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Integration of concentrating solar power in cane-based sugar cogenerating plants- a strategic energy option for India

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The presently tapped potential for cogeneration from sugar plants in Indiain India is very low (4.8 GW). There is the good untapped potential of around 10 GW from the sugar sector besides opportunities for enhancing the annual plant load factor (PLF) during the off-season phase. The use of Concentrating Solar Thermal power (CST) in the Indian power sector is gaining importance since 2014 as the linear parabolic trough technology is now available. A number of plants based on CST have been established in Rajasthan and Tamil Nadu. In this paper, the integration of CST plants with sugar based cogeneration plants (where the PLF is limited by the availability of bagasse) is presented in view of the great strategic importance of this combination which does not need the power block for CST and enhances the capacity utilization of sugar mills. By the introduction of CST, during the crushing seasons there is saving in bagasse and during the offseason, generation is ensured. On the overall, by the use of CST, the annual PLF can be increased from 69 % to 77 %.

Key words: *Renewable power, concentrating solar power, cane based cogeneration, sugar mills.*

1. INTRODUCTION

Indian cogeneration and Combined Heat and Power (CHP) is quite different from countries in the temperate and polar zones where space heating is the predominant thermal energy requirement. In India, CHP is for industrial process applications. In Indian conditions, in many cases, power is a by product and not heat unlike in cold countries.

The size of the Captive Power Plants (CPP) sector is around 47 GW. Individual unit wise normative electric capacities are 10-20 MW for bagasse and biomass based cogeneration, 10-100 MW for fuel gas-based cogeneration,10-150 MW for natural gas-based cogeneration and 10-100 MW for other miscellaneous systems. Technology wise the steam based cogeneration accounts for 80 % of the potential. Gas turbine – combined cycle based cogeneration accounts for 15 % and others 5 %. Fuels and source wise bagasse and biomass account for 8 %, flue gasses account for 75 %, natural gas (CNG, LNG, R-LNG) account for 10 % and others account for 7 %. The nominal boiler efficiency for bagasse and biomass is 86 %, flue gasses 80 %, natural gas 90 %, and coal 87 %.

The present (2016) tapped the potential of the Combined Heat and Power (CHP)is around 43 GW of which cogeneration from sugar plants is very low (4.8 GW) [1]. Sugar CHP is an important route of renewable energy utilization through the biomass (bagasse)-steam-power route. The CHP potential in the sugar sector needs to be assessed in the light of the state of the art power generating technology and energy efficiency. In 2010, the potential had been assessed by various agencies

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in the range of 5 GW. The actual achievement in 2013 was is 1.7 GW. The annual sugarcane production (sugar plus Bhandari plus jaggery) is in the range of 280 to 320 million tonnes of cane for 2015. The expected sugar production is in the range of 29-30 million tonnes. The cane to sugar yield or recovery rate is 0.112 p.u. (11.2 %). There are 750 sugar mills with crushing capacity in the range of 500 to 15000 tonne scrushing per day (tcd). Typical sizes are 2500 tcd and 5000 tcd. The national capacity is almost 1 million tcd. There is the good untapped potential of around 10 GW from the sugar sector. The optimal level of turbo-generator size is 8+ MW per 1000 tcd (tonnes crushing per day) capacity [2,3], which is ideal for energy efficient cogeneration projects. This is in contrast with present values of 3-5 MW per 1000 tcd in most sugar mills. Assuming 8 MW per 1000 tcd, the potential could be 10 GW [1]. The annual PLF {energy generated/ (8760 x unit capacity)} of the plants are expected to be in the range of 50-70 %. The expected PLF of the plants during the sugar season is 80+ %.

Most sugar plants are run by cooperatives (50 %) or privately owned (44 %) and there are serious resource constraints and technology gaps in modernization as compared to the full-fledged organized utility power sector. Their boilers and turbines, as well as instrumentation and automation levels, are sub optimal and required to be upgraded in capability as well as volume. This paper highlights the integration of solar thermal power into conventional sugar based cogenerating plants for improving energy efficiency and plant load factor.

Table 1 gives a comparison of three competing generation technology options for powering sugar mills: Solar Photo Voltaic (SPV), CST and wind power based on the present approved capital costs of Central Energy Regulatory Commission, New Delhi [4]. While SPV does not have any water requirement, it cannot be directly integrated into the process. SPV and wind power can be grid integrated with power from the sugar mill. Better overall conversion efficiencies can be obtained by integrating CST with the sugar process.

TABLE 1

A COMPARISON OF SOLAR PV, CST, AND WIND POWER

SL. NO.	PARTICULAR	UNITS	SPV	CSP	WIND
1	Min PLF (also called as CF)	%	16	14	18
2	Max PLF (also called as CF)	%	20	22	53
3	Minimum size	MW	0.005	1	1
4	Maximum size	MW	20	50	100
5	Min energy efficiency	%	10	8	20
6	Max energy efficiency	%	18	16	30
7	Capital cost	Rs. L/ kW	0.5	1.2	0.6
8	Capital cost	Rs. Cr/ MW	5	12	6
9	Capital cost	Rs./W	500	1200	600
10	Max generation	kW/m^2	0.15	0.1	3.125
11	Max generation	MW/ha	1.5	1	31.25
12	Max generation	MW/ acre	0.6	0.4	12.5
13	Max generation	GW/ km^2	0.15	0.1	3.125
14	Theoretical Land	ha/MW	0.7	1.0	0.03
15	Actual land use	ha/MW	2.0	3.0	1.60
16	Efficiency of land use	%	33.3	33.3	2.0
17	Actual generation	kW/m^2	0.05	0.03	0.063
18	Actual generation	MW/ha	0.5	0.33	0.625
19	Actual generation	MW/ acre	0.2	0.13	0.25
20	Actual generation	GW/ km^2	0.05	0.03	0.063

To relate the integration of CST with sugar plants, a brief overview of both systems are given below.

2.0 CONCENTRATING SOLAR THERMAL (CST) COLLECTORS

Concentrating Solar Thermal (CST) based power generation through the steam cycle has now become technically viable. The generation potential is 0.60 MW/ha or 1.66 ha/MW of power. The capital cost as approved by the Central Energy Regulatory Commission (CERC) order of

2016 is Rs. 12.0 Cr/MW as compared to Rs. 5.0 Cr/MW for solar photovoltaic. The size of CST power plants ranges from 1 MW up to 50 MW for Indian conditions.

Since 2014, in India, the concentrating solar thermal collector technology is becoming increasingly viable. Power generation on the basis of CST collectors has not only been demonstrated but also being adopted in several new projects as an alternative to the solar photovoltaic (SPV) systems. The approximate installed capacity is 0.47 GW.

The integration of CST to cane based cogenerating power plants of sugar mills is of great strategic value to the power sector because on one hand the investment in the power block (boiler-turbine-generator-condenser) can be totally avoided and on the other hand the plant capacity utilization factor of the sugar power plant can be considerably enhanced.

The minimum temperature in CST collectors is 200 ºC. The limiting (maximum) concentration achievable for linear collectors is 46,211 and the maximum temperature achievable is the 5500 ºC. The concentrating collector technologies are the circular parabolic dish, linear parabolic trough, Fresnel's reflectors and central towers. Of these, the most proven collectors for power generation at the MW level are the linear parabolic trough collectors. The linear parabolic troughs with concentration ratios of around 10-20 give good efficiency. Both the reflector trough and receiver tube material are based on selective absorption technologies to maximize the heat transmission. Reflective mirror films (spectral reflectivity > 94 %) are used for the collector and collector tubes with absorption efficiency greater than 90 % are used.

The rim angle of the troughs (ψ) is given in terms of aperture (a) and focal length (f) by,

$$\psi = tan^{-1}\left[\frac{(\frac{a}{f})}{2-(\frac{1}{8})(\frac{a}{f})^2}\right] \quad ...(1)$$

Typical collectors have aperture width of 6 m, the focal length of 1.75 m, module length of 14 m and absorber tube diameter of 90 mm.

Concentrating trough collectors are controlled by the non-linear Hottel-Whillier-Bliss (HWB) equation. The HWB equation is for determining the collector efficiency. On the other hand, the upper bound of the efficiency of conversion of steam into electric power is governed by the Carnot efficiency.

The collector efficiency (-) is given by,

$$\eta = \left(F'(\tau\alpha)\right) - \left(\frac{C_1(T_f - T_a)}{I}\right) - \left(\frac{C_2(T_f - T_a)^2}{I^2}\right) \quad ...(2)$$

Where F' is the collector efficiency factor (-), $(\tau\alpha)$ is the optical efficiency (-), I is the solar incident radiation (W/m^2), T_f is the fluid temperature, T_a is the ambient temperature and C_1 and C_2 are constants of the top losses of the collector. Equation (1) is the nonlinear form of the HWB equation since the top losses are nonlinear.

The overall efficiency of the solar energy to power process is given by the product of the collector efficiency and the Carnot efficiency. Hence, when the cycle efficiency increases with temperature, the CST efficiency decreases with temperature (See Figures 1-2). The designs must ensure that the efficiency does not drop drastically with temperatures of 200-500 °C.

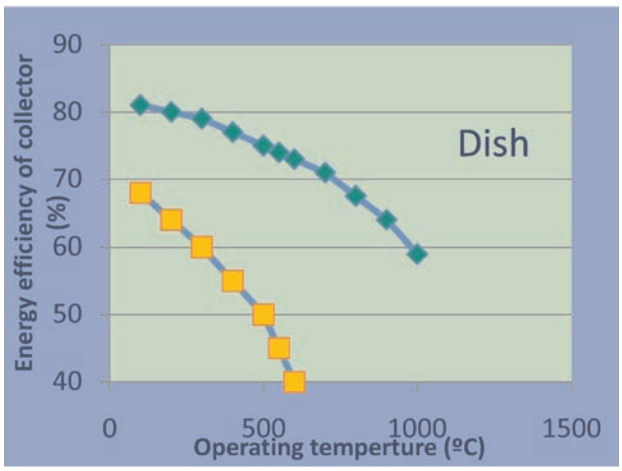

FIG. 1. CONCENTRATING COLLECTOR EFFICIENCY

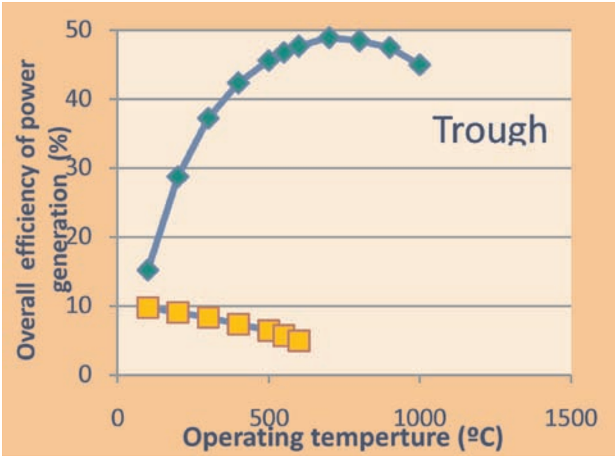

FIG. 2. OVERALL SOLAR CONCENTRATING POWER PLANT EFFICIENCY

The operating efficiencies and energy yields of the CST collectors are primarily dependent on cloud and fog cover; and collector cleanliness factors. The incident solar radiation can be divided into three sections-summers, winter and rainy seasons. To maintain clean receiver surfaces, mechanical cleaning systems have to be in place.

The importance of stochastic losses occurs because many designers provide guaranteed energy based on apercentage of actual incident energy received. The actual incident energy is stochastic while maximum incident energy generated in a given location is deterministic. Firm performance guarantees are not provided and instead the guarantees are given as a percentage of the actual incident energy. If the stochastic efficiency is quantified and bound by predefined limits, the firm performance guarantees can be provided as the maximum radiation levels are deterministic. In other words, if the stochastic element is quantified as a percentage of the maximum value (deterministic), then the errors will be largely reduced.

Stochastic efficiency is given by,

$$\eta_{Stochastic} = \left(\frac{E_{actual\ incident\ solar\ radiation}}{E_{maximum\ incident\ solar\ radiation}}\right)_{year} \quad \ldots(3)$$

Stochastic losses are quantified and indicated but not possible to be controlled or reduced. Though uncontrollable, the quantification of stochastic losses is essential in arriving at the maximum possible generation from a given site over the year form providing performance guarantee and to decouple this from the system (non-module) losses.

The annual solar radiation (kW/m^2) data which represents the global radiation (sum of the diffused and direct components) is compiled as hourly average values for 12 points (0600 to 1800 hours) averaged over the month (for each given hour) for 35 years (1977-2015) (for each month). In all, each set and grand average of the annual data can be represented by 144 values (12 daily values averaged over the month for 33 years x 12 months).

Considering the energy yield the operational year can be divided into three distinct phases:

- Summer season
- Monsoon (rainy) season
- Winter season

Stochastic efficiency can lead to reduced generation by 6-16 % depending on the region. By quantifying the stochastic efficiency, the minimum guaranteed heat output from a collector (Gcal/year) must be specified to ensure that the performance does not go below a guaranteed limit taking into consideration all factors leading to losses.

3.0 CANE BASED SUGAR PLANTS

3.1 State of the art and technological issues

Figure 3 gives a schematic of the main power block of the sugar mill.

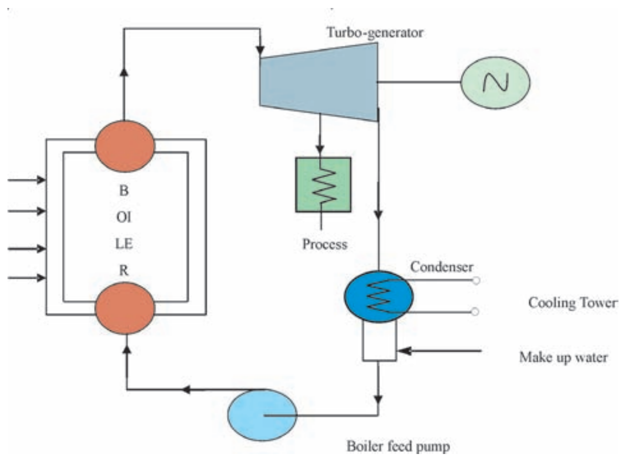

FIG. 3. VIEW OF THE POWER BLOCK OF THE SUGAR MILL

The technology issues with sugar based cogenerating plants are:

- Power to capacity in Indian sugar cogenerating plants are quite low (around 3-5 MW per 1000 tcd).
- Operating steam parameters are inferior to the market best.
- The design of the power block (boiler-turbine-generator) is of vintage technology.
- Levels of automation and associated controls and instrumentation are inadequate for optimal operation.

The power to capacity ratio needs to be improved to over 8 MW per 1000 tcd for optimal steam generation from sugar plants.

Present sugar plants are using steam parameters of 8.9 MPa and 510 ºC which is inadequate. Many plants are using even poorer parameters such as 6.9 MPa and 490º C, etc. State of the art values would be 11.0 MPa and 550º C (standard temperature pressure steam parameters are shown in Figure 4). This would involve replacement of the boiler by a high pressure boiler [5], maintaining stringent water quality, installing controls and instrumentation for high pressure systems and introduction of operational and maintenance practices to suit the boiler. A high level of process automation and operator skill is required. The boiler efficiency and turbo-generator efficiencies must be maintained at high levels. Moisture reduction in fuel can increase energy conversion efficiency in the boiler. Feed water quality plays a major role in the performance.

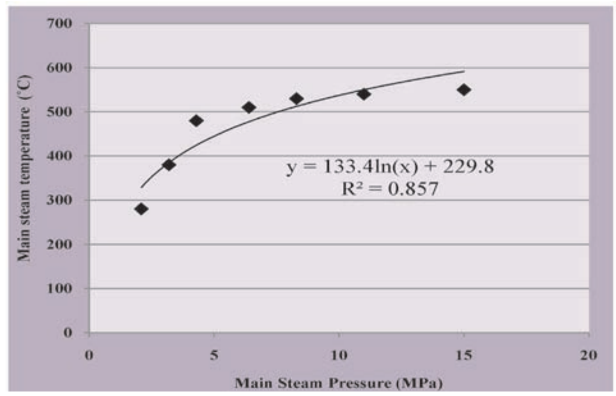

FIG. 4. STANDARD TEMPERATURE, PRESSURE STEAM PARAMETERS USED IN COMMERCIAL STEAMING POWER BOILERS

In most sugar mills, the main power converters of the power block, viz., and the turbo generators are of anobsolete and outdated design and consume far too much higher steam to generate unit power. Installation of state the art impulse-reaction stage optimized steam turbines with 3-d designed blading which give is entropic efficiencies of the order of 92-94+ % is essential.

The PLF in the context of sugar consists of three phases- sugar season (160-210 days), off season (60-110 days) and dry period (rest of the year). The PLF would depend on the size of the turbo-generator and its energy efficiency. The turbo-generator must be able to accommodate maximum power generation during the sugar season. If there is are duction in steam demand it must have the additional margin for a generation. Also if the energy efficiency of the turbine is increased by steam path improvements, the additional margin must be available. The boiler, on the other hand, must be designed to provide good turbine load ability at the minimum energy efficiency of the turbo-generator and under maximum internal steam demand condition. During the off season, the turbine load ability would be low leading to low PLF. The annual PLF would consider all the three periods.

Sugar automation includes power plant automation which is composed of the following components:

- Boiler and boiler auxiliaries
- Turbo-generator and turbine auxiliaries
- Milling system
- Auxiliary electrical network

The automation through distributed control system (DCS) would include parameter monitoring, performance monitoring, and condition monitoring to achieve surveillance as well as energy efficiency and equipment health status. Equipment safety against catastrophic/end life failures and against continual accelerated degradation is greatly enhanced by the power process automation. Some of the essential requirements of sugar automation are:

- Open architecture
- Data highways of sufficient size for future capacity addition.
- Smart primary sensors
- Field instruments to be intelligent with remote communication interfaces.
- Sequence of event recording
- Performance trend indicator and optimizer
- Condition monitoring systems

The power block and sugar process automation will result in reduced auxiliary steam consumption and increased energy efficiency of turbo-generator. Control of inhabitation water flow, mill speed control, juice level (Calendria level) control, temperature control in molasses conditioning, melt temperature control, the negative pressure at filtration process, lime flow rate control set to juice flow rate, etc., result in the high energy efficiency of the process. The above automation issues have to be addressed if energy efficiency is to be increased.

The Key Performance Indices (KPI) [2] of a sugar based power plant are as follows:

i. Gross electric generation (capacity) (p_{gross}) [(kWh_{gross}/t of cane)≡24 x (MW/1000 tcd)]

ii. Net electric generation (p_{net}) (kWh_{net}/t of cane)

iii. Net unit heat rate (UHR) (kcal/kWh) [=860 x 100/(efficiency in %)]

iv. Unit CHP efficiency (η_{chp}) (%)

v. Plant load factor (PLF) (%)

vi. Power to heat ratio of overall plant (PHR) (dimensionless ratio)

All these KPI need to be maximized for achieving high energy efficiency.

The indicators of internal consumption are:

i. Process and auxiliary power demand (kWh/t of cane)

ii. Process and auxiliary steam demand (kg/t of cane)

The internal consumption needs to minimized for maximization of the KPI [6].

Table 2 gives the normative values of turbo generator capacity of sugar based CHP plants and Table 3 gives the KPI and internal consumption indicators.

TABLE 2

NORMATIVE VALUES OF TURBO GENERATOR CAPACITY OF SUGAR BASED CHP PLANTS IN INDIA

Sl. No.	**Particular**	**Capacity (India) (MW per 1000 tcd)**
01	Best practice and above average	>8
02	Average value	7.5
03	Below average	7
04	Poor	< 6

TABLE 3					
NORMATIVE VALUES OF KPI AND INTERNAL CONSUMPTION INDICATORS					
Sl. No.	**KPI and internal indicators**	**Units**	**Above average values**	**Average values**	**Below average values**
01	Net electric generation	kWh/t of cane	150-200	150	<150
02	Unit Heat Rate (UHR)	kcal/kWh	3500-4000	4100-5000	5100-6000
03	Unit CHP efficiency	%	>50	45-50	<45
04	Plant Load Factor (PLF)	%			
05	Power to Heat Ratio of overall plant (PHR)	-	0.8-0.2	0.16-0.12	<0.1
06	Process and auxiliary power demand	kWh/t of cane	<20	21-32	>32
07	Process and auxiliary steam demand	kg/t of cane	<200	200-300	>300
08	Water consumption	l/kg of cane	0.40	0.41-0.60	0.61-1.0
09	Total manpower	Persons per 1000 tcd*	<15	16-20	21-30

*tcd: tonnes crushing per day

Figure 5 gives the sizes of few of the existing turbines in sugar plants vis-à-vis their crushing capacity. The most common existing capacity is 5000 tcd and the average net power in present usage is in the range of 3 to 5 MW/1000 tcd.

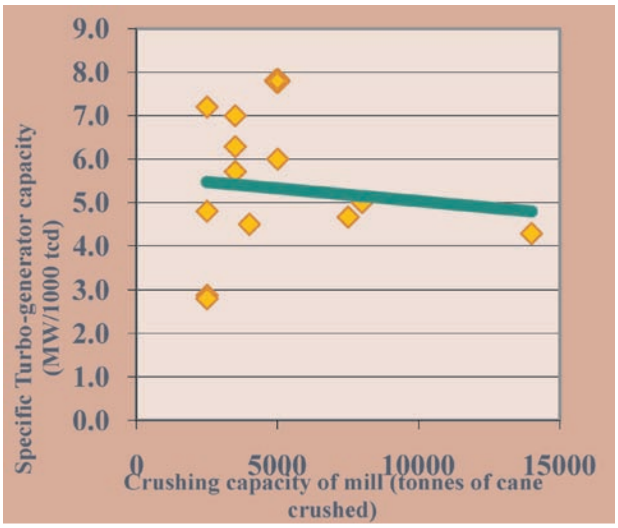

FIG. 5. TURBO-GENERATOR CAPACITY (MW) PER 1000 TONNES OF CANE CRUSHED

Figure 6 gives the effect of power to heat ratio on overall efficiency. As the power to heat ratio increases, the overall efficiency decreases because the electrical conversion efficiency is 35-45 % while steam conversion efficiency is as high as 85-92 %.

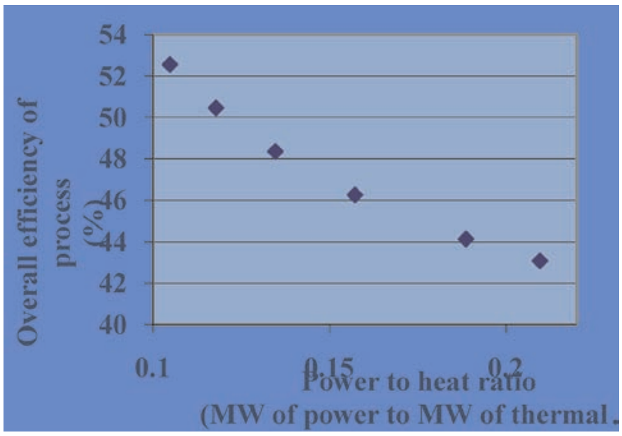

FIG. 6. OVERALL EFFICIENCY OF THE PROCESS (%).

Figure 7 gives the net heat rate (kcal/kWh) (inversely proportional to energy efficiency) with increased captive steam consumption. It is seen that when the captive steam increases the overall efficiency decreases and hence the net steam consumption of the plant increases.

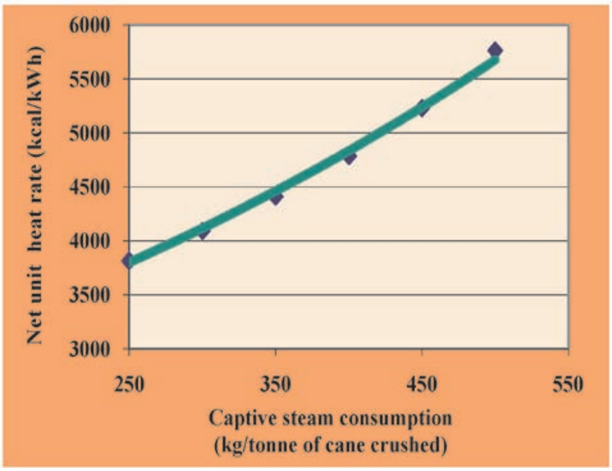

FIG. 7. NET UNIT HEAT RATE (KCAL/KWH)

The KPI can be maximized through the following measures:

i. Maximization of UHR through elevation of working temperature and pressure of the steam to 11.0 MPa and 550 ℃ as described above.

ii. Minimizing process and auxiliary steam consumption [5,6]. This would involve steam audits and minimizing steam losses not only in the process but in the power plant (boiler and turbine-related steam consumption). The internal steam demand could be brought down from 300+ kg/t of cane to below 200 kg/t of cane through energy efficiency measures such as stringent steam management.

iii. Minimizing process and auxiliary power demand. This would involve minimizing power losses not only in the process but in the power plant (boiler and turbine related auxiliary power for pumps and fans). The internal power demand could be brought down from 35+ kWh/t of cane to below 20 kWh/t of cane through technological interventions such as drives and improved mechanical efficiency of the equipment.

iv. For sugar based CHP project the average level of turbo-generator size is 7.5 MW per 1000 tcd. Superior values like 8 MW per 1000 tcd capacity would be ideal for energy efficient CHP projects. While sugar based generation is divided into sugar season, off sugar season and lean season, the PLF during the sugar season must be designed to be 80+ % through minimization of in-house steam and electric demand to below 300 kg/tonne of cane and 34 kWh/tonne of cane respectively.

v. Maximization of Plant load factor (PLF) during all the three phases of generation.

vi. Unit heat rate (UHR) and CHP efficiency. The UHR depends on the PHR. High PHR gives a high UHR. The way to maximize UHR is to increase PHR, decrease in-house and auxiliary demand for steam and power; and to have avery high energy efficiency of the power plant (boiler and turbo-generator through enhanced working temperature and pressure of steam). Operation at high steam pressures and temperatures is essential.

3.2 Seasonal operation of conventional plants in India

The Indian weather is composed of three seasons:

- Rainy season: June-October
- Winter season: November-February
- Summer season: March-June

There are considerable overlap and shifting of the seasons in various parts of the country due to staggered onset and phase out of the South West and North East monsoons. The cane based powergeneration in three phases:

- Crushing season phase of 180 days (October-March)
- Off season phase of 120 days (April-July)
- Shut down phase of 60 days (August-September)

Cane, within 24 hours of being harvested is brought to the mill for crushing during the crushing season. During off season period there is no crushing or sugar production. The excess bagasse accumulated during the preceding crushing season is stored for this off season period and used in power only mode of operation. The bagasse is accumulated due to backed down power demand in the grid or plant outage. It must not be concluded that bagasse is saved during the power generating process because the present plants are designed for maximization of power from a given quantity of bagasse and not minimization of bagasse usage from a given power output. As a thumb rule, nearly 33 % of the unutilized bagasse is stored for the off season period.

Table 4 gives the main performance parameters of a conventional Sugar based CHP plant.

TABLE 4			
PERFORMANCE PARAMETERS OF A CONVENTIONAL PLANT.			
Sl. No.	**Particulars for typical sugar plants**	**Units**	**Value/range**
01	Normal size of sugar plants	tcd	2500-5000
02	Electric capacity	MW/tcd	3-5
03	Best practice electric capacity	MW/tcd	8-9
04	Crushing season	days	90-130
05	Off season period	days	60-100
06	Shut down period	days	135-215
07	Plant load factor (PLF) crushing period	%	90
08	Plant load factor (PLF) off season period	%	90
09	Plant load factor (PLF) annual	%	65-70
10	Net energy generation	kWh/t of cane	150-200
11	Specific steam consumption	t/MWh	8-9
12	Specific water consumption	t/t of cane	0-4-0.6
13	CHP composite efficiency	%	50-55
14	Heat rate	kcal/kWh	3500-4000

4.0 INTEGRATION OF CST WITH SUGAR PLANTS

The steam generated from the CST system is fed into the steam turbines of the sugar plant power block. The steam from the CST plant will minimize the use of bagasse fueled steam to a large extent. Table 5 gives the improvement in sugar based CHP plant with theintegration of CST power source.

Figure 8 gives a schematic of the main power block of the sugar mill. Figure 9 gives the integration of CST with sugar based CHP plant.

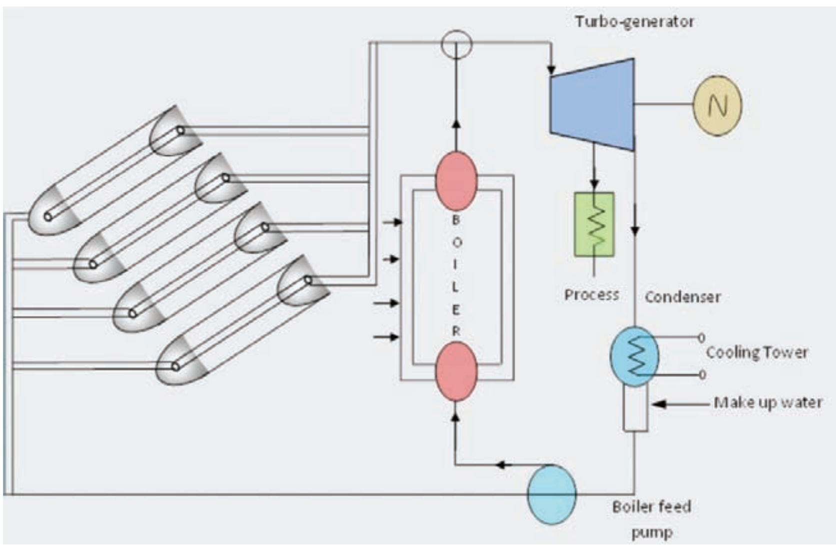

FIG. 8. VIEW OF THE INTEGRATION OF CST SOURCE TO THE POWER BLOCK OF THE SUGAR BASED POWER PLANT.

TABLE 5

PERFORMANCE IMPROVEMENT IN SUGAR BASED CHP

Sl. No.	Particulars for typical sugar based CHP plants	Units	Value/range
01	Sugar based power plant capacity	MW	20
02	PLF of CST based power	%	30
03	PLF for bagasse based power	%	69
04	Present Plant PLF without CST	%	69
05	Improved PLF with CST	%	77
06	Energy generated with existing system (without solar power)	MWh/day	335
07	Energy generated from CST	MWh/day	145

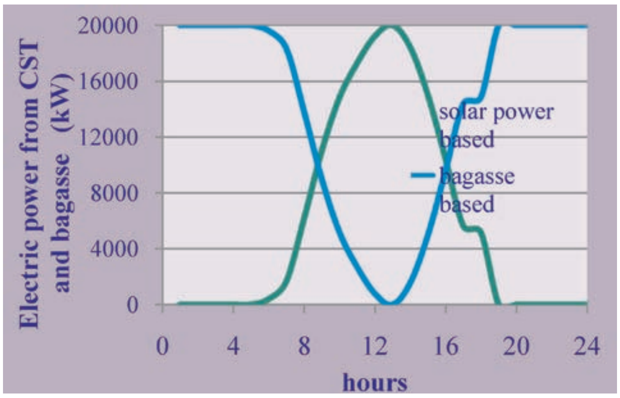

FIG. 9 POWER GENERATION PATTERN FROM CST PLANT WHEN INTEGRATED WITH SUGAR (BAGASSE FUELED) BASED PLANT.

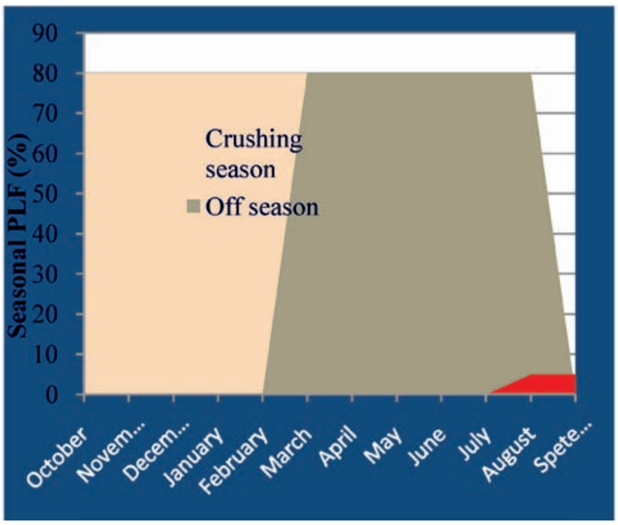

FIG. 10. TYPICAL SEASONAL PLANT LOAD FACTORS FOR THE CONVENTIONAL SUGAR BASED CHP PLANT WITHOUT CST.

Figure 10 gives the plant load factor for the three seasons

It can be seen that the shutdown period provides opportunities for power generation and the other two seasons provides opportunities for saving in bagasse.

5.0 CONCLUSIONS

i. Repowering of sugar (bagasse) based combined heat and power plants by concentrating solar thermal (CST) can enhance the power production by 30 % without any investment in the power block. Since there is the integration of processes, the capital cost is kept low.

ii. The bagasse based power plants greatly benefit from the use of CST for enhancing their PLF from 65-70 % to 77 %. This combination technology is of great strategic value to India since the CST plant does not need a power block and the sugar based plant capacity utilization can be enhanced. During the main seasons, there is saving in bagasse and during the shutdown period generation is facilitated through solar power.

iii. The technological option of using high-pressure boilers (> 11.0 MPa and 540 C) and 3-d designed stage optimized steam turbines with high is entropic efficiencies of 92-94+ % will considerably enhance the CHP potential of sugar mills and other CPPs sized above 10 MW.

iv. The present levels of auxiliary steam and power demands are unusually high. Increasing energy efficiency of auxiliary and in-house steam consumption and power demand through stringent energy efficiency measures is essential for achieving high CHP overall efficiency and minimizing the CHP heat rate.

v. For rapid installation of CHP plants, steels for high temperature–pressure parts of boilers and steam paths of turbines must be indigenously manufactured because of the projected demand. Though the technology is not a constraint, the demand is an issue with the indigenous manufacture.

REFERENCES

[1] M S Bhatt, Combined heat and power systems-potential and opportunities for India redefined, Electrical India, Vol.51, No.12, pp. 102-111, Dec. 2011.

[2] M S Bhatt, Mapping of general combined heat and power systems, Energy conversion & Management, Vol. 42, pp. 115-124, 2001.

[3] M S Bhatt and N Rajkumar, Mapping of combined heat and power systems in sugar cane industry, Applied Thermal Engineering, Vol. 21, pp. 1707-1719, 2001.

[4] CERC, Order on Determination of Benchmark Capital Cost Norm for Solar PV power projects and Solar Thermal power projects applicable during FY 2016-17, Petition No. 17/SM/2015, dated 23.03.2016, Central Electricity Regulatory Commission, New Delhi, pp. 1-31.

[5] K S Venkatesh and A S Roy, Development and installation of high-pressure boilers for co-generation plant in sugar industries, Smart Grid and Renewable Energy, Vol. 1, pp. 51-53, 2010.

[6] M Premalatha, S S Priya, V Sivaramakrishnan, Efficient co-generation schemes for sugar , Journal of Scientific & Industrial Research, Vol. 67, pp. 239-242, March 2008.