European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out

Technical Report TA User Project

Validation of Flexibility to Generators - Offered by Virtual Power Plant (for Ancillary Services) VFG-VPP(AS)

Grant Agreement No:	**654113**
Funding Instrument:	**Research and Innovation Actions (RIA) – Integrating Activity (IA)**
Funded under:	**INFRAIA-1-2014/2015: Integrating and opening existing national and regional research infrastructures of European interest**
Starting date of project:	**30.09.2019**
Project Duration:	**2 months**

Contractual delivery date:	**6/12/2019**
Actual delivery date:	**6/12/2019**
Name of lead beneficiary for this deliverable:	**Jibran Ali, Enel Produzione S.p.A, Italy**
Deliverable Type:	**Report (R)**
Security Class:	**Public (PU)**
Revision / Status:	**Final**

Project co-funded by the European Commission within the H2020 Programme (2014-2020)

Document Information

Document Version: 1

Revision / Status: Final

All Authors/Partners

Jibran Ali, Enel Produzione S.p.A, Italy
Giacomo Petretto, Enel Produzione S.p.A, Italy
Stefano Massucco, University of Genova - DITEN, Italy
Federico Silvestro, University of Genova - DITEN, Italy
Davood Babazadeh, OFFIS, Germany
Felipe Castro, OFFIS, Germany
Anand Narayan, OFFIS, Germany
Shoaib Ansari, OFFIS, Germany

Distribution List

Enel Produzione S.p.A, Italy
University of Genova - DITEN, Italy
OFFIS, Germany

Document History

Revision	Content / Changes	Resp. Partner	Date
1	For review	Jibran Ali, Enel	06.12.2019

Document Approval

Final Approval	Name	Resp. Partner	Date
Final review	Shoaib Ansari, Felipe Castro	OFF	23.01.2020

Disclaimer

Copyright Notice

Table of contents

Abbreviations

DER	Distributed Energy Resource
TA	Trans-national Access
VPP	*Virtual Power Plant*

Executive Summary

VPP is a new actor in Power System. It can give flexibility to power plants, which have to provide service to TSO. The service includes reactive power, real power support etc., which are in principle divided in terms of major ones as reactive power, real power, and power system protection that form the competitive basis for VPP. The objective is to use VPP for the service. The VPP is developed and simulated within MEAN4SG EU Project, and the final validation is done through OPAL-RT within this TA Access.

VPP involves the coordinated use of distributed energy resources by TSO and DSO, and the idea is to employ VPP for ancillary services provision based on regulatory constraints of different countries w.r.t the participation of distributed energy resources. Communication delays for the service form an important aspect, and is the demarcation point under this work.

1 General Information of the User Project

USER PROJECT PROPOSAL	
User Project acronym	VFG-VPP(AS)
User Project title	Validation of Flexibility to Generators - Offered by Virtual Power Plant (for Ancillary Services)
Main scientific/technical field	Electrical Power Systems
Keywords (5 max., free text)	TSO, DSO, power plants, protection systems, ancillary services.

LEADER OF THE PROPOSING USER GROUP	
Name	Jibran Ali
Phone	+39-351-096-1985
E-mail address	jibran.ali@enel.com & jibranali.mean4sg@gmail.com
Nationality	Pakistani (resident in Italy)
Gender	Male
Age	29
Organization name	Enel Produzione S.p.A.
Organization address	Via Andrea Pisano 120, 56122 Pisa, Italy
Organization website	https://www.enel.com/
Position in organization	Technical Specialist Expert & ESR-MEAN4SG
Activity type and legal status of organization[1]	Main electricity producer in Italy, and also other countries
MEMBERS OF THE PROPOSING USER GROUP (repeat for all Users)	
Name	Giacomo Petretto
Phone	+39-324-909-6231
E-mail address	giacomo.petretto@enel.com
Nationality	Italian
Gender	Male
Age	42
Organization name	Enel Produzione S.p.A.
Organization address	Via Andrea Pisano 120, 56122 Pisa , Italy
Organization website	https://www.enel.com/
Position in organization	Senior Researcher/Research Supervisor
Activity type and legal status of organization[1]	Main electricity producer in Italy, and also other countries
MEMBERS OF THE PROPOSING USER GROUP (repeat for all Users)	
Name	Stefano Massucco & Federico Silvestro
Phone	-
E-mail address	stefano.massucco@unige.it and federico.silvestro@unige.it
Nationality	Italian
Gender	Male
Age	64 and 45
Organization name	DITEN – University of Genova
Organization address	Via Opera Pia 11a, Genova , Italy
Organization website	http://iees.diten.unige.it/
Position in organization	Full Professor & Associate Professor
Activity type and legal status of organization[1]	Research and Higher Education Institution

2 Research Motivation

The project relates to the flexibility a VPP can offer to conventional coal and combined cycle power plants. This puts the scope to the four relevant actors in power systems:

1-VPP as new actor in power system
2-TSO as operator for transmission level
3-DSO as operator for distribution level
4-Conventional power plants as supplier of real power and reactive power to TSO and DSO

The idea is to see how VPP can give flexibility to TSO, DSO, and power plants in terms of major ancillary services (voltage support, frequency support, and system protection). This overall gives flexibility to conventional power plants.

Use cases are developed w.r.t regulations of major European countries, and primarily Italy. The use cases discriminate amongst different ways these VPP interact with 2-4 Entities of the previous list in terms of ancillary services provision.

The use cases are validated in OPAL-RT with a HIL system, as described below.
The objectives include checking:
1- TSO needs fulfilled by power plants
2- TSO-DSO Interaction

It develops a validated VPP tool, which supports ancillary services provision to give flexibility to conventional generators, irrespective of the regulatory mechanism.

2.1 Objectives

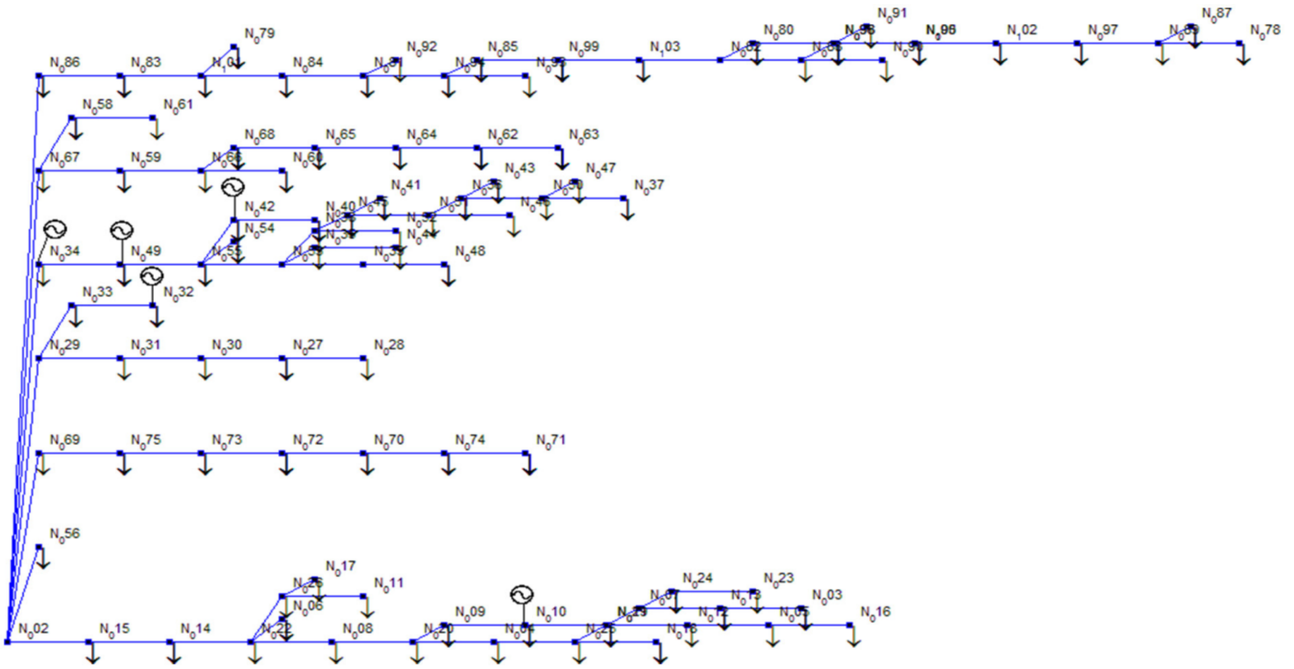

Figure 1: IEEE test distribution system (EU Project ATLANTIDE [1-2])

Under MEAN4SG project, the VPP model is developed and simulated with the two possibilities:

1- A co-simulation environment is created for windfarm (DIgSILENT), customers DR (LabVIEW), and storage system (MATLAB/Simulink). These co-simulators are communicated via OPC, and VPP interface is modeled with LabVIEW-RT. Then, DSO asks for service during congestion and over-voltage issues. The possibility for reactive power provision is analyzed, and OPC tags are the source of communication amongst VPP and DMS.

2- A co-simulation environment is created for windfarm (DIgSILENT), customers DR (Lab-VIEW), and storage system (MATLAB/Simulink). These co-simulators are considered part of distribution substation, and then these co-simulators communicate with other substation IEDs with IEC 61850. Service provision is then seen, and time for the service is noted.

A VPP at distribution level, named as VPP-model, with the following components:

A test distribution system [1], as shown in Figure 1, from EU ATLANTIDE Project. The 20 KV MV network consists of 103 nodes, and 7 feeders to feed the 190MV loads.

1- The distribution grid is modelled in MATLAB/Simulink under Opal-RT.
2- Storage system model is used too, along with customers (consider as VPP)
3- At DMS level, there is request for reactive power provision. Time for service is noted with OPC communication.
4- Time of service is noted when IEC 61850 communication is utilized at substation

The steps include:

1- The system in Figure 2 is modelled in MATLAB/Simulink with the operating values for distribution grid and storage system (Initiate without storage system).
2- Protection scheme and node-voltages (voltage loading) is validated.
3- DER added at node 9; protection device failure and node voltage violations at selected nodes is observed.
4- Storage system is added; and flexibility margins are noted for violated nodes (with/without storage, peak shaving, and load shifting), and protection system. For protection, DER at node 9 and storage system are communicated via IEC 61850 standard.

KPIs are compared for theoretical, simulated and the validated platform cases.

Criterion for failures:

1- 0.95 per-unit to 1.05 per-unit (node voltage; pessimistic bound)
2- Primary protection in less than 80 m-seconds
3- Backup protection in less than 40 m-seconds

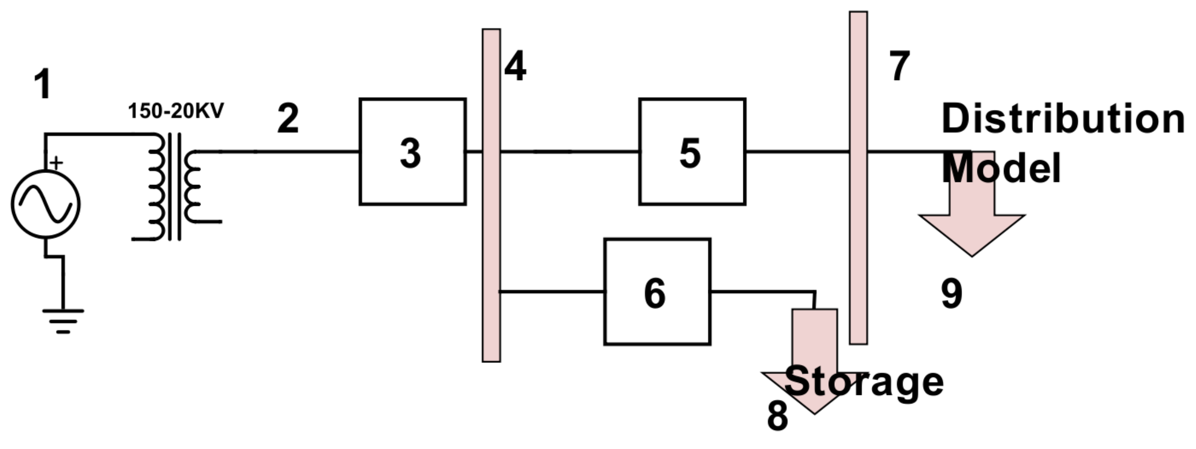

Figure 2: Single line diagram for test-system

2.2 Scope

Quantification and estimation of:

1- Flexibility by VPP in terms of reactive power VS time of service

2- Flexibility by VPP in terms of reactive power VS point of service
3- Flexibility by VPP in terms of real power VS type of reserve
4- Flexibility by VPP in terms of reduction in number of faults
5- Flexibility by VPP in terms of reduction in time of isolation after faults

Identification of:

6- Adapting changes in regulatory aspects in different European countries in terms of deployment of VPP.
7- Technical competitiveness of VPP in comparison with the existing market solutions.
8- Flexibility to operators, specifically TSO in terms of controlling the transmission grid as a whole
9- Opportunity for better TSO-DSO interaction schemes
10- Flexibility to power plants in terms of their abilities to produces reactive power and real power.
11- A better protection scheme in terms of fault identification and isolation
12- Validation for ease of adaptiveness

3 State-of-the-Art/State-of-Technology

The concept of VPP is widely discussed in literature, with the coordinated use of distributed energy resources by TSO and DSO as in [3], distribution level VPP as in [4], and an IEC 61850 based VPP for grid services as in [5]. The main advantage of using this VPP is to provide flexibility to operators and power plants, as discussed in [6-7].The idea to employ VPP for ancillary services provision is dependent on regulatory constraints of different countries w.r.t the participation of distributed energy resources [8-9], with different potential schemes of their participation as in [10-12].

This project considers flexibility from the perspective of power plants, as conventional generators with the aim of satisfying TSO service needs in a more convenient manner.

An architecture of VPP is developed and economically validated in [13]. Implementation of the VPP is discussed in component level in [14]. The services are divided in terms of major ones as reactive power, real power, and power system protection which form the competitive basis for VPP. Reactive power test-cases and TSO-scenarios are developed in [15]. Protection system test-cases and TSO scenarios are elaborated in [16]. The architecture in [13] is divided into three sub-systems as customers' demand-response [17], distributed energy resources [18], and storage systems. Storage system, and the communication amongst different sub-systems are discussed in [14], and the implementation is under draft for two separate publications.

The objective is to perform the validation of this architecture (already simulated) by RTDS-simulator (real time simulator) using Erigrid lab facilities.
The project is part of another EU-H2020 project [19], and the specific idea is relevant to ESR-6. From [20], the project is on development of replicable solutions for optimal management of distributed energy resources at customer sites, coordinated with larger generation assets, enabling the provision of energy services to the ancillary services market, following a Virtual Power Plant (VPP) concept.

From [20], solutions will be scalable and applicable to different and heterogeneous contexts, from a geographical, social and economic point of view and will demonstrate the whole energy services value chain.

From [20], the projects steps are:

1- identification of interaction schemes that may allow customer active participation to the electric markets
2- Modelling of customer capabilities to interact in active demand response programs and development of predictive algorithms to estimate actual customer willingness/capabilities to offer flexibility on the market
3- Development of decision support system that identify optimal customer's resources configuration/set-point and of an energy brokerage tool to allow VPP interaction with energy and services market
4- Development and integration of steady-state and real time tools in a distributed intelligence system to guarantee customer heat and power supply and to enable interaction with Virtual Power Plant centralized manager [21-22]
5- Extension to other ancillary services [23], and approaches involving substation digitalization [24]
6- Validation of developed tools (Proposed activity for Erigrid lab access)

4 Executed Tests and Experiments

Objective: Time taken by the back-up relay to operate/receive the signal to trip?
Design case:

1- Feeder 2 with an overcurrent relay (line 2-27) at beginning of all laterals.
   Voltage at 20KV
   S = 25 MVA, CT selected is 150:5
   Fault analysis leads to Ipick_up as 210 Ap, and thus TAP = 7As with TD = 2
   Fault at Node 28(consider a 3-phase fault) occus, consider a non-bolted **apply just a ground signal at node 28**.

2- Time of over current relay operation can be considered as **time for switch to operate in OPAL-RT (depends on the selected switch). Data sheet of switch.**

3- Differential relay at feeder 4, provides the backup. **The settings are K1 is 0.4 and k2 is 20%. However, it is to observe the time taken for IEC 61850 communication to give signal to switch at Feeder 2 from feeder 4.** Both are two different feeders within a same distribution grid.

OPAL-Scenario:

1- Time for a switch to operate at feeder 2
2- Time for communication between the two feeders (2 and 4)

4.1 Test Plan

The test plan aims to find the communication delay by backup protection, which demonstrates the delays the VPP will suffer during its service provision. This will confirm to the flexibility a VPP can offer to conventional coal and combined cycle power plants.

4.2 Standards, Procedures, and Methodology

The Function(s) under Investigation (*FuI*) is the Time for tripping. The Objects under Investigation (*OuI*) are the Relays – Overcurrent and differential. The Domain under Investigation (*DuI*) is the Electric Power system protection. The Purpose of Investigation *(PoI)* is to verify if the backup protection communicates the VPP, before the conventional backup.

4.3 Test Set-up(s)

The System under Test (*SuT*) is the Relays – Overcurrent and differential, Circuit Breakers, CTs, distribution grid. The Function under Test (*FuT*) is the Communication delay when the tripping signal is sent from differential relay to overcurrent relay.

4.4 Data Management and Processing

The target is to check the time in seconds for the communication. Delay to be less than 1 seconds, when Feeder 4 OC relay to trip, when the signal is sent by differential relay at point of interconnection.

5 Results and Conclusions

The host institution has OPAL-RT system with real time simulator (model based support), which was uised for the validation proposal, i.e. a PHIL platform. The VPP model was developed with the used simulation models. IEC 61850 and OPC communication support was there, and the IEC architecture at lab was perfect for DMS based test-case. The distribution grid and the storage system were tested within OFFIS simulator, and the KPIs were compared.

Result 1:

The distribution grid was validated within the OPAL-RT; and the full model (compliant with OPC) was developed in OPAL-RT. The platform was set for the GOOSE IEC 61850 substation communication. The validation includes power flow, static and quasi-dynamic analysis(and to check the node voltages), and the OPC communication. The following were verified:

1- 0.95 per-unit to 1.05 per-unit (node voltages)
2- Primary protection in less than 80 m-seconds
3- Backup protection in less than 40 m-seconds

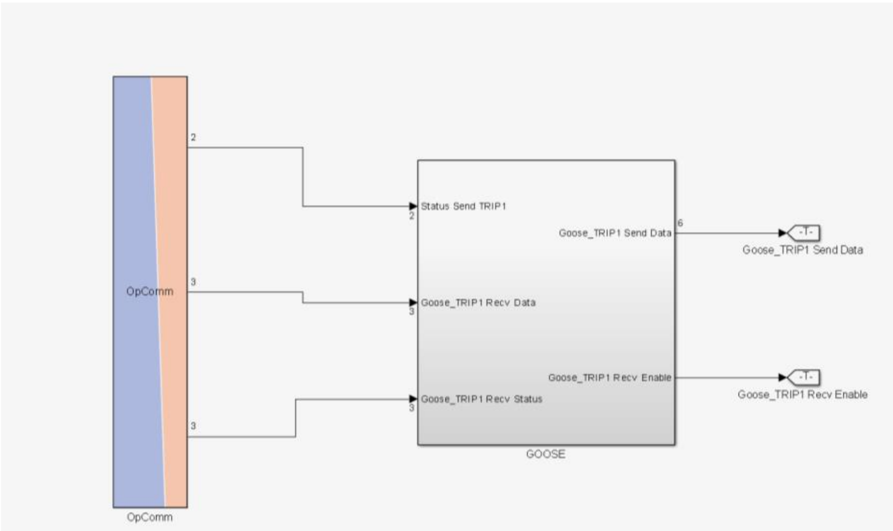

Figure 3: OPAL-RT distribution grid – GOOSE Command

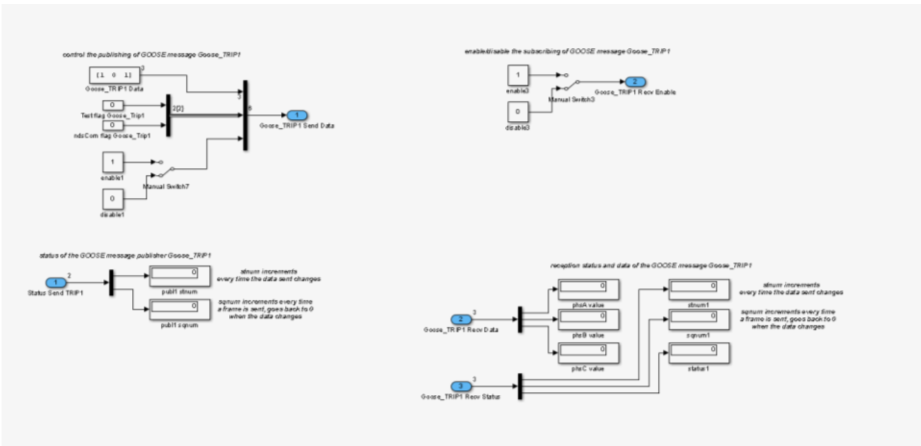
Figure 4: OPAL-RT distribution grid – GOOSE Time Logic

Result 2:

GOOSE message was sent within a substation (between overcurrent and differential protection feeder based nodes), and the time of communication was observed (i.e. to be less than 100ms)

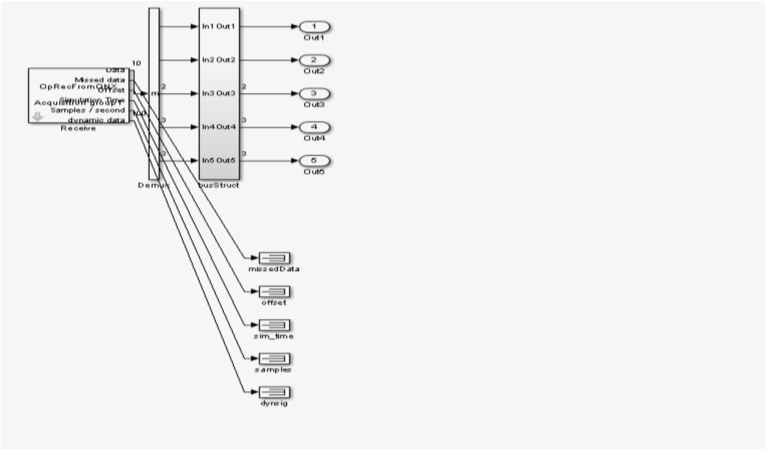

Figure 5: OPAL-RT distribution grid – GOOSE Logic

Time at which GOOSE is subscribed, and published are noted:
Time for start of subscription: 11,5600000000000s
Time for publish 11,5800000000000s
Communication delay for VPP: 20 msec(less than 100 msec for VPP)

Result 3:

Object oriented excel sheets generated within OPAL were tested in DIgSILENT. It was deduced that the DGS based DIgSILENT sheets can be transformed into the import facility for OPAL-RT. The results in #1, were compared with both ways, and were found the same.

Bus	Base Voltage (V)	Voltage (V, pu)	Angle (deg)	Type
N_0002	20000	1.106379417	-4.973655545	PQ
N_0003	20000	1	5.666699546	PQ
N_001	150000	1	0	SLACK
N_002	20000	0.960127838	-3.014459871	PQ
N_003	20000	1.041080367	-0.392702233	PQ
N_004	20000	1.06458484	-2.898636244	PQ
N_005	20000	1.058773214	-2.988355675	PQ
N_006	20000	1.051528734	-1.691517243	PQ
N_007	20000	1.058291083	-3.022999226	PQ
N_008	20000	1.064057438	-2.529792403	PQ
N_009	20000	1.098065194	-4.144528596	PQ
N_011	20000	1.050496556	-1.68562052	PQ
N_012	20000	1.059124004	-2.987083002	PQ
N_013	20000	0.960658279	-3.016649625	PQ
N_014	20000	1.046074298	-1.140329585	PQ
N_015	20000	1.043507251	-0.698104608	PQ
N_016	20000	0.962357166	-2.988962987	PQ
N_017	20000	1.050471746	-1.679720013	PQ
N_018	20000	1.061865971	-2.908494201	PQ
N_019	20000	1.106235557	-4.973010986	PQ
N_020	20000	1.068433653	-2.823377268	PQ
N_021	20000	1.059930107	-2.990408074	PQ

Figure 6: OPAL-RT distribution grid – Nodes 1-21 Details

N_083	20000	1.03520223	-0.523240422	PQ
N_084	20000	1.028979516	-0.686061348	PQ
N_085	20000	1.018427325	-0.977709872	PQ
N_086	20000	1.039972744	-0.404492093	PQ
N_087	20000	1.00073248	-1.496686865	PQ
N_088	20000	1.004444791	-1.418722526	PQ
N_089	20000	1.001218933	-1.48669138	PQ
N_090	20000	1.004200232	-1.420274014	PQ
N_091	20000	1.006598777	-1.328635134	PQ
N_092	20000	1.023986961	-0.819238871	PQ
N_093	20000	1.022027397	-0.873983419	PQ
N_094	20000	1.02207313	-0.874175236	PQ
N_095	20000	1.006539207	-1.328241646	PQ
N_096	20000	1.00664281	-1.328752387	PQ
N_097	20000	1.001460165	-1.48821973	PQ
N_098	20000	1.002539906	-1.487897246	PQ
N_099	20000	1.017308135	-1.010298319	PQ
N_100	20000	1.002011608	-1.488874083	PQ
N_101	20000	1.033715584	-0.560892284	PQ
N_102	20000	1.001679348	-1.488742458	PQ
N_103	20000	1.010057988	-1.231037476	PQ
N_3	20000	1.024041662	-0.819457275	PQ

Figure 7: OPAL-RT distribution grid – Nodes 83-103 & 3 Details

Result 4:

For real power service, the time between two substations is estimated within OPAL-RT. It is greater than 20 msec, and therefore the pessimistic bound is not compliant for the VPP. Hence, the service controller needs to be modified for services from different substations.

Time at which IEC 61850 MMS is expected, and published are considered:
Time for start of subscription: 11,5600000000000s
Time for publish >11,5800000000000s
Communication delay for VPP: >20 msec(not suitable for VPP)

6 Open Issues and Suggestions for Improvements

For the VPP;

1- Service for protection is verified.
2- For real power service, the model has to be improved.

7 Dissemination Planning

1- PhD thesis under MEAN4SG(submitted)
2- MDPI journal (under draft)

References

[1] F. Pilo et al., 2014, "Advanced active distribution simulations with the ATLANTIDE web cloud facilities", *CIRED Workshop,* Italy
[2] F. Pilo et al., 2012, "ATLANTIDE – Digital archive of the Italian electric distribution reference networks", *CIRED Workshop*, Portugal
[3] D. Pudjianto, G. Strbac, and D. Boyer, “Virtual power plant: managing synergies and conflicts between transmission system operator and distribution system operator control objectives”, in CIRED - Open Access Proceedings Journal, vol. 2017, no. 1, 2017.
[4] E. Dall'Anese et al, “Optimal Regulation of Virtual Power Plants”, in IEEE Transactions on Power Systems, vol. 33, no. 2, pp. 1868 – 1881, 2018.
[5] N. Etherden, V. Vyatkin, and M. H. J. Bollen, “Virtual Power Plant for Grid Services Using IEC 61850”, in IEEE Transactions on Industrial Informatics, vol. 12, no. 1, pp. 437 - 447, 2016.
[6] D. Koraki, and K. Strunz, “Wind and Solar Power Integration in Electricity Markets and Distribution Networks Through Service-Centric Virtual Power Plants”, in IEEE Transactions on Power Systems, vol. 33, no. 1, pp. 473 - 485, 2018.
[7] A. Thavlov, and H. W. Bindner, “Utilization of Flexible Demand in a Virtual Power Plant Set-Up”, in IEEE Transactions on Smart Grid, vol. 6, no. 2, pp. 640 - 647, 2015.
[8] G. Plancke et al, “Virtual power plants: Definition, applications and barriers to the implementation in the distribution system”, in 12th International Conference on the European Energy Market, Portugal, May 2015.
[9] V. K. Sampath et al, “Barriers to implementation of smart grids and virtual power plant in sub-saharan region—focus Botswana”, in Elsevier Energy Reports, vol. 4, no. 2018, pp. 119 – 128, 2018.
[10] http://smartnet-project.eu/
[11] H. Gerald et al, “Coordination between transmission and distribution system operators in the electricity sector: A conceptual framework”, in Elsevier Utilities Policy, vol. 50, no. 2018, pp. 40 – 48, 2018.
[12] F. Pilo et al, “Control and Automation Functions at the TSO and DSO Interface – Impact on Network Planning”, in 24th International Conference on Electricity Distribution, Glasgow, June 2017.
[13] Jibran. Ali, Stefano. Massucco, and Giacomo. Petretto, “Reactive Power Provision to TSO/DSO by Aggregators and Conventional Generators,” in Proc. IEEE International Conference on Smart Grid Communications.
[14] Jibran. Ali, Stefano. Massucco, and Federico. Silvestro, “Architecture of Virtual Power Plant for Ancillary Services,” in Proc. CIRED 2018 Workshop.
[15] Jibran. Ali, “Coordinated Control Mechanism for Voltage Stability Utilizing Aggregation of Reactive Power Compensation Techniques,” in Proc. IEEE International Conference on Environment and Electrical Engineering
[16] Jibran. Ali and Federico. Silvestro, “Virtual Power Plant for Improving Power System Protection Issues – Solution to the Problem of Power System Reliability under Distributed Energy Resources,” in Proc. IEEE Australasian Universities Power Engineering Conference.
[17] Jibran. Ali, Stefano. Massucco, Federico. Silvestro, and Andrea. Vinci, “Participation of Customers to Virtual Power Plants for Reactive Power Provision,” in Proc. International Universities Power Engineering Conference; publisher IEEE.
[18] Jibran. Ali, Stefano. Massucco, and Federico. Silvestro, “STATCOM Applications for Voltage Profiling of a Distribution Grid with High Penetration of Distributed Energy Resources,” in Proc. IEEE Mediterranean Conference on Power Generation, Transmission, Distribution, and Energy Conversion.
[19] This project has received funding from European Union’s Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 676042
[20] http://www.mean4sg-itn.eu/
[21] Jibran. Ali, Stefano. Massucco, and Federico. Silvestro, “Distribution Level Aggregator Platform for DSO Support - Integration of Storage, Demand Response, and Renewables" Frontiers of Energy Research Journal, 2019 (https://doi.org/10.3389/fenrg.2019.00036)
[22] Jibran. Ali, Stefano. Massucco, and Federico. Silvestro, “Aggregation Strategy for Reactive Power Compensation Techniques – Validation”, Energies Journal, 2019 (https://doi.org/10.3390/en12112047)
[23] Jibran. Ali, and Federico. Silvestro, “Conventional Power Plants to TSO Frequency Containment Reserves – A Competitive Analysis for VPP Role”, RTSI 2019, Firenze, September 2019.
[24] Jibran. Ali, Stefano. Massucco, and Federico. Silvestro, “Flexibility to DSO by VPP – Benefits, Regulatory Barriers, and Potential Solutions”, CIRED 2019, Madrid, June 2019.