Selection of number of SG modules per secondary sodium loop for a Prototype SFR

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1. Introduction

A steam generator is one of the most critical components determining the plant availability. SG is a vertical counter flow shell and tube heat exchanger with sodium on shell side and water-steam in tubes. The concept of steam generator modularization is discussed and the advantages of large and small steam generator modules are presented. To estimate the economics of the steam generator modularization for the PGSFR, detailed optimization studies were carried out for 1, 2, 3, 4 and 5 steam generator modules per loop, taking into consideration the effect of capital cost, operating cost, and outage cost.

2. Cost Estimations

The total cost consists of capital, outage, and operating costs. The capital cost is SG, accessories, and piping cost. The SG module cost is estimated using the "Economy of Scale" parameter.

$$SG\ module\ cost = \left(\frac{Ref.SG\ capacity}{Module\ SG\ capacity}\right) \times ref.\ SG\ cost \times \left(\frac{Module\ SG\ Capacity}{Ref.SG\ capacity}\right)^{ESP}$$

The Economy of Scale parameters of 0.1 and 0.53 are used for parametric studies. An ESP value of 0.1 is deduced from PFBR studies indicating that there is reduction of ~23% in total capital cost of SG when the number of modules is reduced from 4 SG/loop to 3. An ESP value of 0.53 is the U.S. historical value for NSSS equipment [2]. The reference SG cost is from LWR SG of Shin-gori 3 and 4.

The accessory and Piping costs are assumed to be about 14% of SG capital cost [1].

Accessories include the rupture disc, sodium leak detection systems, isolation valve, pipes, etc.

The outage cost accounts for cost owing to the operation without one defected SG module. A defective SG module is repaired during a planned shutdown. For repair of a defective SG, a defective SG module is isolated by sodium and steam/water side valves. The plant will operate using an [n-1] SG module until the planned shutdown.

The operating cost is the pumping power cost to compensate for the pressure loss of the tube and shell sides of the SG.

The total cost over the plant life is considered for two IHTS loops. A spare SG is not considered because each SG has 10% plugging margins, and number of plugged tubes during 60 years of operation are much less than 10% of the SG tubes.

The operating experience of BN-600 shows 2.16x1E-5 welds/yr (12 leaks for 14 years) and JAEA research presented 5.3x1E-5 tube-tube sheet failures/yr [3]. A failure rate of 2.0x1E-5 was used for the reference case. 1x10-5, 2x1E-5, 5x1E-5, and 10x1E-5 were used for the parametric studies.

Table 1. Assumptions for cost estimation [4]

Item	Value
Electric power of PGSFR (MWe)	150
SG heat capacity per a SG (MWt)	197.25
Weld failure probability (welds/years)	2.0E-5
Number of tubes in a SG	767
Tube plugging margin (%)	10
Number of SGs (Reference)	2
Total number of tubes	1534
Total number of tubes w/o plugging margin	1380.6
Cycle length (EFPD)	290
Refueling interval (days)	365
Capacity factor without any occurrence	0.79
Number of welds per a tube	2
Design lifetime (years)	60

Figures 1, 2 and 3 show the Itemized Costs, Total Cost, and Availability when ESP=0.1. Figure 1 shows that the total cost is at minimum for one SG/loop although outage cost is at maximum (Failure Rate 2.0x1E-5). From the parametric study in Figure 2 (Failure Rate: 1x1E-5–10x1E-5), the design with less SG modules is found to be more economical, if the failure rate is less than 5.0x1E-5 failure/year. The availability increases with SG modules as expected.

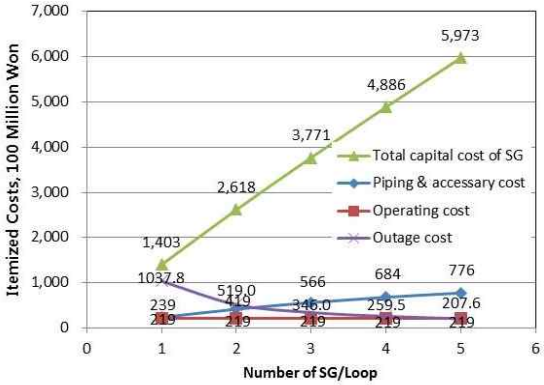

Figure 1. Itemized Costs(ESP=0.1)

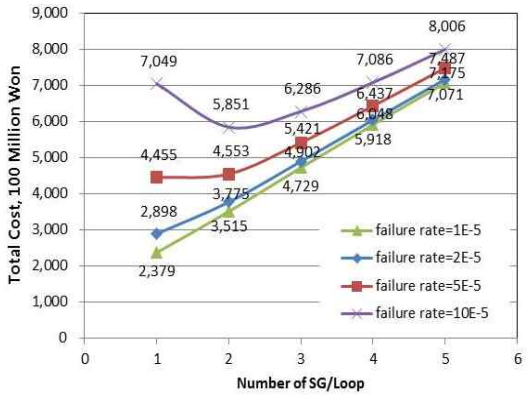

Figure 2. Total Cost (ESP=0.1)

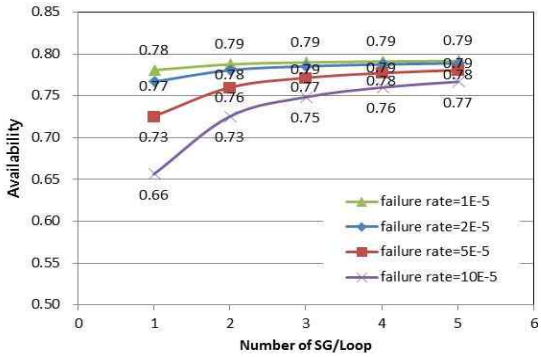

Figure 3. Availability (ESP=0.1)

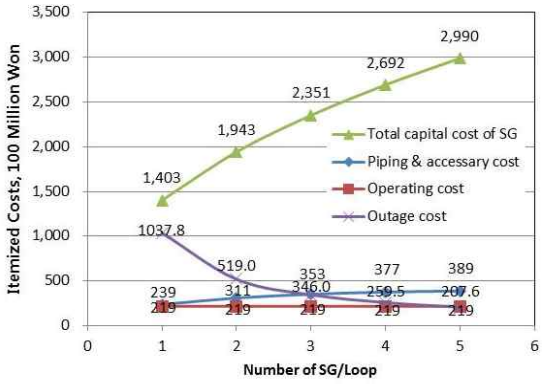

Figure 4. Itemized Costs (ESP=0.53)

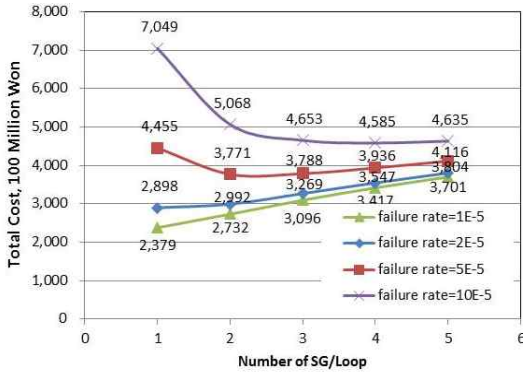

Figure 5. Total Cost (ESP=0.53)

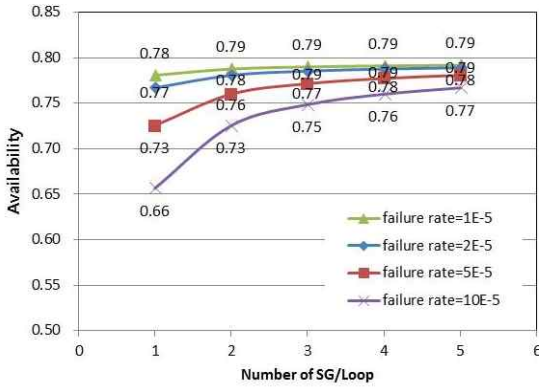

Figure 6. Availability (ESP=0.53)

3. Effects of SG Modularization on Design

The capital cost of a steam generating system decreases with the increased size of the module. Large units, however, may impose other several disadvantages. Table 2 shows some of the advantages of large and small modules. In addition, for a long straight vertical configuration of an PGSFR SG (OD, ~1.2 m; tube length, ~25 m), the stiffness and support of the SG will be one of the problems to consider for installation if modularized with a smaller capacity. Modularization requires additional systems and components such as a leak detection system, isolation valves, and rupture discc.

Possible valve malfunctions of the SG isolation valves in an IHTS loop can reduce the plant reliability.

The thermal rates of a recently designed PFBR and CFBR using current technology are 157 and 210 MWt. From a capacity viewpoint (197 MWt), PGSFR SG may have a modular concept and is extendable to a large plant with modularization.

Table 2. Advantages of large and small modules

	Monolithic with large capacity	Advantage comparison	Modular with small capacity
Fabrication, assembly, shipping, handling		<	
Capital cost		>	
Plant operability after SWR		<	
Simpler to isolate a leak		<	
Easier flow control		>	
IHTS pipes and No. of components		>	
Fewer number of isolation valves		>	
Fewer number of dump & relief systems		>	

3. Conclusions

For the economics of the steam generator modularization for a PGSFR, detailed optimization studies were carried out for 1, 2, 3, 4 and 5 steam generator modules per loop. The effect of capital cost, operating cost, and outage cost were taken into consideration. The studies indicated that the design with less SG modules is found to be more economical, if the weld failure rate is below 2.0x1E-5 failure/year. From the economics of the modularization, thermal rate of SG, reliability, operability considerations, appropriate number of SG modules required for PGSFR will be 1 SG module per loop.

ACKNOWLEDGEMENT

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