Sensitivity analysis of the technical and economic feasibility of converter-interfaced CHP System

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***Abstract*— The adoption of small-to-medium sized (1MW~20MW) combined heat and power (CHP) system is lagging, especially in industrial and commercial applications. Our prior research has proved that interfacing CHP with grid-ready converters can increase its economic value and technical benefits; this paper is focused on investigating the critical parameters impacting profitability of converter-interfaced CHP, including CHP sizing scenario, energy price, generator cost, converter cost, voltage support price, converter to engine size ratio and interconnection delay. An automatic toolkit for evaluating CHP return on investment (ROI) is developed to enhance the computation capability and efficiency. Based on varying the value of critical parameters, 975 use cases are analyzed. Results show that the profitability of converter-interfaced CHP over directly-coupled CHP is more sensitive to energy price, delays in interconnection process, converter cost and much less to generator cost or voltage support price.**

Keywords*— *converter, CHP, ROI, economic feasibility, sensitivity analysis

I. Introduction

Converter-interfaced CHP system (Fig.1.) can overcome the barriers challenging the adoption of small-to-medium sized CHP applications, which can remove the requirement for oversizing the CHP generator, limit the short-circuit contribution of the generator and simplify the grid integration process [1]. Prior literature [2-6] have proven its profitability for traditional directly-coupled CHP system. We have evaluated and proved the technical viability of converter-interfaced CHP systems in [7-8]. Our prior work ([1]) developed a platform for evaluating annualized ROI for industrial and commercial CHP applications and proved that for majority of the use cases analyzed, a converter-interfaced configuration leads to higher annualized ROI than its directly-coupled counterpart. The dominant drivers making interfacing converter for CHP an economically viable option are: 1) it trades generator size (25%) for converter and achieves greater reactive power capability to support interfacing grid; 2) it significantly reduces interconnection cost and delays.

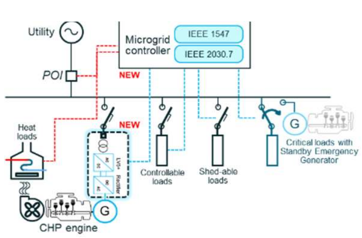


Fig. 1 Diagram of converter-interfaced CHP system

This paper further investigates the profitability of converter-interfaced CHP and analyzes its sensitivity against critical parameters, including CHP sizing scenario, energy price, generator cost, converter cost, voltage support price, converter to engine size ratio and interconnection delay. Such study is performed using an automatic toolkit for CHP ROI evaluation, which is built to enhance computation capability.

The remaining of the paper is organized as follows: Section II introduces the automatic toolkit for CHP ROI evaluation; Section III details the sensitivity analysis on critical parameters while Section IV summarizes the conclusion.

II. Automatic toolkit for CHP ROI evaluation

In [1], the developed platform of economic analysis is consist of two major parts: 1) the timeseries simulation is set up to simulate the CHP system and achieve the consequent performance (such as thermal and electrical energy profile, fuel consumption, exportable power to the grid) and the potential profits of adopting CHP systems from selling energy and ancillary service to the connecting grid; 2) annualized ROI evaluation for CHP system is achieved by evaluating CapEx, OpEx and other financial parameters.

Sensitivity study requires to run tens or even hundreds of scenarios for analyzing the impact of critical parameters, thus the computation capability should be enhanced significantly. Thus, the automatic toolkit for sensitivity study is developed for conducting ROI evaluation, which automates the entire process and extends the capability and efficiency to run more case studies within a limited time frame. As shown in Fig. 2, it starts with assembling the input files. Based on the given parameters for a particular use case, such as location, CHP unit size and financial parameters, it will fetch the corresponding load profile, utility rate, Locational Marginal Pricing (LMP) and ancillary service prices from the pre-established database pool, to generate the required input files and prepare the results file based on the template pool. The input file will pass to conduct timeseries simulation of CHP system, which can obtain hourly performance of the targeting CHP system. Then continue with annualized ROI calculation and post-processing procedures.

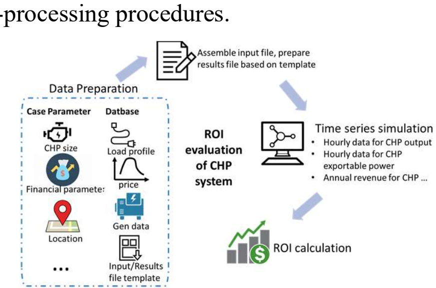


Fig. 2 Automatic toolkit for CHP ROI evaluation

III. Sensitivity analysis

This section conducts the sensitivity analysis on applications and geographical locations of CHP systems, CHP sizing scenario and other critical parameters. Specifically, the converter to engine size ratio is calculated as the installed capacity of converter divided by the installed capacity of prime mover; it indicates the oversizing level when determining the system configuration. The parameter of interconnection delay is the time consumed from the project initiation until "Permission to Operate" is granted by the hosting utility after standard interconnection requirements (such as IEEE 1547) have been satisfied. The interconnection processing time for the directly-coupled CHP system is longer than that of the converter-interfaced configuration and the relative processing time difference is considered as loss of production for the directly-coupled CHP system.

A. Application and location

The 5 representative use cases are extended to 25 scenarios (5 applications across 5 ISO/RTO territories) by investigating all 5 applications in each ISO territory. This captures the variation in load profiles, which is correlated to customer behaviors (e.g. heating and cooling needs are different in CAISO and NYISO). Power to heat ratio, calculated as annual power consumption divided by annual thermal consumption, is a representative factor for characterizing the various applications. Fig.3. describes the power to thermal ratio for the 25 use cases. It can be observed that power to thermal ratio varies through location and application. The factor of location bundles multiple sub-factors, such as fuel price, energy price and ancillary service price. Fig.4. shows the hourly LMP among the 5 ISOs from the market clearing price data in 2018. The dataset is available at each ISO's official website. CAISO has a relatively higher LMP, while NYISO and ERCOT have relatively lower prices. Table I summarizes the parameter settings for the base case.

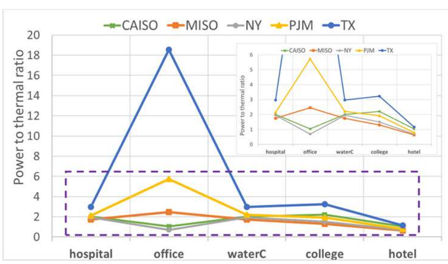


Fig.3 Power to thermal ratio of investigated cases

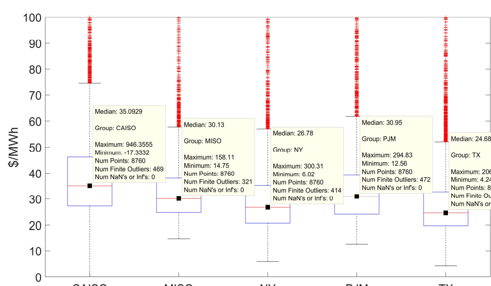


Fig.4 Box plot for hourly LMP in 2018

Applying the 25 use cases in the automatic toolkit for CHP ROI evaluation and yields the results summarized in Table II. The number in each cell represents ΔROI calculated as in equation (1). A positive number indicates that converter-interfaced CHP has a higher ROI in this application than directly-coupled.

$$\Delta ROI = \frac{(ROI_{converter} - ROI_{direct})}{ROI_{direct}} \quad (1)$$

TABLE I. PARAMETER SETTINGS FOR BASE CASE

	Gen. Cost, $/kVA	Converter to engine size ratio			Voltage support price, $/kVar
Hospital	44	1.7		**CAISO**	6
Large office	47	1.69		**MISO**	6
Water Rec.	115	1.25		**NYISO**	2.79
College/Univ.	117	1.42		**PJM**	3
Hotel	44	1.44		**ERCOT**	4

As shown in Table II, for 19 out of 25 cases, the converter-interfaced CHP has a relatively higher annualized ROI with an average increase of 2.3% at ΔROI. From the perspective of locations, CAISO, MISO and ERCOT are highly favorable for converter-interfaced CHP as its comparative ROI is consistently higher than that in the directly-coupled system. Conversely, PJM and NYISO will be challenging territories. From the perspective of application, hospitals and hotels will be regularly more favorable for converter-interfaced CHP. Based on the load profiles studied, college campuses will be the least favorable. Their specific load profiles due to the reduced summer loads and similar condition for winter break are not favorable for installing the converter-interface CHP. Indeed, the efficiency of interfaced converter drops for operating at partial-load condition and this reduces its profitability.

TABLE II. ROI EVALUATION RESULTS

Application	**CAISO**	**MISO**	**NYISO**	**PJM**	**ERCOT**
Hospital	3.98% (18.73%)	3.51% (13.64%)	0.82% (10.26%)	1.25% (9.56%)	2.69% (10.08%)
Large office	9.15% (12.44%)	5.73% (12.87%)	1.94% (11.12%)	**-0.62%** (9.62%)	3.89% (10.08%)
Water Rec.	3.48% (12.95%)	2.51% (11.21%)	**-4.78%** (10.52%)	**-9.68%** (9.68%)	0.70% (10.60%)
College/Univ.	3.06% (14.78%)	1.30% (15.62%)	**-5.39%** (13.67%)	**-8.47%** (11.39%)	**-1.15%** (14.27%)
Hotel	4.67% (18.33%)	5.06% (15.63%)	1.12% (13.61%)	0.85% (13.49%)	2.23% (14.33%)

* number in parentheses is the ROI value for directly-coupled CHP system.

B. CHP sizing scenario

CHP has load following capability and can be set to track either the electrical or the thermal demand. Three common CHP sizing scenarios are observed [9]: average thermal load (denoted as "AvrgThem"), average electric load (denoted as "AvrgElec") and peak electric load (denoted as "PeakElec"). The analysis in Section III.A is based on the most commonly utilized settings– "AvrgThem". Thus, in this subsection, the CHP size is selected to match average electric load (peak electric load) in scenario of "AvrgElec" ("PeakElec"). An additional 50 use cases are investigated through the toolkit of CHP ROI evaluation and the results are summarized in Table III and Table IV. Winning rate is defined as the proportion of use cases with positive ΔROI to the total number of use cases investigated. The winning rate for "AvrgElec" and "PeakElec" is 72% and 68%, respectively. Fig.5. describes ΔROI of each use case among the three CHP sizing scenarios. There are 19 cases in which the standard deviation of ΔROI is less than 3%, which indicates that CHP sizing scenario does not significantly impact the performance on relative profitability of converter-interfaced CHP to directly-coupled. For "WaterCNY", "HospitalPJM" and "officeTX", the best performance varies with CHP sizing scenario; while for "WaterCMISO", "officePJM", and "waterCTX", there is no change in the best sizing scenario but the standard deviation of ΔROI is larger than 3%. The varying factor behinds CHP sizing scenario is actually the prime mover size. Take "HospitalPJM" as an example, the prime mover size is 2200 kW, 4800 kW and 6800 kW for "AvrgThem", "AvrgElec" and "PeakElec", respectively, while the corresponding ΔROI is 1.25%, 1.52% and -6.2%. One explanation could be the tradeoff between increased revenue and increased CapEx. If the revenue increase dominates (from "AvrgThem" to "AvrgElec"), the converter-interfaced CHP is observed to win more in profitability; if the CapEx increase dominates (from "AvrgElec" to "PeakElec"), converter-interfaced CHP loses in the profitability competition. However, this observation may not generalize to all hospital cases in PJM territory, since the relative profitability of converter-interfaced CHP to directly-coupled is impacted by multiple factors. This study can only conclude that for most investigated use cases, CHP sizing scenario does not have a statistically significant effect on ΔROI; however, we recommend that the decisions on the CHP installation size should be made after evaluating all three CHP sizing scenarios, for a particular use case.

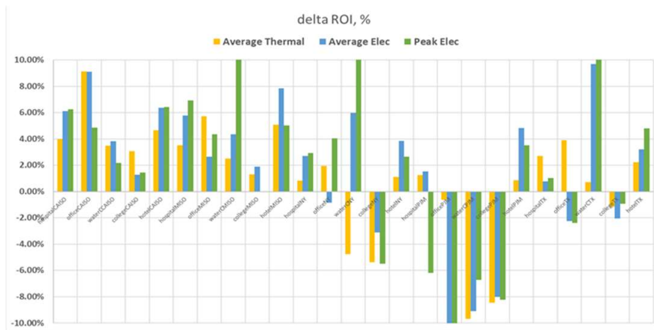


Fig.5 ΔROI for each use case by different CHP sizing scenarios

TABLE III. ROI EVALUATION RESULTS ("AVRGELEC")

Application	CAISO	MISO	NYISO	PJM	ERCOT
Hospital	6.12%	5.78%	3.50%	1.52%	1.17%
Large office	9.10%	2.65%	2.39%	**-88.72%**	**-1.36%**
Water Rec.	3.83%	4.35%	5.98%	**-9.11%**	9.70%
College/Univ.	1.84%	1.88%	**-2.10%**	**-6.90%**	**-1.27%**
Hotel	6.38%	7.85%	3.86%	6.52%	3.98%

TABLE IV. ROI EVALUATION RESULTS ("PEAKELEC")

Application	CAISO	MISO	NYISO	PJM	ERCOT
Hospital	6.26%	6.92%	2.93%	**-6.20%**	1.02%
Large office	4.85%	4.34%	4.03%	**-18.24%**	**-2.39%**
Water Rec.	2.17%	22.34%	157.02%	**-6.73%**	49.66%
College/Univ.	1.43%	**-0.03%**	**-5.49%**	**-8.24%**	**-0.93%**
Hotel	6.41%	5.02%	2.65%	3.52%	4.81%

C. Sensitivity analysis on critical parameters

As discussed previously, the ROI evaluation is a complex process and many parameters contribute to it. We narrowed the sensitivity analysis to 6 most critical parameters for the converter-interfaced configuration, including energy price, voltage support price, converter and generator cost, converter to engine size ratio and interconnection delay. For CHP sizing by average thermal load, varying the value of these parameters as described in Table V leads to 325 cases.

TABLE V. CRITICAL PARAMETERS AND VARYING SCENARIOS

Critical Parameters	Varying Scenario	Critical Parameters	Varying Scenario
Energy price	Up 50%; Dn 50%	Generator cost	Up 25%; Dn 25%
Voltage support price	Up 50%; Dn 50%	Converter to engine size ratio	Up 25%; Dn 25%
Converter cost	4 cent/W; 8 cent/W	Interconnection delay	6 months; 18 months

The results are summarized in Table VI. They are shade-coded. Darker shades indicate that the relative profitability of converter-interfaced CHP to directly-coupled is more sensitive to the variation of that parameter. The overall conclusion is that the profitability of converter-interfaced CHP is highly sensitive to energy price, interconnection delay, converter cost and almost insensitive to generator cost and voltage support price. The possible reasons are analyzed in the subsections.

1) Generator cost

Converter-interfaced CHP trades generator cost for converter cost. When generator cost increases (e.g. due to size), it is favorable for this option. However, take water reclamation use case in NY as an example (shown in Table VII), with generator cost declines by 25%, the CapEx for converter-interfaced CHP decreases about $34k, while $38k decrease for directly-coupled CHP. The CapEx gap does decline from $32k to $28k. However, directly-coupled CHP has relatively larger revenue, which dominates the change and makes the converter-interfaced CHP still not win the comparison. Thus, in the investigated cases, generator cost does not significantly change the win position of converter-interfaced CHP.

TABLE VI. SENSITIVITY ANALYSIS ON CRITICAL PARAMETERS

Critical Parameter	Change in winning rate	Average change of ΔROI	Standard deviation of change in ΔROI
Energy price up 50%	24.00%	2.75%	-2.40%
Energy price dn 50%	-36.00%	-21.33%	57.33%
Converter cost at 8¢/W	-36.00%	-2.61%	0.41%
Converter cost at 4¢/W	8.00%	2.68%	-0.27%
Converter to engine size ratio up 25%	-36.00%	-3.10%	1.92%
Converter to engine size ratio dn 25%	8.00%	1.65%	0.08%
Intercnntn delay as 18 months	8.00%	2.34%	0.89%
Intercnntn delay as 6 months	-36.00%	-2.22%	-0.78%
Generator cost up 25%	0.00%	0.23%	-0.03%
Generator cost down 25%	0.00%	-0.23%	0.02%
Voltage support price up 50%	0.00%	0.17%	0.11%
Voltage support price dn 50%	0.00%	-0.17%	-0.08%

2) Converter cost

As mentioned in the previous section, directly-coupled CHP is required to size the generator to 125% of engine size for reactive power provision; while for converter-interfaced CHP, due to the presence of the converter, the generator does not need to provide reactive power and therefore can be sized exactly to the engine. The saving on generator cost allows to partly offset the cost of the converter as observed in the CapEx in most of the investigated cases. When converter cost increases by 50% from 6 ¢/W , the converter-interfaced CHP becomes less profitable, resulting in a 36% lower winning rate (shown in Table VI). When converter price reduces to 4 ¢/W, converter-interfaced CHP has slightly higher profitability and there is an 8% increase in its wining rate. It does not increase the winning rate significantly since the current converter price at 6 ¢//W is already favorable.

3) Energy price

The profitability of converter-interfaced CHP changes in the same direction as energy price varies. The winning rate increases by 24% when energy price goes up by 50% from the baseline value. Table VIII gives the example of the water reclamation case in ERCOT. Converter-interfaced CHP has relatively less efficiency due to additional energy loss in the converter in particular for low load conditions. The difference in yearly revenue can be estimated as $(\eta_{direct} - \eta_{converter}) \times LMP \times 8760$ (η is effeciency). When the energy price increases, there are two effects, one is that because of the lower efficiency of converter interfaced CHP, the revenue gap increases from $2k to $4k; the other effect is that for directly-coupled option, the production loss due to interconnection delay increases by around $140k, which dominates the overall impact. Thus, higher increased energy prices significantly favor converter-interfaced CHP configuration.

TABLE VII. WATER RECLAMATION USE CASE IN NY

	Base case		Generator cost goes down 25%	
	Directly coupled	Converter interfaced	Directly coupled	Converter interfaced
Engine size, kW	1000	1000	1000	1000
Generator size, kVA	1320	1175	1320	1175
Converter size, kVA	/	1250	/	1250
Annual CHP output, kWh	6,165,883.50	6,194,046.43	6,165,883.50	6,194,046.43
Annual exportable CHP, kWh	1,714,235.37	1,672,884.92	1,714,235.37	1,672,884.92
% CHP usage	35.19%	35.00%	35.19%	35.00%
Annual Fuel consumption, MBTU	29592200.43	29560361.07	29592200.43	29560361.07
Annual Energy Cost Savings, $	$270,170.54	$268,678.05	$270,170.54	$268,678.05
Annual Demand Charge Savings, $	$40,423.68	$40,019.44	$40,423.68	$40,019.44
Annual Thermal Savings, $	$87,016.48	$86,930.82	$87,016.48	$86,930.82
Annual Profit from exporting kW, $	$54,756.87	$53,461.15	$54,756.87	$53,461.15
Annual Profit from exporting kVar, $	$0.00	$0.00	$0.00	$0.00
Annual Revenue (no fuel cost), $	$452,367.56	$450,414.87	$452,367.56	$450,414.87
CAPEX, $	**$3,032,224.47**	**$3,000,476.82**	**$2,994,274.47**	**$2,966,695.57**
ROI	**10.52%**	**10.02%**	**10.96%**	**10.42%**

TABLE VIII. WATER RECLAMATION CASE IN ERCOT

	Base case		Energy price goes up 50%	
	Directly coupled	**Converter interfaced**	**Directly coupled**	**Converter interfaced**
Engine size, kW	1000	1000	1000	1000
Generator size, kVA	1320	1175	1320	1175
Converter size, kVA	/	1250	/	1250
Annual CHP output, kWh	6,165,883.50	6,194,046.43	6,165,883.50	6,194,046.43
Annual exportable CHP, kWh	1,714,235.37	1,672,884.92	1,714,235.37	1,672,884.92
% CHP usage 1	35.19%	35.00%	35.19%	35.00%
Annual Fuel consumption, MBTU	29602414.03	29567867.96	29602414.03	29567867.96
Annual Energy Cost Savings, $	$283,347.00	$281,907.04	$425,020.50	$422,860.57
Annual Demand Charge Savings, $	$45,936.00	$45,476.64	$45,936.00	$45,476.64
Annual Thermal Savings, $	$71,149.38	$71,071.33	$71,149.38	$71,071.33
Annual Profit from exporting kW, $	$69,976.91	$68,314.30	$104,965.37	$102,471.45
Annual Profit from exporting kVar, $	$0.00	$0.00	$0.00	$0.00
Annual Revenue, $	$470,409.30	$468,179.40	$647,071.26	$643,995.12
CAPEX, $	**$3,032,224.47**	**$3,000,476.82**	**$3,032,224.47**	**$3,000,476.82**
Interconnection delay	**$90,832.22**	**/**	**$230,339.34**	**/**
ROI	**10.60%**	**10.67%**	**25.60%**	**26.42%**

4) Voltage support price

Voltage support price is related to revenue attained from exporting reactive power to the utility grid. With higher voltage support price, converter-interfaced CHP will have more revenue and is expected to have a higher winning rate. However, only 8 out of 25 use cases (5 application across 5 locations) have non-zero revenue from exporting reactive power, and in all these cases the converter-interfaced CHP is already preferred. Higher voltage support price just makes converter-interfaced CHP win by a greater margin, as shown in average change of ΔROI, but it does not move the overall winning rate, as shown in Table VI.

5) Converter to engine size ratio

As manufactured converter sizes take discrete values, we utilize 1250kVA as size increments in this study. As mentioned previously, the converter is oversized to be at least 125% of the engine in order to be able to operate at 0.8 pf at full load as required for directly-coupled. Discretely sized available products aggravate the oversizing. Take the use case "Hotel in PJM" as an example, with converter to engine size ratio increases by 25%, there are two factors taking effects. One effect is that CapEx increases by $75k and the other effect is that with increasing available capacity from the converter, a significant revenue increase is observed from providing voltage support, however, this portion of increase is only $4.5k/year. Estimate for 20 years (project life) in total is about $90k revenue increase, however, larger CapEx has multiple effects, such as rising debt payment, tax, insurance and other related payments, making yearly net cash flow increase less than $4.5k. The combined consequence is that annualized ROI decreases and loses the competition to directly-coupled CHP. Thus, the CapEx increase dominates this comparison, making oversizing the converter unfavorable for converter-interfaced

CHP despite the potential increased revenue from voltage support.

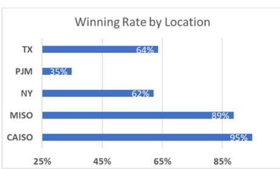
The change in winning rate is not significant when bringing down the converter to engine size ratio, because for the majority of the use cases, the converter size is quite close to 1.25X of the engine size, which is lower bound. Considering the technical constraints, the winning rate does increase slightly when less oversizing converter but not that significantly as the opposite direction.

6) Interconnection delay

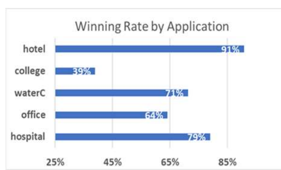
The longer delay in interconnection procedures indicates a larger production loss for directly-coupled CHP, and the converter-interfaced CHP has a better chance to win since it can collect revenues sooner than the directly-coupled option. Thus, when the interconnection delay is reduced to 6 months from 1 year, the winning chance declines by 36%. However, when the loss of produce increases from 1 year to 18 months, the winning rate of converter-interfaced CHP only decreases by 8%, which indicates that the 1 year baseline is already highly favorable to converter-interfaced CHP.

D. Other observations

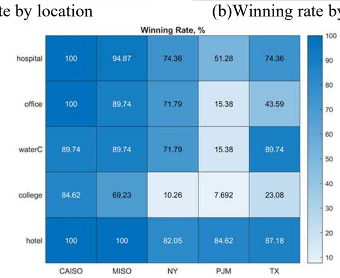
In order to achieve more general conclusions about the winning rate of a predefined cases, the critical parameters variations are repeated for CHP sizing scenarios as in “AvrgElec” and “PeakElec”. Thus, a total of 975 use cases are evaluated and the results are summarized in Fig.6.



(a)Winning rate by location



(b)Winning rate by application



(c)Heatmap of winning rate by use case

Fig.6. Winning rate by location, application and use case

For MISO and CAISO, converter-interfaced CHP is highly favorable; for ERCOT and NYISO typically favorable while for PJM, a case by case analysis should be conducted before selecting this option. In terms of application, except for offices and college campuses, a converter-interfaced CHP is likely to be more profitable than a directly-coupled installation. Fig.6(c) provides the winning rate for each individual case, which could serve as a reference when a developer making selections on CHP type. In CAISO and MISO territories, converter-interfaced CHP should be adopted regardless of the application as this could bring more revenue from voltage support, which leverages the relatively higher payment that service in those territories.

IV. Conclusion

This paper develops an automatic toolkit for evaluating annualized ROI of CHP system, which saves extensive labor work in accessing CHP use cases, especially in sensitivity study. Based on this toolkit, this paper calculates the ROI of converter-interfaced CHP in different scenarios and analyze the sensitivity of its profitability compared to directly-coupled CHP against critical parameters, including interconnection delays, converter to engine size ratio, generator and converter costs, energy and voltage support price. Results obtained suggest that the comparative profitability of converter-interfaced CHP is more sensitive to energy price, interconnection delays and sizing of the interface converter. Indeed, a decrease of energy price or overly sized interface converter drastically changes the number of winning cases for converter-interfaced CHP due to the penalty on efficiency and low value of voltage support. However, the profitability of converter-interfaced becomes extremely robust and insensitive to most parameters variations if interconnection delays of directly-coupled are higher than 12 months, which can be typical. It is also observed that the territories of CAISO and MISO tend to be more favorable for installing converter-interfaced CHP; while hotel and hospital applications are ideal candidates for implementing converter-interfaced CHP.

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References

[1] X. Guo, I. Ndiaye, etc. “Feasibility Analysis of Converter-Interfaced Combined Heat and Power System.” IEEE PES General Meeting 2020, IEEE, 2020.

[2] Mone, C. D., D. S. Chau, etc. "Economic feasibility of combined heat and power and absorption refrigeration with commercially available gas turbines." Energy Conversion and Management 42, no. 13 (2001): 1559-1573.

[3] X. Q. Kong, R. Z. Wang, etc. "Energy efficiency and economic feasibility of CCHP driven by stirling engine." Energy Conversion and Management 45, no. 9-10 (2004): 1433-1442.

[4] Wood, S. R., and P. N. Rowley. "A techno-economic analysis of small-scale, biomass-fuelled combined heat and power for community housing." Biomass and Bioenergy 35, no. 9 (2011): 3849-3858.

[5] N. Isa, H.Das, etc. "A techno-economic assessment of a combined heat and power photovoltaic/fuel cell/battery energy system in Malaysia hospital." Energy 112 (2016): 75-90.

[6] J. Wang, C. Zhang, etc. "Multi-criteria analysis of combined cooling, heating and power systems in different climate zones in China." Applied Energy 87, no. 4 (2010): 1247-1259.

[7] H. Liu, I. Ndiaye, etc. "Harmonics and Stability Evaluation of Converter- Interfaced Combined Heat and Power Units", to be presented at IEEE T&D 2020.

[8] Y. Jiang, I. Ndiaye, etc. "Integration Study of Converter-Interfaced Combined Heat and Power Plants ", to be presented at IEEE T&D 2020.

[9] Centrica Buisness Solutions. A guide to CHP unit sizing. https://www.centricabusinesssolutions.ie/sites/g/files/qehiga126/files/CBS_TECH_CHP_Unit%20sizing%20guide_A4_RGB.pdf.