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Nuclear Hybrid Energy Systems: Challenges and Opportunities

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I. INTRODUCTION

The growing demand for energy, coupled with environmental concerns, has resulted in an increased interest in alternative energy sources. Nuclear hybrid energy systems (NHES) that incorporate renewable energy sources, such as solar or wind energy, combined with a nuclear reactor and energy storage are currently being considered. Recognizing the variability in renewable energy resources, integration of nuclear energy with renewable sources would provide reliable, baseload energy to meet the peak electricity demand imposed on the grid. Excess energy, produced either during times of low demand or high renewable availability, would then be diverted to alternate output stream, such as providing process heat for potential industrial or chemical applications. NHES could potentially satisfy various energy demands (electrical and thermal) while providing system reliability, robustness, and resilience. Hybridization also offers economic and net efficiency gains, particularly in comparison with a renewable plant producing electricity alone. This paper briefly describes potential NHES system architecture and anticipated challenges to implementation.

II. NUCLEAR HYBRID ENERGY SYSTEM

A NHES would integrate a nuclear reactor, energy storage device, renewable energy source, electricity generation and a thermal energy output stream to drive a process application, such as high-temperature steam electrolysis. Such a hybrid system would have a point of common coupling to establish rapid response to power grid fluctuation, with the nuclear reactor being used for constant baseload power [1]. Hybridization enables the nuclear reactor to run at high capacities while essentially providing load following to meet grid demand. As the coupled renewable energy source ramps up / down, the reactor can maintain steady-state operation by shifting output between electricity generation and thermal energy application. The system would additionally include thermal, electrical, and chemical (in the form of chemical products for future use) energy storage to maintain stability on the electrical grid. The hybrid system design allows for a stable electricity supply to the grid with increased penetration of low carbon, renewable generation without grid-scale storage. Fig. 1 provides a schematic of potential NHES system with various interconnections and coupling.

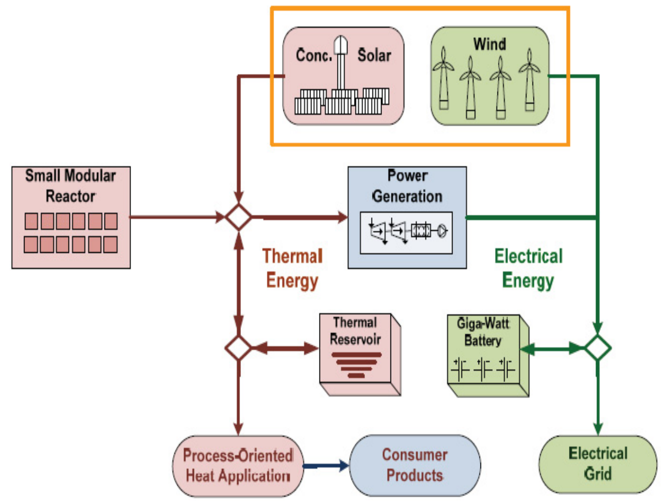

Figure1. Nuclear hybrid energy system [1]

In addition to mitigating the variability of renewable energy sources, NHES provides opportunities to produce revenue from different product streams and avoids capital inefficiencies by matching electrical output to demand, also utilizing excess generation capacity for other purposes when it is available [2]. NHES also provides opportunity and flexibility to enhance revenue collection based on the profitability between power production and industrial application. Hybridization can be accomplished with many small modular reactor (SMR) designs currently under consideration, but the applicable industrial applications vary based on the available reactor outlet temperature. Feasible hybrid system configurations can be roughly divided under two categories based on the anticipated reactor outlet temperature:

A. Current Fleet of Reactors (Light Water Reactors)

The reactor outlet temperature available from current fleet of light water reactors (LWR), or proposed future LWR designs, could be used for lower temperature industrial applications, such as: purification of seawater, district heating, and for biomass energy thermo-chemical conversion processes using pyrolysis [3].

B. Advanced Reactors

The strategic goal for advanced reactors is to broaden the environmental and economic benefits of nuclear energy in the U.S. economy by producing power to meet growing energy demands and to demonstrate applicability to market sectors not being served by light water reactors. These markets might include process heat application for industrial applications, such as hydrogen production via high-temperature steam electrolysis, liquid fuel production, oil sands recovery via steam assisted gravity drainage, natural gas to liquids production, methanol to gasoline production, ammonia production, and ex situ and in situ oil shale.

III. Nuclear Hybrid Energy System - Advantages

A NHES, as described earlier, is an integrated system with multiple inputs and multiple outputs that offers various advantages, including:

1. NHES can be utilized to ensure reliable supply, as integrated renewable energy sources have variable/fluctuating power generation characteristics.
2. NHES can support the production of synthetic transportation fuels by utilizing thermal energy from the plant.
3. NHES has the inherent feature (because of the design) to follow and respond accordingly with the changes in the load or renewable availability while maintaining steady-state reactor operation.
4. NHES can redirect energy production to the more economically lucrative output (electricity production or industrial application) as the value of those products varies.

IV. System Architecture – FigureS of Merit

To establish an effective NHES, figures of merit (FOMs) must be developed to exemplify good NHES architecture for comparison and ranking of proposed systems. These characteristics include items that fall within the categories of technical feasibility, such as compatibility of the individual subsystems that would result in differing system efficiencies; environmental impact; overall economics; and public or political attractiveness. There are two main areas against which the systems must be evaluated [1]:

1. Availability of, or capability to obtain, needed resources to initiate a large-scale deployment. These characteristics are usually measured in terms of:
    a) Market Size: First-of-a-Kind development needs and efforts are much higher; this effort decreases with increased number of units.
    b) Economic Viability: Economic returns on the investment with low uncertainty are of high significance to the industry.
2. Long-term sustainability of the system should be clearly identified as it relates to the risks/opportunities associated with the expected capability of the considered system. The classes of risks and opportunities considered include:
    a) Changes required to the regulatory framework.
    b) Volatility and long term supply/availability of raw supplies.
    c) Volatility of the demand (electricity and other products), both in terms of type and volume.

The following FOMs are also essential and could provide a comparative basis for different NHES [1]:

1. Compatibility with current electric grid architecture.
2. Capital investment consideration—small initial investment leads to more potential investors (i.e., increased market size) and reduced risk.
3. Reduction in Greenhouse gas (GHG) emission—environmental and government incentive.
4. Reliability of the system—directly impacts the economic performance of the system.
5. Flexibility and Diversification—possibility to redirect energy production to the more economically lucrative option with broader scope of energy products (i.e., more diverse process heat options).

V. Nuclear Hybrid Energy System - Challenges

The key challenges that NHES must overcome are as follows:

1. Apart from known technical challenges for the integrated system, the unknown regulatory and political challenges are difficult to predict.
2. The level of complexity of a hybrid system is non-trivial, as a NHES is comprised of various individual integrated components.
3. First-of-a-kind development effort tends to have higher risk and high economic demand.
4. Load following characteristics and diversification is a clear advantage for NHES, as long as it does not disrupt operations and revenue generation.
5. Control and startup strategies for the NHES must be developed and demonstrated.

VI. Conclusions

A NHES describes an integrated energy system comprised of a nuclear reactor (providing base load power), integrated with renewable energy source (wind, solar, etc., providing variable power) with energy storage for electricity generation and industrial processes. The economic risk (volatility) of a hybridized system could be very different from a conventional nuclear reactor. There is a stabilizing effect resulting from diversification of products (use of the thermal energy); however, the increased complexity associated with the hybrid system infrastructure could lead to lower reliability of the overall system. An interesting issue will also arise when considering the elasticity of the local electricity market, although NHES system has a clear advantage of preserving the optimum balance between supply and demand. The possibility to redirect the energy production to the more economically lucrative option whenever possible to increase the attractiveness of the system is a significant advantage for NHES.

References

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