Investment Assessment using Monte Carlo Method for Power Grid Project in Jawa-Madura-Bali System

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Abstract— **The 35,000 MW project, which the Government of Indonesia declared in 2015, was a massive development of a new power plant installed in the Indonesia power system. Along with this 35,000 MW project, there are 108,000 MVA development of new substations and 46,000 km of new transmissions, which benefit and impact the future of the Indonesian power system. Currently, 35,000 MW projects are rapidly studied and discussed, but there are none in-depth-studies for the relation between 108,000 MVA and 46,000 km of circuit projects with 35,000 MW project itself. This paper discussed several points: the progress projects and their impact on the power system, quantify the economic benefit of each power plant, substation, and transmission project. The Monte Carlo simulation performs to describe the uncertainty conditions from investment cost, capacity factor/loading, generation production cost, and electricity sales tariff. The simulation can produce a range of economic benefit probabilities from each project. The assessment result showed that several projects were postponed, and a few projects there are not financially viable and are very vulnerable to input variable changes.**

Keywords—cost-benefit analysis, Monte Carlo method, project management, stochastic processes

I. INTRODUCTION

The power system in Indonesia mainly develops, operate, and resell by PT PLN (Persero). Currently, there are other Electric Utility companies, but only PLN is owned by the Government (state-owned). Therefore, any target by the Government of Indonesia for electricity or other electricity-related program goes to PLN. Through the Government of Indonesia (GoI) Regulation Number 23 of 2014, PLN must have a 10-year planning document to develop an optimal and efficient electric power system called the Electricity Supply Business Plan (RUPTL)[1].

In 2015, the Government of Indonesia (GoI) had targeted increasing Indonesian people's wellbeing by increasing the kWh/capita number. To do that, the Government of Indonesia declares 35 GW new generation development projects, 108 GVA, and 46,000 km-circuits of new transmission development projects. Even though the 35 GW projects were more prevalent politically, in the sight of Power System development, the 108 GVA and 46,000 km-circuits projects benefit and impact the power system. They should be considered as necessary as the 35 GW projects. Several studies and discussions about 35 GW projects were done along with the demand projection re-assessment due to higher demand projection, starting from RUPTL 2015-2024[2]. The status of the 35 GW electricity project is updated every year by issuing RUPTL 2016-2025 up to the RUPTL 2019-2028 [1][3][4][5].

The purpose of this paper is to conduct an assessment related to the continuation of the 35 GW project with consideration of uncertainty consisting of external variables such as investment costs, capacity factors, operating costs, tariffs, and energy not served (ENS) costs. The paper is expected to get information on the feasibility of projects carried out by PLN concerning the 35 GW project. So far, the calculation of project feasibility is still using assumptions that are single values. To conduct the assessment, it will calculate the sensitivity analysis of the ongoing project in the 35 GW electricity project, including transmission and substation project with the external variable condition. Sensitivity analysis to describe uncertainty using the Monte Carlo method.

The Monte Carlo simulation has several advantages over other numerical methods. To begin, it is simple to use. In most cases, if the stochastic process model's sample routes can be simulated, the value can be calculated. Second, its convergence rate is often independent of the problem's dimension. As a result, using the Monte Carlo approach to problems is frequently appealing.

This paper will focus on projects in the Jawa-Madura-Bali System because currently, the most extensive electricity system in Indonesia is the Jawa-Madura-Bali System, so it will significantly impact electricity investment to be carried out by PLN. However, in the future, it will also pay attention to projects in other locations such as the Sumatra System and East Indonesia System. The Java-Madura-Bali System with a peak load in 2019 of 27,973 MW. Total energy production in 2019 was 194.55 TWh. The existing transmission system in the Java-Madura Bali System uses 500 kV transmission as the backbone and 150 kV transmission, and partly 66 kV transmission and 20 kV voltage for distribution network power evacuation to customers. There are many interrelated projects in the 35 GW program (generation-transmission and substation).

This paper will also look at the linkages into four project categories: projects for power evacuation, reliability improvement, sales increase, and revenue increase project.

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II. Basic Theory

A. Project Management

A project is defined as a temporary endeavor undertaken to create a unique product or service. Project management is defined as applying knowledge, skills, tools, and technique to project activities to meet project requirements[6]. Project management, in classical terms, is intended to achieve the goal of the project target measured by time, scope, and cost. But for today, project management aims to fulfill the intended benefit of the project. Today's project constraint is not only limited to time, scope, cost, and quality but also includes risks and resources. So, implementation project management is intended to achieve the project benefit within specified constraints. During an implementation project, the project life cycle is existing and is defined as series of phases that a project passes through from its start to its completion.

Project phases are a collection of logically project-related activities that culminates in completing one or more deliverables. During each phase of the project life cycle, a stage-gate should be filled to move to the next stage. In each step, there is a milestone that should be achieved in order for the project to move to the next phase. The project life cycle in PT PLN (Persero) is defined into five phases shown in Table I.

TABLE I. Project Phasing in PT PLN

No	Project Phase	Stage-Gate Milestone
1	Initiation	RUPTL Published
2	Planning	Feasibility Study Finished
3	Pre-Implementation	Contract effective date
4	Implementation	Construction Finish
5	Closing	Project Handover

In each stage, a gate should be reviewed if the project can be continuing or not based on the benefit and urgency analysis of the project. In order to control and monitor the activity in the project life cycle, PT PLN (Persero) is already implementing activities of project monitoring dan handled as part of project management. The implementation of project monitoring and control covered eight functions: risk, schedule, issue; budget; project governance; scope and contract controlled; project knowledge management; project academy; consultancy & audit; human resource management.

B. Engineering Economic

Economic decision-making for engineering systems is called engineering economy. Engineering economy involves the systematic evaluation of the economic merits of proposed solutions to engineering problems. Solutions to engineering problems must demonstrate a positive balance of long-term benefits over long-term costs to be economically acceptable. In engineering economy involves the collection of techniques that simplify comparisons of alternatives on an economic basis. Engineering economics begins only after the other options have been identified. All engineering economy studies of capital projects should consider the return that a given project will or should produce.

1. The Present Worth Method (PW)

The PW approach is predicated on the notion of the present value of all cash flows relative to some reference or starting point in time termed the present. That is, all cash inflows and outflows are discounted to the present at a rate equal to the MARR (Minimum Attractive Rate of Return)[7]. A positive PW for an investment project is a profit margin that exceeds the minimum needed by investors. It is expected that the alternative generates cash that may be used for other purposes that yield interest at a rate equal to the MARR.

To find the PW as a function of $i\%$ (per interest period) of a series of cash inflows and outflows, it is necessary to discount future amounts to the present by using the interest rate over the appropriate study period (years, for example) in the following manner (1):

$$PW(i\%) = F_0(1+i)^0 + F_1(1+i)^{-1} + F_2(1+i)^{-2} + \cdots + F_k(1+i)^{-k} + \ldots + F_N(1+i)^{-N} = \sum_{k=0}^{N} F_k\,(1+i)^{-k} \quad (1)$$

Here,

i = effective interest rate, or MARR per compounding period

k = index for each compounding period ($0 \le k \le N$);

Fk = future cash flow at the end of period k;

N = number of compounding periods in the planning horizon (i,e, study period)

2. The Internal Rate of Return (IRR)

The IRR method is the most widely used rate-of-return method for performing engineering economic analyses. It is sometimes called by several other names, such as the investor's method, the discounted cash-flow method, and the profitability index. This method solves for the interest rate that equates the equivalent worth of an alternative's cash inflows (receipts or savings) to the equivalent worth of cash outflows (expenditures, including investment costs)[7]. Equivalent worth may be computed using any of the three methods discussed earlier. The resultant interest rate is termed the Internal Rate of Return (IRR).

The IRR is sometimes referred to as the breakeven interest rate. Using a PW formulation, the IRR in (2) is the i% at which:

$$\sum_{k=0}^{N} R_k\left(\frac{P}{F}, i'\%, k\right) = \sum_{k=0}^{N} E_k\left(\frac{P}{F}, i'\%, k\right), \quad (2)$$

Here:

Rk = net revenue or savings for the kth year;

Ek = net expenditures, including any investment cost for the kth year

N = project life (or study period)

However, some critical issues remain unsolved with IRR, such as complex-valued return rates and complex-values capital are devoid of economic meaning, project ranking with

IRR is not compatible with NPV ranking, the IRR cannot measure the return on the initial investment, IRR decision rule may be applied only if the cost of capital is constant, IRR does not exist if the capital is entirely lost or if an arbitrage strategy is undertaken[8].

C. Monte Carlo Method

A project simulation applies a model to adapt the uncertainties indicated at the specific level of the project to their possible impact on the project's objectives. Typically, simulations are carried out using the Monte Carlo technique. In a simulation, the project model is calculated repeatedly (iterated), with the input values randomly chosen from the probability distributions of each variable (e.g., cost of project parts or duration of scheduled activities). Calculate a probability distribution (e.g., total cost or finish date) [6].

Many problems in financial engineering focus on estimating a particular value, e.g., pricing derivative securities, computing price sensitivities, evaluating portfolio risks. The value can often be written as or transformed to an expectation of a complex random variable whose behavior is modeled as a stochastic process[9]. In a project, simulation applies a model to adapt the uncertainties indicated at the specific level of the project to their possible impact on the project's objectives. Typically, simulations are carried out using the Monte Carlo technique. In a simulation, the project model is calculated repeatedly (iterated), with the input values randomly chosen from the probability distributions of each variable [6]. Its use is universal and does not need special knowledge of probability theory. The only information one needs is the relationship between the output and input quantities (3).

$$y = f(x) \; or \; y = f\ (x1, x2, x3, \ldots) \quad (3)$$

and the knowledge of probability distributions of the input variables. The method repeats trials with computer-generated random numbers processed by the relevant mathematical operations. In each trial, the input variables *x1, x2, …, xn* are assigned random values, but their distributions correspond to the probability distribution of each variable.

At the heart of Monte Carlo simulation is the generation of random numbers. Most spreadsheet packages include a RAND () function that returns a random number between zero and one. Other advanced statistical functions, such as NORMSINV(), will produce the inverse of a cumulative distribution function (the standard normal distribution in this case). This function can be used to generate random normal deviates.

III. Methodology

The procedure begins by classifying generation, transmissions, and substations projects in Jawa-Madura-Bali System and then categorizing them according to whether they are operational, ongoing, or canceled projects. Furthermore, the ongoing projects will be classified into four categories: projects to improve system reliability, projects for power evacuation, improving revenue, and projects to sales electricity.

Furthermore, a linkage analysis between the projects will be carried out, then financial analysis and sensitivity analysis will be calculated using the Monte Carlo simulation method with 10.000 random numbers.

The last process in the methodology, an assessment carried out on changes to the COD schedule for the 35 GW project on the Java-Madura-Bali System based on RUPTL 2015-2024 compared to the RUPTL 2019-2028. The assessment is to see the success rate of the project implementation that has been planned in the RUPTL 2015-2024. The methodology used in this paper is shown in Fig. 1.

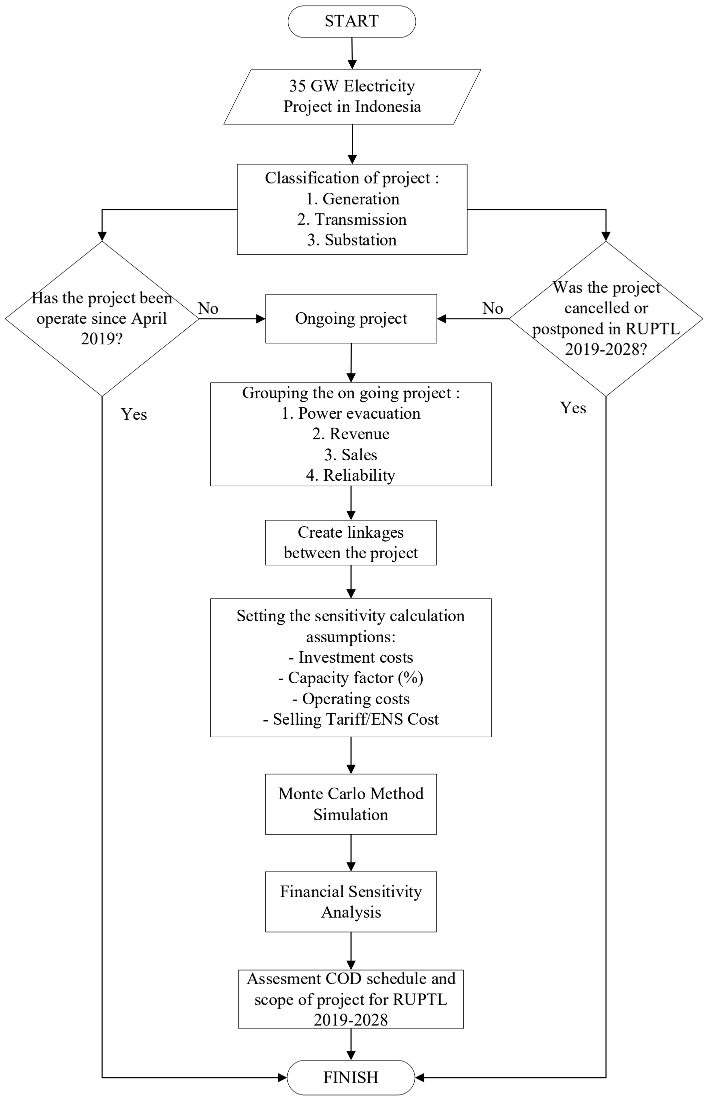

Fig. 1. Flow diagram of the methodology

IV. Status of Projects

This chapter will present an analysis of the progress of generation, transmission, and substation projects. This analysis is needed to align the Government of Indonesia's target and issues in project management. The data used in the study is taken from project status data from the PLN's Project Management Office (PMO).

The capacity generation, transmission, and substations of the 35 GW electricity project are shown in Table II.

TABLE II. 35 GW ELECTRICITY PROJECT

Project	Region	Volume
Generation	Sumatera System	9.56
	Jawa-Bali System	18.45
	East Indonesia System	6.68
	Total (GW)	**34.69**
Transmission	Sumatera System	19,765
	Jawa-Bali System	11,187
	East Indonesia System	12,175
	Total (km-circuit)	**43,127**
Substation	Sumatera System	38.52
	Jawa-Bali System	62.47
	East Indonesia System	3.58
	Total (MVA)	**104.56**

Furthermore, the analysis will focus on projects in the Jawa-Madura-Bali system. By the flowchart methodology, the next step is grouping the projects that have been operating and canceled with the status of April 2021. The projects in operation and postponed or canceled in the Jawa-Madura-Bali system are shown in Table III.

TABLE III. PROJECT IN OPERATION AND POSTPONED OR CANCELLED IN JAWA-MADURA-BALI SYSTEM

Project	Operation	Postponed or canceled
Generation	2.4 GW	0
Transmission	1,919 km-circuit	1,359 km-circuit
Substation	23.5 GVA	5.3 GVA

Most of the projects not in operation, transmission project has worse progress. The project per year completion should be considered by the Government, or significant changes in the project process should be implemented. The main reason that could be postponed or canceled a project in RUPTL are:

- The project is not needed by the system, and specific projects will not give the same benefit as before.
- The workability of the project is impossible to be done or has costly technology to be implemented.
- The particular project was not needed because there are some changes in the project scope.

Therefore, there are new substation projects and new transmission projects. Some of these projects have changes in COD and scope. The recap of COD changes of the 35 GW project in the Jawa-Madura-Bali System based on RUPTL 2015-2024 compared to RUPTL 2019-2028 is shown in Fig. 2. Based on Fig. 2, most of the projects have 1-4 years of delay, which will give a new perspective of determining the COD target, especially in substation and transmission projects. Either the scope changes are needed for the actual condition at the project site or the lack of detailed planning process, GoI's target. It should be reviewed especially for substation and transmission projects because the exact time implementation could not be implemented if there are significant changes in project scope.

Referring to this section, the 35 GW project, which also consists of the 108 GVA and 46,000 km-circuit projects, has not good progress because it was an ambitious program that was set by the Government of Indonesia on RUPTL 2015-2024. Therefore, PLN through RUPTL 2016-2015 to RUPTL 2019-2028 updated this target, which includes updated demand projection and updated 35 GW project lists.

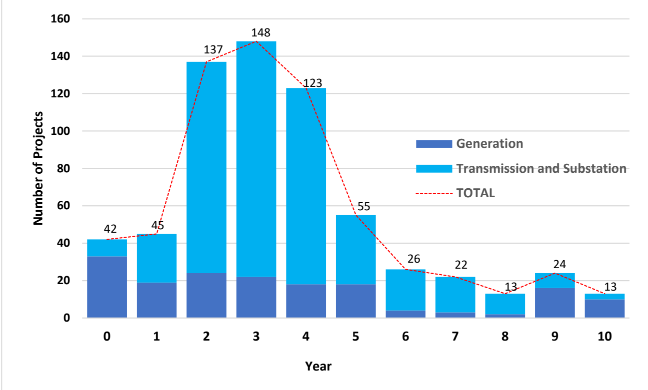

Fig. 2. Jawa-Madura-Bali Project's COD changes from RUPTL 2015-2019 to RUPTL 2019-2028

V. RESULT AND ANALYSIS

The Monte Carlo simulation is using to determine the condition of the NPV in a project, whether it will be positive or negative, along with the resulting deviation. Monte Carlo simulations will be carried out on generation projects, as well as related projects. Referring to project management staging and based on the progress of the project, most project stages are pre-implementation and implementation. It would be interesting to analyze the pre-implementation phase because it has several different steps, such as funding, permit, land acquisition, and procurement.

A. Generation Project

Currently, in the 35 GW project in Jawa-Madura-Bali System, the generation project has an identic type, therefore the generation project only five types which is micro/mini-hydro (MHPP), hydropower plant (HEPP), combined cycle power plant (CCPP), geothermal power plant (GEPP), and coal-fired power plant (CFPP). The result of sensitivity analysis for the generation project is shown in Fig. 3. The least-cost calculation compared with highest sales tariff, lowest sales tariff, and annual generation cost of Jawa-Madura-Bali System. The results show that the baseload, which is the cheapest generation cost, is CFPP and HEPP. With the existing dam and river limitation, the hydro power plant has a lower possibility of being built in Jawa-Madura or Bali Island. The CCPP is the most expensive but needed to fill the load follower necessity and fill the peaker gap.

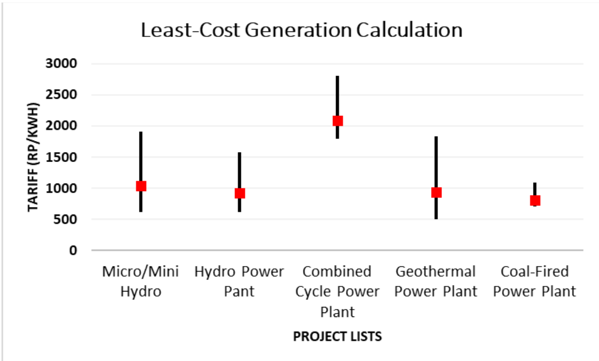

Fig. 3. Sensitivity Analysis for Generation Project

B. Power Evacuation Project

The related project is spread between interconnection, EHV/HV transmission lines, and other power evacuation projects. All the project benefits from maintaining evacuation from the power plant, managing the possibility of energy not being served, and reducing the production cost. Economic calculation compares cost and benefit. The component of the cost is investment cost and more expensive existing production cost. The advantage is the related cheaper solution from each project implementation.

The result of sensitivity analysis for the evacuation project is shown in Fig. 4. In the sensitivity analysis for projects related to power evacuation, it is found that there is one project that has a wide NPV deviation so that it can be said that the project is susceptible to changes in assumptions in the parameter.

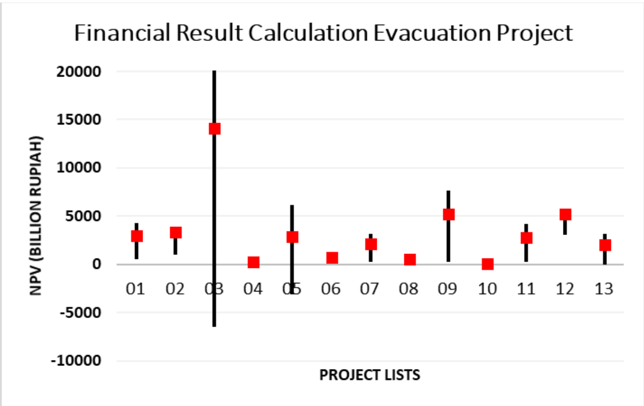

Fig. 4. Sensitivity Analysis for Evacuation Project

C. Revenue Project (EHV Substation)

The related project is an extension 500/150 kV transformer or a new 500 kV Substation. The new 500 kV substation includes the related 500 kV transmission, 500/150 kV transformer, 150 kV substation, and 150 kV transmission outlet. The financial calculation compares cost and benefit. The cost component consists of investment cost, generation production cost, and technical losses. The advantage is the transfer price from the dispatching center to the distribution unit.

The result of sensitivity analysis for the revenue project is shown in Fig.5. In the sensitivity analysis for the EHV substation project for revenue from 17 projects, there is only one project with a negative NPV deviation. It can be said that the project is not feasible with all existing sensitivity conditions. Although there is a negative deviation, all the NPV values are positive for other projects, so the projects are feasible to implement.

D. Reliability Criteria Project

Economic calculation compares cost and benefit. The cost component only all related project investment costs. The related project is spread between the spare transformer, looping transmission, transmission reconductoring, or normalization to fulfill minimum contingency in the power system. The benefit is the risk probability with assuming energy not served and the value of lost load (VoLL). The VoLL uses the indirect method by referring to the macro-economic approach, and it is a monetary indicator expressing the costs associated with an interruption of electricity supply [10].

The result of sensitivity analysis for the reliability criteria project is shown in Fig. 6. In the analysis for project reliability, there is one project whose NPV value is not feasible to implement because, with changing conditions, all NPV values are negative. However, for other projects, the NPV is dominantly positive with varying deviations.

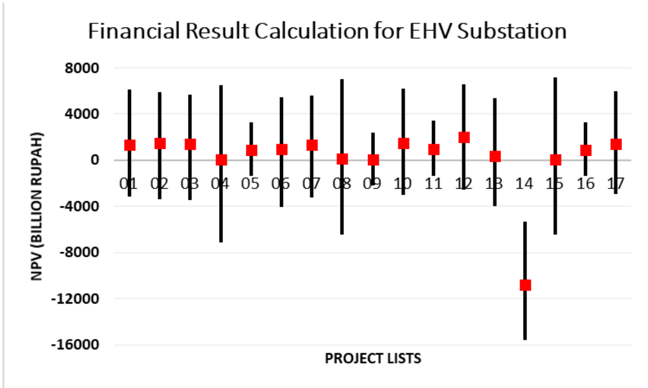

Fig. 5. Sensitivity Analysis for Revenue Project

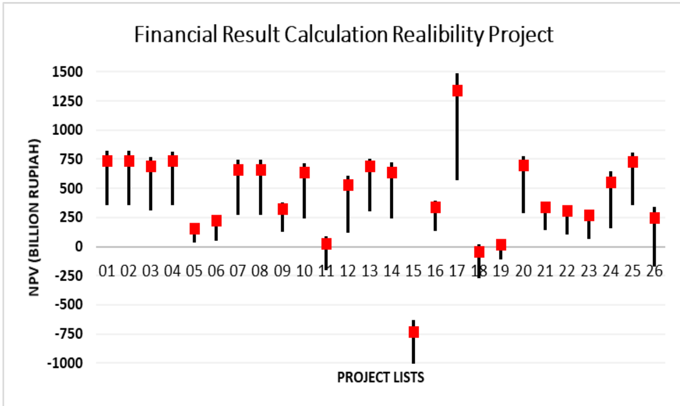

Fig. 6. Sensitivity Analysis for Reliability Project

E. Sales Criteria Project

The related project is an extension 150/20 kV transformer or a new 150 kV substation. The new 150 kV substation includes the related 150 kV transmission. The financial calculation itself is compared between cost and benefit. The cost component consists of investment, transfer price from dispatching center to distribution unit, and technical losses. The advantage is the average tariff to the consumer.

The result of sensitivity analysis for the sales criteria project is shown in Fig. 7. In the sensitivity analysis for sales increase projects, it was found that most projects had a dominant positive NPV value even though they had a negative deviation. So, not all conditions from changes in investment costs, loading factors, operating costs, and tariffs derived from random values in the Monte Carlo simulation will produce negative NPV values. This condition is still acceptable if the dominant NPV value is positive.

The sensitivity analysis also found that the value of the NPV and its deviation are all negative, so it can be said that the project is not feasible to implement.

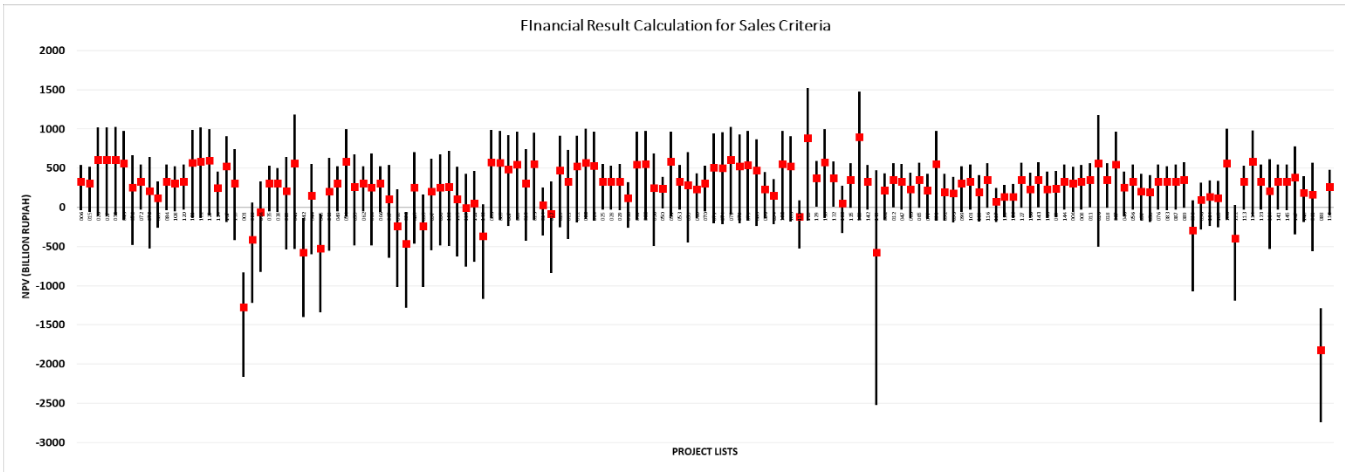

Fig. 7. Sensitivity Analysis for Sales Criteria Project

VI. CONCLUSION

This paper discusses related to investment assessment for a power grid project in the Java-Madura-Bali system. Investment assessment is generally carried out by looking at the project's status, whether it is in operation, ongoing, postponed, or canceled. An analysis also related to the COD changes from the 35 GW program in the 2015-2024 RUPTL to the 2019-2028 RUPTL. Furthermore, sensitivity analysis uses the Monte Carlo method with the external assumption parameters. The results obtained in each scenario include: The generation project results show that the baseload, which is the cheapest generation cost, is CFPP and HEPP. In the power evacuation project, there is one project with a wide NPV deviation so that the project is susceptible to changes in assumptions in the parameter. For the EHV substation project for revenue from 17 projects, there is only one project with a negative NPV deviation. In the project for reliability, there is one project whose NPV value is not feasible to implement because, with changing conditions, all NPV values are negative. However, for other projects, the NPV is dominantly positive with varying deviations. Most of the sales increase projects had a dominant positive NPV value even though they had a negative deviation, not all conditions will produce negative NPV values. From the analysis, also it can be concluded that many projects are currently unfinished, and some have even been canceled, especially the transmission (1,359 km-circuit) and substation projects (5.3 GVA). While the remaining projects are still ongoing from the remaining ones, some projects are not financially feasible to implement, and some projects are susceptible to changes in variables.

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