A Study on Generation Potential of a Small Scale Distributed Generator

An Encouraging Power Market for Distributed Generations using Bio-Fuels

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Abstract - ***This paper presents a case study on cogeneration potential of a sugar plant with 2000 Tonnes Crushing per Day (TCD).The plant under study embedded a Non-Conventional Energy (NCE) Project for power generation using bagasse as fuel, a fiber waste left after juice extraction from sugar cane. Both technical and economic aspects effecting the co-generation were focused with an attempt to improve them. A MATLAB/SIMULINK model is also developed to estimate the power generation capacity of the plant considering various plant parameters related to boiler, turbine, alternator etc., and fuel parameters like calorific value, moisture content etc.,.***

Key Words: *co-generation, tonnes crushing per day, distributed generation, simulink model, calorific value.*

1. INTRODUCTION

The combined local production of heat and power has the advantage of a high efficiency, if the heat is used locally. A CHP based plant can also be categorized as one type of distribution generation, if it is connected within the distribution grid or on the customer side of the network. It can be called as small distribution generation if its generation capability is in between 5KW-5MW [1].

As sugar industry is seasonally run, it can provide energy locally during its operation. In this period, it reduces line losses because of decrease in current flow in some parts of the network. Also they operate on water tube boilers for generation of steam. The startup time for these plants are relatively less when compared to fire tube boilers, hence these plants can meet the changes in load as fast as possible. Technically DG's provide voltage support with improved power quality and reliability. Economically there is an increased encouragement by government for power generation using NCE sources by providing financial incentives and preferential tariff (Rs/MWh) for proper utilization of renewable resources [3].

In comparison to separate fossil-fired generation of heat and electricity, CHP generation may result in primary energy conservation, varying from 10% to 30% depending on size &efficiency of the cogeneration units. Cogeneration involves simultaneous generation of multiple useful energy sources such as power, heat, evaporation, drying, water recycling and cooling [5]. It also leads to increased fuel efficiencies and possibly a lower overall fuel use. CO_2 emitted into the atmosphere when biomass is burned is equal to the amount of CO_2 absorbed during its growth. NO_Xemissions by combustion of bio-fuels is reported to be 20-40% lower than that of fossil fuel plants. SO_2 emissions are reported to be insignificant. As bagasse is one form of bio-mass, it is environment friendly which helps in reduced greenhouse gas emissions [9].

Due to intermittent nature of bagasse availability, capacity utilization factor for these DG's would be in 17% to 70% and 50% higher if auxiliary fuel is used. A target for addition of 1700MW capacity consisting of 500MW of biomass power projects and 1200MW of bagasse based cogeneration has been proposed during XI plan period i.e. up to 2012 [10].

The temperature of the steam generated in CHP plant plays an important role in the amount of power that can be cogenerated. This decides the capital cost of boiler and turbine, which in turn demands for relatively higher capital investment compared to conventional power projects. The net income generated annually is calculated by subtracting the fuel costs from the revenue generated from selling the cogenerated power [6]. At present scenario most of the power plants are equipped with boilers and captive power generation units to meet their plant heat and power requirements. Hence additional capital investment to establish a power project is less. However only criteria become is to save energy for export to grid.

This paper starts first with introductory section-I followed by section-II, defining various definitions and formulae required to estimate the performance of Cogeneration using bagasse as fuel. Then in the section-III, we carry out the case study on sugar plant with cogeneration. In section-IV, a general MATLAB/SIMULINK model will be developed from the defined mathematical model to assess the generation capability of any bagasse based cogeneration plants.

2. DEFINITIONS AND FORMULAE

Plant Load Factor (PLF) [4]:

Plant load factor is defined as the ratio of energy actually produced to maximum energy that could have been installed.

$$PLF = \left(\frac{\left(\frac{Total\ units\ generated}{TG\ running\ hours}\ in\ the\ season\right)}{Capacity\ of\ plant}\right) * 100$$

Utilization Factor (UF) [4]:

Utilization factor is defined as the ratio of maximum power developed to total power that could have been generated.

$$UF = \left(\frac{Maximum\ power\ generated}{Total\ power\ that\ can\ be\ generated}\right)$$

Average Export [4]:

Average export is defined as the total units exported to the grid to the total turbo generator running hours.

$$Average\ Export = \frac{\frac{Total\ units\ exported}{TG\ running\ hours}}{1000}$$

3. CASE STUDY

The Etikoppaka Co-operative Agricultural and Industrial Society Ltd., Etikoppaka, Visakhapatnam in the state of Andhra Pradesh, India is the first co-operative sugar factory established in 1931 with a crushing capacity of 75 TCD. At present this sugar mill has a licensed capacity of 2000TCD and produces a good quality crystal white sugar. It has a 3MW (BHEL) turbo alternator operated in islanding mode to meet the factory and colony consumption and a 1.5MW (JYOTI Ltd.,) turbo alternator which exports power to the APTRANSCO grid.

The factory has installed 40 Tonnes/Hour capacity, 32 Kg/Cm^2 & 380^{0}C 15^{0}C medium pressure boiler with 3.0 MW Turbo Alternator set and 33.5 Tonnes/Hour capacity, 14 Kg/Cm^2 300^{0}C 15^{0}C low pressure boiler with 1.5 MW Turbo Alternator set.

During the modernization of the plant during 1999-2000 season the above mentioned 3 MW alternator along with a medium pressure boiler were introduced. This lead to low fuel consumption with saving surplus bagasse. The steam consumed by the TG set was reduced resulted in insufficient process steam required for sugar manufacturing process. The solutions for their problem are:

a. To supply live steam separately.
b. To supply this live steam through a turbo generator unit.

The later was found to be beneficiary because they get some revenue by selling the electrical power generated by incinerating surplus bagasse available along with meeting the process steam requirements. This lead to the establishment of 1.5 MW cogeneration unit.

Below table .1 shows various parameters related to sugar cane bagasse availability and other steam parameters referred to this plant under study.

TABLE.1

LIST OF PARAMETERS RELATED TO BAGASSE AVAILABILITY AND STEAM GENERATION

S.No	Parameter	Value
1.	*Area Harvested Annually*	4856.23 Hectares
2.	*Average Yield*	45.3 M.Tonnes/Hectare
3.	*Rated Cane Crushing Capacity*	*2000 TCD*
4.	*Bagasse percent Cane*	30%
5.	*Bagasse Moisture*	50%
6.	*Steam to Bagasse Ratio*	1.8Kgs/Kg
7.	*Specific Steam Consumption (1.5 MW)*	16Kg/KWh
8.	*Specific Steam Consumption (3 MW)*	9Kg/KWh

With an inlet steam temperature of 300^{0}C 15^{0}C and pressure of 14Kg/Cm^2, 1.5MW Turbo-generator unit began its commercial operation in the year 2001.It was connected to the nearest Darlapudi substation at a potential level of 33KV.As its capacity is 1.5MW, it can be considered as small scale distributed generator. Power Purchase Agreement (PPA) for a period of 20 years was also made between the Etikoppaka sugar factory (the seller) and Transmission Corporation of Andhra Pradesh (APTRANSCO, the buyer) for the purchase of 1.5 MW power at a preferential tariff in the same year. The plant was not associated with any third party sale.

The exhaust steam obtained from 3MW and 1.5 MW alternators at 1 atm pressure is utilized for sugar manufacturing process. Mill prime movers are driven by steam turbines at 14 Kg/Cm^2 pressure.

Below table .2 shows various economic and electrical parameters that are averaged over its (1.5 MW) span of operation from the season 2000-01 to 2012-13.

TABLE.2

LIST OF COMPUTED ECONOMIC AND TECHNICAL PARAMETERS

S.No	Parameter	Value
1.	*Total Bagasse Produced*	59,835 M.Tonnes
2.	*Bagasse Utilized for Captive Generation*	51,481 M.Tonnes
3.	*Surplus Bagasse*	8,354 M.Tonnes
4.	*Units Exported*	9,40,754 KWh
5.	*No. of days in operation*	112 days
6.	*Plant Load Factor*	23.3%
7.	*Average Export*	0.4 MW
8.	*Utilization Factor*	47%
9.	*Income earned*	Rs.30.9 Lakhs
10.	*Unit rate*	Rs.3.0/KWh

From the above table.2, Plant Load Factor (PLF) was 23.3%. But this value can range from 17%-70% for a biomass based generation plants and it can also be increased to 50% above if other auxiliary fuels are also used [10].In this plant the only fuel used for cogeneration was Bagasse. The availability of this fuel was intermittent i.e. only during crushing season. If other fuels were also used for this generation then the plant load factor can be improved with increased duration of availability of fuel. Utilization factor was only 47% leading to a low value average export of 0.4 MW.

Usually the turbines used in sugar industry are either back pressure or condensing type. Here they are using back pressure turbines for both the TG sets because the outlet exhaust is utilized for sugar manufacturing process.

At the initial stages of the project in operation the unit price fixed was around Rs.3/KWh which was rather satisfactory. But after the revised PPA in the year 2003, it was dropped to around Rs.2.80/KWh.

a. *The technical reasons observed for such low values are listed below*:
   - The turbines utilized are back pressure turbines rather than condensing turbines.
   - They are utilizing low temperature and pressure boiler for supplying steam to the turbine.
   - The auxiliary switchgear equipment's and automatic control circuits in operation are old, obsolete and less reliable.
   - Some parts of the cogeneration are run manually causing technical losses due to error in operation.
   - High value of moisture % in bagasse damping the productivity of bagasse.

b. *The economic reason observed is furnished below*:
   - Usually surplus bagasse is utilized for power generation. At present the unit rate of bagasse was high i.e.Rs.1100-Rs.1500 per M.Tonne. Operating charges for cogeneration include O&M (Operation and Maintenance) charges, salaries to manpower etc. If the net income incurred by cogeneration does not amount relatively more revenue than selling surplus bagasse. Then it is unreasonable to run the cogeneration plant.

c. *The proposed solutions for the above observed technical and economic problems are enumerated as under*:
   - Existing boilers are used for bagasse firing only but not multi fuel firing. Hence it is proposed to accommodate multi-fuel firing boilers using auxiliary fuels.
   - Condensing turbines should be installed rather than back pressure turbines so that these can be run during off-seasons when there is no demand of steam for process.
   - If the generation temperature of the steam increases, the amount of power that can be cogenerated can be increased [6]. Hence high temperature and pressure boiler should be installed rather than the present low pressure and temperature boiler.
   - Modern auxiliary switchgear equipment's and advanced automatic control circuits should be utilized because of their high reliability and efficiency.
   - The mill prime movers should be changed to A.C drives rather than turbine driven.
   - Instrumentation & Automation should be enhanced at critical points of the manufacturing process to observe the actual process parameters.
   - In order to achieve the above proposed solutions, still the utility (or the buyer) has to provide further supportive unit rate than the present unit rate. Then it could be viable for the sellers to run these cogeneration units to their capacity with maximum reliability and efficiency.

The proposed solutions may lead to improved plant load factor and utilization factor .Thus increasing the efficiency of distributed generation with increasing export to the grid.

4. MATLAB/SIMULINK MODEL TO PRACTICALLY ESTIMATE THE POWER GENERATION CAPABILITY OF SUGAR MILLS USING BAGASSE

A. Mathematical Model [11]

The main tool to the production of surplus electricity in a sugar mill is by optimal generation and utilization of steam which results in saving bagasse. This excess bagasse is a scale to measure the electricity production potential of a sugar manufacturing industry.

At a given steam conditions, it is possible to derive a performance equation for surplus power production and is as follows:

$$Bex = Bp - Bc \quad (1)$$

Bex is excess bagasse in tonnes. This is the amount of bagasse that can be made into electricity after meeting the factory steam requirements.
Bp is bagasse produced from milled cane in tonnes.
Bc is bagasse consumed for raising steam needed for sugar processing in tonnes.

$$Bp = b * Yc \quad (2)$$

b is the bagasse percent cane in %.
Yc is weight of cane to be processed in tonnes.

$$Sc = SSC * Yc \quad (3)$$

Sc is the total amount of steam required (tonnes) to process Yc tonnes of cane.
SSC is the specific steam consumption or tonnes of steam per tonne of cane processed into sugar.

$$Bc = 1.05 * \left(\frac{Sc}{rsb}\right) \quad (4)$$

rsb is the steam to bagasse ratio or tonne of steam produced per unit weight of bagasse.
The constant 1.05 allows for 5% loss in bagasse handling and for starting uses.

From (1)

$$Bex = Yc * \left(\frac{b}{100} - 1.05 * \frac{SSC}{rsb}\right) \quad (5)$$

Electrical energy generated can be expressed as:

$$Eg = 0.278 * 10^{-3} * \eta el * Bex * NCVb \quad (6)$$

Ƞel is the electric yield (based on NCV) of the system producing electricity (KJ/KJ).
Eg is electricity produced from the excess bagasse in KWh.
NCVb is the net calorific value of the bagasse (MJ/tonne) that is, after making corrections for all water produced to be in the vapor phase and making allowances for the calorific value of sucrose.

The NCV of bagasse with wb% moisture can be expresses as [7]

$$NCVb = 17643 - 203 * wb \quad (7)$$

The electricity produced per unit weight of cane (KWh/tonne cane) is then

$$\frac{Eg}{Yc} = 0.278 * 10^{-3} * \eta el * NCVb * 10^{3} * \left(\frac{Bex}{Yc}\right) \quad (8)$$

Then the exportable electricity potential per tonne of cane is given by

$$\frac{Eex}{Yc} = \left(0.278 * 10^{-3} * \eta el * NCVb * 10^{3} * \frac{Bex}{Yc}\right) - Ef \quad (9)$$

B. Modeling in Matlab/simulink:

Above derived mathematical analysis can be utilized to model its Matlab model and is shown as follows:

The net amount of cane to be processed by the sugar mill depends upon the area in which sugar cane is harvested and on the average yield that is obtained from the harvested area. Then net cane that is to be processed annually is the product of annual area harvested in hectares and average yield. Matlab/Simulink model of the net input subsystem is shown in fig.1

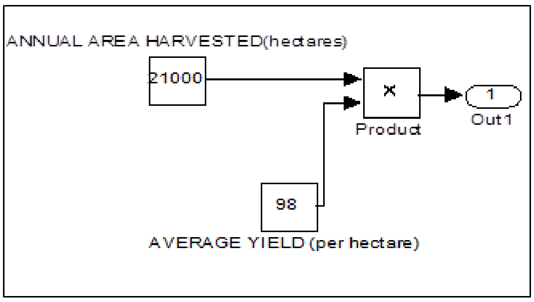

Fig.1. Net Input MATLAB/SIMULINK Subsystem Model

Then the obtained net input is used in calculating the bagasse produced from the milled cane from the eqaution

(2) and its corresponding Matlab/Simulink model is shown in the fig.2.

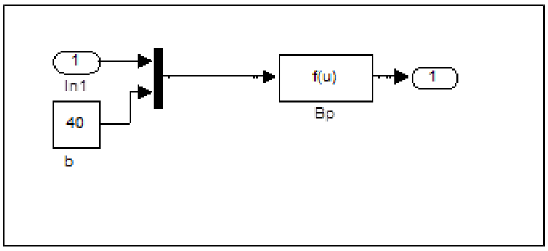

Fig.2. Bp MATLAB/SIMULINK Subsystem Model

Now in order to raise the steam required for sugar processing i.e. in power mill drives as well as for evoporating sugar cane juice some part of bagasse will be consumed(Bc).The matlab/simulink model for Bc can be obtained by considering Equations (3),(4) and is shown in the fig.3 below.

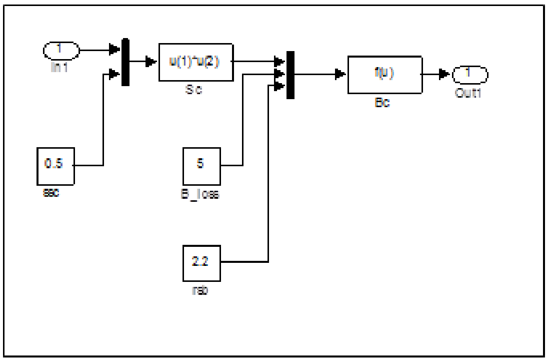

Fig.3. Bc MATLAB/SIMULINK Subsystem Model

Later excess bagasse for power generation after meeting the captive requirements is obtained by equation (1) and is modelled as in fig.4

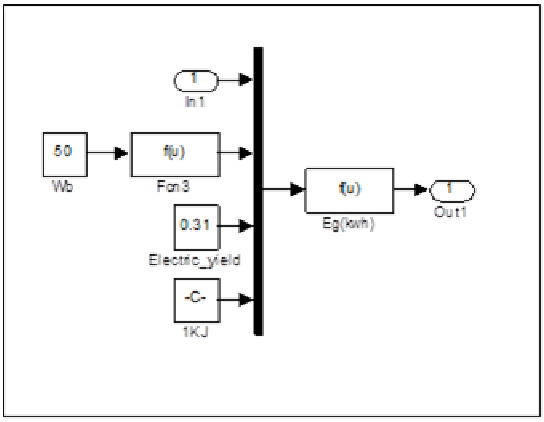

Fig.4. Eg MATLAB/SIMULINK Subsystem Model

Lastly generated power (KWh/tc) and exportable power (KWh/tc)after meeting the factory consumption is modeled by considering the equation (9) is shown in the fig.5 below.

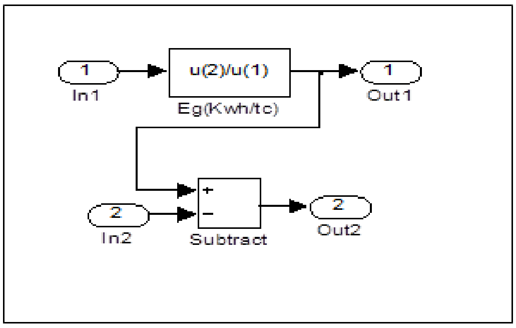

Fig.5. Energy/tc MATLAB/SIMULINK Subsystem Model

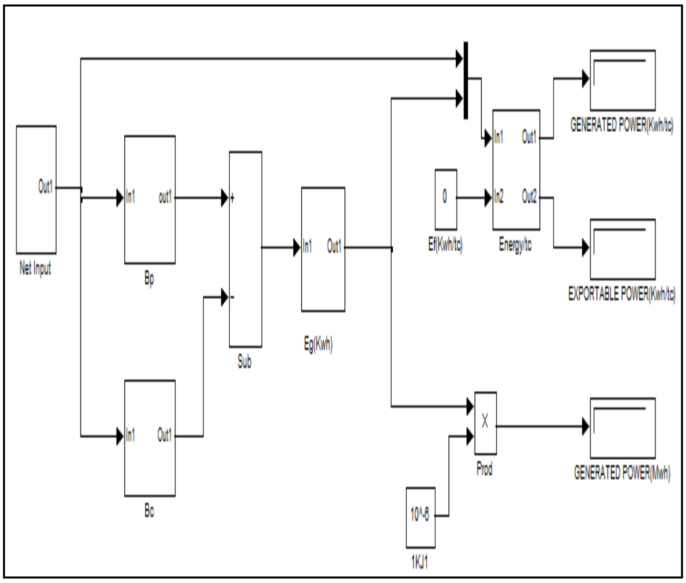

Fig.6. Overall MATLAB/SIMULINK Model to estimate the power generation capacity

TABLE.3
SIMULATION RESULTS OF A EXAMPLE SUGAR PLANT

Parameter	Value
Annual area harvested	21000 Hectares
Sugar cane yield	98 Tonnes/Hectare
b	40%
W_b	50%
SSC	0.50
r_{sb}	2.2
η_{el}	0.31
No. of units utilized by plant	25 KWh/tc
Generated power	104.2 KWh/tc
Exportable power	79.2 KWh/tc

Finally overall Matlab/Simulink model to assess the power generation capability of a bagasse based cogeneration sugar plant is modeled by properly connecting the above subsystems. Overall model is shown in the fig.6.Now an example plant was considered and its simulation results are shown in the table .3.

4. CONCLUSIONS

A case study on bagasse based cogeneration plant was dealt at the beginning with the proposal of possible techno-economic solutions to the problems faced by them in improving their power export. Then a MATLAB/SIMULINK model to assess the cogeneration capability of a sugar plant using bagasse as fuel was modeled and checked its validation with an example system. Considering the system support benefits and also due to their added eco-friendly nature, these types of distributed generators should be energized further.

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APPENDIX

PARTICULARS OF 1.5 MW TURBO GENERATOR

Make:	JYOTI Ltd.,
Phase:	3
Frequency:	50 Hz
Type of Enclosure:	C.A.C.W
KVA:	1875
Voltage:	440V
Current:	2460 A
Power factor:	0.8
Speed:	1500 RPM
Excitation:	52 V/256 A
Connection:	Star
Class:	B

15 KW DC-EXCITER

KW:	15
Speed:	1500RPM
Volts:	55 V
Current:	270 A
Class:	B

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BIOGRAPHIES

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