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Analysis of the Application of Fault Current Limiter in 500 Kv System When the Entry of Power Plants in 2023-2028 to Lower Short Circuit Level at 500 KV Gitet Java Madura Bali System

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ABSTRACT

The Java Madura Bali system is the largest interconnection system in Indonesia, covering about 70% of the national electrical energy market. Electricity sales increased from 125.49 TWh in the first half of 2021 to 133.87 TWh in the first half of 2022. To maintain power balance and support energy consumption growth, additional power plants are integrated according to the RUPTL. This research aims to anticipate the increase in short circuit levels for both single-phase to ground and three-phase faults at the Extra High Voltage Substation due to new power plants, ensuring the short circuit level remains below 40 kA, in line with equipment standards. This prevents the costly replacement of 500 kV transmission system equipment. Using the Digsilent application, the study models the existing system, maps the N-1 contingency, and calculates the short circuit levels after the integration of power plants from 2023 to 2028. The results identify the type and optimal location of fault current limiters. Installing these limiters is expected to reduce the short circuit level by 5%, avoiding the need to replace transmission and substation equipment rated at 40 kA. Consequently, the 500 kV system of Java Madura Bali can operate reliably with the new power plant integrations.

Keywords: Jamali System, Short Circuit Level, Fault Current Limiter, Study Digsilent.

INTRODUCTION

PLN, as the largest electricity company in Indonesia, has 82 million customers, of which 70% are located on the islands of Java, Madura, and Bali (Ahmadi et al., 2023; McCawley, 1971). Electricity reliability and continuity are a must, and PLN's main responsibility is to serve the community. It is undeniable that there are still many disturbances in electricity transmission that result in the inability to distribute electrical energy to the community and even cause customers to suffer economic losses (Ghanem et al., 2016; Hossain et al., 2018; LAMIN, 2023; Makansi,

2007). The increasing demand for electricity will also increase the need for power plants, which is suspected to have a negative side, namely increasing the short circuit level at the time of the disruption (Jasiūnas et al., 2021; Johansson, 2013; Panteli & Mancarella, 2015; Rahman et al., 2022), which can have an impact on the damage of PLN equipment and ultimately cause power outages to customers.

The Java Madura Bali system has the largest interconnection system in Indonesia that can mitigate N-1 contingencies in transmission lines and substations, the JMB system has an electrical energy market share in the range of 70% of the total electrical energy market in Indonesia plays an important role in PLN's revenue and PLN's net profit. According to PLN Press Release data No. 582.PR/STH.00.01/VII/2022, in the 1st semester of 2022 PLN recorded revenue of IDR 211.66 trillion in the first semester of 2022 Electricity sales increased from 125.49 TWh in the first semester of 2021 to 133.87 TWh in the first semester of 2022 PLN's net profit also increased by 162.4% (yoy) to IDR 17.4 trillion.

There is a growth in the burden as planned, as a turning point in the economic recovery after the Covid-19 pandemic, where in the 1st semester of 2022 the realization is 8.93% of the JMB Regional annual operating plan of 3.55%, so that it is necessary to add power plants continuously to maintain the system's power balance is met, and support the growth of electrical energy consumption in the Java, Madura, and Bali systems. With the plan to add power plants in the Java Madura Bali System in accordance with the RUPTL, problems that need to be faced by PLN arise. The addition of generators, and some of them are included in the existing power plant complex, will increase the short circuit level which will later have an impact on the reliability of the equipment to be able to withstand 3-phase and 1-phase interference to the ground with the currently installed equipment rating standard of 40 kA. A solution is needed to deal with the entry of the plant without causing a large financial or operational effect on the Java, Madura and Bali systems. The author will review the use of fault current limiters that will be installed in transmissions and substations in order to reduce the short circuit level when a disturbance occurs in the system.

Fault current limiter technology, which has been widely used in the electricity system of developed countries (Ahmad et al., 2022; El-Ela et al., 2022; Safaei et al., 2020; Shen et al., 2021; Viktorovich et al., 2021), has many advantages in terms of reducing the effect of short circuit levels of electrical transmission interference on installed equipment. To apply the FCL, it is necessary to conduct a short-circuit analysis in the Java, Madura Bali system to determine the priority scale of the installation location the type of FCL to be installed and how effective the installation is so that the system can run reliably.

Based on this framework, it is suspected that the use of FCL in the Java, Madura Bali system can reduce the number of short circuit levels when disturbances occur and reduce the cost of replacing PLN equipment to equipment ratings above 40 kA in the 500 kV system.

RESEARCH METHODS

This research involves computational analysis which is divided into three main stages, namely data collection, technical data processing, and economic calculations (Cavalcante et al., 2016; Dymowa, 2011; Koop, 2013; Philip Chen & Zhang, 2014). In detail, this study includes seven main stages: data collection, modeling of the 500 KV system in Java Madura Bali using the Digsilent application, N-1 contingency modeling, system modeling with the addition of power plants, calculation of short circuit levels for one phase to the ground and three phases, determination of the type of FCL (Fault Current Limiter), and determination of the optimal location of FCL installation. Here is the flow chart in this study.

This research was carried out in three main locations: the PLN Center of the Directorate of Transmission and System Planning, located on the 12th floor of Jalan Trunojoyo, South Jakarta; the West Java Transmission Main Unit, located on Jalan EHV, Gandul Cinere, Depok; and the Jamali Load Control Center Main Unit, also located on Jalan EHV, Gandul Cinere, Depok.

RESULTS AND DISCUSSION

System Conditions and Electricity Development Plans of Java Madura Bali

The peak load of the Java Madura Bali system in 2023 is 31515 MW which occurred on Wednesday, 8-11-2023, at 18:00 WIB, where the Java Madura Bali system bears around 70% of the national electrical energy consumption, with the concentration of generation on the west side to supply the largest load in Jakarta as the capital of Indonesia.

PLN is a state-owned electricity company responsible for planning and implementing electricity projects in the short, medium and long term. A long-term electric power system development plan, which is 10 years, is needed in order to accommodate the needs of PLN and to have an efficient investment plan in the sense that PLN implements an electric power project with good planning. The Electricity Supply Business Plan (RUPTL) is a document for the optimal development of the Electricity system in PLN's business area for the next 10 years, which is prepared to achieve certain goals and based on certain planning policies and criteria.

In the RUPTL in line with Law no. 30/2009, where the provincial government is obliged to make a Regional Electricity General Plan (RUKD) in the RUPTL there is also regional electricity planning, there is also infrastructure development both for power plants, transmissions, and substations, as well as cooperation in the use of electric power networks both PLN and the private sector through power wheeling schemes according to regulations where possible. The RUPTL that is currently officially in effect is the 2021-2030 RUPTL, which has accommodated the impact of COVID-19 on the development and growth of PLN's electrical energy consumption. Electricity

demand also continues to grow in the Java, Madura and Bali systems, with the following growth projections in accordance with the RUPTL.

Table 1. Projected Electricity Demand 2021-2030

Description	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Household	75.414	77.633	79.836	82.032	84.217	86.110	88.001	89.893	91.790	93.646
Business	33.187	34.966	37.134	39.708	42.271	44.919	47.762	50.737	53.879	57.140
Public	9.895	10.382	10.924	11.514	12.126	12.763	13.418	14.091	14.790	15.509
Industry	62.356	64.422	67.464	70.691	74.586	78.280	81.708	85.017	88.500	92.404
Total	180.852	187.403	195.358	203.945	213.201	222.072	230.888	239.738	248.959	258.699
Growth (%)	3.6	3.6	4.2	4.4	4.5	4.2	4.0	3.8	3.8	3.9
Per capita electricity consumption (kWh/capita)*	1.149	1.182	1.222	1.267	1.315	1.360	1.404	1.448	1.495	1.544
Non-coincident peak load (MW)	29.533	30.543	31.726	33.012	34.398	35.718	37.003	38.339	39.740	41.171

*kWh in electricity consumption per capita only looks at electricity consumption

The growth rate is predicted from 4.2% in 2023 to 3.9% in 2030. This will give rise to additional infrastructure in terms of generation, transmission lines, substations and distribution channels to the point of consumption. PLN has planned infrastructure development in accordance with the realization of the use of electrical energy, issues of developing city and

provincial areas, consumer waiting lists and national strategic issues for the development of energy needs in Indonesia. In terms of generation, there are also energy mix criteria targeted in each RUPTL year to be in line with the Net Zero Emission target that has been launched by the Indonesian government.

Table 2. Jamali Energy Mix Projection 2021-2030

No	Fuel Type	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
1	Water	6.559	6.779	7.603	8.184	10.327	10.560	10.560	11.937	13.324	13.463
2	Geothermal	9.397	9.397	10.308	10.764	13.066	13.985	15.998	17.096	17.897	19.366
3	Other EBT	1.444	2.994	4.221	6.116	17.878	16.068	14.669	13.703	13.932	014.152
	Sun	-	300	642	1.472	3.351	3.519	3.737	3.954	4.165	4.382
	Bayu	-	-	-	381	619	619	619	619	619	619
	Rubbish	59	90	89	217	1.416	1.402	1.426	1.408	1.406	1.399
	Biomas	516	1.731	3.352	3.914	12.335	10.333	8.681	7.511	7.511	7.511
	Other	869	873	128	131	158	195	206	211	231	240
4	Gas	33.229	35.413	37.314	36.790	36.790	36.372	38.918	45.267	47.491	49.945
	Gas	13.910	14.444	14.672	14.523	14.539	14.475	14.926	15.467	16.570	19.168
	LNG	19.319	20.969	22.642	22.863	22.251	21.898	23.993	29.800	30.921	30.777
5	BBM	2.028	2.036	298	306	368	456	482	492	539	560
	HSD	89	97	60	68	130	217	244	254	301	322
	MFO	1.939	1.939	238	238	238	238	238	238	238	238
	IDO	-	-	-	-	-	-	-	-	-	-

	HFO	-	-	-	-	-	-	-	-	-	-
6	Coal	152.87	155.937	161.324	162.486	173.912	180.003	182.414	188.414	188.799	194.859
7	EBT Potential	-	-	-	-	-	-	-	-	-	-
8	Import	-	-	-	-	-	-	-	-	-	-
	Amount	205.53	212.536	221.556	230.017	240.916	251.353	260.630	270.909	281.982	292.345

In the RUPTL, there is a continuous addition of generation, both fossil energy, new energy, and renewable energy. The addition of existing plants can potentially increase the short circuit level in the Java, Madura and Bali systems.



Figure 1. 500 kV Network Projection of Jamali System 2021-2030

In the RUPTL, the development of an extra-high-voltage transmission system with transmission and substation in the Java, Madura, and Bali systems has also been planned until 2030.

Table 3. Projection of Transmission Network and Substation Development 2021-2030

Transmission	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
500 kV	1.319	72	440	28	537	41	321	128	107	720	3.713
150 kV	729	772	1.141	1.232	1.755	459	602	1.199	729	372	8.991
70 kV	-	-	-	-	12	-	-	-	-	-	12

Total											
Substation	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
500/ 150 kV	1.00	4.00	3.50	2.00	5.50	1.50	1.50	4.00	3.00	3.00	29.00
	0	0	0	0	0	0	0	0	0	0	0
150/ 70 kV	100	-	-	-	100	-	-	-	-	-	200
150/ 20 kV	2.13	2.52	1.92	1.02	1.74	900	1.08	1.14	1.47	1.68	15.
	0	0	0	0	0		0	0	0	0	600
70/ 20 kV	120	60	-	-	-	-	-	-	-	30	210
Total	3.35	6.58	5.42	3.02	7.34	2.40	2.58	5.14	4.47	4.71	45.01
	0	0	0	0	0	0	0	0	0	0	0

The addition of Substations and Transmissions is divided into planning for each province, for the following example:

Table 4. Examples of Adding Transmissions and Substations

No	Voltage (kV)	New/ ext./ Uprate	Capacity (MVA/ Bay/ Dia)	COD target	Status
1	Penggilingan	150 kV	Ext	2 LB	Construction
2	Penggilingan II/ Rawa Kuning	150/20 kV	New	60	Construction
3	Abadi Papan	Guna 150/20 kV	Ext	2 LB	Plan
4	Plumpang Sunter	II/ 150/20 kV	New	60	Plan
5	Grogol	150 kV	Ext	2 LB	Construction
6	Tomang	150 kV	New	120	Construction
7	Gambir Lama II	150/20 kV	New	120	Construction
8	Kebon Sirih II	150/20 kV	New	60	Construction
9	Cibinong	150 kV	Ext	2 LB	Construction
10	Gandaria	150 kV	Ext	2 LB	Construction
11	Pulo Gadung II	150/20 kV	New	120	Construction
12	New Senayan	150 kV	Ext	2 LB	Construction
13	Senayan Ulujami	III/ 150 kV	New	60	Construction
14	Pulo Gadung II	150 kV	Ext	2 LB	Construction
15	Cipinang Jatinegara	II/ 150 kV	New	120	Construction
16	Duren Tiga Ragunan	II/ 150/20 kV	New	60	Construction
17	Karet Lama	150 kV	Ext	1 LB	Plan

18	Gambir Lama II	150 kV	Ext	1 LB	Plan
19	Pondok Kelapa II	150/20 kV	New	60	Construction
20	Duri Kosambi	150 kV	Ext	-	Plan
21	Duri Kosambi	500 kV	Ext	500	Plan
22	Duri Kosambi	500 kV	Ext	500	Plan
23	Budi Kemuliaan	150 kV	Upr	2 LB	Plan
24	Muara Karang Lama	150 kV	Upr	2 LB	Plan
25	Cawang	500 kV	Ext	2 Dia	Plan
26	Gandul	500 kV	Ext	1 Dia	Plan
27	Cawang Baru II/ Cililitan	500/ 150 kV	New	1000	Plan

No	From	To	Voltage (kV)	Scope of work	Long (kms)	COD Target	Status
1	Gandul	Kemang	150 kV	New, 2 cct, SKTT	24.0	2022	Plan
2	Penggilingan II/ Rawa Kuning	Penggilingan	150 kV	New, 2 cct, SKTT	12.0	2022	Construction
3	Cawang Baru	Taman Rasuna	150 kV	New, 1 cct, SKTT	11.2	2022	Plan
4	Cawang Baru	Abadi Guna Papan	150 kV	New, 1 cct, SKTT	10.6	2022	Plan
5	Plumpang II	Inc. (Plumpang – Gambir Baru)	150 kV	New, 4 cct, SKTT	1.0	2022	Energize
6	Tomang	Grogol	150 kV	New, 2 cct, SKTT	8.1	2022	Construction
7	Gambir Lama II	Inc. (Kebon Sirih – Gambir Lama)	150 kV	New, 4 cct, SKTT	2.0	2023	Construction
8	Kebon Sirih II	Inc. (Gambir Lama – Pulo Mas Tanah Tinggi)	150 kV	New, 4 cct, SUTT	2.0	2023	Construction
9	Gandaria	Cibinong	150 kV	New, 2 cct, SUTT	24.0	2023	Construction
10	Priok	Muara Tawang	500 kV	New, 2 cct, SUTET	30.0	2023	Construction

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11	Taman Rasuna	Abadi Guana Papan	150 kV	New, 1 cct, SKTT	2.8	2023	Plan
12	Pulo Gadung II	Pulo Gadung Rekondisi	150 kV	New, 2 cct, SKTT	1.0	2023	Construction
13	Senayan III/ Ulujami	New Senayan	150 kV	New, 2 cct, SKTT	6.4	2023	Construction
14	Cipinang II/ Jatinegara	Pulo Gadung II	150 kV	New, 2 cct, SKTT	10.0	2024	Construction
15	Duren Tiga II/ Ragunan	Depok II	150 kV	New, 2 cct, SKTT	16.7	2024	Construction
16	Kebon Jeruk	Duri Kosambi	150 kV	New, 2 cct, SKTT	20.0	2024	Plan
17	Pondok Kelapa II	Inc. (Bekasi – Pondok Kelapa)	150 kV	New, 4 cct, SKTT	4.0	2024	Plan
18	Muara Karang Lama	Budi Kemuliaan	150 kV	New, 2 cct, SKTT	24.0	2025	Plan
19	Budi Kemuliaan	Kebon Sirih	150 kV	New, 2 cct, SKTT	4.0	2025	Plan
20	Senayan	Petukangan	150 kV	New, 2 cct, SKTT	20.0	2025	Plan
21	Danayasa	Abadi Guna Papan	150 kV	New, 2 cct, SKTT	4.0	2025	Plan
22	Cawang Baru II/ Cililitan	Cawang	500 kV	New, 2 cct, SKTET	1.0	2026	Plan
23	Cawang Baru II/ Cililitan	Gandul	500 kV	New, 2 cct, SUTET	40.0	2026	Plan
24	Tx Cawang Baru	Tx Ragunan	150 kV	New, 2 cct, SKIT	3.6	2026	Plan
25	Duren Tiga II/ Ragunan	Tx Ragunan	150 kV	New, 2 cct, SUTT	2.6	2026	Construction

The appendix contains additional data on transmissions and other substations in the Java, Madura and Bali systems.

Simulation of Short Circuit Flow of Javanese Madura Bali System

Conditions In 2023

In the Power Factory Digsilent software, a short-circuit calculation simulation was carried out on the Jamali System to determine the short-circuit values of 1 phase and 3 phases in each

GITET. In 2023, it is assumed that there will be large power generation projects that will enter the Jamali system, namely the Java 1 PLTU 924 MW, the Cilamaya #2 PLTGU 880 MW, and the Muaratawar PLTGU Block 3 and 4 Add-On with a total capacity of 500 MW. The results of the short circuit simulation on the system obtained the following data.

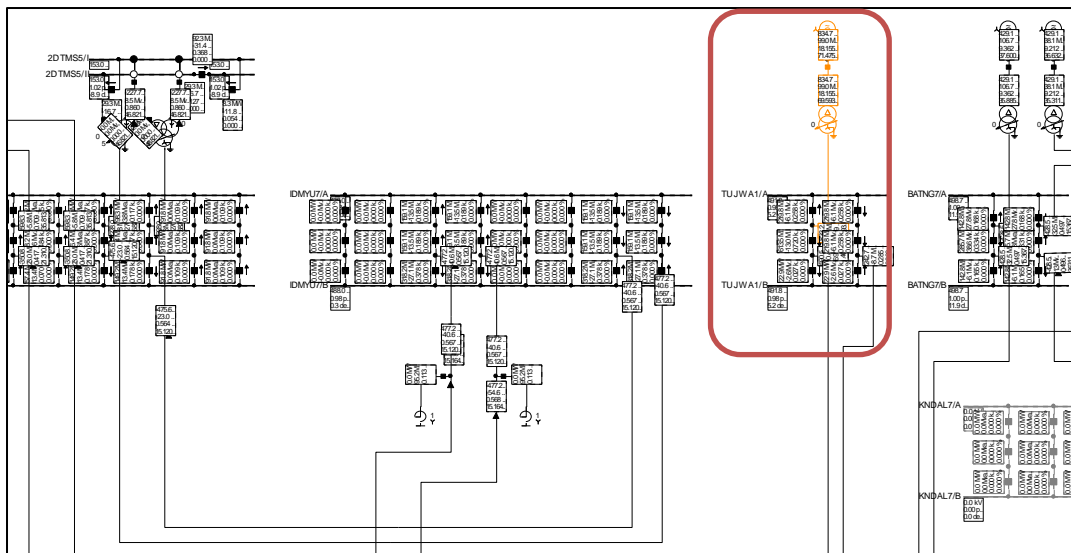


Figure 2. Digsilent Modeling of PLTU Java 1

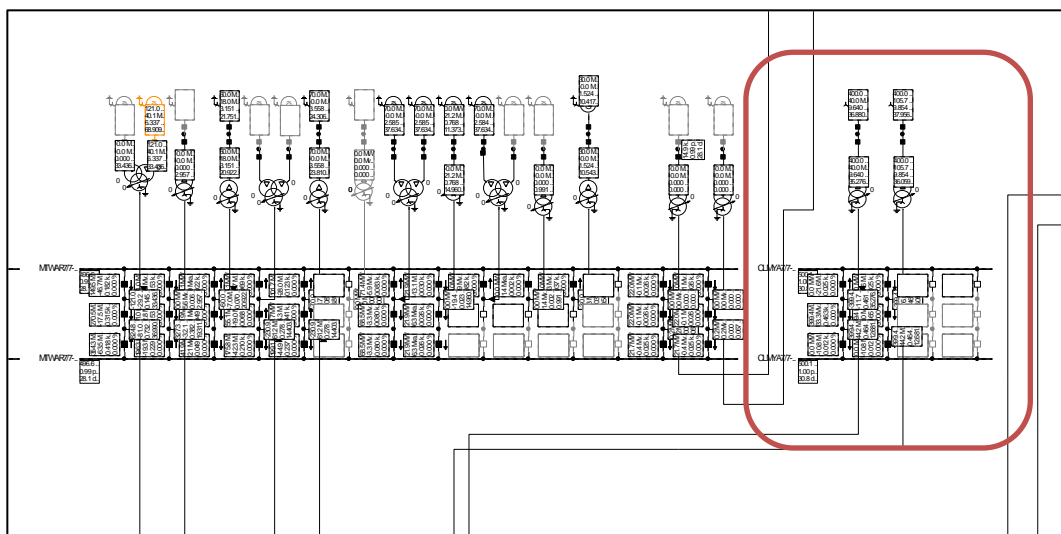


Figure 3. Digsilent Modeling of Cilamaya PLTGU

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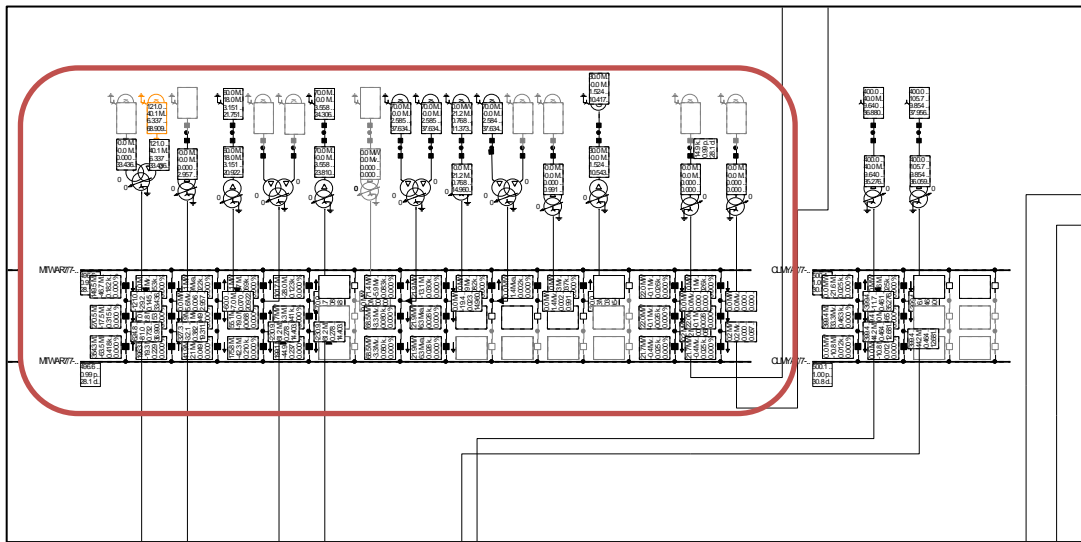


Figure 4. Digsilent Modelling Add on PLTGU Muara Tawar block 3 & 4

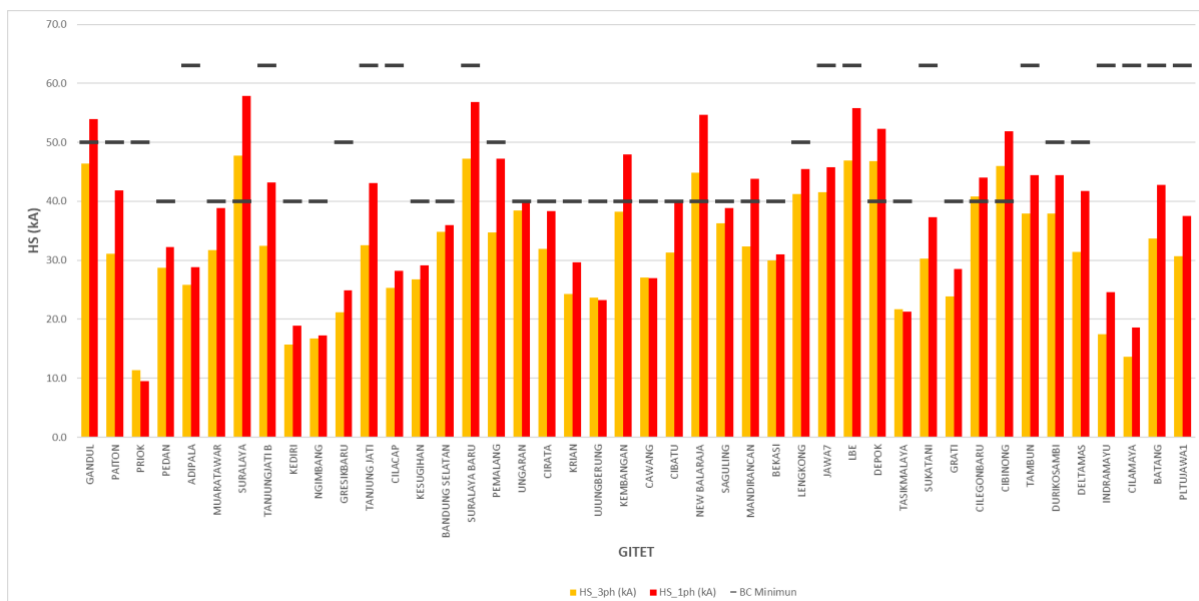


Figure 5. GITET Short Link Chart 2023

From the results of the short-circuit simulation above, there are 9 GITETs with short-circuit current conditions exceeding the minimum breaking capacity of PMT in the related GTET.

System Conditions in 2024

Referring to the 2021-2030 RUPTL, several large projects, especially in the 500kV Jamali system, will greatly affect the increase in short-circuit current. In this case study, it is assumed that several major projects will enter the system in 2024, as shown in the following table.

Table 5. COD projects in 2024

No	Project name	Type	Capacity
1	GITET AMPEL	Substation	200 MVA
2	GITET BANGIL	Substation	500 MVA

Assuming the two GITET projects above operate in 2024, the results of the short-circuit simulation in the Jamali System are obtained as follows.

From the data above, it can be seen that after the operation of two GITETs (GITET Ampel and Bangil) with a total IBT capacity of 2500 MVA, there will be 17 GITETs with a short-circuit current value greater than the smallest breaking capacity of PMT in the related GTET.

The installation of the FCL series on 500kV systems is one option to reduce short-circuit currents in the network. FCL series will increase the effective impedance of the network so that the short-circuit current that occurs becomes smaller. The criteria set are to meet the normal and contingency conditions of the N-1 conductor of 500 kV by observing the channel loading, voltage, short-circuit current, and CCT (Critical Clearing Time) of the channel. With these considerations, the location of the FCL series determination on the 500kV system is considered as follows.

Table 6. Installation List of FCL Series 500 kV in 2024

No	SUTET	V (kV)	Z (Ohm)	Amount
1	Suralaya - Suralaya Baru	500	20	2
2	Depok - Gandul	500	15	2
3	Cibinong - Depok	500	20	2
4	Cibinong - Tambun	500	20	2

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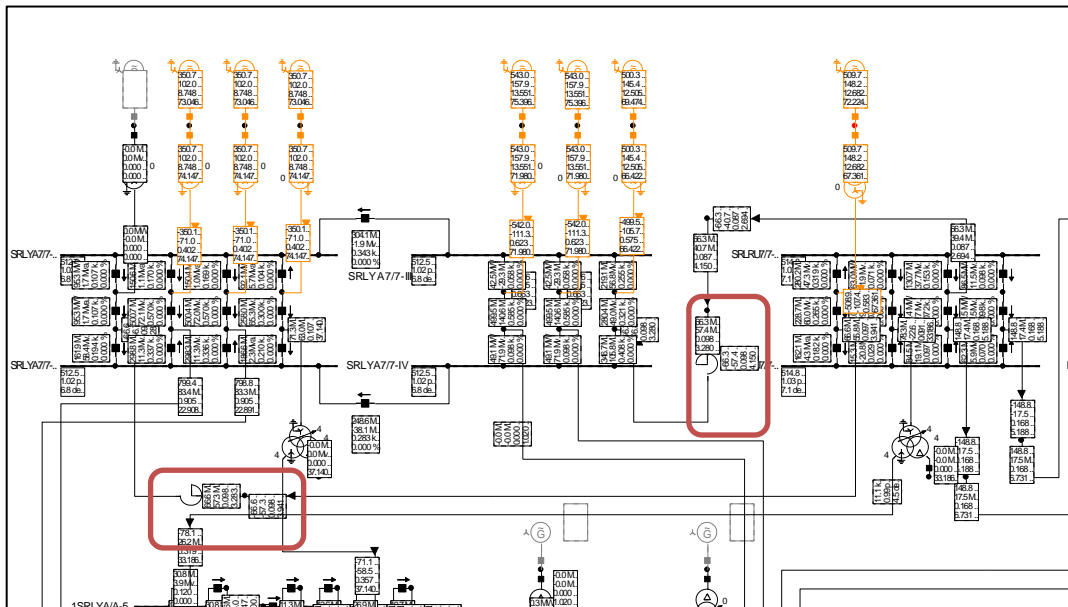


Figure 6. Modelling Digsilent FCL Suralaya – Surayala Baru circuit 1 and 2

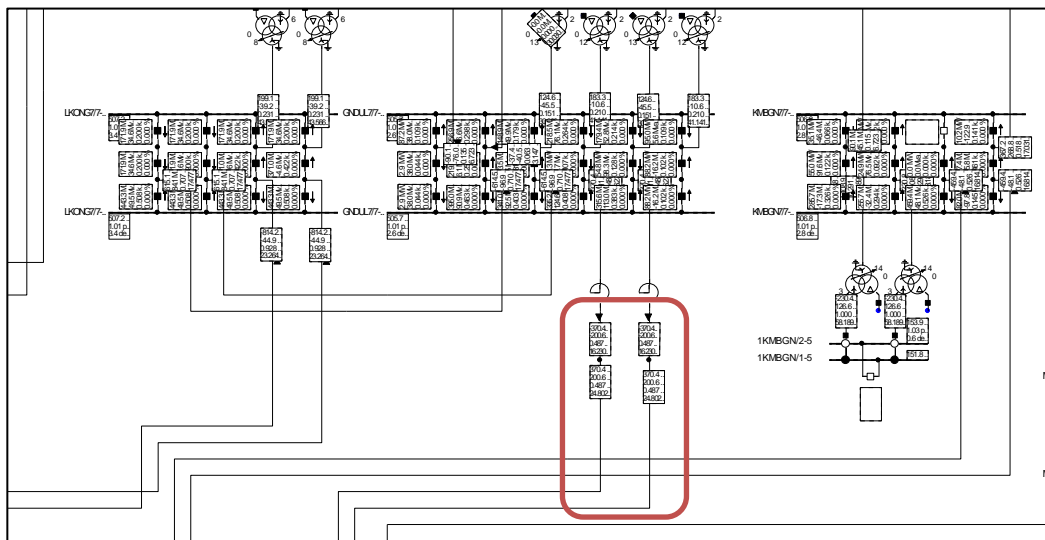


Figure 7. Digsilent FCL Gandul – Depok circuit 1 and 2 modeling

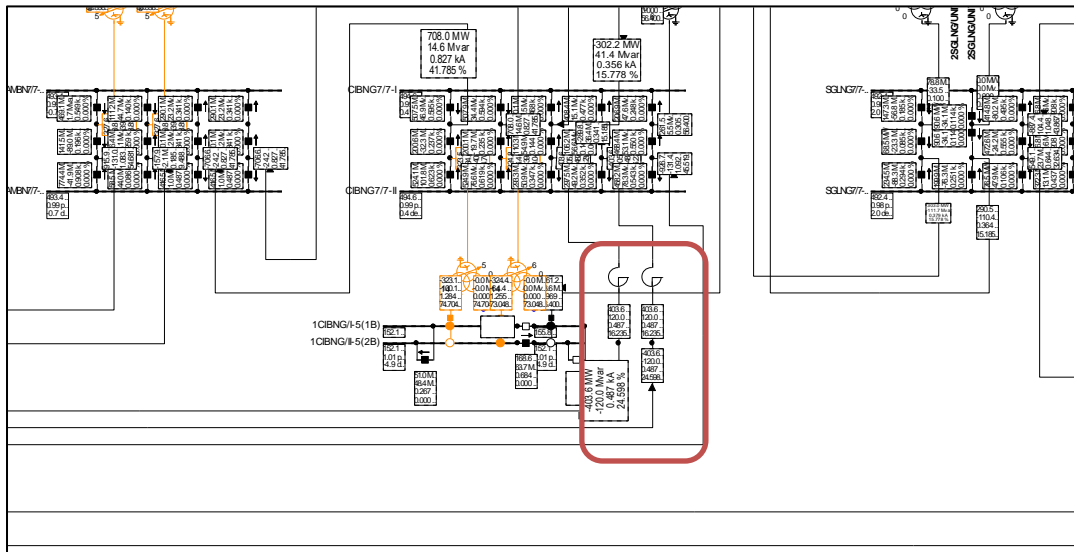


Figure 8. Modelling of Digsilent FCL Cibinong - Depok circuit 1 and 2

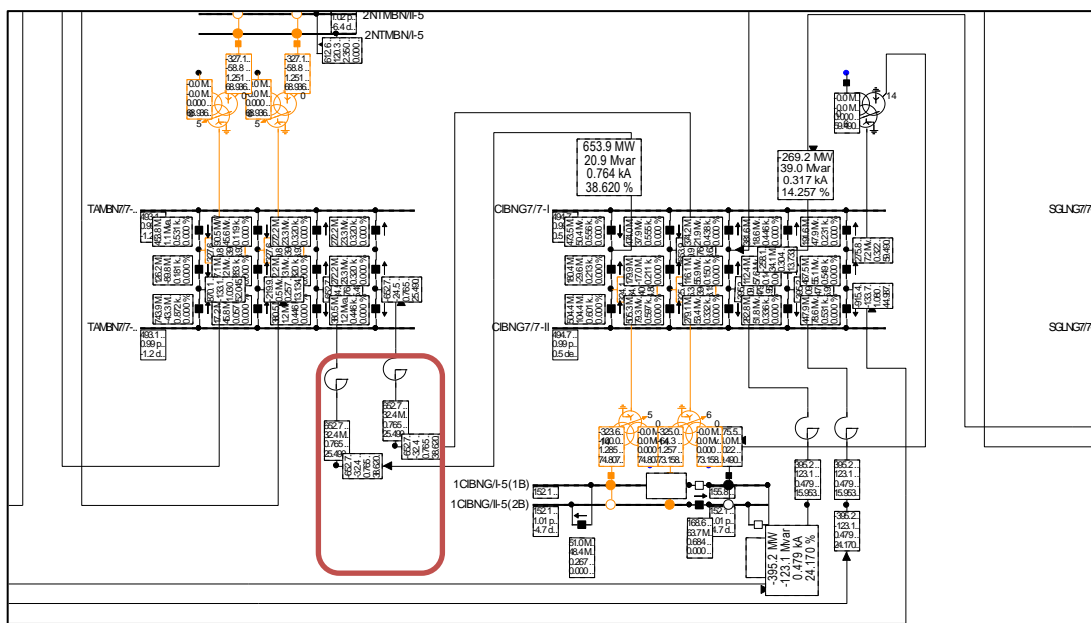


Figure 9. Modelling Digsilent FCL Cibinong - Tambun Circuit 1 and 2

With the plan to install FCLseri on the 4 transmission segments, it can be seen gradually the effect on the decrease in short-circuit current in each GITET. By operating 8 series FCL on 4 SUTET segments in 2024, short-circuit current calculation data was obtained based on simulation results with the condition of 13 GITET, which still has a short-circuit current value above the smallest PMT breaking capacity rating. When compared to the condition before the installation of the FCL series, there is a significant decrease in GITET, which is close to the location of the FCL installation. The decrease in the short-circuit current can be seen in the following table.

Table 7. GITET Short-Link Current Decline in 2024 After the Installation of FCL Series

Substation	Voltage (kV)	Before FCL installation		After FCL installation		Decline	
		HS_3ph (kA)	HS_1ph (kA)	HS_3ph (kA)	HS_1ph (kA)	HS_3ph (%)	HS_1ph (%)
Gandul	500	48.7	55.9	36.9	43.4	24%	22%
Paiton	500	40.9	55.6	40.9	55.6	0%	0%
Priok	500	33.5	30.2	31.2	28.9	7%	4
Pedan	500	31.3	34.5	31.3	34.5	0%	0%
Adipala	500	26.2	29.1	26.1	29.0	0%	0%
Muaratawar	500	39.2	46.6	35.6	43.1	9%	7
Suaralaya	500	48.5	58.7	41.6	49.6	14%	16
Tanjungjati B	500	32.7	43.5	32.7	43.5	0%	0%
Kediri	500	39.1	50.1	39.1	50.1	0%	0%
Ngimbang	500	19.7	19.5	19.7	19.5	0%	0%
Gresikbaru	500	30.8	34.6	3.8	34.6	0%	0%
Tanjung Jati	500	32.8	43.4	32.8	43.4	0%	0%
Cilacap	500	25.7	28.5	25.6	28.4	0%	0%
Kesugihan	500	27.2	29.5	27.1	29.4	0%	0%
Bandung Selatan	500	36.6	37.2	35.3	36.3	4%	2%
Suralaya Baru	500	48.1	57.7	30.8	34.7	36%	40
Pemalang	500	35.5	48.3	35.3	48.2	0%	0%
Ungaran	500	40.0	40.9	30.8	40.9	0%	0%
Cirata	500	34.6	40.7	35.4	39.1	5%	4
Krian	500	40.1	52.0	39.9	52.0	0%	0%
Ujungberung	500	24.4	23.8	32.8	23.5	2%	1
Kembangan	500	39.3	49.1	40.0	42.5	15%	13
Cawang	500	28.9	28.2	23.9	26.5	9%	6
Cibatu	500	35.2	44.7	33.3	42.6	6%	5
New Balaraja	500	46.0	55.9	26.4	50.1	12%	10
Saguling	500	38.9	40.8	33.3	38.9	6%	5
Mandirancan	500	33.9	45.9	40.5	45.4	1%	1
Bekasi	500	31.7	32.2	36.5	29.6	11%	8
Lengkong	500	42.7	46.6	33.4	40.1	17%	14
Jawa7	500	42.2	46.3	28.2	36.2	24%	22
LBE	500	47.7	56.6	35.3	34.8	35%	39
Depok	500	49.5	54.4	32.2	36.6	30%	33
Tasikmalaya	500	22.1	21.5	30.9	21.4	1%	1

Sukatani	500	35.5	42.5	34.6	40.1	7%	6
Grati	500	38.4	49.4	21.8	49.4	0%	0%
Cilegonbaru	500	41.5	44.6	33.3	40.3	11%	0
Cibinong	500	49.3	54.6	40.5	43.0	22%	10
Tambung	500	41.4	47.5	36.5	40.0	19%	21
Durikosambi	500	41.4	47.5	33.4	40.0	19%	16
Deltamas	500	35.3	46.4	28.2	44.2	5%	5
Indramayu	500	20.5	28.7	35.3	28.4	1%	1
Cilamaya	500	14.6	19.8	32.2	19.3	3%	3
Batang	500	34.4	43.7	30.9	43.5	0%	0%
PLTUJawa1	500	32.0	38.9	34.6	38.6	1%	1
Ampel	500	34.6	40.5	21.8	40.4	0%	0%
Bangil	500	41.2	55.8	33.0	55.8	0%	0%

System Conditions in 2025

In 2025 there will be 4 GITET projects that will be included in the Java, Madura and Bali systems. The operation of these projects will increase the number of short circuits in the system.

Table 8. COD project in 2025

No	Project name	Type	Capacity
1	GITET WATUDODOL	Substation	1000 MVA
2	GITET CIKUPA	Substation	1000 MVA
3	GITET WARU	Substation	1000 MVA
4	GITET CIKANDE	Substation	1000 MVA

System Conditions in 2026

In 2026, 6 GITET and IBT projects with a total capacity of 6000 MVA will enter the Java, Madura, and Bali systems. The operation of these projects will increase the level of short circuits in the system.

Table 9. COD projects in 2026

No	Project name	Type	Capacity
1	GITET ANTOSARI	Substation	1000 MVA
2	GITET CISOKAN	Substation	1000 MVA
3	GITET KARAWANG	Substation	1000 MVA
4	GITET TANJUNG AWAR AWAR	Substation	1000 MVA
5	GITET SURABAYA SELATAN	Substation	1000 MVA
6	IBT DURIKOSAMBI	IBT	1000 MVA

Table 10. COD project in 2027

No	Project name	Type	Capacity
1	GITET CIKALONG	Substation	1000 MVA
2	IBT KESUGIHAN	IBT	1000 MVA
3	SUTET MANDIRANCAN-BANDUNG	Transmission	-
4	SUTET MUARA KARANG-PRIOK	Substation	-

Table 11. COD Project Table in 2028

No	Project name	Type	Capacity
1	GITET KALANGANYAR	Substation	1000 MVA
2	IBT NGIMBANG	IBT	1000 MVA
3	SUTET TASIK-UBRUG-CIKALONG	Transmission	-

System Conditions in 2029

Assuming that no large projects operate in 2029, the results of short-circuit simulations in the Jamali System are almost the same as in 2028, as shown in the following table.

There are 30 GITETs with a short-circuit current value greater than the smallest PMT breaking capacity in the related GTET. To reduce the number of short circuits in the Jamali system, the installation of FCL series on 500kV systems by 2028 is needed.

Table 12. Installation List of FCL Series 500 kV in 2028

No	SUTET	V (kV)	Z (Ohm)	Amount
1	Muara Tawar - Priok	500	20	2
2	Muara Tawar - Sukatani	500	20	2
3	Durikosambi - Kembangan	500	20	1

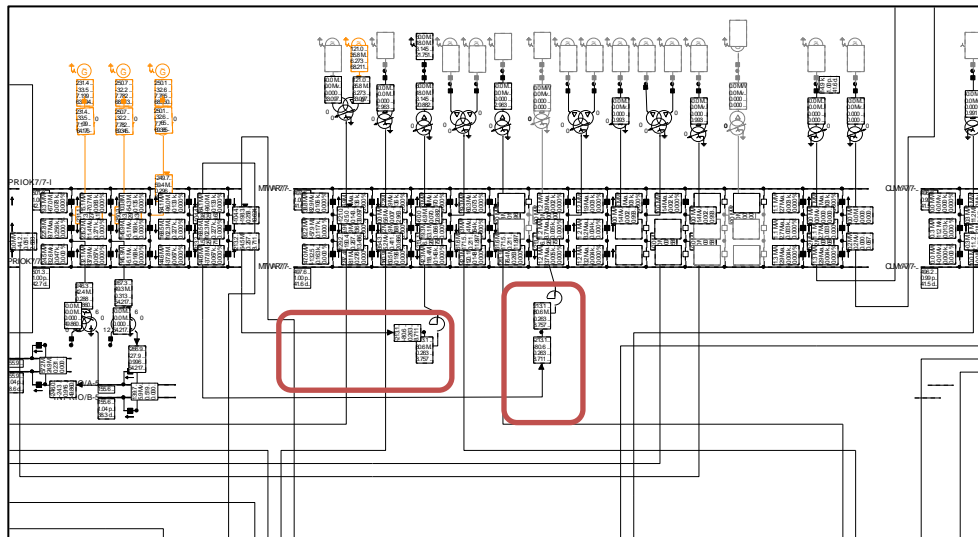


Figure 10. Modeling of Digsilent FCL Muara Tawar - Priok circuit 1 and 2

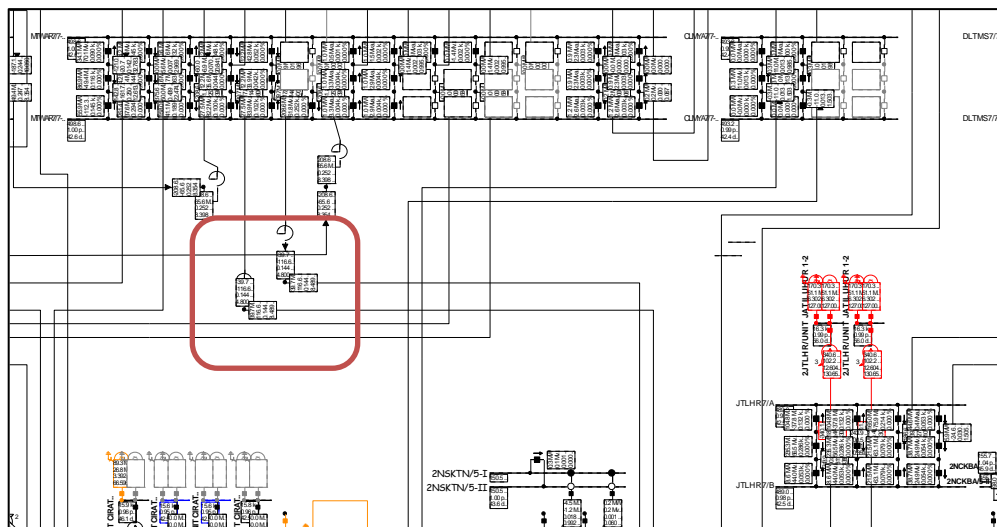


Figure 11. Modeling of Digsilent FCL Muara Tawar - Sukatani circuit 1 and 2

Analysis of the Application of Fault Current Limiter in 500 Kv System When the Entry of Power Plants in 2023-2028 to Lower Short Circuit Level at 500 KV Gitet Java Madura Bali System

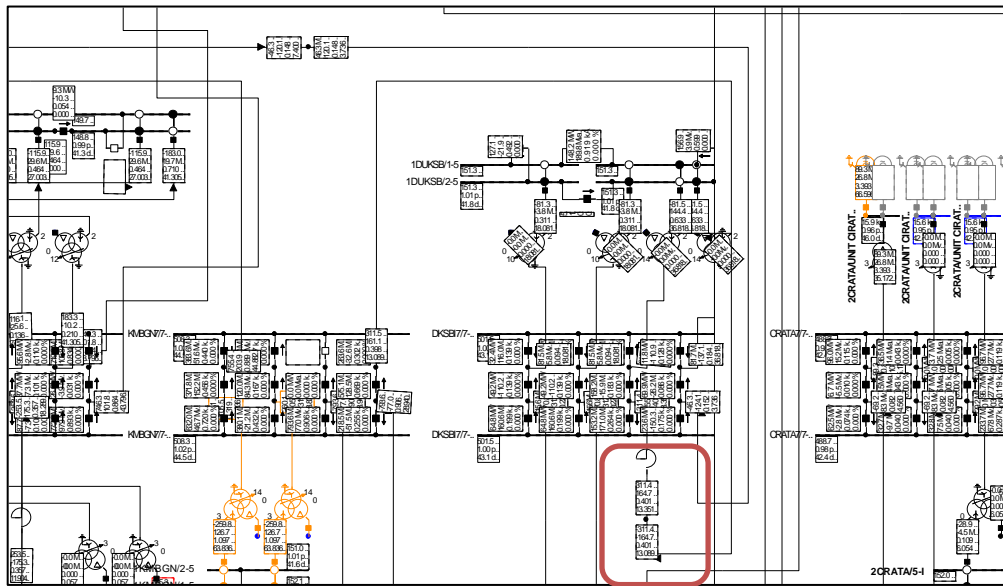


Figure 12. Digsilent FCL Durikosambi Modelling - Development

With the plan to install FCLseri on the 3 transmission segments gradually in 2028, the effect on the short-circuit current reduction can be seen in each GITET. The simulation results are as follows.

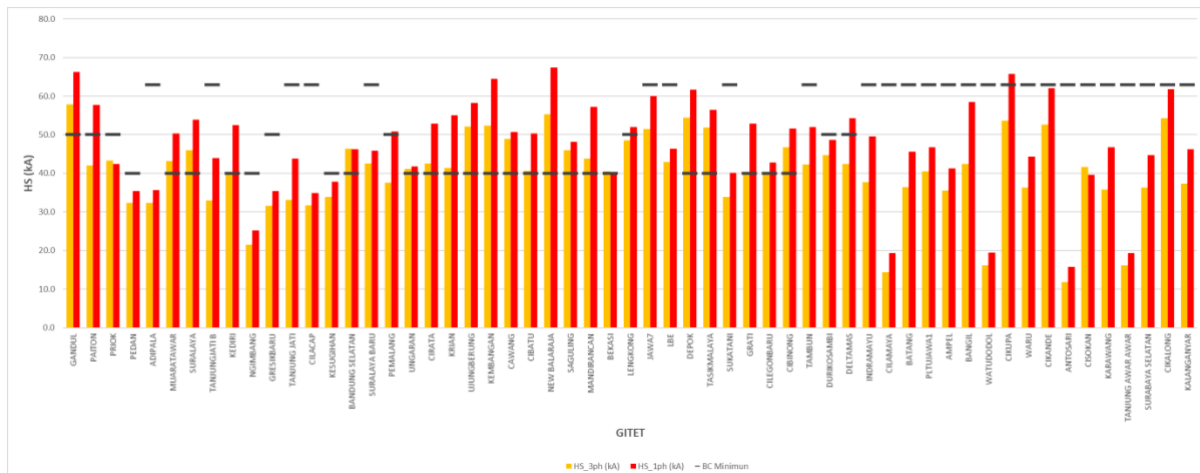


Figure 13. GITET 2028 Short Link Chart After Installation of FCL Series

By operating 5 series FCLs on 4 SUTET segments in 2028, short-circuit current calculation data is obtained based on simulation results with the condition of 26 GITET, which still has a short-circuit current value above the smallest PMT breaking capacity rating. When compared to the condition before the installation of the FCL series, there is a significant decrease in GITET, which is close to the location of the FCL installation.

Cost Comparison

With the installation of 8 FCLs in 2024, short-circuit currents at 3 GITET, namely GITET Gandul, GITET Saguling and GITET Cirata, decreased to below 40 trains.

By mapping GITET equipment that has a rating of 40 KA in each GITET, the price of the equipment uprating range is as follows:

Table 13. The price range of GITET Gandul equipment uprating

No	GI Equipment	Number of Units	Unit price	Total
1	PMT 500 kV single pole	17	4.508.000.000	76.636.000.000
2	PMS 500 kV single pole	34	758.703.260	25.795.910.840
3	CT 500 kV 5 core	29	514.231.200	44.738.114.400
4	LA 500 kV	6	130.747.353	2.353.452.354
Total				149.523.477.594

Table 14. GITET Saguling equipment uprating price range

No	GI Equipment	Number of Units	Unit price	Total
1	PMT 500 kV single pole	13	4.508.000.000	58.604.000.000
2	PMS 500 kV single pole	26	758.703.260	19.726.284.760
3	CT 500 kV 5 core	23	514.231.200	35.481.952.800
4	LA 500 kV	8	130.747.353	3.137.936.472
Total				116.950.174.032

Table 15. GITET Cirata equipment uprating range price

No	GI Equipment	Number of Units	Unit price	Total
1	PMT 500 kV single pole	17	4.508.000.000	76.636.000.000
2	PMS 500 kV single pole	34	758.703.260	25.795.910.840
3	CT 500 kV 5 core	31	514.231.200	47.823.501.600
4	LA 500 kV	4	130.747.353	1.568.968.236
Total				151.824.380.676

By referring to the FCL price per pair according to the manufacturer's offer of IDR 86,364,000,000, it can be compared; in 2024, GITET uprating cost savings will be obtained by installing 8 FCLs as follows:

Table 16. FCL Usage Savings in 2024

No	Item	Unit price
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1	Uprating GITET Gandul	149.523.477.594
2	Uprating GITET Saguling	116.950.174.032
3	Uprating GITET Cirata	151.824.380.676
4	8 pieces of FCL	-345.456.000.000
Total Savings		72.842.032.302

In the installation of 5 FCLs in 2028, a decrease in short-circuit current was obtained at 2 GITET, to below 40 trains, namely GITET Priok, GITET Jawa 7

By mapping GITET equipment that has a rating of 40 KA in each GITET, the price of the equipment uprating range is as follows:

Table 17. GITET Priok equipment uprating range price

No	GI Equipment	Number of Units	Unit price	Total
1	PMT 500 kV single pole	15	4.508.000.000	67.620.000.000
2	PMS 500 kV single pole	30	758.703.260	22.761.097.800
3	CT 500 kV 5 core	22	514.231.200	33.939.259.200
4	LA 500 kV	4	130.747.353	1.568.968.236
Total				125.889.325.236

Table 18. The price range of GITET Java 7 equipment uprating

No	GI Equipment	Number of Units	Unit price	Total
1	PMT 500 kV single pole	10	4.508.000.000	45.080.000.000
2	PMS 500 kV single pole	20	758.703.260	15.174.065.200
3	CT 500 kV 5 core	18	514.231.200	27.768.484.800
4	LA 500 kV	2	130.747.353	784.484.118
Total				88.807.034.118

By referring to the FCL price per pair according to the manufacturer's offer of IDR 86,364,000,000, it can be compared, in 2028, there will be cost savings in GITET uprating with the installation of 5 FCLs as follows:

Table 19. FCL Usage Savings in 2028

No	Item	Unit price
1	Uprating GITET Priok	125.889.325.236
2	Uprating GITET Saguling	88.807.034.118
3	5 pieces of FCL	-215.910.000.000

Total Savings	-1.213.640.646
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It can be seen that adding FCL in 2028 will not result in savings compared to carrying out equipment upgrades at GITET Priok and GITET Java 7.

CONCLUSION

The installation of Fault Current Limiters (FCLs) in the 500 kV system across Java, Madura, and Bali effectively reduces the short-circuit current at various GITET substations. In 2024, deploying 8 FCLs in locations such as Suralaya-Suralaya Baru and Depok-Gandul successfully reduced the short-circuit current at GITET Gandul, Saguling, and Cirata to below 40 kA, eliminating the need for equipment upgrades and resulting in savings of IDR 72,842,032,302. Similarly, in 2028, the installation of 5 FCLs in areas like Muaratawar-Priok and Durikosambi-Kembangan reduced the short-circuit current at GITET Priok and Jawa 7 below 40 kA, though no cost savings were observed when compared to the upgrading costs. Thus, the strategic placement of FCLs can effectively manage short-circuit currents and potentially offer significant cost benefits, addressing the research questions on their impact and cost-effectiveness.

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