CIGRE-281 **2020 CIGRE Canada Conference**
Toronto, Ontario, October 19-22, 2020

Alternative network development – need for flexible solutions for operation and planning of distribution and transmission grids

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SUMMARY

Power systems around the world are faced with a wide range of challenges to meet the objective of integrating an increased amount of renewable energy in the electricity grids. As the amount of renewable energy sources increase in distribution grids, together with electrification of the transport sector, the grid operation becomes increasingly challenging with temporary congestions and fluctuating voltage profiles. In addition, the uncertainties in future development lead to increased risk of stranded investments if traditional investment procedures are followed. Development of alternative, and agile, solutions are therefore required to cope with these situations in a sustainable manner.

Active Network Management (ANM) provides the ability to increase grid utilisation of distribution grids through alternative means to conventional grid reinforcements. ANM are based on advanced control solutions which are often relying on increased monitoring of key network quantities in the grid and enhanced communication between flexibility providers, grid operators and other stakeholders. Flexible network assets include load, production, as well as other controllable equipment in the grid, which can support the flexibility needs of the grid.

This paper provides insights into grid development trends, the flexibility needs found in the distribution grids, and how these needs can be supported through Active Network Management solutions.

KEYWORDS

Network expansion; Investment planning; Grid development; Flexibility; Active Network Management

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1. INTRODUCTION – AN EVOLVING POWER SYSTEM

Developments of the power system are highly driven by the need to decrease the environmental footprint of our global energy use pushing for fossil-free energy system. In the decades to come, the transition towards clean energy will result in a transformed power system on a global scale with significant investments needed in fossil-free electricity production and transport. Renewable Energy Sources (RES), mainly as power electronic interfaced generation, play an increasingly important role in the power system, and it is likely that these will become the main source of electricity in the future. In order to fully utilize available renewable sources, the power systems need to evolve.

Transmission grid investments are driven by several factors, such as: the integration of bulk-scale RES plants, the need to supply concentrated load centers, as well as enabling closer integration of electricity markets between countries and regions. Since large installations of renewable production plants are often located in remote areas, there is an increasing and urgent need for expansion of the high-power high-voltage transmission grids calling for substantial and long-term investments.

Distribution grids host a significant part of the renewable production installations, which calls for increased needs to enhance the local grids to new and complex tasks (flows optimization, balancing, local dispatching, selective protection, etc.). The rapidity in small-scale investments calls for grid investments with agility to handle the fast investment decisions required to meet challenges arising from the demand, with distributed renewables as well as the electrification of transport and heat sectors as the main influencing factors.

Alternatives to traditional network expansions are developing, with new technologies and markets emerging to provide increased flexibility to support the grid. The deployment of distributed controllable equipment (e.g. power electronic interfaced devices) provide opportunities for advanced control to support the dynamic behavior of the system as well as solutions to increase the transfer capacity for operation and planning purposes. Active Network Management solutions provides alternative methods to plan and operate the power system, depending on monitoring and active control of various equipment in the grid.

Section 2 of this paper gives an overview of the two grid development trends, the micro and the MEGA perspectives. In section 3, we describe two categories of flexibility needs related to distribution grids, and in section 4 we illustrate how these needs can be supported through Active Network Management solutions.

2. PERSPECTIVES ON THE DEVELOPMENTS OF THE POWER SYSTEM

Spawning from the aim to enable very high penetration of renewables, two trends are emerging with significant impact on the grid evolution. These trends are illustratively presented in Figure 1, and further described below.

In order to reduce the climate impact from electricity generation, significant amounts of Renewable Energy Sources (RES) are integrated into the distribution and transmission grids. The volatility of weather-based electricity production increases the strain on the power system which are resulting in the needs for solutions addressing the security and capacity of the power system.

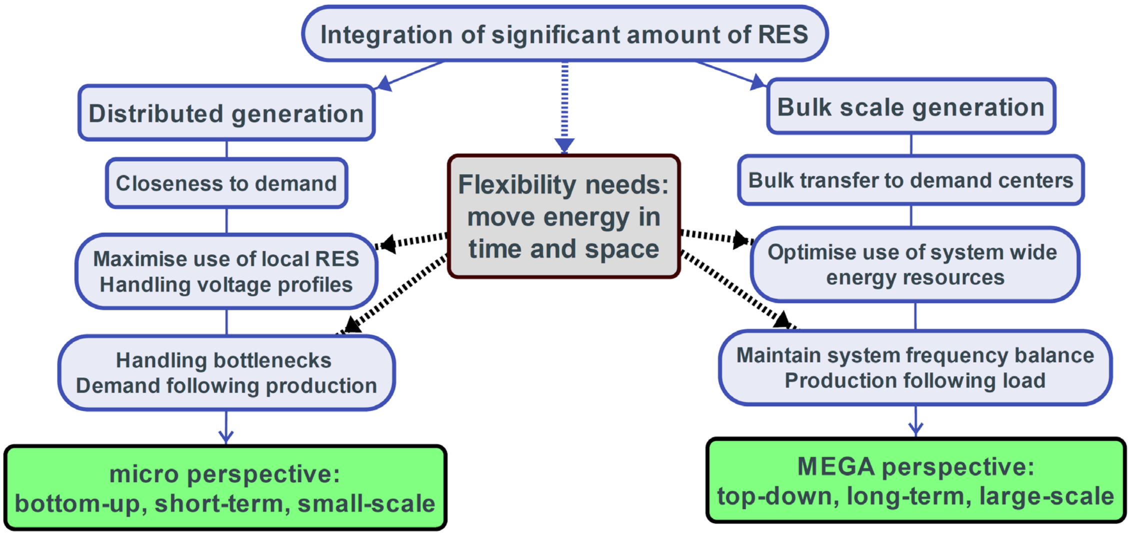


Figure 1: Holistic view of the electricity system developments, modified from: [1].

Distributed generation:

- Benefit of being relatively close to demand, reducing transfer needs and losses. However, this may result in an increased amount of temporary congestions and possibly unprofitable down-regulation of renewable electricity. Here, the need for moving energy in time arises to reduce peak flows. The power flow in distribution grids often becomes bi-directional, as the result of higher production than demand during certain time periods. Fault currents also change and may have impact on various protection systems, e.g. setting of distance protections, which must be carefully handled. Furthermore, the voltage profiles in distribution grids will drastically change when introducing distributed generation. Resulting in increasingly fluctuating voltage levels, depending on the production and demand profiles.

Bulk scale generation:

- Benefit of economy-of-scale, and the ability of supplying energy for concentrated demand centers. However, to be able to make an optimized use of the system wide resources there is a need for increased power transfer capacity on the transmission level. Furthermore, on a system level, the increased amount of variable RES requires additional balancing resources and solutions for maintaining the frequency.

The two trends, or perspectives, on the power system development are in [1] described as the micro and the MEGA perspectives:

- micro: focusing on the local, with a consumer centric bottom-up view, where small-scale solutions require short-term investment horizons, including large number of actors and an inter-sectorial development.
- MEGA: focusing on the system or even the intra-system wide levels, with a top-down view, where bulk-level large-scale solutions require long-term investment horizons and often intergovernmental agreements, involving a small number of stakeholders within the power and energy sector.

The developments from both these perspectives are very much depending on national policies, subsidiaries and strategies, which may result in the favoring of one of the investment strategies at the expense of the other. As described in [1], both the micro and the MEGA perspectives are required to enable an optimal system development.

3. FLEXIBILITY NEEDS ON THE LOCAL AND REGIONAL LEVEL

Power system flexibility is an expression which has gained significant momentum during the last years. Flexibility in general has been seen as an enabler for the power system to cope with the challenges mainly arising from the increased amount or RES in the power system, as illustrated in Figure 1. However, since these needs can be seen from various perspectives the expression flexibility is used to express rather different phenomena.

Four categories of flexibility need have been presented in [2], differentiating the needs between system level (related to maintaining frequency stability and energy balance) and more local needs (related to capacity and bus voltages) as illustrated in Figure 2.

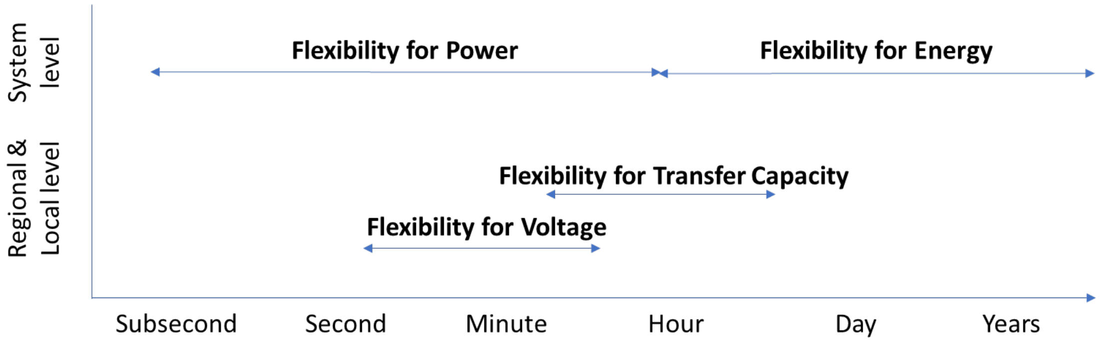


Figure 2: Flexibility needs on different power system levels and their respective relevance in time, source: [2]

In the local perspective, flexibility supporting an increase in distributed generation, as well as increased demand, may be categorized as: Flexibility for transfer capacity & Flexibility for voltage.

For distribution grids, transfer capacity is typically limited by thermal overload rating (i.e. ampacity) but stability limitations could as well be the case. In the broader view, one could also argue that the transfer capacity may be limited by specific bus voltages – thus the flexibility for transfer capacity is interconnected with the flexibility need for voltage.

The main need for flexibility for voltage comes from the increased voltage fluctuations in a radial distribution grid with significant amount of RES. The volatile power flow may result in voltages fluctuations from minimum to maximum in the extreme ends of the radial, which calls for dedicated solutions to provide secure voltage levels.

4. ACTIVE NETWORK MANAGEMENT

Active Network Management (ANM) is a way to address the flexibility needs in the distribution grids through alternative solutions to the conventional grid reinforcements. ANM solutions are utilizing advanced controllers which are often relying on increased monitoring of key network quantities in the grid and enhanced communication between flexibility providers, grid operators and other stakeholders. The benefits of ANM are intended to speed up connection processes and reduce costs for customers, as well as decreasing the investment needs and the impact on environment.

The ANM4L (Active Network Management For All) project is a three year long European Research and Demonstration project, with partners from Sweden, Germany and Hungary, which started in December 2019 [3]. The ANM4L project will develop and demonstrate innovative ANM solutions with the goal to decrease the need of curtailment of renewable energy, theoretically enabling further integration of distributed generation potentially even above the current design limitations of the electricity network.

Since ANM has no commonly accepted definition, the ANM4L project define ANM as:

> **ANM is the exploitation of flexible network assets for the purpose of providing secure means of increasing grid utilisation.**

ANM controls maintain the currents and voltages within their limits during operation of the grid through a holistic and coordinated control of active and reactive power together with the use of other controllable assets such as tap-changers. An ANM solution is the concept of a control system, integrated with ICT and the power system, with the ability to manage generation, load and electrical tolerances for DSO-driven purposes. Thus, ANM solutions offer alternatives to conventional grid expansion plans considering forecasted flexibility scenarios.

Technical methods and algorithms for ANM are being developed for various assets found within the distribution grids, and in the following some of the first results of this work are presented. These results illustrate a stepwise approach toward the complex task to have a techno-economical optimal control of a large number of assets within the distribution grid.

In the initial phase of the ANM4L project, a novel voltage limitation algorithm in grid connected power electronic converters is proposed as an alternative to conventional distribution grid development strategies. Traditionally, most low and medium voltage grids have been designed for unidirectional power flow. In such networks, decreasing voltage levels along radial feeders during periods of high load is typically a topic of concern. In many cases the issue is addressed through a fit-and-forget approach, which is focused on network dimensioning rather than active grid operation. To ensure that the voltage at the end of the feeder does not violate the minimum grid constraint, transformer tap-changers are adjusted to sustain the substation voltage level above the nominal grid voltage.

Feeders with large RES production capacity can instead experience rising voltage levels during a worst-case peak production scenario when the power flow reverses, e.g. at noon in a residential area with PV installations. The RES penetration level is then restricted by the maximum grid voltage constraint. The voltage level rise margin is bounded by the substation voltage level which, if set under the assumption of unidirectional power flow, gives the available voltage range according to Figure 3.

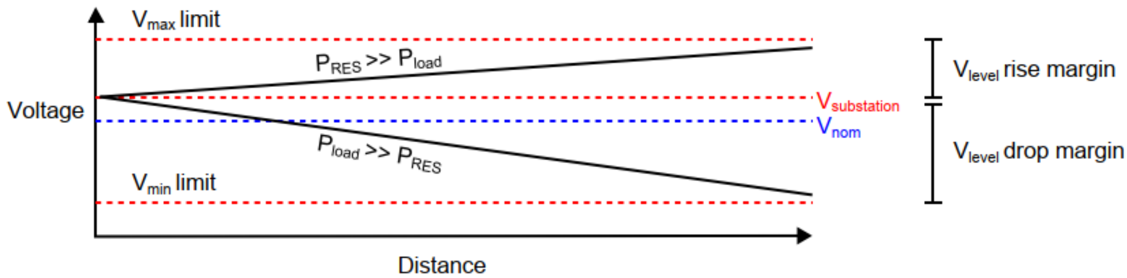


Figure 3: Voltage profile along a distribution feeder with voltage level margins indicated.

The ANM algorithm developed in this work eliminates overvoltage by capitalizing on the impact of reactive power transfer on bus voltage levels to enable a more efficient and costeffective utilization of networks with high RES penetration levels. The ability of power electronic converters to control the flow of both active and reactive power is exploited to control the bus voltage level at the connection point of converter interfaced RES. Previous work has demonstrated that voltage-dependent reactive power control strategies for PV inverters in a low voltage feeder allow for an increase in PV capacity without compromising the maximum voltage requirement [4], [5]. It has also been shown that local reactive power control and active power curtailment through separate PI-controllers in distributed generation units in low and medium voltage networks can mitigate overvoltage issues [6].

It is proposed that the voltage is measured and controlled locally at each RES connection point and that the flow of reactive and active power is controlled sequentially by a local PI-controller, see Figure 4. The maximum grid voltage is set as voltage reference and saturation of the output control signal limits the controller to act only on violations of the upper voltage limit. Since no control action is taken during operation under acceptable voltage conditions, unnecessary transfer of reactive power and associated losses are avoided.

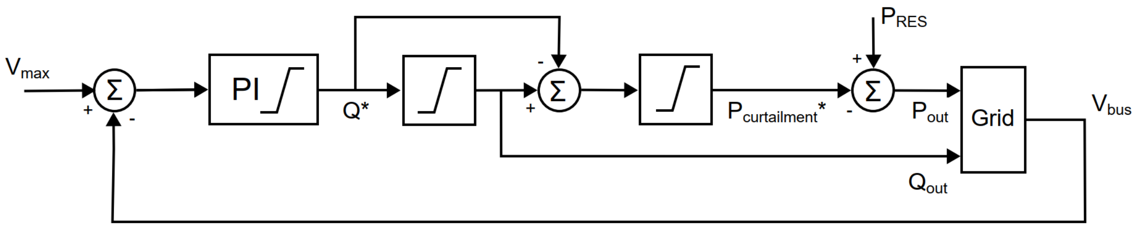


Figure 4: Block diagram of ANM voltage limiter controlling active (P_{out}) and reactive power (Q_{out}) of RES inverter to keep bus voltage (V_{bus}) below the maximum limit (V_{max}).

The ANM algorithm shown in Figure 4 prioritizes the use of reactive power, a set-up intended to reduce curtailment in distribution grids without energy storage or flexible loads. When the reactive power reserve is depleted, the controller simply starts curtailing active power.

The algorithm has been implemented in a Simulink® model of a radial feeder [5]. The model is illustrated in Figure 5. The 5-bus 0.4 kV feeder is connected via a 150 kVA transformer to a Thévenin equivalent, emulating a 20 kV medium voltage grid. The equivalent source voltage is set to 1.02 p.u and the maximum grid voltage is set to 1.1 p.u. The low voltage buses are connected by 150 m long underground cables. Five identical PV systems are added, each rated 30 kW. The PV inverters are rated at 30 kVA and can absorb the amount of reactive power equal to the vector magnitude difference between the rated power and the active power output, according to [7]. Each PV system represents one prosumer household during a worst-case peak production scenario at noon. It is assumed that load is negligible compared to production at this time.

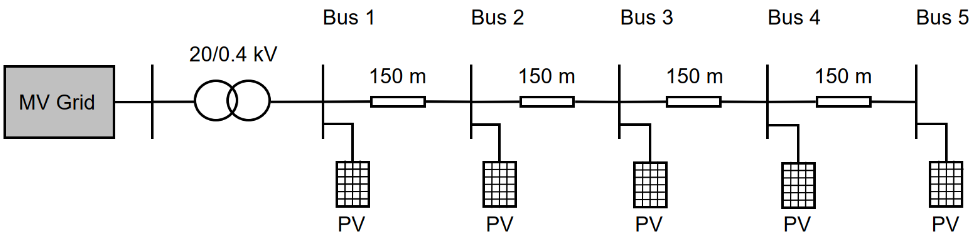
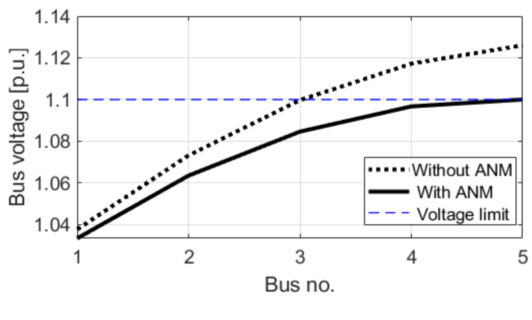


Figure 5: Single-line diagram of 5-bus radial feeder simulation model.

Dynamic power-flow simulations give the voltage profiles during peak production, shown in Figure 6a. Without an ANM solution present, the voltages at the end of the feeder violate the upper constraint. Thus, the grid operator must fully rely on active power curtailment to reduce the voltage if grid reinforcement is to be avoided. In the simulated scenario, the ANM algorithm can, by using reactive power, reduce the curtailment needed to keep bus voltages within the limits. Figure 6b shows the distribution of power production and reactive power absorption magnitude. Since the local algorithm only manages local voltage constraint violations, the major control effort is made at the location of the highest measured voltage. Without an ANM solution, the output at bus 5 must be curtailed to 29 % of rated capacity to avoid an overvoltage scenario. With the ANM algorithm implemented the curtailment is down to 55 %, as indicated in Figure 6b. Still, there is an unutilized reactive power reserve since the voltages at buses 1, 2, 3 and 4 remain within the limits.

An improved solution for reactive power utilization could in this case include a local control scheme that operates on individual set points below the maximum voltage. Alternatively, by coordinating control of controllable assets, optimized reactive power usage [5] could be achieved. However, these solutions are site-specific and any major changes in network topology require adjustments of the control parameters. In contrast, the developed local ANM algorithm, is truly plug-and-play through its identical implementation in all controllable assets and independence from the given network structure. Future work includes an adaption to a centralized control environment to further increase the efficiency of the developed algorithm, as it is expected that the control effort then can be distributed among all available assets while the generic and flexible structure of the local algorithm is preserved.



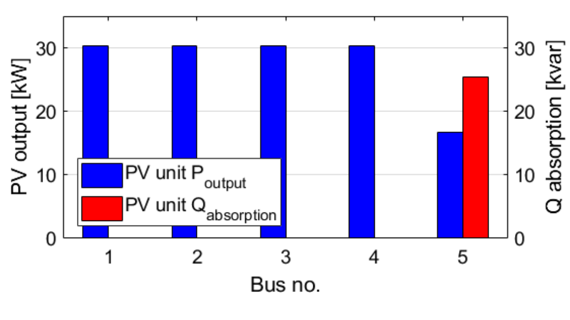


Figure 6: a) Radial feeder voltage profiles, b) P and Q at feeder buses using ANM algorithm.

The influence of reactive power transfer on bus voltage levels ultimately depends on the network characteristics, with line length and X/R ratio being important parameters. As seen in Figure 6b, the limited impact of reactive power transfer forces the use of active power for voltage control in the 5-bus model. In a scenario where a battery energy storage system or a flexible load is connected at bus 5, the local algorithm can divert active power from curtailment to storage or consumption simply by reprioritizing the control action sequence. This shows the potential of the developed ANM algorithm and highlights the possible benefits of including multiple production and load assets for voltage control purposes to further improve grid utilization and minimize curtailment.

5. CONCLUSIONS AND FURTHER WORK

The ongoing evolutionary process within the distribution systems, with significant levels of renewable generation and large-scale electrification of the transport sector, there is a need for novel solutions supporting the grid development in a sustainable manner.

The initial work within the ANM4L project shows that the developed voltage limitation algorithm can provide an alternative to conventional grid reinforcement when significant RES production capacity is connected to a low voltage feeder. It is also demonstrated that using reactive power for voltage control purposes can reduce curtailment during periods of peak production.

Early results have indicated that further increase in grid utilization is possible through centralized control algorithms and the inclusion of multiple types of flexible assets in both local and coordinated voltage control schemes. Such solutions are to be pursued in the future work within the ANM4L project, together with the development of ANM algorithms for congestion management.

Within the framework of the ANM4L project, a toolbox to support grid planning and operation will be developed. The technical ANM algorithms and methods will, together with business models and financial aspects, be implemented and tested in this toolbox and the functionalities will be demonstrated in distribution grids in both Sweden and Hungary.

6. ACKNOWLEDGEMENTS

We would like to thank Ahmet Elmas, Lund University, who, through his work in the ongoing M.Sc. thesis project "Reglering av solcellers omriktare", has contributed to the development of the simulation model presented in this work.

This work has received funding in the framework of the joint programming initiative ERA-Net Smart Energy Systems' focus initiative Integrated, Regional Energy Systems, with support from the European Union's Horizon 2020 research and innovation programme under grant agreement No 775970.

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