

New Approaches for Smart Device Integration and Maintenance of Power System Models Utilizing a Unified Data Schema

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Abstract— A ‘green button’ concept was recently proposed to challenge the energy industry to provide customers with immediate access to real-time energy usage. This challenge was just the latest in a series of government initiatives that require vast amounts of data (both static and real-time) to be integrated into the operational decisions of those who control the electric grid. Due to decisions made during a 2004 market redesign, the Electric Reliability Council of Texas (ERCOT), the independent authority for most of the electric grid in the state of Texas, began development of a centralized data warehouse with an overarching model schema to contain, maintain and deliver consistent model data representative of the Texas electrical grid. This paper describes the implementation of the ERCOT operational data management systems for the nodal market, and specifically, the development of the Common Information Model (CIM) for ERCOT and the development of the Network Model Management System (NMMS) used to maintain the CIM representation of the Texas electric grid. This methodology of using CIM and the built-in flexibility inherent with its implementation are the key to providing ERCOT with low-cost/low-risk strategies for meeting future data requirements such as those associated with the ‘green button’ challenge.

Index Terms—CIM, ERCOT

I. INTRODUCTION

Information system technology is currently transforming the power industry. The ubiquity of vast amounts of real-time streaming point-source operational telemetry, combined with a vast assortment of devices being integrated into the power system at all levels (transmission, distribution, meters, even individual appliances), is creating a pressing need for change.

Customer expectations on service have outpaced ability for power industries to deliver. The historic nature of closed proprietary software which runs energy management systems, coupled with closed loop communications systems utilizing SCADA protocols, is creating situations where merging in new technologies is both prohibitively expensive and operationally risky. These new devices, in theory, will allow the power grid to be operated closer to its physical limits without risking the loss of any operational security. In

addition, implementation of these new devices promises to lower the socialized costs of grid operation by reducing the need for generation and transmission infrastructure required for the support of things such as peak system load shaving.

This clash of customer driven demand versus closed proprietary systems creates a stark choice for the power industry, to either keep the existing platforms and the status quo (with its higher fixed cost, and possibly overbuilt infrastructure) and slowly move to incorporate new technologies over the course of years as they are incorporated into the baseline of vendor software platforms, or take the risk and attempt to integrate these emerging technologies into the grid operations internally, with the possibility of high integration costs, operational dangers of the new unproven technologies, and the danger that the implemented solution once integrated will not have support in the future.

This paper’s objective is to illustrate that by leveraging existing industrial standards when approaching the process of integrating these emerging technologies, both internally utilizing them in data structures, and employing only vendor software conforming to standards, the dangers of costs and operational risks may be mitigated to a point to where the power industry may safely embrace these new technologies and quickly merge them into existing operational infrastructure. By describing forces driving integration, the selection of a common platform, explanation of a common schema, and a case study highlighting the integration methodology, the argument is advanced that utilizing a unified data schema eases integration of new devices into the data model.

II. DRIVING FORCES OF POWER SYSTEM INTEGRATION

In December 2010, the Electric Reliability Council of Texas (ERCOT) successfully transitioned to a new node-based market design. Transferring to the new nodal market required significant changes to both systems and processes. The implementation required the roll out of several entirely new components including the Day-Ahead Market, the Security Constrained Economic Dispatch, and the Congestion Revenue Rights Auction, all of which needed to be supported by a single integrated modeling platform.

Less than a year later, in September of 2011, Aneesh Chopra, the US Federal Chief Technology Officer (CTO) for the Office of Science and Technology Policy proposed a concept. Based on the “Blue Button” initiative, (work

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announced by Health and Human Services Secretary Sebelius and the US Department of Veterans Affairs involving a new website enabling consumers to download their personal health data and share it with health providers and care givers, all by “the click of a button”) a challenge was issued to the power industry: Apply the same idea to the energy industry with a “Green Button”.

This “Green Button” is just the latest in a long list of items requiring integration into the ERCOT data model. As technologies evolve, new data services such as phase-angle measurements, market products such as distributed controllable load resources, and new methodologies such as solar and wind power generation forecasting, need to be merged into an already complicated energy management process. In order to understand how the “Green Button” initiative, and others like it, will become reality at ERCOT, it’s important to understand how (due to decisions made during the market development) ERCOT is currently set up, the nature of the ERCOT systems that currently feed data into the nodal market, what industrial standards are currently being utilized and why, and how these new and emerging technologies will be integrated into both IT infrastructure and into the operational decision making that maintains the reliability of the electric grid.

III. NETWORK MODEL MANAGEMENT SYSTEM DESIGN

The Network Model Management System (NMMS) was designed around the concept of flexibility and including (to the extent possible) the use of accepted industrial standards for the transmission of model related information to downstream systems.

A. Integration Methodology

The desire to use industrial standards drove the design toward the use of IEEE standards for data exchange and IEC standards for the modeling of information. ERCOT decided to utilize the Common Information Model (CIM) standard as part of an effort to integrate a number of task specific applications that shared common data elements. Specifically, the Resource Description Framework (RDF) standard was utilized within an eXtensible Markup Language (XML) file, to describe Common Information Model (CIM) data. The CIM standard was considered the superior option for several reasons. First, as an open-source standard, it was encumbered by fewer intellectual property issues, and offered superior documentation and collaboration to vendor specific propriety systems. Second, the standard was understood by vendors, and was relatively mature in its application; most vendors already have CIM-based importers that can read XML-based CIM files and populate their internal propriety databases. Finally, the CIM schema can be easily extended and altered. The rule set for modification of the schema allowed for easy manipulation which aided reduction of costs associated with database schema changes.

B. System Communications using CIM

By using industrial accepted standards like CIM, generic

data adapters that can be coded by individual vendors as interfaces to translate data from CIM format to their internal proprietary format used in their downstream system. This greatly simplifies integration of components as it allows all coding being done by different vendors to program against a common data source in a common format. For a vendor’s application to be considered CIM compliant, it is required to ignore anything that it doesn’t actively use. While this may seem like a small requirement, its impact on costs of schema change implementation is significant.

IV. MODEL IMPLEMENTATION USING CIM

CIM is an open standard for representing power system components originally developed by the Electric Power Research Institute (EPRI) in North America and now is a series of standards being sponsored by the International Electrotechnical Commission (IEC). The standard was started as part of the Control Centre Application Programming Interface (CCAPI) project at EPRI with the aim of defining a common definition for the components in power systems for use the Energy Management System (EMS) Application Programming Interface (API), now maintained by IEC Technical Committee 57 Working Group 13 as IEC 61970-301. When speaking of “CIM”, it’s commonly understood to consist of three separate IEC standards:

1. The IEC standard 61970-3011 is a semantic model that describes the components of a power system at an electrical level and the relationships between each component.
2. The IEC 61968-112 extends this model to cover the other aspects of power system software data exchange such as asset tracking, work scheduling and customer billing.
3. The CIM for Electricity Markets then extends both these models with IEC 62325-3013 to cover the data exchanged between participants in electricity markets.

These three standards collectively known as the “CIM standard” were developed for power systems and have three primary uses:

1. Facilitate the exchange of power system network data between organizations.
2. Allow the exchange of data between applications within an organization.
3. Exchange market data between organizations.

As mentioned earlier, CIM was originally designed only as a semantic language for data exchange; the ERCOT NMMS also uses it as a schema for information presentation and storage.

A. CIM Classes

CIM is an expression of UML and the basis of this organization is the Class. A Class represents a specific type of object that is to be modeled. A Class hierarchy is the abstractions of the modeled Class that define every type of component within an organization as a separate class. Each

Class can have its own attributes and relationships with other classes. A Class can be instantiated into any number of separate instances (objects in the object-oriented programming) each containing the same number and type of attributes and relationships, but with their own internal values.

B. Class Inheritance

Inheritance (Generalization in UML syntax) defines a class as being a type of another class. When a class is a type of another class, it inherits all the attributes of its parent, but can also contain its own attributes. All classes can be abstract or concrete, depending on whether they are to be instantiated. If the class is in the schema to define an abstract class that represents a common parent for many other classes then it is considered abstract, but if class may be instantiated then it is concrete. An example of a class schema and class inheritance, an *IdentifiedObject* Class contains the attribute *name* and other attributes necessary to identify an object, a *Stadium* is a Class type representing a stadium, an *ApartmentComplex* is a Class type representing an apartment complex, and Class of *Building* representing a building. Please note that the Class is a representation of the instance, not the instance itself. A building will have attribute *GPScoordinates* representing the GPS coordinates, a stadium will have an attribute of *seatingcapacity* representing the seating capacity, and an apartment complex will have an attribute of *numberOfApartmentUnits* representing the number of apartments in the complex.

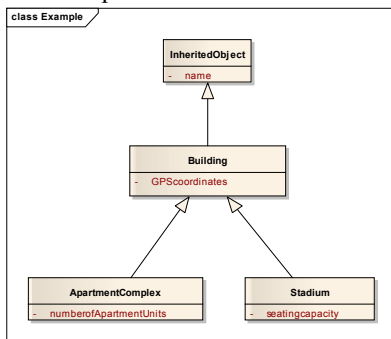


Figure 1: Class Inheritance Example

Figure 1 denotes this graphically. In this example, an instance of *ApartmentComplex* will have the “personal” attribute *numberOfApartmentUnits*, in addition, it will have the inherited attributes of *GPScoordinates* from the class *Building*, and the attribute *name* from the *IdentifiedObject* class. An instance of *Stadium* will have all of the same inherited attributes as *ApartmentComplex* but will have its own unique attribute of *seatingcapacity*. In RDF/XML format, an instance of *ApartmentComplex* is would take the format of the instance described in the following partial model file:

```

<?xml version="1.0" encoding="UTF-8"?>
<rdf:RDF xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
  xmlns:cim="http://iec.ch/TC57/2006/CIM-schema-cim10#"
  xmlns:spc="http://www.siemens-ptd/SHIMM1.0#"
  xmlns:etx="http://www.ercot.com/CIM11R0/2008/2.0/extension#">
  <etx:ApartmentComplex rdf:ID="Apat_1">
    <cim:IdentifiedObject.name>
      APART_1
  
```

```

    </cim:IdentifiedObject.name>
    <etx:Building.GPScoordinates>
      30.29128,97.73858
    </etx:Building.GPScoordinates>
    <etx:ApartmentComplex.numberOfApartmentUnits>
      121
    </etx:ApartmentComplex.numberOfApartmentUnits>
  </etx:ApartmentComplex>
</rdf:RDF>

```

C. CIM Association

In Figure 1, the only class relationship depicted is that of inheritance. Classes may have other relationships defined that represent linkages between classes showing relationships. For instance, a *Building* may need to be linked to classes of *Walls*, *LightFixture*, and *Street*. This need to associate objects brings into play three important concepts, that of cardinality, aggregation, and composition.

1) Cardinality

Cardinality is a property of associations that defines numerically how the association exists. An association will have cardinality on both sides of the association. For instance, a building could have zero, one, or more (possibly infinite) number of streets next to it, and any street could have zero, one, or more (possibly infinite) number of buildings along the path that runs. In this case, the association is considered zero-to-many from both street and from building. But in the case of a light fixture to building association, the light fixture can only be contained within one building, while the building could have zero, one, or more (possibly infinite) number of light fixtures associated with it.

2) Aggregation

Aggregation is a special kind of association that defines a relationship between classes, indicating that one is a container class for the other. In Unified Modeling Language (UML) syntax class diagrams, associations of this type will be denoted with a clear diamond on the side of the association that is the container. It’s important to note that an aggregation association (sometimes referred to a clear or white diamond association), does not preclude an instance either class from existing independently. For example, a building can contain many light fixtures, but if the building is removed, the light fixtures may still exist on their own, but if they do exist, contained within a building, they must follow the cardinality of the schema.

3) Composition

Composition is another special kind of association that is a specialized form of aggregation where the contained object is a fundamental part of the container object. In Unified Modeling Language (UML) syntax class diagrams, associations of this type will be denoted with a filled diamond on the side of the association that is the container. It’s important to note that with a composition association (sometimes referred to a black diamond association) the objects associated with the instance may not exist independently. For example, a building can have many walls, but if the building is removed, the walls cannot exist by themselves (i.e. if the building is destroyed, by association, the walls have been removed as well).

Figure 2 denotes the types of associations, and it's worth noting that both the *LightFixture* class and the *Wall* class also both inherit the attribute name from the *IdentifiedObject* class.

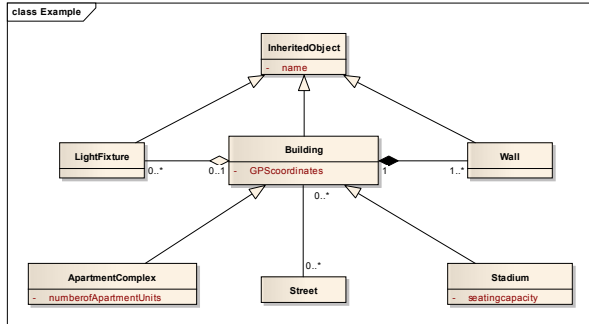


Figure 2: Associations example

V. INTEGRATION CASE STUDY

To explain how new items required for supporting the “Green Button” initiative can be incorporated into the ERCOT CIM model, it is useful to look at a case study of how other items have been incorporated into the model. Any new items will follow basically the same process. For the purposes of modeling, ERCOT defines combined cycle plant as a set of one or more combustion turbines (CT) powered by some type of fossil fuel, oil, natural gas, etc., each with a heat recovery steam generator (HRSG), and a set of one or more steam turbines (ST) where the exhaust heat from the combustion turbines is recovered in the HRSG to make steam for the steam turbines resulting in greater overall plant efficiency. A graphical representation of a 3x1 combine cycle plant is shown in Figure 3, in this physical plant, the individual HRSGs are all directing steam to a single steam generating unit.

Each steam turbine and each combustion turbine have an electrical generator that produces electric power (CTG and STG). An electrical representation of a 3x1 combine cycle plant is shown in Figure 4; in this representation the three combustion turbine generation units and the steam generating unit all appear as individual generating units supplying energy to the electric grid.

Typical configurations contain one, two, or three combustion turbines each with a HRSG and a single steam turbine. Because of high thermal efficiency, low initial cost, high reliability, relatively low gas prices and low air emissions, combined-cycle gas turbines have been the new resource of choice for bulk power generation for well over a decade.

The combine cycle plants created unique challenges for ERCOT because they can operate in a number of different configurations. For example, a “2x1” power block (2 combustion turbines with 1 steam turbine) may have as many as three individual configurations in normal operation and six if the plant has the ability to bypass the HRSG and operate simple-cycle. With the use of various power augmentation methods, the same power block can have upwards of twelve configurations. A “3x1” power block (3 combustion turbines with 1 steam turbine) may have as many as seven individual configurations in normal operation and fourteen if the plant has the ability to bypass the HRSG and operate simple-cycle.

With the use of various power augmentation methods, the same power block can have upwards of twenty six configurations. The stations thermal operating and electrical generating characteristics differ from one state to another and the transition from one state to another has its own operational limits and costs.

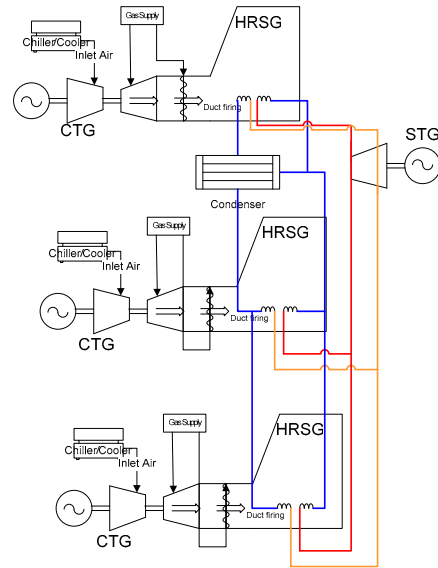


Figure 3: 3 x 1 Plant Physical Layout

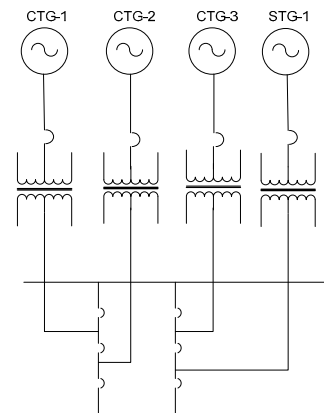


Figure 4: 3 x 1 Plant Electrical Layout

1) CIM Modeling of Combine Cycle Plant

Combined cycle plant modeling using the standard industry CIM presented several challenges, while CIM did contain a *CombinedCyclePlant* class, the schema did not contain a way to model the level of granularity necessary to truly describe a combined cycle plant's operation. Most notably, was the lack of operating states and transition states, the knowledge of which was required for proper dispatching of the combined cycle plant as a unit. For instance, during normal operations, the ERCOT Energy Management System (EMS) would need to calculate which units need to be dispatched to maintain grid reliability, however, a modeled generating unit powered by steam could not be dispatched by itself, since it would have no waste heat to power it unless a thermal generating unit was also being dispatched. To prevent the improper dispatching of these units, clearly the EMS application need to be aware of what valid operating states were available and not attempt to

dispatch units into invalid operating states. Also important was how the combined cycle plant would be dispatched when transitioning from one operating state to another; in some cases it was important that the thermal generating units be brought up one at a time, and operationally, could not transition from one fossil fuel unit feeding one steam unit directly to a three fossil units feeding steam to one steam unit configuration. The combine cycle plant had transition first to a two fossil fuel unit feeding one steam unit, then to a two fossil units feeding one steam unit, and then finally to a three fossils unit providing steam to one steam unit. Added to the complexity was the additional design consideration that combined cycle plants had to be settled with the ERCOT nodal market as a single “unit”. This created an additional complexity because non-combined cycle plant units are settled at their point of interconnection to the grid, while combined cycle plants, due to their nature, may have multiple points of interconnection. To mitigate these shortcomings with the baseline IEC CIM standard, several additional ERCOT CIM modeled classes were added to as well as several changes to existing CIM classes:

1. *CombinedCyclePlant* - while the *CombinedCyclePlant* class did exist in baseline CIM, several additional attributes were added to support ERCOT markets functions. This included the attribute *logicalresourcenodename*, used to store the name for the abstract point that the market would use for settlement and the attribute *qualification*, used to determine if the combined cycle plant was eligible for market participation.
2. *LogicalConfiguration* - the ERCOT CIM model utilizes a *LogicalConfiguration* as a collection of all configurations in a combined cycle plant that can be physically operated using the primary combustion turbines and primary steam turbines, one, two, or many logical configurations may be present at a combined cycle point (black diamond association). The *LogicalConfiguration* class allows for the aggregation of multiple configurations of the same type. For example a one-on-one configuration, where one combustion turbine is supporting one steam turbine in a large combined cycle plant with multiple combustion turbines and multiple steam turbines where any one of the combustion turbines could be powering any one of the steam turbines, the *LogicalConfiguration* class allows for the collection of all of these configurations which only one combustion turbine is powering only one steam turbine.
3. *Configuration*-the ERCOT CIM model utilizes instances of type *Configuration* to define the constituents and operational characteristics of various combinations of combustion turbines and steam turbines that may operate in tandem within a combined cycle plant. In the ERCOT implementation, a configuration exists only as a construct within a logical configuration (black diamond association) additionally, every configuration will be linked to one or more configuration members (black diamond association). The *Configuration* class is used for holding number of operational parameters defining the capabilities of the combined cycle plant in that specific configuration, and essentially allows for the multiple generating units of the combined cycle plant to be treated as a single unit. These aggregated operational parameters include things such as the high reasonability ramp rate limit, the maximum amount of time that the combined cycle plant may operate in that configuration and, if more than one configuration has been modeled for a logical configuration, the configuration will denote whether it is the primary configuration or is an alternate configuration. Also, the *Configuration* class includes information about whether the configuration is a startup or shutdown configuration. This attribute is necessary since combined cycle plants cannot start up with every possible configuration, nor can they shut down from every possible configuration.
4. *TransState* -ERCOT CIM utilizes instances of *TransState* type to define the available transitions between the various configurations of a combined cycle configurations. One or more *TransState* may be defined for every configuration of a combined cycle plant. Every *TransState* is defined as either an “up-transition” where the total number of primary members in the destination configuration is greater than or equal to the number of primary members in original configuration, or as a “down-transition” where the total number of primary members in the destination configuration is less than to the number of primary members in original configuration (this is done with a single Boolean attribute on the *TransState* class). The *TransState* class has two associations both going to *Configuration* class, a “to” configuration association and a “from” configuration association. For every *TransState* class both associations must exist, this means for a *TransState* to be modeled two or more configurations must exist.
5. *ConfigurationMember*-the ERCOT CIM data dictionary utilizes instances of type *ConfigurationMember* to identify (via associations) the generating units that are part of the combined cycle plant *Configuration* instance along with its operational nature i.e. gas or steam turbines and the primary/alternate status of the associated generating unit. With any *Configuration* instance, one or more *ConfigurationMember* instances may be defined to describe the configuration.

2) Usage

By adding these ERCOT specific CIM classes, it made it possible to document all of the operational states of a combined cycle plant from which generating units would take part: the startup configurations, how these configurations transitioned to other configurations that might be more economically or operationally viable, which thermal and steam units could operate in which configurations, and how after operation, combined cycle plant could then be transitioned into a configuration for shutdown. For Example, a 2 thermal generating unit, 1 steam unit (“2x1” power block) as mentioned earlier. In this example, the unit can be operated in the 3 following logical configurations.

- Logical Configuration 1: 1 Thermal, No Steam
- Logical Configuration 2: 1 Thermal, 1 Steam
- Logical Configuration 3: 2 Thermal, 1 Steam

And four actual configurations (configurations where the thermal generators (TG_1, TG_2) and the steam generator (SG_1) are specified):

- Configuration 1: TG_1
- Configuration 2: TG_1, ST_1
- Configuration 3: TG_2, ST_1
- Configuration 4: TG_1, TG_2, ST_1

Figure 6 displays graphically how the CIM model mapping is interpreted, where the arrows represent TransStates depicting configuration changes. The transition path may also be shown in the form of a matrix, as displayed in Figure 7, the ERCOT convention is that if the transition has the same or more generation units on-line then the transition is considered a “up” transition, if less, then it is considered a ‘down’ transition.

The CIM XML/RDF modeling for such a unit would include an instantiation of a single CombinedCyclePlant class, 3 instances of LogicalConfiguration, 4 instances of Configuration, and 11 TrasStates. While not denoted in Figure 7, eight members of the ConfigurationMember class are also modeled between the ThermalGeneratingUnit class and the Configuration class.

By extending the industrial standard CIM model with extensions necessary for a specific implementation, several efficiencies are gained, such as lessening development costs and risks associated with new implementations, both of which will be extremely important in the incorporation of any smart device data.

VI. CONCLUSION

This paper describes the NMMS data management system and the industry standards currently employed by ERCOT. By embracing, extending, and implementing these common industrial standards (specifically CIM), new items can be quickly and efficiently incorporated into a common data schema with low risk, saving both money and time. This methodology can easily be scaled to meet integration needs (Smart Meters, Distributed Resources, PMUs, etc.) and is only constrained by technological pace of systems consuming and utilizing the data.

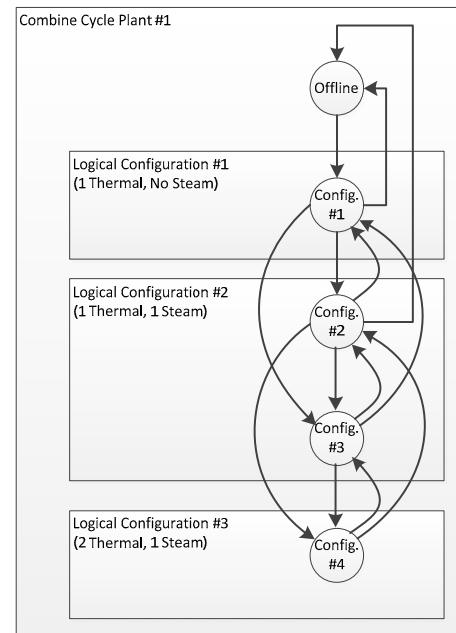


Figure 6: Block Diagram

| Transition Matrix | | To Configuration | | | | |
|--------------------|-----|------------------|---|---|---|---|
| | | Off | 1 | 2 | 3 | 4 |
| From Configuration | Off | | ↑ | | | |
| | 1 | ↓ | | ↑ | ↑ | |
| | 2 | ↓ | ↓ | | ↑ | ↑ |
| | 3 | | ↓ | ↑ | | ↑ |
| | 4 | | | ↓ | ↓ | |

Figure 7: Configuration path matrix

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VII. BIOGRAPHIES

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