Unified representation of data and model for sparse measurement based fault location

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***Abstract*—Transmission line fault location methods typically need measurements from at least one end of the faulted line. Sparse measurement based fault location method using phasor measurements from different substations located near the faulted line can be applied if the measurements are not available from any of the line ends. This method uses data and model described in both bus-branch and node-breaker representation. This requires use of nomenclature correlation tables to correlate between different data and model, which is a very cumbersome process as for each substation separate nomenclature correlation tables are required. The proposed solution uses standard formats of data and model (IEC 61970-CIM for describing power system model and SCADA data; IEC 61850-SCL for describing substation model and COMTRADE for describing event data triggered by IEDs) all expressed in node-breaker format, which allows for unified data and model representation by using simple rules.**

***Index Terms*-- Fault location, CIM, COMTRADE, SCL, SCADA data.**

I. Nomenclature

The following list contains the meaning of abbreviations used in this paper.

CIM	Common Information Model
COMTRADE	Common Format for Transient Data Exchange
DFR	Digital Fault Recorder
DPR	Digital Protective Relay
IED	Intelligent Electronic Device
PMU	Phasor Measurement Unit
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition System
SCL	Substation Configuration Language
SER	Sequence of Event Recorder

II. Introduction

LOCATION of transmission line faults without the presence of measurements from any of the line-ends is difficult to achieve as there is no straightforward way to directly solve circuit equations to estimate it. Sparse measurement based fault location method [1-2] estimates the location of fault by using measurements captured by variety of recording intelligent electronic devices (IEDs) triggered in the vicinity of the faulted line during the fault. The pre-fault condition of the power network is updated using SCADA measurements obtained from remote terminal units (RTUs) located in the substations near the fault. Merging such diverse data requires unified representation of data and model which is not readily available today.

For successful implementation of sparse measurement based fault location method, it is desirable that efficient handling of data and model is performed automatically and seamlessly. While the integration of data and model through manual work is tedious, much easier process is achieved through interoperability using unified data and model representation. Interoperability in this context requires correlating data and model expressed in different formats but having similar descriptions seamlessly (syntactic interoperability), extracting useful information from them automatically (semantic interoperability), and using such information in any fault location application requiring similar data and model descriptions consistently [3].

In this paper, a unified representation of data and model is proposed where the following standards are used to represent data and model: a) IEC 61850-6 SCL [4] and IEEE COMTRADE [5] for DFR data and b) CIM [6] for power system model and SCADA data. Several harmonization efforts to properly use all these standards can be found in literature [7-10]. Formal integration of CIM and SCL by bi-directional mapping between them is addressed in [7]. Mapping for topology processing application is proposed in [8]. Harmonizing these two standards to develop a unified semantic model is discussed in EPRI report [9]. In [10] mismatches between those two standards are addressed and solutions for all types of mismatches are proposed without modifying the original CIM and SCL information model. Unified model representation is discussed in [11].

This paper addresses the drawbacks of existing practice of customized data handling in sparse measurement based fault location application. Description of data and model used in this fault location method is discussed, followed by data and model matching issues. Unified representation of data and model scheme is proposed and illustrated by using a simple case study.

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III. DESCRIPTION OF DATA AND MODEL

Different types of data and model used in sparse measurement based transmission line fault location method will be discussed in this section. Typically a fault location algorithm requires voltage and current measurements from either or both end of the faulted transmission line as well as pre-fault loading conditions and transmission line parameters. The sparse measurement based fault location method does not require measurements from any end of the faulted line (measurements in the vicinity are sufficient). This method works best if different types of measurements recorded in pre-fault and faulted conditions are used in combination properly.

A. Substation data

Traditionally in a substation, RTUs acquire analog measurements such as bus voltages, flows (amps, MW, MVAR), frequency, transformer tap position etc) and status (breaker switching state) signals and send them to the energy management systems (EMS) in every two to ten seconds. These are called supervisory control and data acquisition system (SCADA) scans and those measurements are gathered in a SCADA database in a centralized location.

With the rapid advancement of technology, large scale deployment of IEDs became a reality. When triggered by an event, these computer-based devices can record a huge amount of data (both analog and status) with much higher sampling rate than SCADA scans. The substation analog signals at high power level are measured and transformed to instrumentation level using current and voltage instrument transformers. The signals are then filtered, digitized, and processed in IEDs. Finally, the measurement data is extracted and supplied in digital computer words as output of these devices. This is the typical measurement chain for the data acquisition. Various databases are used to store these data and make it available for further processing.

The third type of data acquisition devices, phasor measurement units (PMUs) continuously calculate time-synchronized phasors with high sampling rates. Phasor data concentrators (PDC) gather PMU measurements from all the substations to a centralized location.

The basic idea of integration of data is to collect all the IED data in a substation database and use it for extracting information automatically and then utilize the extracted information for several power system applications. The functional diagram for substation data flow is shown in Fig.1.

B. Power system model

Sparse measurement based fault location method requires power system model information in addition to the measurements and the information extracted from them. Two representations of power networks are in use simultaneously by different applications.

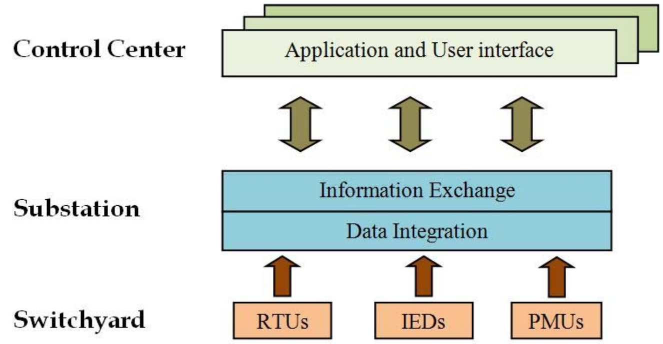

Fig. 1. Data flow in a substation

Node-breaker or real-time model represents actual connections between nodes, breakers and isolator switches. Bus-branch or planning model is a less detailed model where power network is represented by buses (combination of several nodes connected by closed circuit breakers) and branches connecting them [11].

Our fault location method performs short circuit study of possible fault location points using PSS/E [12], which requires representation of power system model in bus-branch format. On the other hand it also needs measurements captured by IEDs and RTUs whose nomenclature is represented in the detailed substation node-breaker model.

C. Standards to represent data and model

Several standards either in use or proposed for data description and exchange purpose are prepared by both IEEE and IEC. [13-14]. Smart Grid Interoperability Panel also has defined a catalog of standards to achieve interoperability in the proposed smart grid [15]. Related standards for data and model representation of fault location application are [4-6,16-19].

Among those standards, we will primarily use three of them to represent data and model for sparse measurement based fault location application.

(a) Common Information Model (CIM): CIM (IEC 61970) is an abstract model representing all objects in an electric utility typically contained in EMS information model [6]. CIM represents common semantics for classes and attributes for these objects as well as their relationships which are defined using object–oriented modeling techniques (unified modeling language, UML). CIM has been implemented in eXtensible Markup Language (XML) to provide a comprehensive power system data exchange format within control center.

CIM consists of several interrelated packages of models. Each package contains a number of defined classes and one or more class diagrams showing their relationships graphically. Descriptions of class packages are shown in Table I.

TABLE I
PACKAGES OF COMMON INFORMATION MODEL

Package	Class		
	Name	**Description**	**Base Class**
Core: Contains definition of the parent classes which are inherited in classes defined in other packages.	IdentifiedObject	Provides common naming attributes to the classes needing that.	
	BaseVoltage	Collection of base voltages are presented in this class.	IdentifiedObject
	GeographicalRegion and SubGeographicalRegion	Represents a geographical region and a subset of geographical region.	IdentifiedObject
	PowerSystemResource	It can be equipment, a collection of equipments or an organizational entity.	IdentifiedObject
	ConnectivityNodeContainer	A base class for all objects that may contain ConnectivityNodes or TopologicalNodes (in topology package).	
	Equipment and ConductingEquipment	Equipments are parts of the power system that are physical devices and ConductingEquipments are those that carry current.	Equipments, PowerSystemResouce
	Terminal	This is an electrical connection point to a piece of conducting equipment.	ConductingEquipment
	EquipmentContainer	A modeling construct to provide a root class for all Equipment classes.	
	Substations, Bays and Voltage Levels	They are used to model aggregation of equipments.	EquipmentContainer
Topology: Defines how the equipments are electrically connected in the network.	ConnectivityNode	These are points where terminals of conducting equipments are connected together with zero impedance.	IdentifiedObject
Wires: Defines all pieces of equipments electrically connected in the network.	Line	They represent part of the power system extending between adjacent substations.	EquipmentContainer
	Conductor	These are combination of conducting materials with consistent electrical characteristics.	ConductingEquipment
	ACLineSegment	These are used to carry alternating currents.	Conductor
	PowerTransformer	A device consisting of two or more coupled windings.	Equipment
	TransformerWindings	They represent winding at each terminal of a power transformer.	ConductingEquipment
	Switch	They close or open one or more electric circuits.	ConductingEquipment
	Breaker and Disconnector	They close or open one or more electric circuits.	Switch
	BusbarSection	They connect with other conducting equipment within a substation.	ConductingEquipment
	RegulatingControl	Set of equipments work together to control a power system quantity.	PowerSystemResouce
	RegulatingCondEq	They are conducting equipment which regulate a power system quantity.	ConductingEquipment
	SynchronousMachine	They operate synchronously within a power system.	RegulatingCondEq
	EnergyConsumer	Point of energy consumption.	ConductingEquipment
Generation: Contains different types of generators in two packages: Production and GenerationDynamics.	GeneratingUnit	Single or set of synchronous machines.	Equipment
Meas: Defines measurements taken from a particular power system resource.	Measurement	Represents any measured or calculated or non-measured or non-calculated quantity.	IdentifiedObject
	MeasurementValue	Represents value of measurement.	Measurement

(b) Substation Configuration Language (SCL): SCL (IEC 61850-6) is a standard to describe substation configuration allowing semantic interpretation of substation data. This is also expressed in XML but the data model is not defined using UML. Substation functions are modeled into different logical nodes (LN) which are grouped under different logical devices (LD). Data exchanged between LNs are modeled as data objects, which consist of data attributes. The different components of SCL are described in Table II.

The following files types are the components of SCL:

- **System Specification Description (SSD):** single line diagram of substation and logical nodes.
- **IED Capability Description (ICD):** capabilities of an IED.
- **Substation Configuration Description (SCD):** complete substation configuration.
- **Configured IED Description (CID):** an instantiated IED with all configuration parameters relevant to that IED.

(c) IEEE Standard Common Format for Transient Data Exchange (COMTRADE): COMTRADE describes syntax of the following files extracted from the raw measurements captured by substation IEDs:

- **Configuration files (*.cfg):** information for interpreting the allocation of measured data to the equipment (input channels) for a specific substation.
- **Data files (*.dat):** analog and digital sample values for all input channels (described in configuration file) in substation.

IV. Sparse Measurement Based Fault Location Method

The basic idea of transmission line fault location is to estimate the distance of the fault point from any one end of the line on which the fault occurred.

In Fig. 2 a fault with resistance R_F has occurred on point F between two ends (S and R) of a line section S-R. Considering a homogeneous line, the distance can be expressed as a function of the impedance measured from one end $\left(xZ_L\right)$.

TABLE II
CONTENTS OF SUBSTATION CONFIGURATION LANGUAGE

Section	Object
Substation section: describes functional structure of substation in terms of LNs and IEDs associated.	**Substation** **VoltageLevel:** electrically connected part of substation having same voltage level. **Bay:** part or subfunction of substation within same voltage level. **ConductingEquipment** **SubEquipment** **ConnecitivityNode** **Terminal** **Function** **Subfunction** **PowerTransformer** **TransformerWinding**
Communication section: communication connections between IEDs	Not used
IED section: describes configuration of IEDs and LNs associated	**IED** **Server:** Communication entity within an IED **LDevide:** LD contained in server of IED **LNode:** LN contained in LD of IED **DO:** Data contained in LN
DataType section: describes data objects contained in LNs defined for IEDs	Not used

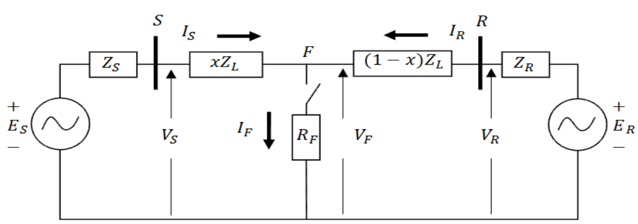

Fig. 2. Faulted circuit model

The above circuit can be solved accurately if voltage and current measurements from both ends are available.

Installing recording devices (DFRs in our case) at the ends of all the transmission lines may not be feasible, as the case is with tapped lines. Although protective relays exist on every transmission line and isolate the faulted line by opening associated circuit breaker when sensing fault immediately, most of them may still be electromechanical and they do not have capability to record measurements. As a result, in some cases it may happen that there are no recordings at all available at line ends close to a fault. System-wide sparse measurement based fault location method can be applied in such instances [1-2].

In sparse measurement based fault location method, phasor measurements from different substations located in the region where the fault has occurred are used. The measurements are considered sparse, as they may come from only some of many transmission line ends (substations) in the region. This method requires synchronization of the samples and extracted features (measurements), which may be obtained by using DFRs connected to Global Positioning System (GPS) receivers.

Besides the sparse measurements, the technique also uses a commercial short circuit program tool PSS/E, which is initialized with power system model (expressed as bus branch model) and tuned with SCADA PI Historian [20] data scan, which is a set of RTU measurements associated with the time of the fault occurrence.

The method uses waveform matching technique between the current and voltage phasors calculated from the samples of waveforms recorded in a substation (nearby the faulted line) and phasors simulated using short circuit calculation of possible fault locations. The calculated and simulated phasors are compared while the location of the fault is changed in the short circuit program. This process of placing faults in different locations is repeated automatically until the difference between measured and simulated phasor values reaches global optimum (minimum), which indicates that the fault location used in the short circuit program is the actual one in the field. The criteria for the minimal difference are based on a global optimization technique that uses Genetic Algorithm.

In this approach field-recorded samples of waveforms are used to calculate phasors and they are in turn matched with the phasors obtained using short circuit study. The matching degree between the recorded and the simulated phasors can be formulated as [1]:

$$f_c(x, R_F) = \sum_{k=1}^{N_V} r_{kV} \left|V_{ks} - V_{kr}\right| + \sum_{k=1}^{N_I} r_{kI} \left|I_{ks} - I_{kr}\right| \quad (1)$$

Where,

$f_c(x, R_F)$: The cost function using phasors for matching

x, R_F : The fault location and fault resistance

r_{kV}, r_{kI} : Weights for the errors of the voltages and currents respectively

V_{ks}, V_{kr} : Simulated and calculated from measurements during-fault voltages respectively

I_{ks}, I_{kr} : Simulated and calculated from measurements during-fault currents respectively

N_V, N_I : Total number of voltage and current phasors to be matched respectively

k : The index of voltage or current phasors

Ideally when the simulated phasors and phasor calculated from the recorded waveforms match completely, the cost function should become zero. In practical solution, the cost function is not zero and should be minimized using some mathematical optimization method. To obtain good phasor matching the fault search range should be extensive. All possible faulted branches and fault resistance should be included in the search range which makes the search two-dimensional and exhaustive. For a large system, multiple searches should be run in parallel which can be achieved using population based optimization methods such as Genetic Algorithm (GA) [21]. The flowchart of this method is shown in Fig. 3.

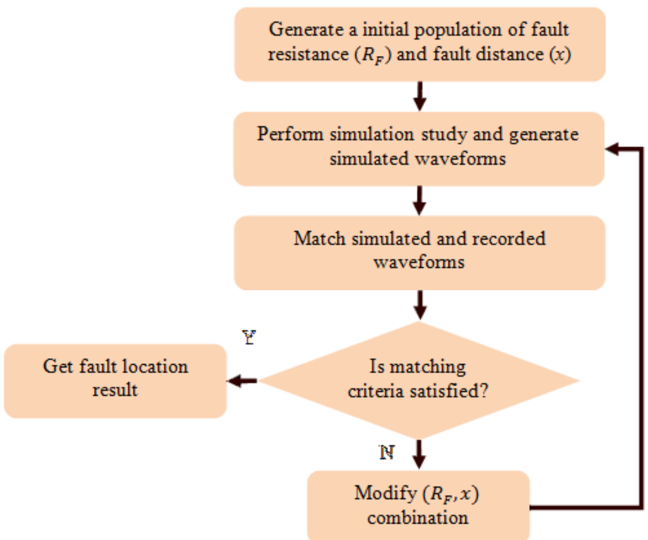

Fig. 3. Flowchart of sparse measurement algorithm

V. Unified Representation of Data and Model

Data and information flow in this fault location method is shown in Fig. 4. As the substations are generally modeled in a detailed node-breaker model while power system static model is less detailed bus-branch model, the names and numeric designations of same power system components described in those two models may become different due to different nomenclature used by various utility groups that maintain given models and data acquisition devices. Nomenclatures used in IED database follows that of substation model while nomenclature used in SCADA database follows slightly different but similar yet less detailed static system model expressed in bus-branch. It requires nomenclature correlation tables to correlate between them, which is a very cumbersome process as for each substation separate nomenclature correlation tables are required. Therefore significant number of mappings between all types of data and model are required to create a unified correlation between the nomenclatures. Sometimes the mapping has to be done manually or semi-automatically resulting in longer operating time.

Therefore a scheme to represent data and model used in this application in a unified form is required which should have the following features:

- Reduce number of mappings between data and model.
- Correlate different types of data and model without any user intervention.

The above can be achieved if standard formats for data and model representation (for example CIM for describing power system model and SCADA data; SCL for describing substation model and COMTRADE for describing event data triggered by IEDs) all expressed in node-breaker format are used.

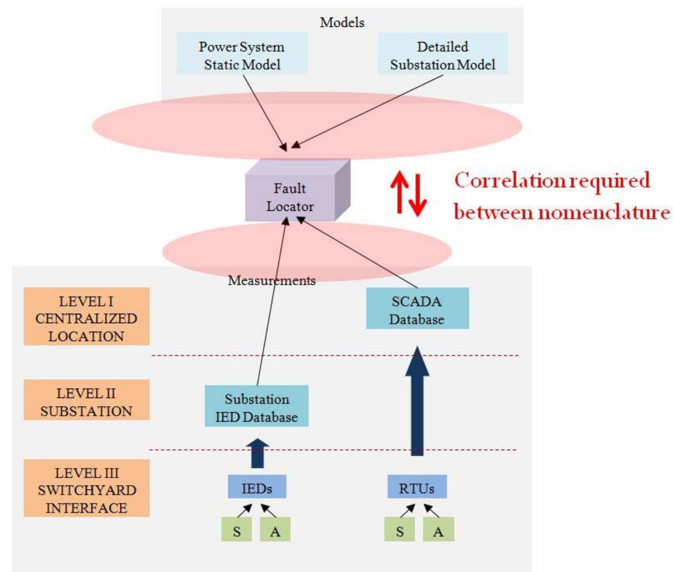

Fig. 4. Data and information flow for fault location application

A unified representation of data and model for this fault location method is shown in Fig. 5. Here all measurements and models are expressed in CIM, SCL and COMTRADE. Correlation of COMTRADE files with SCL is easy as they correspond to same substation model. Mapping is required only to correlate between the model and measurements represented in CIM and that of SCL to obtain a uniform representation. Though both CIM and SCL are described in node-breaker model and most of the objects are modeled in a similar way and share same name, some discrepancies are also present.

For our fault location application, we are considering the subset of whole CIM model (CIM profile) for power system network and SCL models for each of the substation where DFRs triggered. Each of the models has numerous objects to define power system components.

The correlation between CIM profile and SCL profiles of different substations is done using the following simple rules:

- **For similar objects:** Common data structure is used to represent those objects present in both standards.
- **For dissimilar objects:** Some objects are defined in either of the standards, for those no mapping is needed. Separate data structures for each model are used.

By using the very simple rules mentioned above, data and model used in this fault location application are represented in a unified way. That way automatic correlation can be achieved. Besides, the information extracted from the data and model representation can be used properly in the application to estimate fault location correctly.

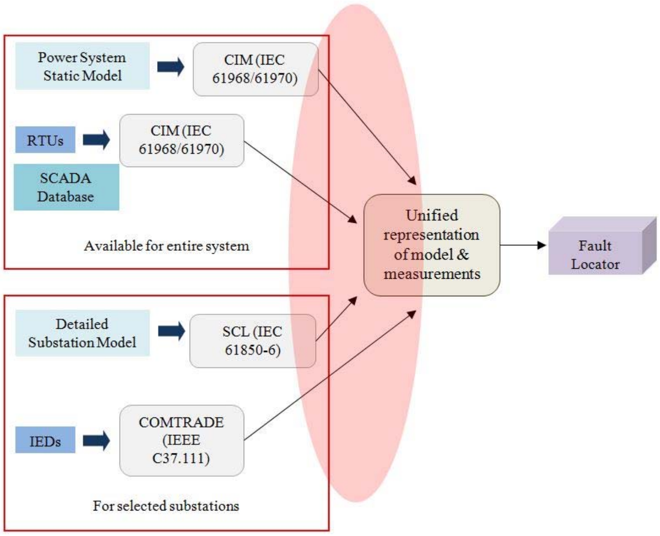

Fig. 5. Unified representation of data and model for fault location application

The detailed description of this scheme will be illustrated in the following section with a case study.

VI. Case Study

The unified representation of data and model is implemented on a small power system model for simplicity. As there are no standard test cases available for both CIM model and SCL model, we have used the following data and assumptions to artificially generate a fault case:

- 3 bus power system network (expressed in CIM model) is chosen, which is obtained from a sample system used in [22]. The detailed node-breaker representation of the power system network is shown in Fig. 6.
- Several faults on the line between Bus-2 and Bus-3 are considered. We are assuming that DFR installed on Bus-1 is triggered due to the fault. Fig. 7 shows the one-line diagram of the faulted power system network. The fault is simulated in ATP [23] and the pre-fault, during-fault and post-fault voltage and current signals at Bus-1 are recorded and converted to COMTRADE format using the Output Processor [24].
- As no corresponding SCL models are available for the substation 1 (Bus-1) of the 3 bus power system, example from IEC 61850-6 standard is used. The detailed node-breaker diagram for the substation is shown in Fig. 8.
- The following changes are made in the above models for uniformity:
  a) As the voltage levels in CIM model and SCL models were different we have changed the voltage level in SCL model to that of CIM.
  b) In SCL a switch and breaker combination (QB1 & QA1) is present between Busbar (W1) and transformer (T1) while in CIM only a switch (S16) is present between Bus1 and TR1. For uniformity we have added a breaker (B8) in CIM xml file.

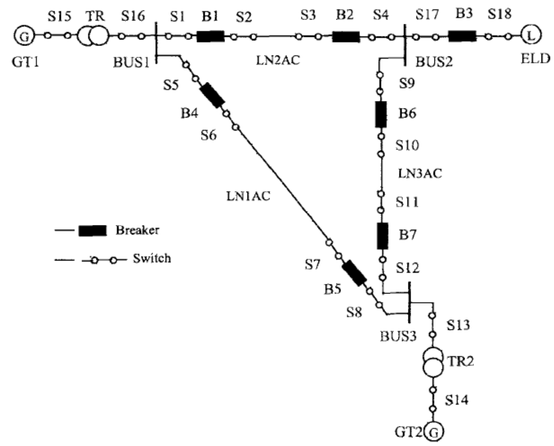

Fig. 6. Node breaker representation of 3 bus power network [22]

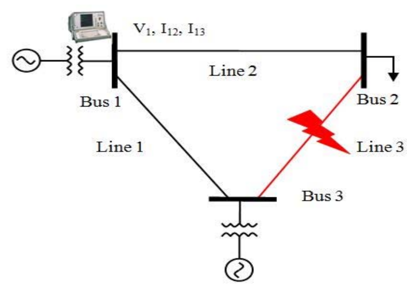

Fig. 7. One-line diagram of 3 bus power network

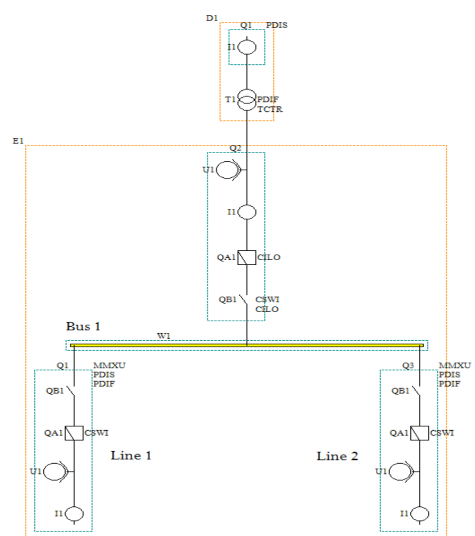

Fig. 8. Node breaker representation of Substation-1

The unified representation of data and model is achieved using the following rules:

- Common data structures are used for similar objects. For example both of the models have substation object in common. Fig. 9 shows the CIM representation and Fig. 10

shows the SCL representation.

```xml
<cim:Substation rdf:ID="_ID_SUBSTATION1">
    <cim:IdentifiedObject.name>Substation1</cim:IdentifiedObject.name>
    <cim:IdentifiedObject.localName>Substation1</cim:IdentifiedObject.localName>
    <cim:Substation.Region rdf:resource="#_ID_SubGeographicalRegion"/>
</cim:Substation>
<cim:VoltageLevel rdf:ID="_ID_SUB1_VLevel_220KV_EF4559BF7EB">
<cim:VoltageLevel rdf:ID="_ID_SUB1_VLevel_15KV_EEF4559BF7EB">
```

Fig. 9. Substation in CIM

```xml
<Substation name="S12" desc="Substation1">
  <Text />
  <VoltageLevel sxy:x="10" sxy:y="10" name="D1" xmlns:sxy="http://www.iec.ch/61850/2003/SCLcoordinates">
  <VoltageLevel sxy:x="10" sxy:y="185" name="E1" xmlns:sxy="http://www.iec.ch/61850/2003/SCLcoordinates">
</Substation>
```

Fig. 10. Substation in SCL

A class substation defined in our program has the following description:
Substation.name.cim="Substation1"
Substation.name.scl="S12"
Substation.VoltageLevel.high.name.cim="Substation-1 220KV"
Substation.VoltageLevel.low.name.cim="Substation-1 15KV"
Substation.VoltageLevel.high.name.scl="E1"
Substation.VoltageLevel.low.name.scl="D1"

The other objects inside Substation object are defined in same fashion.

- Separate data structures for each model for dissimilar objects. For example CIM has ThermalGeneratingUnit but SCL doesn't. Fig. 11 shows the CIM representation.

```xml
<cim:ThermalGeneratingUnit rdf:ID="_ID_SUB1_GenUnit1">
    <cim:SynchronousMachine rdf:ID="_ID_SUB1_ShynchMachine_Gen1">
    <cim:Terminal rdf:ID="_GEN1C5712A0D2F431594B0638457202CBC">
    <cim:ConnectivityNode rdf:ID="_ID_Sub1_GEN1_C1">
    <cim:Analog rdf:ID="_D0E86D5181654BFDABCD81AD6F6A0E2A">
    <cim:Analog rdf:ID="_D0E86D5181654BFDABCD81AD6F6A0E2B">
    <cim:RegulatingControl rdf:ID="_8230B69E80F9402FA09E7D3D8B547CB6">
```

Fig. 11. ThermalGeneratingUnit in CIM

A class ThermalGeneratingUnit within substation is defined in our program has the following description:
Substation.ThermalGeneratingUnit.name="GEN1"

- In some cases both similar and dissimilar objects are present which represent same electrical equipment. Both common and separate data structures within the object are used. For example both CIM and SCL have PowerTransfrmer object while SCL also include IED associated to that (TCTR i.e. current transformer LN here). Fig. 12 shows the CIM representation and Fig. 13 shows the SCL representation of PowerTransformer.

A class PowerTransformer within substation defined in our program which has the following description:
Substation. PowerTransformer.name.cim="TR1"
Substation. PowerTransformer.name.scl="T1"
Substation.PowerTransformer.Lnode.iedname="D1Q1SB1"

```xml
<cim:PowerTransformer rdf:ID="_ID_PowerXfr_TR1">
    <cim:TransformerWinding rdf:ID="_ID_TR1_W1">
    <cim:Terminal rdf:ID="_T1W1C5712A0D2F431594B0638457202CBC">
    <cim:ConnectivityNode rdf:ID="_ID_TR1_W1_C1">
    <cim:TransformerWinding rdf:ID="_ID_TR1_W2">
    <cim:Terminal rdf:ID="_T1W2C5712A0D2F431594B0638457202CBC">
    <cim:ConnectivityNode rdf:ID="_ID_TR1_W2_C1">
```

Fig. 12. PowerTransformer in CIM

```xml
<PowerTransformer sxy:x="386" sxy:y="95" name="T1">
  <Text />
  <LNode lnInst="1" lnClass="PDIF" iedName="D1Q1BP2" ldInst="F1">
  <LNode lnInst="1" lnClass="TCTR" iedName="D1Q1SB1" ldInst="C1">
  <TransformerWinding name="W1">
  <TransformerWinding name="W2">
</PowerTransformer>
```

Fig. 13. PowerTransformer in SCL

- Name and corresponding measurement channels for IEDs are located from SCL. If an IED is triggered, corresponding COMTRADE files (configuration and data) can be located from the database using the name of the IED. Fig. 14 shows a part of SCL corresponding to triggered IED.

```xml
<VoltageLevel sxy:x="10" sxy:y="185" name="E1" xmlns:sxy="http://www.iec.ch/61850/2003/SCLcoor
  <Text />
  <Voltage unit="V" multiplier="k">220000</Voltage>
  <Bay sxy:x="10" sxy:y="320" name="Q1">
    <Text />
    <LNode lnInst="1" lnClass="MMXU" iedName="E1Q1SB1" ldInst="C1">
    <LNode lnInst="1" lnClass="PDIS" iedName="E1Q1BP3" ldInst="F1">
    <LNode lnInst="1" lnClass="PDIF" iedName="E1Q1BP2" ldInst="F1">
    <ConductingEquipment sxy:x="183" sxy:y="75" name="QA1" type="CBR">
    <ConductingEquipment sxy:x="183" sxy:y="15" name="QB1" type="DIS">
    <ConductingEquipment sxy:x="183" sxy:y="135" name="U1" type="VTR">
    <ConductingEquipment sxy:x="183" sxy:y="195" name="I1" type="CTR">
      <Text />
      <Terminal connectivityNode="S12/E1/Q1/L3" substationName="S12" voltageLevelName="E1" bay
      <Terminal connectivityNode="S12/E1/Q1/L4" substationName="S12" voltageLevelName="E1" bay
      <SubEquipment name="A" phase="A">
        <Text />
        <LNode desc="CT phase Line1" lnInst="1" lnClass="TCTR" iedName="E1Q1SB1" ldInst="C1">
          <Text />
        </LNode>
      </SubEquipment>
```

Fig. 14. Part of SCL corresponding to triggered IED

A class within Substation.VoltageLevel.high is defined which corresponds to measurements (as MMXU corresponds to measuring unit LN in SCL). For the measuring unit corresponding IED name and analog measurement channel are also stored. The class and subclasses are shown below:
Substation.VoltageLevel.high.mmxu.iedname="E1Q1SB1"
Substation.VoltageLevel.high.mmxu.iedname.CTR.name="I1
"

- SCADA measurements are updated in the following classes:

Substation.VoltageLevel.high.Meas.value
Substation.VoltageLevel.high.Meas.type
Substation.VoltageLevel.high.Meas.accuracy

By using the rules mentioned above, correlation between data and models are achieved automatically. After correlation of data and model, required information (voltage and current phasors for pre-fault and faulted network for each of the monitored channel mentioned in COMTRADE configuration file, status of the breakers from COMTRADE data file, SCADA measurements) are extracted as in [2].

Different types of fault cases are tested on this network. The result is summarized in Table III. From the table it can be concluded that though measurements are unavailable from the faulted line end, by using sparse measurement based fault location method location of the fault is estimated properly. The unified representation scheme mentioned in this paper helps achieving this automatically without any need for complicated nomenclature correlation tables between each type of data and model used.

TABLE III
FAULT LOCATION RESULTS

Case No.	Fault Type	Actual Location From Bus-2 (pu of line length)	Estimated Location From Bus-2 (pu of line length)
1	ag	0.1	0.160784
2	ab	0.8	0.788235
3	abg	0.4	0.345098
4	abc	0.9	0.980392
5	abcg	0.9	0.956863

VII. CONCLUSIONS

A unified data and model representation for sparse measurement based fault location method is discussed. The implementation has the following features:

- The proposed fault location method that produces accurate results even with sparse measurements is facilitated
- Integration of substation data and model is simplified in comparison to the nomenclature table correlations
- Standard data and model representation helps achieving interoperability by correlating different types of data and model seamlessly without any user intervention.
- Straight forward rules to correlate different data and model simplify the implementation.

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IX. BIOGRAPHIES

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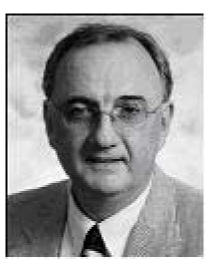

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