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Requirements for distributed generation from the electricity system flexibility point of view

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Abstract. Nowadays distributed generation is developing perspective technology that influences among others on electricity system flexibility. This paper represents analysis of foreign and Russian works and describes main flexibility sources, distributed energy role in providing flexibility, advantages and disadvantages of distributed energy appliance. Electricity flexibility is discussed from distributed generation point of view. Also requirements for distributed energy are defined providing maximum efficiency of distributed energy included in electricity system appliance.

1 Introduction

The idea of 'electricity system flexibility' appeared in English research works about electricity system control in 2000s. Nowadays unified definition of electricity system flexibility still does not exist. But that is well-known that at first electricity system flexibility is some ability of system to cope with variety and indetermination of energy consuming and generation in economic good and efficient way in accordance with requirements for that system. The electricity system flexibility is quite important in case of emergency situations caused by consuming level prediction mistakes such as generator abrupt fault or imbalances in system in real time. One of the most often emergency occurrence is loss of significant power source for example generators or transmission lines.

Electricity system can be flexible if it can perform:

1. Providing stable functioning during peak load including network load without shortage.
2. Keeping consuming and generation levels balance at normal values during whole time of system functioning and provide appropriate capacity level for smart decreasing or increasing of load speed change and system fast response during functioning with low load level.
3. Having sufficient energy storage ability (electrical or other type) for providing good balance between energy consuming and generation with appliance of variable renewable energy sources (RES).
4. Switching in means for potential system response to redundant power generation or short circuit consequences.
5. Excluding opportunity of emergency occurrences due to bad prediction mistakes.

Technically electricity system flexibility presents some technologies combination which basically includes such capabilities as:

1. Generation capability to react to abrupt network load change
2. Consuming capability to react to abrupt change of power supply generation.
3. Energy storage capability to balance discrepancy of consuming-generation proportion in a certain time.
4. Reasonable electricity system infrastructure for performing low-cost energy supplying for any consumer wherever it is located in system.

2. Flexibility main sources

Flexibility main sources are [1]:

1. Energy storage systems.
2. Demand response technology.
3. Interconnection of electricity systems with different flexibility level.
4. Multi-mode operation of co-generation units
5. Distributed generation included in distribution network.

2.1 Energy storage systems

In general energy storage systems can be classified to distributed generation but since these systems have occupied quite wide niche of energetic field it would be preferable to discuss it separately. Originally energy storage systems were used as energy generation regulator. It supplies power system when voltage level is low and stores energy when voltage level is high enough. This function was basically aimed to prevent huge and expensive generators from divergence and also for keeping electricity cost on constant level.

Nowadays energy storage systems play quite important role in reduction of large number of variable renewable energy sources negative influence on power system. Due to RES generation process is not stable

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enough and can be frequently interrupted or work with numerous shortages energy storage system can definitely help it to keep energy quality on appropriate and comfortable for consumers level. Energy storage systems must have some characteristics for providing efficient functioning of grid. These characteristics are: quick operation; power capacity; energy capacity. Also energy storage systems are preferred to have appropriate economic parameters as for example roundtrip efficiency, capital investments and maintenance expenditure.

Currently energy storage systems technologies consist of various types of batteries storage, to be briefly described - ultracapacitors, superconducting inductors (SMES), flywheels and compressed air (CAES). [2]. However there is about 96 % (of global storage capacity in mid-2017) of energy storage systems are represented nowadays with pumped hydro systems due to its wide economic and technical advantages. These advantages are: long-term energy storage capability, reasonable cost, well-known maintenance and other technical application of technology, quite high flexibility and inertia characteristics and etc. Modern pumped hydro storage systems are basically able to provide functioning with various speeds in efficient way enough as other relevant energy storage systems do. In the long run actually battery storage is supposed to be the most efficient and eligible talking about the best pattern for energy storage system That is mostly because of battery storage has very-low minimum power output limit, short start-up and shout-down time and minimal time for increasing or decreasing output power. But in spite of all batteries storage bright advantages there are some quite significant technical disadvantages such as limited number of charge/discharge cycles

In general notwithstanding that energy storage systems are so technically suitable and efficient it is still only developing technology nowadays

2.2 Demand response

Demand response technology is something like brand-new one and it is obviously quite interesting but it is also something not so easy to apply. But actually demand response technology is monumentally able to change electricity system into flexible grid.

Demand response technology is aimed to kind of manipulate and manage consumer's behavior to maximize the demand when grid can deal with it and otherwise minimize it – when system is out of high level depending of current parameters of grid. It can be achieved by operating with different cost-politics and long-term direct-control agreements with "prosumers". Where prosumers mean consumers who are able to generate their own power, besides consuming it from the grid. As a result supplier company can change consumers manner and type of using energy in favour of electricity system flexibility.

Demand response technology can be potentially represented as industrial, commercial and groups of residential consumers. But it must be kept in mind that operation speed of group prosumers is by an order more fast than industrial or commercial ones. Though the logical conclusion is that such massive industrial companies of course play more important and huge role in making large grid more flexible in spite of its aggravating inertia characteristics. Besides that, big industrial companies actually consume much more energy which makes it easier to control and predict but integration of such big industrial companies in grid is quite complicated task.

2.3 Interconnections of electricity systems with different flexibility level

Interconnections of electricity systems can be described as a specific bridge between two main system parameters such as supply-demand side and off-net imbalances which are connected in real time [3]. It basically means that different flexibility level grids, connected to each other can act help compensate lack otherwise redundancy of flexibility sources of themselves. This way it is possible to directly impact on grids with different flexibility level without any negative aspects for them. For example low level flexibility grid can be some limiting factor for other high level flexibility grid with great share of hydropower where potential hydropower flexibility is locked. The developing of interconnections between grids especially international grids is also quite good for electricity trade. It definitely enhances costs and electricity quality But realization of such great project has a lot of challenges which makes it labor-intensive and quite expensive task.

2.4 Multi-mode operation of co-generation units

Co-generation heat-and-power units or co-generation thermal power plants (TTP) generate energy due to heat generation or alternatively transmit receiving heat from electricity generation process to satisfy other needs of consumers. There are three main types of co-generation units or plants:

1. Industrial TTP.
2. Regional TTP.
3. Combined Micro-TTP.

Co-generation units or plans actually cannot be determined as flexiblility sources, but the multi-mode operation of such units or plans is quite close to determination of flexibility sources. Because multi-mode operation which means using both heat and electricity of plant can be aimed to storage generated heat energy for example. Talking about the micro-TTP for example it generates heat and transmit it directly to consumer so the generated by this TTP electricity is sort of secondary product of their main producing process. Such micro-TTP can transmit excess generated electricity to the grid making this way system more flexible. One more advantage of micro-TTP is its convenience talking about produced power registration.

In addition the heat recovery process as a rule is quite harmful for plants, it damages downstream cycle equipment getting it into really extreme conditions.

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Equipment which has to withstand such severe forces obviously cannot stand against abrupt power changes on top. Such TTP units have typically really long start-up and shut-down time and quite limited range of network load change. But in case of generated heat will be refocused and heat recovery process will be disposed it effectively makes start-up time shorter and range of network load change – wider.

Main disadvantages of such multi-mode combined co-generation units are first of all necessity of previous primary designing these units starting with designing project phase and due to this actually quite expensive producing of multi-mode combined co-generation units. Besides multi-mode combined co-generation units also need more expensive maintenance and it has basically shortcut in-service life duration.

2.5 Distributed generation included in distribution network

Distributed generation is represented as resources which generate energy close to consumer it can be often isolated from centralized electrical grid and can include variety of co-generation systems.

Because of distributed generation high competitive ability and wide extra unavailable for centralized grid features it is really topic of the hour. So that is why analysis of distributed generation as a source of flexibility is performed more thoroughly.

3. Distributed generation

Distributed generation technologies are applied for electricity supplying consumers of three types:

1. Autonomous energy supply with little distribution generation units which are working separately in isolated grids.
2. Peak and standby energy supply with distributed generation within centralized electricity system.
3. Decentralized energy generation within centralized electricity system with distributed generation as a main source of power but strictly adjusted to centralized system. [4].

Distributed generation basically involves three technologies:

1. Technologies using burning of solid and gaseous fuel.
2. Wind turbines.
3. Solar radiation technologies.
4. Small hydro power plants and nuclear power plants.
5. Energy storage systems as it is mentioned before.

All above-mentioned technologies use for producing electricity energy of course generators which can be defined as flexible generators due to its special features such as not high level output power and quite close location to consumer.

Flexible generators are such generators that are able to increase or decrease functioning rate and have low triggering threshold and short start-up and shut-down time.

For example hydro generators and open-cycle gas turbines are considered as the most flexible sources of conventional generation. And for example so popular today large steam or coal turbines and nuclear generators are by an order less flexible compared to hydro generators and open-cycle gas turbines. But actually there are a lot of ideas of less flexible generators (especially coal ones) modification nowadays due to growing tendency to create possibly more flexible grids. Distributed generation impact to the electricity system flexibility is estimated as affluent as demand response technology that means it is really important.

3.1 Disadvantages of distributed generation

There are main disadvantages of distributed generation for electricity system operation:

1. Including of distributed generation in power system means also including of extra active power that increases voltage in connection points and near the Distributed Energy Resources (DER) location. In case of low load in system it can lead to voltage overload and create possibility to damage equipment or whole system and consumer's equipment too. That basically shows the risk of having really bad electric power quality in grid. So this way the further extra power including of distributed generation the worse power quality is and higher risk of voltage overload appearance in electricity system.
2. Majority of existing distribution networks are designed the way that centralized generation network energy of high voltage transmitting network supplies consumers of low voltage level located in network, apparently not vice versa. But integrated distribution generation can basically surpass local loading that respectively leads to reverse power flow happening. Whereupon it is required to keep control of load bearing capacity limitations and power flows of electricity system.
3. Distributed generation also can be reason of congestions in grid. Typically adjusting the scheduled generation of power plants so called re-dispatching is used against congestion at transmission system level. But it is really difficult to plan for distributed generation located in distribution systems because of its stochastic nature.
4. Because of that fact that distributed generation has an impact on total power of network there are two factors that lead to grid losses: quantity of entered power and distributed generation location in grid. In case of distributed generation is located close to loading it means that entered power will be most commonly consumed, this balance even causes that grid losses will be basically less compared with grid losses without integrated distributed generation. But there are huge grid losses in case of long distance between distributed generation resource and loading in grid. Also grid losses consistently increase with loading decreasing in system, for example at night when most of the consumers are not active and let us

suppose that wind is becoming stronger making wind turbines generate more energy.

3.2 Advantages of distributed generation applying

There are some useful features of distributed generation being in use either as main energy source or as additional integrated in centralized grid one which can be determined as distributed generation advantages:

1. More high level of consumers energy independence.
2. Smoothing of peak load.
3. Lowering of necessary power reservation level.
4. Minimizing of energy carriers transporting.
5. Loss minimizing during secondary energy carriers transporting.
6. Opportunity of local energy resources applying.

Integrated distributed generation basically changes the centralized electricity system profile and also whole system, it adds new elements in grid with new dynamic characteristics and control possibilities of its. Because of decentralized position of distributed generation resources and their big amount it actually makes consumers energy independence level higher and also due to this power quality improves.

Indeterminate stochastic mode of distributed generation operation which is also quite difficult to predict (especially for renewable energy sources) improves grid adapting possibilities to the competitive vague business environment that actually can help to reduce risks of investment. Occurrence of distributed generation in distribution network also allows keeping node voltage level going by means of possibilities of generators of distributed generation to generate reactive power in contradistinction from conventional distribution network where power losses are more the more long distance from supplying high voltage substation. In case of supplying high voltage substation fault distributed generation in distribution network of grid can basically provide troubleproof electrical power supplying of many of consumers of system.

Also electricity system with strong distributed generation communications there are no occurrence of difficulties with keeping frequency stable going, voltage regulation or providing parallel working of generators. But electricity system with weak distributed generation communications special automatic equipment is needed that limits value of power flow in communication line and affects operation regimes regulation.

3.3 Virtual power plant

Besides all above-mentioned advantages of distributed generation there is also one fact that due to distributed generation advancing spreading and its integration to the centralized electricity system ‘virtual power plant’ concept appeared.

This concept basically represents union of distributed generation units with ultimate control system of these units operation regimes. The main reason of such virtual power plant appearance is that dispatching control office is not able to take into account all distributed generation units at once thereby power supply efficiency, storage system elements (that usually are used for inequality regimes compensation) and active consumers activity recording decline.

Besides technical advantages of virtual power plant such as smart grid control, complicated relay protection system and automatics there are also capability of virtual power plant to provide efficient demand response control and opportunity to optimize consumers loading graphs as much as possible. Interconnection of generation power and consumers (including prosumers) like that allows to smooth on-peak loads and to decrease power supply cost. Virtual power plant also can be efficient in economic way in point of electric power trading on commercial market or for example. Technically virtual power plant can easily perform system functions such as frequency and active power regulation, power quality maintaining and etc. Also it can be useful even in both ways, economic and technical [5].

As can be seen from the above virtual power plant can basically perform several quite important tasks of electrical engineering. Such as normal and emergency regimes optimization, electricity system working with determined and stochastic generators stabilization, flexible power generation control, capability to coordinate power generation and current consuming level and opportunity to integrate various generation type resources all together.

4 Flexibility from the distributed generation point of view

4.1. Flexibility attributes

Technically electricity system flexibility reflects system capability to adapt to power changes located in definite place of grid in a certain moment of time during some period of time. This way flexibility can be characterized by five provided below attributes [6]:

1. Power flow *direction*.
2. *Power capacity* (Maximum load hours).
3. *Time* response to control signal.
4. Available *duration* of work.
5. Distributed generation resource *location*.

There is interrelation between flexibility five attributes which is represented on fig.1.

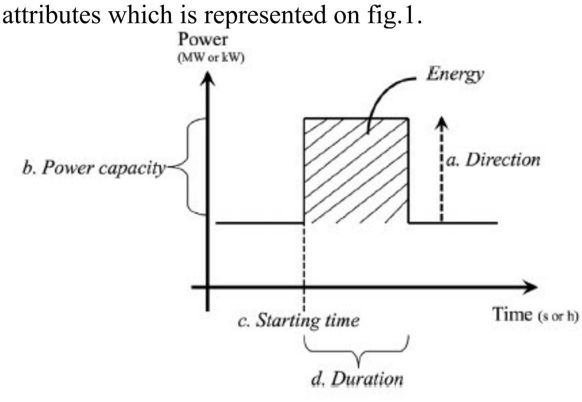

Fig. 1. Interrelation between flexibility attributes [6].

4.1.1 Power flow direction

Some resources of distributed generation are unidirectional (for example household load). It means that its power flow has only one direction, as a rule it is direction from source of energy to consumers.

There also bidirectional resources of distributed generation which are able both to generate and to consume energy (for example energy storage systems and electric vehicles).

4.1.2 Power capacity (maximum load hours)

This criterion actually can be associated with main indicator for distributed generation source of what kind of system flexibility needs it would be applicable. Also this criterion can be defined as some differentiation between power and energy resources which actually represents power capacity of source in addition.

For example if resource has quite low energy/power ratio it means that basically it can provide grid with a high power value but it cannot keep such high power level up for a long time. Conversely, if distributed generation resource has high energy/power ratio it shows that the resource is able to withstand power changes during long period of time.

Calculating of power capacity criterion (or energy/power ratio) requires to estimate maximum power time duration. In other words maximum time during which distributed generation resource is able to generate its maximum power compared to rated value. This criterion can be transformed in a way for some distributed generation resources types. For example it can be estimated with maximum capacity value for energy storage systems, considering battery with charging\discharging power equal to 10 kW*h and capacity equal to 60 kW*h maximum power (or load) hours value is 6.

The less value of this criterion the more capacitive distributed generation resource basically is and the converse is also true.

4.1.3 Time response to control signal

According to the name of criterion it takes in account that some DER are able to actuate or react to any changes faster or slower other resources. That is quite important attribute because of dependence of power quality on switching time.

Nowadays there is practically every electricity supply that has short time to react to control signal except for co-generation heat-and-power units or co-generation thermal power plants.

4.1.4 Available duration of work

Talking about DER one must bear in mind the fact that some types of resources work only for specific periods of time. For example photovoltaic panels (solar PV) work only during daylight hours, tidal substations work during flood period and so on.

As a matter of calculating convenience statistically average time of resource working is used (estimated in hours) divided by one week total amount of hours. That is also convenient for comparison different distributed generation resources towards available duration of work criterion.

4.1.5 Distributed generation resource location

Distributed generation resource location affects to this resource appliance efficiency depending on demand response technology. Resource location actually shows what way would be the most efficient to use demand response. For example resource location can indicate is it good for local congestion management or for other distributed generation resources optimization depending on demand response interest.

Also it is quite reasonable to apply resource in distribution network if it is situated close to consumers and improves quality of energy distribution among them.

Table 1 presents analysis of some existing DER in accordance with above-mentioned attributes [7].

4.2 Requirements for distributed generation

Main requirements for providing flexibility (especially talking about distributed generation) are directed to perform abrupt changes compensation and high level fluctuations of generation compensation.

For example wind power generation changes has generation variation about -4,5 +5,5 GW/hour. Talking about solar PV generation changes could achieve 12 GW/hour value and these generation kicks happen quite often – about 10-15 times per year.

From the perspective of analysis above-mentioned information it is not unthinkable to formulate requirements for distributed generation resources integrated in flexible grid with maximal efficiency more in detail.

1. *High control ratio*
   Any distributed generation resource must be always ready to adapt to voltage profile or grid frequency changes. Also as a result of high control requirements it is necessary for resource to have highly accurate digital automatized protection of its systems. Only sensitive wide-ranging working digital protection is able to provide multi-plane control in accordance with abrupt appearing power deviations or changes. Because distributed generation is really susceptible to such changes or deviations.
2. *Fast initial response and switching time.*
   That is not enough just to be ready for power changes or fluctuations and to be highly-controlled for distributed generation resources. To prevent emergency situations of electricity system and to maintain power quality on appropriate level it must be expeditious. Time response is critically important feature for whole electricity system state at power change moments. One second time delay could be reason of false response or even malfunction of system automatized protection hence power quality

Table 1. Analysis of some existing distributed generation resources.

	Distributed generation resource	Direction	Power capacity (maximum load hours)	Available duration of work (%)	Predictability	Time response	Network type
Consum-ption	Residential continious loads (hearing/cooling)	Unidirection-al	≈15min	From 40 to 100	High	Seconds	Distribu-tion
Consum-ption and genera-tion	Energy storage systems (kW-MW)	Bidirection-al	From 4sec to 10 h	≈100	Perfect	From seconds to minutes	Distributio n or transmitting
	Electric vehicle (kW)	Unidirection-al or bidirectional	From 30min to 6h	From 50 to 90	High	Seconds	Distribu-tion
Genera-tion	Solar PV units	Unidirection-al	Very limited	From 25 to 40	Good several hours ahead	Minutes	Distribu-tion
	Micro-CHP units (kW)	Unidirection-al	Unlimited	≈100	Perfect	Minutes (5%/min)	Distribu-tion

degradation or equipment breakdown occur with high final cost of energy for consumers as a result.

3. *Minimal output or produced power level.*
Even very flexible electricity system needs to have limited minimal output power threshold to provide stable and good working. And to pass it over is strictly prohibited due to system disorder occurrence possibility. Unfortunately nowadays DER do not display its own self-sustainability in this way. Distributed generation resources often demand adding conventional generation resources to maintain unified required minimal output power level. Or it can be combined with other distributed generation technologies the way to compensate each other for keeping system minimal produced power level.
4. *Integration level of efficiency.*
Distributed generation resources had already proved to be one of the best working in isolated electricity systems. But DER integration in grid the most efficient way remains an open question. This challenge requires taking in account direction of distributed generation working and its influence on centralized grid. Considering that a lot of DER work bidirectional way it apparently perplexes DER integration in grid process in accordance with maximal efficient way aim.

5 Conclusion

This paper represents comprehensive analysis of existing researches about Distributed Energy Resources (DER) integrated in electricity system including foreign reviews. The paper basically focuses on distributed generation role in flexibility providing of grid with an indication of advantages and disadvantages of DER integration. Requirements for distributed generation are defined with reference to system flexibility technical attributes for providing maximal efficiency DER integration in system

It can be concluded in terms of performed modern flexibility sources analysis that distributed generation clearly has already set its limits for integration of DER in electricity system. And such limits must be held especially talking about the foreseeable future energy and ecology challenges. Rapid development of distributed generation technologies and its appliance in grids inevitably changes electricity system profile. With a view to all above-mentioned there is clear need to create well-formed requirements for distributed generation for its further cooperative development with electricity system. Such requirements may also result in creating even new DER for better integration in flexible electricity system without any negative affect. The requirements proposed in the article are: high control ratio; fast initial response and switching time; minimal output power level and integration level of efficiency.

References

1. ECOFYS, TRACTEBEL Engineering, SWECO pwc, “Study on the effective integration of Distributed Energy Resources for providing flexibility to the electricity system. Final report to The European Commission”, (2015)
2. B. Mohandes, M. El Moursi, N. Hatziargyriou, S. El Khatib, “A Review of Power System Flexibility with High Penetration of Renewables”. IFEEE Transactions on Power Systems, (2019)
3. IRENA. “Power System Flexibility for the Energy Transition: Overview for Policy Makers”, (2018).
4. В. Батенин, В. Бушуев, Н. Воропай, *Инновационная электроэнергетика* – **21**. – М.: ИЦ «Энергия», (2017)
5. О. Селяхова, О Тарновская, Е. Фатеева, О. Юрчук, *Виртуальная электростанция* // Энергорынок, (2016)
6. C. Eid, P. Codani, Y. Perez, J. Reneses, R. Hakvoort, “Managing electric flexibility from Distributed Energy Resources: A review of incentives for market design”, Elsevier, (2016)
7. C. Eid, P. Codani, Y. Chen, Y. Perez, R. Hakvoort, “Aggregation of Demand Side flexibility in Smart Grid: A review for European Market Design”, In: Proceedings of the 12th Int. Conf. Eur. Energy Mark., Lisboa, (2015)

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