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Development of Community Grid: Review of Technical Issues and Challenges

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***Abstract*— The concept of a community grid is presented here. It involves the distribution grid and an increased use of renewable energy coming from distributed resources along with the consumers/prosumers engagement in energy trading mechanism. The possible operation and management with energy trading flexibility are briefly outlined. Under such scenario, the classical operation of the distribution grid is challenged by the issues brought by the large penetration level of the new energy resources. This paper presents a status review of the technical issues that may appear under the community grid scenario. Building upon those surveyed issues, this work also reviews and discusses approaches to solutions, which are required in order to make the community grid highly renewable and sustainable.**

***Index Terms*— Community grid; microgrid; power systems; power converter; resonance; stability; harmonics; islanding**

I. Introduction

Traditionally the distribution grid was a radial system handling a unidirectional power flow from the power plants to the consumers. It is now-a-days changing with the consolidation of technologies that enables massive use of distributed energy resources (DER) like renewable generation and storage. The scenario brings new challenges to the grid that is now required to connect a variety of generation-consumption points by means of two-way power flow branches. In this grid, consumers can also produce energy becoming prosumers, with the possibility to interact among themselves and with the grid in new ways.

Driven by economic incentives, regulations, or by an increased citizen awareness, combined with equipment price dropping, residential consumers are connecting with increased number of renewable energy generators. The type of generation with the largest impact on the distribution grid is the photovoltaic (PV), which generates DC and injects AC into the network through some power electronics converters. With the introduction of early PV generators started the investigation of their effects on the grid. Some initial analysis on possible effects are found in [1, 2] that already covered aspects like harmonic distortion and resonances. Although those works did not detect major problems, later on, with increased use of PV, some installations were showing the effects related to the operational issues [3]. Around that time, regulation authorities and utilities carried out investigation on the possible effects of PV and other renewables on the distribution grid [4, 5]. According to those reports, the negative impact was mostly related to power quality (PQ) disturbances such as voltage regulation, islanding detection, anti-islanding protection failure, and some possible, though unlikely, resonance cases.

In recent times, with increased penetration of renewables, renovated concerns on possible negative effects were raised [6]. Some of the reported issues were related to the voltage level and regulations [7, 8]; increased harmonics distortion which could derived from resonances [3] or not [9, 10]. The reports [11, 12] show that small-signal instabilities can also manifest large harmonic distortion. Transient stability could also be impacted, sometimes by action of anti-islanding relays [5]. Therefore, nowadays efficient and intelligent operation and management of multiple renewables in distribution grid without lessen the stability is a major concern.

Development of microgrid in different forms and its operation in on/off-grid condition are also playing an important role in expanding the DER integration in the distribution network [13]. Though the interconnection between the microgrid and the utility/smart grid network also exposes their respective inner PQ disturbances, such as harmonics, unbalances, it is better to isolate the grid through a power quality conditioner [14]. Hence, to improve the PQ in microgrid and distribution network, the custom power devices such as STATCOM and UPQC are getting importance as well [15, 16].

Now-a-days, the idea of community based microgrid systems are also being well-accepted by the community consumers/prosumers. This is acting as a powerful tool to empower the energy active citizens. Researchers are proposing different structural solutions for the benefits (more focus on the economic sustainability) of community users [17, 18].

With all of these improvement in DER based integrated energy system development and integration, maintaining the grid stability, improved power quality and efficient energy management with high penetration of renewables from a large number of micro-generation systems in the distribution network are still a matter of great concern. Therefore, a concept of community grid structure in the form of virtual

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microgrid embedded in the distribution network is presented in this paper. A major goal of the proposed community grid structure is to increase renewable energy usage by facilitating the consumer transition to active prosumers, and giving them a scenario to develop the solution using their existing setup. This implies large amount of distributed renewables being injected into the distribution grid whose effects have to be addressed [19].

This work then compiles and discusses previous studies and findings about the technical issues and challenges appearing when injecting increasing amounts of renewable energy in the distribution grid. Many articles have been published on the broad topic covered by this survey. It is not the goal of this work to be exhaustive on the review. It is rather preferred to record the type of possible issues, while also giving special attention to those backed by measurements on grid similar in structure and operation to the community grid. This is an extension of the paper [20] which was partly presented in the IEEE IAS conference.

II. Community Grid

The proposed community grid is a type of virtual microgrid system that can be developed within the existing distribution grid network. It involves the operation and management of a virtual microgrid system through a central community grid controller (CGC). Fig.1 shows the simplified diagram of a community grid structure, proposed in a low-voltage (LV) distribution network (residential). One of the key objectives of the development of community grid is to minimise the costs of electricity consumption from the transmission/distribution grid by prioritizing self-sufficiency. The solution is more focused on high penetration of renewable energy from distributed and micro-generation systems (µGen) without lessening the grid stability as well as to achieve the µGen sustainability through the empowerment of energy active citizens. This community grid approach will be highly appreciated where µGens or distributed RE based solutions are not popular due to the absence of or limited renewable energy fed-in-tariff (REFIT) policy.

A. Operation and Management

Operation deals with the physical control of the proposed network such as power & energy matching, power quality improvement and grid stabilization issues. Whereas, management deals with the energy balance (within the supply, demand and storage) and energy trading (to empower energy citizen) within the residential neighborhoods as well as with the utility operator.

B. Operational Flexibility

The novelty of the proposed community grid structure is that it will not physically change the existing national grid structure/distribution network. Rather, the central/distributed controller (CGC) for this virtual structure will be developed in such a way so that the existing physical grid network can be separated and operated as a real community microgrid system, if needed in future. Thus the flexible operation can be achieved. This requires the self-healing capability of the real microgrid. At this stage, the proposed virtual microgrid system will have its self-healing capability and disturbance neutrality in the eyes of distribution system operator. This disturbance neutrality can be achieved by the community grid controller by developing the proper power and energy matching, supply

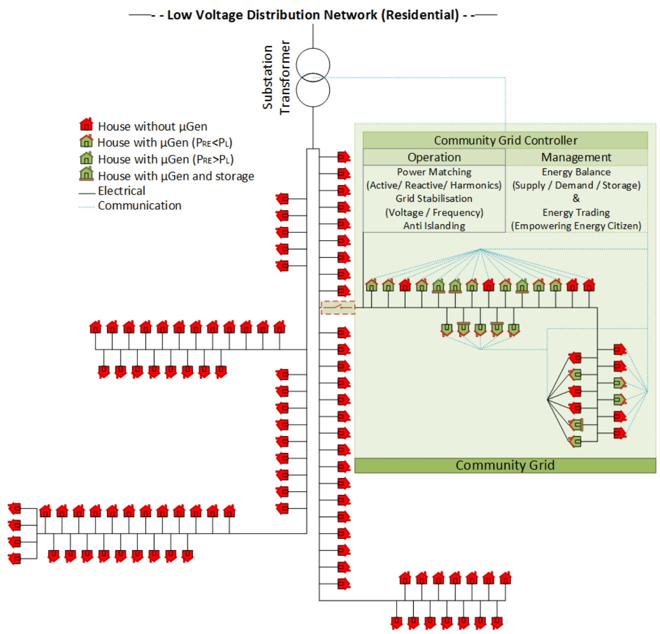

Fig. 1. Community grid concept.

and demand energy balancing, reactive and harmonic power compensation, microgrid network stabilization and anti-islanding facilities.

C. Energy Trading Flexibility

To increase the active participation of consumers and prosumers, a community energy trading platform can be introduced in a flexible energy trading mechanism so that prosumers can trade excess energy with other consumers/prosumers in the same community grid network as well as with the utility operator. In future, this trading can be extended to other community grids in the same or different distribution network. Thus community grids would achieve operational and energy trading flexibility in an organized/structured way within the smart grid network.

D. Sustainability

A brief techno-economical sustainability analysis of this proposed community grid system is presented by the authors in [21]. The grid model baseline as shown in Fig.1 corresponding to a typical urban residential distribution in Ireland is simulated in Matlab. Considering the Irish grid code and condition for µGen integration and penetration limit, analysis shows that penetration of 100% renewable energy from PV based µGen system is possible with some degree of control for stabilization. A simple economics for the development of CGC for 50 prosumers based community grid system with a stabilization unit (storage capacity - 300kW/300kWh capacity), suggest that energy trading cost will vary from 12-19 cents (euro) per unit, as shown in Table1.

This cost is lower than the present utility electricity cost in Ireland. At present, Ireland also does not allow REFIT cost for μGen system. Thus this community grid solution could open a door for consumers/prosumers to become energy active citizen. Interestingly, a cost of DSO CARE is introduced here, which we are proposing to pay the DSO/utility operator as a service charge to allow the community users to use the existing network infrastructure.

Based on the community grid concept, a research and demonstration project is being developed in Dublin, Ireland [22] where the consumers/prosumers will have a better choice of supply, access to reliable energy price, possibility to produce and sell their own electricity, increased transparency and better regulation as proposed in [23].

Table 1: Economic Sustainability of Community Grid System

50 Prosumers based Community Grid		
Prosumer's Energy Production Cost from (6-3)kW μGen System	0.09 - 0.15	€/kWh
CGC (O & M) Cost	0.02 - 0.03	€/kWh
DSO CARE* (service charge)	0.01	€/kWh
Energy Trading Cost	**0.12 - 0.19**	€/kWh

* Clean And Renewable energy Exchange

Details of operation and management, operational flexibility and sustainability study are out of the scope of this paper. As the concept of developing community grid is new, from the operational perspective, the following section discusses more on the technical issues that the community grid could face to turn into a zero emission community.

III. Review of Technical Issues

A summary of the technical issues appearing when distributed generation (DG) is added to the distribution grid is presented in this section. Special focus is given on the high penetration of DGs including renewables that are interfaced through the power electronics converters and mostly connected to the low voltage distribution network.

A. Voltage level and generation variability

The power injection at the load points directly impacts the active power flowing through the distribution network in magnitude and eventually direction. The operation of DG also alters the reactive power flowing through the network. In a typical radial distribution grid, the change of both active and reactive power will directly impact the voltage profile along the distribution feeders. Voltages at the point of load/generation coupling will rise when generation becomes greater than the consumption. This issue has been studied for three-phase [8] and mostly single-phase systems [7].

Because voltage deviations could exceed tolerance bands, it becomes necessary to compensate those variations. Use of on-load tap changers could help, but they are rarely used in the distribution grid [24], and have slow response. More effective would be to use reactive compensation devices, like statcoms, to keep the distribution voltage under limits [25]. Other possibilities include using the power converters, like the PV inverters, to inject reactive power for voltage support [8],[26]. Nevertheless, this last option requires increasing the rating of those inverters. Energy storage devices connected to the grid, could also be used to support the voltage profile. One of the possibilities is that the storage comes from EV batteries [27].

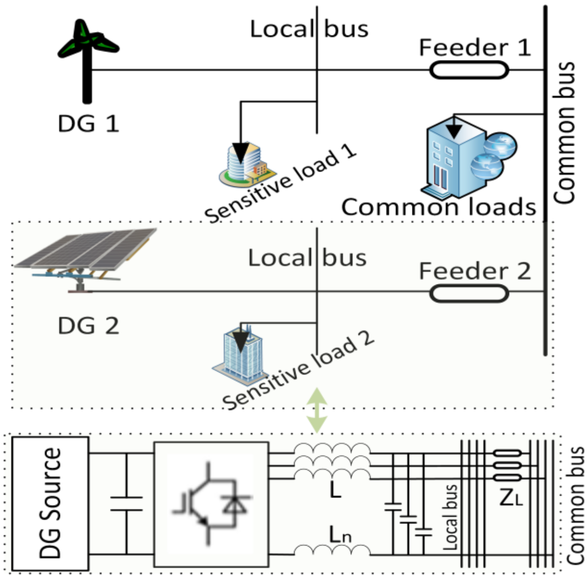

Fig. 2. Example of the three-phase system with 4-leg inverters.

When single phase equipment is used in three-phase systems, there is the risk of creating unbalance. This could affect some of the three-phase loads. In some cases, a solution to improve voltage balance could be implemented using 4-leg inverters, as shown in Fig.2. However, in many cases such a solution is costly [28].

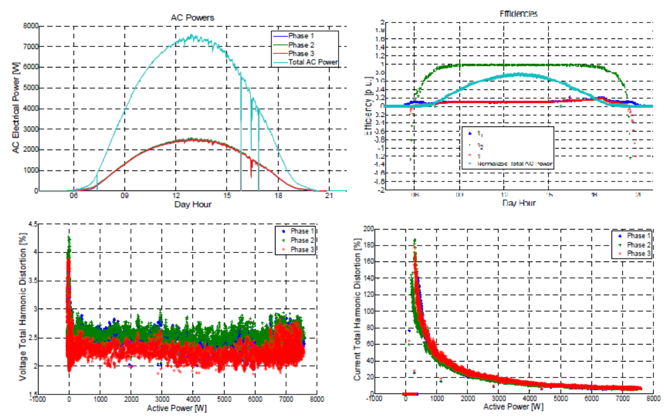

Fig. 3. Performance of a 3-ph PV inverter - unbalanced load condition

B. Harmonic Distortion

Power converters used for DG interface introduce harmonics into the grid, as shown in Fig. 3, where it is found that the performance of PV inverter degrades due to weather and unbalanced load conditions [29]. Hence, the current harmonics also cross the standard limit. However, well designed equipment that follows established standards, introduces only a limited harmonic distortion. Possibilities of increased intolerable harmonic levels could come from an aggregation of distortion making the local network highly polluted [30], negatively impacting the converter behavior. In addition, such inverters can also introduce inter-harmonics with possible flicker impact [31]. Other possible undesirable contribution of some network nonlinear elements, or resonance excitation, could rise voltage and/or current harmonic components [32].

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Solutions for increased levels of harmonics would usually consist of controlling the source of distortion or adding filters, either passive or active. Although filtering is a viable alternative, it has costs implications. On the other side, the reduction of the distortion source would require involving the power converter; possibly modifying designs that already comply with established standards. A possibility, not yet included in the standards, that involves the interfacing converter making use of its filtering capacity is proposed in [33].

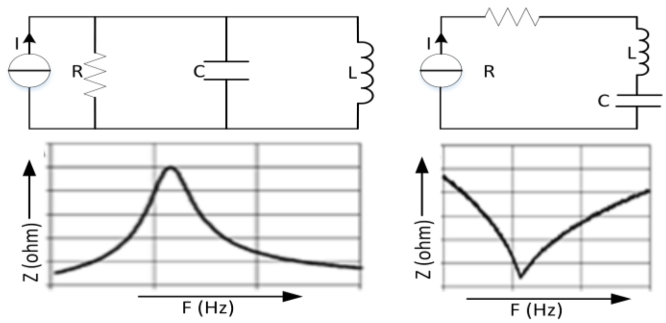

Fig. 4. Mechanisms of (a) parallel and (b) series resonance

C. Resonances

Experience shows that in many cases increased harmonic distortion is related to the resonances. This is found for both mostly single phase [3], and three-phase [34], distribution grids. Resonances could also contribute to overvoltage creation [35]. Series or parallel resonances, as shown in Fig. 4, can be created by the combination of purely physical reactive elements [36]; but in most systems employing equipment with feedback controls, resonances are created by a combination of control action with reactive elements [10],[37].

The capacitive component of the resonant circuit could come from actual capacitors, or from parasitic parameters of other elements, e.g. cables. In many cases the presence of shunt connected capacitors in the grid plays a crucial role in establishing the resonance [34],[36]. The shunt capacitors can be part of reactive banks for power factor compensation, or of power converter line filters, like the LCL filters. For those

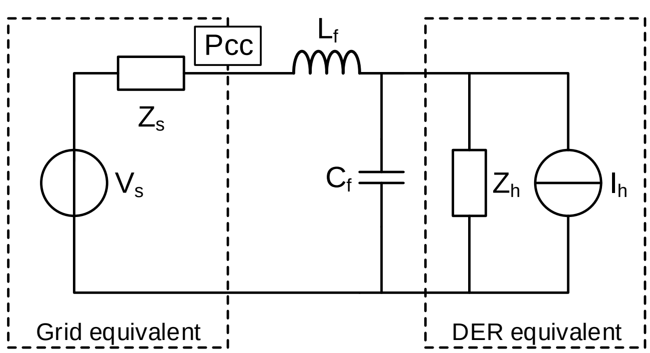

Fig. 5. Equiv. circuit of grid-connected converter & possible resonance paths

filters, the practice to increase the capacitor size in detriment of the inductance has the risk of placing the resonances at frequencies where they could become excited by the harmonic components of the converter PWM waveforms [3],[38]. Fig. 5 shows an equivalent circuit for resonance studies where it is possible to observe the possibility of both series and parallel resonance. L_f and C_f are the line filter components, V_s and Z_s are the grid Thevenin equivalent; and I_h and Z_h are the DG interface inverter Norton equivalent. Pcc is the point of common coupling.

D. Stability

Stability of electrical systems can be broadly classified in small- and large-signal with the last implying sudden changes in the operating conditions created by events while the first type mostly driven by interactions among equipment in a slowly changing scenario [39].

In distribution grid, the unstable behavior could be responsible for serious disturbances and equipment disconnection. It could also happens that the instability does not disengage equipment, but is responsible for large perturbations which affects the power quality [11]. Small-signal instability could be determined by using the impedance criterion [12]. In this type of analysis, the stability is related to the source-load impedance ratio providing insight into the aspects that could determine the allowable level of DG penetration [10]. The presence of some specific equipment, like induction motors, could negatively impact the grid stability [40].

In terms of large signal stability two major aspects have been taken into account: rapid variations in the primary source, e.g. clouding effect on PV, and the behavior following a sudden grid loss [5]. The source variability, though relatively slow in electrical terms, creates a generation-load unbalance that must be covered by energy from other sources available, and whose impact also depends on the PV penetration level [41].

In case of microgrid system with high penetration of renewables, the stability issues are divided into three

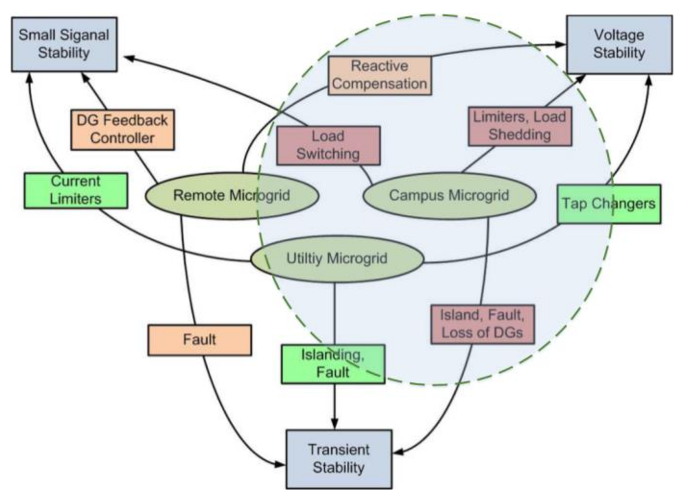

Fig. 6. Stability issues in different types of microgrid

categories; (i) small signal, (ii) transient and (iii) voltage stability, as show in Fig 6 [42]. In addition to the small signal stability, a fault with loss of power and subsequent island operation poses a transient stability problem. Voltage stability problems occurs due to the reactive power limits, load dynamics, under voltage load shading and tap changers voltage regulation. When it comes to the development of community grid as a virtual microgrid, it should consider mostly the stability issues related to campus and utility microgrid, as shown within the dotted circle in Fig.6.

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E. Network Protection

The possibility of feeding the network from the load connection point certainly affects the operation of protection relays and the selectivity of the protection scheme. The changes in the distribution network operation, produced by the introduction of DG has drawn a good amount of attention driving both research work and standardization [43],[44].

Effects of DG in the distribution grid include different possibilities of protection miss-operation and relay malfunctioning that are related to the power injection at the user point of connection modifying the fault current patterns. Some of those possible effects are: relay not seeing the fault, either primary or backup; loss of coordination and/or selectivity; fuse improper operation; unsynchronized or unavailability of reclosing [45],[46]. In case the operation is islanded, microgrid operation issues can appear. Use of power conversion interfaces, like the ones used for PV or batteries, has some advantages against other type of equipment because of their faster controls and protections enabling quick and accurate responses. However, full use of these capabilities may still require developing adequate algorithms [47]. Use of fast communications could be useful for providing effective protection as well [48].

F. Islanding Operation

At the distribution level, it is a common practice that DG is required to disconnect from the grid in case a fault is detected. If that disconnection is done fast enough then utilities would need to do little adjustment on their protection settings because after a few milliseconds the DGs get disconnected from the grid and this would be back operating under the well-known radial unidirectional power flow condition [45]. Although this situation may have the benefit of not altering a setting that has proven operational for decades, it also allows little space for improvement and may impact the cost of increasing DG penetration. Moreover, when penetration levels become large it could have negative effects on the grid, as pointed in [5]. The problem worsens if anti-islanding protections create unnecessary disconnections [49].

The requirements for anti-islanding protection in DG connected to distribution grids have given place to a good amount of research. The work in [50] offers a summary of algorithms for islanding detection. It also classifies them into four categories that are passive, which are only based on measurement of electrical magnitudes; active, which inject an electrical magnitude and analyses the system response; hybrid, which try to combine the benefits of the active and passive; and communication based, which make use of fast communications between the DG and the grid protection. In general, anti-islanding detection and protection algorithms are integrated into the power converter controllers [51].

Having these network protection and islanding operation issues in mind, community grid controller needs to develop appropriate control strategy to operate the community grid in future as a real microgrid, if needed. Therefore, the community grid also needs to select its physical node point at the distribution grid as its virtual entity.

IV. OVERCOMING THE CHALLENGES

Reaching high levels of renewable energy penetration in community grid requires properly addressing the described issues. An integral approach to them would enable reaching high level of clean energy penetration in an efficient and cost effective manner. A large amount of research has been done, but improvements are still possible, desirable, and in several cases necessary. The next paragraphs briefly discuss on the possible solutions, their development status, and some of the items that require more attention.

A. Power Interface - Converter Technology

Improvements in the power converters interfacing the DGs involve better control functionalities and an enhanced reliability with larger medium time between failures (MTBF). Beyond those basic characteristics, the converters could contribute enhancing the grid behavior in the following items.

1) Increased capacity to inject reactive power without detriment of active power

As forced commutated converters have the capability to quickly inject power with any power factor, they can be used to inject reactive power supporting voltage regulation. This has already been proposed [4],[52]. The expense is that the converter rating must be adequate to the increased currents along the desired power factor operation range. Therefore, the

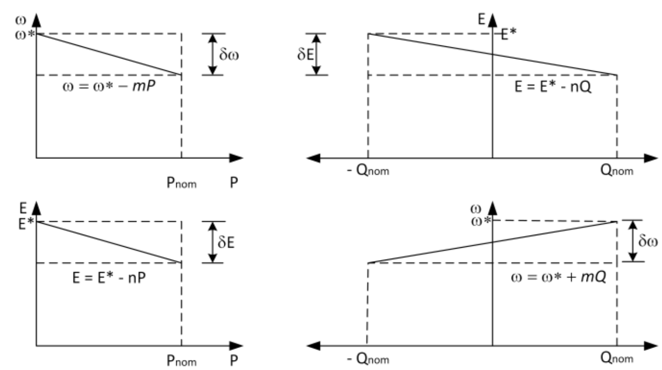

Fig. 7. Droop characteristics of P–ω and Q–E

cost of the converters with this capability will be larger than for a converter that injects only active power. In case of parallel operation of multiple inverters in distribution network, the implementation of droop controller, as shown in Fig 7, could take the advantage of coordinated control without the communication among the inverters [16].

2) Reduction of harmonic current injection

Power converters must not contribute to creating or amplifying harmonics due to resonance or instabilities [10]. Moreover, control algorithms implemented in the digital controllers of the power converters connecting the DERs to the grid have improved considerably in recent years enabling for low distortion current and compensation of specific harmonic orders at reasonably computation expense [53],[54]. In addition, the raising capacity of power converters associated to fast and accurate controls could bring the possibility of using the same converter that interfaces the DGs for harmonic compensation. This has been analyzed in low power and for residential PV inverters [33],[55].

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It is to be noted that the current equipment certification does not properly address the testing of equipment under grid distortion conditions where a large amount of power converters are connected. As the equipment behavior is impacted by the grid distortion, this issue requires to be properly addressed. Some of the grid-connected PV inverter manufacturers, such as SMA, are developing inverters these days with advanced control to take care of injecting active and reactive power to maintain the grid stability, when needed [56].

3) Advanced management of grid loss/islanding condition

Current standards and regular practices by utilities require the implementation of anti-islanding protection schemes for inverters connected to the LV distribution grid. However, the negative effects of that requirement have already been pointed out in [5]. Anti-islanding algorithms require improvement in order to reduce unnecessary trips which lowering the network performance [49]. In addition, increasing amounts of renewable generation is affecting the network stability pointing to the necessity to re-evaluate the impact of anti-islanding requirements in current standards. The recent version of the IEEE 1547-2018 standard has updated the required criteria for interconnection of DGs related to voltage regulation, voltage and frequency responses at abnormal conditions to overcome the anti-islanding issues, improved converter performances to maintain the grid stability with high penetration of renewables [57].

B. Reaching High Levels of Renewable Penetration

One of the features of the community grid is to meet the full load demand from renewable energy supply. Achieving large penetration of renewable energy sources has always been a concern [1]-[8]. The next paragraphs discuss on some of the possible actions that could be adopted in order to reach higher levels of renewable energy penetration.

1) Microgrid Paradigm

The microgrid concept has been proposed in the past and represents a grid that can operate in stand-alone mode feeding a diversity of loads from one or more generation sources. They can also be connected to a larger network [58]. This means that the equipment used in the microgrid must be able to operate in both scenarios; additionally, the change of conditions must be properly handled by the microgrid as a system [51]. Although the community grid is intended primarily for grid connected operation but in virtual microgrid structure with a real physical node of entity; the mentioned microgrid features are relevant as the prosumers may be interested in having the capability to continue operating in case of network loss [59]. Thus, the microgrid/community grid involves the connection of DGs like renewable generation, energy storage, and EV chargers. Additionally, power conditioning like statcom or stabilizer devices and the grid connection point. The operation is under the control and supervision of the microgrid/community grid controller (CGC) that also allows connection to other entities.

The other important feature of the community grid (virtual microgrid) is to operate and control in such a way so that the disturbance neutrality from the distribution network perspective is exist. Hence, the communication between CGC and DSO/DNO (distribution system/network operator) for a coordinated control is very important.

2) Energy Storage

Energy storage becomes relevant when the majority of the supply comes from intermittent energy generators like renewables. If most of the energy comes from PV generation then the amount of storage necessary to support for night long operation becomes considerably large. This fact challenges traditional energy storage technology, especially batteries. To assume larger amounts of energy storage flow batteries provide a possible solution. However, this has to be fully validated. Distributed energy storage systems also playing important role in microgrid operation and control, as it helps to improve the local reliability and resilience, also mitigate challenges caused by high penetration renewable generation. As it incurs additional cost, to get the best outcome, optimal sizing and placement in very important [60].

Hybrid and electric cars also have embedded energy storage capacity; their possible usage for the benefit of the grid have already been studied [27]. However, they have an unpredictable component because their primary use is not to support the electric grid.

3) Grid Protection and Enhanced Communications

Use of communications for protection of the grid with renewable resources and the microgrid has already been studied and new protection schemes for them have been proposed [48],[61]. Some of these methods require reliable broadband communication channels. As these become available enhanced control and protection of grid connected elements become a reality. In any case, it is foreseeable that development in better communication will enhance the protection by enabling new functionalities or enhancing existing ones, like selectivity, coordination, and detection of grid conditions.

C. Specific Equipment

There are some specific equipment for microgrid already exist that can support the community grid development, providing solutions to the challenges previously mentioned.

1) Microgrid controller

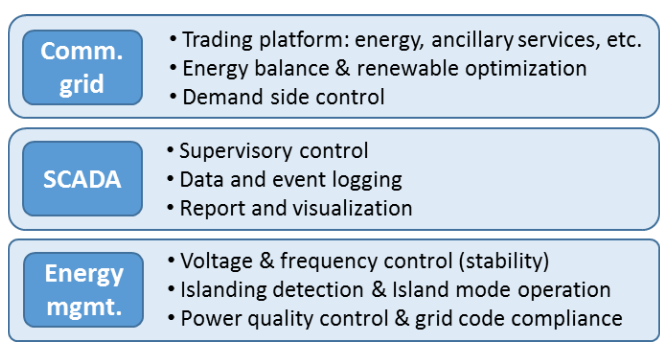

Fig. 8. Microgrid and community grid control functions

The community grid controller has the functionality to enable the community grid operation under the defined objectives. In addition, it has to overview the operation of the grid, verifying that electric magnitudes remain inside allowable ranges, and enable the interaction among prosumers and with the grid operator [62]. The functionality that such controller must have is closely related to the microgrid safe and reliable operation as discussed in [63],[64]. In addition, the controller must include the community grid functionality. Fig.8 summarizes the microgrid controller functions with the addition of the community grid requirements.

2) Statcom

Due to the intermittency of the renewable generation and the voltage regulation issues previously mentioned, fast response voltage control is required. This capacity can be provided by dedicated equipment like a statcom, as shown in Fig. 9 [65].

Nevertheless, DG interfacing power converters can also contribute to voltage control. If the amount of inverters with voltage regulation capacity is enough, they can also serve as a statcom. Use of PV inverters to regulate the voltage has already been proposed [25]. Moreover, issues on how the converters will take part in the voltage regulation and share the duty of injecting reactive power are still a matter of study. Some schemes for that in a microgrid have been proposed in [66].

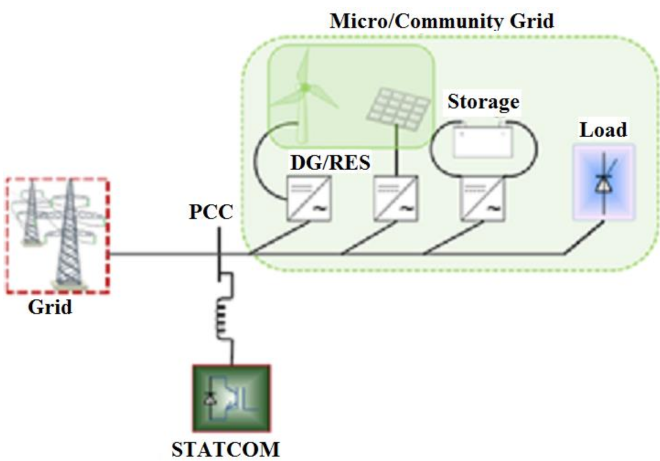

Fig. 9. STATCOM in microgrid operation

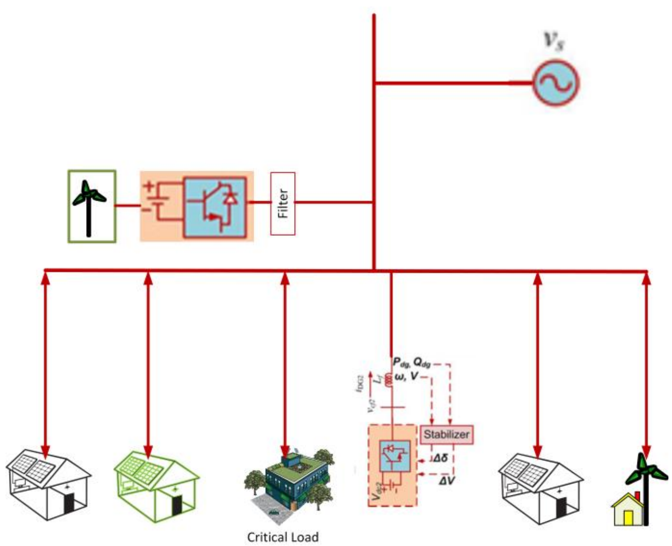

Fig. 10. Stabilizer for DGs in microgrid

3) Microgrid Stabilizer

The balance between load/demand may be affected by the different events in the grid. The microgrid stabilizer is conceived as a device that contributes to restore that balance by using energy storage, as shown in Fig. 10 [42]. In isolated microgrids, mostly fed from renewable energy, such stabilizer is seen as a critical piece of equipment that allows achieving a reliable operation with good service quality [67] while minimizing the need of non-renewable reserve like diesel groups. Microgrid stabilizers with flywheel or battery energy storage have been developed and are currently being commercially offered by some of the manufacturers [68],[69]. In grid connected microgrids, like community grids, the stabilizer can provide a stabilizing resource to the grid. Custom power devices can also provide stabilizer functionalities in addition to the harmonic voltage and current compensation capabilities [70],[71]. Having all of those capabilities, stabilizers can strongly help in increasing the penetration level of renewable energy in community grids.

4) Transfer Switch and Seamless Transition

Community grids are conceived primarily as a virtual microgrids. However, islanding operation may be required in future. In such a case, the transfer switch allowing operation in grid connected or islanded modes becomes necessary. Therefore, such devices can be used in the grid connection and the operation of the microgrid in order to reach a seamless transition between operation modes [71],[72].

V. Conclusion

To achieve the de-carbonization of grid network and empowering energy citizens, a way of penetrating high renewables in the low voltage distribution network through the development of community grid is presented here. This will allow multiple integration of μGens and other DGs in a sustainable way.

The path to future community grid using mostly renewable energy requires reaching penetration levels of DG from renewables consistently higher than the current established practices. This generation will be connected at the distribution level with a vast majority of the generators interfaced through power electronics converters. An overview of the technical challenges that would arise under such circumstances, the reasons, and possible ways to overcome them have been discussed in this paper.

All the technical issues discussed in the previous sections limit the DG penetration level. However, solutions that mitigate the undesirable effects could be developed and implemented. Overall, in order to achieve an energy supply coming mostly from renewable sources the solutions must address all the issues previously discussed. Good system engineering will be the one that allows reaching those desired goals while employing the smaller amount of resources; becoming therefore, most cost effective.

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