On the Micro-Grid and Multi Micro-Grid Impact Assessment: Cost and Benefits Evaluation

Towards the power system of the future: Active distribution networks

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SUMMARY

The implementation of innovative network solutions to allow for an increase of micro-generation and demand side integration are highly dependent on building scale and cost effective infrastructures, where sharing of responsibilities among different stakeholders is the basis for a proper implementation of an active distribution network concept. In order to integrate large amounts of small and micro-generation (µG) units that exploit different power sources (with high or no intermittency) together with controllable loads and storage devices it is necessary to develop flexible management and control solutions where responsibilities for the system operation are shared between Distribution System Operators (DSO), customers and Distributed Generation (DG) units according to a regulatory environment.

The incentives provided to the different parties (stakeholders) may have a major impact on their decision to adopt Micro-grid and Multi Micro-grid concepts. Therefore, an identification of the benefits and costs associated with these concepts adoption is needed in order to recognize the real value of their deployment. Moreover, only by proper allocation of these costs and benefits, each stakeholder affected may receive the right incentive to opt for Micro-grid and Multi Micro-grid solutions. The DSO is interested in maximizing profits, by minimizing the capital and operational costs related to the distribution service (for instance, loss reduction and reinforcement costs) and at the same time achieving the performance goals imposed by the regulators [1]. Micro-generation developers make decision considering capital and operational expenditures, the connection costs, and use of system charges. Incomes from energy selling (which may include RES incentives) are the main goals (benefits) for the µG investors. Therefore, one of the priorities of regulators is to ensure that these benefits are perceived by µG developers. Finally, customers may be asked to share with the DSO the responsibility for an increased reliable system and for having the possibility to reduce their bills when exploiting the best market options offered by different traders.

This paper presents a detailed identification and characterization of the different benefits and costs for each stakeholder involved. Some of these benefits can be identified and allocated directly to a certain stakeholder, while others need to be shared among a large group of players, involving the society in general (for example CO₂ emissions reduction, job creation).

KEYWORDS

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1. INTRODUCTION

Micro-Grid and Multi Micro-Grid concepts have been seen as a promising option when tackling with large scale integration of micro-generation (with high or no intermittency) together with controllable load and storage devices [2]. However, the adoption of Micro-Grid and Multi Micro-Grid solutions present to the DSOs, end consumers and µG developers several technical and economic challenges requiring a development of internal transaction mechanisms for correct allocation of cost and benefits among the affected agents.

A specific Multi Micro-Grid control and management architecture should be based on local trading mechanisms, where the different decisions performed at different control levels should distribute the benefits to the affected parties, in a way that all the involved stakeholders would benefit from such an operation. For that purpose, relevant optimization studies should be carried out at each control level, with a specific objective function which maximizes the benefits due to the specific agent [2], [3].

Regarding cost allocation, cash-flow analysis should address market-related transactions which occur either internally to the Micro-Grid or between the Micro-Grid and the upstream network (within the Multi Micro-Grid). Therefore, the primary aim is to analyze how different transaction models would affect different agents, resulting in different allocation schemes of costs and benefits.

In general, two levels of power flow interactions may be acknowledged within the Micro-Grid and Multi Micro-Grid:

- Power generated and consumed within a Micro-Grid;
- Power exported to/imported from the upstream grid,

In that sense, two business models have been explored in [4], namely, local energy trade and local ancillary service trade, according to which cost and benefit allocation schemes are to be developed.

Cost and benefits allocation schemes may also differ due to different Micro-Grid ownership models, driven by particular stakeholder’s objectives. Purely driven DSO Micro-Grid or end consumer owned Micro-Grid would enable full access of benefits only to the particular party [4], [5]. Nevertheless, free market Micro-Grid model, potentially driven by various motives (economic, technical, environmental, etc.) from various stakeholders (DSO, consumers, etc.) and daily operation decisions based on real time prices may disseminate Micro-Grid and Multi Micro-Grid benefits to a large number of stakeholders and according to a more fair and transparent scheme [4], [5].

2. MULTI MICRO-GRID CONTROL ARCHITECTURE

Figure 1 illustrates a hierarchical MMG control structure of a free market model, adopting decentralized decision making where the cash flow interactions among different agents are presented for both local retail and local service market.

An internal market model may be central to each Micro-Grid operation, driven by different objectives (economic, technical, environmental, etc.) [3]. Economically driven Micro-Grid, for instance, tries to minimize the total Micro-Grid operation cost, based on the controllable µG units’ bids, controllable load bids and the wholesale electricity prices, assuring minimum electricity cost for the Micro-Grid consumers. In addition to the controllable load bids (corresponding to load shifting), further Demand Side Integration (DSI) actions may be adopted at this control level, such as controllable load reduction bids (equivalent to load curtailment), leading to additional revenue for the Micro-Grid consumers [6].

Under an internal retail market, performed at MGCC control level (Figure 1) [6], the upstream grid could not force the Micro-grid to use its own controllable µG (C-µG) or fuel-consuming units instead of importing all demand (in time intervals where the wholesale market prices are lower than the controllable µG units’ bids), so as to impose certain operation constraints upon a particular Micro-grid in order to improve Medium Voltage (MV) or even High Voltage (HV) level grid performance. Similarly, the DSO cannot oblige the consumers of a particular Micro-Grid to opt for controllable load shifting/curtailment, in order to resolve a potential upstream technical constraint violation, such as for instance, overloads or excessive voltage drops (below the technical limits). Nonetheless, if adequate price signals related to the need for potential upstream technical services could be attached to the base
energy price signals, the controllable µG units would be boosted to produce and the controllable loads (C-Loads) may agree to be shed for a certain time period [2]. Non-controllable µG units (nC-µG) are considered as non-competitive units, always dispatched in the internal retail market, once their primary source is available. They correspond in general to µG units using renewable power sources under a feed-in tariff scheme.

While the authors in [7] may argue that Multi Micro-Grid concept adoption should account for technical services provision up to the highest voltage level and deserve both DSO and Transmission System Operator recognition, the most convenient approach will limit controllable DG (C-DG), µG and load contribution to the local voltage level of its connection, addressing local DSO only.

The local service market (performed at control level 3 and control level 2, Figure 1) may act towards recognition of technical contribution at Low Voltage (LV) and upstream network level (Medium Voltage level), such as:

- Network losses reduction;
- Voltage support via control of active and reactive power;
- Congestion relief and voltage drop resolution which could potentially lead to network upgrade deferral;
- Frequency support service via control of active power;
- Balancing, spinning or stand-by reserve services,

due to controllable µG, controllable load and energy storage at Micro-Grid level (control level 3, Figure 1), and controllable DG units and controllable loads at Multi Micro-Grid (control level 2, Figure 1).

Local service markets acknowledgement may be seen as an opportunity benefit for several stakeholders, such as:

- DSO may see the local service market as an option to set off his opportune revenue loss due to potential reduction of system charge as a result of local trading mechanism (for instance, internal retail market) for the part of the energy produced and consumed within the Micro-Grid. Additionally, the DSO may benefit, for instance, from peak load reduction service due to
normal µG unit trading behaviour (in the internal retail market under MGCC), without having to pay for the service.

- Controllable µG units, whose bids are not accepted in the local retail market under MGCC, may bid in upper level service market, under CAMC at potentially higher prices. Additionally, in situations of trading services, such as peak shaving and voltage regulation via generation reduction, the DSO could use part of the avoided line upgrade fee to award the respective µG or DG unit(s) for their service. However, the generation reduction contribution may experience difficulties with recognition in the service market, as the DSO may accuse the particular µG or DG unit as an initiator of the overload problem and refuse to pay for the potential service provision [5].

- Multi Micro-Grid consumers whose load reduction bids are not accepted in the retail market under MGCC, may obtain additional revenue by bidding in an upstream service market, for instance, for load curtailment due to technical constraints violation, such as overloads and excessive voltage drops below the technical limit due to natural load growth or grid reconfigurations.

Energy storage units may be installed at LV/MV transformer level or in feeding node of a MG, for instance, by the DSO for maintaining a certain level of technical performance of a single Micro-Grid or even in a Multi Micro-Grid [2]. In such a case, the DSO has the control over the unit’s location and he may choose the most beneficial location to place the unit due to for instance, most overloaded line(s) or the MV bus with most critical voltage drop [8]. Alternatively, energy storage units may be dispersed over a whole MG in a similar pattern as µG units (e.g. electric vehicles applications). In that way, renewable energy spillage may be avoided that may result from violation of grid technical restriction due to large DG and µG production levels [9].

Local markets acknowledgement requires development of specific control functionalities to be built at different network control level (MGCC, CAMC, etc., Figure 1) due to specific objectives (for instance, dealing with technical constraint violation, such as overloads and excessive voltage drops at MV level) [2]. Furthermore, only by adequate Multi Micro-Grid control and management architecture, the potential benefits due to large scale integration of µG (controllable and non-controllable), together with controllable load and storage devices may be fully recognized and exploited [2], [9].

3. COST AND BENEFITS ALLOCATION UNDER FREE MARKET MULTI MICRO-GRID MODEL

The decision due to Micro-Grid and Multi Micro-Grid concepts deployment may be made by different stakeholders due to different motivations. Figure 2 depicts the main drivers towards Micro-Grid and Multi Micro-Grid solutions adoption due to the three major stakeholders’ perspective: the DSO, end consumers and the µG developers. As shown in Figure 2, Micro-Grid and Multi Micro-Grid solutions may be seen as hedging tools for the DSO due to increased loading levels, which could cause premature replacement of infrastructure [10], or due to unreliable distribution network. As a result of the “prosumer” concept, due to Micro-Grid deployment, the end consumers may opt to purchase their own µG units so as to hedge against high retail tariffs and supply interruptions. Finally, the µG developers may accept Micro-Grid solutions as a way to expand its energy portfolio in order to offset high wholesale price peaks [11].

Figure 3 summarizes the potential benefits and costs due to Micro-Grid and Multi Micro-Grid concepts deployment.

The installation cost of putting in place the Micro-Grid and Multi Micro-Grid concepts stands for:

- Cost due to local controllers, such as: µG units’ controllers, load controllers, storage units’ controllers, Micro-Grid central controllers (MGCCs) and Central Autonomous Management Controller (CAMC);
- Communication infrastructure (installation of remote advanced metering, such as smart meters – [12]),

and it is assumed to be shared between the DSO and the consumers since both parties enjoy the benefits due to Micro-Grid and Multi Micro-Grid concepts adoption. However, different installation cost sharing mechanisms between the DSO and the Multi Micro-Grid consumers should be explored.
Furthermore, the cost due to controllable \( \mu \)G and DG units dispatch, energy storage dispatch together with controllable load shifting/curtailment in a local service market is assigned to the DSO. Technical services, such as thermal branch levels reduction or excessive voltage drop resolution due to natural load growth or grid reconfigurations may be seen as an alternative option for the DSO due to more expensive and sometimes infeasible network reinforcement investments.

Negative externalities, such as additional losses and voltage rises due to high penetration levels of \( \mu \)G and network reinforcement to accommodate large amount of controllable and non-controllable \( \mu \)G units may decrease with adoption of specific control functionalities (optimization procedures) to be performed at different control levels within the Multi Micro-Grid in such a way to deal with periods of network constraint violation [2], [9].

Economically driven Micro-Grid operation assures minimum price for the Micro-Grid consumers, considering the wholesale electricity prices, controllable \( \mu \)G units’ bids and controllable load bids/controllable load reduction bids [6]. In addition, DSI actions due to controllable (non-critical) load curtailment providing technical services to the DSO may result in additional revenue increase for the Multi Micro-Grid consumers.

Moreover, the ability of each Micro-grid to work as a controllable entity with the possibility of functioning isolated from the main grid may improve the global network reliability, providing higher reliability levels for all or some (important) loads, allowing the DSO to achieve his performance goals, imposed by the regulators.

Local consumption acknowledgement as a result of Micro-Grid and Multi Micro-Grid concepts may provide the \( \mu \)G units with possibility of obtaining quasi retail prices (in general higher than the wholesale market prices and lower than the retail market prices), as a result of producing and selling locally to minimize network charges [4], [5]. Additionally, under real time prices operation, each Micro-Grid performs local optimization procedures with a specific objective function (for instance, assuring minimum operation cost for the single Micro-Grid and therefore minimum electricity cost for the Micro-Grid consumers) or maximizing Micro-Grid’s profit (and \( \mu \)G developers revenue) by selling back \( \mu \)G energy in periods when the \( \mu \)G cost is below the selling (wholesale market price) [4], [5].

However, the controllable \( \mu \)G units (which do not enjoy a fixed Feed-In Tariffs) would still lack competitiveness in the wholesale market, explained by the application of additional system charges on top of basic electricity price in the wholesale market.

Under full recognition of \( \mu \)G units contribution by the DSO due to Multi Micro-Grid operation at upstream network level, in local service market (at control level 1 or 2, Figure1), some of the system charges imposed on \( \mu \)G units and loads may be reduced, if not totally retracted for the energy produced and consumed locally. This initially may be seen as potential for the \( \mu \)G units to obtain more competitive prices at wholesale market level.
Furthermore, under sufficiently high level of social and political support, Micro-Grid and Multi Micro-Grid concepts may act towards minimization of the end consumer electricity cost (between the local µG units and external market) as well as maximization of the µG units revenue by selling µG energy using real time prices, in merged (wholesale and retail electricity market) [5].

**Figures and Tables: Figure 3. Cost and benefits allocation due to Multi Micro-Grid free market model deployment**

A single Micro-Grid may be driven by purely environmental objective by taking advantage of participating in the emissions markets and sharing part of the additional benefits with the Micro-grids stakeholders. In [3] it is shown that combined participation in energy and CO₂ emissions market provides significantly higher environmental and economic benefits compared to maximising the earnings from participating only in energy market and considering the CO₂ remuneration as an additional income.

In addition to the general emission reduction via diversification of primary energy sources, Micro-grid and Multi Micro-grid concepts could also contribute to environmental protection by increasing energy utilization efficiency within the system. Efficiency improvement measures could include use of CHP units, DSI to reduce energy consumption, dispatch priority for less pollutant µG units, etc.

### 4. CONCLUSION

This paper deals with identification of costs and benefits due to Micro-Grid and Multi Micro-Grid concepts deployment and potential allocation schemes among major stakeholders, such as DSO, end consumers and µG developers. Different Micro-Grid ownership models, either due to the DSO or the end consumers’ ownership can easily grant the owner with full access to all benefits and prevent other stakeholders from sharing the benefits. Contrariwise, a free market trading mechanism may disseminate Micro-Grid benefits to a large number of stakeholders and according to a more fair and transparent scheme.

Building a proper Multi Micro-Grid control and management architecture, including local markets for energy and services, is a key factor towards full recognition of benefits and their allocation among
the affected parties. Moreover, an adequate control and management structure would efficiently link the µG units and DG units with active demand, leading to minimization of negative externalities, attributed to the DSO, in order to accommodate large scale integration of µG.

Under an internal retail market at Micro-Grid level, the DSO cannot force the Micro-grid to use its own µG units (instead of importing all demand) in order to improve MV or even HV level grid performance. Therefore, local and upstream network level recognition of a set of technical contributions to the DSO due to local µG, load and energy storage is needed for the DSO to opt for Micro-Grid and Multi Micro-Grid solutions, setting off in that way the potential reduction of system charges for the µG units and the consumers due to the energy produced and consumed locally.

Micro-grid and Multi Micro-grid concepts as enablers of large scale integration of diversified primary energy sources, such as renewables and less-emission fuel technologies may also contribute to environmental protection by increasing energy utilization efficiency within the system. Combined participation in the energy and CO₂ emissions market may bring additional benefits for all Micro-Grids stakeholders.

Finally, both, the DSO and the Multi Micro-Grid end consumers enjoy the benefits due to this concept deployment. In that sense, the cost due to Micro-Grid and Multi Micro-Grid installation and communication infrastructure should be shared between these two stakeholders. However, Micro-Grid and Multi Micro-Grid operation cost as a result of technical service transactions is assigned to the DSO only, where the DSO may rather opt for Micro-Grid and Multi Micro-Grid solutions, instead of performing more expensive and sometimes infeasible network upgrades due to natural load growth or grid reconfigurations.

5. BIBLIOGRAPHY