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# An Application Of A Protective Relaying Scheme Using the UCA/MMS Standard

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**Abstract**— This paper describes an installation where GOOSE messages over an Ethernet LAN/WAN are used between substations to protect 27 kV feeders in a blocking scheme. The 27 kV network consists of 5 main stations and 37 load modules distributed over the territory. Load feeders connect two main stations and are operated in an open loop configuration

The Utility Communication Architecture Version 2 (UCA2) is a suite of protocols specifically prepared to address all communications needs of an utility. UCA2 implemented a peer-to-peer architecture and uses the Manufacturing Message Specification (MMS) for the exchange of real time control signals between relays.

UCA utilizes object models called General Object Model for Substation and Field Equipment (GOMSFE) for the representation of physical or logical objects. One of the key services provided by this protocol is the unsolicited event notification. UCA2 uses the unsolicited event from MMS as a data model called GOOSE message (Generic Object Orientated Substation Event).

The communications system for the 27 kV network consists of relays, 10BaseF Ethernet Switches and Synchronous Optical Communications (SONET) nodes connected in a ring topology. The relays perform protective relaying, control, monitoring and data acquisition. The Ethernet Switches are the local area network providing communication between relays within the substation and interface with the optical SONET for wide area communications.

Two 51.84 Mbps Synchronous Optical Network (SONET) rings provide backbone communications over the wide area. SONET was selected because of the variety of services it supports, including Ethernet and its self-healing capabilities. Two HMI workstations in different stations provide SCADA functionality.

**Index Terms**—GOOSE messages, overcurrent blocking, bus blocking.

## I. INTRODUCTION

Toronto's Lester B. Pearson International Airport (LBPIA) is Canada's largest airport and North America's fourth busiest international airport. A non-stop flight from Pearson can link individuals to three-quarters of the world's population. Anticipated annual growth rates for passengers and aircraft movements are expected to be 3.3% and 2.3% respectively. Presently LBPIA is ranked fourteenth in the world, and fourth

in North America in terms of international passengers. In 1998 the total number of passengers handled was 26.7

million. This is expected to grow to 39.8 million in 2010. The airport is located only 25 km northwest of Downtown Toronto and occupies an area of 4 km x 6 km approximately.

To handle this growing demand, the Greater Toronto Airport Authority (GTAA) has developed a strategic plan for the improvement of the airport infrastructure – the Airport Development Program includes three major projects: Terminal Development, Airside Development, and the Infield Development Project. There are also four intermediate projects: The Central Utilities Plant, the Utilities Development, Terminal 3 Modifications and the South Development Project.

Within the Utilities Development Plan (UDP), the original dual radial distribution system fed by two 27 kV dedicated feeders, will be replaced by a totally new distribution system fed by four dedicated 27 kV feeders from three diversely located transformer stations. The design of the distribution system within the airport calls for four full capacity dual loops, all connecting to the incoming feeders.

The ultimate electrical load at the airport, to be fed from this system, is expected to be about 60 M (85 MW with a diversity factor of 70%). The intent is that each feeder to the airport will be loaded to approximately 15 MW, and in a contingency any two feeders could handle 60 MW for a short period.

Provision is being made to construct a co-generation facility adjacent to the new Central Utility Plant; the capacity has not yet been determined. The intention is that under normal operation all of its electrical output would be exported to the Provincial Electrical Grid, and in the event there is a major grid failure (as happened in the 1998 Quebec Ice Storm) the co-generation facility would feed the airport.

The new 27 kV electrical distribution system, in addition the basic power carrying system of power cables, circuit breakers, switches and transformers, will feature a fully integrated network protection scheme and a state-of-the-art SCADA system to facilitate remote monitoring and control from the local electrical utilities control room.

## II. THE 27 kV DISTRIBUTION NETWORK

The ultimate Airport Electrical Distribution System consists of four 27 kV incoming feeders, five main substations, and 37 load modules distributed throughout the complex, interconnected by underground cables.

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For increased reliability the incoming feeders arrive from different transformer stations of the operator of the provincial High voltage grid into three main substations at the airport. The Main substations are the indoor metalclad switchgear type equipped with vacuum circuit breakers.

Four major 27 kV dual feeder loops serve the load modules. Each loop feeder supplies a number of load modules (8 or 9) and connects to two different Main substations. Feeders are operated in an open loop configuration with the open point approximately midway between the substations.

Load modules throughout the airport complex consist of three, four, five or six load-break switches with vacuum interrupters in series. Each load break switch and its associated vacuum interrupter is referred to as a "way". Ways 1 and 2 in all load modules are reserved for connection to the loop feeder. The remaining ways are for the local loads or sub-loops.

There are basically two arrangements of load module: single and dual. Less critical loads are fed with single load modules that permit the local load to be fed from either end of the Main feeder. Critical loads can be fed from two load modules supplied by different Main feeders. For further redundancy, the two load modules are connected via a tie switch that allow the load to be supplied from any Main feeder.

The Greater Toronto Airport Authority (GTAA) has arranged that a local electrical utility, Enersource, (Hydro Mississauga) will operate, maintain and manage the 27 kV distribution system..

### III. THE PROTECTION AND CONTROL SYSTEMS

#### A. Protection and Control Requirements

The protection and control system will be used to protect the high voltage equipment and remotely monitor electrical parameters and equipment status at load modules and substations located throughout the complex. The system will also provide remote switching operations.

The overall protection schemes for the airport consist of bus differential, instantaneous overcurrent, time overcurrent and unit feeder protection using a blocking scheme configuration.

At each load center the way that supplies a local load is protected with a device that mimics the time-current characteristic of a type "E" high voltage fuse. Unlike a fuse, the vacuum interrupter in these ways can be remotely closed after tripping, reducing restoration time.

#### B. Human/ Machine Interface (HMI) and SCADA

Two operator HMI workstations are provided within the airport at two Main substations. Each HMI will allow operations personnel to monitor and control the entire system and will include engineering functions such as making changes to system protection settings and software reconfiguration for each intelligent electronic device within the network. Each

HMI provides complete system functionality for all indications as well as control functions on the entire electrical network. Following are the main functions supported by the HMI system:

- Access control and security features
- Single Line diagrams for on-line control and status indication
- Metering and Trending
- Alarm processing with time stamping
- System clock synchronization
- Fault recording, retrieval and analysis
- Event recording and time stamping
- Historical data storage
- Communication network management.

The HMI systems are synchronized with a time signal from a GPS receiver. Event data collected from each intelligent electronic device (IED) is time stamped in accordance with the system time.

The operation of the 27 kV distribution system is also possible from the local utility control centre via SCADA. Besides functioning as a local command post for the 27 kV network, the workstations also act as a slave in a Master/ Slave relationship to the remote utility SCADA. In this case, the HMI workstations in the substations have the function of system monitoring and data collection as well as sending control commands to operate downstream devices via the relays. A modem connected from each workstation to the utility SCADA system is provided for remote access via dedicated phone lines using the DNP3.0 protocol.

With the information transferred to the utility control room via SCADA an alarm message, including problems with the HMI, relays or communication network, can be received and trouble crews timely dispatched.

### IV. THE USE OF GOOSE MESSAGES

#### A. The Utility Communications Architecture (UCA)

The power and functionality of microprocessors has led the way to the next generation of digital relays. One particular characteristic of these new microprocessors is the tight integration of the processor with a high performance communication controller. Given this new communication capability an international effort has ensued to create a single communication protocol that utilizes the advanced capabilities of these new processors. That effort has been centred on the Electrical Power Research Institute's Utility Communication Architecture work in applying the Manufacturers Messaging Specification (known as UCA/MMS), including a definition for the relay-to-relay communication of binary state data known as GOOSE messages.

UCA originated in 1990 as the framework for the ensemble of communication requirements that exist in the utility enterprise. It was at this time that utility managers were looking to consolidate communications among their SCADA system,

planning, metering, protection and control departments. In attempting this consolidation, the cost of integration of diverse communication protocols was realized and a drive towards communication commonality was begun.

The goal behind UCA was to identify a suite of existing communication protocols that could be easily mixed and matched, provide the foundation for the functionality required to solve the utility communication issues and be extendable into the future. UCA provides a network solution to the interconnection of data sources.

The UCA defines a “profile” of a communication structure for the substation. (This profile is shown below in Figure 1.)

The goal in defining this substation profile was to implement a high speed, networkable, peer-to-peer architecture. In addition, the goal of user data interoperability required the definition of standard names for commonly used data objects.

The profile developed uses Ethernet for the Physical and Data Link layers. Although Ethernet is “non-deterministic” when operated in a “shared access” mode (due to collisions), Ethernet technology has advanced to provide “switched access” which minimizes collisions. In addition, Ethernet provides a growth path to higher-speed Ethernet networks with 100 Mbps and 1 Gbps bit rates in common use, besides the existing 10 Mbps.

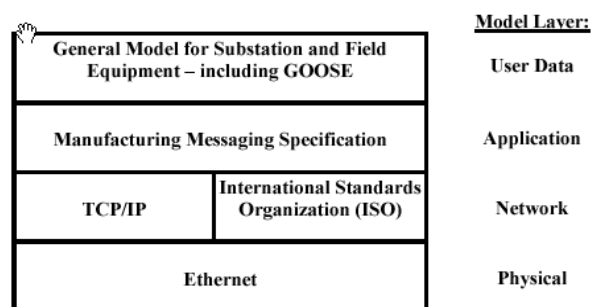


Fig. 1. UCA Substation Communications Profile

For the “networking” layers the popularity of the Internet dictated the selection of TCP/IP as networking protocol. The inclusion of TCP/IP makes data from the substation available over the utility intranet, WAN as well as over Internet.

For the Application or service layer, the Manufacturing Message Specification (MMS) -ISO 9506 standard- was selected as the most appropriate source protocol. This protocol provides a rich set of services to read, write, define, and create data objects. It is MMS and its ability to manipulate logical objects that differentiates this profile from all others existing.

### B. UCA GOOSE Messages

One of the unique functional requirements identified for UCA was a high-speed (goal 4 ms) device to multi device

communications of simple binary state information (see Figure 2).

As sending multiple messages to multiple devices would incur an unacceptable time delay, an implementation was chosen that could send the same message to multiple devices simultaneously, in a communication mode known as “multicast.”

The implementation of this function was done via the MMS information report service. The information report was used to deliver a binary object model (a collection of binary states maintained in a device) known as the Generic Object Orientated Substation Event or GOOSE.

In essence a GOOSE message is the asynchronous reporting of a digital state within an IED to other PEER (enrolled) IEDs on the network.

There are a number of issues that must be addressed for peer-to-peer communications between protective relays. In general, this type of communications:

- is mission sensitive and time critical
- must be highly reliable.

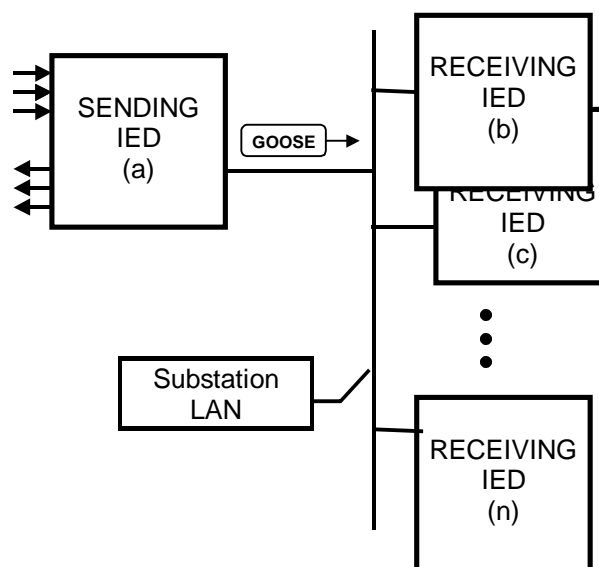


Fig. 2. GOOSE Multicast Concept

GOOSE works in a mode known as “Publisher/ Subscriber”. In this mode, the sending device “publishes” the user-selected state bits in the device (in our specific application the blocking signals generated by one relay when it picks up upon occurrence of a fault). Any device interested in any of the states of the publishing relay is programmed to “subscribe” to the publishing device’s GOOSE message.

To achieve a high level of reliability, messages are repeated a number of times. Thus, GOOSE messages need not be acknowledged and so may be multicast. GOOSE messages are

launched under the three following events. The first event that launches a GOOSE is when an IED is powered-up and becomes operational, to inform all subscribers of the present status of the digital states. The second event that launches a GOOSE is on a change of state of any of the binary variables in the message. The third type of event that launches a GOOSE message is on a user selectable periodic basis. The reason for the latter is that in the absence of a variable change-of-state, subscribing devices cannot determine that the publisher is alive. When the subscribing device fails to receive an expected GOOSE message in the expected time, it can declare the publisher “dead” and set default states on the binary variables expected from the publisher.

## V. COMMUNICATION INFRASTRUCTURE

Communications is a vital component of a wide area protection and control system as it has the task to carry not only real time control signals but distribute and manage the information needed for the operation of the electrical system.

The communication system was designed to be independent of the relay system and its failure modes. Common failure modes between the power and communication systems have been a frequent source of problems in the past. To meet these difficult requirements, the communications networks had to be designed for fast, robust, and reliable operation.

Being an integral part of the relay and control system, a communication network for a critical application such as an airport needs to be as reliable if not more reliable than the relay system itself. This is especially the case when communication is needed to be part of a relay trip decision as in this case. In order to participate in the tripping decision, the communicated information must be accurately and timely delivered.

An FSC SONET (Synchronous Optical Network) system was chosen because of its inherent reliability characteristics. The selected system is a SONET OC1 (Optical Carrier 1) having a transmission rate of 51.8 Mbps commercially known as JungleMux. The FSC SONET system supports 10 Mbps Ethernet among other type of traffic such as voice and video. The ability to carry Ethernet traffic was decisive for the selection of the communication system as the GOOSE messages are defined over Ethernet.

SONET networks support ring topology and dual SONET rings are implemented in the airport to connect all substations and load modules. The self-healing (or survivability) capability is a distinctive feature of SONET networks and made possible because of its ring topology. This means that if

communication between two nodes is lost, the traffic between them switches over to the protected path of the ring. This switching to the protected path can be as fast as 4 ms, acceptable in a wide area protection and control system.

## Time Synchronization

One Global Positioning System (GPS) receiver will be used to set and synchronize the time on all IEDs and the HMI. The time signal from the receiver is delivered over the SONET FSC system using an IRIG-B modulated signal. Each FSC node has an analogue party-line card and its output is daisy chained to the IEDs using a No. 18 AWG twisted-pair shielded cable. The signal is broadcast on a regular basis automatically, updating the IED internal clocks.

## VI. PROTECTION STRATEGY

### A. Protection Overview

An identical philosophy was adopted for the protection of the entire 27 kV system. Basically, it consists in the exchange of GOOSE messages over the local LAN at the substation level or across the WAN between different substations. Each substation and load module has a 10 Mbps Ethernet switch inter-connecting local IEDs; substations are inter-connected over a SONET WAN. Note that the UCA/MMS specifications require the use of switches rather than shared hubs in order to guarantee the timely delivery of GOOSE messages. This architecture is shown in Figure 3.

Intelligent relays provide protection for the complete system. These relays provide two phase and neutral instantaneous and time overcurrent elements. In addition to protection, the relays provide control and monitoring functions such as event recording, oscillography, and metering, rendering unnecessary the use of additional hardware such as RTUs. The relays include native 10 Mbps Ethernet optical fibre port and support TCP/IP network protocol.

All circuit breakers; motorized switches and vacuum interrupters can be operated locally or remotely from the HMI/SCADA via the relays.

### B. Protection at Main Substations

There are two types of relays at the Main substations; one for the Main incoming feeders, the other for outgoing distribution feeder loops. The Main incoming feeders are protected with F60 relays, which include directional overcurrent elements. All other feeders and tie breakers are protected with F35 relays. One directional overcurrent element of the F60 on the Main incoming feeders will detect faults on the upstream utility system.

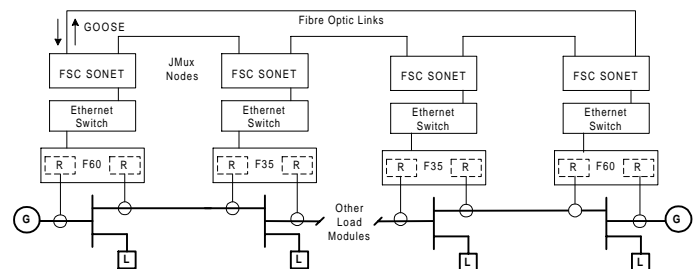


Fig. 3. Protection & Control Architecture

### C. Main Substation Bus Protection

Bus protection on the main substations is accomplished using a non-directional overcurrent blocking scheme during the normal single-source configuration. The system operates such that for an external fault, two relays (the incoming circuit and one other circuit) will detect the flow of current above their pick-up setting and start timing to initiate tripping. At the same time each of these relays will send a block signal as a GOOSE message. Because both relays receive a block signal there is no tripping.

However, for an internal fault only one relay operates, and because it is not blocked it will trip at timeout. This is because the overcurrent elements on the load feeders will not pick up since it is assumed that there is no back-feed current from the loads. All breakers on the bus operate in this manner. If an internal fault is experienced during switching, when multiple sources are connected to the bus, the blocking scheme will not operate but the fault will be cleared by backup time overcurrent protection.

As in any blocking scheme a coordinating time, to wait for the arrival of the blocking signal, is required. The coordinating time is a function of the channel delay and in this case it is the time for the deliver of GOOSE messages over the LAN. GOOSE messages in this case are exchanged over the local substation LAN as all the relays intervening in bus protection are connected to the same Ethernet switch. The coordinating time interval is 60 ms. Upon detection of a bus fault all breakers will be transfer tripped using GOOSE messages and the relays will indicate “Bus Fault Trip.”

With 60 ms coordinating time and three-cycle circuit breakers, the total clearing time for bus faults will be in the order of 120 ms.

### D. Main Feeder Section Protection

Every section of the Main load feeders between switching devices is also protected by a non-directional overcurrent blocking scheme similar in operation to the bus protection scheme. In these feeder protection schemes the relays at each end of the section exchange GOOSE Messages over the SONET/WAN, and backup time overcurrent is provided.

Figure 4 shows the logic that is used to accomplish the main switchgear bus protection scheme and the line protection scheme for a feeder section between a switchgear breaker and a load module by the exchange of GOOSE messages. Similar logic is used for all feeder sections.

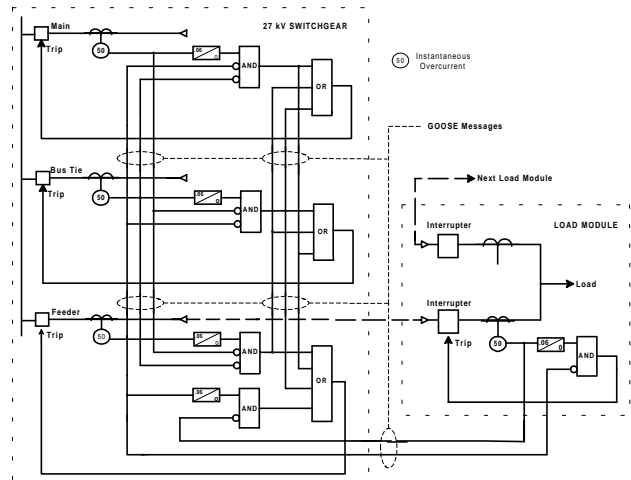


Fig. 4 Tripping Logic Using GOOSE

### E. Load Module Bus Protection

A partial bus differential scheme is provided at each load module. In this protection the current from the incoming-way relay is subtracted from the current in the outgoing-way relay. A current pickup setting above the maximum possible load current is used to cause a trip for a bus fault.

## VII. CONCLUSION

The UCA/MMS suite of services has been specifically designed for electrical utility communications purposes. UCA defines GOOSE messages as data objects for real time control that can be exchanged between nodes on the network.

The ability to perform relay-to-relay communications with the UCA protocol has enabled the implementation of innovative protection and control applications that use real time messaging over Ethernet; in this application not only locally at the substation but also between substations

The critical nature of this application has resulted in the selection a self-healing, OC1 (51.84 Mbps), FSC SONET optical system with Ethernet services as a communication backbone. Protection relays and other IEDs that support the UCA/MMS protocol are now being applied in installations demanding high-reliability, such as the Lester B. Pearson Airport, operated by the Greater Toronto Airports Authority.

Two non-directional overcurrent blocking schemes for the protection of the 27 kV electrical network distributing power at the airport have been implemented to protect switchgear buses and feeders operating in an open loop configuration. The system outlined uses GOOSE messages to implement protection schemes that produce rapid fault interruption.

## VIII. REFERENCES

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## IX. BIOGRAPHIES

**Gustavo Brunello** received his Engineering Degree from the National University in Argentina and a Master in Engineering from the University of Toronto. He also attended a 2 year post-graduate course in Power Systems Engineering at Polytechnic of Turin (Italy). After graduation he worked for the National Electrical Power Board in Argentina where he was involved in testing and commissioning the 500 kV backbone transmission system. From 1990 until 1999 he worked with ABB Relays and Network Control both in Canada and Italy where he became Engineering Manager for protection and control systems. In 1999, he joined GE Power Management as an application engineer. He is responsible for the application and design of protective relays and control systems. He is a Professional Engineer in the Province of Ontario and a member of PES of the IEEE.

**Bogdan Kasztenny** received his M.Sc. and Ph.D. degrees from the Wroclaw University of Technology (WUT), Poland. He joined the Department of Electrical Engineering of WUT after his graduation. Later he was with the Southern Illinois University in Carbondale and Texas A&M University in College Station. From 1989 till 1999 Dr. Kasztenny was involved in a number of research projects for utilities, relay vendors and science foundations. Since 1999 Bogdan works for GE Power Management as a Chief Application Engineer. Bogdan is a Senior Member of IEEE, has published more than 100 technical papers, and is an inventor of 5 patents. His interests focus on advanced protection and control algorithms for microprocessor-based relays, power system modeling and analysis, and digital signal processing.

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