DESIGNING A MICROGRID TO IMPROVE CONTINUITY OF SERVICE AND FLEXIBILITY: THE CASE OF POLITECNICO DI MILANO LEONARDO CAMPUS

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ABSTRACT

The widespread of Distributed Generation calls for more advanced solutions in the management of local electric grids. In this sense, Microgrids allow increasing reliability of supply and quality of service in local distribution of electricity. Moreover, a proper management of private grids helps increasing hosting capacity of Distribution Networks, reducing costs sustained by end users for electricity consumption, and keeping the electric system balanced through the exploitation of local dispatching resources. In this paper the Microgrid implemented in the Campus of Politecnico di Milano is described. The Microgrid of Campus Leonardo hosts a Combined Cooling, Heating and Power plant (2 MW_{el}) and two backup generators (1.6 MW_{el}), plus some smaller PV plants. The advanced load management solution is based on Schweitzer Engineering Laboratories (SEL) components. It provides new capacity for facing network requirements in case of emergency and allows maintaining a high level of quality of service. Moreover, it enables the participation of the Campus to the Italian Ancillary Services Market as a virtual unit.

INTRODUCTION

Distributed Generation (DG) has introduced new economic opportunities and challenges for users connected to the Distribution Network (DN). In particular, the possibility to become prosumers, rather than mere consumers, transformed energy services from a pure cost to a business opportunity also for industrial and tertiary companies not directly involved with the energy sector.

In this context, the development of private Microgrid constitutes a challenge for both final users and system operators. Among the main issues to be dealt with, islanding operation is one of the most critical.

The capability to disconnect from the external grid, and ~~to~~ continue feeding local loads in emergency condition until grid operating conditions allow reconnection, is typical for many industrial plants; however, the development of DG and of smart solutions on DN opened to the possibility of exploiting islanding for multiple purposes:

- optimizing continuity and reliability of supply and providing black start capability in case of system blackouts,
- providing demand response services to the electric system through a proper coordination of local generators and loads,
- avoiding undue peaks in power withdrawal from the grid[1].

The Campus of Politecnico di Milano located in Piazza Leonardo da Vinci (Leonardo Campus) is connected to the public MV DN (23 kV) and has a contractual power of 3.5 MW with the local DSO. The internal MV grid distributes energy to 8 Secondary Substations (SS) and feeds 25 buildings hosting classrooms, laboratories and offices, with more than 20.000 people working every day.

The eight substations are distributed along two branches (B1 and B2), which can be independently fed by two Main Switches (MS1 and MS2, which are normally closed) and are connected by a Tie-Switch (TS), as presented in Figure 1. The private network hosts one Combined Cooling, Heating and Power (CCHP) plant rated 2 MW_{el} that guarantees the provision of a large part of the energy needs; the Campus is also equipped with small diesel generating sets (GenSets), UPS (used as emergency supply in case of loss of the external grid) and small PV plants.

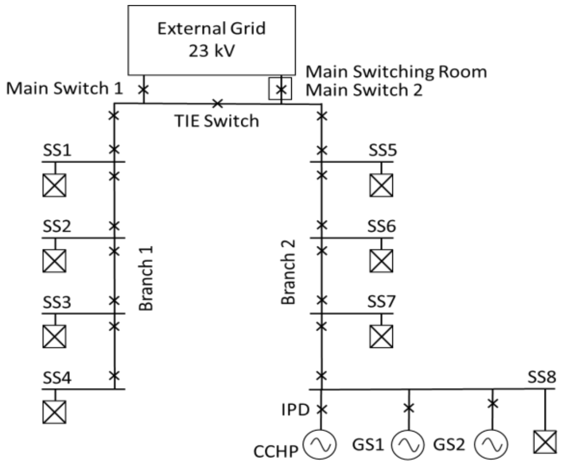

Figure 1: structure of the Microgrid of Campus Leonardo.

1 As for network costs and general system charges, the Italian electricity bill for MV users foresees a large burden on power components (€/kW) of the tariff, rather than energy components (€/kWh).

The Standard operation of local network is based on the continuous matching of local demand, regulated by a PLC that aims at keeping the energy exchanged with the external grid equal to zero. When CCHP capacity is exceeded, electricity is withdrawn from the external grid. This normal situation is presented in Figure 2.

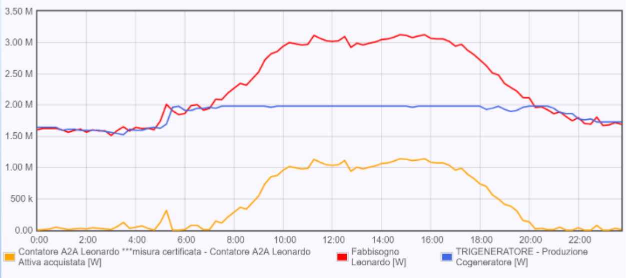

Figure 2: daily management of local demand. CCHP production (blue) is used to satisfy local demand (red), while the remainder is withdrawn from the external grid (yellow).

In the following chapters we present first the main objectives of Microgrid implementation; then the control logic is described. Network components and structure are analysed, and finally an economic evaluation is performed.

TARGETS OF MICROGRID DEPLOYMENT

The project aims at creating a Microgrid, including all the loads of the Campus (about 3,5 MW), the CCHP plant (2 MW), two GenSets (800+800 kW), plus small PV plants. The Microgrid will achieve further improvements beyond electricity self-consumption; in the following, main issues are described and new future solutions are presented.

Long interruptions (> 3 min)

In the past, the CCHP and GenSets were not coordinated: in case of loss of external grid, only some buildings (the ones equipped with GenSets and UPS) could recover their operation after a temporary interruption. The remainder of the Campus was out of service until the external grid was restored. Moreover, the CCHP would immediately shut down, being unable to work in islanding conditions.

With the Microgrid in place, in case of service interruption CCHP will not shut down, but will continue to work in islanding mode, feeding a proper amount of the Campus loads from Branch 1 (B1), as shown in Figure 1. If the CCHP capacity available in islanding mode is not sufficient, the GenSets are switched on and eventually connected in parallel to CCHP so that the whole Campus will be completely reactivated.

In case the CCHP unexpectedly shuts down after an interruption, the two GenSets restore the network supply and subsequently get the CCHP ~~to~~ switches-on in parallel mode. Therefore, the main part of the Campus will not be affected by public network interruptions, and the remainder will be disconnected for just a few minutes.

Microinterruptions

Microinterruptions[2] cause limited problems to university loads, but trip the Interface Protection Device of the CCHP (IPD in figure 1): this leads to a sudden increase of withdrawal from the public network (up to 2 MW if the CCHP is working at its nominal power). After some minutes the CCHP starts again and the absorption gets back to its original level, as presented in Figure 3.

Since a relevant part of the bill depends on the monthly peak of absorbed power3, even a short peak (as shown in Figure 3) can lead to considerable costs. The relevant tariff equals 4 €/kW/month, meaning that even a single disconnection of the CCHP can increase the electricity bill by 8 k€/month.

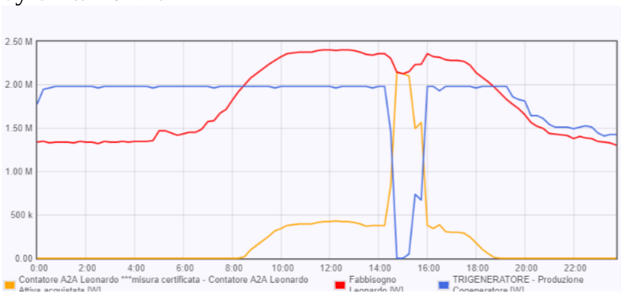

Figure 3: voltage dip causing a sudden increase in power withdrawal.

Moreover, the unexpected trip of the CCHP protection device (IPD) may cause damages to the engine mechanical parts, potentially leading to economic losses for both maintenance and forced downtime.

With the implementation of the Microgrid, the CCHP is able to sustain microinterruptions in islanding mode, so that the costs in the bill related to undue withdrawal peaks are avoided, and possible damages to the engine are avoided.

In case of failure of the islanding procedure for the CCHP, the withdrawal peak will be avoided by the rapid turn on of GenSets, thus bringing back the withdrawn power to small values in few minutes.

Ancillary Services Market (ASM) participation

Thanks to the ASM reform ongoing in Italy, a user can be remunerated for reducing its withdrawal from the network, upon a command delivered by the TSO via aggregator. According to the experimental regulation currently in force [1], this service is remunerated with a twofold stream of money:

- a capacity payment (about 60k€/year/MW);
- an energy payment, based on the volume of dispatching orders actually fulfilled by the user.

The Microgrid will be equipped with a control logic that allows the reduction of withdrawal by fully exploiting the CCHP capacity and by switching on the two GenSets, while keeping the Campus continuously fed.

2 Microinterruptions include transient interruptions (< 1 s) and voltage dips (as defined in EN 50160).

3 The monthly peak is the maximum of the mean values of withdrawal calculated on each quarter of an hour of the month

CONTROL LOGICS

Islanding and reconnection

In normal conditions, all (SS) are connected to the public grid and the CCHP plant is following the Campus load, up to its maximum capacity (2 MW).

In case of disconnection (at time t_0) from the public network, two relays equipped with SyncroCheck open MS1 and MS2, and block their reclosing upon external network presence. The instantaneous power production of the CCHP plant in islanding mode is compared with the power absorbed by each SS in Branch 2 (B2) the moment before t_0. If the consumption from B2 is higher than the power production of the CCHP, then an load shedding sequence is operated: following a priority order, the transformers to be disconnected of the SS's of B2 are selected and their circuit breakers are rapidly opened.

The CCHP plant is set to islanding mode (frequency and voltage control) and the local load profile of B2 is automatically followed. After a short time from the disconnection event, a command is sent to the GenSets to begin the start-up procedure (which lasts some tens of seconds) and, after that, to connect in parallel to the CCHP plant. If the available production capacity (CCHP + GenSets when active) is adequate, loads shed from B2 are sequentially reconnected. If there is still spare capacity, the procedure to reconnect loads from B1 is started: MS1 reclosure has been disabled and all B1 SS CB's are opened. The Tie Switch is closed and, sequentially, the transformers from B1 are connected, until the proper spare production capacity is available. At this point, all the Campus is fed by local generation units. This control logic is graphically described in Figure 4.

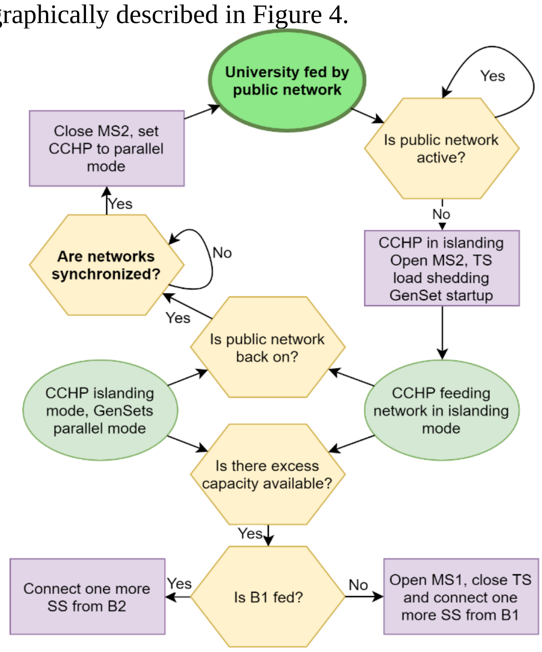

Figure 4: Control logic implemented when CCHP is on

When the public network is back on, the Synchrocheck is enabled to close MS2. Once synchronism is achieved, MS2 is closed and the CCHP plant is set to parallel mode.

CCHP outage

If, anytime, the CCHP shuts down, a different procedure is started: B2 is properly isolated and the two GenSets are started up in islanding mode (frequency and voltage control). When ready, they are loaded with transformers from B2 and, if spare capacity is still available, B1 is connected through the TS and the remaining transformers are sequentially connected.

When the locally consumed power is higher than the sum of the minimum power of CCHP and GenSets, the CCHP is switched on and put in parallel to the GenSets. In order to better follow the load profile and reduce diesel consumptions, the frequency and voltage control should not be performed by GenSets, but by CCHP plant.

For switching the control of the network, an innovative operation has been set up: in a condition where the system is in a stable equilibrium, the GenSet islanding mode is disabled and the power setpoint is set to a very low value (e.g. 10 kW). At the same time, the islanding mode is enabled in the CCHP plant. As the GenSet power output decreases because of the low setpoint, the CCHP plant takes more and more load. As soon as the production from the GenSets reaches 50% of their nominal power, the setpoint is set to 50% of nominal power. The operation is successfully completed and the whole Campus is fully fed.

NETWORK COMPONENTS

The critical logic described before requires very reliable and fast controllers. SEL (Schweitzer Engineering Laboratories) provides a whole set of devices that have proven to be suited for controlling a Microgrid [1] [2] [3] [4]. The architecture is based on the use of SEL real-time automation controller (SEL 2240 - Axion) and local IEDs for control. Figure 5 represents a simplified architecture of the Microgrid, according to five layers.

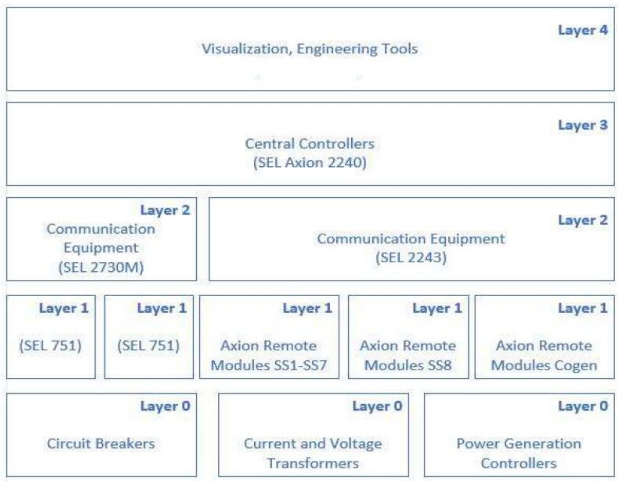

Figure 5: control logic layers

The central controller is installed in the Main Switch Room and in SS8; the two nodes are connected via the multi-mode fiber optic EtherCAT network of the Campus to remote modules, installed in all the local substations.

The inter-tie connection with the external grid is in the Main Switch Room: in this substation, two SEL-751 IED's serve as Synchrocheck relays for each part of the Campus network that can operate as separate island.
The central controller is also interfaced with the CHPP and the GenSets local controllers, communication is based on Modbus TCP protocol, and relies on substation hardened ethernet switches.
The control logic is written in IEC 61131-3 standard and has been designed as a decision tree.

The control system

The SEL-2240 Axion [1] is a fully integrated, modular input/output (I/O) and control solution suited for utility and industrial applications. It combines the communication, built-in security, and IEC 61131 logic engine of the SEL Real-Time Automation Controller (RTAC) family with a durable suite of I/O modules that provide high-speed, deterministic control performance over an EtherCAT network.
The system is designed to be flexible and modular: by using the right combination of distributed modules and nodes in almost any arrangement it is possible to build a control network with the desired degree of complexity and spatial distribution.

The central controller

The 2241 RTAC Module is a dedicated 4-port RTAC module for the Axion family. It is used to integrate I/O, substation IEDs, SCADA communications, and security applications all in one device.
It is strongly programmable according to the standard 61131and allows a minimum logic execution cycle of 1 ms with real-time operation.
The maximum number of modules that a single controller can manage is 60. In the current application, the total number of modules exceeds the limit: for this reason, two Axion nodes, each with a CPU, have been considered.
The central controller and the distributed I/O modules are organized in a multimodal optical network and interfaced using the EtherCAT protocol.
The controller communicates with the other devices using Modbus TCP and IEC 61850 client sessions; a 61850 MMS Server is available for remote connections.
The web-based human machine interface is embedded in the controller, it uses secure protocols and does not require additional client software. This feature allowed to use an existing PC-HMI, installed in the Main Switch Room.
All the Axion modules are mounted on a back plane.
The power coupler, SEL-2243, is the Axion system power supply. Thanks to reliability of the service power, a single power coupler has been provided, but in principle an even higher system availability could be reached by using redundant power couplers in each node. Additionally, each SEL-2243 provides two dedicated EtherCAT ports to accommodate the integration of multiple nodes.

The local modules

The local Axion modules installed in the substations from 1 to 7 are equipped with DI/DO modules to interface with the local loads.
The local Axion modules installed in the substations hosting the CCHP and the GenSets (SS8) are equipped with DI/DO, DC inputs and AC inputs modules from current and voltage transformers in order to interface with the local generators.

The Protection devices

Two SEL-751 relays are installed at the inter-tie with the public grid as Synchrocheck to ensure that the islands are re-connected in parallel with the external network only when the correct synchronizing conditions are met.
SEL-751 provides complete feeder protection, with current, voltage and frequency based protection and can be used as a BCU. The relay is suitable for easy integration in existing systems without cutting or drilling existing cut-outs, given the relay's small form factor and multiple mounting adapters (see Figure 6).

Figure 6: SEL-751 relay

The TLC network

Since the several procedures previously described require very fast response times, the most critical data is delivered through a dedicated EtherCAT network which directly connects the Central Controller's CPUs (located in 2 substations) to the I/O modules. Communication to the 2 Synchrocheck relays and between the CPUs is implemented through GOOSE messages. Both these communication technologies are designed to provide high reliability and very fast response time (less than 10 ms).
The measurements of electric power absorbed by each transformer are obtained from the metering devices already installed in the substation and are collected through a different network dedicated to power monitoring using Modbus TCP/IP protocol. These data are less critical for the Microgrid application, and therefore it is acceptable that the Central controller collects them every few seconds, and then stores them for some minutes: they are needed only to provide the basis for the load shedding logic, and to give an estimate of the electric load that a disconnected transformer would absorb if reconnected to the grid.

ECONOMIC CONSIDERATIONS

The correct management of assets connected to the Microgrid allows realizing economic savings over multiple levels. In particular, three main aspects entail an economic advantage that can be directly monetized:

- the increase in the continuity of supply and in the Quality of Service (QoS) of local grid.
- the provision of ancillary services to the operator of the external network and
- the reduction of peaks of power withdrawn from the external grid.

Continuity of supply

Since, following Decision 646/2015/R/eel, the occurrences of long interruptions are communicated by DSOs to network users, it was possible to study the historical data about continuity of supply in Campus Leonardo. This allowed estimating an average of 2 long interruptions per year, each one lasting on average for 5 minutes. Hence, supposing 10 minutes of energy interruption per year, considering an average demand equal to 1.5 MW, the total amount of energy lost per year is equal to 250 kWh.

Moreover, according to Decision 2/2017 [7], it is possible to define a value of 54 €/kWh for any unit of energy not delivered to users. The final costs linked to long interruptions are quantifiable in about 13.5 k€/year.

Ancillary services provision

The exploitation of Microgrid structure allows providing demand response services to the system operator. In particular, starting from December 2018 in Italy it is possible to provide flexible resources by aggregates of consumption and production units located on the DN [1].

The availability of GenSets, to reduce the withdrawal from the DSO grid, allows to perform demand response actions upon request of the transmission system operator (TSO).

Flexibility is traded on the Italian Ancillary Services Market (ASM). An evaluation of the possible revenue streams coming from the participation to ASM has been performed considering historical demand and production data, together with rules defined in the UVAM project [8]. This input data have been elaborated using an ad-hoc market simulator [9]. Results obtained show that possible revenues could vary from 20 to 40 k€/year depending on the possibility to receive only an energy payment or also a capacity remuneration.

Peak shaving

The cost of undue peaks has been determined according to Decision 922/2017/R/eel [10]. In fact, since January 2018, the structure of general system charges changed. In particular, for both system charges and grid services a trinomial structure is foreseen, where a component of the tariff is paid in terms of €/kW. The reference power peak, to compute the monthly payment due, is defined according to the rules explained above.

As for the number of undue peaks, this was possible thanks to Decision 646/2015/R/eel [11]; according to this rule, the occurrence of microinterruptions is communicated by DSOs to grid users. A study of historical data of Campus Leonardo allowed to estimate an average of 7 microinterruptions per year causing CCHP shut down. Again, based on historical data, each interruption causes a peak power increase of about 1.5 MW with respect to normal operations peak. Therefore, considering that the power component of the tariff is about 4 €/kW/month, a total of 42 k€/year surplus in electricity bill is attributable to voltage events occurring on the external grid. The implementation of the Microgrid could hence save this cost by properly managing microinterruptions.

CONCLUSIONS

The implementation of a Microgrid in Leonardo Campus gives the possibility to improve quality of local energy services and to exploit distributed resources for system needs. The selection of reliable and fast controller components and of the logic to be implemented allows managing effectively local demand through existing generation assets; this implies good expected economic returns together with contained investment costs.

The project management and realization of the Microgrid have been conducted under the direct supervision of the Energy Commission (Commissione Energia) of Politecnico di Milano.

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