IEC61850 based contingency driven fast load shedding solution to achieve demanding performance for larger networks

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Summary

Abstract

Generally the Oil & Gas infrastructure is designed to import power from the grid depending on several factors and it is necessary to have a mechanism to ensure power balance with faster response in improving the system stability. It is essential to analyze issues of dynamic performance for infrastructures with embedded power generation and apply modern approaches to ensure the availability of power to key electrical processes under various contingencies.

This paper discusses the need of tools for operating time performance estimation of an Ethernet based 61850 system during design of EMCS for large Oil & Gas refineries. We discuss an intelligence based model that works on Pre-selection computation based approach to identify contingencies that improve the dynamic performance of the system and maintain balance between Generation & Load.

The paper illustrates the results of the proposed model based on a simulation environment with a simple power system network.

Introduction

Frequency stability refers to the ability of a power system to maintain a steady frequency following a severe system upset resulting in a significant imbalance between generation and Load. Power systems are required to operate at a state that is not only able to maintain various steady-state operational limits but also able to withstand possible contingencies without losing its dynamic stability performance. Stability of power system network is highly dependent on frequency range it is being operated on. As well, operation of electrical equipment like Power Drives, Motors play a vital role in ensuring the power balance.

Frequency instability may appear as sustained frequency swing that may lead to tripping of generating units and/or loads. Generally, frequency instability is caused by a sudden load throw off, loss of generation, increase in load, faults etc. Small magnitude of disturbances will allow the system with sufficient time to settle down with turbine governor action. However, the significant magnitude of disturbances require control actions to counter frequency instability that include load shedding and generator tripping, where the former reacts for generation loss and the latter responds for load loss.

As an effective emergency control action, Load Shedding for frequency instability prevention can comprise of response-driven and event/contingency driven strategies. Response-driven Load Shedding is triggered by a system frequency response following disturbance(s), known as under frequency LS. When the system post-fault frequency drops below the pre-determined threshold, the UFLS devices shed a certain percentage of load according to their settings. By contrast, Fast Load Shedding is Contingency-driven & is automatically activated by a recognized event, and trips load immediately (based on presimulations) without waiting for observing frequency declines. For enhanced power system frequency stability, both LS schemes are necessary in practice, and they should be appropriately coordinated. Generally, the FLS is designed for very severe events with high probability; the UFLS, on the other hand, is applied for less likely contingencies.

Historically, the calculation of the FLS has been based on deterministic approaches, which suffers heavily from intensive computation burden and mismatching problems. To overcome / supplement the conventional methods, this paper proposes a methodology for enhanced FLS against severe contingency events. This methodology consists of a fast and accurate prediction model which acts on-line for predicting the required Load to be shed for a given contingency.

The remaining section of this paper is organized as follows. Section II introduces and compares the two LS strategies, and identifies the problems for FLS. Section III proposes the methodology for a real-time FLS prediction, which also includes the proposed architecture & the data flow. In Section IV, simulation of the proposed methodology on a simple power system network is explained. Section V concludes the whole paper.

Problem description

A. Response driven load shedding vs Contingency driven load shedding.

The response driven based load shedding / isolation approach, widely uses Under Frequency based Load Shedding solutions. The inherent closed loop / feedback based control scheme in UFLS system as illustrated in Fig. 1, makes them efficient in acting against the disturbances.

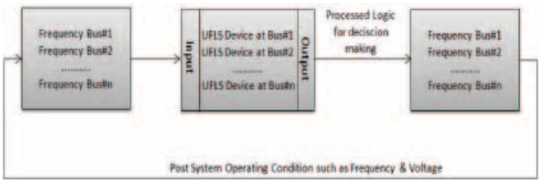

Fig.1
UFLS Process Flow

As frequency is a very good indicator of Power Mismatch, the operation based on under frequency relays has high control precision and robustness with respect to uncertainties. However, it can have many difficulties and challenges. The setting of the UFLS is highly complex, which involves many parameters including the number of LS stages, percentage of load allowed to be shed, the time delay for each stage, real time topology etc. Together these variables make the UFLS settings a non-linear and multi dimensional problem. Secondly, UFLS is triggered after the frequency has already declined to certain low values causing a time delay, which makes the solution more reactive in nature and the system stability requires more time.

On the other hand FLS is determined preventively and triggered in real time just after the contingency is detected. This process is illustrated in Fig. 2.

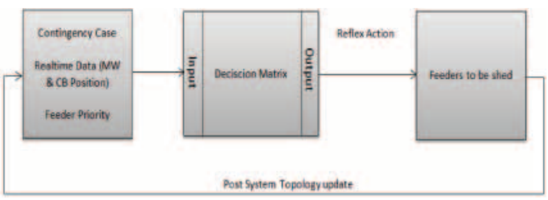

Fig.1
UFLS Process Flow

The core of the FLS strategy is a decision Matrix (as shown in Fig. 2), which is featured by input and output. The input is a system operating condition (such as power flow quantity) and contingency (characterized by the status of the system elements), and the output is the number of LS feeders, the amount of (MW) to be shed to bring the network balance. Once the input is fed, the output can be immediately indexed and corresponding LS actions can be triggered by a signal through high speed IEC61850 based Ethernet network; thus influencing the FLS to act much faster with stronger control efficiency over UFLS.

Generally, each LS strategy has its merits and demerits, so both of them need to be adopted in power systems practice. All most all of the contingency driven approaches are using UFLS triggers as one of the vital input (contingency) in their predictive analysis. The right selection of communication medium & the protocol implementation such as IEC61850 for data acquisition & load shedding control action is also playing a key role in FLS performance operating time.

Recent blackouts happened in India on 30th & 31st July'12 have affected around 40000MW and kept 600 million people including critical services such as railways, hospitals, airways etc in dark for the entire duration. It was observed that apart from the operational issues, there is a significant need to have different load shedding approaches with faster performance operating times and online prediction to act against such critical disturbances caused by a combination of sudden increase in drawl, loss of generation, consecutive/multiple events etc.

Problem description (cont.)

B. State of the art approach

In practice, the FLS decision table is prepared based on presimulation and associated analysis. Though most of the contingency driven approaches consider the dynamic operating conditions such as total generation, topological association of various generators and respective loads, in many cases the prediction process is kept offline or limited to few contingency cases where prospective operating conditions are forecasted and contingencies are imagined at specific lead time. For each contingency scenario, the FLS decision table is calculated with respect to the given limits and frequency stability requirements. However, with the increased penetration of non-conventional energies such as wind & solar power, modern power systems have become uncertain and highly unpredictable, making the approach insufficient.

Based on the continuous advancements of computing hardware, algorithms, faster communication architecture, it is now feasible to move the off-line calculation to the on-line stage. With IEC61850 implementation, the acquisition process can become real faster, which can in turn help the load shedding controllers in making faster decisions against disturbances. The FLS decision table against possible, visible / invisible contingencies can be refreshed by 'on-line pre-computation'. This scheme can significantly enhance the accuracy and robustness of the decision table since it can track the practical power system operating states.

However, because of the deterministic nature, both off-line and on-line approaches can only accommodate a limited number of contingencies. In the case of unlimited possible event scenarios, such as complex generation loss patterns, combinational / consecutive events, the decision table by deterministic approach could suffer from mismatching problems. Hence there is a need for more efficient tools to determine quickly the required amount of load shed to restore system stability. The proposed methodology can meet this demand as it can be applied in real time for FLS prediction and can generalise the prediction on both visible and non-visible scenarios as it works on distributing available power to all the crucial feeders for any kind of contingency.

Methodology

A. General Description

The main objective of FLS is to ensure the power system stability by distributing the available power to the critical loads as per their priority in a fastest possible time through real time supervision & control of entire power system network. During this process it is essential to ensure right amount of load reduction with respect to the magnitude of the disturbance such that the system stability can be achieved within a short period of time.

The Fast Load Shedding scheme works on a concept of prediction/anticipation of system response to different disturbances (contingencies) under the actual system operating conditions and uses the proven and robust design based on IEC61850 protocol. Based on prediction analysis results, trip pre-selection matrix is updated as per the priority of each feeder depending on their criticality. The prediction analysis considers various contingencies such as complex generation loss patterns, combinational / consecutive events like cascading tripping etc.

Before preparing the decision table, a comprehensive FLS database is primarily generated based on various Nodes (Bus), Links (Bus tie, Transformers), Sources and Consumers (Feeders/ Motors) along with their nominal & operating limits, which leads to the formation of static power system network. Based on the above data, the proposed model identifies all possible power supply connectivity chains, sub networks, islands from the derived static model. The database also consists of various possible combinations of contingency cases to be acted upon. Secondly, the relationship between contingency scenario and the required load to be shed to maintain the frequency stability is extracted by an automatic learning model-based power flow study running on iterative optimization process basis, which shall be introduced in the subsequent sections. Unlike deterministic schemes, the proposed methodology characterizes a contingency by the resulting total loss of generation (MW), total loss percentage of generation (%), total generation-load imbalance (MW), operation condition by active output of each generator (MW) and active power load of each bus (MW). As a result, the contingency and operating condition can be generally detected rather than deterministically identified.

Methodology (cont.)

B. FLS Database

The FLS database is characterised by system pre-fault operating condition and the contingency (event) information to produce the corresponding optimal LS (subject to the frequency stability requirement). As power system frequency stability is strongly related to the active power balance of the system, steady-state system power generation and load variables have been selected to characterize an operating condition, and the contingency events are represented by the resulting active power imbalance. Some of the operating conditions relate to active MW output of each generator, active MW load of each bus, total MW generation, total MW load etc. Contingencies related to loss of generation, loss of busbar, loss of % generation, total generation load imbalance etc. In addition, the feeder priorities play a vital role in FLS database.

C. Computation of optimal FLS :

In practice, the selection of LS buses involves power supply priority, operating rules, as well as human judgment. When it comes to minimizing the required Load to be shed for restoring the frequency stability to a desired level, the problem can be formulated as

$$\Delta Fi = \min \sum_{i=1}^{n} \Delta Li \qquad \text{- - - - (i)}$$

Steady State Power Flow Equations - - - - (ii)

Operating Limits - - - - (iii)

(i) is the objective function defining the amount of load shed action to be taken to bring the frequency deviation from the nominal frequency within the acceptable operating range. ΔLi is the load mismatch at bus i and n indicates the maximum number of buses configured in the load shedding database for the proposed power system network. Larger the ΔFi , the greater is the need for control effect. However, for practical scenario there needs to be a user defined limit to permit the maximum allowable amount of Load Shed.

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Based on above, algorithm creates a static topological model by identifying the Links (Bus tie, Transformers), Sources and Consumers (Feeders/ Motors) along with their nominal & operating limits and groups them into various power supply chains through IEC61850 SCD file from the preconfigured system. In order to make the overall preSelection scheme consistent a snapshot of the topology

D. Load Shedding System Architecture:

is taken at the beginning of acquisition cycle through IEC61850 and computes all possible combinations by superimposing them with the real time topological operating conditions. FLS Central Automation computes the power balance equations against each possible contingency such as loss of generation, loss of bus bar, sudden load thrown off, Under Frequency, Loss of critical equipments / processes or combination of events etc. As a result of this computation, the FLS Central Automation creates a preselection matrix which consists of various feeders / motors to be tripped to maintain the power balance of the system. The results of the preselection computation shall be passed on to the decision module for final verification of the results and for getting itself ready to act upon occurrence of the contingency.

Upon receipt of one predefined contingency, the Decision Module checks the current preSelection matrix for circuit breakers to be tripped in response. It creates a TRIP-ORDER command to be sent as a IEC61850 fast Goose message to the respective Load Shedding Units to act. If several contingencies occurred almost at the same time, all preselected circuit breakers for each occurred contingency will be tripped. If the delay between consecutive contingencies is larger, the Anticipation/Prediction module can receive the updated topology and thus updates the preSelection matrix. This new preSelection matrix is then used to trip adequate circuit breakers.

Unlike the conventional approach of shedding the least important feeders, the proposed model ensures the availability of critical resources with the available power generation in hand and helps shed only the required amount of load depending on the magnitude of the disturbance. The results have shown that this approach helps in avoiding over curtailment over conventional approach.

Fig.3 shows the typical architecture of a substation with real time monitoring along with load shedding solution. The field acquisition units of a substation could be of any IEC61850 IED, which can report all real time statuses, analogs, events & records to the local operator HMI. The Substation Electrical Network Control & Monitoring System (ENCMS) is interconnected with FLS network for acquisition of Circuit Breaker positions, active & reactive power measurements along with system frequency through the dedicated IEC 61850 /IEC 61850 Gateways. This interconnection strategy ensures that the FLS equipments are not disturbed with network data produced to manage the Electrical Network Control & Monitoring features.

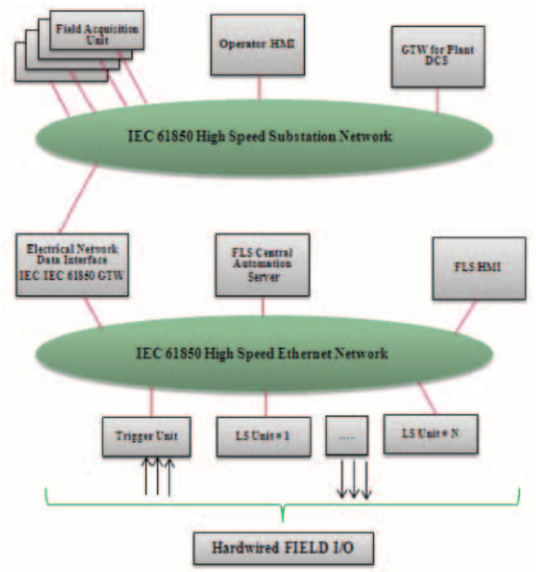


Fig.3
Network architecture of an intelligent Fast Load Shedding Scheme

Methodology (cont.)

E. FLS Data Flow

Fig.4 demonstrates the data flow between various key components of FLS system. In a Centralized FLS System, FLS Central Server computes the preSelection matrix and sends the trip matrix consisting of load to be shed against the specific contingency cases as report to FLS HMI for information on IEC61850. Also there is a provision from FLS HMI to set the initial feeder priorities as well as to adjust them under various contingencies such as non-availability of any load shedding units or the feeders for tripping, partial loss of some of the key process etc. FLS Critical events / contingencies (Trips, System Overload, etc.) that require a specific reaction from FLS are directly acquired by a Trigger Unit, which sends those messages as fast IEC61850 Goose messages to FLS Central Automation Server.

FLS Central Computer computes required actions upon contingency occurrence (with regards to the current preSelection matrix) and builds the Trip Decision Scheme. As a result, Trip controls are propagated as fast IEC 61850 messages to the respective Load Shedding Units.

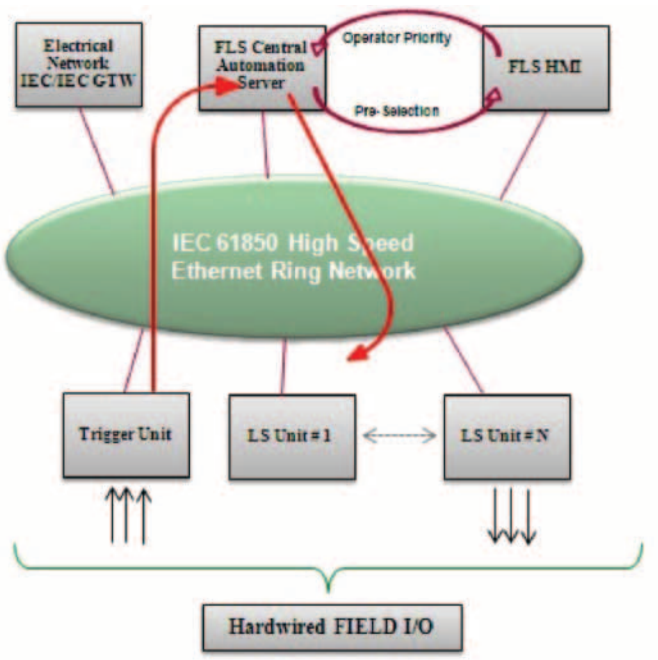


Fig.4
Data Flow of iFLS

Simulation results of proposed model on a sample power system network

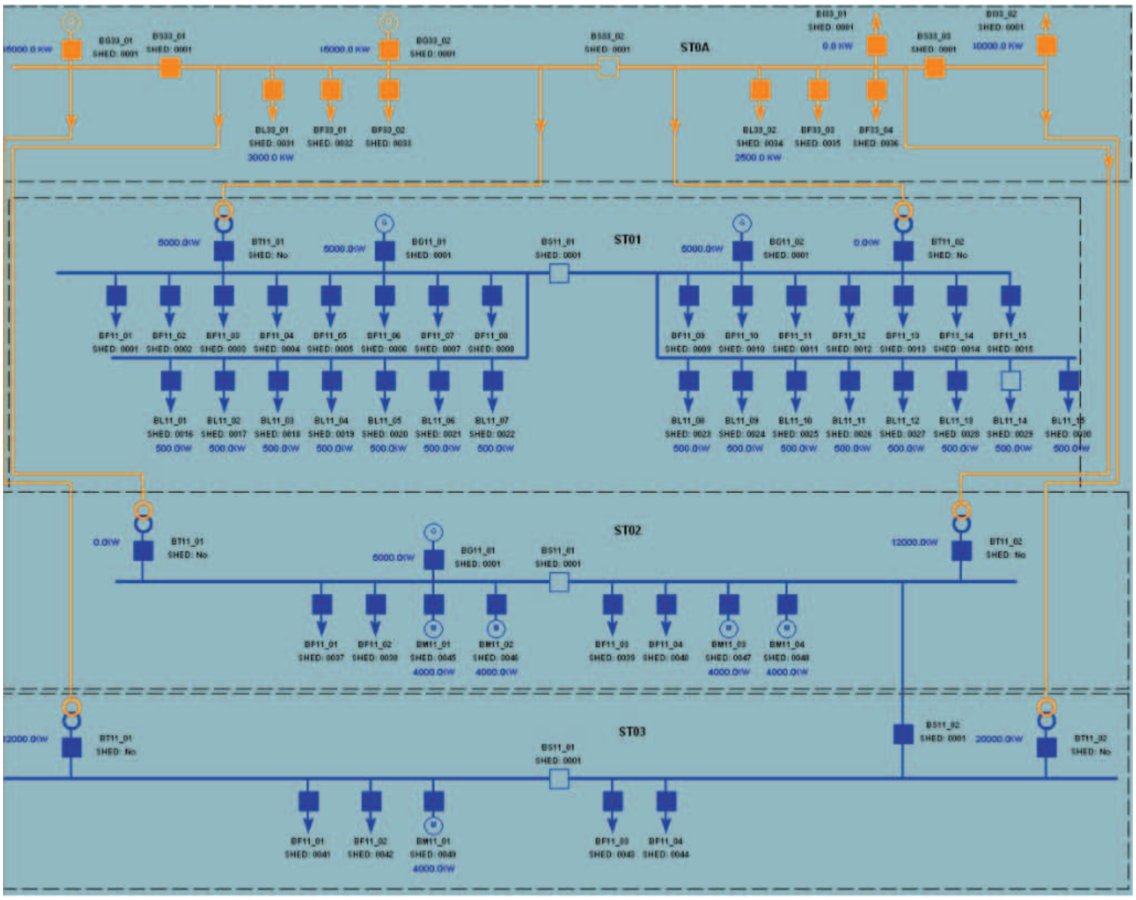


Fig. 5
Typical Single Line Diagram

Fig.5 shows the typical SLD used on a simulation test platform which consists of three 11 kV substations which are being fed from primary 33 kV substation consisting of 2x15MW internal generation and two utility incomers of 50MW. There is also an in-plant generation of 3x5MW. The above system is supplying 49 feeders assigned with a specific priority & the total load amounts to 80 MW.

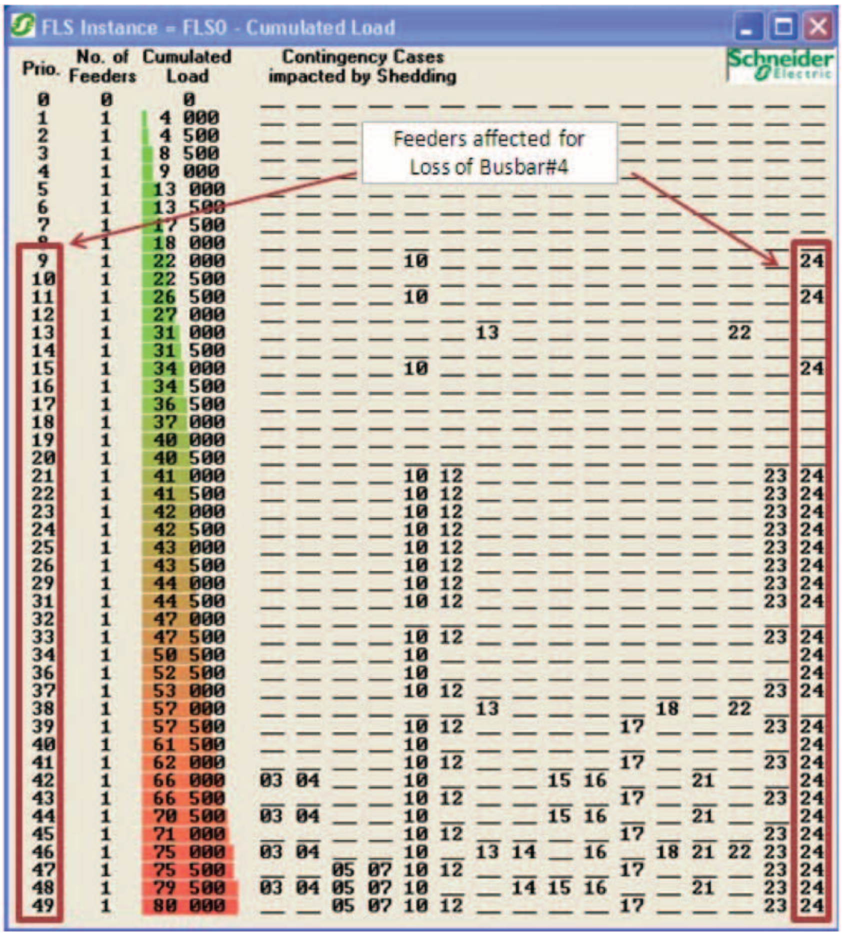
Fig.6 indicates the 24 contingency cases designed for the above SLD in the FLS scheme, which includes loss of generation to loss of critical equipment, reduced power output, busbar trips etc.

Contingency Case	Description
1	Gradual Overload
2	Under Frequency Shed
3	Loss of Generation-1 (STOA - BG33_01)
4	Loss of Generation-2 (STOA - BG33_02)
5	Loss of Generation-3 (ST01-BG11_01)
6	Loss of Generation-4 (ST01-BG11_02)
7	Loss of Generation-4 (ST02-BG11_01)
8	Loss of Generation-4 (ST02-BG11_01)
9	Loss of Incomer-1 (STOA-BB3_01)
10	Loss of Incomer-2 (STOA-BB3_02)
11	Loss of Transformer (ST01-BT11_01)
12	Loss of Transformer (ST01-BT11_02)
13	Loss of Transformer (ST02-BT11_01)
14	Loss of Transformer (ST02-BT11_02)
15	Loss of Transformer (ST03-BT11_01)
16	Loss of Transformer (ST03-BT11_02)
17	Capacity Reduction of Transformer (ST01-BT11_02)
18	Capacity Reduction of Transformer (ST02-BT11_01)
19	Spare
20	Spare
21	Loss of Busbar-1
22	Loss of Busbar-2
23	Loss of Busbar-3
24	Loss of Busbar-4

Fig.6
Operating Contingencies for FLS

Simulation results of proposed model on a sample power system network (cont.)

Fig.7 also highlights one of the contingency case i.e. loss of Busbar#4 (i.e. sudden loss of 40MW generation), the system acts quickly in distributing the available power as per set priorities. This leaves the system to trip 26 feeders amounting to 43MW load to bring the frequency stability back on track. The entire operation gets completed in a span of <20 msec i.e one cycle. However, the operating time relies on various parameters such as complexity of the power system network, amount of load to be shed & the number of feeders etc. However, maximum operating time is well



Prio.	No. of Feeders	Cumulated Load	Contingency Cases impacted by Shedding															
0	0	0	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
1	1	4 000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
2	1	4 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
3	1	8 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4	1	9 000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	1	13 000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
6	1	13 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
7	1	17 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
8	1	18 000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
9	1	22 000	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	24
10	1	22 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
11	1	26 500	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	24
12	1	27 000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
13	1	31 000	—	—	—	—	—	—	13	—	—	—	—	—	—	22	—	—
14	1	31 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
15	1	34 000	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	24
16	1	34 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
17	1	36 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
18	1	37 000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
19	1	40 000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
20	1	40 500	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
21	1	41 000	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
22	1	41 500	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
23	1	42 000	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
24	1	42 500	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
25	1	43 000	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
26	1	43 500	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
29	1	44 000	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
31	1	44 500	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
32	1	47 000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33	1	47 500	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
34	1	50 500	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	24
36	1	52 500	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	24
37	1	53 000	—	—	—	—	10	12	—	—	—	—	—	—	—	—	23	24
38	1	57 000	—	—	—	—	—	—	13	—	—	—	—	18	—	22	—	—
39	1	57 500	—	—	—	—	10	12	—	—	—	—	17	—	—	—	23	24
40	1	61 500	—	—	—	—	10	—	—	—	—	—	—	—	—	—	—	24
41	1	62 000	—	—	—	—	10	12	—	—	—	—	17	—	—	—	23	24
42	1	66 000	03	04	—	—	10	—	—	—	15	16	—	—	21	—	—	24
43	1	66 500	—	—	—	—	10	12	—	—	—	—	17	—	—	—	23	24
44	1	70 500	03	04	—	—	10	—	—	—	15	16	—	—	21	—	—	24
45	1	71 000	—	—	—	—	10	12	—	—	—	—	17	—	—	—	23	24
46	1	75 000	03	04	—	—	10	—	13	14	—	16	—	18	21	22	23	24
47	1	75 500	—	—	05	07	10	12	—	—	—	—	17	—	—	—	23	24
48	1	79 500	03	04	05	07	10	—	—	14	15	16	—	—	21	—	23	24
49	1	80 000	—	—	05	07	10	12	—	—	—	—	17	—	—	—	23	24

Fig.7
Trip pre-selection matrix of FLS

Conclusion

Offered Model makes the best utilization of IEC-61850 Report & Goose messages for fast & reliable message transfer for real time data acquisition and tripping of the feeders, which ensures the execution of load control action within 60 msec. Designs based on latest technologies like IEC61850 enables the system to be ready for future expansion at any point of time. Though the contingency driven approaches are faster in nature, they might suffer from load mismatch problems. Also their action is more precise for learned contingencies than the other. On the other hand, actions based on UFLS are highly reliable as they are able to shed more loads till the frequency is within the limits. Hence it is advisable to apply a combination of contingency driven Fast Load Shedding as well as Under Frequency Load Shedding systems to serve the system needs in an optimal & reliable manner. With the increased uncertainty of power system networks, authors feel the necessity of having an online simulator to help the controller in learning the new / unimagined contingencies so that the prediction can be even more accurate.

Nomenclature

UFLS: Under Frequency Load Shedding

FLS: Fast Load Shedding

LSU: Load Shedding Units

ENCMS: Electrical Network Control & Monitoring System

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