Protection Assessment Method for Flexibility of Hybrid Power System Protection Improvement: Study Case Sumbawa Subsystem, Indonesia

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Abstract

Indonesia has targeted 23% renewable energy contribution in 2025 power production plan to drive the utilization of renewable energy potentials spreading in various grid locations. Location and capacity of Photovoltaic (PV) has been planned to obtain optimum operation in each area and subsystem. However, PVs' integration challenges reliable protection and flexibility of network for TSO and DSO companies, then should be improved to adapt grid and its protection system for such new challenges. This paper examines the Sumbawa subsystem as a hybrid power system including photovoltaics according to the energy mixed roadmap in 2025. In the absences of DER, the setting of devices are calculated selectively. The Protection Security Assessment (PSA) method automatically evaluates the operation of devices in the present network. To validate the protection system, three-phase and single-phase faults are studied at predefined locations. Adaptive rules are developed to correct miscoordinations by proposing new settings and evaluated again by implementing the new proposals schemes. This paper focused is the identification of proper adaptive rules and it is assumed that the schemes are transferred to devices using utility workforces with manual or automated workflow based on proper communication infrastructure.

1 Introduction

Indonesia's government has committed to developing the renewable energy sector for 23% in 2025 in various locations. Sumbawa was located in West Nusa Tenggara province of Indonesia has large potential of solar radiation in and has 9.14% average electricity demand growth per year [1]. In 2025, national energy plan considers installing 75 MW of photovoltaic in Sumbawa, where the suitable location has been selected by the optimum combination of capacity using knapsack brute-force method developed by [2] to calculate the cheapest cost (based on LCOE and nearest connection to the grid), and highest solar potential radiation aspect.

However, PVs' integration, short circuit contribution, volatile power output, and multi-directional load flow in grid challenges the reliable protection of network for TSO and DSO companies. Reliability and flexibility design regarding switching status and network configuration changing overtime should be improved to adapt grid and its protection system for such new challenges. The performance should remain selective, sensitive, and fast despite volatile and flexible operation conditions of DERs.

Adaptation of settings in some scenarios are needed protection engineers to reconfirm new settings. [3] and [4] has been discussed the adaptive rules when DERs penetration on the distribution network, whereas [5] has assessed and improved the existing protection of transmission system, nevertheless it doesn't focus on DERs penetration influences.

This paper focuses on improving protection system configuration and setting on distribution and transmission system using the PSA method on presence and absences of PVs to the grid on chosen locations. By the PSA, protection engineers easily observe and analyse the weak point of the network protection, and immediately improve it selectively.

2 Transmission and Distribution Protection system

Transmission line normally combining distance relay and overcurrent including directional unit protection. Overcurrent is the simplest and least expensive form of fault protection that can be applied for transmission and distribution network. The operating principles of these schemes depend only on the magnitude of the current and time applied to the relay [6]. The IEC normally inverse characteristic curve of relay operation time to trip in the presence of fault current is according to the equation $tTrip = T_p \frac{0.14}{\left(\frac{I_F}{I_P}\right)^{0.02} - 1}$ (*1*):

$$t_{Trip} = T_p \frac{0.14}{\left(\frac{I_F}{I_P}\right)^{0.02} - 1} \quad (1)$$

Where $\boldsymbol{t_{Trip}}$ is relay tripping time, $\boldsymbol{T_p}$ is time multiplier setting (TMS) parameter, $\boldsymbol{I_F}$ is fault current, and $\boldsymbol{I_P}$ is relay pickup current parameter. Parameters $\boldsymbol{I_P}$ and $\boldsymbol{T_p}$ are relays settings while fault current depends on the network model and short-circuit fault condition. The settings $\boldsymbol{I_P}$ should be higher than the maximum load current that measured by the current transformer of the relay with enough safety factor:

$$I_P = SF * I_{max.load} \qquad (2)$$

The

Distance relays are mainly operates based on line fault impedance measurement *(Z_f)* through the fault [7]. This relay using fault voltage *(V_f)* and fault current *(I_f)* to determine if a fault is in the protection zone of the relay, as mention in$Zf = \frac{V_f}{I_f}$ (3)

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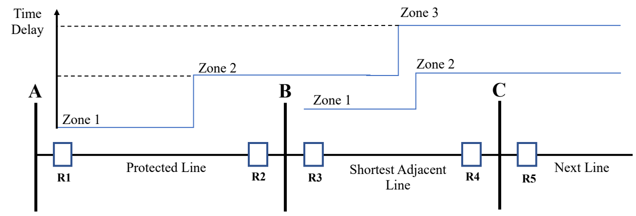

Fig. 1. Typical zone coordination for distance protection [8]

The basic characteristics of distance protection are impedance, mho, offset mho, reactance, quadrilateral, lenticular, and polygon [6], and commonly equipped with tele protection function. Several zones are set up to protect a transmission line and provide backup protection of a remote bus (or buses) and some portions of the lines emanating from the remote bus. As shown in Fig. 1, the first zone (zone 1) is normally set to trip with no intentional time delay and set for approximately 80% to 90% of the transmission line impedance. The second zone (zone 2) typically time delays are in the order of zone 2 is usually set from 250ms to 400ms with 120% coverage line impedance. And zone 3 as a remote backup and coordinated with the zone 1 and zone 2 will cover the protected line, plus all of the longest line emanating from the remote station [6].

3 Methodology

3.1. Network Study

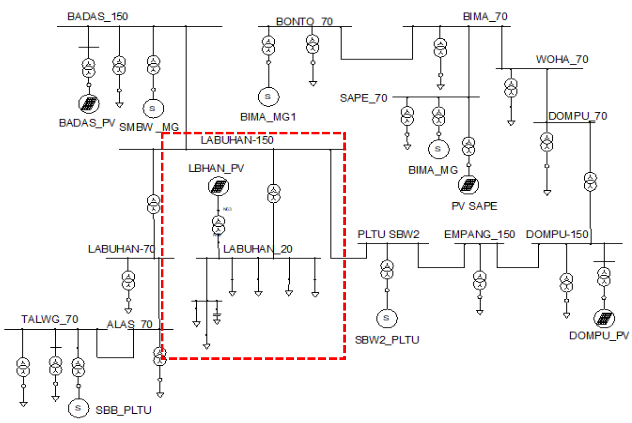

Fig. 2. Sumbawa-Bima Power System

This paper performs Sumbawa-Bima power system in 2025 plan scenario. The power system consists of Sumbawa and Bima subsystem which has 70 kV voltage level each, then connected each other by 150 kV transmission line. The network has 177 MW load through their substations and 20 kV distribution network. Recently, Sumbawa are dominantly supplied by diesel power plant. On 2025, the diesel generation plant will be replaced by 84 MW coal-fired power plant, 160 MW gas engine power plant and 75 MW photovoltaic spread on four substations.

The optimum combination of PV placement results of 75 MW PV's should be installed on four substations: Badas (20 MW), Labuhan (20 MW), Dompu (20 MW) and Sape (15 MW). This study simulates with PSS SINCAL 16.0 software in the normal operation of generation and focuses on Labuhan Substation.

3.2. Protection Setting and Simulation

This study will examine both of transmission and distribution protection system over 75 MW PVs penetration and will be focused on Labuhan Substation. The transmission line is protected by distance and overcurrent, while overcurrent implements also on the distribution system. The load flow simulates to identify the power and current flow through the load. The short circuit simulation conducted to examine the current contribution and equipment's tripping behaviour within the fault.

When the absences of PVs, overcurrent devices were timely coordinated considering with CTI=300ms between each relay coordination pairs. Relay settings were calculated based on the maximum load current, and the maximum or minimum short-circuit current at relay locations. Resulted settings for pickup current and time multipliers were added to relays on the test model. This enables the test model for protection simulations needed for PSA evaluations. The distance on transmission line were applied as main protection and overcurrent as a backup. The LABUHAN_150 – PLTU_SBW2 protection line was examined respecting the PVs penetration to the grid.

3.3. Protection Security Assessment (PSA)

Three-phase and single-phase short-circuit fault scenario were considered along the entire buses and nodes test model in every 10% of all lines. The PSA method places all fault scenarios and simulates relay behaviours until a fault be cleared. PSA automatically determines network zones which is a group of network elements with a boundary consisting set of relays that responsible for clearing zone faults. The combination of fault scenarios, fault locations in entire of each zone is simulated and evaluate how each fault scenario is cleared in each zone of the protection devices. Correct relay operation (selective) are marked with green, more relay operation (over-function) or less relay operation (under-function) are marked with yellow or orange colour respectively. While, faults cannot be cleared by relays marked with RED. Results aggregated in a coloured matrix-like where rows indicate zones of protections, and columns are fault location along the line for the given fault scenario.

The PSA result matrix is the protection engineers start point to conduct an in-depth analysis for PSA identified vulnerabilities. Protection engineers should develop rules or schemes to improve identified vulnerabilities either through adapting protection relay settings or adding new protection functions, e.g., directional overcurrent. We adapted and optimized relay settings during this study wherever needed

4 Case Study

This study focus on Labuhan substation which supplied by 150 kV LABUHAN_150 – PLTU_SBW2 line with 80 km length, and five 20 kV outgoing feeders load as shown Fig. 3.

4.1. Basic Scenario (before PV integration)

The basic scenario was discussed without any photovoltaic contribution. Normal transmission and distribution protection were implemented through the line and substations. Table *1* shows the distance protection at line Labuhan-PLTU 150 kV and overcurrent among the feeder of the substation were coordinated selectively during three-phase faults.

Table 1 Assessment result before PV Integration on Labuhan Substation

17 Routes, 17 Selective, 0 Not cleared, 0 Underfunction, 0 Overfunction, 0 Not calculable, tclear [s]

Zones	Start	End	Start	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	End
Zone 1	TULA_1511	TULA_1512	0.33	0.33	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33
Zone 2	TULA_1521	TULA_1522	0.33	0.33	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33
Zone 3	LABA_1511	LABA_1512	0.33	0.33	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33
Zone 4	LABA_1521	LABA_1522	0.33	0.33	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33
Zone 5	R_LAPE1	R_LAPE2	0.483	0.483	0.483	0.483	0.483	0.487	0.495	0.503	0.512	0.52	0.527
Zone 6	R_L_LAPE2	N68	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166
Zone 7	R_KERATO	N74	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257
Zone 8	R_MOYO	R_KOTA	2.458	2.454	2.45	2.445	2.441	2.437	2.441	2.445	2.45	2.454	2.458
Zone 8	R_MOYO	PV 1	2.458	2.445	2.436	2.435	2.433	2.432	2.43	2.429	2.428	2.426	2.425
Zone 8	R_MOYO	LABUHAN-20kV	2.458	2.456	2.454	2.452	2.449	2.447	2.445	2.442	2.44	2.438	2.437
Zone 8	R_MOYO	N51	2.458	2.439	2.463	2.488	2.512	2.537	2.562	2.588	2.613	2.639	2.662
Zone 8	R_KOTA	PV 1	2.458	2.445	2.436	2.435	2.433	2.432	2.43	2.429	2.428	2.426	2.425
Zone 8	R_KOTA	LABUHAN-20kV	2.458	2.456	2.454	2.452	2.449	2.447	2.445	2.442	2.44	2.438	2.437
Zone 8	R_KOTA	N51	2.458	2.439	2.463	2.488	2.512	2.537	2.562	2.588	2.613	2.639	2.662
Zone 8	PV 1	LABUHAN-20kV	2.425	2.426	2.427	2.428	2.43	2.431	2.432	2.433	2.434	2.435	2.437
Zone 8	PV 1	N51	2.425	2.428	2.432	2.435	2.459	2.492	2.526	2.56	2.595	2.629	2.662
Zone 9	R_L_LAPE1	N79	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189

Overcurrent protection was considered as timely coordinated with predefined CTI=300ms between each relay paired, as well as pickup current and time multipliers were applied to relays on a network model. Distance protections were considered at 80% impedance on zone1 and 120% for zone2 with 200ms time delay in paired.

Single-phase and three-phase short circuit faults were applied along the network model, considering faults on all buses and nodes and every 10% of all lines. The PSA method places all fault scenarios and simulates protection relay behaviours until a fault be cleared. The assessment result indicates that the protection setting was selectively designed for both distance and overcurrent setting which represent green matrix colours as Table *1*.

4.2. Protection Challenges during Photovoltaic Penetration

The configuration was representing condition on 2025 planning, with addition of 75 MW of PVs connected to the grid, which 20 MW penetrates on Labuhan Substation. Some challenges observed during these conditions are: Additional short circuit level of the power system increased since coal and gas power plant operation on 2025 planning combined with PVs contribution. Secondly is consideration of high penetration of renewable energy resources current flow and short circuit contribution. And third is the switching status and network configuration were changing over time, could lead to whole protection coordination updated regularly. Whenever the engineers using Time Coordination Charts (TCC) to coordinate and review the network protection system, this manual method is a time-consuming process. They should analyse several TCCs and confirm correct operation of protective devices.

The present transmission and distribution protection system have been evaluated and assessed by PSA automatically. This method verifies the whole performance of the protection system and identifies the possible weak points. Table 2 shows the result assessment protection system when the PVs penetrate the grid on the 20kV side of Labuhan substation. The selective protection behaviour was identified as green matrix colours, while the unselective as red. Three-phase faults setting were corrected and successfully clear the faults.

Table 2 Assessment result after PV Integration on Labuhan Substation for single-phase faults

15 Routes, 2 Selective, 7 Not cleared, 0 Underfunction, 6 Overfunction, 0 Not calculable, tclear [s]

Zones	Start	End	Start	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	End
Zone 1	TULA_1511	TULA_1512	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33	0.46
Zone 2	TULA_1521	TULA_1522	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33	0.46
Zone 3	LABA_1511	LABA_1512	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33	0.33
Zone 4	LABA_1521	LABA_1522	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33	0.33
Zone 5	R_LAPE1	R_LAPE2	0.168	0.168	0.169	0.169	0.169	0.169	0.17	0.17	0.17	0.171	0.171
Zone 6	R_L_LAPE2	N68	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143
Zone 7	R_KERATO	N74	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153	0.153
Zone 8	R_MOYO	R_KOTA	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384
Zone 8	R_MOYO	N65	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384
Zone 8	R_MOYO	LABUHAN-20kV	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384
Zone 8	R_MOYO	N51	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.385	0.385	0.385	0.385
Zone 8	R_KOTA	N65	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384
Zone 8	R_KOTA	LABUHAN-20kV	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.384
Zone 8	R_KOTA	N51	0.384	0.384	0.384	0.384	0.384	0.384	0.384	0.385	0.385	0.385	0.385
Zone 9	R_L_LAPE1	N79	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143	0.143

While over-function of particular zones still occurred for single-phase faults. The observation results in the area of PV connection could lead unselective trip because of addition short circuit current contribution from the PV. It was represented on zone 8 at load of Moyo and Kota.

Two examples of the non-selective issue was performed on Fig. 3 and Fig. 4 respectively. The presences of PV on

LABUHAN_20 lead to additional short circuit contribution through overcurrent protection either for single-phase and three-phase faults on distribution network i.e. relay Kota was unselective (Fig. 3).

Three-phase faults setting were corrected and successfully clear the faults. While over-function status still occurred for single-phase faults on the tip of each transmission line, so that engineers determine the improvement by developing new setting grading rules of ground protection.

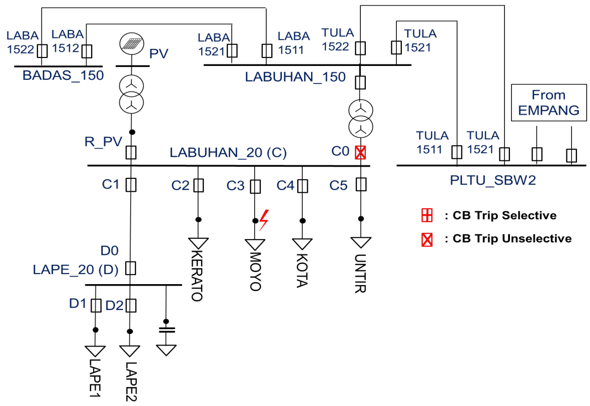

Fig. 3 Unselective overcurrent Protection System During PV Penetration on Labuhan Substation

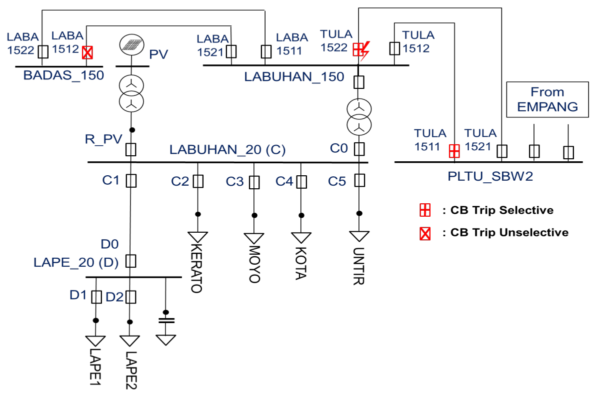

Fig. 4 Unselective Distance Protection System during PV Penetration on Labuhan Substation

4.3. Evaluation and Improvement of the Protection System

Table 3. Result of The Protection System Improvement

17 Routes, 17 Selective, 0 Not cleared, 0 Underfunction, 0 Overfunction, 0 Not calculable, tclear [s]

Zones	Start	End	Start	10 %	20 %	30 %	40 %	50 %	60 %	70 %	80 %	90 %	End
Zone 1	TULA_1511	TULA_1512	0.33	0.33	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33
Zone 2	TULA_1521	TULA_1522	0.33	0.33	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33
Zone 3	LABA_1511	LABA_1512	0.33	0.33	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33
Zone 4	LABA_1521	LABA_1522	0.33	0.33	0.13	0.13	0.13	0.13	0.13	0.13	0.26	0.33	0.33
Zone 5	R_LAPE1	R_LAPE2	0.483	0.483	0.483	0.483	0.483	0.487	0.495	0.503	0.512	0.52	0.527
Zone 6	R_L_LAPE2	N68	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166	0.166
Zone 7	R_KERATO	N74	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257	0.257
Zone 8	R_MOYO	R_KOTA	2.458	2.454	2.45	2.445	2.441	2.437	2.441	2.445	2.45	2.454	2.458
Zone 8	R_MOYO	PV 1	2.458	2.445	2.436	2.435	2.433	2.432	2.43	2.429	2.428	2.426	2.425
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Zone 8	PV 1	N51	2.425	2.428	2.432	2.435	2.459	2.492	2.526	2.56	2.595	2.629	2.662
Zone 9	R_L_LAPE1	N79	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189	0.189

To improve the effectiveness of the new configurations, new settings were implemented and applied to the network model, and the protection assessment was repeated. The assesment result for new settings proposed shown in **Error! Reference source not found.**.

While resulting in the same selective protection setting for distance through three-phase and single-phase faults before and after PV penetration, improved the settings were significantly achieved to enhance the performance against single-phase faults. Single-phase fault on a start transmission line was over-function on zone 1 up to zone 4, while only zone 1 and zone 3 on the end point. New grading rule was implemented to improve the selectivity of the ground fault protection scheme.

5 Conclusion

Labuhan substation which represents distribution and transmission system of Sumbawa subsystem was modelled on this study. Protection security assessment method was applied and observed selective protection settings in absences of PVs. In case presences of PVs on distribution bus, the assessment method defined the weak point immediately. Both three-phase and single-phase fault were improved significantly clear the faults. Otherwise, the new recommendation for ground faults rule was improved it selectively.

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