Voltage Drop Mitigation in Comparison Analysis fo Low Voltage Shore Connection (LVSC)

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Abstract. This paper is based on an ongoing project to evaluate the voltage stability from shore to ship during connection which is currently a concern for ship operators. The voltage drops produced by the ship motor load during connection affect the anomalies of the electronic equipment on board. Stability Analysis Function (RMS) and Power Flow Analysis are studied for possible operating conditions at low voltage shore connection (LVSC) using Digsilent Power Factory. This study compares Upsize Converter, Transformer On Load Tap Changer (OLTC), Uprate Voltage Setpoint at Substation, and Static Synchronous Compensator (STATCOM) methods for voltage drop mitigation. Simulations shows that STATCOM has the capability to maintain reactive power compensation and Upsize Converter has current limits for balancing voltage during normal and dynamic operation as well as when voltage drops appear.

Keywords: *Low Voltage Shore Connection, Induction Motor Starting, Voltage Drop, Digsilent Power Factory.*

1 Introduction

Indonesia Green Port combines sustainable business practices by prioritizing social responsibility and customer satisfaction with relevant economic income. The use of renewable energy and environmentally friendly facilities such as wind turbines, solar panels, Shore Power Connection can help reduce exhaust emissions, as the amount of exhaust gas from diesel engines on docked ships is increasing and produces Sulfur Oxide (SOx), Nitrogen Oxide (NOx), Particulate Matter (PM), and Carbon Dioxide (CO2).

Tanjung Priok Port, the main entry point for export-import distribution in Indonesia, has been equipped with Low Voltage Electricity Connection (Shore Connection) infrastructure. When the ship berths, the utility operator sells electricity from the shore electricity connection to the ship operator. Over the past two years, customers have shown dissatisfaction. The evidenced by the realization of electricity sales of only 5.5% of the ship's potential when berths, which one of the causes is voltage instability when connected to the LVSC which impacts the

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anomaly of electronic equipment onboard and stability of the grid. Power measurements have been carried out when connecting shore electricity to ships. It was concluded that fluctuations in active power and reactive power often exceed 5% - 10% of the nominal voltage because Direct Online (DOL) Starter Motor on board loads when the ship is berthing.

The IEC/IEEE 80005-3 standard establishes the operational standards for Low Voltage Shore Connections and IEC 60038 for voltage standart. It states that the steady-state voltage drop shall not exceed -± 5% -10% from the nominal voltage. Power factor, cable length, cable size, and the load is too inductive where the current lags behind the voltage are significant elements that influence the voltage drop [1]. When the ship is berths, the ship still uses quite a lot of energy to operate pumps, control systems, ventilation, cooling, heating, and so on [2]. The system load line can be represented in models 1 & 2.

$$P_1 = \frac{V_1 V_2 \sin\delta}{X_L} \tag{1}$$

$$Q_1 = \frac{V_1(V_1 - V_2\cos\delta)}{X_L} \tag{2}$$

If the system load is increasingly inductive, the current lags behind while Q is also greater, meaning it absorbs more reactive power, conversely if it is increasingly capacitive, the current precedes the voltage V and supplies reactive power Q.

$$\Delta V = E - V = Z_S \,.\, I \tag{3}$$

$$\Delta V = (R_S + jX_S)\left(\frac{P - jQ}{V}\right) + j\left(\frac{R_S P - X_S Q}{V}\right) - j\left(\frac{X_S - R_S Q}{V}\right) \tag{4}$$

$$\frac{\Delta V}{V} = \frac{X_S Q}{V^2} \approx \frac{Q}{S} \tag{5}$$

$$V \approx 1 - \frac{Q}{S} \tag{6}$$

It means that changing the Q value will affect the Bus voltage. The greater the Q value supplied, the higher the V voltage. By adding a compensator installed parallel to the load, it is possible to maintain |V|=|E|. The reactive power of the load on the compensator is replaced by the amount of Qs = Q + Qγ, and the reactive power of the compensator Qγ is adjusted in such a way as to rotate the phasor V so that |V|=|E|.

STATCOM is a FACTs device that is non-thyristor based. It is a shunt connected to the power system. The exchange of the reactive power occurs between the STATCOM and the alternating current (AC) system. The reactive power (Q) is injected into the AC system when its voltage magnitude is low and Q is absorbed when the system voltage magnitude is high. The reactive current drawn by the synchronous voltage compensator depends on the magnitude of the system voltage V, i.e. the converter Vo and all circuit reactance.

$$I = \frac{V - V_0}{X} \tag{7}$$

The reactive power exchange Q is represented by :

$$Q = \frac{1 - \frac{V_0}{V}}{X} V^2 \tag{8}$$

Most of the research on shore connections studied how to determine the capacity of OPS [3], Ship-to-Shore versus Shore-to-Ship Synchronization Strategy [4], Harmonic measurement on ships and cold ironing [5], Voltage Drop Estimation During Shore Connection Using Modified Drive Motor as Static Frequency Converter which proved that the combination of tap changer position and frequency converter can overcome voltage variation according to marine classification rules [6].

Therefore, the main contribution of this paper is to effectively reduce the voltage drop during steady state and start the inductive motor using appropriate options of Upsize Converter, Transformer On Load Tap Changer, Uprate Voltage Setpoint at Substation, and STATCOM to improve the voltage profile. STATCOM is chosen because it can detect and recover faster by injecting appropriate reactive power into the system in situations where the load is dynamic.

2 Methodology

The purpose of flowchart belows to facilitate understanding and the goals to be achieved in the program simulation for LVSC. Simulations are performed using DIgSILENT PowerFactory.

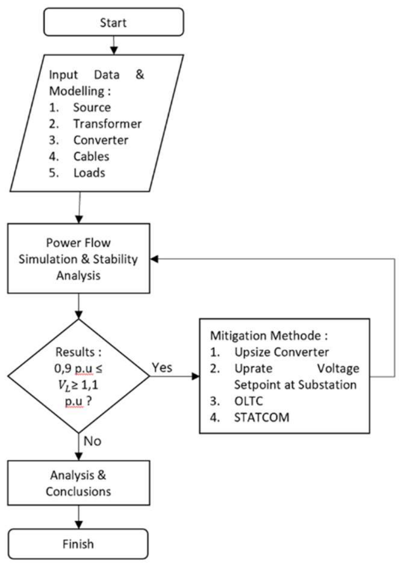

Fig. 1. Flowchart Methodology

In Figure 1 show, a simulation will be conducted by maintaining the reliability and availability of power in the LVSC subsystem in Tanjung Priok Port. The parameter conditions of each bus will be known by first conducting a power flow simulation before starting the dynamic response simulation. The simulation then analyzes the findings from the simulation results and finds the right mitigation for voltage improvement.

2.1 System Modelling

Fig 2 shown The Low Voltage Shore Connection (LVSC) simulation model is developed including the external grid (represented PLN source), shoreside transformer step down, shoreside isolation transformer, connection cables, frequency converter, and the low voltage main switchboard.

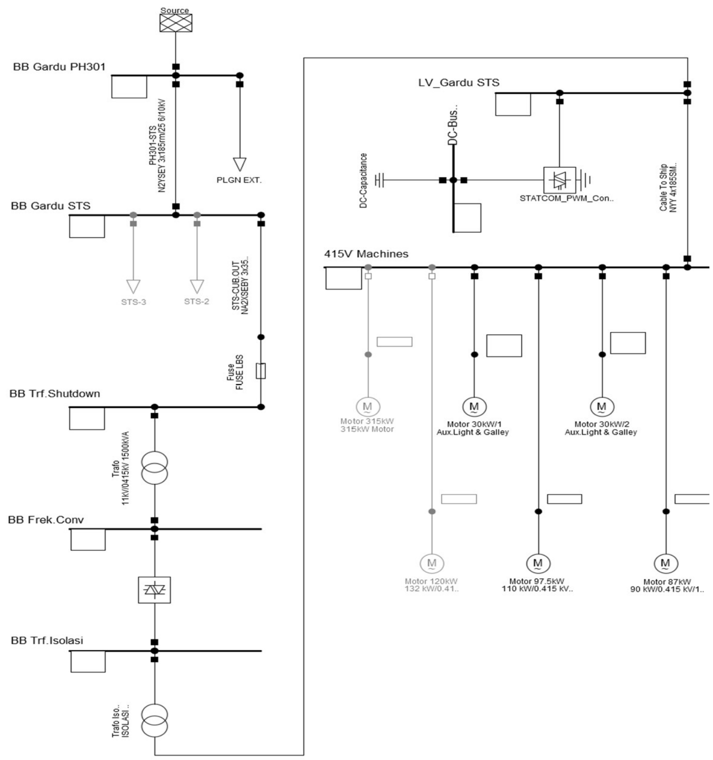

Fig. 2. LVSC Single Line Diagram

The LVSC is modeled with a capacity of 2x500 kVA with a 12 MVA external grid power source at 6.6 KV voltage. The load on PH301 is 5 MVA (PF: 0.75) which is assumed to be constant. The shoreside voltage is reduced by 0.415 kV to adjust the ship's voltage. Table 1 provides a concise summary of the chosen components for shore connection.

Table. 1. LVSC Components

System Components	Descriptions
Transformator Stepdown	630 Kva, 20 kV/415V, 50 Hz, Dyn5, Eff. 95%, Tap Changer & Position 1.2% / 0.
Fuse	MV Protection, 7,2 Kv, 630 A, 50 Hz.

System Components	Descriptions
Transformator Isolation	630 Kva, 415 kV/415V, 50 Hz, Dyn5, Eff. 95%, Tap Changer & Position 1.2% / 0.
Cables MV	NA2XSEBY 3x35 mm, 6,6 KV,1 kA,50Hz
Cables LV	NYY 4x185mm,1 kV, 0,398 kA, 50Hz

The frequency on ships is usually 50 Hz according to the frequency of the distribution network in Indonesia, while some ships operate at a frequency of 60 Hz .Therefore, the converter is needed on the LVSC for balance the frequency. The Converter is modeled using the Softstater model defined in the Digsilent Global Library which has the same behavior as the installed frequency converter. The converter has 2,3 kA thermal current with 110%-150% limited maximum current. The control system will avoid overloading by limiting the current and regulating the output voltage. The simulation runs in off mode since the ship's load operates at a frequency of 50 Hz.

2.2 Loads Modelling

Large Cargo Ships with LOA > 150 meters are most often provided by 3 units (2 ON + 1 Back Up) of diesel engine generators with a capacity of 800 KW connected to the main electrical panel and the motor load as shown in Table II. The load synchronization of the oil and ventilation, auxiliary light, galley, and auxiliary air conditioner motor loads occurs when the ship is berthing. Direct-On-Line starting is the most commonly used method for starting marine engine induction motors. The ballast pump motor load starting when the ship needs balance in the water and stops when it reaches a steady position. Additionally, the ship's main deck and unloading 1 engine will start while the ship is loading and unloading. Dynamic load simulation will be adjusted to approach the real load specifications in the project (see Table II).

Table. 2. Ships Loads

Motor Loads	Mechanic Power (kW)	Active Power (MW)	Speed (rpm)	PF	Eff (%)
Aux Light	30	0,03	1455	0,7	95
Galley	30	0,03	1455	0,7	95
Oil & Ventilation	110	0,097	989	0,84	95

Motor Loads	Mechanic Power (kW)	Active Power (MW)	Speed (rpm)	PF	Eff (%)
Aux Air Conditioning	90	0,087	1483	0.87	95
Ballast Pump	132	0,12	1490	0,85	94,5
Unloading Cont.Docking	315	0,3	1780	0,88	95

2.3 Scenario Simulation & Parameters

The scenarios that have been tested to determine steady-state and dynamic as follows :

1. Scenario 1 : Load Flow Analysis

   Based on single line diagram and data system in Figure.2, the results of load flow simulation for normal LVSC operations to determine the normal conditions before analyzing power system stability. It is defined that 6,6 kV nominal voltage for BB_PH301, BB_Gardu STS, BB_Trf Shutdown and 0,415 kV nominal voltage for BB_Frek Conv, BB_Trf Isolasi and LV_Gardu STS. The busbar of ship is BB_415 Machine that defined 0,415 kV nominal voltage. The simulation has conducted with the condition of the peak load on March 17, 2024 which is around 72% from LVSC capacity with system profile as shown belows:

Table. 3. System Profile in Peak Load Condition

Segmen Busbar OPS	Active Power (kW)	Reactive Power (kVAR)	PF	Current (A)	Loading (%)
Source/External Grid	5737	1140	0,98	511	-
BB_PH301	737	440	0,86	75	19,2
BB_Gardu STS	734	447	0,85	75	7,6
BB_Trf.Shutdown	722	449	0,85	75	68,7
BB_Frek.Conv	721	420	0,86	1204	68,7
BB_Trf.Isolasi	721	420	0,86	1204	68,7
LV_Gardu STS	719	396	0,88	1198	75,3

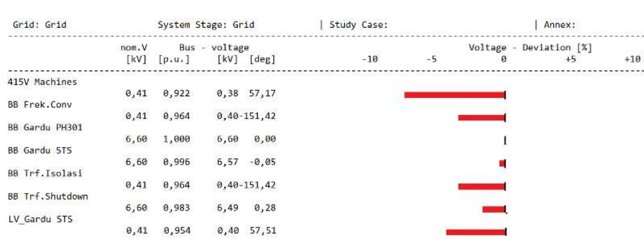

Fig. 3. Voltage Profile in Peak Load Condition

Table 3 and Figure 3 show that all busbars on the LVSC are still within 5%-10% of the nominal value, which is in accordance with the standard.

In normal operation, when the onboard CB is open, there is no load connected to the LVSC. After the onboard CB is closed, loads are connected with an average of 90% of the total power engine which is usually followed by a voltage drop and current synchronization. The majority of connected ship loads consist of Aux Light, Galley, Aux AC, Oil & Ventilation with an average 250 kW as represented belows.

Table. 4. System Profile in Normal Condition

Segmen Busbar OPS	Active Power (kW)	Reactive Power (kVAR)	PF	Current (A)	Loading (%)
Source/External Grid	5251	847	0,99	465	-
BB_PH301	251	147	0,86	25	6,6
BB_Gardu STS	251	156	0,85	25	2,6
BB_Trf.Shutdown	250	160	0,84	26	23,7
BB_Frek.Conv	250	156	0,85	415	23,7
BB_Trf.Isolasi	250	156	0,85	415	23,7
LV_Gardu STS	248	148	0,86	408	25,7

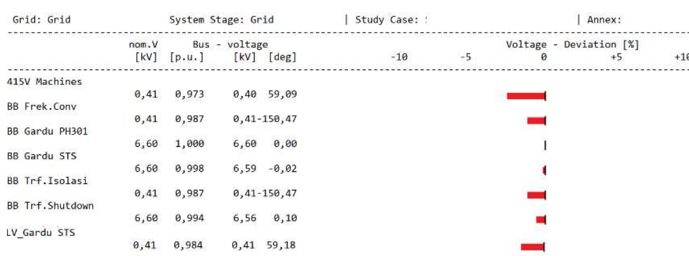

Fig. 4. Voltage Profile in Normal Condition

In Table 4 and Figure 4, it is known that when the normal operating load is 25,7%. All busbars on the LVSC are still within 5%-10% of the nominal value, which is in accordance with the standard.

2. Scenario 2 : Motor Starting Analysis

The purpose of RMS Simulation to determine the voltage changes on the LVSC busbars due to current fluctuations from the ship's induction motor machines. The motor machine model is defined by the Digsilent Power Factory template which has specifications in Table 2. In this study, The ballast pump & Unloading Cont.Docking loads start for 10 seconds simultaneously.

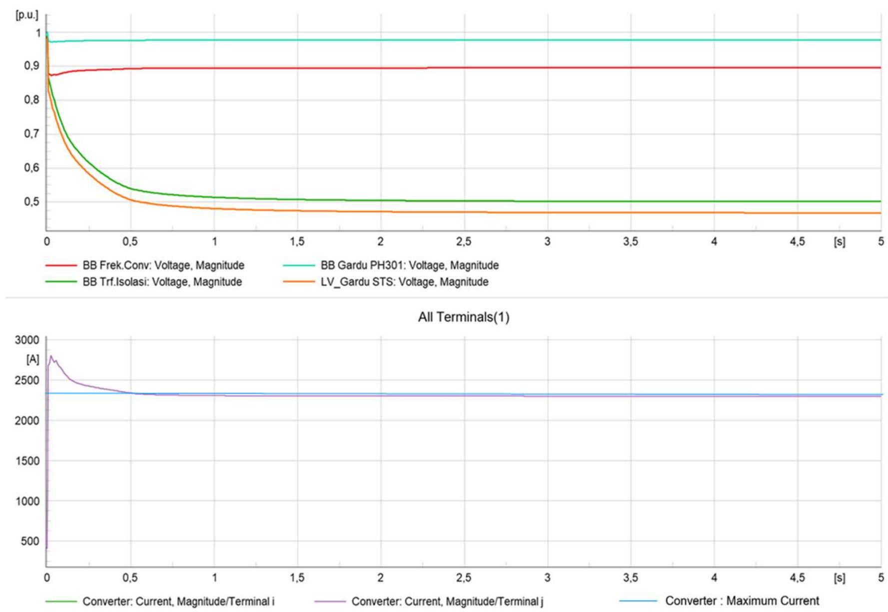

Fig. 5. Voltage Response After Motor Starting

In Figure 5, a significant voltage drop is seen on the BB_Trf Isolasi with value 0,50 PU and LV_Gardu STS with value 0,47 PU. The starting current is above the maximum converter current, so current limitation occurs with a voltage drop in the converter, which impacts the BB_Frek Conv, BB_Trafo Shutdown, BB_STS, and BB_PH301. When started, the steady state condition must return to its set point because the power supply from the source is very limited.

2.4 Voltage Mitigation Methods

1. Methods 1 : Upsizing The Converter
   The sizing of converter was changed with value 2 Ka thermal current and 3 kA for maximum value to adjust inrush current. The results show in Table 5.

Table. 5. Result of Upsizing Converter

Segmen Busbar OPS	Inrush	I steady state	V (PU)	P (Kw)	Q (Kvar)
BB Gardu PH301	3059	77	0,99	756	449
BB Gardu STS		78	0,99	753	455
BB Trf.Shutdown		78	0,97	741	457
BB Frek.Conv		1243	0,96	739	426
BB Trf.Isolasi		1243	0,96	739	426
LV_Gardu STS		1237	0,94	738	401

2. Methods 2 : Uprating Voltage Setpoint at Substation.
   The voltage setpoint was changed from 1 PU to 1.1 PU at PH301 Substation. The results show in Table 6.

Table. 6. Result of Upsizing Converter

Segmen Busbar OPS	Inrush	I steady state	V (PU)	P (Kw)	Q (Kvar)
BB Gardu PH301	2969	155	1,07	592,5	1813,2
BB Gardu STS		156	1,07	580	1812
BB Trf.Shutdown		156	1,05	528,9	1810,4
BB Frek.Conv		2487	0,99	524,9	1683,6
BB Trf.Isolasi		2487	0,55	524,9	841,8
LV_Gardu STS		2483	0,52	524,3	764,1

3. Methods 3 : Using On Load Tap Changer (OLTC).
   The automatic on load tap changing 1 PU at low voltage controlled node transformator. The results show in Table 7.

Table. 7. Result of Upsizing Converter

Segmen Busbar OPS	Inrush	I steady state	V (PU)	P (Kw)	Q (Kvar)
BB Gardu PH301	2803	175,5	0,97	617,2	1848,2
BB Gardu STS		176,2	0,96	601,6	1842
BB Trf.Shutdown		176,6	0,95	536,2	1837,6
BB Frek.Conv		2504	0,99	532,1	1709
BB Trf.Isolasi		2504	0,56	532,1	854,5
LV_Gardu STS		2500	0,52	531,5	775,7

4. Methods 4 : Using STATCOM.
   The STATCOM is modeled using model defined in the Digsilent Global Library with controller as shown in Fig.9 belows :

	Parameter
Kp Active Power Control Gain [p.u.]	20,
Tp Active Power Control Time Constant [s]	0,002
Kv Voltage Control Gain [p.u.]	4,
Tv Voltage Power Control Time Constant [s]	0,002
droop	0,02
Trdc	0,001
Trac	0,01
i_min	-2,67
i_max	2,67

Fig. 6. Statcom Control

Placement of the STATCOM on the bus with the lowest power flow which is on LV_Gardu STS and the sizing used is the amount of reactive power required when starting the induction motor with value 300 kVA. The results show in Table 8.

Table. 8. Result of Upsizing Converter

Segmen Busbar OPS	Inrush	I steady state	V (PU)	P (Kw)	Q (Kvar)
BB Gardu PH301	2455	91,1	0,99	1041	-24
BB Gardu STS		91	0,99	1037	-19
BB Trf.Shutdown		91	0,97	1011	-17
BB Frek.Conv		1447	0,97	1010	-60
BB Trf.Isolasi		1447	0,97	1010	-60
LV_Gardu STS		1716	0,97	1008	655

3 Result and Analysis

In order to ensure the performance of the proposed method, voltage deviations and time response will be monitored before and after operation methode as follow :

3.1 Comparative Analysis of Voltage Stability

The results of the Power Flow Analysis performed with Digsilent PowerFactory are presented in Table 9. The power generated for STATCOM load needs requires a smaller losses of (58,86 kW, 65,41 kVAR) and the smallest generating power compared to the others.

Table. 9. Result of Upsizing Converter

System Summary	Parameters	Normal Operate	Method-1	Method-2	Method-3	Method-4
External Grid PH301	Active Power (kW)	5737	5737	6776	5737	5730
	Reactive Power (kVAR	1140	1140	1303	1140	831
Toral Load	Active Power (kW)	5000	5000	6050	5000	5000
	Reactive Power (kVAR	700	700	847	700	700
Total Motor Load	Active Power (kW)	672	672	672	672	672
	Reactive Power (kVAR	360,5	360,5	393	360,5	360,5
Total Losses	Active Power (kW)	65,06	65,06	54,18	65,06	58,86
	Reactive Power (kVAR	80,27	80,27	63,25	80,27	65,41

In Fig. 6, most of the voltages are close to the normal operating case except method-1 which is higher than others. However, all conditions are still within 5%-10% of the nominal voltage when the motor load has been connected to the LVSC.

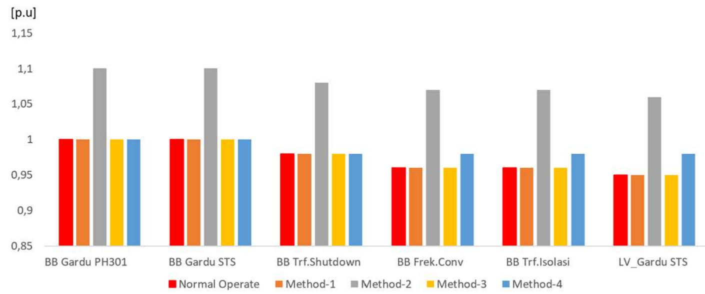

Fig. 7. Statcom Control

3.2 Comparative Analysis of Motor Starting

The voltage comaprison results of the Stability Analysis Function (RMS) performed with Digsilent PowerFactory are presented in Figure 9. A significant voltage drop occurred at BB_Trafo Isolasi and LV_Gardu STS. This is because the motor inrush current increased by about 5-6 times the nominal current. The cable transient current is the sum of the motor starting current and the current that has been connected to the LV panel, resulting in a decrease in busbar voltage of up to 50% of the nominal voltage as shown in starting operation graph.

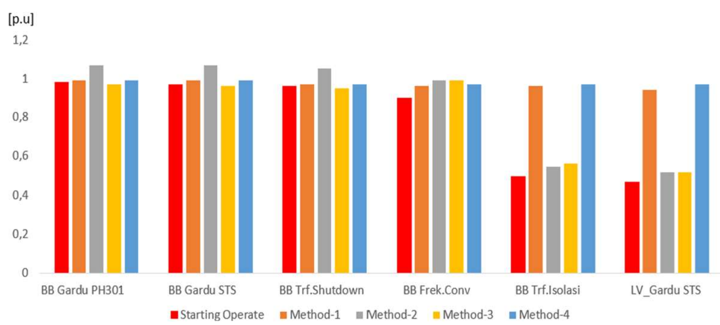

Fig. 8. Voltage Comparison in RMS Simulation

In Methode 1, shows that the power supplied to the load remains optimal even though there are changes in voltage and current, especially at BB_Trafo Isolasi & LV_Gardu STS. The converter can limit the current so that the voltage can be compensated when the voltage drop reaches with a result of 0.94 PU at the LV_Gardu.

In Methode 2, the substation voltage increased and stabilized until a grid change occurred at the stepdown transformer (6.6 kV to 0.415 kV), the voltage at BB_Trafo Isolasi and BB_LV Gardu still exceeded 45% of the nominal voltage, which was 0.55 PU, which had not reached the expected voltage standard

In Methode 3, the automatic tap changer managed to maintain the voltage at BB Frek Conv by 1 PU. Ultimately, the voltage decreased at BB_Trafo Isolasi and BB_LV Gardu by 0.56 PU, which had not reached the expected voltage standard. In Fig 13. shown automatic tap transformer works according to voltage changes up to position -9.

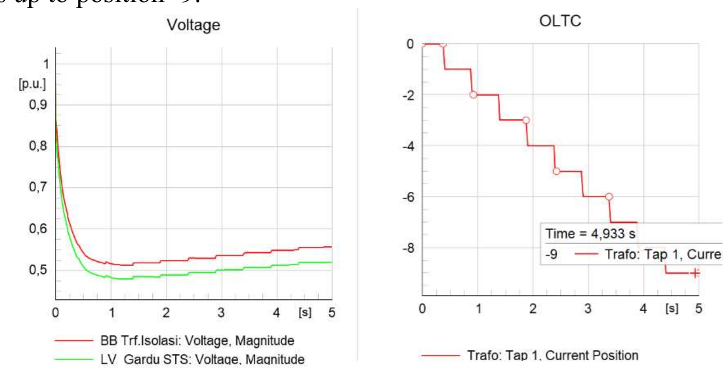

Fig.9. Graph of OLTC

The optimal results are shown in Methode 4, The installation of STATCOM on a weak bus can compensate for the voltage drop by providing the required reactive power supply according to the load requirements. This is shown when 2 units of induction motor start, the voltage on each busbar is 0.97 - 0.99 PU which means it is close to the nominal voltage.

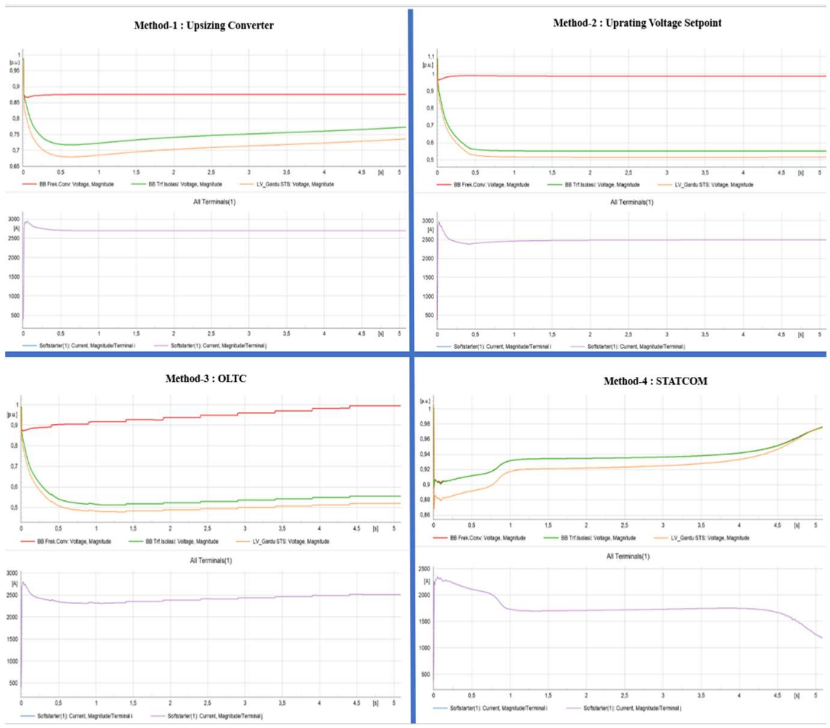

Fig. 10. Graph of OLTC

Fig.10 displays inrush current and voltage recovery time which is the motor rotor slows down and the impact of these current currents becomes insignificant. The fastest voltage recovery is shown in Case 4, which is within 0.5 seconds.

4 Conclusions

The presented paper focuses on the compatibility issue of voltage dip mitigation methods at the shore connection. The LVSC model is created in Digsilent Power Factory. Voltage drop during shore connection is studied through simulation in normal and dynamic condition with upsizing the converter, transformer On Load Tap Changer (OLTC)
setting, uprating voltage setpoint at Substation, and addition of Distribution Static Synchronous Compensator (DSTATCOM). The simulation confirmed that the addition of STATCOM better than other methode which can be suitable solution for the stability voltage within the permissible limits. The maximum voltage drop was observed during induction motor starting at a nominal voltage of 0.415 kV

is 0.97 PU. This value is still within the limit because according to the rules, the voltage variation can be up to 5%-10%. Furthermore, STATCOM can provide oscillation damping with a recovery time of less than 0.5 seconds. It means it does not affect the onboard electrical equipment and expects to increase customer satisfaction so that they are interested in using LVSC.

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