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Energy Efficient Thermodynamic Systems for Modern Power Generation Infrastructure and De-Carbonized Economy

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Abstract—*The continuous growth of CO2 concentration creates severe impact on environment. The fossil fuel combustion during power generation is playing key role for this emission. The thermal (coal fired, diesel and natural gas) power generation is greatly contributes in world power generation sector. The power generation technology is now turning towards adaptation of modern infrastructure with super-critical rankine power system, organic rankine cycle (ORC) system for heat recovery and heating-power effect. The alternative refrigeration technology also employ for combined cooling and heating generation. The present paper summarizes the new trends of energy and power generation systems with the integration of renewable energy based combine cooling, heating & power system. The result of proposed study concludes supercritical power generation system can improve 1% thermal efficiency and reduces 2-3% of toxic emission. The alternative refrigeration system produces considerable cooling by utilization of wastage heat of industry and cut the carbon emission.The extensive review outcome of this article well explain modern infrastructure of power plant able to map the de-carbonized economy.*

Keywords: *Supercritical power generation, Alternative refrigeration, Carbon Emission*

1. INTRODUCTION

Energy in one of the most important building blocks in human development, and as such, acts as a key factor for economic development of all the countries. The day by day energy demand for all need of human being, industrial development, transportation sector, all are depend on the power generation. More than 65% world power generation is basically generated from fossil fuel based (thermal power generation) and the one unit of thermal power generation is responsible for 750 gram of carbon discharge into environment [1,2].EPA reported that30% of carbon emission globally accounted from coal fired thermal power plant[2].The alternative technology of power generation, renewable energy resources and the various thermal systems of heat recovery are playing key role for the development of new trends or modern infrastructure of power sector. The concept of super critical rankine (SCR) power cycle is expansion of basic thermal power generation system. The plant operate at above the 230 bar of steam pressure can provide higher thermal efficiency (43%-44%) where as at present thermal power (sub critical rankine power system) only gives 30%-35% of efficiency.[5]. The other supportive pillars of modern power plant is integrated with tri-generation (cooling, heating and power) thermal system like ORC, CCHP (combined cooling heating & power) unit, cogeneration unit and the alternative refrigeration systems for dumped heat recovery of power plant, steel plant, iron-textile industry, petroleum refineries. Cooling systems like vapor absorption, vapor adsorption, steam jet ejector refrigeration, etc are have tremendous capacity for cooling effect without any high grade energy consumption, no toxic emission and no carbon discharge.

2. THERMODYNAMIC SYSTEMS FOR MODERN POWER GENERATION INFRASTRUCTURE.

The energy conversion of steam, fossil fuel, and energy recovery materials for the purpose of power, cooling and heating generation is possible by the integration of thermodynamic systems. The fundamental working principle of all mentioned thermal energy conversion (TEC) system are basically deals mass-energy conservation law, entropy generation principle. The brief detail of TEC are given below sections.

2.1 Super Critical Power Generation System (Clean coal power generation)

The present coal fired thermal power plant is basically working on steam power generation cycle. The rankine power cycle is fundamental concept of steam power generation. The working medium water in terms of steam has higher thermal capacity to produce high pressure and high temperature. The critical pressure and temperature of water is 221 bar and 374.15 ^{0}C respectively. When the boiler of power plant is operate at critical state of water, the latent heat of conversion during steam formation is zero, so highly pressurized water directly convert into superheated steam. The thermal power plants are currently designed to operate on the supercritical Rankine cycle (i.e. with steam pressures exceeding the critical pressure of water 22.1 MPa, and turbine inlet temperatures exceeding 600 °C. The present thermal power plants are working normally below critical stage of water, and its called subcritical power cycle (SPC). The Fig. 1 T-S plot of both cycle have shown.

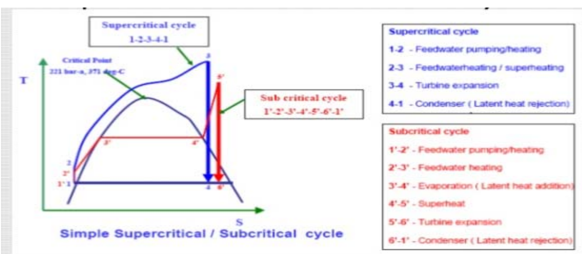

Fig. 1: Supercritical and Subcritical Power Cycle.[4]

Supercritical fossil fuel power plants, have efficiencies around **43%**. Most efficient and also very complex coal-fired power plants that are operated at **"ultra critical" pressures** (i.e. around 30 MPa) and use multiple stage reheat reach about **48%** efficiency [5].The subcritical thermal power plant have maximum efficiency about 30-34%, and consumes more coal as compare to super or ultra critical power generation.

How to reduce emission from super & ultra critical power generation technology.

For typical "low-sulphur" coal containing 0.5 per cent of sulphur when fed into the boiler, every tonne of coal will contain 5 kilograms of sulphur. When burnt, this sulphur turns into 10 kilograms (kg) of SO2. (Every sulphur atom joins with two oxygen atoms to produce one SO2 molecule which is twice as heavy as a sulphur atom [6]

If we consider 1000 MW of power generation with x ton of fuel consumption for steam production and consider best calorific value (cv) 5500 KJ/KG of coal as fuel.

Thermal Efficiency (η_th) = Power Output/ Heat of fuel Consumption

Heat of fuel consumption- x kg of coal * cv of coal

<u>For subcritical power generation-</u>

Consider maximum η_th = 38%

So, coal consumption = 410 Tonn/ hour

And SO2 emission = 4100 tonn (01 tonn of coal generate 10 kg of SO2 during coal combustion)

<u>For supercritical power generation-</u>

Consider maximum η_th = 44%

So, coal consumption = 350 Tonn/ hour

And SO2 emission = 3500 tonn (01 tonn of coal generate 10 kg of SO2 during coal combustion)

That means 14% of reduction in coal consumtion and as well as SO2 or NO2 emission.

The national thermal power corporation (NTPC) has commissioned the super & ultra critical thermal power plant. NTPC reported that 18980 MW (11.35% of total thermal power generation) of electrical power generation by the NTPC itself [3].The summary of Indian power sector of SPC is available as following-

Operating condition and efficiency[3]-

Steam temp : 540 Deg.C

Steam Pres: 256 kg/cm2

Re-Heater pressure : 51.6 kg/cm2

Re-Heater Temp : 568 ^{0}C

Feed water Temp : 291 ^{0}C

Efficiency Comparison

CAPACITY	500 MW	660 MW	800 MW
BOILER EFFICIENCY (%)	85.61	86.27	86.33
TURBINE HEAT RATE (kCal/kWh)	1944.4	1904	1826
PLANT HEAT RATE (kCal/kWh)	2271.23	2207.02	2115.13
PLANT EFFICIENCY (%)	33.78	38.96	40.68

Fig. 2: SPC efficiencies [3]

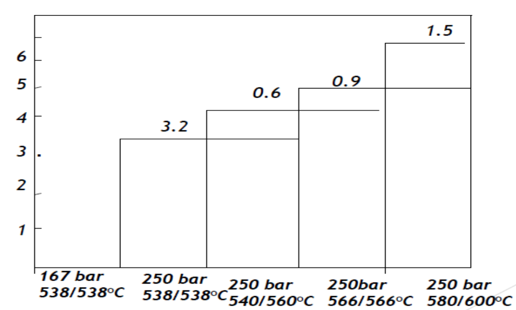

Fig. 3: Efficiency increment with high operating pressure[3]

State	Station	Capacity
Bihar	Barh (NTPC) #4	660
	Barh (NTPC) #5	660
Chattisgarh	Sipat (NTPC) #1	660
	Sipat (NTPC) #2	660
	Sipat (NTPC) #3	660
Maharashtra	Koradi #8	660
	Tirora TPP(Phase 1) #1	660
	Tirora TPP(Phase 1) #2	660
	Tirora TPP(Phase2) #1	660
	Tirora TPP(Phase2) #2	660
	Tirora TPP(Phase2) # 3	660
Andhra Pradesh	Painampuram TPP #1	660
Gujrat	Mundra UMPP #3	800
	Mundra UMPP#4	800
	Mundra UMPP#5	800

State	Station	Capacity	Date of Commissioning
Punjab	Rajpura TPP#1	700	24.01.2014
	Rajpura TPP#2	700	06.07.2014
	Talwandi Sabo TPP #1	660	17.06.2014
Madhya Pradesh	Sasan UMPP #1	660	21.05.2014
	Sasan UMPP #4	660	25.03.2014
	Sasan UMPP #5	660	24.08.2014
	Sasan UMPP #6	660	19.03.2015
	Nigri TPP #1	660	29.08.2014
	Nigri TPP #1	660	17.02.2015
Rajastan	Kawai TPP #1	660	28.05.2013
	Kawai TPP #2	660	24.12.2013
Haryana	Jajjar TPP #1	660	11.04.2012
	Jajjar TPP #2	660	

Fig. 4: Existing SPC generation in India[3[

The efficiency of SPC depends of higher operating pressure, highly pressurized superheated steam carry large amount of heat which cause the higher temperature and pressure at the inlet of steam turbine. That higher order of operating condition provide maximum output in terms of turbine work and further electrical power generation.Fig2&3 are showing the SPC efficiencies with the variation of operating pressure & temperature.Fog-4 listed the existing SPC power generation in India.

2.2 Combined Heating-Power Generation Systems-

The concept of combined heat and power (CHP) Cogeneration or is use to generate electricity and useful heat or process heat of plant at the same time through coupling of two different power cycles like gas turbine (Brayton power cycle) and steam turbine systems (Rankine power cycle). In power generation,the production of electricity, some energy must be discarded as waste heat, but in cogeneration this thermal energy is put to use. The authors have reviewed a number of combined energy production plants operating globally. They Analyzed different schemes of combined energy production including different cooling and engine technologies [7-8]. BEE summarized the popularity of topping and bottoming cycle concept of co-generation system which are suitable for heat utilisation at high temperature in furnaces and kilns, and reject heat at significantly high temperatures. Typical areas of application include cement, steel, ceramic, gas and petrochemical industries. The waste gases coming out of the furnace is utilized in a boiler to generate steam, which drives the turbine to produce electricity.[9-10].Another study of GT-ST analysis investigated for different combustible natural gas combustion at operating condition of gas compression ratio, GT inlet pressure and temperature. Five fuel gases (methane, ethane, propane, octane & petane) have been tested and methane has considerable output for higher temperature operation and give maximum olant efficiency [11]. Fig. 5 shows the concept of combined GT-ST power generation .

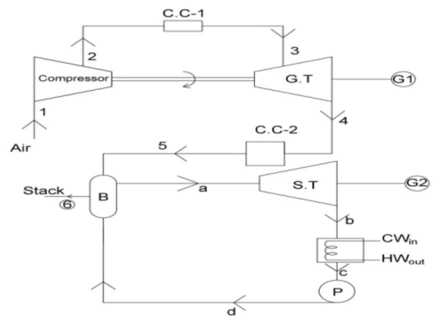

Fig. 5: Combined GT-ST power generation system[11]

2.3 Tri-Generation System (combined cooling, heating & power generation) –

Tri-generation technology provide simultaneously three forms of output of energy; electrical power, heating and cooling. Tri-generation is also known as CCHP (Combined Cooling, Heating and Power) or CHRP (Combined Heating, Refrigeration and Power). In essence, tri-generation systems are CHP (Combined Heat and Power) or co-generation systems, integrated with a thermally driven refrigeration system to provide cooling as well as electrical power and heating. Tri-generation systems can have overall efficiencies as high as 90% compared to 33%-35% for electricity generated in central power plants. [9,12].Fig. 6 explain the lauout of tri-generation unit.

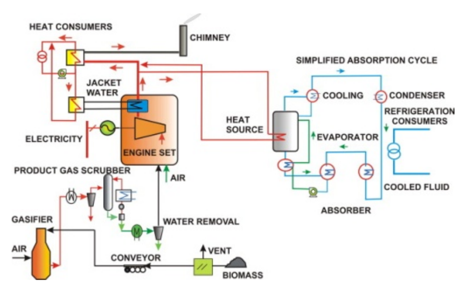

Fig. 6: Biogas operated components and layout of Tri-generation system [13]

2.4 Organic Rankine Thermal System (ORC)

The ORC applies the principle of the steam Rankine cycle, but uses organic working fluid with low boiling points, instead of steam, to recover heat from a lower temperature source. Organic Rankine Cycle is a power generation Plant; on a mini-scale; typically in the range of 10 to 250 kW. The main differences between the large thermal power plants which operate on conventional steam based Rankine cycle and ORC are working fluid is an Organic fluid typically a refrigerants.[14]

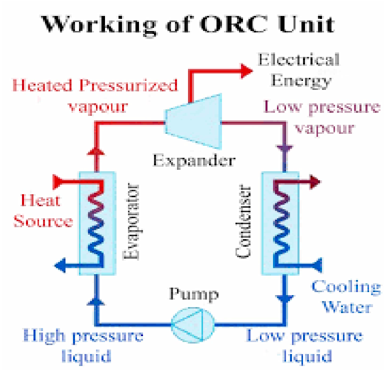

Fig. 7: Components of ORC [14]

2.5 Binary Fluid Power System (Kalina Thermal System)

The another thermal system is very popular in modern energy sector, combined power and cooling generation. The heat discharge through the plan, heavy industry or heavy engineering works are not in use, so the kalian model of combined effect of power and cooling has considerable potential for power and refrigeration effect. The out of this system is small but very efficient for utilization of waste heat [15].

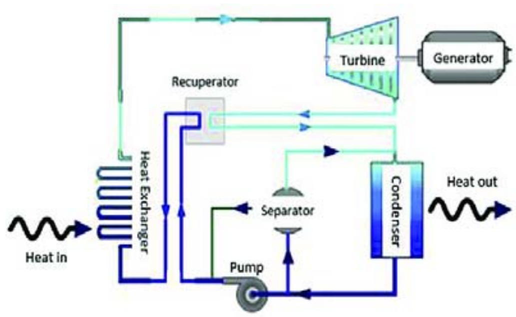

Fig. 8: Combined cooling and power generation system-Kalina Model [15]

2.6 Alternative and energy efficient refrigeration system

In this context the opportunities of alternative refrigeration technology playing key role for heat recovery and as well as valuable cooling effect for space cooling, food preservation, water chiller, etc. Vapour absorption& adsorption refrigeration system (VARS &VAdRS), vapour jet ejector refrigeration system (VJER). All these system does not require high grade energy (electrical power supply), its operate by using plant unused heat. The generator part of these system only require heat source, it may be discharged steam , flue gases, hot air, hot water, and the temperature variation for this only 50 ^{0}C-250^{0}C [16].

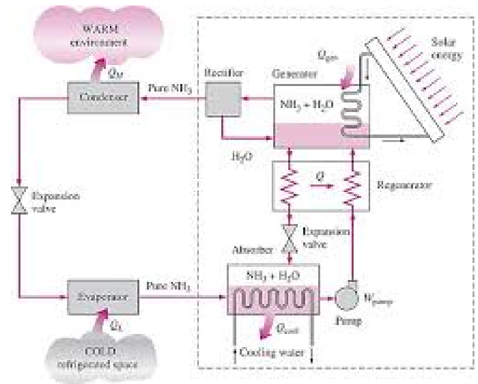

Fig. 9: Vapour absorption refrigeration system [19]

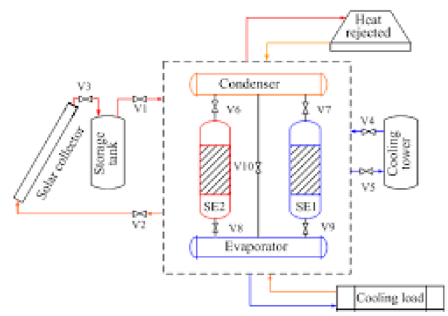

Fig. 10: Vapour adsorption refrigeration system [17]

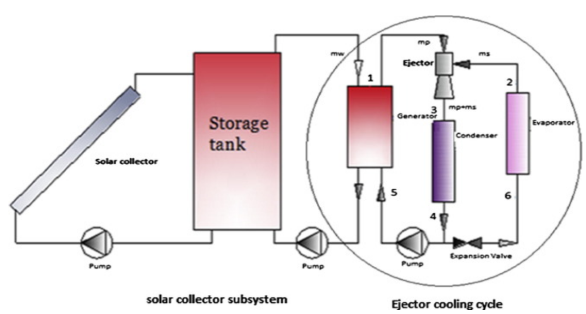

Fig. 11: Vapour ejector refrigeration system [18]

All above mentioned refrigeration units are basically integrated with solar thermal energy source and the working medium for cooling effect is libr-h2o/h2o-nh3 solution in VARS,Fig. 9, the activated carbon with eco-friendly refrigerants use in VAdRS, Fig. 10 and steam utilize in VJERS, Fig. 11. The very common observations of all above systems are well accepted for heat recovery purpose and zero carbon emission. The generator of this system directly operated with discharge heat of plant. The cooling capacity of these system varies from 03 ton to 50 ton generally, but multi staging of system as per availability of heat source, cooling effect may increases. This valuable cooling may replace the conventional refrigeration called vapour compression refrigeration system (VCRS).The VCRS always consumes high grade energy power and also responsible for carbon emission , ozone depletion and GHG emission [16].

Table 1: Comparison of carbon emission from VCRS & VARS (At 01 ton cooling effect)

Energy and Carbon Emission Estimation			
S. No.	**Energy Saving & Carbon Emission Parameters**	**Conventional VCRS Cooling System**	**VARS Cooling system**
1	Energy consumption (08 hrs daily)	08×01×1.5=12 unit daily	No electricity is required (only heat source like, hot air, steam or solar heating are required)
2	Carbon Emission (daily and yearly	Carbon Emission Estimation [As per EPA – 707g of CO_2 per unit] 12 unit ×750 grams =09 Kg of CO2 daily = 3.2 Ton of CO2 in one year	No emission (GWP and ODP values are much low)
3	Cost of Energy Saving (Daily and yearly)	No	12 unit × 20 INR =240 INR=3.5 USD daily or 1150 USD yearly (commercial tariff of electricity as per BSES,01 UNIT =20INR)[16]
4	Cost of Carbon emission saving	no	3.2 T CO2 × 20 USD= 64 USD yearly (The possible Cost of TCO2 globally is about 20 USD/TCO2 as per World Bank data).
5	Totalsaving (energy saving with carbon emission)	More energy consumption with more carbon emission	Yearly 1210 USD saving is possible.

3. CONCLUSIONS-

The current infrastructure of thermal power generation is mostly depends on the traditional power generation. The integration of different thermal systems with old age power plant can help to enhance the efficiency, decreases the toxic emissions and able to map the decarbonized economy. The highlights of present study have mentioned in following points-

1-Super critical or ultra critical power generation is 1-2 % more efficient than conventional thermal power generation, and reduces the 14-15% of NOx-SOx emission as well.

2-Trigeneration systems can have overall efficiencies as high as 90% compared to 33%-35% for electricity generated in central power plants.

3-The ORC and Kalina system helps to recover the dumped energy and produces simultaneously heating, power and cooling effect with small and considerable amount. These system able to enhance 1-2 % of overall efficiency of plant.

4-The employment of LiBr-H_2O/NH3-H2O based eco-friendly and less energy consumption vapour absorption refrigeration or other alternative systems integrated with the any massive infrastructure of industry and able to generate valuable cooling effect by utilization of uncover heat of plant. These systems can replace the conventional refrigeration system and able to save energy, earn carbon economy additionally with no harm-full emission.Table-1 explain the carbon and energy saving by the alternative refrigeration.

5-The overall study about all possible thermal technology always support and act as re-powering to old age or conventional power plants. The integration of all these systems enhance the efficiency by 1-2% not much higher but able to generate multiple effect of energy like power, heating and cooling. The waste heat recovery is most important concern in this title because the unused energy can be utilize and provide the strength to attached plant.

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REFERENCES

1.Ministry of Power, Government of India, Annual Report 2017-18 & 218-19 (www.powermin.nic.in).

2. https://www.epa.gov/energy, EPA(2018)AVERT,US national weighted average CO2 marginal emission rate, year 2017 data,EPA, Washington, DC.

3 https://www.power-technology.com/features/feature-the-top-10-biggest-thermal-power-plants-in-india/

4.https://www.sciencedirect.com/book/9780081008041/fundamentals-and-applications-of-supercritical-carbon-dioxide-sco2-based-power-cycles.

5.https://www.nuclear-power.net/nuclear engineering/thermodynamics/thermodynamic-cycles/rankine-cycle-steam-turbine-cycle/supercritical-rankine-cycle

6 https://energypost.eu/how-much-do-ultra-supercritical-coal-plants-really-reduce-air-pollution/

[7] E. Bazques, D. Strom, Cogeneration and interconnection technologies for industrial and commercial use, in:Proceedings of 18th IECEC American Institute of Chemical Engineers, 1983, pp. 2060–2065.

[8] G.G. Maidment, R.M. Tozer, Combined cooling heat and power in supermarkets, Applied Thermal Engineering22 (2002) 653–665.

[9]https://beeindia.gov.in/sites/default/files/2Ch8.pdf

[10]Yunus A. Cengel, Michael A. Boles, Thermodynamics: An Engineering Approach, 4th edition,McGraw-Hill, 2002.

[11] Kaushalendra.Kr Dubey,R.S.Mishra Statistical Analysis for Parametric optimization of Gas Turbine-Steam Turbine Combined Power Cycle with Different Natural Gas Combustion, International Journal of Recent Technology and Engineering (IJRTE),Volume-8 Issue-3\4, November 2019.

[12]*Renewable Energy Institute*: Trigeneration Technologies Available. [online], [cited: June 2011], Available on internet< http://www.trigeneration.com

[13]https://www.sciencedirect.com/science/article/pii/S0196890411000574

[14]https://contest.techbriefs.com/2016/entries/sustainable-technologies/6990 .

[15] https://www.researchgate.net/figure/Configuration-of-a-Kalina-cycle-consisting-a-Recuperator-and-Separator-103_fig16_324811679.

[16] Kaushalendra.Kr Dubey, R.S.Mishra, Solar Integrated Combined Cooling-Power Generation Systems for Waste Heat Recovery Using Different Energy Efficient Materials Special Issue of international journal of digital signals and smart systems 2020,Indersciencehttps://www.inderscience.com/info/ingeneral/forthcoming.php?jcode=ijdsss

[17]https://www.sciencedirect.com/science/article/pii/S0196890415004574.

[18]http://www.pvamu.edu/aam/wpcontent/uploads/sites/182/2016/12/05_Rouf_AAM_Special_Issue_02_Posted_05192016_R.pdf.

[19]https://www.ijareeie.com/upload/april/12_Performance.pdf