HW5

Energy Conversion & Supply

1]

The present electrical power of the country is 575000 MWh/year. In order to amend the power outages, the power needs to be increased by 20% to the following changes:

Total new MWh/year= 690000

Addition MWh/year to be added=115000

(i)

All the options are assessed as follows:

a) Coal Plant Enhancements

The new mine has an estimated **6 million Short Tons** of sub-bituminous coal.

1 Short Ton = 0.907 Ton [1]

Capacity of plant=0.907*6=5.442 million Ton

Efficiency=0.28

Energy density of sub-bituminous coal=18-23 MJ/kg [2]

Consider the value: 20.5 (Average of 18, 23)

For current coal consumption:

$E = \frac{5.75*10^5}{0.28} = 2.53 * \frac{10^6 MWh}{year}$

Required tons per year: $T = \frac{2.53*10^6*3600}{20.5*1000} = 3.4 * 10^5\ tons$

Number of years it will last, $n_{years} = \frac{5.442*10^6}{3.4*10^5} = 16\ years$

We also calculate the amount which can be generated uniformly every year.

Energy content of coal= $20.5 \frac{MJ}{kg} * 5.442 * 10^6 * 10^3 kg = 1.11 * 10^{11} MJ = 3.09 * 10^7 MWh$ [3]

For 10 years, Energy content required per year=$3.09 * 10^6 MWh$

For 28% efficiency, Power output increase=$0.28 * 3.09 * \frac{10^6 MWh}{yr} = \mathbf{8.67 * 10^5 \frac{MWh}{yr}}$

[1] https://www.metric-conversions.org/weight/short-tons-to-kilograms.htm
[2] https://energyeducation.ca/encyclopedia/Sub-bituminous_coal#:~:text=Sub%2Dbituminous%20coals%20are%20among,coal%20resources%20being%20sub%2Dbituminous.
[3] https://www.unitjuggler.com/convert-energy-from-J-to-MWh.html

b) <u>Nuclear Reactor with Rankine cycle</u>

$\dot{m} = 600\frac{kg}{s}, T_{turbine} = 320\ C, T_{condenser} = 75\ C, \eta = 0.3$

$\Delta W_{pump} = 0$

$\eta = \frac{Work\ done\ by\ turbine}{Heat\ supplied} = \frac{W}{h_3 - h_2}$

To get W, we need h_3& h_2

From steam table:

$h_3 = 2700.1\frac{kJ}{kg}, h_2 = 2635.3\frac{kJ}{kg}\ (Since\ h_2 \sim h_1)$

Power output, $P = 0.3 * (2700.1 - 2635.3)\frac{kJ}{kg} * \dot{m} = 11.664\ MW$

For 1 year, $P = 11.664 * 24 * 365 = \mathbf{1.02 * 10^5 \frac{MWh}{yr}}$

c) <u>Wind Farm</u>

The on-shore site uses Gamesa G11/2000 wind turbines which has the features:

V=7 m/s (Range is 7-7.5 m/s from the readings for class 4), Turbine diameter=114 m

$A = \frac{\pi}{4} * D^2 = 10201\ m^2, P\left(\frac{W}{m^2}\right) = 401.7$

$P(W) = 0.3 * 401.7 * 10201 = 1.227\ MW$

For 25 such turbines, $P(W) = 30.675\ MW$

Thus, for 1 year: $P(W) = 30.675 * 24 * 365 * 0.458 = \mathbf{1.23 * 10^5\ MW}$

d) <u>CSP Station</u>

The area is 85 hectares=$85 * 10^4 m^2$

100 cells occupy an area of 40000 m^2

Thus, 85 hectares can accommodate the following: $100 * \frac{4*10^4}{85*10^4} = 2125\ cells$

Area of solar collection, $A = 2125 * 250 = 5.3 * 10^5 m^2$

Incoming irradiance, $R = A * Rate\ of\ irradiation = 5.3 * 10^5 * 1750 \frac{kWh}{m^2 * year} = 9.2 * \frac{10^5 MWh}{year}$

Collector to grid efficiency, $\eta = 0.15$ [4]

Power output, $P = 0.15 * 9.2 * \frac{10^5 MWh}{year} = \mathbf{1.38 * 10^5 \frac{MWh}{year}}$

[4] Wikipedia, Parabolic trough

e) <u>PV Solar Farm</u>

For the PV Farm, a cell requires 2 m^2 collection area and 2.5 m^2 land area

Number of cells for 85 hectares, $n = \frac{85*10^4}{2.5} = 34 * 10^4 cells$

Area of solar collection, $A = 34 * 10^4 * 2 = 68 * 10^4 m^2$

Efficiency, $\eta = 20.3\%$ [5]

Power output is evaluated in the same way as Part (d).

Power output, $P = 0.203 * 3.4 * 10^5 * 1750 * \frac{10^3}{10^6} = \mathbf{1.207 * 10^5 \frac{MWh}{year}}$

[5] https://www.lg.com/us/business/solar-panels/lg-lg395n2w-v5

f) <u>Ethanol to electricity</u>

Average annual ethanol yield=450 gallons per acre [6]

Total yield per year=450*25000=1.125*10^7 gallons

Energy content=76330 BTU/gallon [7]

Total energy content=76330*1.125*10^7=8.5*10^11

1 BTU= 2.93*10^-7 MWh [8]

Total energy content=2.4*10^5 MWh

General efficiency of natural gas turbine power plant=0.3 [9]

Energy output=0.3*2.4*10^5 MWh=$\mathbf{0.74 * 10^5}\ \boldsymbol{MWh/year}$

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[6] http://www.ethanolproducer.com/articles/3334/miscanthus-versus-switchgrass#:~:text=However%2C%20on%20marginal%20cropland%20in,or%2079%20gallons%20per%20ton.

[7] https://afdc.energy.gov/fuels/fuel_comparison_chart.pdf

[8] https://www.convertunits.com/from/Btu/to/MWh

[9] http://needtoknow.nas.edu/energy/energy-sources/fossil-fuels/natural-gas/#:~:text=A%20gas%2Dfired%20plant%20was,as%20much%20as%2060%25%20efficient.

(ii)

Tabulating the outputs we have:

Option	Additional Generation Capacity (per year in MWh)
Coal Plant Enhancement	8.67*10^5 (maximum)
Nuclear Reactor	1.02*10^5
Wind Farm	1.23*10^5
CSP Station	1.38*10^5
PV Solar Farm	1.21*10^5
Ethanol to Electricity	0.74*10^5

Based on the options put forth, I recommend using **Wind Power** to scale-up the production to meet the requirements of the country's scale-up.

Explanation:

<u>Advantages of Wind:</u> Based on the calculations, wind power is capable of generating satisfactory amount of power every year which would help in catering to the growing needs of power. Another advantage of using wind power is that as the nation is prone to typhoons, using typhoon proof wind turbines could help in alleviating the problem. Further, being renewable it would also help in catering to the environmental needs.

<u>Disadvantages:</u>

1. Coal Plant: Being a fossil fuel and exhaustible, the capacity of the sub-bituminous coal is constant and can barely cater to the need of the nation, considering the current estimates. Assuming that more coal is not found over the years, it would be risky to solely depend on this fuel type.
2. Nuclear Reactor: Based on the proposed specifications, the capacity of the nuclear reactor would not be feasible to cater to the growing needs of the nation. Further scale-up and investment is thus necessary. Moreover, building nuclear is a lengthy and risky process, especially for a nation of this country's scale.
3. CSP Station & PV Farms: As the nation is dependent on agricultural for its GDP, employing these systems for energy production could hamper other aspects which generate GDP.
4. Ethanol: The nation has a limited biomass energy distribution which is mainly used for local heating and cooking. Disrupting this energy distribution would not prove to be feasible for the country.

<u>Disadvantage of using wind power:</u>

The calculations for the wind power here is assuming a maximum and ideal efficiency of 59.3%. However, it is not possible to achieve this extent of energy efficiency and could therefore reduce the amount of energy available. Moreover, construction of wind farms is a lengthy and time-consuming process and thus, rapid infrastructure development is necessary, the absence of which could lead to delayed production of electricity.

2]

a)

Offshore location: Siemens Gamesa SWT-6.0-154

Onshore location: Gamesa G114/2000

From the table in part b, Gamesa G114/2000 does not have an off-shore possibility and thus it must be used for on-shore applications. On the other hand, Gamesa SWT-6.0-154 has an offshore possibility and thus, both of these turbines are appropriate.

b)

Sources: https://www.thewindpower.net/turbine_en_807_siemens_swt-6.0-154.php

https://www.thewindpower.net/turbine_en_860_gamesa_g114-2000.php

Feature	Gamesa SWT-6.0-154	Gamesa G114/2000
Power Rating	6000 kW	2000 kW
Wind Speed	13 m/s	12.5 m/s
Rotor Diameters	154 m	114 m
Possible hub heights	Site specific	80-125 m
Off-shore possibility	Yes	No

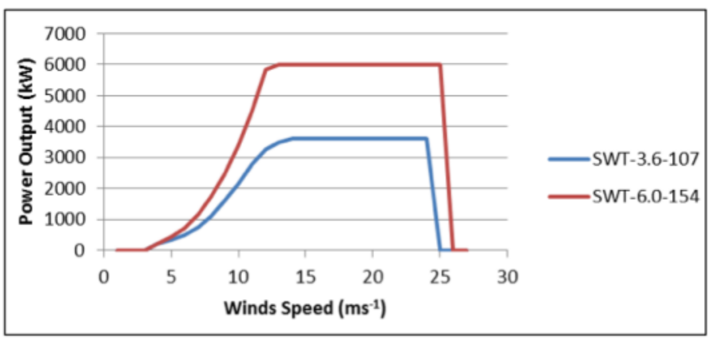

Figure 1: Power Curve for SWT models

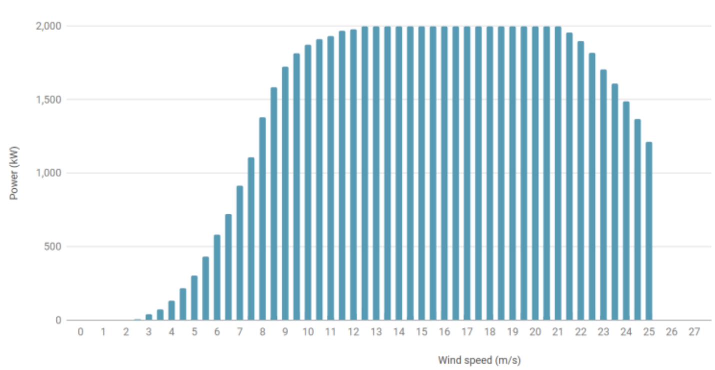

Figure 2: Power curve of G114/2000

c)

Maximum power output can be estimated as:

$P\left(\frac{W}{m^2}\right) = 1.91 * 0.5 * 1.225 * v^3$

$P(W) = E * 1.91 * 0.5 * 1.225 * v^3 * Area\ swept\ by\ the\ turbine$

For SWT model (Offshore_:

V=8.5 m/s (Range is 8-8.8 m/s from the readings for class 6), Turbine diameter=154 m

$A = \frac{\pi}{4} * D^2 = 18627.06\ m^2, P\left(\frac{W}{m^2}\right) = 718.45$

$P(W) = 0.3 * 718.45 * 18627 = \mathbf{4.015\ MW}$

For G114 (Onshore):

V=7 m/s (Range is 7-7.5 m/s from the readings for class 4), Turbine diameter=114 m

$A = \frac{\pi}{4} * D^2 = 10201\ m^2, P\left(\frac{W}{m^2}\right) = 401.7$

$P(W) = 0.3 * 401.7 * 10201 = \mathbf{1.227\ MW}$

d)

Estimating capacity factors:

For SWT (Offshore): $P_{max} = 6\ MW$ (From specification sheets), P=2 MW (From Power curves)

$Capacity\ factor, C = \frac{2}{6} = \mathbf{0.33}$

For G114 (Onshore): $P_{max} = 2\ MW$ (From specification sheets), P=0.917 (From Power curves)

Capacity factor, $C = \frac{0.917}{2} = \mathbf{0.458}$

e) From the calculations in (c), it can be observed that the SWT turbine has a higher power output per hour than the G114/2000 turbine.

f)

$n_{turbines} = \frac{Nameplate\ capacity * Capacity\ Factor}{Power\ per\ turbine}$

For Offshore:

$n_{SWT} = 12 * \frac{0.33}{2} = \mathbf{2\ turbines}$ (For Pilot plant); For future: $n_{SWT} = 2600 * \frac{0.33}{2} = \mathbf{429\ turbines}$

For Onshore:

$n_{G114} = 228 * \frac{0.458}{0.917} = \mathbf{114\ turbines}$

g)

Off-shore:

Life expectancy=20 years

Current discount rate=2.25%

NPV=300 million $

$LCOE = \frac{Total\ annual\ cost}{Total\ annual\ output}$

$P = A * \frac{(i+1)^N - 1}{i(i+1)^N}$

$A = 300 * 10^6 * (0.062) = 18.6\ million\ \$$

$Total\ annual\ output = 12\ MW * 0.33 * 24 * 365 = 34.67 * 10^3\ \frac{MWh}{year}$

$LCOE = \frac{18.6*10^6}{34.67*10^6} = \mathbf{0.54}\ \$/\boldsymbol{kWh}$

h)

Power in 1 month for the offshore plant, $P = 0.33 * 12 * 24 * 30 = 2851.2\ \frac{MWh}{month}$

Number of households,$N = \frac{2851.2*10^3}{1120} \sim \mathbf{2545\ houses}$