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RESEARCH ARTICLE

Power Quality Improvement for Voltage Sag Issue in Industrial Customers

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Abstract
Customer demand today is no longer limited to ensuring the reliability of electricity supply, but also includes the continuity and delivery of high-quality electrical power. One of the main challenges affecting power quality is voltage sag, a condition frequently experienced by industrial customers, particularly at PT. Samator Gas Industri Palembang. This study aims to analyze the causes of voltage sag problems and evaluate the effectiveness of technical solutions. The methodology involves analyzing field observation data, recordings from a Fluke Power Quality Meter (PQM), and simulations of Line-to-Line (LL) and Three-Phase (L-3P) short-circuit faults using ETAP software. The simulation results are evaluated using the ITIC Curve to determine whether the observed voltage levels fall within acceptable operational boundaries or enter the prohibited zone. Simulations were conducted under normal operating conditions by integrating three technical solutions: Static VAR Compensator (SVC), IS-Limiter, and Diesel Rotary UPS (DRUPS). The findings indicate that although SVC can accelerate voltage recovery after a disturbance, its effectiveness is lower compared to the others. The IS-Limiter provides a rapid response to limit fault current and prevent the propagation of disturbances throughout the system. Meanwhile, DRUPS offers the fastest and most reliable voltage recovery, restoring voltage to 100% in less than 20 milliseconds.

Keywords: Voltage Sag, Power Quality, Short-Circuit Current, ITIC Curve, ETAP

1. Introduction

Power quality is one of the critical aspects in electric power systems, especially for industrial customers who are highly sensitive to voltage fluctuations. One common issue is voltage sag, which refers to a short-term reduction in voltage magnitude that can interfere with equipment performance and disrupt industrial processes. In Indonesia, this phenomenon is often found in industries operating large loads with sudden power changes, such as large-capacity induction motors, electric furnaces, or compressors.

International standards such as IEC 61000-4-15 are used to quantify voltage sag events using measurement techniques and performance evaluation methods [1]. Additionally, the ITIC Curve (CBEMA Revised 2000) serves as a key reference for evaluating voltage tolerance over time [2]. Bollen (2000) also explains that short-term disturbances causing voltage sag are significantly influenced by system impedance and load response [3].

According to Timbus et al., the use of SVCs in industrial environments significantly improves power quality and mitigates voltage sag events [4]. IEEE 1159-2019 provides general guidelines for power quality monitoring, including voltage sag characterization and assessment [5]. Books by Gonen [6] and El-Hawary [7] provide foundational theory in distribution and energy systems relevant to disturbance and power quality contexts.

Additionally, IEEE 519-2014 [8] and the work of Hingorani and Gyugyi [9] on FACTS offer further understanding on harmonics mitigation and reactive power control. ETAP's simulation use is supported by its official user manual [10] and this study is fully referenced to the author's thesis research [11]. The methodology for short-circuit and power flow analysis is further supported by Das's book [12].

Several studies have been conducted to improve power quality in industrial distribution systems, particularly focusing on the mitigation of voltage sag using devices such as Static VAR Compensator (SVC), IS-Limiter, Dynamic Voltage Restorer (DVR), and Diesel Rotary UPS (DRUPS) [3] [13] [14] [15] [16] [17] [18] [19]. These studies emphasize the importance of maintaining voltage stability in supporting sensitive industrial processes by evaluating the performance of these devices against international standards such as the ITIC (CBEMA) curve. The existing literature also highlights various control strategies and compensation methods, including improved SVC control, DVR applications, and DRUPS deployment, which have been proven effective in keeping voltage profiles within acceptable limits during disturbances such as voltage sag.

This research is conducted on the medium-voltage distribution system supplying PT. Samator Gas Industri in Palembang, which experiences periodic voltage sag issues. Simulations are performed using ETAP software to analyze the impact of various disturbances on voltage profiles and to evaluate the mitigation effectiveness of SVC, IS-Limiter, and DRUPS with reference to the ITIC Curve standard. The objective is to identify the most effective technical solution that ensures system stability and maintains continuous operation of industrial processes. The structure of this paper includes an introduction, research methodology, simulation results and analysis, and conclusions.

2. Research Metology

This research adopts a case study approach focusing on an industrial customer experiencing recurring voltage sag issues. The study was conducted by collecting field data, analyzing Power Quality Meter recordings from May 18, 2023, to September 5, 2023, and running fault simulations using ETAP software. The effectiveness of each mitigation solution was assessed using the Information Technology Industry Council (ITIC) curve tolerance as a reference.

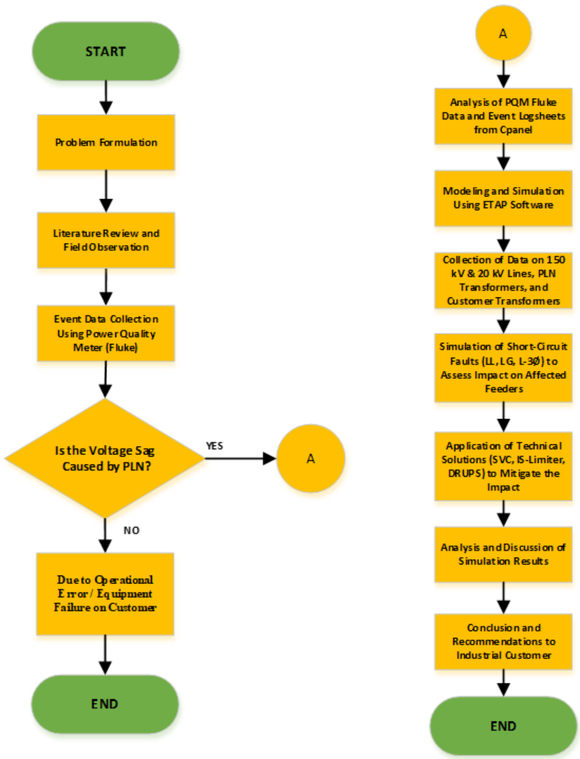

Figure 1. Flowchart of the Research Methodology

2.1 System Object and Network Data

The object of study is a 20 kV medium-voltage distribution system supplying PT. Samator Gas Industri in Palembang. The main supply comes from the Kenten Main Substation (GI Kenten), which includes several feeders. Network data was gathered in the form of a single-line diagram including distribution transformer characteristics, customer loading, and line impedance. Field observations were also carried out using a Fluke Power Quality Meter (PQM) Analyzer Plus to capture disturbance events in the customer's electrical system.

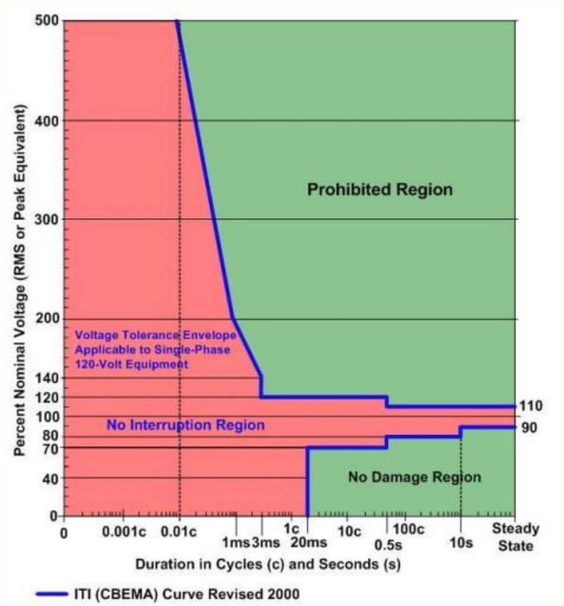

Figure 2. ITIC Curve in Duration of Cycles (c) and Seconds (s)

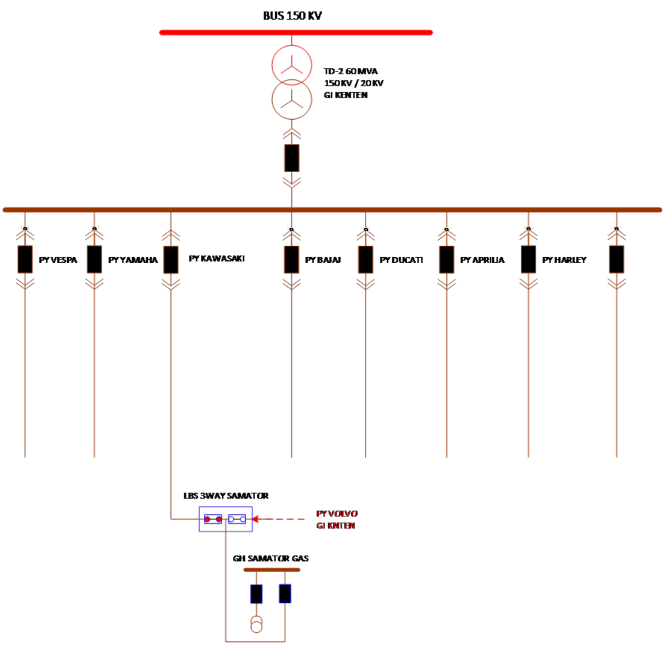

Figure 3. Single Line Diagram of Kenten Main Substation – Distribution Transformer #2

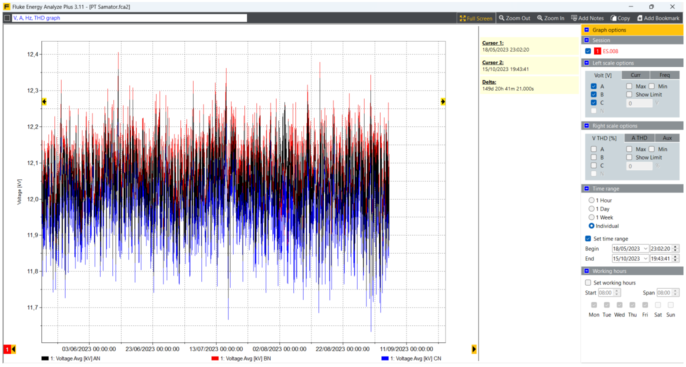

Figure 4. Voltage, Ampere, Hz & THD Graph Fluke

Based on Figure 4, the voltage measurements recorded by the PQM Fluke Energy Analyzer Plus during the period from May 18, 2023 to September 5, 2023 at PT. Samator Gas Industri Palembang showed significant voltage variations across all three phases. The maximum voltages were recorded at 21.244 kV (AN), 20.973 kV (BN), and 20.948 kV (CN), exceeding the nominal voltage of 20 kV ±5%, indicating a potential overvoltage condition. Meanwhile, the minimum voltages for each phase were recorded as low as 1.751 kV (AN), 1.306 kV (BN), and 1.277 kV (CN), indicating extreme voltage sags that pose a serious risk to sensitive equipment.

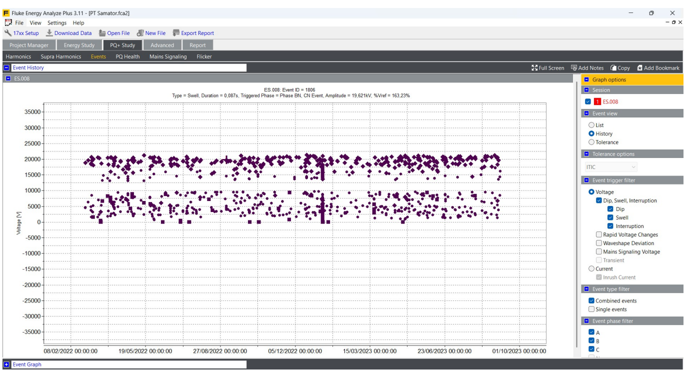

Figure 5. PQM Fluke Event: Voltage Disturbances (Dip and Swell) at PT. Samator

Figures 5 and 6 illustrate voltage dip and swell disturbance events recorded by the PQM Fluke software at PT. Samator Gas Industri, plotted against the ITIC curve (Information Technology Industry Council). The purple dots represent voltage disturbance events on each phase (A, B, and C). The ITIC curve serves as a standard reference for voltage tolerance limits over time, where equipment is expected to continue operating normally as long as the voltage remains within the safe zone. It can be observed that most dip and swell events fall outside the ITIC tolerance boundaries, particularly for durations between 10 ms and 1 second with voltage dropping below 80% of nominal.

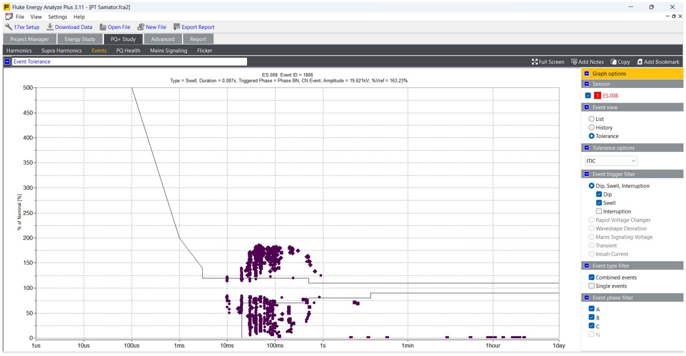

Figure 6. PQM Fluke Event, Distribution Dip & Swell Analysis Based on ITIC Curve Tolerance

This indicates that the system is experiencing frequent and severe power quality disturbances, which may negatively affect the performance of sensitive customer equipment.

Table 1. PQM Fluke Event Summary – PT. Samator Gas Industri

Events	Phase A	Phase B	Phase C	Neutral	Combined Events
Dip	214	245	228		492
Swell	272	250	262		411
Interruption	84	86	81		65
Inrush Current	8	10	9	0	
Waveshape Deviation	1262	1233	1236		
Rapid Voltage Changes	377	369	356		480
Mains Signaling Voltage	12	12	12		

2.2 Planned Design of Fault Simulations

Two types of short-circuit faults were selected for simulation as they are relevant to field conditions and the voltage sags characteristics observed:

1. Line to line fault
2. Three phase fault

This figure illustrates the single-line diagram of the 20 kV medium-voltage distribution network supplying PT. Samator Gas Industri, modeled in ETAP software. The left panel shows the system configuration, including the Kenten Main Substation (GI Kenten), various feeders (Yamaha, Kawasaki, and Bajaj), key switching devices (reclosers, circuit breakers, LBS), and customer loads. Technical solutions such as SVC, IS-Limiter, and DRUPS are placed at strategic locations for simulation scenarios.

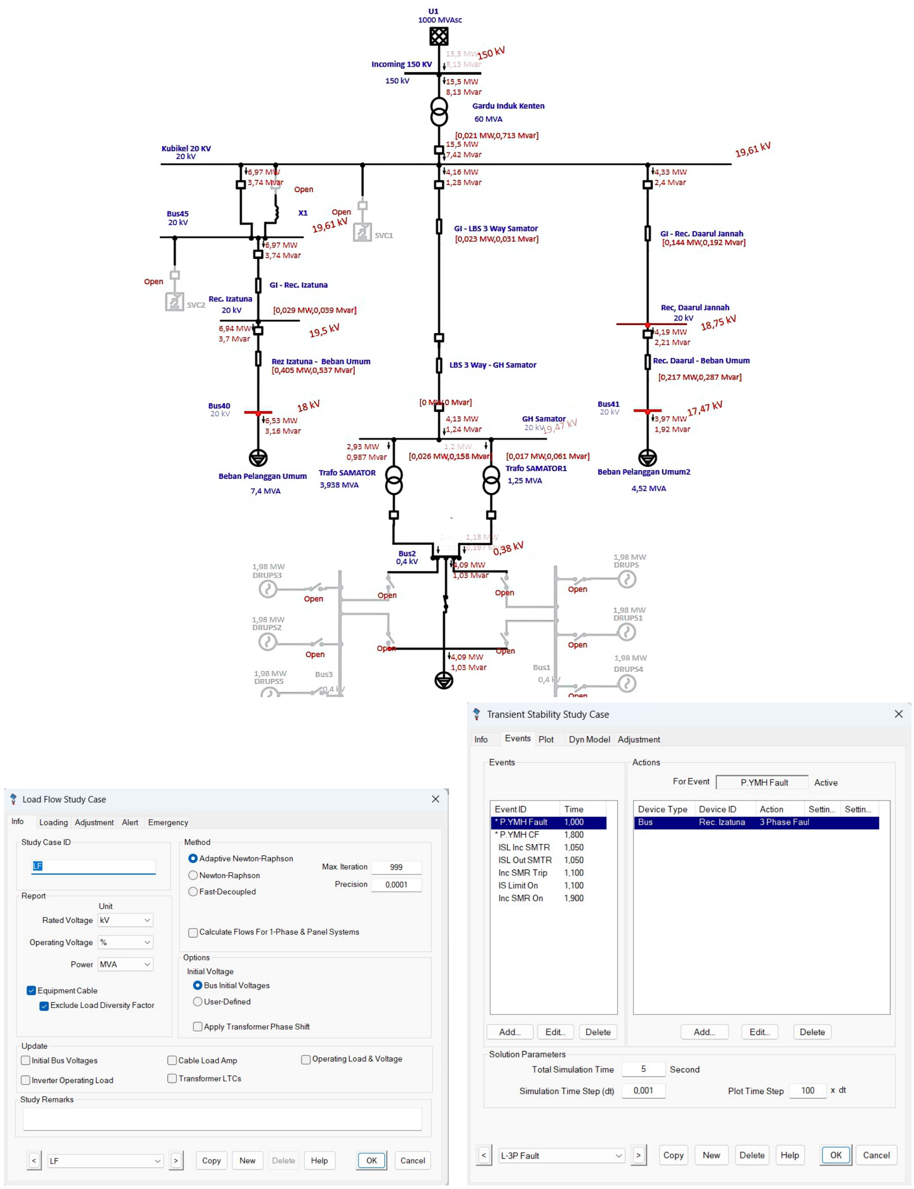

Figure 7. ETAP Simulation Design Under Normal Operating Conditions

The top-right panel displays the Load Flow Study Case configuration, where adaptive Newton-Raphson method is used with system voltage and MVA base parameters. The bottom-right panel shows the Transient Stability Study Case setup, where a line-to-line (LL) fault is applied on the Rec. Izatuna feeder at t = 1.000 s, followed by IS-Limiter trip actions and DRUPS activation sequences for evaluating system recovery.

The fault was applied temporarily for 2 milliseconds before being cleared, to reflect actual events captured in the PQM recordings. The fault location was set on a different feeder that is still connected to the same transformer at the main substation. The objective was to observe the extent of the voltage dip's impact on duration and to determine whether it falls within the prohibited zone of the ITIC curve.

Table 2. Bus Loading Summary Report

Project:		ETAP	Page: 1
Location:		19.0.1C	Date: 27-04-2025
Contract:			SN:
Engineer:		Study Case: LF	Revision: Base
Filename:	LIMITER DI F TERGANGGU		Config.: Normal

Bus Loading Summary Report

Bus			Directly Connected Load								Total Bus Load			
			Constant kVA		Constant Z		Constant I		Generic					Percent
ID	kV	Rated Amp	MW	Mvar	MW	Mvar	MW	Mvar	MW	Mvar	MVA	% PF	Amp	Loading
Bus2	0.400										4.217	97.0	6402.3	
Bus13	0.400		3.337	0.836	0.754	0.189					4.217	97.0	6402.3	
Bus40	20.000		5.994	2.903	0.540	0.261					7.260	90.0	232.8	
Bus41	20.000		3.661	1.773	0.310	0.150					4.413	90.0	145.8	
Bus42	20.000										4.318	95.8	128.0	
Bus45	20.000										7.908	88.1	232.8	
GH Samator	20.000										4.318	95.8	128.0	
Incoming 150 KV	150.000										17.486	88.5	67.3	
Kubikel 20 KV	20.000										17.147	90.2	504.8	
Rec, Daarul Jannah	20.000										4.736	88.4	145.8	
Rec. Izatuna	20.000										7.864	88.2	232.8	

* Indicates operating load of a bus exceeds the bus critical limit (100.0% of the Continuous Ampere rating).

2.3 Simulation Design Using ETAP Software

In this simulation design, the analysis focuses on the voltage response at the Samator Switching Substation (GH Samator) and other feeders connected to the same distribution transformer at the Kenten Main Substation (GI Kenten). The simulation aims to observe the impact of faults or short-circuit currents originating from the Yamaha feeder via the Izatuna Recloser.

The following simulation scenarios were conducted:

1. Simulation 1, Short-circuit testing for Line-to-Ground (LG), Line-to-Line (LL), and Three-Phase faults under normal operating conditions.
2. Simulation 2, Short-circuit testing for Line-to-Line (LL) and Three-Phase faults with a Static VAR Compensator (SVC) Installed at the Incoming Busbar of Kenten Main Substation (GI Kenten)
3. Simulation 3, Short-circuit testing for Line-to-Line (LL) and Three-Phase faults with an SVC Installed at the Fault-Affected Feeder of Kenten Main Substation (GI Kenten)
4. Simulation 4, Short-circuit testing for Line-to-Line (LL) and Three-Phase faults with an IS-Limiter Installed at the Fault-Affected Feeder of Kenten Main Substation (GI Kenten)

5. Simulation 5, Short-circuit testing for Line-to-Line (LL) and Three-Phase faults with an IS-Limiter Installed at the Outgoing Side of Samator Switching Substation (GH Samator)
6. Simulation 6, Short-Circuit Testing with DRUPS Installed at the Outgoing Side of Samator Switching Substation (GH Samator)

2.4 Evaluation of Fault Simulation Results Using the ITIC Curve

Under both normal operating conditions and technical solution scenarios, evaluations were conducted using the ITIC curve (CBEMA Revised 2000). This curve illustrates the upper and lower voltage tolerance limits with respect to duration. If the voltage profile during a fault enters the Prohibited Region, it is considered to pose a high risk of equipment damage. In contrast, if it falls within the No Damage Region or No Interruption Region, the disturbance is still considered tolerable and not likely to cause equipment damage. Each simulation result was evaluated and compared against the ITIC (Information Technology Industry Council) curve, which serves as the standard reference for voltage versus time assessment.

3. Simulation Results

3.1 Simulation Results, Short-Circuit Testing Under Normal Operating Conditions

The initial simulation was carried out under normal operating conditions without any technical mitigation. The results showed that Line-to-Ground (LG), Line-to-Line (LL), and Three-Phase (L-3Ø) faults produced different voltage responses. Inparticular, the three-phase fault caused the voltage to drop by as much as 20% of nominal and entered the Prohibited Region of the ITIC curve. The voltage remained below the allowable threshold for more than 200 milliseconds, posing a high risk of to industrial equipment and leading to potential operational failure or tripping.

However, for the Line-to-Ground (LG) fault, the simulation indicated that the voltage drop was not as severe compared to the LL and L-3Ø faults. The voltage decreased only by about 5–10%, with a minimum value of 93.5%, which recovered within less than 100 milliseconds. The voltage profile resulting from the LG fault remained within the No Interruption Region of the ITIC curve. Therefore, LG faults are considered to have no significant impact on the operation of industrial equipment.

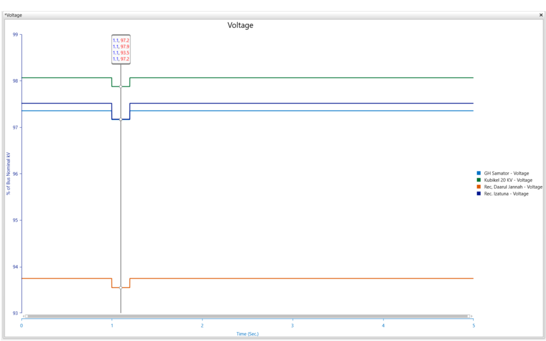

Figure 8. Voltage Response During Line-to-Ground Fault Under Normal Operating Conditions

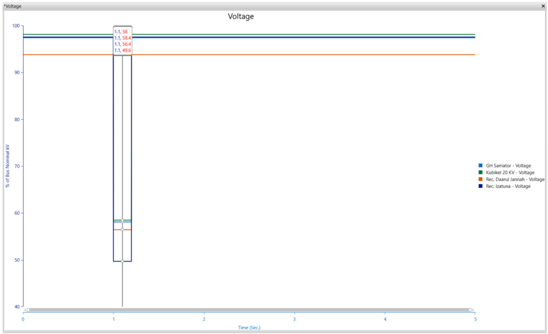

Figure 9. Voltage Response During Line-to-Line Fault Under Normal Operating Conditions

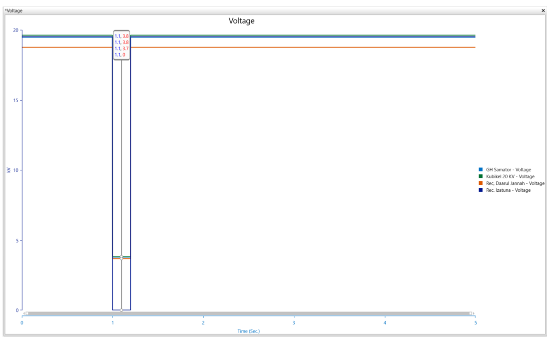

Figure 10. Voltage During Three-Phase Fault Under Normal Operating Conditions

3.2 Results 2: Short-Circuit Testing with SVC Installed at the Incoming Busbar of Kenten Main Substation (GI Kenten)

Figure 11 shows the system voltage response to Line-to-Line (LL) and Three-Phase (3Φ) short-circuit faults in the distribution system, with a Static VAR Compensator (SVC) installed at the 20 kV busbar on the incoming side of Kenten Main Substation. In Figure 4.15, the voltage at GH Samator and several other points dropped to approximately 12 kV, or 58.6% of nominal voltage, with the fault and recovery duration lasting 0.2 seconds (200 ms). According to the ITIC curve, this condition entered the Prohibited Region.

In Figure 12, the voltage drop was even more extreme, with the voltage falling as low as 3.8 kV, or only 18.9% of nominal. Based on the ITIC curve, this condition also falls into the Prohibited Region because it remained below 40% for more than 20 milliseconds. Although the SVC contributed to accelerating voltage recovery after the disturbance, the system condition during the active fault still remained within the Prohibited Region of the ITIC curve, posing a high risk of equipment damage to industrial customers and potential tripping at PT. Samator.

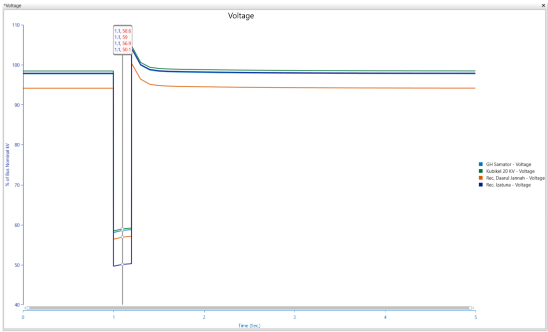

Figure 11. Voltage Response to Line-to-Line Fault with SVC Installed at the 20 kV Incoming Busbar of GI Kenten

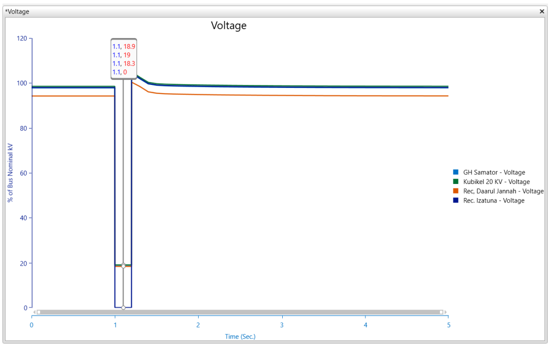

Figure 12. Voltage Response to Line 3 Phase Fault with SVC Installed at the 20 kV Incoming Busbar of GI Kenten

3.3 Simulation Results 3, Short-Circuit Testing with SVC Installed at the Fault-Affected Feeder of Kenten Main Substation (GI Kenten)

In Figure 13, the voltage at GH Samator, which serves as the main supply point for the industrial customer PT. Samator Gas Industri, dropped by up to 59% of the nominal voltage for a duration of 0.2 seconds (200 ms). The installation of the SVC had a positive impact on the system, enabling a rapid voltage recovery and reaching stability up to 112% within the same 0.2-second period.

In Figure 14, a more extreme voltage drop occurred, where the voltage at GH Samator fell to as low as 18.8% of the nominal value for 200 ms, which clearly places it within the Prohibited Region of the ITIC curve. These results indicate that under line-to-line and three-phase fault conditions, even though the SVC was installed on the fault-affected feeder, the voltage recovery did occur; however, according to the ITIC curve, the voltage at GH Samator still entered the Prohibited Region, posing a high risk of severe damage to industrial equipment and potential operational failure or tripping.

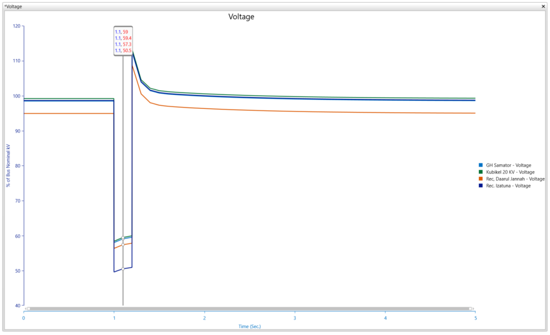

Figure 13. Voltage Response to Line-to-Line Fault with SVC Installed at the Fault-Affected Feeder of Kenten Main Substation (GI Kenten)

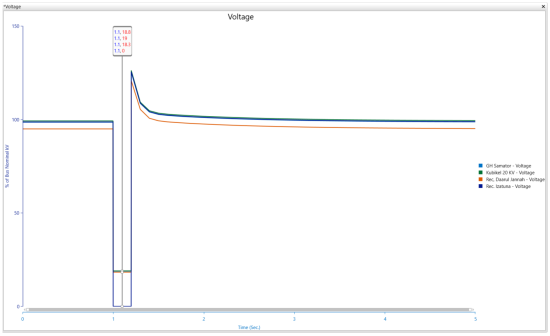

Figure 14. Voltage Response to Three-Phase Fault with SVC Installed at the Fault-Affected Feeder of Kenten Main Substation (GI Kenten)

3.4 Simulation Results 4, Short-Circuit Testing with IS-Limiter Installed at the Fault-Affected Feeder of Kenten Main Substation (GI Kenten)

In Figure 15, the voltage at the Samator Switching Substation (GH Samator), which serves as the main supply point for PT. Samator Gas Industri, dropped to approximately 58% of nominal voltage before recovering to 88.6% within less than 0.05 seconds (50 ms). This 58% voltage dip briefly entered the Prohibited Region on the ITIC curve. However, thanks to the IS-Limiter's fast fault current isolation, the voltage sag duration was extremely short and met the criteria for classification within the No Interruption Region (Safe zone with no equipment damage) based on the ITIC curve.

In Figure 16, the voltage drop was deeper and more critical, with the voltage at GH Samator falling to 20% of nominal before recovering to 79.3% within less than 0.05 seconds (50 ms), placing it within the No Damage Region (Safe zone, but equipment damage may still be possible) of the ITIC curve.

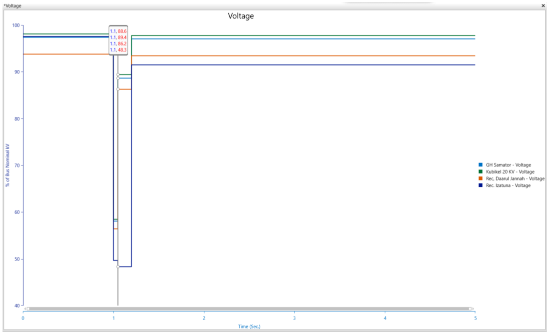

Figure 15. Voltage Response to Line-to-Line Fault with IS-Limiter Installed at the Fault-Affected Feeder of Kenten Main Substation (GI Kenten)

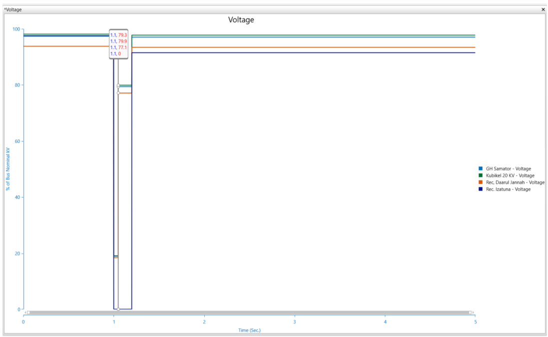

Figure 16. Voltage Response to Three-Phase Fault with IS-Limiter Installed at the Outgoing Side of the Fault-Affected Feeder of Kenten Main Substation (GI Kenten)

3.5 Simulation Results 5: Short-Circuit Testing with IS-Limiter Installed at the Outgoing Side of Samator Switching Substation (GH Samator)

In Figure 17, the voltage at GH Samator, which is the main supply point for PT. Samator Gas Industri, dropped to approximately 57.1% of the nominal voltage. After the IS–Limiter disconnected the fault current, the voltage rose only to 58% within 0.05 seconds (50 ms). This voltage drop entered the Prohibited Region of the ITIC curve. In Figure 18, the voltage drop was deeper and more critical, with the voltage at GH Samator falling to as low as 18.6% of nominal and recovering only to 19% before the fault was cleared within 0.2 seconds (200 ms). This event clearly falls into the Prohibited Region of the ITIC curve.

Such a condition presents a high risk of serious damage to industrial equipment and potential operational failure or system tripping. Therefore, it can be concluded that installing the IS–Limiter at the outgoing side of the faulted feeder in the main substation (GI) is significantly more effective than installing it at the outgoing of GH Samator.

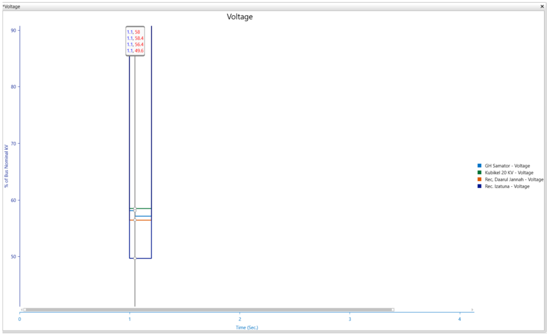

Figure 17. Voltage Response to Line-to-Line Fault with IS-Limiter Installed at Samator Switching Substation (GH Samator)

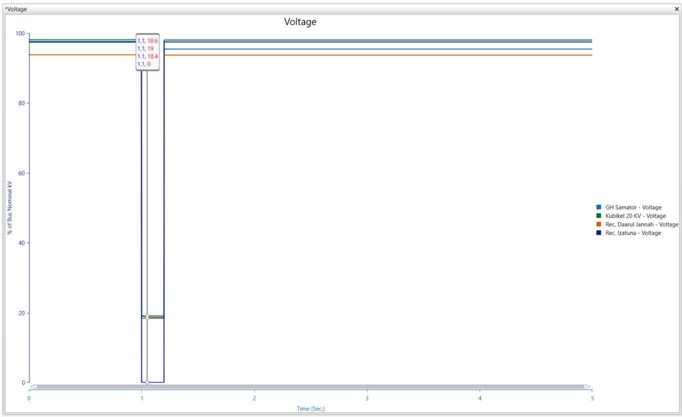

Figure 18. Voltage Response to Three-Phase Fault with IS-Limiter Installed at Samator Switching Substation (GH Samator)

3.6 Simulation Results 6, Short-Circuit Testing with DRUPS Installed at the Outgoing Side of Samator Switching Substation (GH Samator)

In both figures, the disturbance begins at the 1-second mark and is cleared at 1.2 seconds, resulting in a total fault duration of 0.2 seconds (200 ms). During the active fault, at 1.05 seconds, the voltage at GH Samator dropped to approximately 62% of nominal under the line-to-line fault and 26.6% under the three-phase fault. These conditions entered the Prohibited Region of the ITIC curve. However, at 1.1 seconds, the voltage was rapidly restored by the DRUPS. For the LL fault, the voltage recovered to 97.9%, and for the three-phase fault, it reached 91.6%—both within just 0.05 seconds (50 ms).

According to the ITIC curve evaluation, although the voltage at GH Samator temporarily dipped below 70%, the very short duration and fast recovery provided by DRUPS ensured that the voltage profile remained within the No Interruption Region (i.e., safe zone with no equipment damage). This demonstrates that DRUPS is highly effective in mitigating voltage sags caused by short-circuit faults, and its placement at the outgoing of GH Samator provides direct and rapid protection for PT. Samator. Thus, the implementation of DRUPS in this scenario has successfully maintained voltage stability and is considered a viable primary protection solution to ensure supply continuity and prevent industrial equipment disturbances.

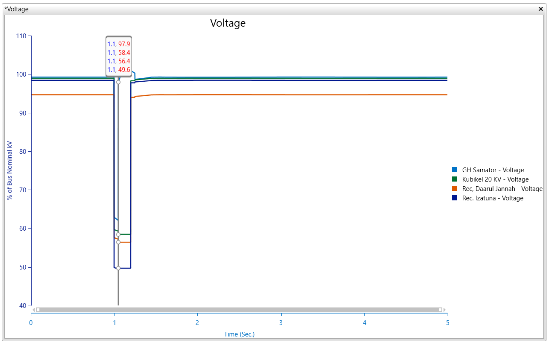

Figure 19. Voltage Response to Line-to-Line Fault with DRUPS Installed at Samator Switching Substation (GH Samator)

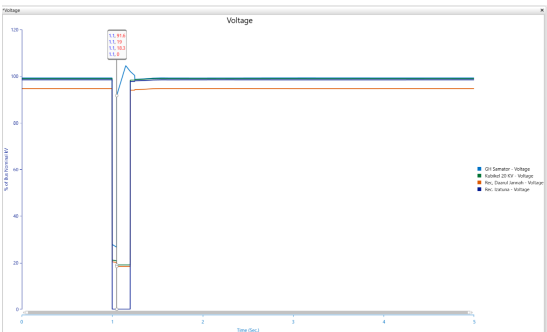

Figure 20. Voltage Response to Three-Phase Fault with DRUPS Installed at Samator Switching Substation (GH Samator)

3.7 *Simulation Results Comparison*

The following table presents a comparison of the six simulation scenarios based on installation location, type of solution, minimum voltage, recovery time, and evaluation against the ITIC curve.

Based on the simulation results presented in Table 2, it can be concluded that the Diesel Rotary Uninterruptible Power Supply (DRUPS) demonstrates the most superior technical performance in mitigating Line-to-Line (LL) and Three-Phase (3-Phase) short-circuit faults compared to the other two solutions, namely the Static VAR Compensator (SVC) and IS-Limiter.

Table 3. Comparison of Simulation Results Against the ITIC Curve

No	Jenis Gangguan	Solusi Teknis	Lokasi Pemasangan	Tegangan Minimum	Tegangan Perbaikan	Waktu Perbaikan	Evaluasi Kurva ITIC
1	**LL & L 3 Phase**	**SVC**	**Busbar Incoming GI Kenten**	58% / 18.9%	112,5%/104,1 %	200 ms	Prohibited Region
2	**LL & L 3 Phase**	**SVC**	Penyulang Terganggu	58% / 18.8%	104%/125.2%	200 ms	Prohibited Region
3	LL & L 3 Phase	IS-Limiter	Outgoing GH Samator	57.1% / 18.6%	58% / 19%	50 ms / 200 ms	Prohibited Region
4	**LL & L 3 Phase**	**IS-Limiter**	Penyulang Terganggu	58% / 20%	88.6% / 79.3%	<50 ms	No Damage Region
5	LL & L 3 Phase	DRUPS	Outgoing GH Samator	62% / 26.6%	97.9% / 91.6%	<50 ms	No Interruption Region

This conclusion is supported by three main indicators: the minimum voltage during the fault, the voltage recovery time, and the evaluation zone based on the ITIC curve.

First, in terms of voltage recovery speed, DRUPS is capable of restoring the system voltage to above 97% in less than 50 milliseconds. This is significantly faster than the SVC, which requires up to 200 milliseconds, and more stable than the IS-Limiter, which only limits the fault current without providing instantaneous voltage restoration. This speed is particularly crucial for strategic industrial customers such as PT. Samator, which operates sensitive loads prone to voltage sag. Fast voltage recovery ensures that production processes continue uninterrupted without tripping or disruption to critical machinery.

Second, regarding voltage stability after the disturbance, DRUPS achieves an excellent recovery level, reaching above 97.9%, and even up to 100% at several simulation points. This indicates that DRUPS not only acts quickly but also maintains system stability during and after the fault. In contrast, the IS-Limiter only restores voltage to 88% or 79.3%, which remains below the safe threshold for certain types of sensitive electronic equipment.

Third, when evaluated using the ITIC Curve standard (CBEMA Revised 2000), DRUPS is the only solution that consistently falls within the No Interruption Region, meaning the disturbance poses no risk of equipment malfunction. Meanwhile, the IS-Limiter falls into the No Damage Region, indicating that while equipment may survive, it is still susceptible to functional disturbances. As for the SVC—whether installed at the incoming busbar of Kenten Main Substation or on the faulted feeder—it consistently places the system within the Prohibited Region, which indicates a high risk of equipment damage or tripping.

The superiority of DRUPS lies in its unique working mechanism compared to the other two solutions. DRUPS is a motor-generator-based system that stores kinetic energy and is capable of delivering seamless power during disturbances. This technology actively takes over the power supply in less than 20 ms, ensuring that customers experience no significant voltage fluctuation. In contrast, the SVC only provides reactive compensation, and the IS-Limiter merely limits peak fault currents without supplying replacement energy.

Considering all of these aspects, it can be concluded that DRUPS provides the most comprehensive protection against voltage sags in a 20 kV distribution system. Its implementation is highly recommended for industrial customers with high demands for power continuity and quality, such as PT. Samator Gas Industri Palembang.

4. Conclusion

The voltage sag issues experienced by PT. Samator were confirmed to originate from short-circuit faults in the 20 kV distribution system, particularly on feeders supplied by Kenten Main Substation (GI Kenten), as validated by logsheet data from UP2D S2JB and Fluke PQM records showing high frequency of sag and swell events. Field and simulation evaluations revealed that voltage at GH Samator frequently entered the Prohibited Region of the ITIC curve during Line-to-Line and Three-Phase faults, posing serious risks of equipment failure and operational tripping.

Comparative simulations across five mitigation scenarios showed that DRUPS consistently delivered the best performance, with recovery to over 97% from a 62% dip within 50 ms under LL faults, and recovery to 91.6% from a 26.6% dip within 50 ms under L-3P faults—both falling into the No Interruption Region, indicating full protection for industrial loads. IS-Limiter, when placed on the faulted feeder, also showed strong results with recovery from 58% to 88.6% (LL) and from 20% to 79.3% (L-3P), both categorized in the No Damage Region. In contrast, SVC performance remained suboptimal regardless of placement, with slow recovery times (200 ms) and voltage dips remaining in the Prohibited Region, offering less protection for critical equipment. These findings support the conclusion that DRUPS and IS-Limiter are the most effective technical solutions for mitigating voltage sag in industrial distribution networks and are strongly recommended for customers with high continuity and power quality demands such as PT. Samator Gas Industri.

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