INTEGRA

Integrated Smart Grid reference architecture of local intelligent distribution grids and virtual power plants

Robert Priewasser · Tobias Gawron-Deutsch · Friederich Kupzog · Christian Neureiter · Wolfgang Prüggler

Abstract – INTEGRA explores how influential a safe and stable system operation in the presence of a large number of mutually interdependent and smart grid services can be organized taking into account the European energy markets. Against the background of different frameworks of policy and regulation it is necessary to reconcile the requirements of various markets with local network conditions. Results are available as a largely standardized Smart Grid Reference Architecture and a "unifying" instance, the "Flexibility operator". Thus, a concrete basis for the necessary discussions and next steps set up and strengthened the strategic positioning of Austria at the European level.

1. Introduction

INTEGRA addresses a central issue in the implementation of smart grid approaches: How can safe and stable operations of intelligent medium and low voltage networks be organized, taking into account a variety of influences of mutual and interdependent smart grid services and at least the actual regulations of European Energy markets? Objective is to prepare the target system of the Smart Grid Model Region Salzburg (SGMS), and to guarantee a homogeneous and efficient operation of the power system (market AND network requirements) on the basis of a single Smart Grid Reference Architecture. INTEGRA develops an internationally visible Smart Grid Reference Architecture, which allows to bring the requirements of the common European market and the nationally authorized, individual schemes in the market system in line, considering a special focus on security and privacy policies by design.
Another goal of INTEGRA is the "missing link" in the form of a toolbox (e.g., interfaces, software modules, ...), to develop the relationships between the different smart grid applications and to provide them for the market. With it the integrated application of smart grid functionality will be enabled, as soon as the relevant applications are feasible from an economic perspective. Technically, the project defines and develops among other things a Flexibility Operator (FlexOP) which was also tested as a proof of concept in SGMS. Thus, organizational and technical interaction of the grid and market-specific processes of the smart grid are made possible. The findings of this project and the transnational cooperation will strengthen the strategic position of Austria in standardization bodies and in the debate at the European level in the aforementioned subjects. Clear recommendations for policy and regulation as well as for the standardization work are derived.

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2. Conclusions

2.1 SGAM based Smart Grid modelling and reference architecture

As part of the INTEGRA project, a concept for the model based on the development of smart grid systems has been realized. Moreover, this concept was applied in the modeling of a reference architecture. Particularly noteworthy is that this reference architecture demonstrates the integration of the US "NIST Logical Reference Model" and the European "Smart Grid Architecture Model". In INTEGRA, the best of both worlds has been combined. A significant contribution of SGAM is the context (the reference system) for the display of smart grid system architectures. The NIST LRM is characterized by a specific reference architecture with an integrated and expandable security concept. The integration of these two concepts in both the SGAM Toolbox as well as in the modeled system bridges the gap between conceptual activities of standardization and practical application in projects. In addition, it points to a path of a holistic development system: it allows bridging the boundaries between domain experts on the one hand and technology experts on the other side. This approach is a feasible way towards "domain-specific systems engineering" which allows to see smart grids as a whole - which in turn is an essential prerequisite for the implementation of Security by Design.

The approach in its current form provides promising concepts, and it could attract attention in the community. It can be concluded that the implemented design is a step in the right direction, but many more are needed. In addition to a stronger integration of different standardization activities (for example NIST and SGCG), on the side of applicability there are still improvements to be made. Further work on these issues is necessary to refine the concepts presented and to assist with current tools. Moreover, it was visible in this project that besides the technical interface between "Grid" and "ICT" there is also a gap in the human interface between "domain experts" and "technology experts" which has to be closed.

Developed as part of the INTEGRA project concepts, especially the architecture modeling and the developed reference architecture model are already further developed in subsequent projects. The modeling approach will be further researched and developed in the Josef-Ressel Centre at FH Salzburg. Since 2015 SIEMENS CT Munich is a partner at JRZ, where an explicit focus is put on this issue. In addition to the theme of "applicability" the investigation of architectural models based on KPIs is being prioritized.

The developed reference architecture is also further used. In the project "RASSA Architecture" on this basis on a generalized Austrian reference architecture is worked. Here the deficits identified in this project will as a first step be addressed and will then be carried out on the basis of the Austrian "domain model .AT" an instantiation for Austria.

Based on the findings of the INTEGRA project different recommendations can be given. In addition to specific recommendations for the integration of different standardization activities as well as individual technical recommendations (extension of SGAM concepts to dependability aspects, integration of interfaces with power system analysis tools, ...) a recommendation on education and training has been made. Here training offers in tertiary education are required, making it possible to build a bridge between domain and discipline experts. For example, in the form of ICT Master courses for experienced energy experts or energy master courses for experienced ICT experts. Moreover, it would be desirable to place more emphasis on systems thinking (keyword "Systems Engineering") in various configurations to connect the human interface between ICT and energy.

2.2 Coordinated Voltage Regulation

A purely technical comparison of the studied control strategies without considering economic aspects is of limited use, because the solutions examined differ significantly in CAPEX and OPEX. The results of this case study cannot be generalized, nevertheless, some lessons can be learned from the case study:

- The need for control in the low voltage level related to both PV-reactive-power-control as well as on-load-tap-changer- (OLTC) regulation over the entire considered medium voltage network is very low. If wide-area-control in primary substations optimizes the voltage level across the medium voltage network, the coordinated operation with Q (U) control is only active in a very few low-voltage networks. This is a result of the significantly higher degrees of freedom of the coordinated control.
- A combined voltage regulation on medium-voltage and low-voltage-level does not necessarily lead to a significant increase of the reactive power flows in the grid.
- The reactive power control at a certain voltage level has a positive influence on the voltage situation on the other voltage level. This means that both, a reactive power control in the LV shows a positive impact on the voltage in the MV, as well as a reactive power control in the MV has positive effects on the voltage in the LV.
- The simulation results do not show a significant increase in the network losses by a cross-level voltage regulation.
- If the integration of photovoltaics (PV) is homogeneously distributed over the entire medium voltage network, a very high density of PV systems can be achieved.
- A cosPhi (P) control leads to much higher reactive power flows than a Q (U) control. In the case study network, the same voltage-decreasing effect can be achieved with a Q (U) control when less reactive power flows were necessary.

• Adverse interactions between uncoordinated reactive power control and tap changer control were analyzed in a stability study. The result of this study was that adverse interactions can be largely avoided by a sensible parameterization of all control components which adapted to the respective network parameters. One way to exclude unwanted interactions can be the use of coordinated control approaches.

2.3 Flexibility Operator

In INTEGRA a market-based approach for the coordination of market and network called Flexibility Operator (short FlexOP) was developed. This approach was designed based on the traffic light model and in accordance with a specially designed regional flexibility market, which could allow a future market-oriented distribution network operation.

The basic applicability of the approach has been demonstrated by simulative Proof-of-Concepts. A clear explanation of the tasks and operation of Flexibility Operators can be accessed http://www.siemens.at/flexop on the website.

Based on the proof-of-concepts a FlexOP and subsequently a prototypical Flexibility Operator platform were implemented in the context of an intelligent secondary substation. For testing the prototypes were combined with the Smart Grid Co-simulation framework mosaic. This coupling allows the test of the FlexOp in different network scenarios and applications with a variety of system elements. Even in the case of the Flexibility Operator platform the applicability of the approach has been successfully demonstrated. The functionality of the Flexibility Operator platform will be further developed in subsequent projects with other forms of interference and other market models and will be tested in the field. Also there are plans to extend the approach to smart contracts and block chains for a better verification of the compliance of the negotiated contracts.

2.4 Building Energy Agent

The Building Energy Agent (BEA) is a key component in an intelligent building, it is based on supply- and load-forecasting to optimize the energy use in buildings. On the other hand the BEA raises flexibility potentials, forwards them to the FlexOP and realizes flexibility requirements from FlexOP by adjusting the current energy use plans.

For the proof-of-concept considered in the project, these properties of BEA were simulated and tested in a laboratory environment. Another goal of the project was also to complete the BEA which is used in the field with requirements developed in INTEGRA.

These changes have been very challenging, even when a suitable software base in the form of OpenMUC of Fraunhofer ISE was found. The planned improvements and enhancements were implemented. Moreover, some extensions to start preparing for the already launched follow-up project "LEAFS" have been implemented. The completion of this work and a detailed field test will be conducted in this follow-up project.

2.5 Economic evaluation and conditions

The economic evaluation of the use of a flexible operator in combination with virtual-power-plants (VPP) strategies in the case study Köstendorf showed that the cost benchmark of an implementation for an observation period of 50 years was a few euros euros or in an ideal case a few hundred euros.

From the technical side equalizing effects of load and generation in the regional existing network infrastructure were observed and due to the existing planning approaches network restrictions therefore only occurred in very few cases. This resulted in a lower utilization of the FlexOP-concept and correspondingly in low profit margins due to few interventions and little amounts of lost energy that would have been traded by VPPs.

To achieve cost parity compared to reactive power control the loss of income on the tertiary control energy market caused by the flexibility operator must have been much higher. However, these market price developments have not been foreseeable. These results are of course linked to the case study and cannot be generalized.

A local active power limitation seems to be the most cost effective solution for PV integration in the considered case study. When an appropriate and cost-effective communication- and controller-infrastructure (driven by other applications, for example smart metering or DSM) is available in the future, the use of Flexibility Operator concepts can possibly avoid active power limitation for small producers and loads.

Future research should focus on larger loads and buildings (for example the flagship project of the Seestadt Aspern) and possible economies of scale.

Based on a position paper the following positions on Network State Estimation, Re-Dispatch, the provisioning of network services and the establishment of regional market platforms are noted:

• Appropriate network analysis tools and sensors in combination with state estimation in the low-voltage-level can avoid network restrictions by scheduling changes through the market players. The frequency of occurrence of local network restrictions caused by decentralized virtual power plants is a decision criterion for the use of state estimation. At the moment state estimation is only required in selected network areas because of alternative solutions (for example reactive power control of inverters). Nevertheless, state estimation currently provides a very good cost/benefit ratio for the grid integration of decentralized generators. The future potential of state estimation solutions is limited because it is difficult to estimate future price developments on the energy markets.

• A "Re-Dispatch" in the distribution network is indeed conceivable in principle but many questions remain unanswered. This mainly concerns the relationship of costs and benefits of such a method and the question of the possible allocation of costs. In individual cases this can currently be solved by individual contracts and recourse to the experiences in the transmission networks.

• A future market model using existing decentralized power reserves and flexibility on the producer and consumer side has to pass necessary schedule changes to the parties concerned (for example, balancing groups) in time. The temporal resolution of the data transmitted must be adapted to the current market conditions.

• In general the establishment of small market segments and traded services is difficult, especially with regard to market liquidity and existing risks for the players.

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