Flexible High-Speed Load Shedding Using a Crosspoint Switch

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***Abstract*—Industrial load-shedding systems must address electric power system stability criteria as well as industrial process operations requirements. Industrial plants of all varieties may be operated in different modes that increase or decrease the criticality of individual electrical loads in the plant. An effective industrial load-shedding system must provide a method to increase survivability of both the electric power system and the industrial process being powered.**

Industrial load-shedding applications can be greatly simplified by using protection-class crosspoint switches. By their nature, crosspoint switches lend themselves well to load-shedding applications where high-speed, secure decisions have to be made. Load-shedding tables can be easily implemented with crosspoint switches, which dynamically change based on system conditions and plant operation priorities. With intelligent crosspoint switches, the communications system can be fully supervised to prevent false load-shed signals and communications outages from causing false trips.

This paper examines the concept and application of high-speed crosspoint switches to implement load shedding in an industrial plant setting. This design is currently being installed in an oil refinery and uses a load-shedding processor, protection logic processors with crosspoint switch functions, microprocessor protective relays for status input and analog quantities, and a power management system for operator load table inputs. The load-shedding scheme uses a substation-grade computer to process the current state of the power system (e.g., generation, load, topology, etc.) and write the load-shed table into three crosspoint switches. Several contingencies are defined in relay logic that may trigger load shedding, including generator trips, utility tie-line trips, bus-tie breaker trips, and underfrequency conditions.

I. Introduction

Two distinct concerns exist in an industrial plant relating to the implementation of a load-shedding scheme: power system stability and process survivability. Power system stability requires fast tripping of the correct quantity of load (kW) in response to a specific event on the power system. Process survivability requires that individual loads (i.e., motors, heaters, etc.) be selected intelligently to minimize the effect of load shedding on plant operation. The optimal set of loads to be tripped will change according to the power system topology and the present mode of operation of the industrial process. For example, one pump may be of great importance in some operating situations and of lesser importance in other situations. This paper examines one approach used to address the distinct load-shedding concerns of the power system and the industrial process. The power system configuration and the specific load-shedding requirements this paper references have been adapted from a recent project that used this approach.

A. Power System Overview

Fig. 1 is a simplified one-line diagram that illustrates the plant power system this paper references. The plant receives power from four on-site generators and two tie-line connections to the local electric utility. Each source feeds one of two buses in a 20 kV double bus arrangement. The two buses can be connected together through a tie breaker. A series of feeders connects load centers throughout the facility to the 20 kV bus. Each of these feeders can be connected to either of the 20 kV buses. Loads are connected throughout the plant to 6 kV switchgear and 380 V motor control centers.

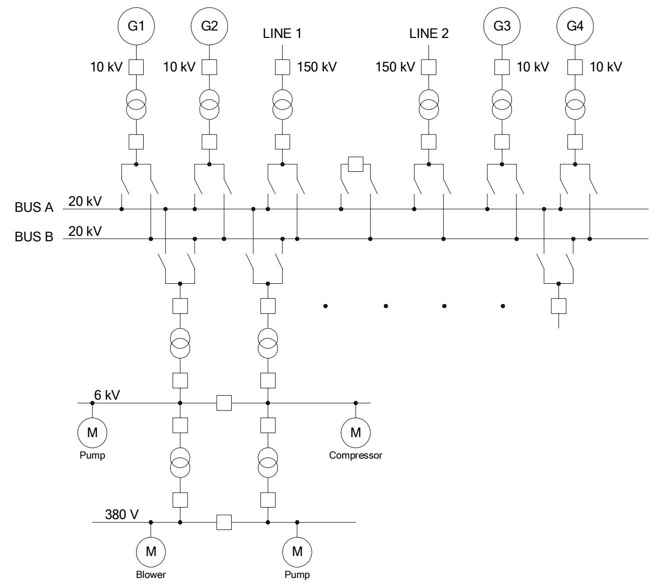

Fig. 1. Simplified one-line diagram of plant power system

B. Load-Shedding System Overview

A load-shedding system must perform the following general functions:

- Initiate load shedding in response to specific contingency trigger signals.
- Trip the correct amount of load quickly to maintain stability.
- Disturb the production process as little as possible.
- Avoid unnecessary operations.

The load-shedding system includes two different schemes for initiating load shedding. The primary scheme is based on the predicted power deficit resulting from pre-defined trip events (i.e., source trip or tie breaker trip). The secondary scheme is based on underfrequency thresholds. Each threshold corresponds to an amount of load that must be tripped before the power system can recover from the underfrequency condition. This paper refers to these trip events and underfrequency conditions as contingencies.

The following detailed requirements further refine the list of general requirements:

- Dynamically calculate the quantity of load to shed for each primary contingency.
- Use an operator-settable quantity of load to shed for each secondary contingency.
- Dynamically select individual loads to shed based on settable priorities, measured power consumption, and the present topology of the connected power distribution system.
- Support operation of the power system with the 20 kV tie breaker open or closed.
- Use secure methods with high noise immunity to propagate contingency trigger and load-shed signals.
- Respond to a contingency trigger in less than 80 msec.
- Supervise all signals with communications quality indications.

II. Conceptual Architecture

The structure of the solution closely parallels the structure of the problem. The solution must be very flexible to accommodate the requirements for process survivability. The solution must also be high speed and deterministic to accommodate the requirements for maintaining power system stability. For this reason, the solution splits into two distinct functional categories: pre-event calculations and event actions. Fig. 2 illustrates the conceptual architecture of the load-shedding system.

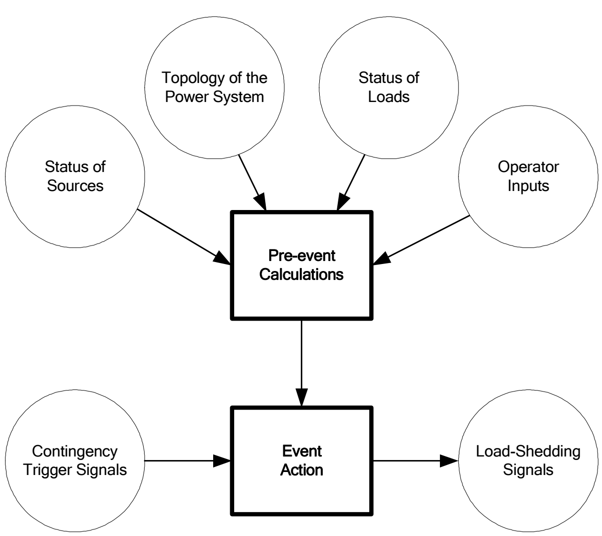

Fig. 2. Conceptual architecture of the load shed system

A. Pre-event Calculations

The load-shedding system collects and processes the following data to dynamically select the loads that will be shed for each possible contingency.

- Status of Sources: This includes the online status of each generator and utility tie line, as well as the 20 kV bus to which the source is presently connected. Additionally, this includes the present power output of each source.
- Topology of the Power System: This includes the status of breakers and disconnect switches located throughout the distribution network.
- Status of Loads: This includes the run status and present power consumption of each individual load.
- Operator Inputs: This includes a list of operator-settable priorities. The operator assigns each load in the system a unique priority. Additionally, this includes operator-settable parameters related to source capacities.

The load-shedding system uses these calculations to intelligently determine which loads to shed, and determines a separate set of loads for each possible contingency. Think of the pre-event calculations as a series of "What if" scenarios (e.g., what if generator 1 trips, what if utility line 1 trips, what if there is underfrequency on Bus A, etc.). The calculations occur before any contingency trigger, so they do not affect the speed at which an event action will occur.

The pre-event calculations do not need to occur at high speed. In fact, the load-shedding system filters all analog measurements to provide a smooth representation of system power flows. The pre-event calculations are executed every 2 seconds to dynamically update a load-shed table for use by high-speed event actions.

B. Event Actions

Event actions occur at high speed in response to contingency trigger signals. When the load-shedding system detects a contingency (e.g., a generator trips offline), the system trips the set of loads corresponding to the contingency, as determined by pre-event calculations. All decisions regarding which loads to trip were already made before the load-shedding system detected any contingency, therefore the event action can be executed very quickly.

C. Allocation of Functions to Devices

The two distinct functional categories have different device requirements. The pre-event calculations require programming flexibility for implementing the load selections algorithm. The event actions require high-speed and deterministic processing, as well as secure communications channels to propagate contingency triggers and load-shedding signals. The solution uses a substation-grade computing platform running a soft PLC to implement the pre-event calculations, and protection logic processors with crosspoint switch functions to implement the event actions.

Processor-intensive calculations take place in the substation-grade computing platform. The load-shedding system writes the results of these calculations to the crosspoint switch in three protection logic processors, each of which solves Boolean logic at high speed.

Contingency trigger and load-shedding signals are propagated throughout the plant at high speed through the use of a secure protection-oriented protocol. When the load-shedding system detects a contingency trigger, the system maps the contents of the crosspoint switch directly to the communications channels to trip the pre-determined loads.

III. Physical Architecture

The physical architecture of the load-shedding system consists of the dedicated devices that provide the core functions and the peripheral devices that provide metering and status data.

A. Core Components

A substation-grade computing platform serves as a load-shedding processor (LSP). The LSP and three protection logic processors provide the core functions. In addition, remote input/output (I/O) modules are located throughout the plant and connect to the logic processors via fiber-optic cables. Fig. 3 illustrates the physical architecture of the core of the load-shed system.

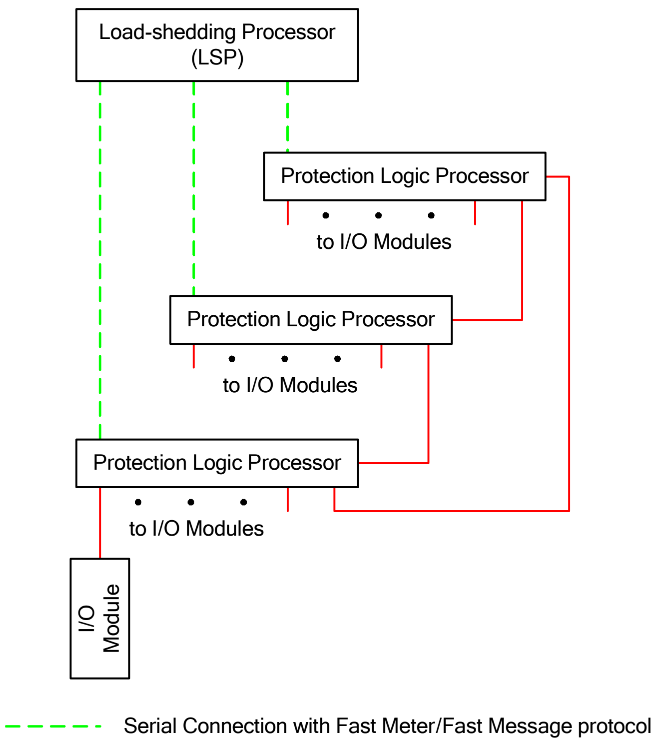

Fig. 3. Physical architecture of the load-shedding system

The LSP uses a supervisory control and data acquisition (SCADA)-oriented protocol (Fast Meter/Fast Message) to communicate with each of the logic processors via copper serial cables. The dynamically determined load table is written to the crosspoint switch in each of the logic processors. Additionally, the communication link supports several command and status messages.

The logic processors communicate with a collection of remote I/O modules located throughout the plant. These high-speed, secure communications links consist of fiber-optic cables and use a protection-oriented protocol (MIRRORED BITS®). Contingency trigger and load-shedding signals propagate over these communication links.

The logic processors communicate with each other using the same MIRRORED BITS protocol. The three logic processors communicate contingency trigger signals, as well as several status points, to ensure that the three processors respond as a single load-shed system.

B. Peripheral Components

Microprocessor-based relays protect the power system. Many of these devices also provide data to the plant power management system for SCADA functions. A subset of the relays in the plant also contains data important to the load-shedding system. The load-shedding system uses these relays as sources for essential power system data.

The facility includes several substations. A substation-grade computing platform serves in each substation as a substation data processor (SDP). The SDP and a variety of protective relays provide necessary metering and status data. Fig. 4 illustrates the physical architecture of the system that collects data within each substation.

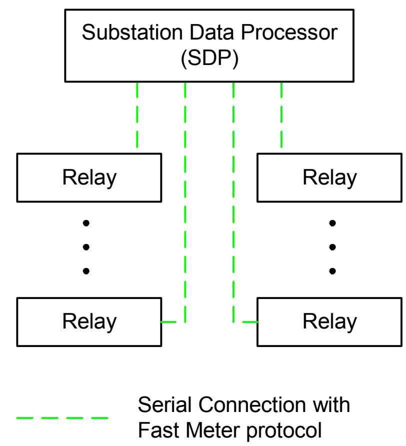

Fig. 4. Physical architecture within each substation

The SDP uses Fast Meter protocol to communicate with each of the protective relays in the substation via serial cables. The SDP also collects and organizes metering and status data.

The power management system includes a SCADA-oriented human machine interface (HMI). The load-shedding system shares the HMI with the power-management system. Displays related to the load-shedding have been integrated into the overall power-management operator-interface design.

C. Plant Local Area Network

An Ethernet-based local area network (LAN) exchanges data between each substation data processor (SDP) and the load-shedding processor (LSP). The load-shedding system shares this LAN with the plant power-management system. The power-management system uses the LAN for SCADA, retrieval of relay-specific reports such as oscillograghy and sequence of events, and relay setting management. This paper does not discuss the power-management system. However, it is of interest to note that the LAN, the HMI, and many of the components within each substation were required for power-management or protection functions. These devices were not added specifically to support load-shedding.

Each SDP in the plant sends one message to the LSP to update all relevant metering and status values from the substation. Fig. 5 illustrates the physical architecture of the LAN that exchanges data between the SDPs and the LSP.

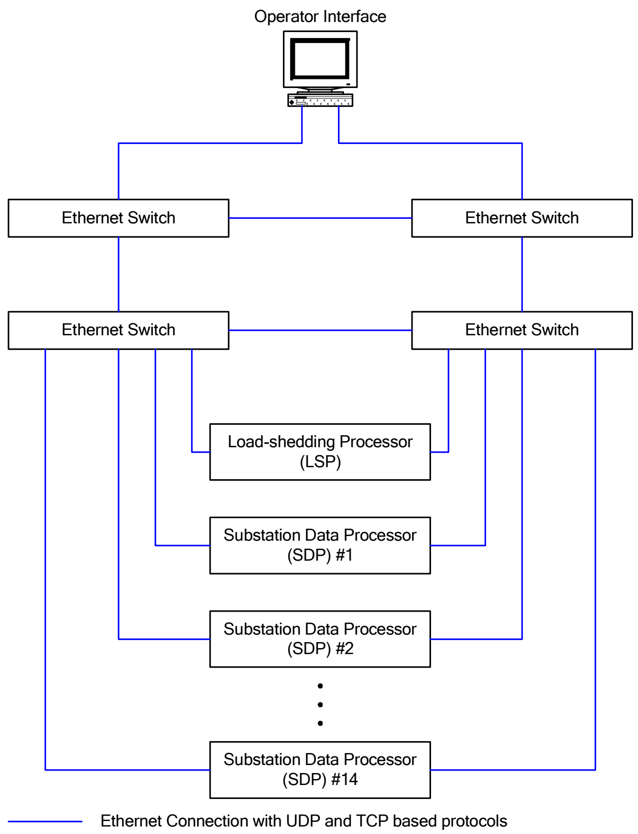

Fig. 5. Physical architecture between substations

The LAN consists of four rugged Ethernet switches connected in a ring topology using fiber-optic cables. Each processor in the system (LSP or SDP) has two Ethernet ports. Each port connects to a different Ethernet switch in the ring. The operator interface also has two Ethernet ports connected to different switches in the ring. With this network design, an Ethernet switch or cable can fail without affecting the ability of the system to exchange data.

IV. Contingency Details

A. Primary Contingencies

The primary scheme is based on the predicted power deficit that would be caused by a contingency. There are eleven (11) primary contingencies that may initiate load shedding:

- Generator 1 10 kV breaker trip
- Generator 1 20 kV breaker trip
- Generator 2 10 kV or 20 kV breaker trip
- Generator 3 10 kV breaker trip
- Generator 3 20 kV breaker trip
- Generator 4 10 kV breaker trip
- Generator 4 20 kV breaker trip
- Utility tie line 1 150 kV or 20 kV breaker trip
- Utility tie line 2 150 kV or 20 kV breaker trip
- 20 kV tie breaker trip (Bus A overloaded)
- 20 kV tie breaker trip (Bus B overloaded)

Two contingencies are used for each of generators 1, 3, and 4 because of the presence of tapped load between the 10 kV breaker and the 20 kV breaker for these generators. Although the remaining generation capacity will be the same for the two contingencies, the remaining load will be different. Referring to Fig. 6: if the 10 kV breaker trips, the system loses 10 MW of generation while the system load remains unchanged. However, if the 20 kV breaker trips, the system loses 10 MW of generation and 2 MW of load. Therefore, the amount of additional load that may need to be shed will be different and these two events must be considered different contingencies.

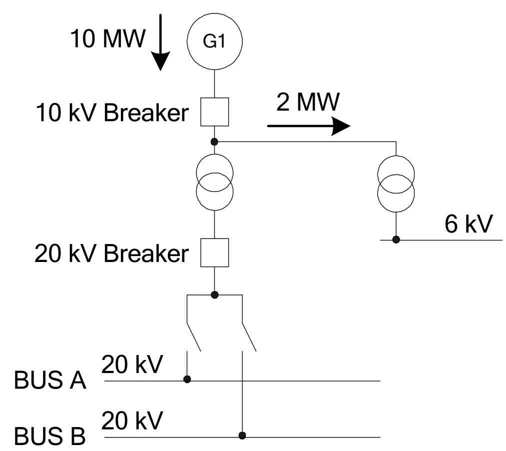

Fig. 6. Generator with tapped load

Generator 2 has one contingency that includes the 10 kV breaker trip or the 20 kV breaker trip. The load-shedding system considers both of these events to be a single contingency because the remaining capacity and the remaining load will be the same for both events.

Each utility tie line is also considered to be a single contingency. There is no load tapped between the 150 kV breaker and the 20 kV breaker. Therefore, the remaining capacity and the remaining load will be the same for both the 150 kV breaker trip and the 20 kV breaker trip events.

Depending on the configuration of the power system, power may transfer across the 20 kV tie breaker. Power may transfer from Bus A to Bus B or vice-versa. If the tie breaker trips, there will be no loss of generation. However, there may be a power deficit created on one of the two 20 kV buses. Fig. 7 illustrates a case where Bus B will experience a power deficit if the tie breaker trips.

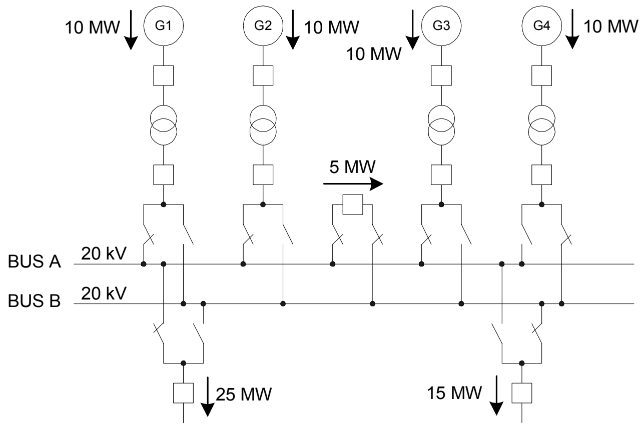

Fig. 7. 20 kV tie breaker trip (Bus B overloaded) contingency

In this example, generators 1, 2, and 3 are connected to Bus A with a total generating capacity of 30 MW. Generator 4 is connected to Bus B with a generating capacity of 10 MW. At the same time, 25 MW of load is connected to Bus A and 15 MW of load is connected to Bus B. With the tie breaker closed, 5 MW transfers from Bus A to Bus B to balance the generation with the load. In the event that the tie breaker trips, Bus A will have plenty of generation to support the 25 MW of load connected to Bus A. However, Bus B will have only 10 MW of generation to supply 15 MW of load. If no other capacity is available, Bus B will need to shed load to address this 5 MW deficit. For clarity in the programming of the load-shed processor, the 20 kV tie breaker trip contingency has been separated into two contingencies. One addresses the case where Bus A has a power deficit, and the other addresses the case where Bus B has a power deficit.

B. Secondary Contingencies

The secondary scheme is based on underfrequency thresholds. Each threshold corresponds to an amount of load that must trip before the power system can recover from the underfrequency condition. The secondary contingencies that can initiate load shedding are the following:

- Underfrequency level 1 detected on 20 kV Bus A
- Underfrequency level 2 detected on 20 kV Bus A
- Underfrequency level 1 detected on 20 kV Bus B
- Underfrequency level 2 detected on 20 kV Bus B

Power system simulation helped determine the actual amount of load required for each underfrequency level. The system operator can adjust these quantities based on operating experience.

V. Dynamic Load Selection

The solution must be very flexible to accommodate process survivability requirements. The load-shedding system performs a series of pre-event calculations to dynamically select a set of loads to be tripped for each contingency that can occur.

To determine the set of loads to trip, the load-shedding processor performs the basic algorithm shown in Fig. 8 every 2 seconds.

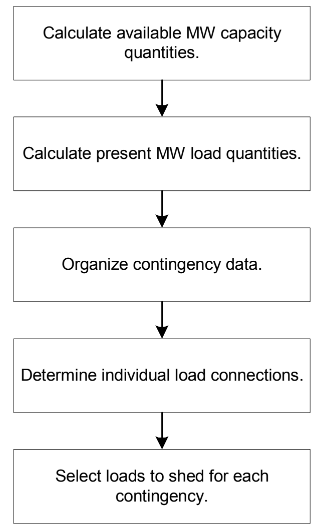

Fig. 8. Basic load selection algorithm

The following sections describe each step in the basic algorithm shown in Fig. 8.

A. Available Capacity Quantities

As Fig. 9 illustrates, the load-shedding processor (LSP) determines three available capacity quantities for use later in the algorithm: capacity connected to Bus A, capacity connected to Bus B, and total capacity connected to either bus.

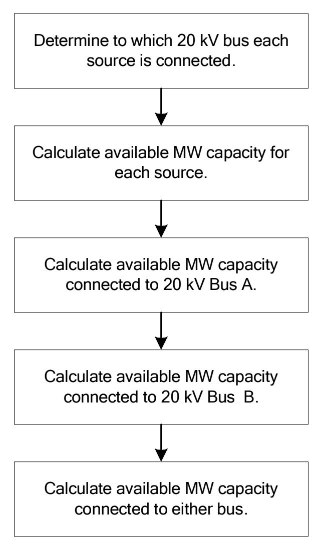

Fig. 9. Calculate available capacity quantities

The load-shedding processor (LSP) examines status inputs from the circuit breakers and disconnect switches to determine if each source is connected to Bus A or Bus B or offline.

Each source has a capacity that the source can provide on demand. For the utility tie lines, the available capacity quantity is manually entered at the operator interface. Typically, the capacity equals the rating of the transformer. The operator can enter a capacity larger than the transformer rating and allow the transformer to be overloaded to save the process. For generators the capacity is calculated based on a delta value entered at the operator interface. This parameter is the incremental amount of capacity that a generator can provide in the event that a contingency occurs. The load-shedding system adds this parameter to the present power output of the generator to obtain the available capacity of the generator.

The LSP examines each source in the system. If the source is online and connected to Bus A, the LSP will include the capacity of the source in the capacity connected to Bus A. If the source is connected to Bus B, the LSP will include the capacity of the source in the capacity connected to Bus B. The LSP then adds the Bus A capacity and the Bus B capacity to determine the total capacity of the system.

B. Present Load Quantities

As Fig. 10 illustrates, the LSP determines three load quantities for use later in the algorithm: load connected to Bus A, load connected to Bus B, and total load connected to either bus.

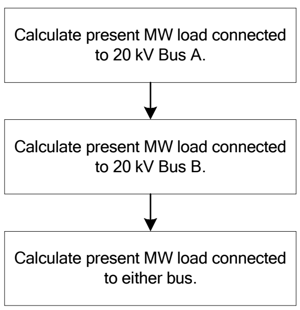

Fig. 10. Calculate present load quantities

The LSP calculates the load connected to each of the 20 kV buses based on the connected sources. At any moment, the total load on a bus equals the total MW going into the bus. The LSP examines each source in the system. If the source is online and connected to Bus A, the LSP includes the present output of the source in the load connected to Bus A. If the source is online and connected to Bus B the LSP includes the present output of the source in the load connected to Bus B. The LSP also examines the present power transfer across the 20 kV tie breaker. If the transfer is from Bus A to Bus B, the power transfer is added to the load connected to Bus B and subtracted from the load connected to Bus A. If the transfer is from Bus B to Bus A, then the power transfer is added to the load connected to Bus A and subtracted from the load connected to Bus B.

C. Contingency Data

The load-shedding system must predetermine the set of loads to shed for each possible contingency that can occur. The LSP organizes data in terms of the possible contingencies, illustrated in Fig. 11.

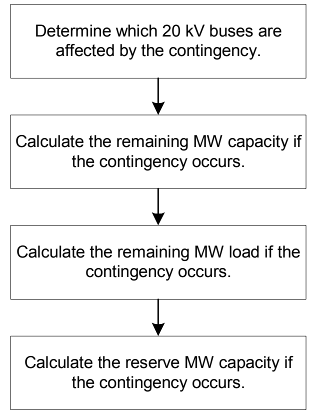

Fig. 11. Organize contingency data

Based on the status of each source in the system and the present state of the 20 kV tie breaker, the LSP determines which of the two buses each contingency will affect. For example, if Generator 1 is online and connected to Bus A and the 20 kV tie breaker is open, the 'Generator 1 10 kV breaker trip' contingency will affect Bus A and not Bus B. However, if the 20 kV tie breaker is closed, the same contingency will affect both Bus A and Bus B.

The LSP examines which buses are affected by each contingency and calculates the maximum capacity remaining for each contingency. For example, if the load-shedding system determines that the 'Generator 1 10 kV breaker trip' contingency affects Bus A and not Bus B, the capacity remaining for this contingency equals the capacity connected to Bus A minus the capacity of Generator 1.

The LSP examines which buses are affected by each contingency and calculates the load lost and the load remaining for each contingency. For example, if the load-shedding system determines that the 'Generator 1 20 kV breaker trip' contingency affects Bus A and not Bus B, the load remaining for this contingency is equal to the load connected to Bus A minus any load that will be lost if the 'Generator 1 20 kV breaker trip' contingency occurs.

The LSP then calculates the reserve for each contingency by subtracting remaining load from remaining capacity.

$$\text{Reserve}_{\text{Contingency}} = \text{Capacity}_{\text{Contingency}} - \text{Load}_{\text{Contingency}} \quad (1)$$

If the resulting reserve is positive, this contingency requires no load shedding. If the resulting reserve is negative, a power deficit will exist if this contingency occurs. In this case, the LSP selects enough loads to account for the deficit.

D. Individual Load Connections

To intelligently select loads to be shed in some circumstances, the LSP must determine which 20 kV bus feeds each sheddable load.

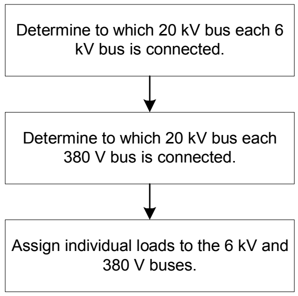

Fig. 12. Determine individual load connections

As Fig. 12 illustrates, the LSP examines the topology of the power distribution system to identify the 20 kV bus that feeds each load. Loads are connected to 6 kV and 380 V switchgear throughout the plant. Each of these lower voltage buses can be fed from one of two feeders. The load-shedding system collects and analyzes circuit breaker and disconnect switch statuses to determine the 20 kV bus to which each load connects.

Fig. 13 illustrates a typical connection of a motor load to the power distribution system. The switching devices between the 20 kV bus and the motor are labeled S1 through S14. There are eight possible paths that can connect the motor to a 20 kV bus.

- S1-S3-S4-S10-S11
- S2-S3-S4-S10-S11
- S1-S3-S4-S9-S12-S13-S14
- S2-S3-S4-S9-S12-S13-S14
- S5-S7-S8-S9-S10-S11
- S6-S7-S8-S9-S10-S11
- S5-S7-S8-S12-S13-S14
- S6-S7-S8-S12-S13-S14

The statuses of the switching devices are collected from protective relays throughout the system. The LSP then monitors communication with each relevant relay to determine whether the collected status is valid.

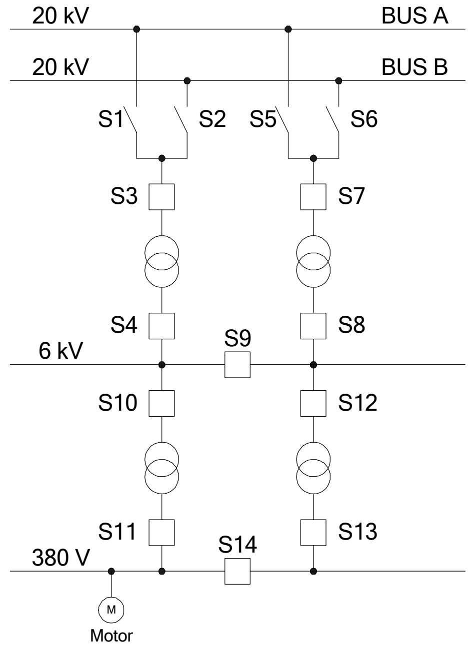

Fig. 13. Connection of a load to the 20 kV bus

The algorithm starts at the 20 kV bus and examines each switching device in series to identify the 20 kV bus supplying each of the lower-voltage buses. There are three possible results for each lower-voltage bus in the system:

- There is positive confirmation of which 20 kV bus is supplying power.
- It is not possible to determine which 20 kV bus is supplying power. This may be caused by relay communications failures.
- There is no positive confirmation of which 20 kV bus is supplying power. However, it is possible to infer a bus based on positive confirmation that the other bus is not supplying power.

The first two results are straightforward. The following example, based on the network in Fig. 13, illustrates the third result.

- S1, S3, S4, and S10 are confirmed to be closed.
- S2, S9, and S14 are confirmed to be open.
- S11 status is unknown because of relay communication failure.

In this case, there is no positive confirmation that 20 kV Bus A is supplying the 380 V bus with the motor load. However, there is positive confirmation that 20 kV Bus B is not supplying the load. Therefore, if the motor is running, then the LSP will infer that 20 kV Bus A is supplying the load.

E. Loads to Shed

The system operator assigns each sheddable load in the system a unique priority. These priorities reflect the relative importance of each load with respect to plant operation. The LSP examines each sheddable load in the system in order of priority. For each contingency, the LSP examines each load to determine whether it should include the load in a load-shed table. Fig. 14 illustrates the selection process.

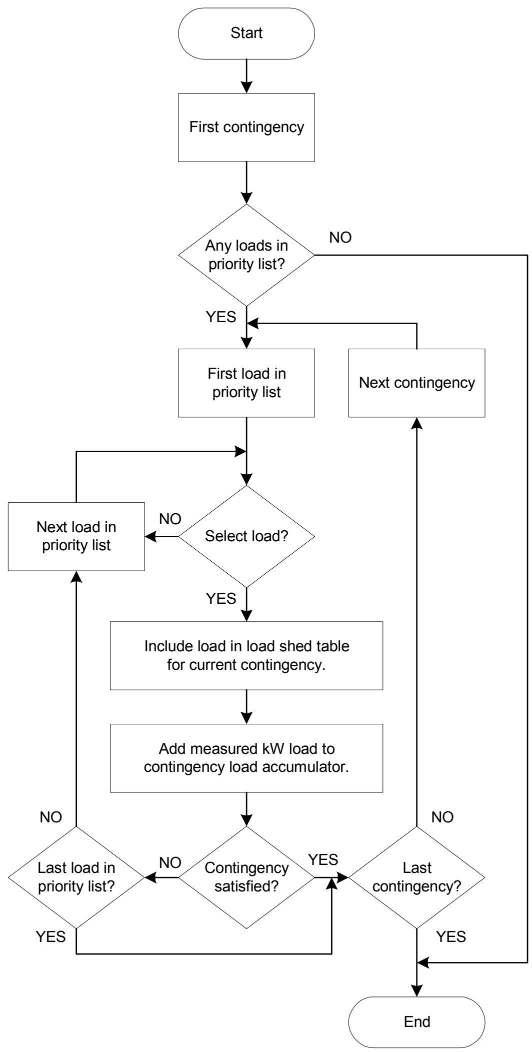

Fig. 14. Select loads to shed for each contingency

The LSP excludes a load from the selection process for any of the following reasons.

- The communication channel used to trip the load is not healthy.
- The communication channel used to collect kW measurements for the load is not healthy.
- The communications between the LSP and any of the three protection logic processors is not healthy.
- The kW measurement for the load is out of range.
- The 20 kV tie breaker is open and the LSP cannot determine which 20 kV bus is supplying power to the load.
- The contingency being processed involves the 20 kV tie breaker, and the LSP cannot determine which 20 kV bus is supplying power.

The following criteria must be met before the LSP includes a load in a load-shed table.

- The load has not been excluded.
- The load is connected to a 20 kV bus that is affected by the contingency being processed.
- Not enough loads have been selected to offset the power deficit calculated for the contingency being processed.

The LSP accumulates the amount of load selected for each contingency. The actual power measured for each individual load is used in the accumulation. Once the amount of load selected is greater than or equal to the calculated power deficit, the contingency is satisfied and the LSP stops selecting loads for this contingency. The LSP continues the load selection process until all contingencies are satisfied or there are no more sheddable loads available to select. The LSP organizes the results of this process into three load-shedding tables and writes these table values to the crosspoint switches in the three protection logic processors.

VI. Crosspoint Switch

The protection logic processor quickly responds to contingency triggers to shed load. The logic processor receives contingency triggers via Mirrored Bits communications links on fiber-optic connections from remote I/O modules. The logic processor combines the received contingency triggers with information contained in the crosspoint switch matrix to determine which loads to shed. The logic processor then delivers load shed signals to the remote I/O modules, again using Mirrored Bits communications links and fiber optics.

The crosspoint switch uses simple rules to combine received contingency triggers and the load-shedding table present in the crosspoint switch matrix to generate load-shedding signals. As shown in Fig. 15, each row of the matrix corresponds to a contingency trigger. Each column corresponds to a load-shedding signal. If a contingency trigger occurs, the crosspoint switch asserts all load-shed signals with a "1" in that contingency trigger row.

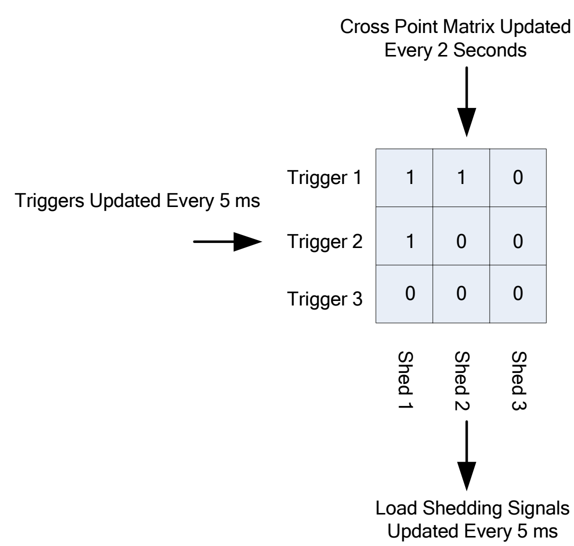

Fig. 15. Example 3x3 Cross Point Switch Matrix

Using the example matrix shown in Fig. 15, when Trigger 1 occurs, signals Shed 1 and Shed 2 are generated. When Trigger 2 occurs, only Shed 1 generates. Shed 3 never generates using this example matrix, indicating that the present system configuration will never cause shedding of load 3. The load-shedding processor updates the matrix every 2 seconds based on the new load-shedding table.

The example matrix in Fig. 15 contains only three triggers (rows) and three load-shedding signals (columns) for clarity. The actual crosspoint matrix has 32 triggers and as many as 120 load-shedding signals. The load-shedding processor downloads a unique crosspoint matrix to each of the three logic processors shown in Fig. 3. The load-shedding signals directly control transmit MIRRORED BITS communications on as many as 15 ports of the logic processor. Some of the load-shedding signals carry contingency triggers and other status information to the other two logic processors. Most of the load-shedding signals travel to Remote I/O Modules, which control circuit breakers or motor contactors to shed load.

VII. High-Speed Load Shedding

The solution must be high speed to accommodate the requirements for maintaining power system stability. The load-shedding system addresses the high-speed requirement through the use of logic processors and a communications protocol typically used to implement protection-related schemes.

The logic processors include the crosspoint switch features that accept the load-shedding table from the load-shedding processor. The logic processors perform all of the necessary processing to detect the contingency trigger signals, perform logic functions, and output the desired load-shedding signals according to the present contents of the crosspoint switch.

The speed at which a load-shedding event action occurs depends on the following delays:

- Input and output processing in the remote I/O modules
- Signal propagation between the remote I/O module and the logic processor
- Signal propagation between logic processors
- Program execution time of the logic processors

The worst-case total system delay occurs when the contingency trigger must pass through all three logic processors. Table 1 summarizes the delay times.

Table 1: Event Action Delay Times

Task	Delay (ms)
Input processing in remote I/O module	4
Propagation from remote I/O module to logic processor #1 (Two consecutive messages required for security)	8
Program execution in logic processor #1	10
Propagation from logic processor #1 to logic processor #2	4
Program execution in logic processor #2	10
Propagation from logic processor #2 to logic processor #3	4
Program execution in logic processor #3	10
Propagation from logic processor #3 to remote I/O module (Two consecutive messages required for security)	8
Output processing in remote I/O module	4
Total end-to-end	62

This case was tested and found to be 62 ms, well under the 80 ms requirement for the example project.

VIII. Supporting Functions

In addition to the load-shedding contingency processing, the logic processors provide the following support functions in the load-shedding system:

- Primary scheme enable/disable
- Secondary scheme enable/disable
- Load-shedding signal latching
- Load-shedding system reset
- Communications supervision with the LSP, I/O modules, and adjacent logic processors
- Load shedding in progress blocking

The operator interface provides the ability to enable and disable primary and secondary schemes. If a logic processor detects a communications problem with the LSP, it immediately disables both the primary and secondary schemes. Each LSP monitors the load-shed scheme enable status from adjacent logic processors to ensure that all three logic processors agree that the system is enabled. If they are not in agreement, the scheme is immediately disabled. Additionally, the scheme is immediately disabled if the communications channel between adjacent logic processors fails.

When a contingency triggers, the contents of the crosspoint switch are sent to the protection communications channels to shed the preselected loads. Each channel latches to prevent restarting of the affected loads until the operator resets the load-shedding system.

The operator can reset the load-shedding system through the operator interface. The LSP receives the reset command from the operator interface and forwards this command to all three logic processors. Each logic processor then forwards the reset command to the adjacent logic processors. This allows the system to reset in the case that one or two of the logic processors are not communicating with the LSP.

When a power system event occurs, the power system needs time to stabilize. Additionally, there is a finite period of time necessary for the LSP to update. Therefore, the logic processors block all subsequent primary load-shedding triggers for 60 seconds after a primary contingency trigger to allow the system to stabilize and new measurements to become available. The LSP blocks recalculation of the crosspoint switch for 60 seconds after any contingency trigger to avoid erroneous load selections.

IX. Conclusions

Load-shedding strategies for the industrial plant environment must address both power system stability and process survivability concerns. Process survivability requires dynamic load selection. Power system stability requires high-speed load shedding. These distinct requirements can be addressed separately using technology that best fits each purpose. The crosspoint switch allows the two technologies to exchange the necessary data in an efficient format. With this approach, load selection algorithms can be quickly implemented in the LSP to populate the crosspoint switch for a wide range of criteria.

X. Biographies

Will Allen received the BSc. degree in electrical engineering from the University of Alberta in 1993. He has experience in the fields of industrial control systems and power system automation. He joined Schweitzer Engineering Laboratories in 2000 as an Automation Engineer and currently serves as an Integration Application Engineer. He is a member of the IEEE and a professional engineer in the province of Alberta and the state of Washington.

Tony J. Lee received his B.S. degree in electrical engineering from Washington State University in 1987. Mr. Lee then worked for Texas Instruments in Dallas, Texas from 1987 through 1991, when he joined Schweitzer Engineering Laboratories, Inc. as a hardware design engineer. He presently holds the position of Principal Systems Engineer at SEL. Mr. Lee holds three U.S. patents and several foreign patents regarding arc suppression and has several patents in process.

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