at 20% Penetration

Ramping Load	Before Penetration	After Penetration
Ramp up/30minutes	320 (MW/30minutes)	1970.82 (MW/30minutes)
Ramp up/hour	1483 (MW/hour)	2767.54 (MW/hour)
Ramp down/30minutes	660 (MW/30minutes)	1101.835 (MW/30minutes)
Ramp down/hour	1320 (MW/hour)	2203.67 (MW/hour)
Ramp up average/hour	355.76 (MW/hour)	824.05 (MW/hour)
Ramp down average/hour	1272.85 (MW/hour)	1514.51 (MW/hour)

FIGURE 6.
IRES Generation Penetration Projection ±20% from Peak Load

As indicated in Fig.7, it can be seen that the bottom of the net load profile after penetration was getting lower. An increase was needed for ramping up (per 30 minutes) from 1163 MW/30 minutes (before penetration) to 1970.82 MW/30 minutes (after penetration) in the range 5 pm – 8 pm.

From the comparison of the generator's ramping capabilities and loads, it can be seen that based on the operating data the ramping capacity of generation capability per hour was not able to keep up with the lean upload requirements (after penetration). This condition shows the ramping up and down capability of the generation system were 945.04 MW/30 minutes and 2419.46 MW/30 minutes, while ramping load requirements reached 1970.82 MW/30minutes (ramping up) and 1101.835 MW/30minutes (ramping down). In terms of TML requirement, the ± 20% IRES generation penetration was not violating the limits since it did not touch the current base load of 12164.69 MW.

V. CONCLUSION

To increase the IRES penetration in the system there were some procedure to be evaluated, covering the ramping up and down capability of generating unit, ramping load requirement, the system TML and the generator output control. The very first factor to consider was the ramping requirement. It has been proven that integrating the IRES generation would increase the ramping requirement. It could be proven by the change in the net load profile, especially if large solar power plant were installed in the system.

IRES penetration into the Java-Bali System has dome challenge. First, the increment of the ramping requirement needs to be considered. For 5 % penetration, the ramping up requirement increased from 320 to 732 MW/ 30 minutes, so did for the ramping down requirement. If the penetration increases to 20%, the ramping up requirement would increase into 1970.82 MW/minutes. However, the control infrastructure for Java-Bali system was not adequate to handle the intermittency as can be observed in LFC scenario. For that purpose, the infrastructure should be upgraded to handle the penetration.

VI. FUTURE WORKS

System TML and ramping capability of a system can be changed based on the system operation. Usually the power system operates at the most economical operating point. For that reason, the generators will be shut down during some time-slot. In the considered example, the number of shut-down unit for the Java-

Bali System were 56 units at 11.00 and 48 units at 18.00. If those generators operate, the system's ramping capability would be increased.

For the future work, reformulating the generation scheduling to consider enough ramping capability should be done. Constraints related to the system ramping should be added into the optimization problem.

Basic format for periodicals:

[1] J. K. Author, "Name of paper," *Abbrev. Title of Periodical,* vol. x, no. x, pp. xxx–xxx, Abbrev. Month, year.

Examples:

[2] J. U. Duncombe, "Infrared navigation—Part I: An assessment of feasibility," *IEEE Trans. Electron Devices,* vol. ED-11, no. 1, pp. 34–39, Jan. 1959.

[3] E. P. Wigner, "Theory of traveling-wave optical laser," *Phys. Rev.,* vol. 134, pp. A635–A646, Dec. 1965.

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VIII. Biographies

Musthafa Abdur Rosyied received the B.Eng. degree from Universitas Gadjah Mada, Indonesia in 2018. Currently, he works at PT Hutama Karya. His research interest is focused on power generation planning.

Sarjiya received the B.Eng and M.Eng degrees in Electrical Engineering from Universitas Gadjah Mada in 1998 and 2001 respectively. He received his Ph.D degree in 2008 from Department of Electrical Engineering, Chulalongkorn University Thailand. He has been with Department of Electrical and Information Engineering, Universitas Gadjah Mada since 1999. Currently, his position is the head of department and an associate professor in power system engineering. His research interest includes power system operation and planning, variable renewable energy integration and hybrid renewable energy system.

Lesnanto Multa Putranto received a B.Eng. degree from Universitas Gadjah Mada, Indonesia in 2007, an M.Eng. degree from Chulalongkorn University, Thailand in 2012 and a Ph.D. degree at Hokkaido University, Sapporo, Japan in 2017. He has been working for Department of Electrical and Information Engineering at Universitas Gadjah Mada since 2009. Currently, he is the head of Transmission and Distribution Laboratory. His research interest is focused on analysis, operation, and control of electric power systems. He is interested in renewable energy resource development, real-time monitoring of power systems, and new technology in power system engineering.

Izzuddin Fathin Azhar is a final year student of undergraduate Electrical Engineering program at Universitas Gadjah Mada. His research interest is focused on power system operation and planning.

Eko Yudo Pramono received the B.Eng. degree from Universitas Brawijaya, Indonesia in 1992 and the M.Eng. degree from Bandung Institute of Technology in 2007. Currently, he works at PT PLN (Persero) Indonesia. His research interest includes power system operation and control.