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Evaluation of a Generic Virtual Power Plant Framework Using Service Oriented Architecture

Peter B. Andersen*, Bjarne Poulsen**, Morten Decker***, Chresten Træholt**** and Jacob Østergaard*****
Technical University of Denmark, Kgs. Lyngby, Denmark.
* Department of Informatics and Mathematical Modeling, Email:peterbachandersen@gmail.com
** Department of Informatics and Mathematical Modeling, Email: bjp@imm.dtu.dk
*** Department of Informatics and Mathematical Modeling, Email: morten@mdecker.dk
**** Centre for Electric Technology, Email: ctr@elektro.dtu.dk
***** Centre for Electric Technology, Email: joe@elektro.dtu.dk

***Abstract* - The purpose of this paper is to find and describe a suitable software framework that can be used to help implement the concept of a Generic Virtual Power Plant in the future power system.**

The Generic Virtual Power Plant concept, along with the utilization of distributed energy resources, has many interesting properties that can influence the future shape of power markets.

The concept holds many promises including cheaper power to the consumer, a more flexible and responsive power production and the support of a more environment-friendly development.

In order to realize a software solution supporting the Generic Virtual Power Plant, an array of different software design principles, patterns and architectures must be applied. Especially Service Oriented Architecture (SOA) can aid in implementing the Generic Virtual Power Plant.

An analysis of the Nordic power market has been carried out in order to identify potential issues and barriers, henceforth mentioned as challenges, connected with the introduction of the Generic Virtual Power Plant concept.

In this paper, three use case scenarios will show how each of these challenges can be overcome by the proposed solution framework. The use case scenarios will be tested by a prototype that has been developed as proof of concept.

***Keywords*—Distributed Energy Resources, DER; Future Power Market; Generic Virtual Power Plant; Micro Combined Power and Heat; Generic market and strategy; Service Oriented Architecture**

I. Introduction

The Generic Virtual Power Plant (GVPP) concept is based on the future use of distributed power generation from small energy production units. One such production unit is the Micro Combined Heat and Power unit, abbreviated μCHP. The μCHP is a small production unit that can be placed directly at the consumer, and is capable of covering the consumer's heat and power consumption. A typical output from a μCHP is around 1-10 kW in electrical power and around 10-30 kW in thermal power [1].

The following summarizes the advantages of the μCHP.

Efficient use of energy - Combined generation of heat and power is more efficient than producing heat and power separately.

Low transmission losses - Since both power and heat is produced at the consumer, losses can potentially be reduced.

Cleaner technologies – Production units which are based on new technologies, such as the hydrogen-based fuel cell, can support environment-friendly production.

The μCHP unit is a good example of the type of production unit a GVPP could utilize for distributed power generation. It is however not the only type, and the more general term Distributed Energy Resource (DER) will be used in the following.

The term DER is commonly used to describe a unit that can contribute with a certain amount of electrical energy to the net.

The use of the word "resources" in DER, as opposed to "distributed generation", denotes that the unit can be a power storing unit as a battery; furthermore, the DER is not necessarily stationary, but can move around supplying power to the grid at different locations. This definition of a DER fits well with the expected penetration and utilization of electric cars in the future power system.

If a DER has a production capacity capable of matching the consumers' needs at peak hours, the unit would, during non-peak hours, be able to produce more than is needed by the consumer.

Selling surplus power to the market can be a lucrative idea for the owner of a production, holding the promise of a better return of investment.

It may, however, at first sight seem unlikely that a DER's surplus of power production, which would be considerably smaller than the production of a traditional production facility, would be of interest to the market. It may also seem unlikely that the unit owner would undertake the time-consuming and costly task of becoming a power producer on market terms.

To overcome these barriers, the GVPP is introduced. If the DER owner can cooperate with other unit owners, thus sharing the expenses and administrative overhead in entering and acting on the market, then a more lucrative business model is in place.

The combined production of several DERs would be sold on the market as if produced by a single larger production facility. Thus the term "Virtual" is used. The GVPP should also be able to seamlessly accept power

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from different kinds of DERs, such as e.g. wind turbines. This is why the GVPP has a "Generic" nature.

By joining the GVPP, the DER owners can divide the overhead costs among them, and delegate the trading responsibility to a single trader representing the GVPP on the market.

Fig. 1 shows how the members of the GVPP cooperate to trade on the market as a single entity.

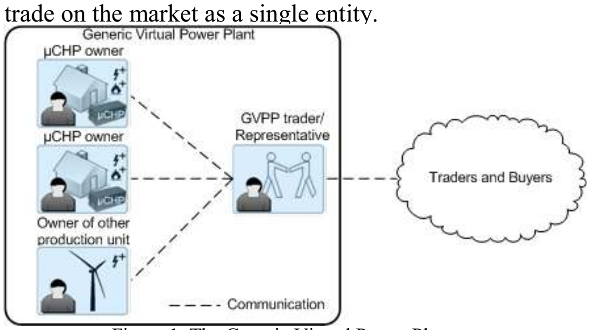

Figure 1. The Generic Virtual Power Plant

The GVPP can compete on the power market on several parameters:

Fast reaction to demand - The GVPP could be able to meet demand on a rather short notice. This is due to the short startup time of the small DERs.

Fine-grained control - Since the power would come from many small units, the GVPP could also get a rather fine-grained control over the production output to prevent the expense of unbalances.

More robust production - Since the power production is distributed, a breakdown of a single production unit would not cause any major unbalances.

Low startup cost - It would be relatively inexpensive to start a production as many DER units would already be running at some capacity.

To achieve these market advantages a software solution capable of overcoming the challenges introduced by the GVPP concept must be in place.

II. STATE-OF-THE-ART FUTURE EUROPEAN POWER SYSTEM RESEARCH

Many projects and much research concerning distributed energy resources (DER) and Virtual Power Plants have been initiated as a result of cooperation between governments, organizations, manufacturers and research establishments at both local and international levels.

Several political and technological tendencies can be identified as drivers of change: the ageing European electric system, the liberalization of the power market, the penetration of DER, environmental concerns and the exhaustion of fossil fuels.

Some of the main focus points within GVPP research have been:

- **Feasibility of DER market participation**
- **VPP control and coordination optimization**
- **Design of VPP and power system**

Within the last category "Design of VPP and power systems" one of three different design approaches can be used.

A. Trends in VPP design

The first approach is the Centralized Controlled Virtual Power Plant (CCVPP) illustrated in Fig. 2.

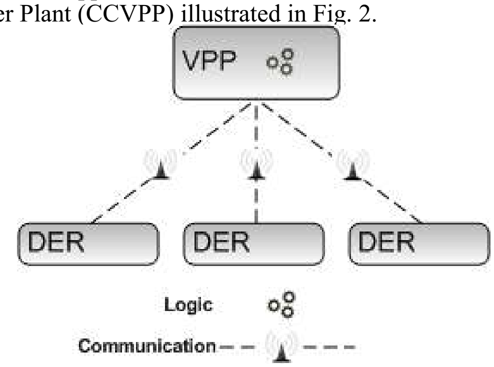

Figure 2. The CCVPP Design

In this design all control logic lies with the VPP and all knowledge about the market and the planning of production is separated from the DER.

The advantage of this design is that the VPP is given a simple way of utilizing the DERs to meet market demand.

A different design is the Distributed Controlled Virtual Power Plant (DCVPP) illustrated in Fig. 3.

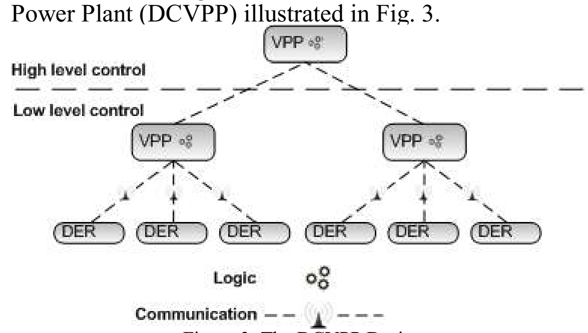

Figure 3. The DCVPP Design

The DCVPP introduces a hierarchical model by defining VPPs on different levels. A local VPP supervises and coordinates a limited number of DER while delegating certain decisions upwards to a higher level VPP. This design can help simplify the responsibilities and communication of the individual VPPs.

The third design is the Fully Distributed Controlled Virtual Power Plant (FDCVPP) illustrated in Fig. 4.

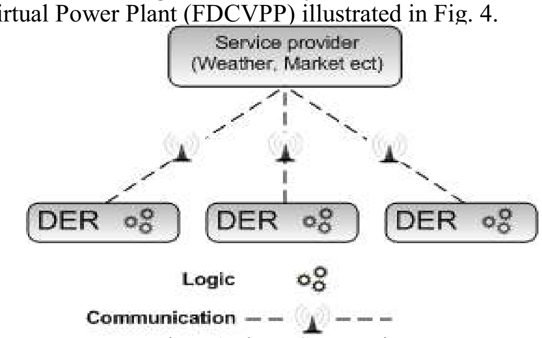

Figure 4. The FDCVPP Design

In this design each DER will act as an independent and intelligent agent that participates and reacts on the state of the power system and market.

This design holds much promise in supplying a dynamic and optimized power system.

B. European projects on DER and VPPs

The following will describe a few of the most significant European projects that in some way or other contribute to the research and demonstration of DER implementation using a VPP setup in the power system.

1) SmartGrid

The SmartGrid concept and vision has been defined by the "European Technology Platform for the Electricity Networks of the Future" organization [2].

This organization was formed in 2005 after a number of industrial stakeholders and research establishments represented at the 2004 "International Conference on the Integration of Renewable Energy Sources and Distributed Energy Resources" conference decided to join forces in order to define a common vision and technological platform for the future power system.

The vision is described in the document "European SmartGrids Technology Platform Vision and Strategy for Europe's Electricity Networks of the Future"[3] and includes an accessibility vision that states that small and locally distributed energy resources based on renewable energy should be supported by the network, and the power that is produced should be accessible by all participants.

The SmartGrid vision outlines the use of DER which the VPP concept builds upon.

2) The Fenix Project

The Fenix Project is a multinational, European funded, initiative.

The overall goal of the project is "To conceptualize, design and demonstrate a technical architecture and commercial framework that would enable DER based systems to become the solution for the future cost efficient, secure and sustainable EU electricity supply system."[4]

The project aims to achieve this by dismissing the traditional fit-and-forget way of connecting small distributed energy resources to the net.

Instead, the DER should be actively integrated into the power system as opposed to merely "connected" to it.

This new active control paradigm should be used to coordinate the numerous DERs that are expected to appear in the future power system as well as the traditional power production facilities resulting in a Large Scale Virtual Power Plant (LSVPP).

The Fenix Project proposes the use of both Commercial and Technical Virtual Power Plants in a hierarchical structure using a DCVPP approach to VPP design.

3) The Ecogrid project

The Ecogrid project is a large European project with more than 20 different countries participating[5].

Building on the visions from Smartgrid and the experience and findings from several other European projects, the Ecogrid project aims at developing an optimized way for end users and system operators to interact and cooperate across borders in the future power market.

To achive this, the Ecogrid introduces the concept of a Distributed Energy Marketplace. The main purpose of the Distributed Energy Marketplace is to put end users at the centre of the power system and provide system operators with access to the most cost effective solutions for system management.

The Ecogrid project will use the small island of Bornholm, located in the Baltic Sea east of Denmark, for VPP demonstrations.

Future activities will introduce electric cars as a DERs into the Distributed Energy Marketplace.

C. Papers on DER control and VPP

Several papers have been written on the subject of ICT for Energy Efficiency.

The paper titled "Theoretical Evaluation of a Generic Virtual Power Plant Framework Using Service Oriented Principles"[6] has described how SOA with Web Services can aid in implementing the necessary communication in a VPP system.

One of the most investigated methods of controlling DERs in a VPP is the use of price signals.

The author Fernando L. Alvarado has written several papers on price signals. In the papers "Is System Control Entirely by Price Feasible?"[7] and "Controlling power systems with price signals"[8] Fernando L. Alvarado argues that using price signals to control DER production in a free market is possible, but that several issues must be carefully considered in the design of such a power system.

III. Challenges

Based on an investigation of the Nordic power system and several projects and papers proposing different approaches to VPP setup and control (of which some are mentioned in the previous section), the main common software and communication challenges have been identified.

Whether a CCVPP, DCVPP or a FDCVPP design approach is followed and whether price signals or another control mechanism is chosen the same following challenges will apply.

A. The challenge of loose coupling

The DER will not be owned by the GVPP. If the GVPP concept is successful, it is quite possible that several GVPPs will operate on the market and the production unit owner should be able to choose freely. The GVPPs group of members is in no way static.

B. The challenge of generic adoption

The GVPP will have to support and communicate with an array of different DER with different properties and software platforms. How will the GVPP be able to dynamically adopt units with different characteristics?

C. The challenge of interchangeable strategies

It is likely that the behavior exhibited by a production unit should change depending on choices made by the unit's owner or the GVPP it participates in. For instance, is a centralized or distributed control scheme used? How independent should the production unit act? Is the DER producing power for the market and should it respond to a price signal? Or is it delivering an auxiliary service to the power system?

When the purpose or control-strategy of a production unit changes, so should its behavior. This change in behavior should be imposed dynamically from outside the production unit.

D. The challenge of security and robustness

It could have serious consequences if the security or reliability of the GVPP is compromised. How can it be guaranteed that the information and communication within the GVPP can be kept confidential and that communication breakdowns are handled properly?

If a solution is found to these challenges, the GVPP will have a better chance of success in the future power market.

IV. Proposal for a Solution Model

The following proposes a way to realize the GVPP model. It is expected that hardware which allow for Internet access and communication can be installed in DERs.

Fig. 5 shows the two major steps involved in the process of finding and becoming member of a GVPP.

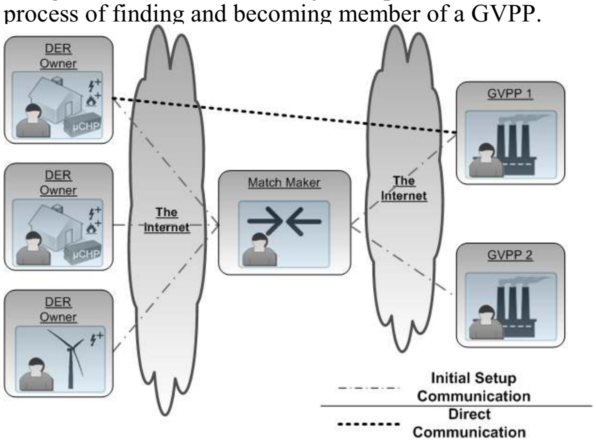

Figure 5. Proposal for a solution model

During the first initial setup step the production unit owner can communicate with a "Match Maker". This entity allows the unit owner to register the production unit at a single location and to search for a GVPP to connect to. This establishes a loose coupling between the production unit owner and the GVPP.

During the second step a connection is set up between the unit owner and the GVPP and they can communicate directly. When the connection is in place, the GVPP should be able to efficiently coordinate the power production of the unit. The next section will in greater detail describe the technologies and designs that can help create this model and handle the four challenges.

V. Solution Technology and Design Proposal

In order to implement a solution capable of meeting the challenges, the following technologies and implementations are proposed.

A. Solution proposal: Loose coupling

Ever since the concept of object oriented programming was introduced in the 1960s, several different high-level architecture and design principles, such as modular programming (1970s) and interface/component design (1990s), have been introduced. Although they differ in name and implementation, their purposes are largely similar.

The all describes ways to divide software into separate and independent "building blocks" or modules with unique responsibilities and functionality. This is done to achieve loose coupling.

Originally, the modularity concept was concerned with the collaboration between modules within a single application. But in more recent times an increased number of technologies has been introduced which allows collaboration between modules residing on different computers in a network.

Within the field of distributed computing, "Service collaboration" is often used in situations where there is a "far link" (for instance spanning the internet) between a module and a consumer. Service oriented collaboration offers interoperability and loose coupling.

1) Service oriented architecture

A very well-known and popular architecture that makes use of service collaboration is Service Oriented Architecture (SOA). SOA inherits many of the attributes of earlier modular architectures in that it helps support low coupling, separation of concerns and Interoperability through functional "building blocks".

A formal definition for SOA is given by the World Wide Web Consortium (W3C) which describes SOA as: "A set of components which can be invoked, and whose interface descriptions can be published and discovered" [9].

SOAs with well defined services and by the use of open standards and protocols defined by the WS-Basic Profile can offer loose coupling between modules and the companies hosting them.

This makes SOA a good candidate in implementing a GVPP as the DER, the Match Maker and GVPP would play the roles of consumers and providers with separation of concerns via loose coupling.

2) The architectural Broker pattern

The architectural Broker pattern can be used to "structure distributed software systems with decoupled components that interact by remote service invocations"

The motivation for the pattern is to "introduce a broker component to achieve better decoupling of clients and servers" [10].

The purpose of the Broker pattern is largely similar to that of the Match Maker in that it provides the consumer with an easier way to interact with a distributed system. One of the main purposes of the Match Maker is to make it easier for small DERs to participate in the GVPP and that is exactly what the Broker pattern can help achieve.

The solution proposal for handling the challenge of loose coupling is thus to implement the solution model using SOA and a Match Maker inspired by the Broker pattern.

B. Solution proposal: Generic adoption

Within the GVPP domain generic adoption means that different DERs can be used by a GVPP despite the potential differences in software platforms and physical differences linked to a specific type of unit.

The subject of generic adoption can be translated into the term interoperability within the software domain and can be achieved through standards and definitions.

The data types, messages and operations that the various participants support must be similar in order to guarantee interoperability using SOA.

It is, in other words, necessary to develop custom and domain-specific standards that all GVPP participants must comply with.

The Web Service Description Language (WSDL) is a XML based language that describes a web service.

WSDL describes which operations a service contains, how to access the operations and the messages that will be used when communicating with the service [11].

WSDL Messages describes the data types that a message can contain by using XML Schemas Definition (XSD) documents. A XML Schema Definition (XSD) file contains certain rules for the form and contents of a XML file.

WSDL offers a machine-readable and standard interface to a web service and XSD describe the data which would be used in the service message communication.

Thus, SOA using Service interface and message standards can allow a GVPP to communicate with several DERs in the same way.

The solution proposal for handling the challenge of generic adoption is to use WSDL and XSD standards to guarantee interoperability.

C. *Solution proposal: interchangeable strategies*

Interchangeable strategies mean that it should be possible to change the strategy or logic of a production unit. It is necessary to have a quick and efficient way of dynamically changing the behavior of a system.

Such a system could in software terms be called dynamic and flexible and several patterns and technologies are aimed at this.

1) Dependency injection principles

Dependency injection allows a module to receive an external dependency while or after it has been being initiated [12].

Dependency injection is typically used within object oriented programming, but the same principle can be applied to systems connected via a network where a subsystem can inject dependency information into another subsystem.

2) Strategy pattern principles

The strategy pattern is a simple pattern which describes a way to dynamically change the behavior of an object. In this pattern each behavior or strategy is described by objects with a common interface [13].

Since objects can be interchanged dynamically through polymorphism and be injected through dependency injection, this allows for great flexibility in changing how a system works from the outside. Its principles can also be applied to systems connected through a network.

3) Assemblies and reflection

Microsoft's .Net Assemblies is another technology aimed at making software modules more reusable and interchangeable. An assembly can be defined as a "self-describing building block" [14].

When using an assembly, its contents can be discovered in a process called reflection. This is possible through the metadata that the assembly contains.

Reflection makes it possible to scan and validate an assembly at runtime.

The patterns and technologies described in this section all contribute with ideas and principles that can be used when encapsulating behavior and injecting it into a system.

Assemblies with reflection describe how modules can be put into self-describing and language-independent packages that grant better reusability; the strategy pattern describes how reusable modules can be used to represent behavior in a system; and finally the Dependency injection patterns describe how such a reusable object representing a strategy can be fed dynamically to a system during runtime.

These principles can be used when developing a way to meet the interchangeable strategies challenge in the GVPP domain.

D. *Solution proposal: Security*

A set of security standards and specifications for web services has been defined as a result of the cooperation between several companies and organizations [15].

The different web service specifications are typically denoted WS-*and has a WS-Security specification subset.

The purpose of WS-Security is to add Authentication, Integrity and Confidentiality to message-based web service communication.

This is achieved by attaching signatures, encryption headers and security tokens to SOAP messages. WS-Security supplies end-to-end application layer security by using the header of a SOAP message.

Microsofts Windows Communication Foundation (WCF) offers a wide range of security configuration possibilities and supports the WS-* standards.

The solution proposal for handling the challenge of security is to use the WS-* standard specifications that can be implemented via WCF.

VI. Case Study

In order to prove that the solution will be able to meet the challenges, several use scenarios have been created. Each scenario involves one or more of the software domain challenges listed previously in this paper.

A. *Scenario 1: Signing up as member of a GVPP*

This Use Case Scenario covers the situation where a Unit owner wishes to register a Production unit at the Match Maker and to find a GVPP to join.

This scenario should be capable of handling **The challenge of generic adoption** since it involves adding new members to the GVPP. The scenario also includes **The challenge of loose coupling** since it covers the process of connecting DERs to GVPPs through a Match Maker.

B. *Scenario 2: Setting up a strategy and communicating*

In this scenario, the DER owner decides to use production communication strategy and sends a message to the Match Maker. The Match Maker then takes care of the communicating the new strategy to the DER and GVPP. Afterwards the DER and GVPP starts communicating using the new strategy.

This scenario covers **The challenge of interchangeable strategies** since it shown how the communication strategy between Production Unit and GVPP is replaced or modified.

C. *Scenario: Handling communication breakdowns*

This scenario will address the challenge of **The challenge of security and robustness.**

In the "Solution Technology and Design Proposal" section, the security aspect of this challenge was covered. This scenario will instead concentrate on the robustness aspect that will be easier to demonstrate. It will show that utilizing certain strategies can make a system more robust when the connection to a GVPP is lost.

VII. PROTOTYPE AND TEST

A prototype software solution has been developed using the methods described in the "Solution Technology and Design Proposal" section in this paper.

Two DERs and two GVPPs as well as a Match Maker have been set up as independent systems using web services for communication. Another application has been created in order to monitor and test the communication between the systems and is shown in Fig. 6. Each GVPP participant system has been given an additional web service operation that the monitor application uses to access and display logs owned by the different systems.

The two gray boxes on the left in Fig. 6 are the DERs, the box to the right is a GVPP and the box in the middle is the Match Maker. The white text in each box is information extracted from the systems log showing the interaction and cooperation between the GVPP participants.

The monitoring application also offers a simple interface which facilitates the introduction of new DERs and GVPPs to the Match Maker. None of the participants have any prior knowledge of each other.

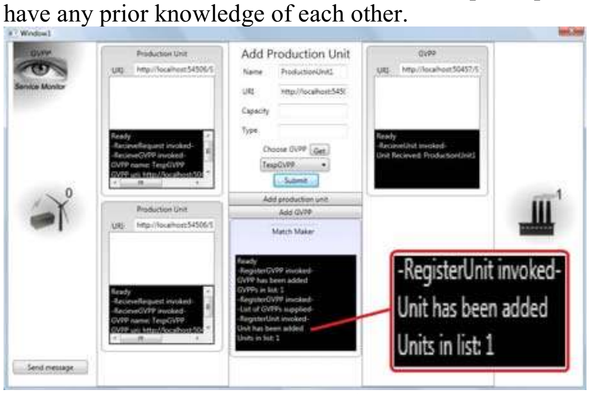

Figure 6. Monitor application

A. Scenario 1 test : Signing up as member of a GVPP

This scenario was tested by first using the monitoring applications interface to add a GVPP. Then a production unit was added and the GVPP was chosen from a list. The match maker then automatically set up the communication between the production unit-GVPP pair, thus completing the scenario.

B. Scenario 2 test : Setting up a strategy and communicating

After having completed the previous test, a strategy was selected from the Match Maker interface between the production unit and GVPP. The GVPP then introduced the members to the new strategy and they automatically started communicating, thereby fulfilling the test.

C. Scenario 3 test : Handling communication breakdowns

An additional production unit and GVPP are registered and connected via the Match Maker. In this test a "robust" strategy is selected for communication. The web service hosted by the GVPP is terminated to simulate a communication breakdown. It is observed how the production unit, having lost the connection to the GVPP, connects to the Match Maker in order to receive a connection to another GVPP. This demonstrates how certain behaviors can improve the robustness of the solution model and fulfill the test scenario. These behaviors are controlled using interchangeable strategies.

VIII. CONCLUSION

This paper has presented the GVPP concept, described some of the projects and papers relating to the concept and shown how a series of software and communication challenges can be defined.

A prototype has been built as proof of concept to demonstrate how the challenges can be overcome by using the following software architectures and patterns

TABLE I.
CHALLENGE TO SOLUTION MAPPING

The Challenge	The Solution Technologies
The challenge of loose association	Service Oriented Architecture and principles from the Broker pattern
The challenge of generic adoption	Service Oriented Architecture and the use of XSD and WSDL.
The challenge of interchangeable strategies	Principles from the injection and strategy patterns as well as .Net Assemblies
The challenge of security	Use of WS-* and WCF security

It is hoped that the technologies presented in this paper can serve as a source of inspiration as to how an ICL framework can be designed to accommodate the future and widespread use of the GVPP concept.

ACKNOWLEDGMENT

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