

Implementing an Intelligent Steam and Electrical Load-Shedding System for a Large Paper Mill: Design and Validation Using Dynamic Simulations

Siddharth Rajan, Payal Gupta, Srikar Malladi, and Prasanna Muralimanohar
Schweitzer Engineering Laboratories, Inc.

Guenther Strunk
International Paper Company

© 2019 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other uses, in any current or future media, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works, for resale or redistribution to servers or lists, or reuse of any copyrighted component of this work in other works.

This paper was presented at the IEEE Pulp, Paper and Forest Industries Technical Conference, Jacksonville, Florida, June 23–28, 2019.

IMPLEMENTING AN INTELLIGENT STEAM AND ELECTRICAL LOAD-SHEDDING SYSTEM FOR A LARGE PAPER MILL: DESIGN AND VALIDATION USING DYNAMIC SIMULATIONS

Siddharth Rajan
Member, IEEE
Schweitzer
Engineering
Laboratories, Inc.
2350 NE Hopkins
Court
Pullman, WA 99163
USA

Guenther Strunk
Member, IEEE
International Paper
Company
Valliant Mill
890 IP Lane
Valliant, OK 74764
USA

Payal Gupta
Member, IEEE
Schweitzer
Engineering
Laboratories, Inc.
2350 NE Hopkins
Court
Pullman, WA 99163
USA

Srikar Malladi
Member, IEEE
Schweitzer
Engineering
Laboratories, Inc.
2350 NE Hopkins
Court
Pullman, WA 99163
USA

Prasanna
Muralimanohar
Member, IEEE
Schweitzer
Engineering
Laboratories, Inc.
2350 NE Hopkins
Court
Pullman, WA 99163
USA

Abstract - An intelligent load-shedding system (ILSS) was designed and implemented in a paper mill to ensure power system stability after the steam turbine generator transitions from back-pressure operating mode to isochronous mode upon loss of the electric grid. The innovative approach taken to validate and optimize the operation of the system in a closed-loop environment by using dynamic simulation is presented. Modeling of the double-extraction steam turbine representing real-time processes was performed. The purposes for implementation of the ILSS were to maintain safe operating conditions and increase the reliability of the mill while minimizing operating costs and capital losses during unplanned events.

Index Terms - Load shedding, dynamic simulator, steam turbine modeling, back-pressure mode, header pressure.

I. INTRODUCTION

Optimal steam utilization is vital to meet the operating process requirements and electrical loads of a paper mill in the state of Oklahoma. Process control alone is inadequate to stabilize the system when a major event occurs. An intelligent load-shedding system (ILSS) was designed and implemented in this paper mill to ensure the stability of all steam headers and loads during unplanned events while maintaining safe operating conditions and avoiding a mill blackout.

This paper contains an explanation of the ILSS operation, with an emphasis on the ability of the ILSS to accommodate various mill power system topologies. Modeling of the double-extraction steam turbine, steam header, and associated loads is presented, in addition to the hardware-in-the-loop testing technique used to validate the ILSS. The ILSS offers a flexible, user-configurable solution that accurately determines the loads to shed on different steam headers during frequency excursions and predetermined contingencies.

II. MILL OVERVIEW

The electric power system of the paper mill, shown in Fig. 1, consists of a 13.8 kV distribution system that is connected to four 138 kV/13.8 kV utility power company-owned 30 MVA transformers (T1, T2, T3, and T4). The paper mill includes a noncondensing 68 MVA steam turbine generator (STG). The turbine serves both the steam and electrical loads that are present in the paper mill.

The paper mill normally runs with two of the utility transformers (T1 and T2) in parallel with the 68 MVA generator. They are interconnected through a synchronizing bus and reactors. The load buses (A, B1, B2, and E) are normally supplied with power from these two sources. Two other utility transformers (T3 and T4), running in parallel (isolated from T1 and T2), supply power to the load buses B3 and G. If the generator is out of service, the two systems can be tied together by closing the tie breaker. Capacitors installed in the generator buses help in alleviating low-voltage issues on the generator bus when the generator is out of service.

The mill normally operates with all four utility tie breakers closed (B-T1, B-T2, B-T3, and B-T4) and the STG running in parallel with the utility. When the utility breakers are closed, the STG operates in a back-pressure mode. In this mode, the STG load is proportional to the steam load in the plant. The mill consists of two types of loads: steam and electrical (S & E) loads and pure electrical loads. Three paper machines and three digesters in the pulp mill are the primary steam loads of the paper mill.

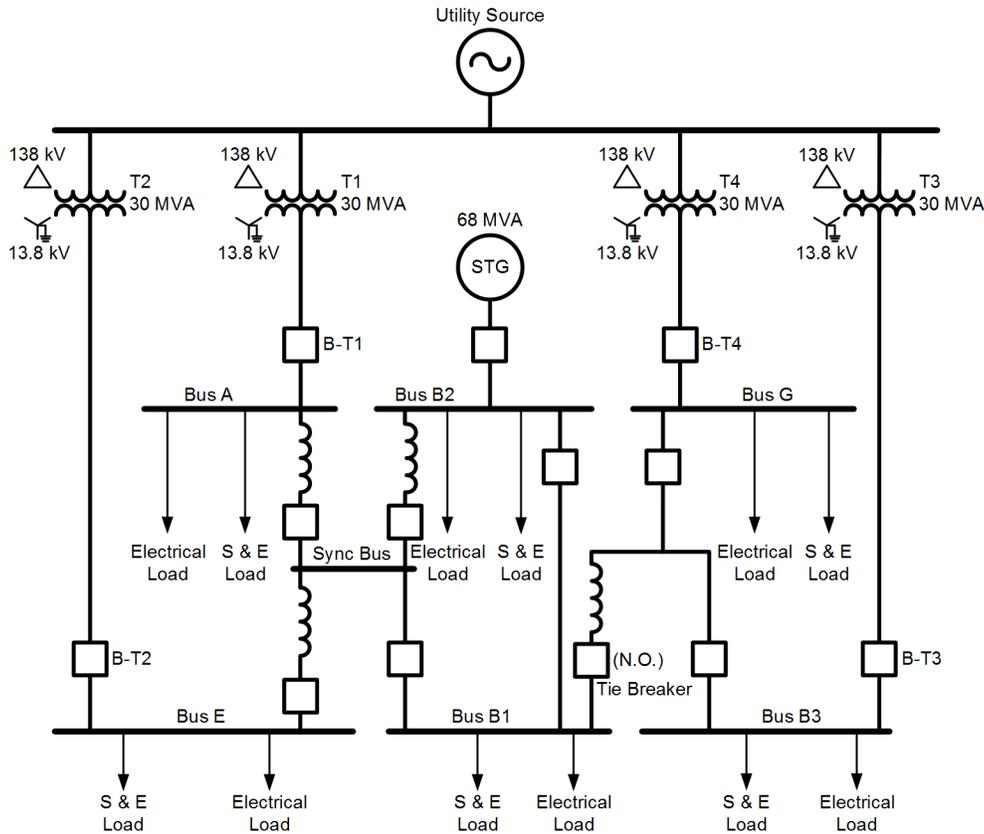


Fig. 1 Mill Electric Power System Overview

III. STEAM TURBINE GENERATOR OPERATION

The STG in this study is an automatic double-extraction, noncondensing type with controlled extractions at 600 pounds per square inch (psi) and 200 psi, and exhaust at 65 psi. Because the STG is a noncondensing type, there are no external condensers in the plant for steam recovery. The 600 psi level is referred to as high-pressure (HP) extraction, the 200 psi level is referred to as low-pressure (LP) extraction, and the 65 psi level is the exhaust level. At each stage, the steam is extracted and used for the processes that are treated as steam and electrical loads [1].

The turbine action is predominantly based on disturbances in header pressures and turbine speed. The differential pressure between the headers helps to produce power as the steam flows across the turbine. The turbine control is accomplished with valve action, which results in either increasing or decreasing the steam flow in the headers. The turbine consists of three control valves: V1, V2, and V3. Control Valve V1 is the main inlet valve, which interfaces between the 1,300 psi and 600 psi (HP) levels. Control Valve V2 interfaces between the 600 psi (HP) and 200 psi (LP) levels, and Control Valve V3 interfaces between the 200 psi (LP) and 65 psi (exhaust) levels (see Fig. 2). A change in steam processes can lead to an increase or decrease in the extraction pressure. If the header pressure

increases, the extraction valves and/or turbine control valves adjust to admit more steam into the next stage of the turbine, which increases the electrical power output of the machine. If the header pressure decreases, then the extraction valves and/or turbine control valves adjust to increase the pressure at the extraction header.

The maximum active power (MW) produced by the generator is limited by the maximum torque on the shaft, which is generated by the steam flow. The steam flow rate through the turbine is, in turn, determined by the amount of steam load in the system. Therefore, when connected to the utility, the generator MW output is determined by the steam loads on the system. The maximum power that can be generated by the STG is also defined by the steam envelope of the turbine. The types of loads in the paper mill are:

1. Steam and electrical loads. These loads consume both steam and electric power for operation. When the load is offline (disconnected), the load does not consume steam, which causes the governor to open the corresponding control valve to admit more steam to the next section, thereby maintaining header pressure in the concerned section.
2. Pure electrical loads. These loads consume only electric power for operation; they do not consume steam. These loads can be shed without any impact to steam processes.

Turbine control is performed by the automatic extraction control (AEC) module. This module considers the steam and electrical requirements of the loads in the system and provides a feedback loop based on the changes occurring in the system. The module issues command signals that enable valve correction based on pressure or speed changes in the system. The V1_POS, V2_POS, and V3_POS signals in Fig. 2 represent the initial valve positions sent to the AEC module. When a disturbance such as loss of steam load or loss of utility occurs, the AEC module maintains the system stability by correcting the valve positions. The V1_OUT, V2_OUT, and V3_OUT signals in Fig. 2 represent the feedback signals sent from the AEC module to adjust the valve positions.

The AEC module compares the real-time pressure with the reference set point in each header, as shown in Fig. 3. In case of a disturbance, the pressure in each header varies, which triggers a corrective action to regulate the steam flow. The valve positions adjust to either increase or decrease the steam flow through the headers, thereby ensuring that the pressure at each header is maintained. In back-pressure mode, when there is a disturbance in the exhaust header the V3 valve position is immediately corrected. This has a cascading effect and triggers the correction of the V2 valve position, followed by the V1 valve position. The turbine is most sensitive to a disturbance at the exhaust level. The extraction flow rates at each header are determined by the amount of

active steam load in the respective header. The maximum power output of the generator is determined by the steam flow in the headers and the MW limit of the generator.

The turbine operates in two modes: back-pressure mode and isochronous mode. The AEC module corrective actions are based on the mode of operation for the turbine. Fig. 3 illustrates the AEC module control parameters.

A. Back-Pressure Mode

The back-pressure mode is the normal and preferred mode of operation when the utility is connected to the paper mill. The speed of the turbine is maintained by the frequency at the utility. In this mode, maintaining the header pressure at desired levels is the priority for governor control. The torque input to the generator from the turbine is based on the steam flow available in each of the headers and the associated valve actions. An increase in steam flow through the headers typically increases the torque output from the governor, and a decrease in steam flow reduces the torque output. When the utility is connected to the mill, the generator is always loaded to its optimum capacity, as determined by the steam process. In this mode of operation, the priority of operation is as follows:

- Exhaust pressure control > LP extraction pressure control >
- HP extraction pressure control

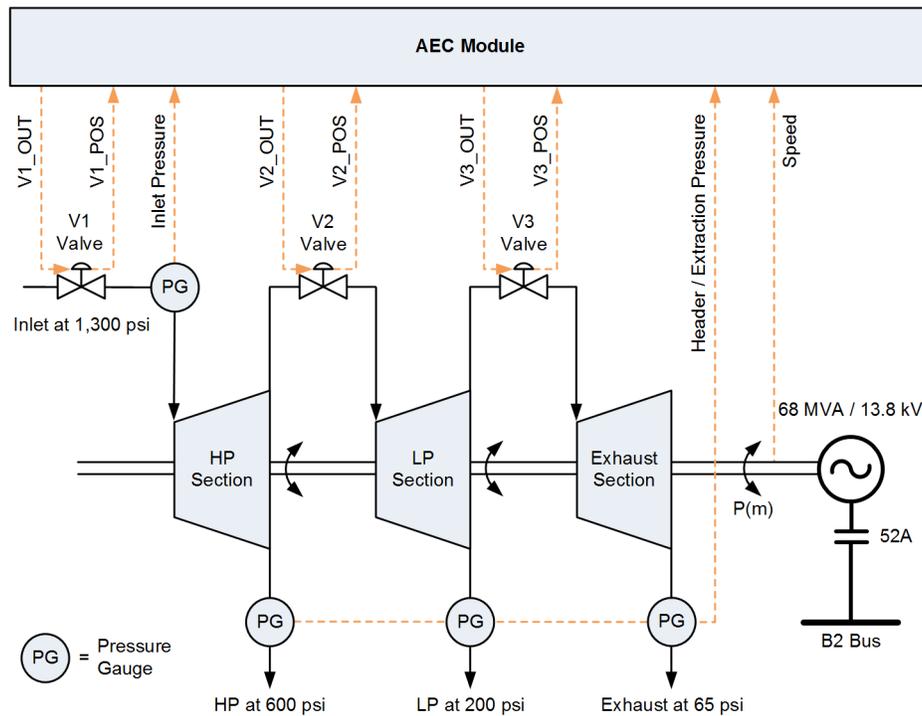


Fig. 2 Double-Extraction STG

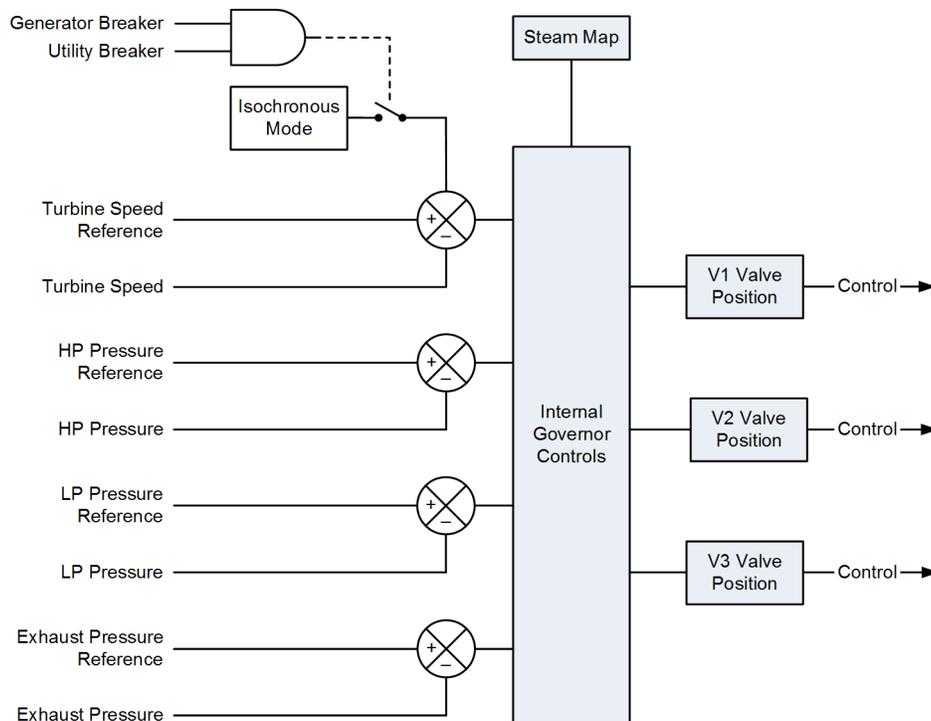


Fig. 3 AEC Module Controls

B. Isochronous Mode

The isochronous mode of operation is preferred when the utility connection is lost and the electrical and steam loads depend on the output of the STG. In this mode, the turbine is focused on speed control. Maintaining the frequency of the plant close to 60 Hz is the priority. The valve operations are based on the speed control required by the turbine, which eventually takes care of the electrical and steam loads. The governor does not perform exhaust pressure control in this mode. The priority of operation is as follows:

Speed control > HP extraction pressure control >
LP extraction pressure control

IV. NEED FOR AN INTELLIGENT LOAD-SHEDDING SYSTEM

In the event that utility power is lost, the STG is the only power source for the mill. Historically, during these events the STG tripped offline due to an overload, underfrequency, or overfrequency condition. The system was unable to sustain reliable STG and powerhouse operations long enough to recover, even during a short-term utility power loss. This caused boilers, and water and air supplies to shut down, leading to a total mill blackout and making recovery to normal operations labor-intensive, costly, and time-consuming. The hardwired scheme provided rudimentary separation from the power grid; therefore, it did not provide the flexibility of load selection and optimized load shed required to ensure continued power to essential mill areas, nor did it ensure an appropriate balance of steam for the STG operation. An ILSS

was needed for this paper mill to provide reliable STG operation and prevent a mill blackout during a loss of utility.

The STG operation depends heavily on steam use in the mill, primarily by the three paper machines and three digesters, which also represent large electrical loads. The mill is unable to operate its paper machines and digesters without utility power. The loss of utility leads to the following problems regarding the mill operation:

1. The generator MW is limited by the steam loads on the system. After the utility is lost, the amount of electrical load needs to be equal to the generator MW. Any mismatch will make the system unstable and hence, may result in tripping the STG, causing a complete mill blackout. With the ILSS, the power deficit is mitigated by shedding the additional loads.
2. Upon loss of utility, it is crucial to keep certain essential loads in the mill running with the STG as the only source. Power interruption to these essential loads can result in a complete mill blackout, requiring an enormous amount of time and effort to bring these loads back online. Setting the load-shed priorities in the ILSS, allows only non-essential loads to be shed during an event and critical loads can continue without disruption.
3. During a loss of utility, isolation of the generator Buses B1 and B2 typically requires venting steam or shedding steam loads to stabilize the boilers and prevent the turbine from over speeding. With the ILSS, this limitation is mitigated by shedding loads that use a large amount of steam.

V. INTELLIGENT LOAD-SHED SYSTEM DESIGN

Upon a loss of utility, the utility tie breakers (B-T1, B-T2, B-T3, and B-T4 in Fig. 1) are opened by a combination of a communications-based direct transfer tripping scheme [2] and a protective relay-based rate-of-change-of-frequency scheme [3]. Upon decoupling the electric power system of the mill from the utility, the generator mode is switched to isochronous to maintain turbine speed and system frequency at 60 Hz. In this mode of operation, the generator is the only power source available for electrical loads in the mill. The load-shedding scheme is supervised by the isochronous mode status of the STG.

A. Design Considerations

The ILSS was designed to accommodate different power system topologies at the mill because process requirements vary. The ILSS allows a different set of loads to be shed based on a user-defined, unique load priority. The priority of the sheddable loads is entered via a human-machine interface (HMI). The user can define critical loads as “inhibit/do not shed,” which allows these loads to be excluded by the load-shed algorithm.

A single paper machine comprises multiple loads connected to different buses. If a single load associated with a paper machine is selected for shedding by the ILSS, all other loads associated with that paper machine are automatically selected to be shed. This is to make certain that the entire paper machine is tripped as one load group. To accomplish this, the loads of a single paper machine are grouped together, such that the user-defined priorities for the paper machine are automatically sorted by the ILSS.

The event triggers received by the ILSS and trip signals sent from the ILSS are propagated through a front-end processor (FEP) with a high-speed protocol (IEC 61850), allowing the ILSS to respond almost instantaneously to an event. For scheme security, all incoming data to the ILSS (such as breaker statuses, inputs, and metering values) are continually supervised by a communications-failure signal to prevent the load-shed algorithm from acting based on a bad-quality signal.

The ILSS comprises three algorithms running in parallel to maintain power system stability at the mill during a major electrical event. The algorithms run on a dedicated programmable logic controller (PLC) that has a 4-millisecond processing interval.

B. Contingency Algorithm

The contingency load-shed algorithm sheds loads based on a predicted power deficit when a contingency (loss of utility) occurs. The algorithm predetermines what loads to shed for every defined contingency. The algorithm takes into consideration the user-defined load priority, topology of the

system, user inputs from the HMI, and the generator mode of operation. To prevent shedding of an excessive amount of load in response to a contingency, the load-shed algorithm considers the pre-event MW value of the generator. It selects loads to shed from the top of the priority list and continues to move to the next load on the list until the required load to shed for a contingency has been met or all available loads have been selected.

The contingency load-shed algorithm runs these calculations continuously during the normal operation of the paper mill. This enables the user to see the power deficit for the current system configuration and the proposed actions by the PLC before any actual event occurs, thereby allowing the user to maintain operations (by adjusting load priorities) and prevent a mill blackout. Also, the mitigation action is faster because there is no post-event calculation delay and triggers are sent out immediately. This algorithm operates only under loss-of-utility conditions.

C. Underfrequency Algorithm

The underfrequency algorithm serves as a backup for the contingency algorithm in scenarios where a utility breaker opens without sending a trigger to the contingency algorithm. Such a scenario occurs when wires break, are removed, or are damaged. The underfrequency load-shed algorithm also operates if actions taken by the contingency load-shed algorithm is insufficient to stabilize the system. This scheme acts as a “last chance” filter to prevent human error. If multiple underfrequency triggers are received simultaneously, the algorithm acts only on the first. Subsequent underfrequency triggers are blocked for a specific time interval. This prevents the scheme from overshedding the loads. The underfrequency algorithm uses the same load priority inputs and power system topology as the contingency algorithm. This algorithm also operates only under loss-of-utility conditions.

D. Transformer Cable Overload Algorithm

The transformer cable overload algorithm is programmed to operate only when the utility is connected to the mill power system. When the STG is running at a constant torque and is loaded to optimum capacity, it will reject any additional load change and the additional load will be transferred to the utility tie transformers. In such scenarios, if one of the utility transformers trips or becomes unavailable, the other transformers can potentially become overloaded. The transformer cable overload algorithm detects the overloaded transformer and mitigates the cable overload condition, saving the crucial cable from damage. The transformer cable overload algorithm uses the same load priority inputs and power system topology as the contingency algorithm.

All three ILSS algorithms are illustrated in the flowchart shown in Fig. 4.

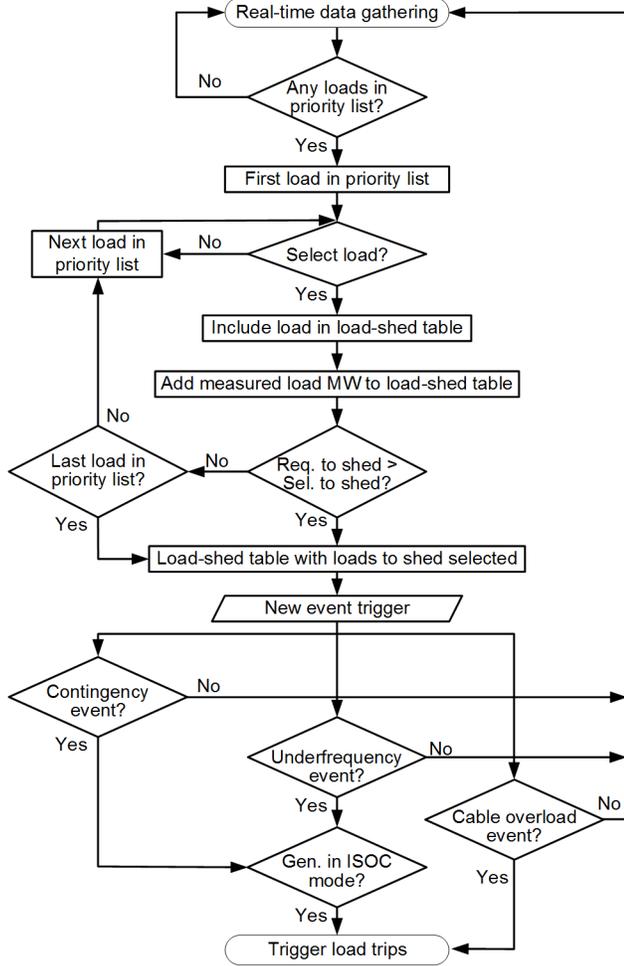


Fig. 4 ILSS Flowchart

E. ILSS Sequence of Operation

It is essential for the ILSS to be high-speed to maintain power system stability. This requirement is addressed by using high-speed communications protocols (IEC 61850 Generic Object-Oriented Substation Event [GOOSE] and Network Global Variable Lists [NGVLs]) and a 4-millisecond processing interval for the PLC. The total round-trip time between contingency detection and the load breakers opening depends on the following delays:

1. Protective relay internal processing time
2. Protective relay event detection time
3. Input and output debounce time
4. Automation controller internal processing time
5. Ethernet packet latency
6. Breaker operating time

Table I shows the typical and worst-case time delays for each operation.

TABLE I
ILSS SEQUENCE OF OPERATION

ILSS Sequence of Operation	Typical Time Delay (ms)	Worst-Case Time Delay (ms)
Protective relay event detection time	4	8
Protective relay pickup delay	100	100
Protective relay output debounce time	4	8
Utility tie breaker operation time (5 cycle)	80	80
STG ISOC mode transition time	< 8	< 16
Communications latency from relay to FEP	< 4	< 8
FEP event trigger update	4	8
Communications latency from FEP to PLC	< 4	< 4
PLC event trigger update and sheddable-load trips	4	8
Communications latency from PLC to FEP	< 4	< 4
FEP sheddable-load trips update	4	8
Communications latency from FEP to I/O module	< 4	< 8
I/O module sheddable-load trips update	4	8
I/O module output debounce	4	8
Load breaker opening time (5 cycle)	80	80
Total ILSS round-trip time	< 312	< 356
ILSS round-trip time without breaker operating time	< 152	< 196

VI. DATA REQUIRED FOR MODELING

A. Mill Electrical and Steam Loads Interaction

An understanding of the electrical power distribution for the mill and the mill steam use is the first step in associating the electrical loads and steam loads. This understanding helps to interpret the impact of losing an electrical load on the steam control system. The electrical one-line drawing and the mill piping and instrumentation diagram were used to understand the correlation between electrical and steam loads. The objective was to identify the number of steam users on each pressure header and the impact on the steam system from the loss of each electrical load.

B. Model of Mill Electrical System

An existing power system model of the mill was used to validate the dynamic model of the steam and electrical system. The results from power flow and short-circuit studies of the existing power system model were also compared to those of the dynamic model.

C. Data From Mill Operations

Periodic machine break (field) data were useful in validating the dynamic model of the steam and electrical system. Similar machine breaks can be simulated in the dynamic model, allowing the response of the governor and its impact on the steam headers and generator power to be compared to the field data. Historic header pressure data, steam flow rates, and power flow data from mill operations were also used to verify the dynamic model. The mill is fed from the same utility line and verifying power flow from historical data ensures that the load distribution across the mill is consistent with the results from the dynamic model.

D. Steam Turbine Generator Control System Parameters

Another key component in the dynamic modeling effort was to use the correct STG governor control parameters. Data from the STG manufacturer were used, including design parameters, data from factory testing, load acceptance and rejection test results, and a functional diagram of the governor control system [4]. While it is recommended to get actual design parameters, in the absence of these, traditional IEEE governor models can be used, depending on the application. Regardless of which parameters are used, it is critical to validate the response of the dynamic model with the actual field data.

E. Additional Steam and Pressure Control Mechanisms

It is typical in extraction-type STGs to have pressure relieving control mechanisms (pressure relieving valves and other PLC-based pressure control systems) in place in addition to the STG control system. A functional understanding of these control mechanisms is necessary to model the dynamic characteristics of the STG. In most cases, these mechanisms are in place for header pressure maintenance and safety. It is important to understand when these control mechanisms will act, the speed of the action, and if the action will interfere with the governor control actions.

VII. DYNAMIC MODELING

The power system for the paper mill was modeled in a real-time dynamic simulator. Part of the AEC module was modeled in the real-time dynamic simulator and the other part was modeled in a real-time automation controller. The dynamic simulator and automation controller communicated with each other every 4 milliseconds using IEC 61850 GOOSE protocol. This ensured that the control system, as well as the power system, was continuously updated in real time.

The flow conditions and valve positions were initialized in the dynamic simulator and sent to the automation controller. Initially, there was no disturbance in the system and the header pressures were at equilibrium; therefore, no corrections were necessary. Once a disturbance was introduced in any of the headers in the dynamic simulator, the pressure equilibrium was lost and the data were sent to the automation controller. The automation controller computed correction factors based on the dynamic simulator input and sent them back to the dynamic simulator to enable valve correction. This correction process took place continuously until a pressure equilibrium was reached in all headers. Because of the valve corrections, there was a change in the steam flow across the headers, represented as delta flows in Fig. 5, and the power generated by the STG also changed. Fig. 5 shows the various parameters that were exchanged between the dynamic simulator and the automation controller.

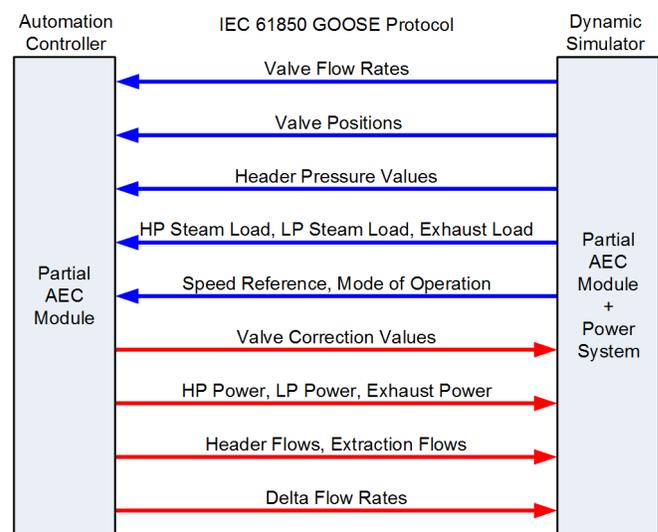


Fig. 5 Power and Control System Modeling

VIII. ILSS VALIDATION

The ILSS was tested and validated extensively by performing hardware-in-the-loop tests. These tests were implemented by connecting the dedicated PLC with the real-time dynamic simulator. Various power system scenarios were created in the dynamic simulator and actions taken by the ILSS for an unplanned utility loss were validated for each system configuration. The stability of the power system was verified by recording the frequency and header pressure values in the dynamic simulator for each configuration. The real power, system frequency, and header pressure (HP and LP) after the ILSS operation are shown in Fig. 6, Fig. 7, Fig. 8, and Fig. 9. Note that the power system stabilized after the ILSS operation. Because of the slow nature of steam processes, the steam loads can take hours to completely shed. Hence, the system parameters were recorded in the real-time dynamic simulator for several hours.

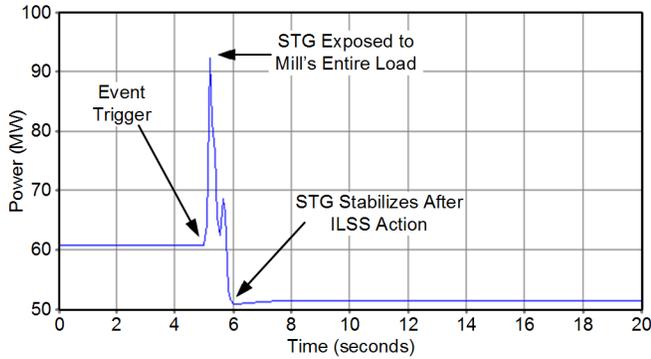


Fig. 6 STG Real Power After ILSS Operation

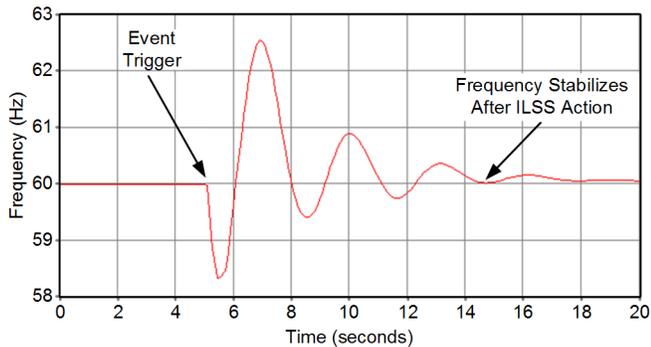


Fig. 7 System Frequency After ILSS Operation

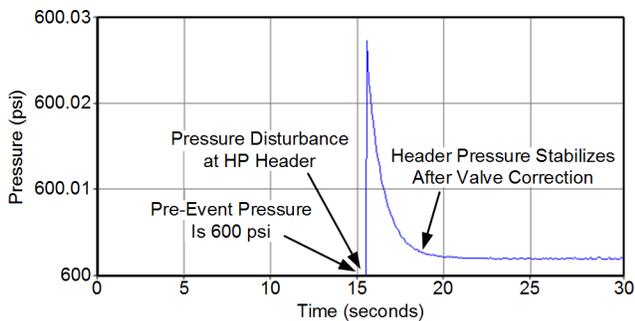


Fig. 8 HP Header Pressure After ILSS Operation

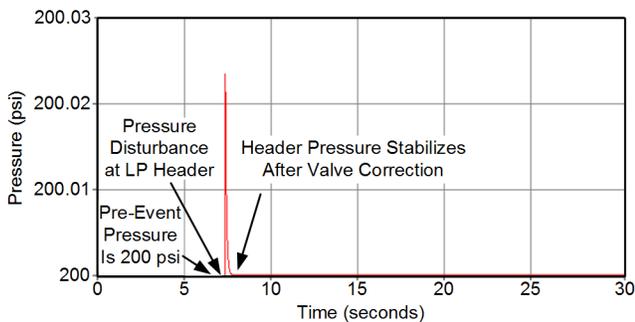


Fig. 9 LP Header Pressure After ILSS Operation

IX. CONCLUSIONS

The ILSS is a reliable, flexible, user-configurable solution that accurately determines the loads to shed during unplanned events and ensures power system stability following a disturbance. Because the ILSS contingency actions are precalculated before an event occurs, the ILSS is a high-speed solution. The loads selected to shed are available to the user, thereby enabling the user to modify the load priorities to sustain critical mill processes and schedules and avoid a blackout. The ILSS will significantly increase the reliability of the mill, while minimizing the operating costs and capital losses due to unplanned events.

X. REFERENCES

- [1] S. Manson, M. Checksfield, P. Duffield, and A. Khatib, "Case Study: Simultaneous Optimization of Electrical Grid Stability and Steam Production," proceedings of the 61st Annual Petroleum and Chemical Industry Technical Conference, San Francisco, CA, September 2014.
- [2] IEEE 1547-2018, IEEE Standard for Interconnection and Interoperability of Distributed Energy Resources With Associated Electric Power Systems Interfaces.
- [3] K. G. Ravikumar, A. Upreti, and A. Nagarajan, "State-of-the-Art Islanding Detection and Decoupling Systems for Utility and Industrial Power Systems," proceedings of the 69th Annual Georgia Tech Protective Relaying Conference, Atlanta, GA, April 2015.
- [4] L. Pereira, J. Undrill, D. Kosterev, D. Davies, and S. Patterson, "A New Thermal Governor Modeling Approach in the WECC," *IEEE Transactions on Power Systems*, Vol. 18, Issue 2, May 2003, pp. 819–829.

XI. AUTHORS' INFORMATION

Siddharth S. Rajan received his B.S. in 2010 from Anna University, his M.S. in Power Systems in 2012 from Arizona State University, and his M.B.A. in 2017 from the University of Houston. He is an electrical engineer with seven years of experience in power system protection, modeling, fault analysis, relay testing, power flow, and system stability studies. He is knowledgeable of industry standards and technologies related to the application of protective relay schemes for industrial and utility systems. He is a registered professional engineer in Texas and can be reached at siddharth_rajana@selinc.com.

Guenther Strunk is an electrical engineer with experience in the reliability and maintenance of industrial electrical distribution systems. Guenther can be reached at Guenther.Strunk@ipaper.com.

Payal Gupta received her B.S. in 2007 from the National Institute of Technology India and her M.S. in Electrical Engineering in 2011 from the University of Houston. She is an electrical engineer with over nine years of experience in the design, engineering, and implementation of power monitoring and control systems for utility and industrial projects. She specializes in distribution network automation, power management systems, substation automation, supervisory control and data acquisition (SCADA), special protection schemes, power systems protection, and project management. Payal can be reached at payal_gupta@selinc.com.

Srikar Malladi received his B.S. in 2009 from Anna University and his M.S. in Electrical Engineering in 2011 from the University of Southern California. He is an electrical engineer with seven years of experience working on utility and industrial power system automation projects. He has experience in the design, development, testing, and commissioning of supervisory control and data acquisition (SCADA), data concentration, and special protection schemes. He is experienced in multiple protocols and technologies, and he has worked on several large automation projects. Srikar can be reached at srikar_malladi@selinc.com.

Prasanna Muralimanohar received his B.E. in 2008 from Anna University and his M.S. in Power Systems in 2009 from Rensselaer Polytechnic Institute. He is an electrical engineer with over nine years of experience providing solutions for electrical system design and protection. His background includes power system protection, protection studies, and the application of protective relaying for industrial and utility systems. He has been involved in the design, review, and commissioning of protection schemes for industrial distribution systems. He is a registered professional engineer in Texas and can be reached at prasanna_m@selinc.com.