Feasibility Analysis of Converter-Interfaced Combined Heat and Power Systems

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***Abstract*-This paper reports on the economic feasibility analysis of converter-interfaced combined heat and power systems (CHP). A converter-interfaced CHP system is coupled to the grid through a rectifier and a grid-ready tied inverter. Compared to the traditional directly-coupled CHP systems, converter-interfaced CHP systems remove the requirement for oversizing the CHP generator, limit the short-circuit contribution of the generator, and are expected to simplify the grid integration process of CHP systems. This paper evaluates the economic benefits of this concept by calculating the Return-on-Investment (ROI) and comparing it to directly-coupled system. The analysis includes timeseries simulations to compute energy transactions with the utility grid as well as sizing the equipment to calculate the capital and operational costs. Obtained results indicate that in the majority of user cases evaluated, the converter-interfaced CHP systems can provide better return on investment than directly-coupled systems. Given the additional technical benefits provided by inverter-based distributed energy resources (DER), the proposed concept can provide additional technical and economic benefits to distribution grids and microgrids systems.**

***Index Terms*—combined heat and power, converter, economic feasibility, ROI, timeseries simulation**

Nomenclature

$kW_{CHP}(t)$, $kVar_{CHP}(t)$	Active/reactive power output from CHP at time t
$kW_{grid}(t)$, $kVar_{grid}(t)$	Active/reactive power output from bulk grid at time t
$kW_{load}(t)$, $kVar_{load}(t)$	Active/reactive load requirement at time t
$PF_{load}(t)$	Power factor of load at hour t
$PF_{CHP,max-min}$	Minimum operating power factor limit when CHP outputs the maximum active power
$PF_{CHP,min}$	Minimum operating power factor limit when CHP does not output the maximum active power
$kVA_{CHP,max}$	CHP generator capacity rating
$kW_{CHP,max}$	CHP primary mover capacity rating
$kVA_{cvt,max}$	Converter capacity rating

I. Introduction

As the most efficient way to produce heat and electricity, Combined Heat and Power (CHP) systems have been widely applied in the power industry in recent years. The adoption of the technology is lagging for small-and medium-sized industrial and commercial applications (between 1MW and 20MW) [1]. The major barriers for a broader adoption include 1) a high initial investment and the lengthy interconnection process involved in satisfying utility standards and grid codes; 2) lack of technical sophistication of small entities to deal with the technical complexity related to CHP deployment; and 3) the unforeseeable change in grid codes due to anticipated higher penetration of distributed energy resources (DER). Thus, a solution consisting of interfacing a converter with the CHP system is proposed to overcome these barriers. For the solution to be adopted by the industry, a detailed analysis is required to validate its technical and economic advantages over directly-coupled systems. This paper seeks to provide such a framework by analyzing five suitable applications for CHP (user cases), each located within a separate Independent System Operator (ISO) territory. The different ISO territories allow to evaluate the impact of the energy costs, revenue from electricity transactions including ancillary services, seasonal variation of the thermal and load profiles and grid code requirements. In each user case the ROI is calculated and compared with the equivalent scenario using a directly-coupled system. The remaining of the paper is organized as follows: Section II analyzes the benefits for converter-interfaced CHPs, Section III models the timeseries simulation in detail; Section IV presents the calculation of annualized ROI. Section V is the case study and describes the analysis results for the five user cases. Section VI summarizes the paper.

II. Benefits of Interfacing Converter for Small-to Medium-Sized CHP Applications

The converter-interfaced CHP is connected through a rectifier and a grid-ready inverter to support local loads and export excess power into the grid, as shown in Figure 1. It is also equipped with a comprehensive control system which enables to limit the Total Harmonic Distortion (THD) at both the generator and grid sides to below 5%. This prevents the oversizing of the generator for harmonics mitigation, to seamlessly comply with grid code interconnection standards (e.g. IEEE 1547), and to optimally dispatch reactive and active power for grid support services with minimal impact to site operations.

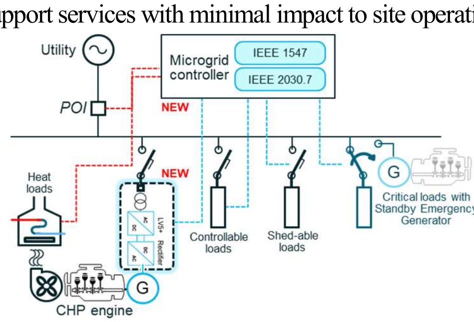

Figure 1. Diagram of converter-interfaced CHP system

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Compared to traditionally directly-coupled CHP systems, the converter-interfaced CHP does not require oversizing the genset generator to provide reactive power. In fact, the power factor at the generator terminals stays consistently at unity regardless of the load, and the grid side inverter provides the required reactive power to the load. While conventional synchronous generators used with CHP systems are designed to provide their rated power at a minimum 0.8 power factor, converter-interfaced CHP will be able to operate at a lower power factor (e.g., 0.6) depending on the sizing of the inverter and the generator. In addition, the converter-interfaced solution provides the limitation on the short-circuit contribution of the CHP, hence reducing the cost of interconnection equipment (e.g. breakers, busbars, relays) and design iterations required by the utility to be granted a "Permission To Operate" approval. The solution facilitates compliance with major interconnection standards such as IEEE 1547 and P2030.7 since many commercial grid-ready inverters (e.g. used in the PV solar applications) are already compliant with those standards [2].

Although a converter-interfaced CHP system has technical benefits over a directly-coupled CHP system, its economic viability needs to be validated before it is widely adopted. Directly-coupled CHP systems have already proven their profitably [3-7]. Converter-interfaced CHP needs to demonstrate equal or higher profitably while providing additional operational benefits such as improved reliability, stability and flexibility both in grid-tied and islanding modes, in order to be widely adopted by the industry. By performing timeseries simulations to evaluate the hourly thermal and electrical energy outputs provided to the local loads, the performance of the CHP system, capacity factor, fuel consumption as well as the amount of the energy exportable to the grid can be determined. Therefore, all potential revenues and savings from the CHP systems can be estimated and included in ROI calculations along with the capital cost of the system. Five user cases are analyzed to evaluate the feasibility of converter-interfaced CHP for small-to-medium sized commercial and industrial applications, proving the economic benefits of converter-interfaced CHP system.

III. TIMESERIES SIMULATION OF CHP SYSTEM

A. Technical constraints and operating regions

Timeseries simulation is utilized to determine the hourly value of the thermal and the electric outputs from the CHP system. Both the active and reactive power are evaluated for electricity output. A full calendar year is considered to capture daily and seasonal variations of load and therefore the dynamic amount of exportable energy to the grid. As described in Figure 2, it is anticipated that the CHP will fall in one of the three operating regions depending on the load level. If the facility load is between the range $(kW_{CHP,min}, kW_{CHP,max})$, CHP unit has the capability to satisfy the load requirement, and this is defined as operating region 1. If the facility load is above $kW_{CHP,max}$, the CHP unit is operated at its maximum output of active power and grid support is necessary to satisfy the load consumption; this is defined as operating region 2. If the facility load is below $kW_{CHP,min}$, CHP unit will shut down due to low operating efficiency and uneconomic factors; this is defined as operating region 3. $kW_{CHP,max}$ and $kW_{CHP,min}$ are the CHP maximum and minimum power outputs, respectively. These two parameters are the most critical constraints for the CHP operation. $kW_{CHP,max}$ is determined by the engine rated power while $kW_{CHP,min}$ is dictated by the engine controls limited performances at low power output. In general, $kW_{CHP,min}$ is set to be 30% of $kW_{CHP,max}$ for operating efficiency. An additional constraint is related to the power factor at the CHP system as the generator is limited by its kVA nameplate. In the simulation, the power factor at the point of injection (POI) is monitored.

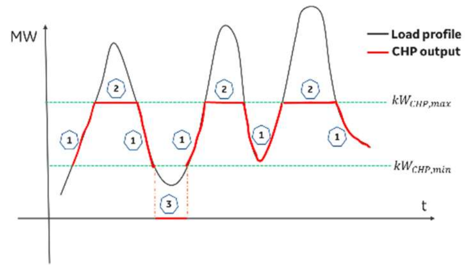

Figure 2. *Operating regions of CHP system*

The hourly output and exportable power from CHP system can be achieved. Furthermore, through additional calculations, the output from the engine, thermal output from CHP unit and fuel consumption can be obtained. As mentioned in the introduction section, all the output data will be used to compute the annualized ROI.

B. Technical formulas for each operating region

The technical formulas governing the same operating regions for directly-coupled CHP and converter-interfaced CHP are slightly different. For directly-coupled CHP system, the generator is typically oversized by 25% to be able to operate up to a minimum power factor of 0.8 at rated output power. However, with a converter interfacing CHP system, the generator does not need to be oversized as it will operate at a unity power factor regardless of the load conditions, with the grid-side inverter providing the required reactive power. The technical formulas for each operating region in each configuration are detailed as follows:

1) *Operating region 1:* $kW_{CHP,min} \le kW_{load} \le kW_{CHP,max}$

a) *Directly-coupled CHP system*

In this operating region, the CHP system can satisfy all the load requirements on active power. The performance of reactive power depends on the power factor of the facility load. If the power factor of the facility load is quite low (less than 0.6, which is uncommon), grid support is required for injecting additional reactive power. Thus, the formulas summarized the CHP behavior are shown in equations (1) to (4).

$$kW_{CHP}(t) = kW_{load}(t) \tag{1}$$

- If $PF_{load} \ge PF_{CHP,max-min}$ Then

$$\begin{cases} kVar_{CHP}(t) = kVar_{load}(t) \\ kW_{grid}(t) = 0,\ kVar_{grid}(t) = 0 \end{cases} \tag{2}$$

- If $PF_{load} < PF_{CHP,max-m}$ Then

$$\begin{cases} kVar_{CHP}(t) = \min\left(kVar_{load}(t), \sqrt{\min\left(\dfrac{kW_{CHP}(t)}{PF_{CHP,\min}}, kVA_{CHP,\max} \right)^2 - kW_{CHP}^2(t)} \right) \\ kW_{grid}(t) = 0 \\ kVar_{grid}(t) = kVar_{load}(t) - kVar_{CHP}(t) \end{cases} \tag{3}$$

The exportable active and reactive power to the grid are:

$$\begin{cases} kW_{CHP,\exp}(t) = kW_{CHP,\max} - kW_{load}(t) \\ kVar_{CHP,\exp}(t) = \max\left(0, \sqrt{kVA_{CHP,\max}^2 - kW_{CHP,\max}^2} - kVar_{load}(t)\right) \end{cases} \quad (4)$$

b) Converter-interfaced CHP system

The converter-interfaced CHP's active power is governed by the same equation as that of the directly-coupled CHP. The maximum reactive power it can produce is only constrained by the capacity of the converter, $kVA_{cvt,max}$. The formulas for the converter-interfaced CHP operation are shown in equations (1), (5) and (6).

$$\begin{cases} kVar_{CHP}(t) = 0, \; kW_{grid}(t) = 0 \\ kVar_{grid}(t) = \max\left(0, kVar_{load}(t) - \sqrt{kVA_{cvt,\max}^2 - kW_{CHP}^2(t)}\right) \end{cases} \quad (5)$$

The exportable active and reactive power to the grid are:

$$\begin{cases} kW_{CHP,\exp}(t) = kW_{CHP,\max} - kW_{load}(t) \\ kVar_{CHP,\exp}(t) = \max\left(0, \sqrt{kVA_{cvt,\max}^2 - kW_{CHP,\max}^2} - kVar_{load}(t)\right) \end{cases} \quad (6)$$

2) Operating region 2: $kW_{load} > kW_{CHP,max}$

The CHP system outputs its maximum active power, as shown in equation (7).

$$kW_{CHP}(t) = kW_{CHP,max} \quad (7)$$

a) Directly-coupled CHP system

The reactive power output from this system is defined as the minimum of two quantities: the maximum reactive power capacity of the CHP generator and the load reactive power requirement, as shown in equation (8).

$$\begin{cases} kVar_{CHP}(t) = \min\left(kVar_{load}(t), \sqrt{\left(\min\left(\frac{kW_{CHP}(t)}{PF_{CHP,\min}}, kVA_{CHP,\max}\right)\right)^2 - kW_{CHP}^2(t)}\right) \\ kW_{grid}(t) = kW_{load}(t) - kW_{CHP}(t) \\ kVar_{grid}(t) = kVar_{load}(t) - kVar_{CHP}(t) \end{cases} \quad (8)$$

The exportable active and reactive power to the grid are:

$$\begin{cases} kW_{CHP,\exp}(t) = 0 \\ kVar_{CHP,\exp}(t) = \max\left(0, \sqrt{kVA_{CHP,\max}^2 - kW_{CHP,\max}^2} - kVar_{load}(t)\right) \end{cases} \quad (9)$$

b) Converter-interfaced CHP system

The reactive power is provided by the grid-side inverter stage of the converter, which is limited by its maximum rating.

$$\begin{cases} kVar_{CHP}(t) = 0 \\ kW_{grid}(t) = kW_{load}(t) - kW_{CHP}(t) \\ kVar_{grid}(t) = \max\left(0, kVar_{load}(t) - \sqrt{kVA_{cvt,\max}^2 - kW_{CHP}^2(t)}\right) \end{cases} \quad (10)$$

The exportable active and reactive power to the grid are :

$$\begin{cases} kW_{CHP,\exp}(t) = 0 \\ kVar_{CHP,\exp}(t) = \max\left(0, \sqrt{kVA_{cvt,\max}^2 - kW_{CHP,\max}^2} - kVar_{load}(t)\right) \end{cases} \quad (11)$$

3) Operating region 3: $kW_{load} < kW_{CHP,min}$

In this operating region, the CHP system is in shut down mode. The load power requirement is supplied by the utility grid. The applicable formulas are as follows:

$$\begin{cases} kW_{CHP}(t) = 0, \; kVar_{CHP}(t) = 0 \\ kW_{grid}(t) = kW_{load}(t), kVar_{grid}(t) = kVar_{load}(t) \end{cases} \quad (12)$$

If the CHP system is reconnected to the grid, the exportable active and reactive power to the grid are as follows.

- For directly-coupled CHP system:

$$\begin{cases} kW_{CHP,\exp}(t) = kW_{CHP,\max} - kW_{load}(t) \\ kVar_{CHP,\exp}(t) = \max\left(0, \sqrt{kVA_{CHP,\max}^2 - kW_{CHP,\max}^2} - kVar_{load}(t)\right) \end{cases} \quad (13)$$

- For converer-interfaced CHP system:

$$\begin{cases} kW_{CHP,\exp}(t) = kW_{CHP,\max} - kW_{load}(t) \\ kVar_{CHP,\exp}(t) = \max\left(0, \sqrt{kVA_{cvt,\max}^2 - kW_{CHP,\max}^2} - kVar_{load}(t)\right) \end{cases} \quad (14)$$

IV. Calculation of the Return on Investment

From a financial perspective, ROI evaluation is a very critical step in determining a project economic viability and performing a trade-off between competing technologies. Thus, the formula of annualized ROI [8] as shown in (15) is utilized to assess the economic feasibility of a converter-interface CHP as opposed to a directly-coupled CHP[1].

$$Annualized\ ROI = \frac{total\ yearly\ net\ cash\ flow}{year\ 0\ equity\ investment} / project\ life \quad (15)$$

To assess the CHP system revenues, monetization of its participation in the energy and ancillary services of wholesale markets needs to be quantified. Currently, CHP systems are entitled for net-metering or behind-the-meter options, depending on which utility grid it is connected to [9]. In this analysis, it is assumed that the excess power from CHP system can be used to participate in the energy and ancillary services markets[2]. Based on the investigation of ancillary service markets across the seven ISOs in the U.S. and the corresponding requirements, the ancillary services a CHP system is qualified to sell to the grid are summarized in Table I. This table is only focused on regulation and contingency reserve services. For regulation reserve service, the provider should be able to immediately increase or decrease output to follow Automatic Generator Control (AGC) set points (4s or 6s). For 10 minutes (/30 minutes) spinning reserves, the provider should be synchronized to the grid and respond within 10 minutes (/30 minutes). For 10 minutes (/30 minutes) non-spinning reserve, the resource should be able to connect, synchronize and respond within 10 minutes (/30 minutes). CHP systems, in particular reciprocating engines, have fast response time that can qualify them for the ancillary services listed in Table I. Additionally, CHP systems have the ability to provide voltage support by exporting reactive power to the grid. This is also included as a revenue stream for CHP systems. The ROI calculation also considers production loss resulting from the interconnection procedures delay. Due to its controllability, its

[1] The calculation of net cash flow is referred to standard methods. For this case, the revenues come from 1) avoided cost of purchasing electricity from utility grid, 2) selling excess energy to grid to provide energy and ancillary services and 3) avoided costs for purchasing thermal. The OPEX includes operating and maintenance costs for CHP and fuel costs. It also considers property tax, insurance premium. investment tax, state tax and federal tax.

[2] This is a reasonable assumption, since ISOs are working on new market designs to incorporate more DERs (e.g., DER roadmap in the NYISO).

embedded grid support functions and limited contribution to short-circuit faults at the utility side, converter-interfaced CHP systems are expected to have a much simpler, less time-consuming, a low cost and speedy interconnection process than their directly-coupled counterparts [10]. The loss of production due to delays in interconnection for the directly-coupled CHP systems is estimated to be approximately the equivalent of one year's net profits. The production loss is included in the ROI comparison between directly-coupled CHP system and converter-interfaced CHP system.

TABLE I. SUMMARY OF ANCILLARY SERVICE AND CHP ELIGIBILITY

	Regulation		Contingency Reserve/ Operating Reserve			
	Reg Up	**Reg Down**	**10min Spin**	**10min N-Spin**	**30min Spin**	**30min N-Spin**
CAISO	√	√	√	√	--	--
MISO	√		√	√	--	--
ISO-NE	√		√	√	--	√
NYISO	√		√	√	√	√
PJM	√		√	√	--	--
ERCOT	√	√	√	--	--	√
SPP	√	√	√	√	--	--

V. USER CASE STUDIES

Based on the population analysis of the DOE CHP database [11], five user cases are selected for further analysis and studies. They each individually represent the predominantly used solutions in each of the five leading ISO territories for CHP installations. For some of these user cases, the system sizing is based on actual projects already commissioned, while for the other cases, the system is sized based on the thermal load profile. The hourly thermal and electric load profiles are obtained from the NREL database which lists examples of commercial loads [12]. The business user cases include a hospital in NYISO, a college in CAISO, a water reclamation plant in ERCOT, a large office building in PJM and a hotel in MISO. For each user case, in addition to collecting the hourly electric and thermal load data, the utility rate, the hourly energy and ancillary service prices, financial parameters, fuel price, and installed costs of CHP [13] are also collected. Timeseries simulations using MATLAB™ 2017b are then performed for an entire year to calculate the annual revenues from the CHP system, including the amount of electricity exportable to the grid. The results from the timeseries simulations are used to calculate the yearly net cash flow and furthermore the annualized ROI. The hospital in the NYISO user case is described in detail below. The results for the other four user cases are summarized in Tables V and VI.

1. NYISO Hospital User Case

The studied hospital is located in Utica, NY and hosts a 2200kW reciprocating engine-based CHP system. The peak load of the hospital is 2190kW, and the average hourly electrical load is 1470kW. The average hourly thermal load is 2573MBtu and the availability of CHP is 98%. Demand charge is \$3.52/kW/month and the hourly electricity rates are obtained from National Grid, the utility serving the hospital. Exportable active power of CHP is distributed between energy, regulation reserve and 10-min spinning reserve in an optimized way to maximize the profits from selling them. The 10-min non-spinning reserve is only applicable when CHP is shut down. Exportable CHP reactive power is utilized for voltage support at a price of \$2.792/kVar/year. The gas price is assumed to be \$4/MMBtu. Tables II and III show the parameters for financial analysis and the CAPEX & OPEX costs. In Table III, the data for directly-coupled CHP is from EPA's CHP catalog [13]; while the cost breakdown for converter-interfaced CHP is adjusted based on our team's engineering judgment and communications with CHP developers. The converter is manufactured as a package, including the power electronics hardware, the control systems, and the switchgear. The interconnection costs are significantly reduced with a grid ready converter, as well as the soft costs required for compliance with the grid code in order to obtain "Permission To Operate". When compared to directly-coupled CHP, the OPEX for converter-interfaced CHP is slightly higher, due to the additional maintenance cost of the converter.

TABLE II. FINANCIAL PARAMETERS

Equity hurdle rate [%]	9%	**Federal tax**	21%
Insurance rate [% of CAPEX/year]	0.5	**Property tax [% of CAPEX/year]**	0.22%
Project life [year]	20	**Debt rate [%/year]**	4.50%
Depreciation schedule	15	**Debt tenor [year]**	15
Investment tax credit	10%	**Debt [%]**	80%
State tax	4%	**Equity [%]**	20%

1. Business energy investment tax credit.

TABLE III. PARAMETERS FOR CAPEX AND OPEX

	Directly-coupled	Converter-interfaced
CHP-primary mover [\$/kW]	262.5	262.5
CHP-gen[\$/kVA]	112.5	112.5
CHP-converter[\$/kVA]	/	70
Heat Recovery[\$/kW]	500	500
Interconnect/Electrical[\$/kW]	100	20
Exhaust Gas Treatment[\$/kW]	500	500
Engineering and Fees[\$/kW]	175	87.5
Labor/Materials[\$/kW]	369	376.4
soft cost [\$/kW]	347	294.9
O&M cost[\$/MWh]	19	19

Table IV shows the results of the timeseries simulations and annualized ROI calculations.

TABLE IV. RESULTS OF TIMESERIES SIMULATION AND ROI

	Directly-coupled	Converter-interfaced
Engine size, kW	2200	2200
Generator size, kVA	3000	2310
Converter size, kVA	/	2500
Capacity to peak ratio	1.005	1.005
Annual CHP output, kWh	12,607,529.34	12,732,548.99
Annual exportable CHP, kWh	5,671,091.46	5,508,267.01
% CHP usage	97.88%	97.86%
Annual Fuel consumption, MBTU	67,412,891.71	68,001,741.99
Table Annual Energy Cost Savings, \$	\$555,714.07	\$555,620.44
Annual Demand Charge Savings, \$	\$87,802.08	\$87,802.08
Annual Thermal Savings, \$	\$90,195.29	\$90,195.29
Annual Profit from exporting kW, \$	\$178,146.27	\$172,918.23
Annual Profit from exporting kVar, \$	\$1,498.14	\$699.44
Annual Revenue (no fuel cost), \$	\$913,355.85	\$907,235.48
CAPEX, \$	\$5,295,200.00	\$5,100,801.00
ROI	7.04%	8.61%

The two CHP architectures use the same engine size, however, the generator is oversized by 25% for the directly-coupled scenario on accounts of reactive power requirement, while in the converter-interfaced scenario the reactive power is provided by the grid-ready inverter. The converter eliminates the need for oversizing the generator as is the case for traditional CHP systems, hence making the converter-interfaced CHP's CAPEX lower than that of directly-coupled CHP. The hospital user case validates this statement. In the timeseries simulation, the energy efficiency of engine, generator, and converter is evaluated and quantified. For all three subsystems, the energy efficiency is affected by the loading level. In addition, the generator energy efficiency is also affected by the power factor at its terminals [14]. As observed in Table IV, the converter-interfaced CHP system has slightly higher fuel cost. This is due to the additional losses in the converter. Accordingly, the avoided costs on energy supply and demand charge is slightly lower than in the directly-coupled scenario. While the annual revenue in the case of the converter-interfaced CHP is lower, the CAPEX is also lower, making the annualized ROI higher than that of directly-coupled CHP.

2. Other User Cases

The fact sheets for the other four user cases is summarized in Table V. The ROI calculation results are shown in Table VI. It can be observed that except for the large office building in PJM, converter-interfaced CHP has a better economic performance than directly-coupled CHP on ROI. The driving reason is the same as in the NYISO hospital user case; the CAPEX for converter-interfaced CHP is lower (than that of the directly-coupled CHP), which is due to the reduced size of the generator. This allows to pay for the converter and to decrease the interconnection costs. However, there is an exception for the hotel user case in MISO, in which a higher CAPEX is observed for the converter-interfaced option. This is because in this case the converter was heavily oversized since only certain ratings of inverters are available in the open market. This discrepancy is an artifact of the inverter market rather than an exception to the rule.

TABLE V. FACT SHEET OF THE OTHER USER CASES

	College in CAISO	Water Reclamation in ERCOT	Large office in PJM	Hotel in MISO
Location	SF, CA	Dallas, TX	Pittsburg, PA	Minnea-polis, MN
Market sector	Education	Chemical	Large office	Large hotel
Engine size, kW	4400	5200	1480	2600
Engine type	Combus-tion	Combus-tion	Reciprocate	Recipro-cate
Peak load, kW	18227	12500	20147	2859
Capacity to peak ratio	0.241	0.416	0.073	0.909
Average electric load, kW	9703	9328	8474	1664
Average ther load, MBTU	15013	10718	1480	8872
Availability of CHP	95%	95%	98%	98%

TABLE VI. RESULTS OF TIMESERIES SIMULATION AND ANNUALIZED ROI

	College in CAISO		Water Reclamation in ERCOT		Large Office in PJM		Hotel in MISO	
	Directly-coupled CHP	**Converter-interfaced CHP**	**Directly-coupled CHP**	**Converter-interfaced CHP**	**Directly-coupled CHP**	**Converter-interfaced CHP**	**Directly-coupled CHP**	**Converter-interfaced CHP**
Annual Revenue	$4,092,552	$4,019,451	$2,510,753	$2,466,087	$1,012,114	$967,676	$1,591,037	$1,598,206
CAPEX	$10,534,150	$10,201,602	$12,449,450	$12,104,166	$3,554,555	$3,553,980	$4,783,925	$4,928,230
ROI	17.89%	18.80%	10.28%	10.41%	9.96%	6.02%	15.42%	15.53%

VI. CONCLUSION

This paper presents a platform for the evaluation of the economic feasibility of converter-interfaced CHP systems. It includes timeseries simulations and ROI calculations for five user cases known as suitable for CHP application. The user cases were scattered in five different ISO territories to capture the impacts of energy price, load seasonal variations, ancillary services entitlements and utility rates on the system economic performance. The results showed that for the majority of user cases (4 out of 5) analyzed, a converter-interfaced CHP system outperforms a directly-coupled CHP system on ROI. It appears that trading generator capacity for the reactive power capability of grid-ready inverters and the ability to simplify the grid interconnection process is a technically and economically valid approach. This enables a seamless integration of CHP system in the distribution grid and helps increase the adoption of small to medium-sized commercial and industrial CHP applications.

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