DISTRIBUTED GENERATION INFLUENCE ON POWER DISTRIBUTION SYSTEM DEVELOPMENT IN POLAND

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ABSTRACT
A lot of individual electricity sources of small power common (called distributed generation) occurred in Polish power sector during the last period. Gradual increases of distributed generation will cover current and future demand of consumers as well as allow to keep essential reserves in distribution and transmission grids. Emphasizing of this problem can upgrade economic efficiency and grid significance of distributed generation for investors and distribution utilities in Poland.

INTRODUCTION
Processes of liberalization and decentralization of power sector in Poland take place not only in a system aspect, but also in individual sectors including a power generation sector. It has caused increase of demand for generation devices of small power [1]. New sorts of energy sources of small power, of many advantageous features and new fields of employment have appeared [2]. Therefore, it can be stated, that development of these sources connected to distribution grid (commonly called distributed generation) creates a new model of the power system [3]. Influence of distributed sources should be considered not only in real time, i.e. operative category, but in categories of long-term development of the power system and grid. Approach of central planning realized by system operator was used so far. Currently, part of obligations in the range of planning of electricity (and other energy carriers) demand was allocated to local governments and is reflected in local development plans. Such plans concern also distributed sources, which should be placed (according to their definition) near a final customer. Connection of these sources to the grid is realized under specific conditions and with using suitable procedure.

CONNECTION OF DISTRIBUTED SOURCES TO THE GRID
Work of a distributed source in the distribution grid in Poland must be preceded by a proper procedure related to its connection. It results from obligatory regulations and requirements defined within order [4] and Instruction of Operation and Maintenance of Distribution Grid – IRiESD. The following letters and documents must be submitted by an investor to the Distribution System Operator (DSO):
• letter about determination of expert’s opinion conditions,
• expert’s opinion related to influence of the connected source on the power system,
• application for connection conditions,
• connection agreement.
Two first letters are optional, required from investors for sources connected to 110 kV grid (except sources with power below 5 MW) [4]. The letter about determination of expert’s opinion conditions specifies range of this opinion. The expert’s opinion related to influence of a connected source on the power system includes:
• technical characteristic of the source with technical parameters of transformers connecting this source with the grid;
• real and reactive power flow, voltage profile in normal and contingency conditions at a connection point and directly connected power grids;
• short circuit power analysis at a connection point and a chosen part of the grid;
• short circuit currents analysis in a chosen part of the grid;
• specifying of influence of the connected source on energy quality;
• analysis of static and dynamic balance behavior;
• analysis of influence of the connected source on protection devices performance;
• influence of connection of the source on power transient stability;
• analysis of chosen reliability indicators.
The detailed scope of expert’s opinion is specified every time by distribution company in response to above mentioned letter.
According to the connection procedure investor must submit application for specifying connection conditions to the distribution company. The connection conditions contained in the application include:
• connection point,
• electricity delivery point,
• installed capacity,
• possibility of connection with grid,
• range of necessary investment resulting from source connection,
• range of binding requirements resulting from IRiESD,
• installation point of measurement and settlement system,
• requirements related to measurement and settlement system and data transmission system,
• requirements related to power system protection,
• values: multiphase short circuit currents and clearance time, earth short circuit current,
• required level of reactive power compensation,
• requirements of adaptation of connected devices to dispatch systems,
• requirements related to grid protection against electric...
interferences caused by the source,
• requirements related to auxiliary devices essential to power system cooperation,
• possibility of energy delivery in abnormal conditions,
• data and information concerning the power system, necessary in order to choose and set up electric shock and overvoltages protection of the source,
• estimated cost of connection.
After consideration of the application DSO specifies connection conditions and hands down agreement project to the investor. After signing the agreement investor can start the design, building and montage works according to conditions specified in the agreement. That ends the procedure of connection of the source to the distribution grid.

FUNCTION OF DISTRIBUTED SOURCES IN PLANNING PROCESS

Approach of central planning of system and grid development in long term, realized by system operator, was used so far. Centrally prepared plans connected with forecast of demand development required determination of path of generation development within the country, taking into consideration exchange within connected systems. These operations were carried taking into consideration environmental protection requirements and influence of signed long term contracts on modernization and restoring existing generation plants. In planning process the special attention was paid to system sources (connected to transmission grid) and to sources connected to 110 kV distribution grid. In these conditions the criteria of planning was defined as minimum of constant and variable costs of maintenance and development of the power system (SEE). Local power industry sets a new direction of planning, in which centrally realized planning of power system development (top-down approach) was replaced by a bottom-up planning. These operations allow to take into consideration requirements resulting from local development plans. These plans are prepared at the level of local government and taken into consideration in province development plans, as well as in central plan (for the whole country) [5]. In this way, it is possible to achieve a balanced development of the region in market conditions, taking into consideration local resources of primary energy (including renewable resources), demand and capabilities of development of distributed sources. Local development plans, supplemented by planned investments in system power plants and forecasts of interconnection exchange, should be a base of monitoring national power and energy balance and indicator of influence on environment.
The integrated program of development of national power grid should be created on the basis of these balances and system technical-economic and ecological analyses. Such an approach to power system development can supply important information to the investors. The information is essential for planning of extension of the grid and can indicate possible requirements and range of government operation.

INFLUENCE OF DISTRIBUTED SOURCES

Planning of grid development can be reduced to determination of schedule and choice of investments, whose purpose is to strengthen grid connections. Such a “reinforcement” allows improving safety and reliability of energy delivery to the consumers, taking into consideration increase of demand (demand for transmission and distribution services).
Growth of demand for transmission services requires investments which will boost capacity of the grid. Using of distributed sources allows us to avoid or postpone the grid investments. In this way, reserves of transmission capacity are obtained, and simultaneously economic incentives for increasing of generation level in that place appear.

Grid aspect
At research of influences of distributed sources on distribution grid performance the proper computer simulation was carried. Drawing was applied for number of sources in system, location of node, where the source was connected and generation level of individual source. Power of the source was chosen from generators which are available on the market and adjusted to produced transformers. The computer simulations were carried out for 110 randomly determined variants. The distributed sources of total power limited to 10 MW were used in the system. Each time the carried computer simulation included calculations of nodal voltages, branch currents, duration of potential break of supplying of customers.
The section of local overhead and cable grid network of nominal voltage 20 kV was object of research. Total load of the grid was 16.9 MW. The load is allocated for 192 customers (points of power consumption). Total length of the modeled section of overhead and cable lines was 207 km. The visual scheme of section is presented on Figure 1.
The reference system, which didn’t include distributed sources, was assumed for the analyzed system. In this way, influence of distributed generation on distribution grid performance was determined. The chosen results in connection with analyzed value are presented below.

The branches currents

Influence of location and power of distributed sources in view of the level of operational currents in distribution grid was presented in Figure 2. It presents change of index of average branch current $\Delta W_{Ig}$, with reference to a base system when number and power of distributed sources $\Sigma P_{DG}$ growth. In comparison with a base system decreasing of load at nodes has followed, but definitely greater effect results from decreasing of net losses and transformers shedding (transformer supplying 20 kV grid). However, it should be noticed, that this phenomenon – in wider perspective – when power of distributed sources growths – has tendency to increase load of the system branch. In analyzed case this phenomena can be noticed at total power equal or below 8 MW. Ineligible localizations of sources also occur in these randomly chosen systems. They cause boosted load of branches in comparison with a reference system. That can lead to overloads and generation of grid contingencies.

Using the grid

The results of analysis based on value of index of utilization of grid in comparison to a base system $\Delta W_L$ is presented in Figure 3. This index is calculated from the so called “grid performance” (sum of product of branch power and branch length). For a given system, comparison of grid performance in different variants gives information about branch load. The higher utilization index, the higher level of branch load. The presented results show that increase of number and power of distributed sources in the power system allows to obtain significant reserves in grid performance (decreasing of system load). It is not linear link nor unambiguous. The growth of power of distributed sources can cause decrease the index in comparison to a base system, and even achieve opposite values to expected ones. Similar to branch flow, there is also an optimum of
distributed generation in a given system. Thanks to use of distributed sources in a range to limit value, the transmission capacities are „freed”. As a result of such a grid investment increase of transmission capacity can be postponed. However, oversized and uncoordinated development of distributed generation can cause decrease of transmission capacity of system branches.

\[ y = -4E-07x^2 + 0.0064x - 2.1099 \]

\[ R^2 = 0.3271 \]

Fig 3. Characteristic of \( \Delta W_L = f(\Sigma P_{DG}) \)

**Economic aspect**

It is possible to show influence of distributed generation on postponing grid investment on example of exchange of the overloaded transformer 110/20 kV. Analysis includes exchange of the transformer of 10 MVA to the transformer of 16 MVA. Estimated investment outlays diminished with value of previous transformer were assumed at the level of 2 million PLN (1 EUR = 4 PLN). Period of analysis results from the period, after which this transformer would require next replacement with the transformer of 25 MVA. This period is dependent from growth of electricity demand. For given values postponing of grid investments is equivalent to added value of source equal to \( C = 728 \) PLN/kW. Analysis of sensitivity of obtained results at change of parameters of economic calculations was carried too. Ratio of discount \( p \) and time \( T \) for next exchange of the transformer is taken into account. The results are presented in Figure 4.

Comparing obtained values with investment outlays for building distributed generation sources, which depend on kind of source and vary from 500 PLN/kW (piston engines and Diesel) to 17 500 PLN/kW (photovoltaic systems), it can be proven that investing in the source may be comparable with replacement of a smaller transformer by bigger one. It creates new possibilities in aspect of DSO investments.

**CONCLUSIONS**

Development of distributed sources will have stronger and stronger influence on future structures of power systems. Therefore, it will be important formulating of such incentives for investors which allow to connect of development of the grid and development of the distributed generation. Besides, introduction of distribution sources can be treated as alternative of grid investments. Currently in Poland costs of connection are divided 50:50 among investor and DSO (to the 2010 year, after it will be 100:0). Gradual increases of generations covering directly consumer demand, allow to save essential operational and power reserves in high voltage lines, in particular, in transmission and 110 kV distribution grids. Emphasizing of this aspect can bring up economic attractiveness and grid (economic) importance of distributed generation for investors as well as for distribution enterprises.

**REFERENCES**


[4] Decree of Ministry of Economy of May 4, 2007 on detailed conditions of power system operation (Legal Magazine of 2007, No. 93 item 623 including later amendments), Poland.

[5] Energy Act (Legal Magazine of 2006, No. 89 item 625 including later amendments), Poland.