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Design of the AM600 Turbine-Generator for NPPs in Emerging Markets

Contents

1. Introduction

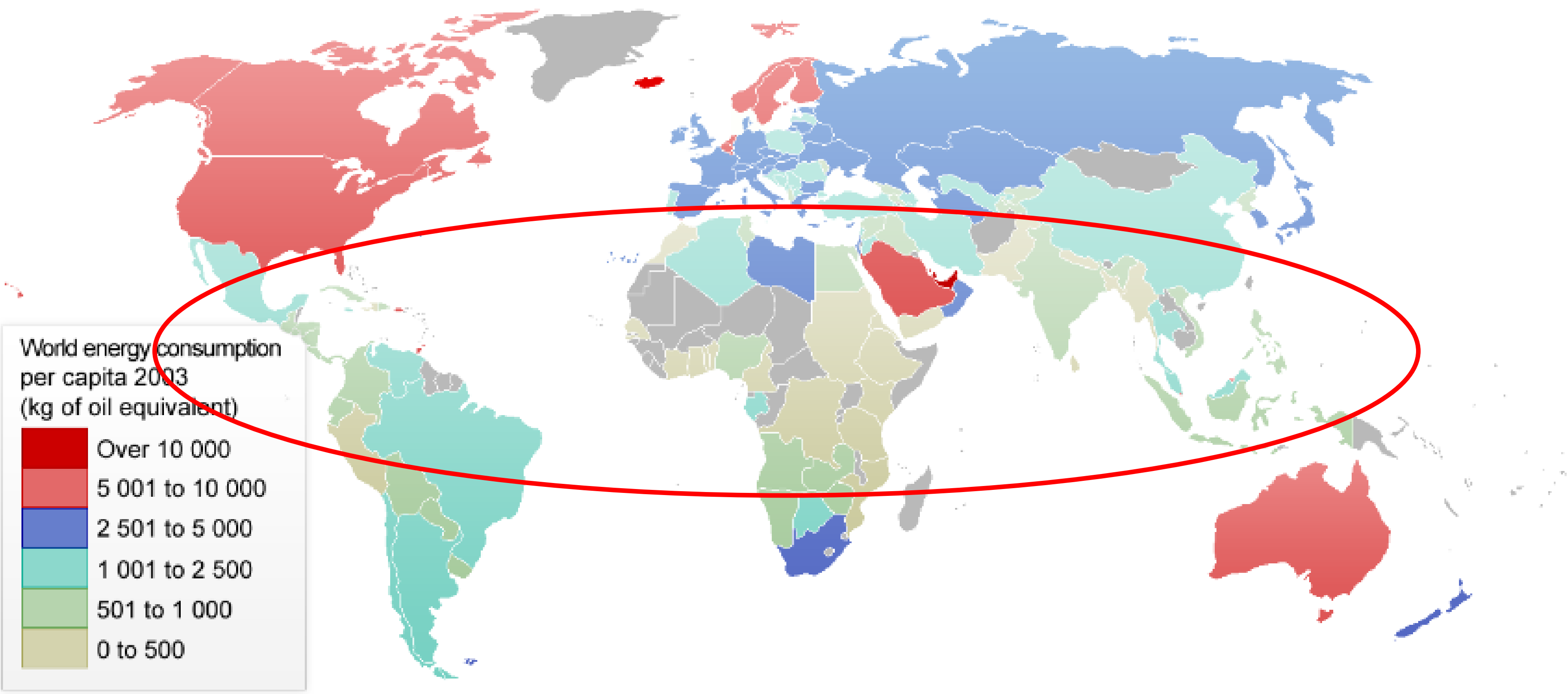
Nuclear Power Challenge in Developing Countries

- Current and near future capacity of electrical grids in many developing countries is insufficient for large units (>1000MWe);
- Many countries have an intermediate grid size which can support 600MWe units;
- Many countries with hydropower resources do not have constant grid frequency throughout the year (e.g., 47 to 57 Hz);
- Fluctuating grid frequency may not support complex shaftline. This is due to vulnerability to torsional vibration.

Design Proposal – AM600

- Robust T/G set (1 flow HP, 2 flow LP);
- Simplified steam cycle;
- Large market share.

2. Target Markets



World Energy Consumption Per Capita (2003)
Target markets are shown inside the red circle.

2. Target Markets

In the aforementioned markets, small reactors have attractive characteristics to large reactors in two specific areas:

1. Grid Stability:

    - Large units (>10% grid flow) may affect grid stability in case of a trip, possibly resulting in a total blackout. Trip of small units (<5% grid flow) will not have severe consequences.

2. Torsional Vibration:

    - Sustained Excitation (NSC) with an ‘un-tuned’ T/G shaftline can result in fatigue damage and crack growth to critical size. For countries with large seasonal variation in hydropower inputs, grid frequency is known to vary beyond recommended range for T/Gs. For these markets, a stiff shaftline with a minimal number of natural frequencies below 150 Hz is recommended.

3. Heat Sink Evaluation

To determine target range of condenser backpressures for AM600, a list of candidate countries has been selected:

Country	City	Annual Average Seawater Temperature	
		°C	°F
Egypt	Marsá Maţrūḩ	22.0	71.5
Bangladesh	Chittagong	25.7	78.3
Vietnam	Cam Ranh	26.9	80.4
Kenya	Shimoni	27.5	81.5
Nigeria	Brass	27.5	81.7
Malaysia	Batu Pahat	28.9	84.2
Indonesia	Tegal	29.1	84.1

3. Heat Sink Evaluation

Taking the average temperature as t_{ri} and introducing it in the formula for $t_c = t_{ri} + \Delta t + \delta t$ (Δt=6-12 C and δt=3-5 C), with which we can determine an approximate average condenser temperature and pressure:

Country	City	t_{ri}	t_c		p_c	
		C	C	F	psia	inHgA
Egypt	Marsá Maţrūḩ	21.95	36	96.8	0.863	1.75
Bangladesh	Chittagong	25.7	39.7	103.46	1.054	2.146
Vietnam	Cam Ranh	26.9	40.9	105.62	1.1235	2.2875
Kenya	Shimoni	27.49	41.5	106.8	1.1597	2.3612
Nigeria	Brass	27.54	41.5	106.8	1.1597	2.3612
Malaysia	Batu Pahat	28.9	42.9	109.22	1.2481	2.5411
Indonesia	Tegal	29.1	43.1	109.58	1.2612	2.5682

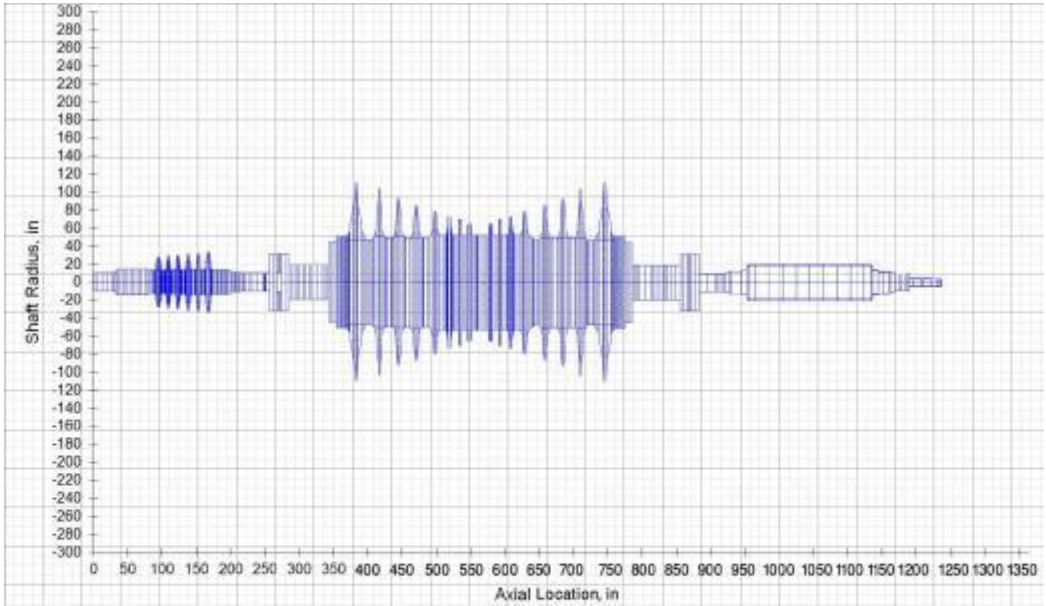
4. AM600 Turbine-Generator

4.1. Number of High Pressure Turbine Flows

- AM600 HPT is selected as a single-flow machine, consistent with historical practice in the US (e.g., Ft Calhoun, Monticello).

- Recent retrofits, converted existing two-flow HPT to single-flow designs with an increase in efficiency (e.g., Surry 1,2, North Anna 1,2).

- A singe-flow machine offers higher efficiency due to longer blading, reduces end losses, and may lead to reduction of inlet and exhaust bowl losses.



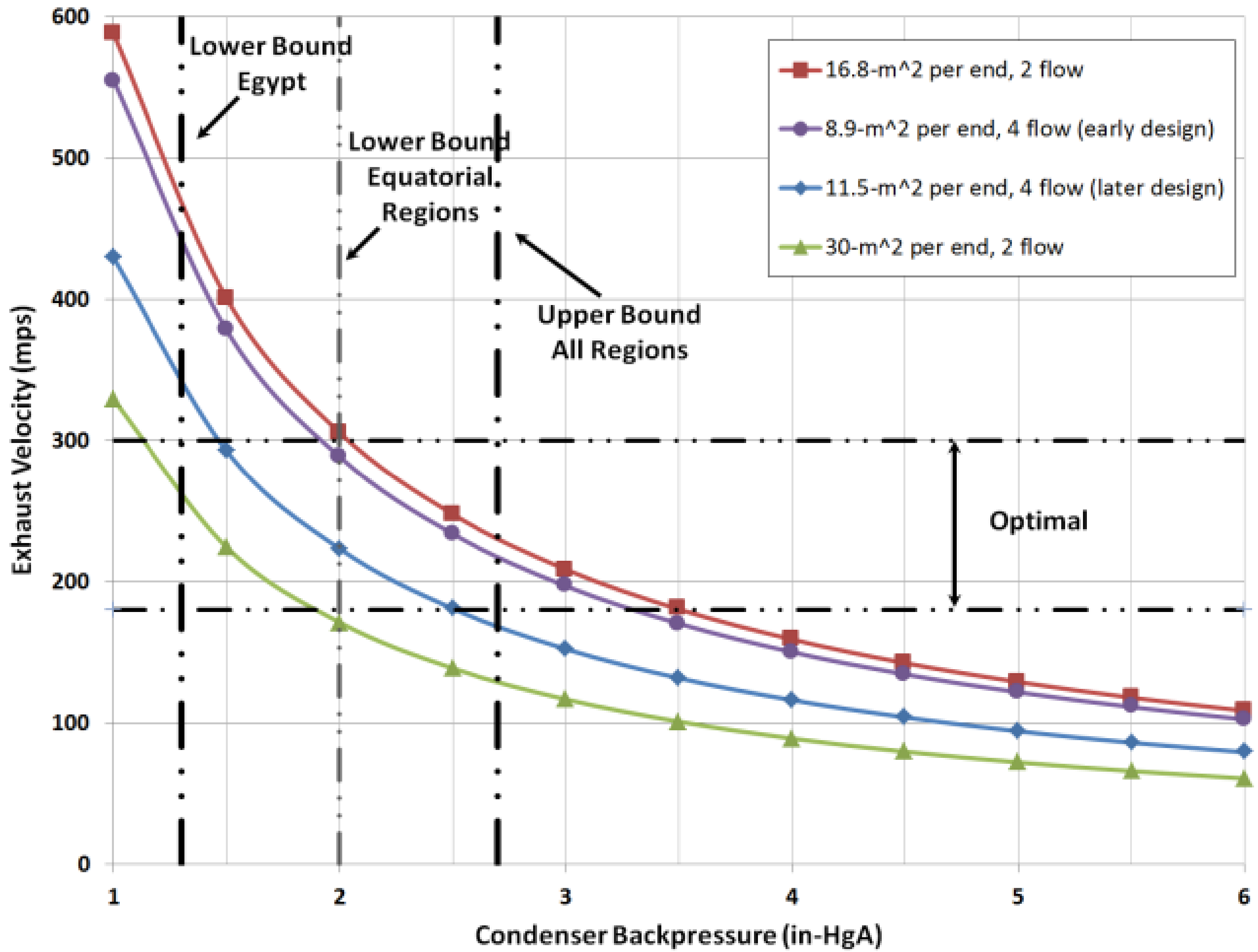
AM600 T/G Design

4. AM600 Turbine-Generator

4.2. Number of Low Pressure Turbine Flows

- AM600 LPT is selected as one two-flow machine.
- It is important to note, that all of the emerging markets considered here operate with a grid frequency of 50 Hz.
- At this lower frequency, the lower rotational speed of 1500 rpm permits the design of longer L-0 blading.
- Considering the range of backpressures previously determined, and the projected mass flow rate for the exhaust flow, the volumetric flow rate can be coupled with exhaust area per end for identified L-0 blading existing on the market to determine the most suitable design.

4. AM600 Turbine-Generator



Exhaust velocity, number of flows and L-0

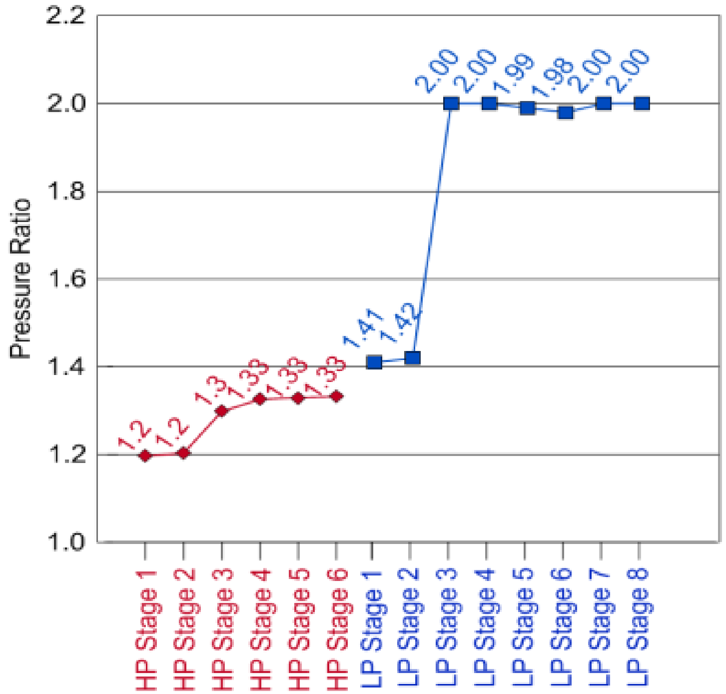
4. AM600 Turbine-Generator

4.3. Stage Design

- Steam flow path performance is based on existing designs for wet steam.

- In general, for internal LPT stages (i.e., not L-0), a two-flow machine with modern design should have higher efficiency than found in existing four-flow units due to higher flows per stage and lower end losses.

- The L-0 design is based on stated performance for similar designs and exhaust velocities.



HPT and LPT stage pressure ratios.

4. AM600 Turbine-Generator

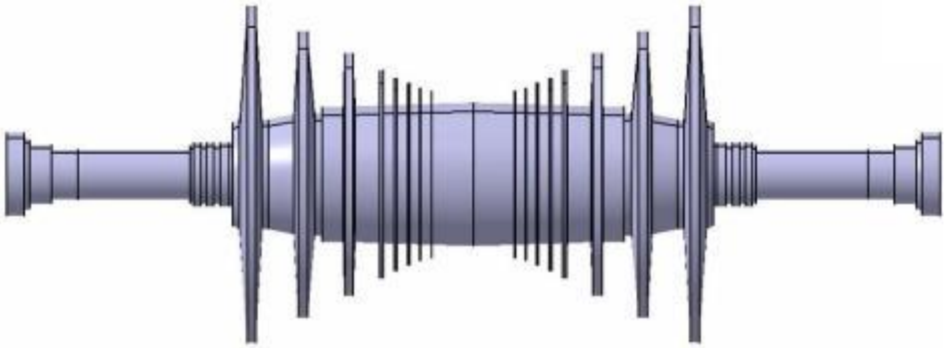
4.3. Low Pressure Rotor Design and Challenges

Component	units	AM600 Rotor (welded drum)
Mass (monoblock)	tonnes	270
Mass (welded drum)	tonnes	175
Journal diameter	mm	760
Rotor diameter	mm	2020
L-0 Blade Length	mm	1600
Rotor Length	mm	13100

Proposed AM600 LPT rotor features.

- Preliminary (simplified) rotordynamic analysis of the AM600 T/G shaftline using ANSYS indicates a that a stiff design with a small number of natural frequencies below 150 Hz can be achieved.

AM600 Rotor 3D dimension executed using CATIA V5.



- The size of the turbine building can be significantly reduced, decreasing construction time and installed cost.

- However, significant challenges in the design of the main condenser exist.

5. AM600 Heat Balance

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5.1. Configuration

- Main consideration is simplicity, reduced capital costs, and minimizing required maintenance, testing and inspection activities.
- Starting parameters are taken from historical designs.

Component	AM600	Comments
HPT Cylinders	1	Single Flow
LPT Cylinders	1	Two Flow
Moisture Separators	2	Two Cross-Around Lines
Reheaters	2	Single Stage
Condenser Zones	1	Seawater Cooling
Hotwell Zones	4	-
Condenser Passes	2	-
HP Feedwater Heaters	2	Fully Cascading
LP Feedwater Heaters	4	Fully Cascading
Condensate Pumps (Radial)	3	3/3 Operating at 50% Capacity
Condensate Booster Pumps	3	3/3 Operating at 50% Capacity
Main Feedwater Pumps (Motor Driven)	2	1/2 Operating at 100% Capacity

Proposed AM600 Component List

5. AM600 Heat Balance

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5.2. Initial Parameters

The T/G will have five steam extractions as follows:

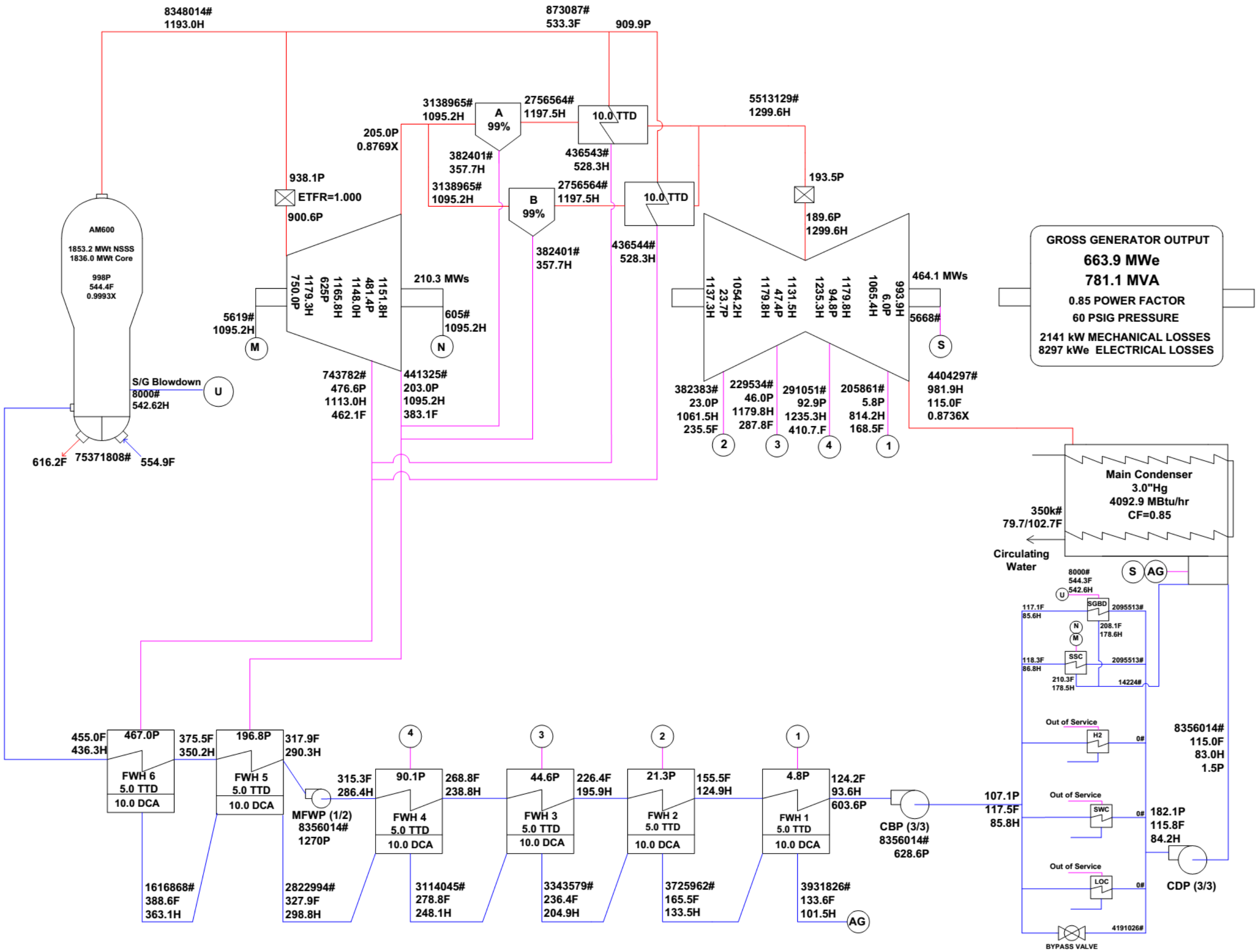
- one extraction in the HP Turbine;
- four (4) extractions in the LP turbine.

The 5th point FWH will receive extraction steam from the cold reheat piping.

Parameter	Units	AM600
Licensed Thermal Power	MWt	1800
Maximum Calculated	%	102.9
NSSS Power (Max Calc)	MWt	1853.2
S/G Dome Pressure	bar	68.8
S/G Leaving Moisture	%	0.07
S/G Leaving Enthalpy	kJ/kg	2774.9
HPT Throttle Pressure	bar	62.1
LPT CIV Inlet Pressure	bar	13.3
Reheat Mass Flow Rate	kg/hr	396,026
Final Feedwater Enthalpy	kJ/kg	1014.9
Final Feedwater Temperature	C	235.0
Feedwater Mass Flow Rate	tonnes/hr	3,790

Heat Balance Initial Parameters

5. AM600 Heat Balance



AM600 Heat balance diagram showing component count and arrangement

5. AM600 Heat Balance

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5.3. Performance Indicators

- The resultant efficiency is competitive with modern T/Gs for nuclear steam conditions.
- Equipment, installation, and operating costs can be reduced further, for example for a design of MSRs with one stage of reheat.

1) 3 in-HgA

Parameter	Units	AM600
HPT Shaft Power	MWs	210.3
LPT Shaft Power	MWs	464.1
Shaft Power to Main Generator	MWs	674.4
Gross Generator Output	MWe	663.9[1]
T/G Gross Efficiency	%	35.82[1]
T/G Gross Heat Rate	BTU/kW-hr	9524[1]

Heat Balance Performance Indicators

6. Conclusions

The conceptual design for the AM600 T/G offers the following:

- a stiff shaftline which can offer robust performance in smaller grids lacking optimal stability relative to grid disturbances and frequency variation,

- a simplified approach to T/G fabrication, installation, operation, testing, inspections, and maintenance due to design with a single LPT cylinder while maintaining high thermal efficiency, and

- a reduced component count for MSRs, FWHs, and power train pumps and drivers (and associated support system components) resulting in lower capital outlays, simplified operations, and further reducing the maintenance, testing, and inspection burden.

Thank You!

Questions?