Opportunities and challenges for Small Modular Reactors for Nuclear Energy of Ukraine and possible deployment of SMRs in the energy mix of Ukraine

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Nuclear Energy of Ukraine
There are 4 NPPs in operation in Ukraine, namely:
- Zaporizhzhya NPP
- South-Ukraine NPP
- Rivne NPP
- Khmelnitsky NPP
SE NNEGC ENERGOATOM IS THE ONLY OPERATOR OF NPP IN UKRAINE

SE NNEGC Energoatom was established on October 17, 1996. The Company is responsible for safety of all operating NPPs of Ukraine: Zaporizhzhya, Rivne, South-Ukraine and Khmelnytskyi NPPs.

The Company operates:

- **15 nuclear power units** with a total installed capacity of **13 835 MW**
- **2 storage pumps** of Tashlyk Hydroelectric Pumped Storage Plant with a total installed capacity of **302 MW**
- **2 hydro power units** of Oleksandrivka Hydro Power Plant with a total installed capacity of **11.5 MW**

**Rivne NPP**

- 4 nuclear power units: 2 units of VVER-440 type
  - 2 units of VVER-1000 type

**South-Ukraine NPP**

- 3 nuclear power units of VVER-1000 type

**Zaporizhzhya NPP**

- 6 nuclear power units of VVER-1000 type

**Khmelnytskyi NPP**

- 2 nuclear power units of VVER-1000 type
Total installed electrical capacity of generating facilities of SE NNEGC “Energoatom”

14 148,5 MW

SOUTH UKRAINE POWER COMPLEX

3 313,5 MW

RNPP - 2 835 MW
ZNPP – 6 000 MW
KhNPP – 2 000 MW

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Tashlyk PSP - 302 MW
SUNPP – 3 000 MW
Oleksandrivska HPP - 11,5 MW
PLACE OF NPP IN THE ENERGY SECTOR OF UKRAINE FOR 4 MONTHS 2019

The structure of generating capacities

- SE NNEGC «Energoatom»: 26%
- HPP and other: 12%
- TPP: 63%

The structure of electricity production

- SE NNEGC «Energoatom»: 54%
- HPP and other: 9%
- TPP: 37%

The structure of electricity output to the energy market of Ukraine

- SE NNEGC «Energoatom»: 55%
- HPP and other: 17%
- TPP: 27%
STRUCTURE OF SE NNEGC “ENERGOATOM”
Safe electricity generation

NPP safety enhancement based on implementation of modern technologies, improvement of safety systems’ performance

Construction of new power capacities and lifetime extension of the operating ones

Purchase of fresh nuclear fuel and shipment of spent nuclear fuel

Establishment of the national infrastructure of spent fuel and radioactive waste management

Physical protection of nuclear power facilities

Re-training and qualification upgrading
There are 15 nuclear power units in operation

Lifetime extended
(9 power units)

- RNPP - №1
  VVER-440/213
  License obtained on 10.12.2010

- RNPP - №2
  VVER-440/213
  License obtained on 10.12.2010

- RNPP - №3
  VVER-1000/320
  License obtained on 17.07.2018

- SUNPP - №1
  VVER-1000/302
  License obtained on 02.12.2013

- SUNPP - №2
  VVER-1000/338
  License obtained on 09.12.2015

- ZNPP - №1
  VVER-1000/320
  License obtained on 14.09.2016

- ZNPP - №2
  VVER-1000/320
  License obtained on 03.10.2016

- ZNPP - №3
  VVER-1000/320
  License obtained on 03.11.2017

- ZNPP - №4
  VVER-1000/320
  License obtained on 12.10.2018

- ZNPP - №5
  VVER-1000/320
  License obtained on 03.11.2017

Work is on-going
(3 power units)

- KhNPP - №1
  VVER-1000/320
  License obtained on 14.09.2016

- SUNPP - №3
  VVER-1000/320
  Design lifetime will end on February 2020

- ZNPP - №5
  VVER-1000/320
  Design lifetime will end on May 2020

Lifetime has not ended
Lifetime will end after 2020
(3 power units)

- ZNPP - №6
  VVER-1000/320
  License obtained on 10.12.2010
  (October 2026)

- RNPP - №4
  VVER-1000/320
  License obtained on 10.12.2010
  (June 2035)

- KhNPP - №2
  VVER-1000/320
  License obtained on 09.12.2015
  (September 2035)
MAJOR INVESTMENT PROJECTS OF SE NNEGC ENERGOATOM IN 2019

Complex (Consolidated) Safety Upgrade Program of Ukraine NPPs
∑ UAH 32 271,6 M

Rehabilitation of 750 kV switchgears of ZNPP
∑ UAH 743,9 M

Modification of the service water supply system of SUNPP
∑ UAH 3 448,9 M

Construction of a building of the Technical Center for automated remote metal inspection devices at RNPP
∑ UAH 177,9

Construction of Complexes for solid waste treatment
∑ UAH 2 153,0 M

Construction of the building of additional cell of EDG of emergency power supply system of power unit #4 of Rivne NPP
∑ UAH 467,3 M

New indicative cost of projects is UAH 165,0 billion

Designing and construction of the Central Spent Fuel Storage Facility
∑ UAH 37 217,5 M

Designing and construction of KhNPP Units 3 and Unit 4
∑ UAH 72 342,9 M

Pilot Project “Power Bridge: Ukraine – European Union”
∑ UAH 1 358.0 M

Completion of Tashlyk HPSPP. Commissioning of storage pumps No. 3-6
∑ UAH 14 254,4 M

«Sonechko-1» solar power plant (SPP) in the area of cooling pond of SS Zaporizhzhya NPP
∑ 399,8 M
Background:

Between **2030** and **2040**, the extended lifetime of 12 nuclear power units will expire resulting in the annual electricity generation reduction by **76 TW*h**

Between **2041** and **2055**, a further 3 nuclear power units will have their extended lifetime expired. As a result, the annual electricity generation will be further reduced by **21 TW*h**
Construction of new nuclear generating capacities depends on:

- Macroeconomic indicators of development and forecast of electricity production/consumption
- Economically justifiable share of each generation type (*thermal, nuclear, wind, solar and so on*), taking into account the energy reserves estimate and solutions for environmental impact mitigation
- Plan of development of the Unified Energy System of Ukraine for the next decade
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Possible Deployment of Small Modular Reactors in the energy mix
In August 2017 a new Energy Strategy for the period until 2035 was approved by the Government of Ukraine. It confirms **further development of nuclear power** in the country by keeping its share in electricity generation at least at 50%. To achieve this goal the following steps have been outlined:

- Completion of construction of Khmelnitsky NPP Units 3 and 4;
- Lifetime extension of the operating nuclear power units;
- Development and approval of long-term Nuclear Energy Development Program;
- Decision making regarding replacement of nuclear power units to be decommissioned after 2030;
- Selection of nuclear reactor technologies for new nuclear power units to replace those ones to be decommissioned after 2030.
Major Challenges in the Energy Sector of Ukraine

- Aging fleet of fossil fuel power plants have adverse environmental impact and they will be definitely decommissioned because of being worn out, outdated and inefficient;
- Partial collapse of energy infrastructure (mainly coal industry) due to the events in the East of the country;
- Commitment to cut GHG emissions by 60% by 2030.
- Slow growth rate of renewable energy sources;
- Lack of load-follow capacities;
- There may be a huge electricity generation gap by 2040:
  - Both nuclear and fossil fuel power plants may be decommissioned from 2025 to 2040 (80% of existing generation capacities (20-25 GW));
  - Between 2030 and 2040 service life of 12 NPP units will expire, which may result in a loss of annual electricity generation by 76 bln. kW-h.
  - By 2055 service life of the remaining 3 NPP units will expire, reducing annual electricity generation by another 21 bln. kW-h.
Drivers for SMR deployment in Ukraine:

1. Increasing lack of load following capacity: the load following capacity is planned to be increased up to 12 GW by 2030.

   **SHORT-TERM DRIVERS FOR INCREASING LACK OF LOAD FOLLOWING CAPACITY IN UKRAINE:**

   • Decline of industrial production in Ukraine
   • Increase in use of electric household appliances.
   • Inefficient state policy in control of power grid loads
   • National Renewable Energy Plan provides for 7 GW (WPP+SPP+hydro).
   • Dependency of Dnieper HPP & HPSPP cascade from availability of water resources.
   • Life of TPP units exceeds the design limits that complicates their use to cover load following range (more than 65% of TPP fleet is worn out).

Life of TPP units exceeds their design limits that complicates their use to cover load following range. It is critical to identify the most prospective areas for introduction of innovative technologies in load control of Ukraine’s power grid taking into account technological, economical and resource trends in development of state energy sector. In this respect use of SMR in the energy mix of Ukraine can be considered.
Drivers for SMR deployment in Ukraine (cont.):

2. PARIS Climate Change Agreement (12 December 2015, COP 21)

14 July 2016 – the Paris Climate Change Agreement from December 2015 was endorsed by the Verkhovna Rada (Parlament) of Ukraine

When accessing to the Paris Agreement the Parties thereto, including Ukraine, agreed to set more ambitious targets to reduce greenhouse gas (GHG) emissions.
Drivers for SMR deployment in Ukraine (cont.):

During negotiations in Paris Ukraine announced a target to reduce emissions by 40% till 2030 as compared to GHG emission level in 1990.

**GHG emissions in 1990-2012 (incl. \( \text{CO}_2 \text{e} \)), Ukraine’s targets for 2020-2030 and proposed target for 2050**

Accession of Ukraine to Paris climate convention and the need to replace load following capacities of outdated Ukrainian TPPs by other capacities (including potential use of SMR).
Drivers for SMR deployment in Ukraine (cont.):

3. Lack of fossil fuels (coal, gas).
4. Decommissioning of operating NPPs starting from 2030 and the need to replace them by new power units with load following capability.
5. The SMR electricity cost can be competitive with other sources of electricity generated in Ukraine:
Drivers for SMR deployment in Ukraine (cont.):

6. Losses caused by scale factor compared to large reactors (cost of installed capacity unit) are compensated for during mass fabrication of modules (SMR).
7. Relatively small absolute costs for implementation of projects and correspondingly less financial risk.
8. Modular construction provides for staged capacity increase and design of NPP with flexible power configuration.
9. The SMR units can be located closer to consumers than large reactors, however, size reduction of sanitary and protective area is subject to justification in each separate case.
10. Small reactors provide for capability to be operated without on-site refueling that releases users from obligations on SNF and HLRW management.
11. The time of SMR construction is several fold less than for large nuclear reactors.
12. Small reactors can easily use existing energy infrastructure, including that of NPP units under decommissioning.
Drivers for SMR deployment in Ukraine (cont.):

13. Capability of plant fabrication (modules); the main factors of SMR compatibility must be their flexibility in operation, modularity of construction technologies, unification of equipment.

14. Small reactors without on-site refueling provide for reactors with capacity of not more than 300 MW(e) designed such that refueling is performed rarely and fuel is secured from proliferation threat. These includes transportable reactors manufactured and loaded with fuel at fabrication plant, as well as reactors with fuel loaded single time by the special team that upon completion of works takes away the refueling equipment. In general the common features of reactors considered in the document are lack of refueling equipment on site and cooling pools for fresh and spent fuel. The campaign varies from 5 to 10 years, safety is much defined by passive systems, and modular construction provides for capability to assemble large reactors if needed.
The main drivers for SMR Deployment in Ukraine from utility point of view

- Anticipated competitive cost of electricity produced by SMR;
- Anticipated lower cost of SMR projects compared to large nuclear reactors;
- The economy of scale due to the mass fabrication of modules;
- SMR construction period is significantly less than for large nuclear reactors;
- Modular construction provides for gradual capacity increase;
- NPP design can have flexible power configuration;
- Anticipated load-follow possibilities provided by SMR;
- The prospect of using SMR for combined heat and electricity generation;
- Simplified design, passive safety systems, long design lifetime;
- SMR units can be located closer to consumers than large nuclear reactors;
- Possibility to use the existing energy infrastructure, including that of NPP units under decommissioning;
- Significant localization opportunities;
Prerequisites for introduction of small nuclear capacities

1. Introducing small nuclear capacities requires a sustainable SMR projects implementation schedule developed by government and supported by the policy to decrease operators risks and increase their investment attractiveness.

2. Development of comfortable environment to increase investor’s confidence is a key aspect in development of small nuclear generation. At the early phase of development (5-10 years) the most important role is set on government. The technology development programme must be elaborated and government needs to develop a reward system to attract investments.
3. The prospects of using small NPPs can be aligned with development of combined cycle power plants and not limited by small generating capacities.

Such approach is substantiated by the fact that small size and relative simplicity in construction of small NPPs can be used to develop additional reliable source of thermal energy to be supplied directly to the cities by hot water pipelines. Additional function of thermal supply will be not than costly for small reactors and future benefits will be significant with development of decentralized heating system:

- Firstly, such decision will increase capabilities in deployment of small nuclear reactors network that will decrease cost of their construction per unit;
- Secondly, it doesn’t require to review the design or readjust production of reactors that in turn will also allow to decrease future costs.
Some possible Impediments for SMR Deployment

• Small modular reactors can be attractive by several features. However, they provide no solution to the most critical industry challenges – high capital costs, ensuring safety and dealing with non-proliferation.
• The SMR licensing period should be short. Spending 3-5 years for licensing and 3 years for construction is unacceptable.
• Second challenge – small reactors should be optimized in economics. There are some engineering solutions. But the most important is to use advantages of modularity of small reactors with quality control of these modules directly at the manufacturer plant.
• There is another critical challenge that is not fully realized by the main suppliers. Many small reactors will require human resources comparable to that for 1000 MW reactor unit. But this is a deadlock! Thus, it is necessary to optimize SMRs in terms of their control. In practice this would mean introduction of completely new approaches to nuclear reactor control.
Some Challenges for SMR Deployment in Ukraine

- Current national licensing, regulatory and engineering framework is applicable only to WWER reactor technologies and cannot be used for advanced innovative reactor technologies;

- Ukrainian manufacturers are not certified by ASME that may become an obstacle to localization of SMR equipment;

- SMR deployment requires a sustainable program of SMR projects implementation adopted by the government;

- No reference SMR in operation;
Conclusions

• In the near term Ukraine will have to replace obsolete generating capacities, first of all TPPs, by new one. In the context of accession of Ukraine and other countries to the Paris Climate Change Agreement (December 2015) replacing outdated capacities by new capacities operating on fossil fuels can be challenging.

• It is forecasted that load following capacities in Ukraine will increase up to 12 GW by 2030. The structure of Ukraine’s UPS installed capacities and plans to renew the fleet of generating equipment will not allow to increase load following capacities. Given the accession of Ukraine to the Paris Climate Change Agreement (December 2015) the dominating role of TPP units in covering fluctuating loads will become a challenge.

• The innovative technologies for power generation and control of fluctuating loads are among the main topics to be actively researched globally. In this respect SMRs subject to solving several issues related to their use can play a valuable role and be used in many countries, including Ukraine, in the near future.
Thank you for attention!