Improvement of Voltage Regulation on the 150kV Isolated System: Study Case of Isolated Ketapang System

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Abstract. The Isolated transmission line in the Ketapang system is one of several systems in the Khatulistiwa, West Kalimantan system that is still not connected to the main grid. Due to the long distance, low load and there is no large plant in the Ketapang isolated system there is potential for a voltage violation on isolated transmission lines in the Ketapang system above the service voltage limit. With the 150 kV nominal voltage still not up to standard (average 127 kV), it is necessary to improve service. This improvement in service certainly needs to be balanced with an increase in equipment performance, therefore it is necessary to improve methods. The method can be improved by setting the Onload Tap Changer (OLTC), adding a reactor, and adding a generator. This article aims to improve electricity quality and reduce potential losses in the Ketapang system with the mentioned method.

Keywords: *Voltage regulation, voltage drop, electricity quality, losses, onload tap changer, reactor.*

1 Introduction

In 2021 the electricity net capacity in the West Kalimantan region was 59.043 MW with a peak load reaching 32.230 MW, while in 2022 the electricity net capacity was 70.677 MW with a peak load reaching 38.490 MW. The isolated Ketapang system itself in 2023 has an electricity net power capacity of 10.813 MW with a peak load of 16.22 MW, consisting of 171,665 customers [1]. Based on the reports from the Ketapang isolated system operator, the highest peak load occurred in May 2024 at night with 47.3 MW.

The lower voltage limit required for the 150 kV busbar is 135 kV. However, the Ketapang isolated system is only capable of being in the range of 125 kV to 129 kV. Voltage that is too low will affect the quality of service and will have an impact on the system.

In this study, we will discuss how to improve voltage to minimize losses and maximize electrical energy delivery to customers in the Ketapang, Sukadana, Kendawangan and Sandai transmission network systems and substations. Several

Received ________, Revised _________, Accepted for publication __________
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approaches to improve the performance of the isolated system will be analyzed as follows:

A. Evaluating a transformer tap operation scheme for each power transformer at the Ketapang, Sukadana, Kendawangan, and Sandai substations.
B. Evaluating the addition of shunt reactors at the Ketapang, Sukadana, Kendawangan, and Sandai substations.
C. Evaluating the addition of synchronous generators to the Ketapang, Sukadana, Kendawangan, and Sandai substations.

Based on the performed analysis, the proper ways to solve the voltage regulation problem can be determined to improve the performance of the isolated Ketapang system, particularly in terms of voltage quality and losses reduction.

2 Isolated Ketapang System

The Ketapang isolated system consists of four substations, such as the Ketapang substation as a supply substation, the Kendawangan substation which is connected via two 150 kV transmission lines with the Ketapang substation, the Sukadana substation which is also connected via two 150 kV transmission lines with the Ketapang substation, and finally the Sandai substation which connected single phi 150 kV with Ketapang and Sukadana substations. The Ketapang isolated system, will be interconnected with Tayan-Sandai transmission line. Tayan-Sandai transmission line will be 165.325 kms. This line is currently under construction and is targeted to be completed in end of 2025.

In actual conditions, the Ketapang isolated system is not in an ideal condition at a voltage of 150 kV. The actual isolated power system in Ketapang can be seen in Table 1.

Table 1 Actual power system isolated Ketapang

No	Parameter	Substation			
		Sandai	Ketapang	Kendawangan	Sukadana
1	150 kV Voltage	133.4 (kV)	132 (kV)	132 (kV)	133.1 (kV)
2	20 kV Voltage	20.5 (kV)	20.7 (kV)	19.9 (kV)	21.1 (kV)
3	P Load	3.4 (MW)	6.3 (MW)	2.8 (MW)	3 (MW)
4	OLTC Position	-13	-17	-11	-15
5	MVAR	-0.3 MVAR	-17.6 MVAR	-0.3 MVAR	0.1 MVAR

The transmission lines and substations built in the Ketapang isolated system can be seen in the following Fig. 1.

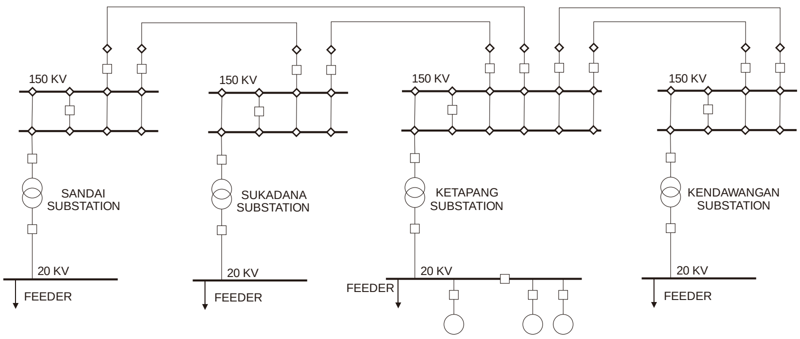

Fig. 1. Ketapang isolated single line diagram

It can be seen in Fig. 1 that the generating center is not close to the load center, with varying transmission lines and has a conductor length of up to 115.8 km (Sandai-Ketapang). This is what causes a voltage drop so that MVAR voltage regulation needs to be done. The longer the conductor, the greater the losses that will arise. This can be done in various ways, such as adjusting an on-load tap changer, adding a reactor, and adding a generator. Reference [2] adding FACTS device, [3] adding SVC and [4] adding TSC-TCR Static Var Compensator can regulate the voltage.

3 Methodology

In this research, the method used to analyze voltage regulation is the simulation method. The simulation was carried out using DIgSILENT PowerFactory. Three voltage improvement methods will be simulated, such as on load tap changer adjustment, adding and adding new power plant.

3.1 On-Load Tap Changer Adjustment Simulation

A tap changer is a device that can perform mechanical movements to shift the tapping on the secondary winding in a transformer, making it possible to change the output voltage. Today's power transformers are equipped with automatic on-load tap changer facilities.

The aim of having an online tap changer is to get good secondary voltage in real time and responsively. Reference [5] stated that the tap change value is influenced by the value of the primary side voltage and the load current flowing. The impact of current on a power transformer greatly affects the output of the transformer. The greater the current, the smaller the output voltage. Therefore, it is necessary to change the tap to a higher level. In his study on the Kaliwungu substation power transformer.

In another study, reference [6] conducted research on 11 tap changer topologies, each of which has its own characteristics and advantages in regulating voltage.

3.2 Adding Reactor Simulation

The active power (MW) and reactive power (MVAR) of Isolated Ketapang are supplied by several generators such as Coal Fired Power Plant and Diesel Power Plant which have different MVAR generation capabilities. MVAR generation can be seen from the capability curve or often called the machine power curve. Reactive power (MVAR) plays a role as a voltage regulator on substation busbars and generator busbars which is expected to maintain voltage stability, while active power (MW) plays a role in maintaining system frequency stability due to load fluctuations.

According to reference [7] the voltage limit required for busbars is -10% and +5% of the nominal voltage of 150 kV. So based on the SPLN the minimum limit for a nominal voltage of 150 kV is 135 kV but the Ketapang isolated system is only capable of being in the range of 127 kV as seen in Fig. 2 below:

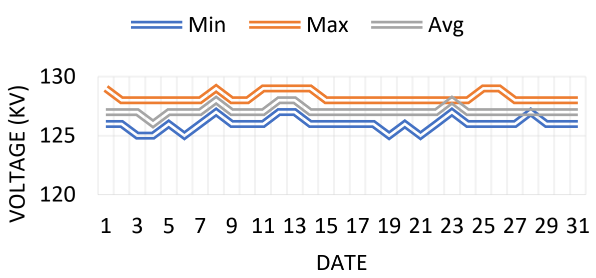

Fig. 2. 150 kV system voltage profile at Ketapang substaion

The Ketapang isolated system is supplied by a generator with a voltage of 6.8 kV which is then stepped up to 20 kV via a step-up transformer and stepped up again to a voltage of 150 kV. This process is at the Ketapang Main Substation as a Node Substation and Supply Substation.

Installation of a 25 MVAR capacitor bank has been proven to be able to improve voltage up to ±5 kV to 6 kV which is applied to the Janhto and Sigli substations. In their research, [8] they prepared 3 scenarios which were simulated. Scenario 1 Aceh sub system which has not had a 25 MVAR capacitor bank added. Scenario 2 of the Aceh subsystem uses the existing capacitor bank of 25 MVAR plus an additional capacitor bank of 25 MVAR. Based on scenario 2, an average improvement of 5.3 kV is obtained from before. The voltage at the Banda Aceh substation, which was initially 144.3 kV, increased to 149.6 kV. Scenario 3 was carried out to see the performance of the new 25 MVAR capacitor bank when the Nagan Raya coal fire power plant unit was disconnected from the Aceh sub system. When the coal fire power plant was removed, the voltage at Banda Aceh substation was 132.5 kV, then a new 25 MVAR capacitor bank was added, the voltage rose to 138.1 kV.

In another study, [9] carried out simulations on 2 types of shunt reactors, such as Static VAR Compensator (SVC) and Static Synchronous Compensator (STATCOM). The simulations show that both types of compensators provide increased reactive voltage stability so that the Static VAR Compensator and STATCOM can significantly increase the voltage on the transmission line.

3.3 Adding Power Plant Simulation

Adding a generator is the most appropriate solution to correct the voltage drop. The generator output will adjust the voltage according to the desired one via a transformer. However, the addition of generators that have speed of development, such as diesel, is increasingly being reduced and is starting to be replaced by renewable energy generators. Renewable energy generators certainly require quite a long study to obtain the energy potential that can be generated. Therefore, the solution for adding generators is a solution to fix voltage drops which take a long time.

In [10] PV voltage regulation strategies, the voltage regulation strategy for large-scale PV certainly needs to pay attention to reactive power first. Based on the data submitted, according to Chinese standards, the allowable voltage is -3% and +7% so that the operating range is 0.97 pu and 1.07 pu as shown in Fig. 3.

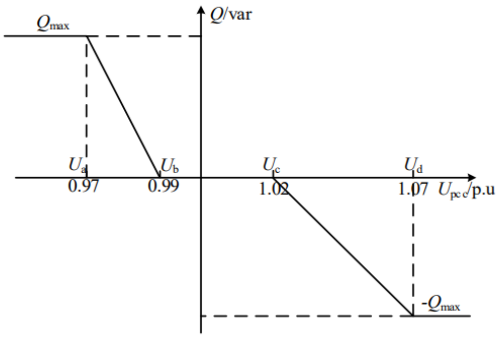

Fig. 3. Reactive power control strategy [6]

By integrating PV plants on a large scale, it will have an impact on voltage stability. In this study, by adjusting the voltage, MVAR fluctuations can be anticipated.

4 Analysis and Result

In this study, the Ketapang system is modeled using DIgSILENT PowerFactory. The modeling of the system to be built is a modeling of the actual 150 kV isolated Ketapang system as in Fig. 1. This system consists of four substations and transmission lines. Apart from that, the modeling will also be equipped with a 20 kV system as the output load and a generator as the source.

On the 150 kV busbar system at each main substation there is a Bay Transformer, Bay Coupler, and two Bay Lines. specifically, for the Ketapang Substation, there are 4 Bay Lines towards the Kendawangan Substation and the Sukadana Substation. For the Sandai Substation, it is connected to a single phi on the Sukadana-Ketapang transmission line, so the distance between line 1 Sandai-Sukadana is 87.31 km while line 2 Sandai-Ketapang is 115.8 km.

The Ketapang Isolated System has several generating sources, including two coal-fired units and 13 diesel units with a total of 18 MVAR of reactive power that can be absorbed by the generators. The voltage configuration at the Sandai, Sukadana and Kendawangan substations, namely the high voltage of 150 kV is step down to a medium voltage of 20 kV via a power transformer with a capacity of 30 MVA, while for the Ketapang substation because it acts as a supply substation, the voltage from the generator is step up from the generator voltage

6,8 kV to 20 kV and step up again to a high voltage of 150 kV with a capacity of 60 MVA. The length of the conductor between Sandai-Ketapang is up to 115.8 km and the load is relatively low, so a voltage drop occurs in the 20 kV system. This model is shown in Fig. 4.

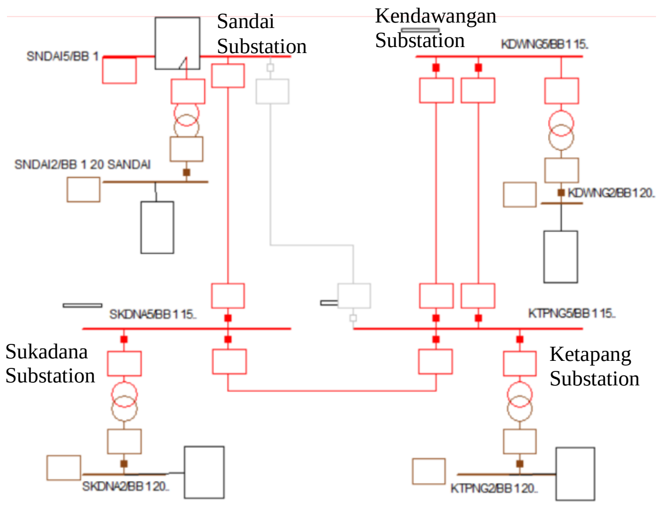

Fig. 4. Single line diagram of isolated Ketapang system

4.1 Analysis

In actual circumstances, from Sandai substation, only Sandai-Sukadana line is operated. If Sandai-Ketapang line is also operated, the losses and line charging will be too large, and the generator's ability to absorb MVAR exceeds its capacity, up to 18 MVAR. Under maximum load conditions, the simulation data can be seen in Fig. 5.

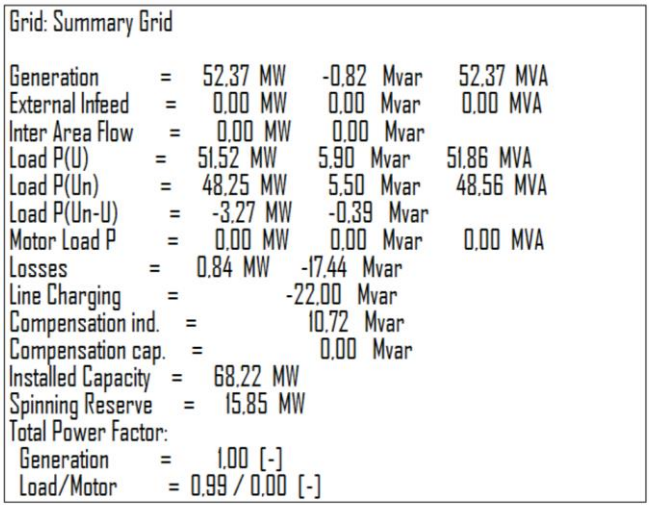

Fig. 5. Grid summary during maximum load condition

Approach 1: Adjustment of On Load Tap Changer Setting.

From the initial conditions the system was running, the 150 kV system voltage was in the range of 133 kV. This is intended so that operating generators can absorb the MVAR of the system. If MVAR is not absorbed, the voltage quality will decrease further, this will also have an impact on the system balance. Therefore, it is very important that MVAR can be absorbed by the generator. In Table 2, the actual tap changer settings and output voltage can be seen. After carrying out the simulation by adjusting the load tap changer settings to get a voltage of 150 kV, it can be seen in Table 3.

Table 2 Simulation result of actual condition OLTC Setting.

Substation	**On-Load Tap Changer (OLTC)**			
	Tap Position	***150 kV Voltage***	***20 kV Voltage***	***MVAR (absorb by generator)***
Ketapang	-17	132 kV	20.7 kV	-17.44 MVAR
Sukadana	-15	133.1 kV	21.1 kV	
Kendawangan	-11	132.2 kV	19.9 kV	
Sandai	-13	133.4 kV	20.5kV	

Table 3 Simulation result of 150 kV OLTC adjustment.

Substation	**On-Load Tap Changer (OLTC)**			
	Tap Position	***150 kV Voltage***	***20 kV Voltage***	***MVAR (absorb by generator)***
Ketapang	-9	149.4 kV	20.9 kV	-20.67 MVAR
Sukadana	-17	150.3 kV	24.5 kV	
Kendawangan	-12	149.5 kV	22.7 kV	
Sandai	-17	150.6 kV	24.5 kV	

Based on the simulation results in Table 3, it can be seen that if the OLTC is set in a certain position so that it obtains a voltage of 150 kV, there will be an increase in the voltage of 20 kV, and all substations produce a voltage of 20 kV above the permitted standard, namely 5% [4] or exceeding 21 kV. This of course will be detrimental to PLN and customers because the voltage does not comply with predetermined standards.

On the other hand, adjusting the OLTC at a voltage of 150 kV also affects the magnitude of the MVAR. From the results of the MVAR voltage settings it rose to -20.67 MVAR which means it exceeds the generator's ability to absorb MVAR so this can cause system instability and is not sufficient for use in this system. This is also in line with research conducted by [2] who was able to regulate the voltage on the 150 kV side.

Approach 2: Adding Reactive Compensator

In this simulation, the placement of the reactor is viewed from the sensitivity of the voltage changes that will be produced by the injection of the same voltage on each busbar. Of the four busbars in four substations, the highest sensitivity value was obtained at the Sandai substation busbar as seen in Table 4. In [11] optimal placement for FACTS shunt device is not fixed meanwhile in [12] using voltage index, voltage sensitivity index, and angle sensitivity index method, the optimal location and type of shunt reactive power compensation device to be installed can be determined.

Table 4 Substation Busbar Sensitivity Value

No	Busbar Substation	Sensitivity Value
1	Sandai	0.0075490
2	Sukadana	0.0062973
3	Kendawangan	0.0057489
4	Ketapang	0.0052721

Based on Table 4, the placement of the reactor is determined at the Sandai substation with the highest sensitivity value. The reactor was then added to the Sandai substation busbar simulation with a working voltage of 150 kV and a capacity of 30 MVAR. Based on the simulation results, the results obtained are as in Table 5.

Table 5 Simulation results of adding a 30 MVAR reactor

<table>
<tr><th rowspan="2">Substation</th><th colspan="4">On-Load Tap Changer (OLTC)</th></tr>
<tr><th>Tap Position</th><th>150 kV Voltage</th><th>20 kV Voltage</th><th>MVAR (absorb by generator)</th></tr>
<tr><td>Ketapang</td><td>-17</td><td>117.9 kV</td><td>19.4 kV</td><td rowspan="4">-13.77 MVAR</td></tr>
<tr><td>Sukadana</td><td>-15</td><td>115.5 kV</td><td>18.3 kV</td></tr>
<tr><td>Kendawangan</td><td>-11</td><td>118.1 kV</td><td>17.7 kV</td></tr>
<tr><td>Sandai</td><td>-13</td><td>111.5 kV</td><td>17.2 kV</td></tr>
</table>

By maintaining the OLTC conditions in the actual condition and adding a reactor, it can be seen that the voltage in the 150 kV system and 20 kV system has decreased. Likewise, the system MVAR fell to -13.77 MVAR. Of course, this situation cannot be accepted by the system, therefore it is necessary to combine additional reactors and OLTC adjustment. In study [7], the application of capacitor banks effectively eliminates undervoltage. In this study, applying a capacitor bank will only contribute when the Ketapang system is isolated, while the Ketapang system will be interconnected with a large system in end of 2025.

Approach 3: Adjusting OLTC and adding Reactor

The combination of additional reactors and OLTC adjustment are shown in Table 6. From Table 6 we know that the combination of adding a reactor with a capacity of 30 MVAR at the 150 kV busbar at the Sandai substation and OLTC adjustment was not successful in regulating the voltage and absorbing the MVAR. In the tap position, the tap setting has been positioned at maximum condition while the voltage is still not reached to 150 kV and 20 kV. This indicates that the transformer is operating at maximum voltage. The higher the voltage is increased, the MVAR will increase too.

Table 6 Simulation result of adding reactor and OLTC

Substation	**On-Load Tap Changer (OLTC)**			
	Tap Position	***150 kV Voltage***	***20 kV Voltage***	***MVAR (absorb by generator)***
Ketapang	-1	142.6 kV	19.3 kV	-20.04 MVAR
Sukadana	-1	139.7 kV	18.6 kV	
Kendawangan	-1	142.9 kV	19 kV	
Sandai	-1	135 kV	18 kV	

Approach 4: Adding Power Plant

As in the simulation of adding reactors, the placement of additional plants considers the largest sensitivity value as in Table 4, so that the Sandai substation is simulated by adding generators to its busbars. The added generating units are diesel generators type with a capacity of 2x2.3 MW which is connected using a step-up transformer to a 20 kV system via a 20 kV busbar at the Sandai substation.

With the same OLTC adjustment as the actual simulation results obtained as in Table 7.

Table 7 Simulation results of adding power plant

Substation	**On-Load Tap Changer (OLTC)**			
	Tap Position	***150 kV Voltage***	***20 kV Voltage***	***MVAR (absorb by generator)***
Ketapang	-17	131.5 kV	20.6 kV	-13.76 MVAR
Sukadana	-15	132.1 kV	20.6 kV	
Kendawangan	-11	131.9 kV	19.8kV	
Sandai	-13	133.2 kV	20.3 kV	

The addition of the plant reduces the system MVAR to -13.76 MVAR. This is because the generator plays a role in absorbing MVAR. Adding a plant requires adding OLTC adjustment to be able to regulate the voltage, so that adding a generator alone is not enough to improve the voltage.

Approach 5: Adjusting OLTC and adding Power Plant

The simulation results when using a combination of additional generators and OLTC adjustment are as shown in Table 8.

Table 8 Simulation results of adding a power plant and OLTC adjustment

Substation	**On-Load Tap Changer (OLTC)**			
	Tap Position	***150 kV Voltage***	***20 kV Voltage***	***MVAR (absorb by generator)***
Ketapang	-9	148 kV	20.8 kV	-17.99 MVAR
Sukadana	-9	148.4 kV	21.5 kV	
Kendawangan	-6	148.4 kV	21 kV	
Sandai	-8	149.2 kV	21.1 kV	

The combined simulation results between the addition of plant and OLTC adjustment are proven to be able to regulate voltage and maintain MVAR being able to be absorbed by the power plant.

4.2 Result

The result of the analysed approaches is summarized in Table 9.

Table 9 Simulation results

Approach	**METHOD**			***Result***
	Adjustment OLTC	***Adding Reactor***	***Adding Plant***	
1	Yes	No	No	Fail
2	No	Yes	No	Fail
3	Yes	Yes	No	Fail
4	No	No	Yes	Fail
5	Yes	No	Yes	Success

In determining the success of the approach studied, the nominal voltage in the Ketapang isolated system follows the applicable voltage standards [4] namely -10% and +5% of the nominal voltage. The next criteria are the permitted MVAR, less than -18 MVAR.

5 Conclusion

The voltage regulation in the Ketapang isolated system has been successfully simulated. The simulation was carried out using DIgSILENT Powerfactory by building a model that corresponds to actual approach. The simulation was carried out using three methods, such as adjusting the Load Tap Changer, adding a reactor, and adding a generator. The simulation was carried out in five approaches, such as OLTC adjustment, adding reactors, adding generators, combined OLTC adjustment and reactor addition, and combined OLTC adjustment and generator addition. The result is that the OLTC adjustment, adding reactors, adding generators, adding combination reactors with OLTC adjustment have not succeeded in regulating the voltage according to the applicable standards and are unable to absorb the MVAR, while the condition of adding combination generators with OLTC adjustment has succeeded in regulating the voltage and absorbing the MVAR according to the applicable standards. So, adding combination generators at Sandai substation with OLTC adjustment will improve the voltage quality.

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