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SMART SOLUTIONS FOR SECURING THE POWER SUPPLY OF SMART CITIES

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ABSTRACT

Every aspect of our lives is determined by the use of electricity. Its availability defines our everyday comfort and security. Smart cities built with smart technologies cannot operate without electricity. This electricity is produced in power plants using specific energy conversion technologies. It is then transmitted through the electrical network to industrial- and residential consumers. In order to ensure that the end-point consumers continuously receive the quality of service specified in the standards and norms, the developers and operators of electricity systems have to perform, day by day, a multitude of tasks. In this process, smart solutions play an increasingly important role. System regulation is a key aspect of electrical power supply security.

KEY WORDS

electricity, security of power supply, power plants, system control, energy storage

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POWER PLANT TECHNOLOGIES OF THE HUNGARIAN ELECTRICITY SYSTEM

Discussions about the emergence of smart cities play an important part in the exchange of thoughts on future developments. Smart devices and digital-based services are making every aspect of our lives safer and more comfortable. These devices are powered solely by electricity. We can only use the electricity we have produced and delivered where needed. The electricity is produced in power plants using special energy conversion technologies. This process uses a primary energy carrier medium to convert its energy into electric energy [1].

The vast majority of power plants are fixed. However, there are also mobile plants available, i.e. plants that can be repositioned or moved. Some of the examples include industrial-sized diesel engines of up to several MW capacity, which can be transported by rail, trailers, ships or helicopters. In emergency situations, these are transported to the site on short notice and are able to supply electricity to the local systems [2].

Floating nuclear power plants can also be relocated. These can be used for military or civil needs. The best example of peaceful usage is the nuclear-powered icebreaker ship, which can supply electricity to communities falling far away from the electricity and natural gas distribution networks [3].

Rooftop solar systems are stationary power plants. Household-scale small power plants have less than 50 kVA installed power. In Hungary, there are more than a hundred thousand small power plants supplying households or producing energy for low voltage electrical distribution networks [4].

Power plants are classified mainly by the nature of their primary energy sources. Among the conventional fossil power plant technologies, the coal-based energy conversion contains subsystems with many different characteristics. We can differentiate between them according to the type of fuel: black coal, lignite or brown coal. The conversion technology can be conventional, fluidised bed, bubbling, circulation, atmospheric pressure, pressurised, supercritical and gasification [5]. In the 1960s and 1970s many coal-based power plants were put into operation. In the 1970s, cheap oil led to the establishment of oil-fuelled power plants worldwide. In Hungary, the Dunamenti Power Plant has been the largest among such power plants for many decades. In Százhalombatta, the units of the power plant burn mazut, the by-product from the oil refinery, and supply the oil refinery with steam and electricity. In addition, they supply to the Hungarian electricity system a significant amount of electricity. Nowadays, light fuel oil is used to operate the gas turbines. Natural gas is an important primary energy source. Conventional gas-fired power plants possess the proper technologies for both heat- and electricity production. In addition, gas turbines are becoming increasingly important and have gained an ever-larger share of the production mix since the 1990s. State-of-the-art combined cycle units can have an energy conversion efficiency of up to 65 %. Open cycle units have an efficiency of around 40 % with a heat recovery stage added to increase efficiency. The heat recovery is used to generate additional electricity. Open cycle units are used to serve rapid changes in the load of electricity systems.

In Hungary at Paks, a nuclear power plant (NPP) was constructed in the eighties. Between 1982 and 1987 four units were put into operation and started the production of electricity. As their operation was extended by 20 years, they are expected to be shut down between 2032. and 2037. The NPP provides approximately 50 % of the domestic electricity capacity of Hungary.

Nuclear power plant technologies have developed worldwide in a wide range, and they are under continuous development and improvement. We can differentiate them according to their fuel, cooling technologies and the material of moderators. In addition to these, there are fast reactors and small and medium nuclear reactors.

The following large group of power plant technologies are associated with renewable energy production. Low-emission power plant technologies with the largest production capacities are supplied by hydropower. Its global capacity surpasses the 10 % share from the global market of nuclear-based production [6].

Hydropower provides more than 50 % of the world's renewable energy [7]. The world's first established power plants used the energy of water.

The role of hydropower is dominant in energy storage, and consequently, in system control activities. Pumped energy storages have accounted for over 90 % of energy storage capacities globally, with an installed capacity of about 160 GW [6]. The technology consists of using the low-cost electrical power coming from the surplus energy production to push the water from a lower reservoir to a higher reservoir. Then, when there is a demand for the stored energy, the water from these reservoirs is let to flow through the water turbines producing electricity into the electrical networks [8].

Other renewable energy sources include geothermal energy conversion technologies that use the earth's heat, and the technologies using waste, biomass and biogas. Wind turbines and solar power plants represent new renewable energy categories. In recent years, these have been among the dominant trends in power plant constructions.

There are many opportunities for the use of solar energy. One of them is the solar thermal power plant. Here the solar energy collected by mirrors is used to heat a working fluid to a temperature by which the water is converted into steam, which is then used for driving the steam turbines. In some technologies, the heated medium can also act as an energy storage medium. In the case of photovoltaic power plants, photons from the sun's rays are absorbed by photosensitive semiconductor elements to produce electricity. The take-up of solar energy in Hungary by the installed photovoltaic capacity has increased almost a thousand-fold during the last 10 years [9]. the Hungarian Electricity Transmission System Operator (in Hungarian: MAVIR) forecasted for year 2031 a total solar capacity of 11 600 MW [10].

The following sections will give a review of power plants according to their roles in electricity systems. Base load power plants provide a constant energy production in time, the so-called "line production". They are characterised by continuous, stable operation with low unit costs. Scheduling power plants follow the planned output variations with their controllable production characteristics. Guided technology means that the amount of input energy can be varied. In case of controllable technology, the output power can be varied. Accordingly, electricity production technologies can have both characteristics or none of them. Top power plants can manage the sudden and rapid changes taking place in the loads of the production system.

THE REGULATORY TASKS OF THE HUNGARIAN ELECTRICAL ENERGY SYSTEM

Nowadays, a revolutionary transformation is taking place in the way electricity systems operate. In traditional systems, the electrical power production was adapted to the needs of industrial and residential consumers. The electrical power was produced in 20 to 30 big power plants in a so-called centralised structure. The electrical power was then distributed to industrial and residential consumers via electricity networks in a predictable one-way flow.

Electrical networks comprise four hierarchical levels defined according to their purpose. Power plant installations with an installed capacity of several hundred up to several thousand megawatts are integrated into the basic network or, according to the current terminology, into the transmission network. The international cooperation between different countries is embodied by the interconnected electricity system through transmission networks. The name of the integrated European electricity network is: European Network of Transmission System Operators for Electricity (ENTSO-E). The typical domestic voltage levels of the basic network are 750 kV, 400 kV and 220 kV. The loss of transmission is proportional to the voltage levels. The higher the voltage level, the higher the transmission loss. For a higher voltage and the same power value, the electrical power level is proportionally lower. In Hungary, in order to reduce transmission losses, large amounts of power are delivered to the 35 transformer stations installed at the core network nodes by means of high-voltage transmission lines. The energy collected in this way is reduced to the 132 kV voltage level of the main distribution network by means of high voltage transformers and is delivered at this voltage level to the territorially competent electricity providers, formally to the network licensees. The electricity is transmitted to the distribution network following the 132 kV medium voltage transformation. The typical voltage levels for medium voltage are 35 kV, 22 kV and 11 kV. Power plants with a capacity of a few tens of megawatts supply electricity to the main distribution and distribution networks. These voltage levels are also used by large industrial consumers. At the lowest level of the distribution network which operates at 0,4 kV, the electricity is delivered via additional transformer stations to residential consumers. The NPP from Paks with an installed capacity of over 2 000 MW is connected to the 400 kV network. The solar power plant from Paks, with a capacity of over 20 MW supplies electricity through the distribution network at 132 kV while the other solar power plant from Felsőzsolca, with a similar capacity, transmits its electricity to the distribution network at 22 kV. Small household power plants with an installed capacity of up to 50 kW are connected to the lowest level of the distribution network at the residential voltage level of 0,4 kV.

The management of the electricity network systems in Hungary is carried out by the MAVIR, a limited company owned by MVM Zrt. At the distribution network level this task is performed by the District Dispatching Services and the Control Centres.

As a result of the transformations described above, the traditional large-scale centrally producing power plants, which are steadily ageing, are being replaced by decentralised small-scale power plants. This change is creating completely new phenomena in the operation of the electricity network, in the nature of electricity production and even in consumer habits. A positive aspect of this systematic transformation is that part of the electricity generated in the decentralised production is already consumed close to the point of production and therefore does not cause any more overloads in the distribution network. Whereas in the past there was a clear separation between the producer and the consumer, today the two functions are increasingly merging together.

In order to ensure the continuous and safe operation of electricity systems, solutions to new challenges need to be worked out.

New renewable-based production technologies use the wind and solar energy to produce electricity. Hungary's geographical conditions favour the expansion of solar photovoltaic (PV) power plants. The total installed capacity of 3 MW of solar PV capacity in 2011 increased to close to 3 000 MW by the end of year 2021. This amount represents more than one third of the total installed capacity at national level. In the decade ahead, this could increase several times according to the National Energy Strategy projections for 2030 [11].

The amount of photovoltaic energy production depends on weather conditions, i.e. the intensity of the solar radiation. The following figure illustrates the diagram of the output power that the sunshine can produce in solar PV power production.

The weather-dependent production is illustrated by the daily production diagram of the 20,6 MW solar power plant at Paks [12]. In the diagram we can observe the switch-on of inverters after sunrise and their switch-off during the evening's low-light period. The production

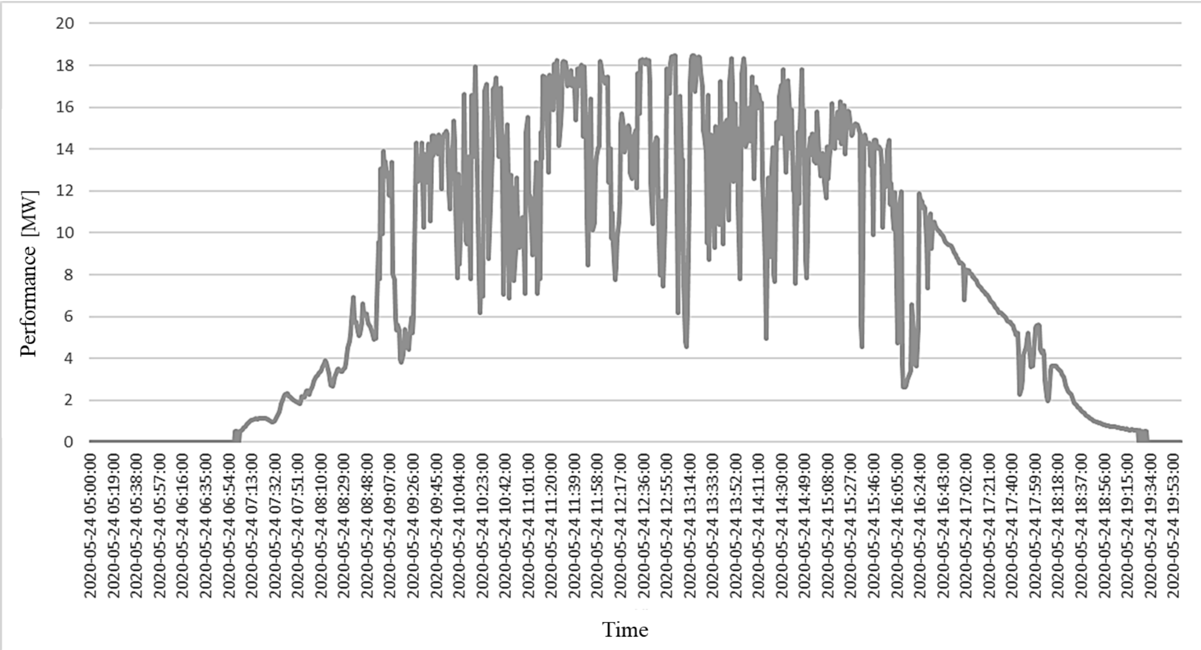

Figure 1. Daily production diagram of the 20,6 MW solar power plant, Paks [12].

curve shows a series of random power drops due to the obscuring caused by passing of clouds. The main findings for the solar PV production, as shown in Figure 1, are as follows. Electricity is needed outside the sunshine season. Production depends on the weather and cannot be adjusted to consumer demand. Because of this, the solar power plant must be connected to a sufficiently stable electricity network that is less sensitive to sudden changes in energy production. The electricity network alone cannot store electricity, so the amount of energy used, and the amount of energy produced must be the same at all times in order to keep the voltage and frequency of the network within the required range. A system regulation is necessary for the operation of conventional power plants that generate on a scheduled basis. This means that the gap between the power plant output generated in this way and the power demand, which varies randomly over time, has to be filled by so-called flexible capacities. In addition to the previous traditional need for regulation, the random power variation on the production side should also be taken into account. Gas turbines, gas engines and other various energy storage technologies can be considered as flexible capacities. The advantage of energy storage is that the electricity produced in surplus can be recovered and used in the event of energy shortages or high market prices. Consequently, these can be used for both DOWN and UP power control.

The following sections will briefly review the new impacts and challenges that need to be addressed in the context of electricity system transformations. The unidirectional power flow in the central system has been eliminated. The energy flow direction in distribution networks changes several times a day, i.e. the excess energy from the unused solar energy production flows from the lower voltage levels toward the higher voltage levels. In many cases, this takes place from the direction of the household-scale production units.

The number of newly emerging electrical devices is fast increasing as a result of the high level of automation that ensures the convenience of smart cities, which increase the load on electrical networks. Consequently, more and more points in the electrical networks are becoming overloaded, which must be managed by the system operator. Electrical heating and cooling and other large-capacity computer systems for smart homes are proliferating, putting electrical networks under pressure. Asymmetries between phases, voltage and frequency fluctuations can develop on these electrical networks.

As traditional rotating engine power plants are losing ground, the voltage regulation capability and the electrical inertia of the power system are reduced weakening the stability of the system.

CONCLUSION

Among the possible solutions we can enumerate the physical upgrades of electricity networks, the extent of which can be reduced by smart solutions. Worldwide developments are under way to achieve the synthetic electrical inertia through the use of performance electronics with smart solutions. New approaches must be implemented into the network modelling. Such an approach could be the investigation of the reliability of electricity transmission using the graph cuts method. A single-phase substitute diagram can be made for a three-phase, symmetrical loop network. By combining the impedance-free return into one node, the geometric shape of the network, free of physical characteristics, i.e. its graph, can be created. By defining graph cuts, we can examine the probability of discontinuity between two selected points of the graph [13]. MAVIR's network design methodology needs to be brought in line with the extension of solar PV production. New test methods are required. The most important of these are partial cloud cover testing and grid reserve training to manage system disturbances and improve resilience [14]. New methods are needed to produce more accurate production and load forecasts that are capable not only to show the expected peak demands but also provide a good indication of the typical time evolution of the characteristic curves. At the same time, meteorological forecasts need to be more accurately matched to production forecasts using artificial intelligence developments. A complete overhaul of electrical protection and automation systems will be necessary. In order to ensure flexible rotating machine production, gas turbines will have to be installed. Energy storage capacities need to be drastically increased. One of the most efficient sustainable solutions could be the pumped storage, by which large amounts of electricity can be stored by increasing the stationary energy of large amounts of water [15]. Beside the technical solutions currently in use, innovations and smart solutions in the field of energy storage can bring breakthroughs in the development of future systems [16].

Last but not least, shifting consumer habits to a positive direction is also an outstanding task of the domestic energy policy. Smart cities can provide indispensable help in this, as they can be particularly effective building blocks of attitude formation due to the constructive power of the community of smart devices. Saving energy is the cheapest and cleanest way to achieve sustainability.

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