TOP 10 REASONS TO CHOOSE INVERTER-BASED ENGINE CHP

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Combined Heat and Power (CHP) recovers the waste energy of power generation and utilizes it as heat. CHP can describe large megawatt power plants or small-scale power generation technologies down to a few kilowatts. In fact, CHP is most efficient when the heating load is in close proximity to the electricity generation. In this sub-megawatt size, CHP applications include not only natural-gas reciprocating engines, but newer technologies such as fuel cells and microturbines.

Until recently, there have been two options for engine-driven power generation: synchronous-based machines or induction-based machines. The terms "induction" and "synchronous" describe the method of electricity production. A synchronous generator can excite or magnetize its own rotor, without relying on an external source such as the grid, and thus generate its own reactive energy[1]. This allows a synchronous generator to operate either connected to the grid or in a standalone situation.

By contrast, induction generators are not able to operate without external excitation from the grid. Upon rotation of an induction generator, the external source produces a magnetic flux. If the generator turns slower than the 60 Hz frequency of the grid (e.g., < 1800 rpm), the induction machine will act like a motor, but if it rotates faster than 60 Hz (e.g., 1820 rpm), the induction machine will generate power. Since induction generators are not operational during black start situations, their applications are limited to cogeneration, as opposed to prime power or standalone applications.

However, the emergence of alternative power generation technologies, such as microturbines, fuel cells, and photovoltaics, has led to advancements in secondary (electrical generating) system platforms in the form of conventional power conversion semiconductor technology, or inverters. An inverter takes DC energy and converts it to AC power, of any voltage or frequency, using semiconductor switching devices (i.e., thyristors, diodes). IC engine-based generation can now leverage these progressive secondary systems along with their own inherent benefits in the sub-megawatt size, namely: attractive first cost, high efficiency, durability and serviceability, and high-grade heat recovery.

As such, the "Top Ten Reasons" to choose Inverter-Based Engine-Driven CHP are as follows:

1. ***BLACK START CAPABILITY*** for convenience power in an outage
2. ***PREMIUM QUALITY WAVE FORM*** with voltage and power factor for special applications (e.g., computer server farms or precision instrumentation)
3. ***UTILITY FRIENDLY*** with low fault current contribution and no reactive power draw

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[1] Reactive power is a component of AC power transmission, due to inductive and capacitive network elements (e.g., motors), that is temporarily stored and then returned to the source. Reactive power is needed to support the transfer of real power over a network; it does not transfer energy.

4. ***STANDARDIZED INTERCONNECTION – UL1741 CERTIFIED***
5. ***MICROGRID COMPATIBLE*** with licensed CERTS[2] power balancing control software
6. ***ENHANCED EFFICIENCY*** from variable speed operation
7. ***PEAK-SHAVING*** at higher than normal outputs for short duration
8. ***ABILITY TO HANDLE NON-LINEAR AND UNBALANCED LOAD***
9. ***RENEWABLE ENERGY COMPATIBLE*** with ease of integration with DC outputs from renewable energy sources such as photovoltaic system**s**
10. ***EASILY ADAPTABLE TO GLOBAL POWER GRIDS*** like the European 400 VAC, 50 Hz power grid

The following discussion will first explore a detailed review of the conventional design approaches for CHP power generation, synchronous and induction, and their limitations. This will provide the foundation for a more in-depth explanation of the compelling benefits of Inverter-Based Engine-Driven CHP.

WHY NOT SYNCHRONOUS?

The principle advantages of a synchronous generator are standalone capability (i.e., ability to power the facility during a blackout) and non-reliance on the utility for magnetizing current or reactive power. Standalone or "black start" operation is increasingly demanded by customers, given recent security concerns for the central power grid and also the well-publicized blackouts in the US and in Europe. Regarding the reactive power issue – while it does not impact system efficiency per se, except in line losses – the positive attributes of the synchronous machine are a definite plus. However, and despite these advantages, the synchronous generator is almost never applied to small CHP packages. The following problems make small, synchronous packages impractical.

- ***Extreme Resistance by Utilities to Grant Interconnection Approval without Expensive Safety Relaying Systems***. The standalone feature is a double-edged sword; utility protection engineers fear the CHP unit may unintentionally electrify a portion of the grid during an outage, a hazard for the utility equipment and its workers. In larger more congested regions, the utilities are particularly conservative in how they process interconnect applications involving synchronous generators. PG&E in Northern California, for example, requires two completely redundant safety systems commensurate with substation design practice, an impossible economic burden on a small CHP project. The New York utility, Consolidated Edison, likewise imposes onerous requirements in most of their system for synchronous-based systems, which essentially bars their use in sub-megawatt applications.
- ***Complexity of Synchronous System Controls***. In its most common application, the small synchronous generator is used as a singular, standby power source. That is, one solitary unit sized for the emergency load of the facility. The controls in these circumstances are simple and reliable. When used in CHP applications, on the other hand, the control design complexity changes dramatically. The unit must be set up to operate in a dual mode: both paralleled to the grid or standalone. This involves a complex

[2] The Consortium for Electric Reliability Technology Solutions (CERTS) was formed in 1999 to research, develop, and disseminate new methods, tools, and technologies to protect and enhance the reliability of the U.S. electric power system and efficiency of competitive electricity markets. For more information, go to http://certs.lbl.gov/

arrangement of synchronizers, reactive power controls, dual-gain governors (one for each mode) and of course safeties to avoid the aforementioned dangers to utility linemen, plus ones to avoid synchronizing errors. However, the most general case will involve multiple units – as one would expect with a modular design philosophy – in which case the control design becomes even more complex (lead/lag, load sharing, reactive power sharing, etc.). While technically feasible, we have found that the added cost of the one-time site-specific electrical engineering design (it must be done on a case-by-case basis) and added service burden (maintenance personnel must be very sophisticated) make the synchronous option not feasible for small packages.

- ***Inability to Obtain Factory Certification for Utility Interconnection***. In principle, many states have processes that permit "fast-track" interconnection permitting. One example used in several states is the so-called Rule 21 – the rule describing the utility interconnection standards in California that provides an innovative solution to obtaining quick and inexpensive interconnect approval for small standard packages: "Simplified Interconnection" for certified or "type-tested" equipment. Certification and the use of certified products is essential for small CHP projects because it allows the interconnection approval process to be brief and inexpensive, and avoids the costly supplemental relays, grounding banks, etc. that would otherwise be required. Instead, pre-certified equipment only must meet several brief site screens and, if passed, the approval will be given in 10 days using only the onboard, factory-supplied safeties on the CHP module. This is a vast improvement in time and cost over the older process. In practice, however, there is extreme resistance to granting certification to any synchronous-based machine. In fact, California Rule 21 certification of any synchronous unit is, for all practical intents, an impossibility; in the Rule's policy development period, PG&E announced in the "Working Group", through which certification is administered, that its representative will strongly oppose certification applications for synchronous products indefinitely[3]. This stance had national impact, as other states use the Rule 21 certification as the default system for establishing certified status. In any case, no synchronous product has been certified or attempted the process to our knowledge.

THE LIMITATIONS OF INDUCTION AC GENERATION

As a consequence of these issues, the small reciprocating engine CHP market is dominated by induction-based products. Induction generators require no paralleling equipment and can be installed in multiples with no inter-unit control requirement – a truly modular design on the electrical interface side. However, induction-based units still have their shortcomings:

[3] Strictly speaking, a synchronous product could be certified for voltage and frequency protection. However full certification requires "anti-islanding" certification for which synchronous generators are not being considered, per the above mentioned PG&E policy. Only full certification matters, however, as the cost of installing anti-islanding protection is virtually the same as installing full protection since multifunction relays are used. It should be noted that synchronous products can still be granted interconnect approval -- it is just that their applications must follow the more traditional, rigorous approach and include reverse power protection at the utility/site interface in lieu of anti-islanding certification, often a very expensive project adder.

- ***Inability to Operate During a Blackout.*** The inherent safety and simplicity of induction generators is the reverse "double-edge sword" of the synchronous unit; namely, as a consequence of being inherently safe, the unit is inoperable during a power outage.

- ***Reliance on Utility Reactive Power for Rotor Magnetizing Current.*** Induction generators require a substantial amount of reactive power, not a significant efficiency impact, but still an added amperage burden for an overstrained grid. Utility engineers are aware of this dependence and, have successfully implemented payback strategies for this otherwise uncompensated assistance. LADWP penalizes customers in their rate structure for power factor when a CHP unit is present in the facility. Also, some state incentive programs such as the California Self-Generation Program will not grant a rebate unless this problem is mitigated with power-factor correction capacitors.

- ***Utility Resistance to Interconnect Applications***. There is a policy in the interpretation of Rule 21 by some utilities to apply DG interconnection requirements along two classes of equipment: *inverter-based* and *machine-based*[4]. The latter is a term for all AC generators, both induction and synchronous. PG&E's "White Paper" on its interconnect policy is clearly prejudicial against machine-based products[5]. PG&E's technical members on the Rule 21 Working Group made it clear that they will oppose machine-based product certification in the future, unless much more stringent generator-specific requirements are added to the type-testing procedure[6]. Since there is no IEEE committee working toward this end, the consequences are clear: the option of certification of machine-based products in California is unavailable. Since the inverter-only policy was adopted, the Working Group was disbanded and the subject closed and in the subsequent years, no machine-based product has been certified, while hundreds of inverter-based systems (primarily, inverters connected to solar, wind, and fuel cells) have achieved certification status. The effects have been national; those manufacturers attempting machine-based system certification have abandoned their efforts and to our knowledge no machine-based systems have achieved certification in any state.

INVERTERS PROVIDE THE ANSWER

Inverter technology is a familiar component in some emerging DG products: solar photovoltaics (PV), fuel cells, and microturbines. Fuel cells and PV produce direct current at a low voltage that is processed through the inverter and related electronics to match the familiar utility voltage waveform (AC/60 Hertz). Most microturbines produce power in a waveform grossly mismatched from that of the utility and therefore require processing through similar power electronics. At initial glance, it would appear that these DG technologies have an extra burden to carry; one from which engine-generator based units are free. In fact, this is no longer the case. Inverter power electronics – due to their large volume base in the variable

[4] PG&E's strong position on this matter is currently unique but their position must be taken seriously as a possible future policy of the others.

[5] For example, and per the "White Paper", machine-based products — regardless of certification status — will require a completely redundant utility protection system. Redundancy is not required for certified inverter-based products. And inter-unit communication links between certified inverters at a facility is permitted in the White Paper, but prohibited for certified machine-based units (certification in such cases is voided).

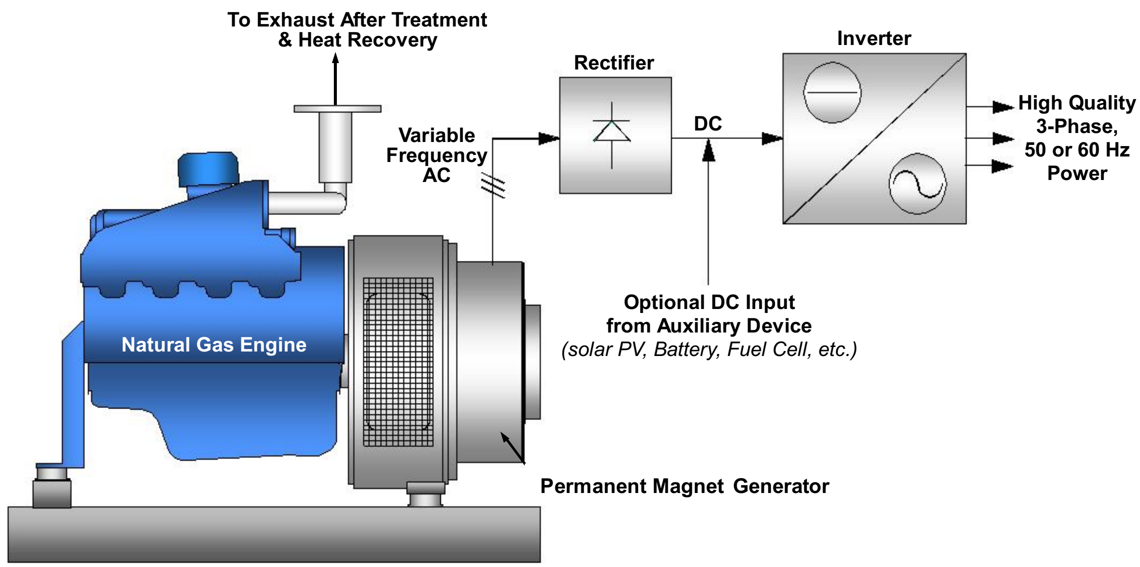
[6] Working Group Bin List Item T102, "Revise certification tests for Synchronous and Induction Machines"

frequency drive (VFD) market – have greatly matured, offering high reliability, 95% efficiency, compact size, and low cost. Moreover, engine-based systems have limitations that would benefit in the same way that these other technologies have from the inverter interface.

INVERTER-BASED ENGINE GENERATOR CONCEPT

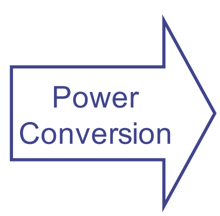
The conceptual design of an inverter-based engine-generator unit is shown in Figure 1. The engine drives a synchronous AC generator, or a permanent magnet generator, while operating at variable speed. In other words, if the generator were a 4-pole design, the engine might operate at 900 rpm to produce the minimum power, but increase its speed to something considerably greater, say 2600 rpm, to make the full rated output. The generator frequencies at these minimum and maximum points would be 30 Hertz (900 rpm) and 87 Hertz (2600 rpm). This variable frequency AC power is first put through a rectifier, a device opposite to an inverter, which converts this variable AC signal to a constant voltage DC signal. The inverter then takes this DC signal, and outputs a near-perfect 60 Hertz waveform to the load, regardless of the input frequency of the generator.

Because the system can now operate at variable rpm, it maintains a high torque regardless of the output, thus maintaining near full-load efficiency throughout its operating range. Additionally, more output can be derived from the same engine if it can be operated to the higher rpm, that is, beyond the typical synchronous speed of 1800 rpm. Another advantage is that the same machine can be applied to the 50 Hertz market, without de-rating or design changes.



Engine/Generator Output

RPM	Volts	Freq (hz)	KW
1000	98	135	39
2200	207	297	93
3000	258	405	130



Delivered kW

Volts	Freq (hz)	KW
480	60	37
480	60	88
480	60	123

FIGURE 1. CONCEPTUAL DESIGN OF INVERTER-BASED ENGINE GENERATOR

TOP 10 REASONS TO CHOOSE INVERTER-BASED CHP

By combining the best attributes of IC Engine-Driven CHP (i.e., a low-cost, highly efficient, and extremely well-supported prime mover) with today's state-of-the-art inverter/semiconductor technology, a modular CHP unit with the features and benefits listed below, is available in a single machine – a truly major innovation in the CHP marketplace.

1. ***BLACK START CAPABILITY*** Since inverter power electronics are coupled with a synchronous generator that is self-excited, off-grid or stand-alone operation is available.

2. ***PREMIUM QUALITY WAVEFORM*** Again, because an inverter can precisely control the frequency of the sine waves, it has excellent power quality with a unity power factor, suitable for computer farms and precision instrumentation. The harmonic content and DC injection meet the toughest industry standards

3. ***UTILITY FRIENDLY*** Inherent in the inverter system design is a limited ability to produce short circuit overload current, unlike with either a synchronous or induction AC generator[7]. Some utilities, such as Con Ed (services 5 NYC boroughs and Westchester), will no longer allow new synchronous generators to be connected to their network because their fault current is too taxing on their network protectors. Additionally, inverters operate at a Power Factor of unity, meaning they have no reactive power requirement. Inverters are also amenable to sophisticated anti-islanding techniques.

4. ***STANDARDIZED INTERCONNECTION – UL 1741*** As described in the discussion on synchronous and induction power generation, utilities pose significant barriers to interconnecting machine-based equipment. However, given the safety attributes stated above, as well as the premium power quality of an inverter (harmonics, DC injection, etc), certification to the nationally recognized UL1741 interconnection standard is unassailable and without controversy or exception.

5. ***MICROGRID COMPATIBLE*** The inverter's ability to precisely control frequency output makes it suitable for the implementation of a sophisticated integrated power balancing algorithm that allows multiple units on a common circuit to operate as an automated microgrid, independent from the grid. A cluster of Tecogen InVerde CHP units can utilize the licensed CERTS software, developed at the University of Wisconsin, to effortlessly and seamlessly align themselves to share the load (both real and reactive power) without complex controls. In fact, this system is "Plug and Play" so units can easily be added to the microgrid or positioned near their thermal loads, but are not tethered to a complicated system of electrical hardware for power control and load sharing. While large CHP systems are not severely impacted by such controls, small systems cannot support the cost and service complexity.

6. ***ENHANCED EFFICIENCY THROUGH VARIABLE-SPEED OPERATION*** As with microturbines, engines – particularly the smaller ones that would be used in modular, prepackaged CHP product – benefit significantly in part-load performance if free to operate over their entire speed range, a benefit obtained by using inverter power electronics. Figure 2 illustrates this point for the Tecogen CM-75/INV-

[7] The degree of concern that an induction generator poses, relative to islanding and short-circuit capability, has been debated for years between manufacturers and utility protection engineers. Suffice to say that if these problems are perceived as reality by the utility community, then they are real.

100 engine. Efficient part-load performance is very desirable in CHP to permit economical operation during reduced load periods. Rather than shutting down at light loads, variable-speed CHP generators can continue to provide both electricity and process heat at high overall thermal efficiencies.

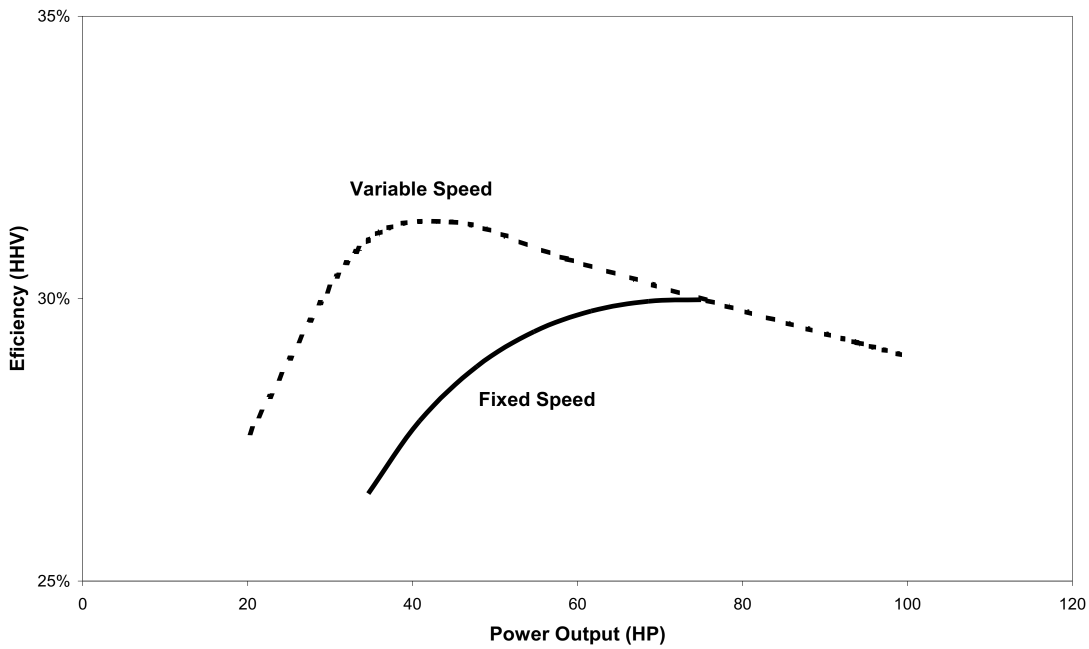


FIGURE 2. ENGINE EFFICIENCY VS. POWER OUTPUT FOR AN ENGINE OPERATING AT FIXED AND VARIABLE SPEED (TECOGEN 75 KW ENGINE)

7. ***PEAK-SHAVING*** Typical AC generators are fixed-speed devices. Tecogen's CM-60/75 models can only run at 1800 rpm where the engine can produce about 100 bhp. When an inverter is used, the engine can be pushed for short periods at higher speeds and therefore proportionally higher output. A 25% increase in output for 200-400 hours per year is a reasonable expectation, based on Tecogen's experience with variable speed compressor products (i.e. chillers).

8. ***ABILITY TO HANDLE NON-LINEAR AND UNBALANCED LOAD*** A standard synchronous generator must be significantly oversized when the required load includes either large motors or non-linear loads. Inverter-based systems are far less impacted by this type of duty and can carry loads of these types at close to their full nameplate rating.

9. ***RENEWABLE ENERGY COMPATIBLE*** A DC output from a renewable energy source, such as a photovoltaic system, can be easily integrated with an IC Engine CHP if it has an inverter interface. As shown in Figure 1, a second variable voltage DC power signal can be delivered to the input side of the inverter. It will then be converted to 3-phase, 60 Hz, AC power to supplement, or offset, the engine's power output.

10. ***EASILY ADAPTABLE TO GLOBAL POWER GRIDS*** Because the inverter is a microprocessor based electronic device, it can be easily programmed for alternative voltages and frequencies to accommodate worldwide power grids. This would come without penalty or de-rating.