Fast Load Shedding Scheme for Enhancing Reliability and Stability of Expanded Liquified Gas Plant

Barry Xu, Jonathan Gao -- GE Grid Solutions, Canada
Brandon Bosley, Julio Garcia — Kiewit Engineering Group, U.S.A.
Ty Clark – BHE GT&S Cove Point LNG, U.S.A.

SUMMARY

A grid-isolated Liquefied Natural Gas (LNG) import terminal has been expanded to include liquefaction and export capabilities. The new electrical system contains two 65MW steam turbine generators and 30 load feeders with two intertie breakers connecting the generation systems of the import and export facilities. To prevent loss of power to the plant, during contingency, it is important to perform load-generation balance within 100ms. In addition, the system frequency should be maintained within the 95% of the nominal frequency to prevent system instability. An IEC 61850 based Fast Load Shedding (FLS) scheme is deployed in this new plant to operate for loss-of-power condition, either from the generators or from the existing intertie connections. Protection relays with communication capabilities to exchange IEC 61850 Generic Object-Oriented System Event (GOOSE) were used over redundant communication networks utilizing Parallel Redundancy Protocol (PRP) for high-speed communications within the plant. Two redundant FLS Controllers exchange GOOSE messages with feeder, motor, transformer and generator relays to capture breaker status and power flow information for reliable operation. In addition, compressor-loading interlocks over the same IEC 61850 PRP network are implemented using motor protection relays to ensure the availability of at least one fuel gas compressor at all times. This paper presents lessons learned from the design and deployment of the FLS scheme by utilizing the available protection relays and adding FLS Controllers. The design strategies, such as IEC 61850 GOOSE communications between relays and Controllers, redundant PRP networks, network quality of service, etc. are discussed. The challenges to integrate non-IEC 61850 devices into the scheme are also discussed. The FLS initiation logic (to arm and disarm the scheme), and adaptive load-generation balance design are presented with test results, with the objective of sharing experiences from the design and deployment of a FLS scheme that guarantees plant's availability and stability.

KEYWORDS

Fast Load Shedding Controller (FLSC), Liquefied Natural Gas (LNG), Protection Relay, IEC 61850 Generic Object-Oriented System Event (GOOSE), Transient Stability Study (TSS), Parallel Redundancy Protocol (PRP), Rapid Spanning Tree Protocol (RSTP), Virtual Local Area Networks (VLAN).

I. Project Description

Refer to Figure 1 below, the Old LNG Plant features six gas turbine generators (GTGs) plus a Utility line. The utility line functions as an emergency power source only. A new plant was engineered and constructed immediately adjacent to the old plant. The new plant is connected to the electrical system of the old plant through two Intertie breakers. The electrical system of the new LNG plant contains two 65MW electrical generators. The LNG plant electrical system also features three MV 7000 Voltage Source VFDs. Each of These VFDs is approximately 30MVA, driving two 20MW GT helper motors and one 26MW compressor motor. There are also three expander generators located in the new plant, which are not shown in the drawing.

On an islanded power system with multiple generators sharing process load and no grid connection, it is essential to maintain grid frequency during loss-of-generation events. Failing to shed an appropriate level of electric load following the loss of a large generator results in a drop-in grid frequency and subsequent cascading failure of the remaining online generators. This typically leads to a complete facility blackout taking several days for production to recover. Shedding strategic loads to avoid a facility blackout results in brief production upsets which can be recovered in just several hours.

The need to validate the FLS scheme during different plant configurations and operating modes is extremely important. To do this validation a Transient Stability Study (TSS) needed to be performed. The TSS objective is to analyze the effects of abnormal operating conditions on the plant electrical system. The TSS covered the modeling of the electrical system, major contributing loads of the FLS scheme, and complex electrical models such as generator governors. Several load shedding scenarios were studied which confirmed that the FLS was an effective and required operation to maintain electrical power system stability.

In the event of a contingency, for example – one of the new-plant generators tripping off line, pre-selected loads in the new plant will be quickly shed in order to maintain power system stability and a corresponding amount of LNG production to avoid significant loss of production and potential damage to equipment as a result of a black plant.

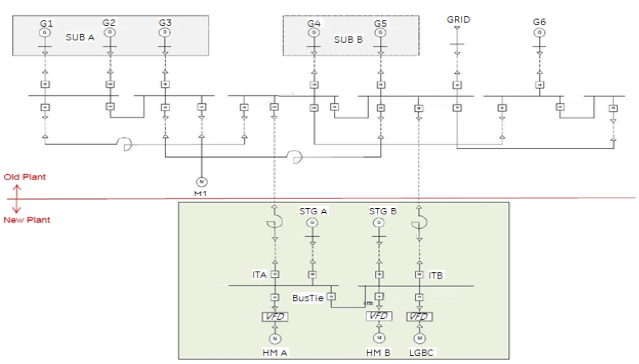


Figure 1: Simplified System One-line Diagram of the Whole Plant

The Fast Load Shed (FLS) Controller is the center of the Fast Load Shed system, it is capable of issuing load shed commands within 100ms from the time a FLS related contingency event occurs to the operation of the appropriate loads required to be shed assuming 3-cycle breaker/contactor opening time (total time of 50ms or less).

The selected FLS loads will be shed in the Controller's adaptive mode according to the predefined load shed group and priority table till the calculated load shed amount has been reached. The Controller's adaptive mode's power balance calculations between sources and loads are limited to the power sources and the selected sheddable loads in the new plant. The two interties between the old plant and the new plant can be used to transfer power in either direction, from the perspective of the FLS, the two interties will only be seen as sources with power flowing from the old plant into the new plant.

After a Fast Load Shed event taken place, the plant must be manually restored to the desired operating condition. Once the plant has been restored to an operating mode as per the appropriate plant procedures, the FLS will be reset and enabled again via the DCS System.

II. Project Executions

This section provides more detailed project executions of the Fast Load Shedding system.

1. Fast Load Shed Triggers

Followings are FLS triggers in the Controller's adaptive mode of operation when the FLS is successfully enabled:

- A tripping element operates in an STG's associated generator relay or an STG generator breaker opens while its associated relay measured real power is larger than 4.00 MW.
- A tripping element operates from any generator in the old plant. These tripping signals driving their associated lockout relays are wired to the contact inputs of the two Intertie relays. When either or both Intertie relays receive tripping signals from the old plant, they trip both Intertie breakers, assuming the combined measured real power from both the Relays is more than 4.00 MW, the FLS will be initiated.
- A tripping element operates or a manual operation opens one of the Intertie relays while the 13.8 KV bus tie breaker is open

and its associated relay measured real power is larger than 2.00 MW.

In Figure 1, each STG is protected by a Modern Relay (Relay A) with IEC61850 Protocol communication function, as well as a non-IEC 61850 Relay (Relay B) for back up protection. Upon a generator trip, the Relay A will send a GOOSE message to the Controller, triggering the fast load shed scheme. At the same time, the Relay B will use hardwired output contacts to send trip signals to the Controller. These two types of tripping signals are logically “OR” together inside of the FLS scheme. Either of these signals would trigger the FLS scheme while the Relay A is in service. A tripping signal alone from Relay B while Relay A is out of service will not be considered as a valid FLS trigger.

Each end device relay uses fast configurable IEC61850 GOOSE to send messages to the Controller containing information such as breaker status, tripping signals and power consumption values. These messages are used by the Controller to keep a real-time calculation of load consumption for the adaptive load shed mode of operation. The real-time power balance calculation interval is approximately 1.0 second. Load shed commands are sent via IEC61850 GOOSE messages to the respective load relays so that the appropriate breakers may be tripped. The internal logic execution time inside of the Controllers and the relays is approximately 1/8 of a power cycle.

2. FLS System Redundancy Design

The FLS network architecture was designed to try to withstand a single point of failure. The redundancy built into the system consists of both network level, node level and hardware level redundancy.

Except for the DCS server, all the hardware in the FLS system is IEC61850 compatible. This includes the Controllers, the protection relays and the Ethernet switches. Every relay has two Ethernet port connections, one to each of the parallel communication networks. The dual network connections offer protection against any single hardware point of failure, except for a possible failure of the relay itself.
The Controller is at the center of the FLS operation, two Controllers are used to back up each other. Full parallel operation adds flexibility into the system. Each Controller has two fiber ports, one connected to each RSTP network.

There are 14 Gigabit Ethernet Switches (1000 Mb) configured in the communication networks for this FLS System. Network level redundancy is provided through the two RSTP rings. Each ring will detect a single point of failure at the network level and automatically recover. Figure 2 below conceptually demonstrates the communication network level redundancy design. Note that A1, A2, B1 and B2 in the figure represent the fiber port numbers of each managed Ethernet switch.

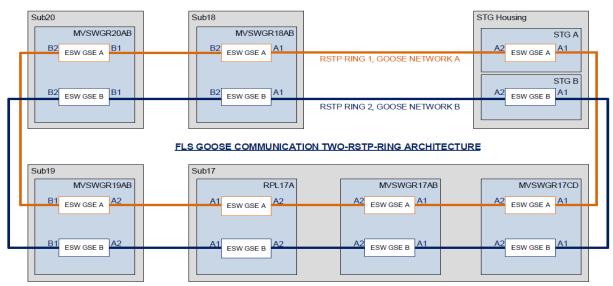


Figure 2: Fast Load Shedding System Overall Communication Redundancy

Each IED included in the FLS system has two Ethernet ports that run in PRP mode. The two ports are running in parallel providing seamless operation. Each Ethernet port of the Controllers and the relays connects to one of the Ethernet switches in one of the RSTP rings.

3. VLAN and Ethernet Switch Configurations

A VLAN is configured on each of the RSTP rings to separate FLS system GOOSE communication traffic from the rest of the devices in the network, which allows GOOSE messages being sent and received only among the FLS devices inside the VLAN, but do not flow out to other portions of the network. VLAN ID “2” have been programmed for the “Transmission Configurable GOOSE” settings in the all 39 FLS relays, including 2 Controllers.

To avoid the traffic among these GOOSE Switches, the Fast Load Shedding Commands are configured as GOOSE VLAN Priority "6", which has higher priority than the other message with VLAN Priority "4".

"Normal RSTP" is enabled under the settings of "Bridge RSTP" for the all FLS Switches with ring connection, and the software contact output of these switches is configured with momentary alarm of "STP/RSTP Reconfigured".

4. FLS Performance

The following are key performance elements for the FLS system.

- Speed: The guaranteed total FLS time is 100ms assuming a breaker/contactor opening time of 50ms or less from the moment a FLS contingency trigger activates to the moment when the load breakers/contractors are tripped.
- Load shed amount: The minimum load shed amount from a contingency trigger will be at least 100% of the related power source loss amount. The actual load shed amount (above 100%) would be dependent on the available loads and the assigned priority ranking.
- Frequency drop limitation: During a FLS event, the system frequency should never drop to under 95% of the system base frequency in order to prevent the system from becoming unstable.

5. Fast Load Shedding Scheme

The Adaptive Mode of the Controllers is used for this LNG Fast Load Shedding project. The FLS Controller issues load shed commands in the event of a contingency based on a predefined load shed priority level list with continuous power balance calculations on measured active power values from the in-feeds and loads in the FLS system.

Load groups with lower priorities are shed first in preference to load groups with higher priorities. Load groups with priority zero are not part of the load shed. Load groups having the same priority are all shed together when any need is raised for that particular priority level.

The load shed requests are sent to the end device IEDs via GOOSE load shed command messages for GOOSE capable devices. The end devices then shed the loads in the requested load groups. When no new infeed have been lost and no new scenarios have detected and the contingency timer expires, the load shed latches will be reset.

6. Participating FLS Sources in the New Plant

The devices are included as sources in the FLS system: STG A Generator, STG B Generator, LNG A Expander, LNG B Expander, Liquid Expander, and Two (plant) Intertie breakers.
Although the three expanders are counted as power sources in the new plant, they are not assigned as FLS triggers.

7. FLS Load Groups and Priority Level in the New Plant

Table below shows 18 predefined load groups in the new plant based on the loads' functions. These load values will then be monitored via the FLS communications network and updated through each associated load IED.

The initial FLS priority levels for each load shed group are also shown in the Table. Load groups with lower priorities (e.g. Priority Level 15) are shed in preference to load groups with higher priorities (e.g. Priority Level 1). Loads with Priority Level 0 indicate these loads are not assigned to get shed. These initially setup priority levels may be updated to reflect the plant operating conditions through the DCS HMI interface via the FLS communication network.

Table 1, Assigned FLS Load Shed Groups and Priority Levels

Group	Loads	KW	Priority Level
1	LNG Loading Pump A, Pump B, Pump C and Pump D	2588	15
2	Cold Flare Drum Heater A, Heater B and Heater C	5200	0
3	Regeneration Gas Compressor A and Compressor B	1092	14
4	Acid Gas Blower A and Blower B	1972	13

5	Fuel Gas Compressor 901A	2100	12
6	Flash Gas Compressor A	820	11
7	Fuel Gas Compressor 901B	2100	10
8	Flash Gas Compressor B	820	9
9	Fuel Gas Compressor 901C	2100	8
10	Flash Gas Compressor C	820	7
11	Helper Motor A	11050	6
12	Helper Motor B	11050	1
13	Vent Fan Motor A1 and Motor A2	424	0
14	Vent Fan Motor B1 and Motor B2	424	0
15	Lean Gas Booster Compressor	20900	5
16	LNG Product Pump A and Pump B	512	4
17	Amine Circulation Pump A and Pump B	3178	3
18	Lean Amine Pump A and Pump B	354	2

8. Compressor Interlocking Function

Due to the production process needs, there is a unique requirement related to the three Fuel Gas Compressor 901A, Compressor 901B and Compressor 901C. The requirement is described as below:

If three compressors are running at the same time, one of them is not allowed to be shed but must remain running, or if two compressors are running at the same time while the third one is stopped, one of the running compressors is not allowed to shed but must remain running.

In order to meet this requirement, the following interlock operations were implemented in the relays:

Compressor 901A will never be shed by FLS Controllers when it is running, therefore "ON" as the unavailability status is sent to the Controllers, which means the real power of Compressor 901A not included in the amount of sheddable load, and FLS load shed command is not configured to trip the breaker. For the same reason, if Compressor 901A is not running, Compressor B will never be shed by FLS Controllers when it is running. If both Compressors 901A & 901B are not running, Compressor 901C will never be shed by FLS Controllers.

9. FLS System DCS Interfaces

The DCS FLS Screen serves as the primary Human Machine Interface to monitor the FLS status and to control the FLS system. The two redundant FLS systems operate in parallel, ensuring high system reliability. Failure in one system will not affect the other system's functionality. In case of DCS server shutdown or communication failures, the two redundant FLS Systems remain functional. The Controller front panel serves as the backup HMI for system status monitoring under this condition.

FLS system operation status is displayed on the DCS FLS HMI screen. The FLS system status includes FLS Armed, FSL Operated, System Enabled, System Blocked, System Communication Alarm and Infeed Breakers' Status. Routine FLS operations include enabling/disabling the FLS system as well as adjusting the load group priority levels, can be easily performed on the DCS FLS Screen. The following figure shows the "FAST LOAD SHED STATUS AND CONTROL" Screen.

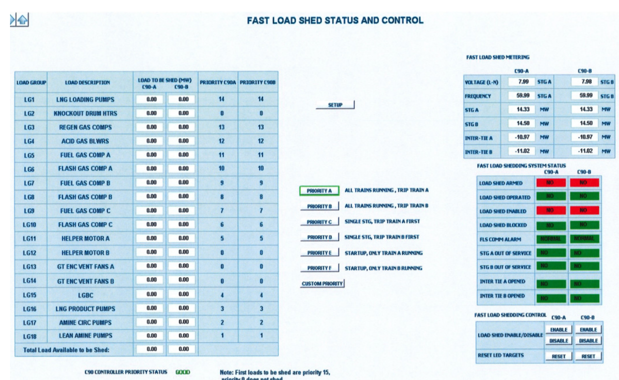
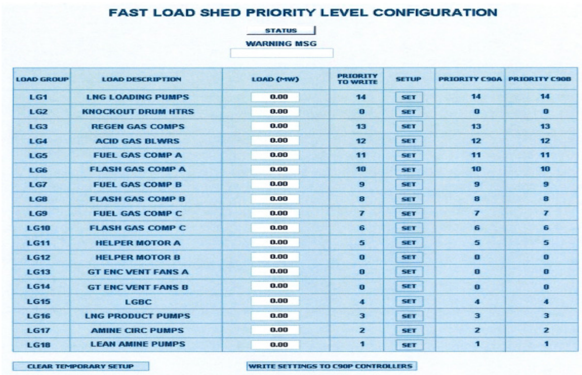


Figure 3: DCS Screen "FAST LOAD SHED STATUS AND CONTROL"

The Load Group Priority Level of the two redundant systems should always be adjusted together. This ensures that the Priority Level of the two FLS systems are identical, which is critical for the correct operation of the FLS system. To Adjust the Load Group Priority Levels first click the "SETUP" button on the

DCS "FLS Status and Control" screen. A new screen will pop as follows:



FAST LOAD SHED PRIORITY LEVEL CONFIGURATION

STATUS

WARNING MSG

LOAD GROUP	LOAD DESCRIPTION	LOAD (MW)	PRIORITY TO WRITE	SETUP	PRIORITY C90A	PRIORITY C90B
LG1	LNG LOADING PUMPS	0.00	14	SET	14	14
LG2	KNOCKOUT DRUM HTRS	0.00	0	SET	0	0
LG3	REGEN GAS COMPS	0.00	13	SET	13	13
LG4	ACID GAS BLWRS	0.00	12	SET	12	12
LG5	FUEL GAS COMP A	0.00	11	SET	11	11
LG6	FLASH GAS COMP A	0.00	10	SET	10	10
LG7	FUEL GAS COMP B	0.00	9	SET	9	9
LG8	FLASH GAS COMP B	0.00	8	SET	8	8
LG9	FUEL GAS COMP C	0.00	7	SET	7	7
LG10	FLASH GAS COMP C	0.00	6	SET	6	6
LG11	HELPER MOTOR A	0.00	5	SET	5	5
LG12	HELPER MOTOR B	0.00	0	SET	0	0
LG13	GT ENC VENT FANS A	0.00	0	SET	0	0
LG14	GT ENC VENT FANS B	0.00	0	SET	0	0
LG15	LGBC	0.00	4	SET	4	4
LG16	LNG PRODUCT PUMPS	0.00	3	SET	3	3
LG17	AMINE CIRC PUMPS	0.00	2	SET	2	2
LG18	LEAN AMINE PUMPS	0.00	1	SET	1	1

CLEAR TEMPORARY SETUP

WRITE SETTINGS TO C90P CONTROLLERS

Figure 4: DCS Screen "FAST LOAD SHED PRIORITY LEVEL CONFIGURATION"

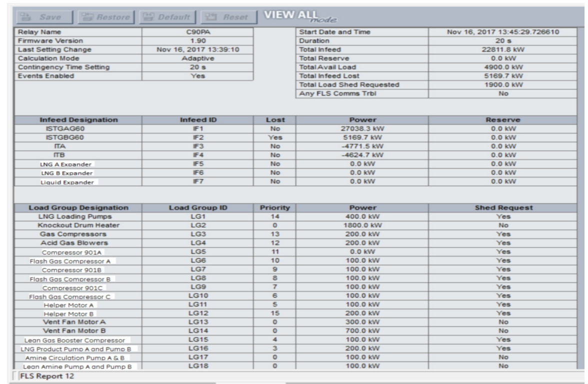
To change the load group priority levels, first click the on "SET" button of each load group row on the table. A small window with priority level settings of 0-15 will appear, and a load group with priority level zero is considered not available for shedding. Type the desired new priority level for the load group, and then click on the CLOSE button in the small window. Finally, click on the "WRITE SETTINGS TO FLS CONTROLLERS" button, the updated load shed priority table will be sent to both the redundant Controllers in sequence, the current load group priorities will be updated after the data are successfully transferred to the Controllers.

III. Testing and Commissioning

The commissioning test for this LNG Fast Load Shedding System verified communications between the field relays and the Controllers (through GOOSE messaging) as well as the communications between the Controllers and the DCS HMI Interfaces. The FLS functions were simulated under various scenarios. The interlocking function of the three Fuel Gas Compressors 901A, 901B and 901C was also verified. Finally, a "One-Shot" fast load shedding live system test was performed to demonstrate the FLS system overall functionality.

The FLS commissioning test was performed during the third week of November in 2017, All applicable FLS triggered scenarios were tested, including one FLS live system test by opening the breaker of the STGB Generator with 5.17 MW of power output being produced. The FLS system operated exactly as per the design.

The FLS live system test report is shown below:



Save | Restore | Default | Reset | VIEW ALL mode

Relay Name	C90PA
Firmware Version	1.90
Last Setting Change	Nov 16, 2017 13:39:10
Calculation Mode	Adaptive
Contingency Time Setting	20 s
Events Enabled	Yes

Start Date and Time	Nov 16, 2017 13:45:29.726610
Duration	20 s
Total Infeed	22811.8 kW
Total Reserve	0.0 kW
Total Avail Load	4900.0 kW
Total Infeed Lost	5169.7 kW
Total Load Shed Requested	1900.0 kW
Any FLS Comms Trbl	No

Infeed Designation	Infeed ID	Lost	Power	Reserve
ISTGAG60	IF1	No	27038.3 kW	0.0 kW
ISTGBG60	IF2	Yes	5169.7 kW	0.0 kW
ITA	IF3	No	-4771.5 kW	0.0 kW
ITB	IF4	No	-4624.7 kW	0.0 kW
LNG A Expander	IF5	No	0.0 kW	0.0 kW
LNG B Expander	IF6	No	0.0 kW	0.0 kW
Liquid Expander	IF7	No	0.0 kW	0.0 kW

Load Group Designation	Load Group ID	Priority	Power	Shed Request
LNG Loading Pumps	LG1	14	400.0 kW	Yes
Knockout Drum Heater	LG2	0	1800.0 kW	No
Gas Compressors	LG3	13	200.0 kW	Yes
Acid Gas Blowers	LG4	12	200.0 kW	Yes
Compressor 901A	LG5	11	0.0 kW	Yes
Flash Gas Compressor A	LG6	10	100.0 kW	Yes
Compressor 901B	LG7	9	100.0 kW	Yes
Flash Gas Compressor B	LG8	8	100.0 kW	Yes
Compressor 901C	LG9	7	100.0 kW	Yes
Flash Gas Compressor C	LG10	6	100.0 kW	Yes
Helper Motor A	LG11	5	100.0 kW	Yes
Helper Motor B	LG12	15	200.0 kW	Yes
Vent Fan Motor A	LG13	0	300.0 kW	No
Vent Fan Motor B	LG14	0	700.0 kW	No
Lean Gas Booster Compressor	LG15	4	100.0 kW	Yes
LNG Product Pump A and Pump B	LG16	3	200.0 kW	Yes
Amine Circulation Pump A & B	LG17	0	100.0 kW	No
Lean Amine Pump A and Pump B	LG18	0	100.0 kW	No

FLS Report 12

Figure 5: FLS Live System Test Report

Based on the Events Record, the FLS operating times from the FLS initiation signal "STGB 52G/a off" to 3 load relay breakers status "BKR 52A Off" were 54.3ms, 51.2ms and 53.2ms, which were within the 100ms requirement.

IV. Conclusions

Fast Load Shedding System (FLS) described in this paper is a necessary requirement for this LNG plant to avoid process or manufacturing interruptions in case of contingencies. FLS is using new technologies available today to achieve several benefits for the system:

- Operating speed of 50-55ms, which would not be possible with an older technology.
- Adaptive approach with continuous monitoring of the power balance and shedding exact amount loads to maintain balance, keeping critical loads not disturbed.
- Continuous monitoring of the health of the system and communications.
- Reduced copper wirings between Controller and relays, ease of commissioning and maintenance.

The design of the FLS scheme utilized the available protection relays with two redundant FLS Controllers to communication using standardized IEC 61850 GOOSE over redundancy networks. The transient stability study is presented to obtain the critical operation time of 100ms for the entire FLS scheme including breaker operation time to ensure the stability of the system. Lesson's learned while applied FLS scheme to develop load priorities and compressor interlocking scheme. The testing results of the complete FLS scheme shows that in all possible scenarios complete close-loop FLS operated from 50-55ms, which is well within required 100ms time to ensure the stability of the plant.

The LNG Fast Load Shedding System has been running successfully since November 2017, It was confirmed by the LNG operators that FLS system saved the facility during several instances by shedding pre-selected loads to maintain power system stability. One instance occurred in March 2019, STGA with 40MW tripped offline, the FLS system was activated and shed several large motor loads based on the preset load group priorities. Plant LNG production only dropped by 35% and Operation was able to immediately begin recovery to full production. Without FLS all production would have been lost and the facility would have suffered a cascading power failure and subsequent blackout.

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