# Economic Evaluation of SMART Deployment in the MENA Region using DEEP 5.0

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## 1. Introduction

Nuclear power is increasingly being seen as the energy of the future. Recent statistics from the IAEA indicate that many countries in the Middle East and North Africa (MENA) region have expressed an interest in or are actively planning to introduce nuclear power [1]. Some countries have officially announced that the development of atomic energy is essential to meet the growing nation's requirements for energy to generate electricity, produce desalination water, and reduce reliance on depleting hydrocarbon resources [2].

SMART (system-integrated modular advanced reactor) is a small-sized advanced integral reactor with a rated thermal power of 330 MW. It can produce 100 MW of electricity, or 90 MW of electricity and 40,000 tons of desalinated water concurrently, which is sufficient for 100,000 residents. It is an integral type reactor with a sensible mixture of proven technologies and advanced design features. SMART aims at achieving enhanced safety and improved economics; the enhancement of safety and reliability is realized by incorporating inherent safety-improving features and reliable passive safety systems [3]. The improvement in the economics is achieved through a system simplification, component modularization, reduction of construction time, and high plant availability. The standard design approval assures the safety of the SMART system.

The economics of SMART are evaluated for the deployment in MENA region in this study. DEEP 5.0 software was selected for the economic evaluation of SMART plant. By using the collected technical and economic data as the input data into DEEP program, the power and water costs are calculated.

## 2. Evaluation Methodology

### *2.1 SMART with Desalination System*

The reactor assembly of SMART contains its major primary components such as the fuel and core, eight steam generators, a pressurizer, four reactor coolant pumps, and twenty-five control rod drive mechanisms in a single pressurized reactor vessel.

The integrated arrangement of the reactor vessel assembly enables the large size pipe connections to be removed, which results in an elimination of large break loss of coolant accidents (LBLOCAs). This feature, in turn, becomes a contributing factor for the safety enhancement of SMART. Eight modular-type once-through steam generators consist of helically coiled tubes producing 30 °C superheated steam under normal operating conditions, and a small inventory of the secondary side water sources at the steam generator prohibit a return to power following a steam line break accident. Four reactor coolant pumps with a canned motor, which has no pump seals, inherently prevent a loss of coolant associated with a pump seal failure. Four-channel control rod position indicators contribute to the simplification of the core protection system and to an enhancement of the system reliability.

The large free volume in the top part of the reactor vessel located above the reactor water level is used as a pressurizer region. As the steam volume of a pressurizer is designed to be sufficiently large, a spray is not required for a load maneuvering operation. The primary system pressure is maintained constant due to the large pressurizer steam volume and a heater control.

The reactor coolant forced by reactor coolant pumps installed horizontally at the upper shell of the RPV flows upward through the core, and enters the shell side of the steam generator from the top of them. The secondary side feedwater enters the helically coiled tube side from the bottom of the steam generators and flows upward to remove the heat from the shell side, eventually exiting the steam generators in a superheated steam condition. The SMART core is composed of 57 fuel assemblies, the design and performance of which are based on a proven 17x17 array with $UO_2$ ceramic fuel rods in commercial PWRs.


Fig.1. SMART deployment overview (one unit)

The present desalination market has been divided into the thermal type and RO type. In the case of the thermal type, the MSF type was generally applied to the large scale plant at over about 400,000 $m^3$/day, the MED-

MVC type at up to 3,000 $m^3$/day, and the MED type at up to about 10,000 $m^3$/day, which makes the MSF and MED-MVC types be excluded from the candidate of a desalination type for the SMART system due to its large capacity. The RO system takes advantage of general aspects such as the energy consumption for fresh water production, the operating cost, and the construction cost. This means that the RO type can produce more fresh water than the MED-TVC type. However, the safety considerations of a desalination plant should be taken to the cases in which the different desalination types would be coupled with a nuclear power plant. The desalination system of SMART consists of RO and MED units as follows:

- Two MED-TVC units each with a unit capacity of 10,000 $m^3$/day.
- Four RO units each with a unit capacity of 5,000 $m^3$/day.

The plant requires high quality fresh water for a boiler make-up and the component cooling. The required water quality from components can be satisfied by supplying the fresh water produced from the thermal desalination plant. Since the production cost from the MED-TVC type is high, the RO plant is needed for the cost reduction of fresh water production. The blending of fresh waters from the MED-TVC (lower than 25 ppm) and RO (200~400 ppm) can meet sufficiently the requirements for a portable water. For portable water, the RO plant is sufficient to operate in a single stage, which reduces the operating cost of the RO system. In the shutdown period of the SMART nuclear power plant, the RO system can supply fresh water continuously using off-site electricity. To improve the water production rate of RO system in the winter, the seawater temperature control supplied to the RO system is need. This temperature control can be done by utilizing the hot brine discharged from the MED-TVC without any additional cost.

### *2.2 DEEP 5.0 and Input Data*

The Desalination Economic Evaluation Program (DEEP) is a tool made freely available by the International Atomic Energy Agency, which can be used to evaluate performance and cost of various power and water co-generation configurations [4]. The program allows designers and decision makers to compare the performance and cost estimates of various desalination and power configurations. Desalination options modeled include MSF, MED, RO, and hybrid systems, and power options include nuclear, fossil, and renewable sources. The co-generation of electricity and water, as well as water-only plants, can be modeled. The program also enables a side-by-side comparison of a number of design alternatives, which helps to identify the lowest-cost options for water and power production at a specific location. Data needed include the desired configuration, power, and water capacities, as well as values for the various basic performance and cost data.
The benefits of the coupling of an energy source and a desalination plant are shown by using the 'power credit' method. This method is based on the comparison between the proposed dual purpose plant and an imaginary reference single purpose plant. The cost of electricity delivered to the desalination plant is valued based on the cost of that product from an alternative imaginary power plant. The cost of heat is taken to be the revenue that would have accrued from lost electricity generation (due to the delivery of heat). As a result, water is credited with all of the economic benefits associated with the plant being dual purpose. The DEEP structure is presented in a modular form in Figure 1.

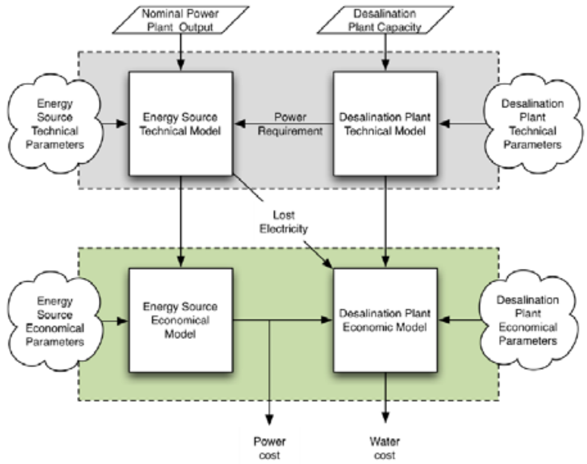



Fig. 2 Modular Representation of DEEP software

DEEP input variables can be split in the following categories:

- User input data: Case-specific input such as power and desalination plant capacity, discount rate, interest, fuel escalation, etc.
- Technical parameters: Technology specific parameters such as efficiencies, temperature intervals, etc., which depend only on the technology used and are subject to physical constraints
- Cost parameters: Specific costs of various components (e.g., construction, fuel, etc), cost factors and other operational parameters (lifetime, availability, etc).

The hybrid type desalination system is chosen in this study, which consists of MED and RO. The desalination capacity for each system is 50%. The MED process needs steam, which is extracted from the intermediate stage of the turbine. An intermediate loop is introduced to minimize the leakage of radioactive material into the desalination system.
Technical parameters are taken directly from plant data or calculated indirectly from the operating condition. The sea water temperature is 28 $^oC$, which is the annual average value of this region. Steam temperature, 298 $^oC$, is from the steam generator operating condition at the

rated power level. The auxiliary load is assumed to be 5%. The condenser temperature parameters are calculated from the seawater and TBN backpressure conditions. The low pressure insentropic efficiency is tuned to synchronize the calculated result with the electric power of a real plant.

### 3. Results and Discussion

The power and water costs are evaluated with DEEP 5.0 software for the case of the deployment in the MENA region. The SMART plant is assumed to be builit for the cogeneration of electric power and fresh water. The desalination process consists of MED and RO, each of which has a 50% capacity, while the MED process requires steam and electricity for the production of fresh water, and RO processes only electricity.
The turbine generator produces 103 Mwe, as shown in Fig. 3. 5 MWe is used for the inhouse load and 3.8 MWe for the desalination process. After7 all, a SMART plant can supply 94 MWe to an external grid system with 40,000 $m^3$/d of fresh water.

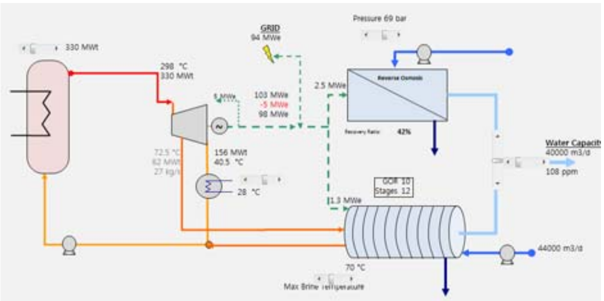
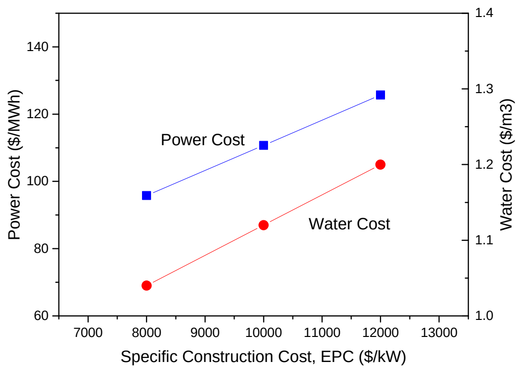


Fig. 3 System configuration and results

The power cost can be broken down largely into the construction, fuel, and O&M costs. There are also many other factors that have an effect on the power cost, such as the discount rate, interest rate, and decommission cost. The EPC (Engineering, Procurement, and Construction) cost takes the largest portion of the power cost in the NPPs.
The thermal desalination process needs heat as well as electricity for the production of freshwater. The amount of heat is transformed into equivelant electricity using the 'power credit' method in this study. The electricity loss due to the operation of thermal desalination plant is about 5 MWe, as shown in Fig. 3.
The SMART EPC cost is about 1 billion US dollars for the domestic deployment. This value can be varied for the case of MENA region due to the loal labor cost and the additional transport of the major components. The power and water costs are evaluated for the several specific construction costs, as shown in Fig. 4.

### 4. Conclusions

Electric power and fresh water production costs for the case of SMART deployment at the MENA region is evaluated using the DEEP 5.0 software in this study. Technical input data are prepared on the basis of the local environmental conditions of the MENA region. The results show that the SMART plant can supply 94 MWe to an external grid system with 40,000 $m^3$/d of fresh water. The power and water costs are calculated for the various specific construction costs.




### Acknowledgements

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