

Generator Efficiency Optimization at Remote Sites



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Summary

Remote generation is used extensively to power sites around the world. Generally, these sites are not optimized for efficiency or fuel savings. Various connection and load sharing schemes may help but significant gains may be possible. Site efficiency gains must come from ICE conversion efficiency gains, load and time shifting using power electronics and storage are techniques that can enhance efficiency and reduce fuel consumption while maintaining site stability.

The Go Electric GEM / ISIM micro grid system provides time shifting and stability functions to increase site efficiency. The system also provides additional benefits such as active power factor correction and seamless renewable integration for even greater fuel savings.

This case study models a 1 MW remote site utilizing three 350kW generators with and without the Go Electric GEM/ISM micro grid system. Adding the Go Electric micro grid system improves energy efficiency 27% and conserves up to 396,000 liters of diesel fuel annually.

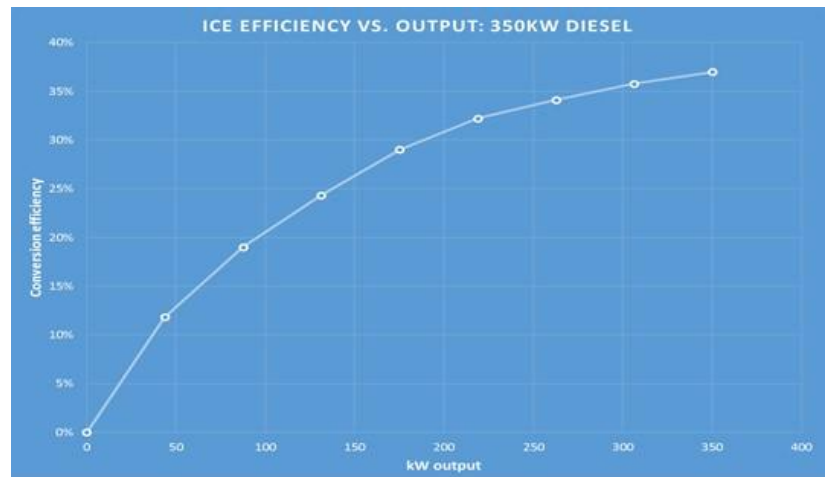
Overview

Utilizing thermal generation for remote sites is a typical and standard practice at various endeavors around the world. Thermal generation efficiency is variable with output. With remote sites, the site load exclusively dictates the local generation and the generation efficiency is a consequence of that load profile. Utilizing a power electronics system with storage to vary the effective load in advantageous ways can lead to sizeable efficiency gains.

Many remote sites operate with local power generation, typically diesel fueled reciprocating engine driven generators. The nature of remote sites requires a generator sized for a maximum potential load while the typical or base loads of a site may be significantly lower than the peak load.

The differences between the maximum and the base can affect the efficiency of electrical energy production from the Internal Combustion Engine, (ICE). Maximizing the efficiency of electrical energy generation can be a significant fuel savings opportunity.

Remote sites are small examples of a larger main interconnected grid; a central power plant supplies an electrical feed consumed by various changing loads. The power plant follows the loads to maintain the specified frequency and voltage within standard limits, the engine speed does not vary however, just the engine torque.



Electrical energy conversion from diesel fuel

Internal combustion engines operate with combinations of fixed and variable losses. Higher operating speeds incur higher fixed losses; higher operating loads incur higher variable losses. Variable losses do not increase as fast as engine output does; generally an engine runs at higher efficiencies at higher, near maximum, loads. As an engine reduces load, the fixed losses consume a larger percentage of the supplied fuel down to a point where the engine output drops to zero but the fuel consumption does not.

Forcing the electrical generation to occur at higher ICE efficiency points requires a total or partial decoupling of the site energy and power requirements from the output of the ICE generation. A large fuel savings can be realized by making the ICE run at higher loads, with higher efficiency, and completely shut off at times of very low site electrical requirements.

Micro Grid Enabled Time Shifting Strategy

A remote site is usually comprised of small numbers of discrete loads and generation, typically with no possibility to connect to the larger 'grid'. This defines a remote micro grid:

'A system of linked sources and loads where individual elements are statistically significant in relation to the total site energy distribution, and where individual loads may make up large percentages, up to and including, the full capacity of the site generation.'

Using this definition, we add a controlled asset to modify the site load and the generator output.

All AC power distribution systems are based on the real time use of generated power, thus the supply and demand always sum to zero. With small numbers of generators and loads, the energy demand and subsequent system efficiency can change rapidly.

Time shifting is a strategy that varies the coupling between generation and demand using power electronics and storage to act as a sink or source for the system. Using time shifting, the energy generation can be moved toward the right side of the graph where less fuel is needed to produce the required electrical energy.

1MW Remote Site Model

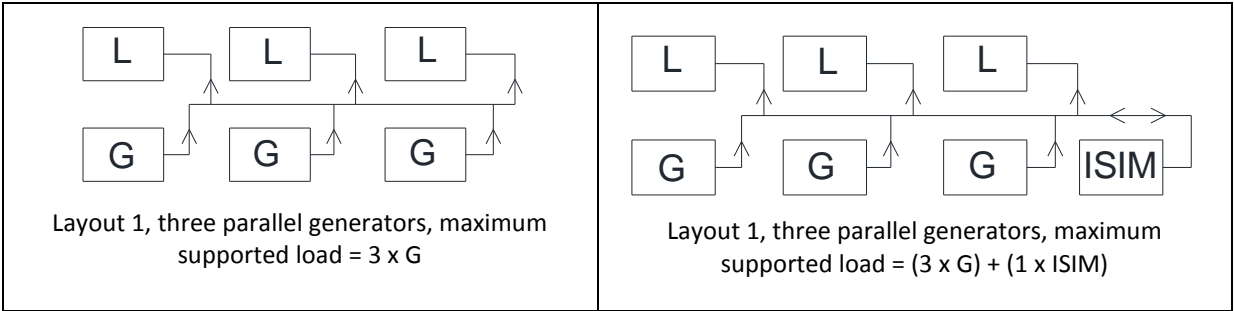
To examine the potential of time shifting on remote site fuel consumption, a model was constructed that allowed variations to the load profile and control scheme.

The model consists of three 350kW generators following the previously defined curves for efficiency and fuel burn along with a paralleling AC bus. An arrangement like this allows the site to maximize the total available power from all generators. The total site power capability is $N \times G$, where G = the maximum power capability of an individual generator and N = the total number of linked generators. The system has a high level of total inertia to balance fast peaks and can evenly spread load across the generators.

The first control simulation considers the three generators as a tied unit where the required generation is split evenly between all three generators, i.e. with a site load of 600kW, each generator would produce 200kW. The divide by N method is usually not the most efficient way to operate a remote grid as the units tend to run towards the left end of the fuel burn and efficiency curves with light to medium site loads.

The second control simulation adds a Go Electric micro grid: power electronics and storage, (ISIM, Integrated Storage and Inverter Module) along with a micro grid controller, (GEM) to time shift energy, (load), so that the generators tend to run at higher efficiency rates and or shut off during times of very low usage.

The utilization of this type of system allows the generators to operate more towards the right side of the efficiency and fuel burn charts. The site energy requirements over a given period remain the same but the conversion efficiency is enhanced. The total instantaneous site power capability is also enhanced to $(N \times G) + (ISIM)$.

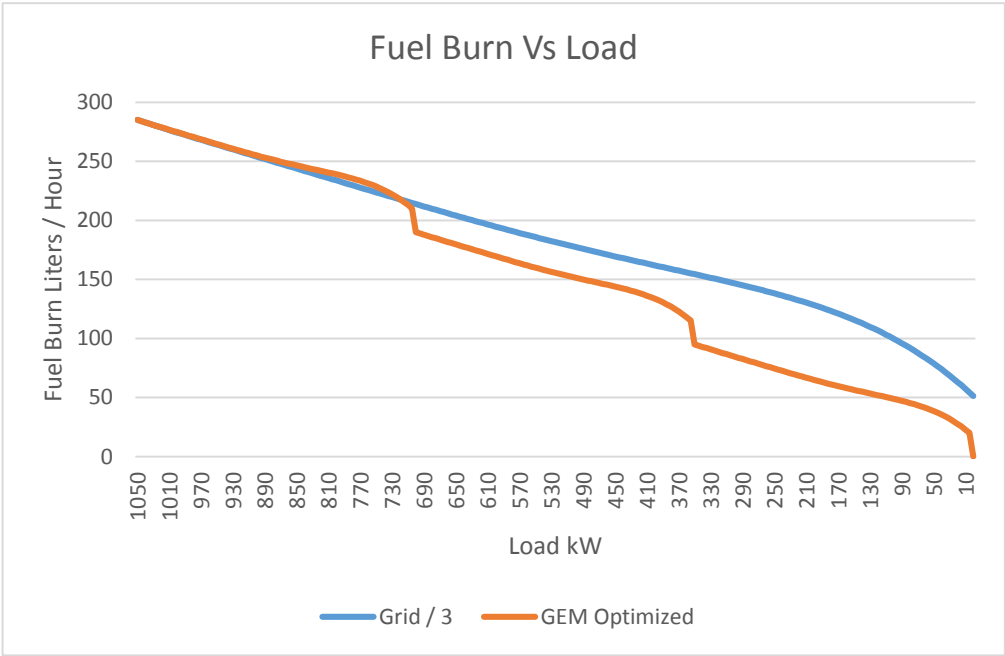


The following graph shows the fuel burn rates for the two different strategies. The upper line, (blue) represents the pure load share system where all three generators run for all loads. The curve follows the same shape as a single unit with a smooth line that goes to a non-zero end point. The lower line, (orange), is the function enhanced with the GEM / ISIM system and load shifting.

The load is not split evenly, rather as the load decreases, one generator out of N generators, (in this case $N = 3$) reduces load while the others stay at a maximum. When the load requirement breaches a level where a generator can shut down, the unit is removed from service and the fuel burn goes to zero for that unit. The shut off points are easily identified on the graph as step function in the lower line.

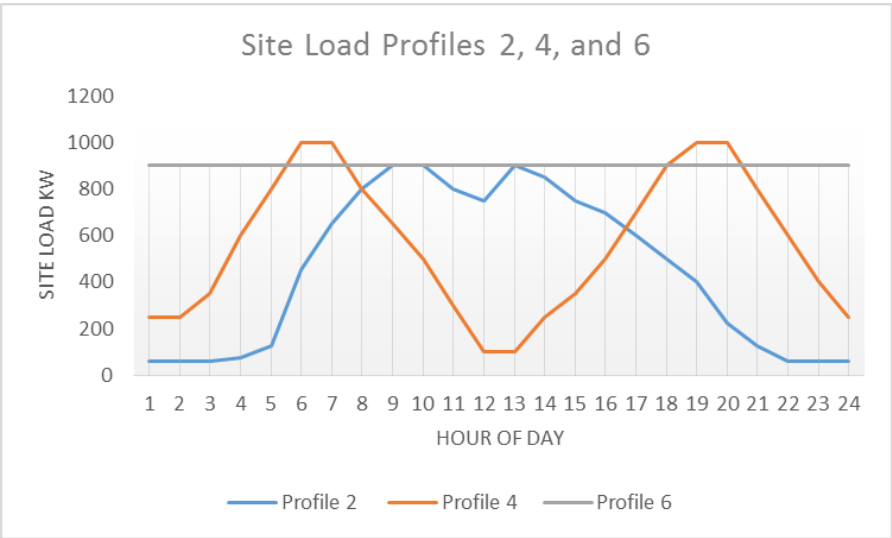
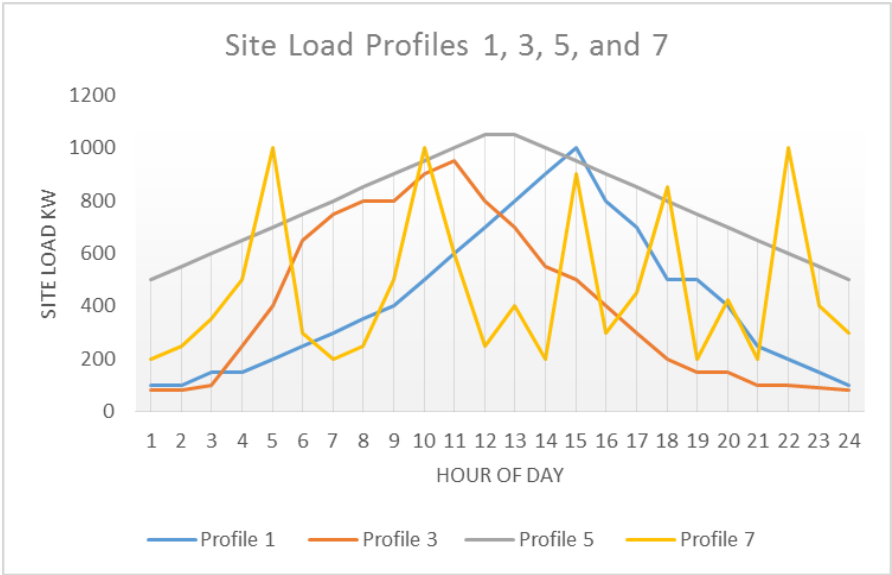
Running generators close to their maximum potential and shutting generation off at the earliest opportune time is made possible by

using the ISIM as a simulated spinning reserve. The ISIM is capable of instantly injecting, (or absorbing) power to balance any fast peaks that may come along, thus no compromise is made to the system stability as the generators are run close to a maximum value.



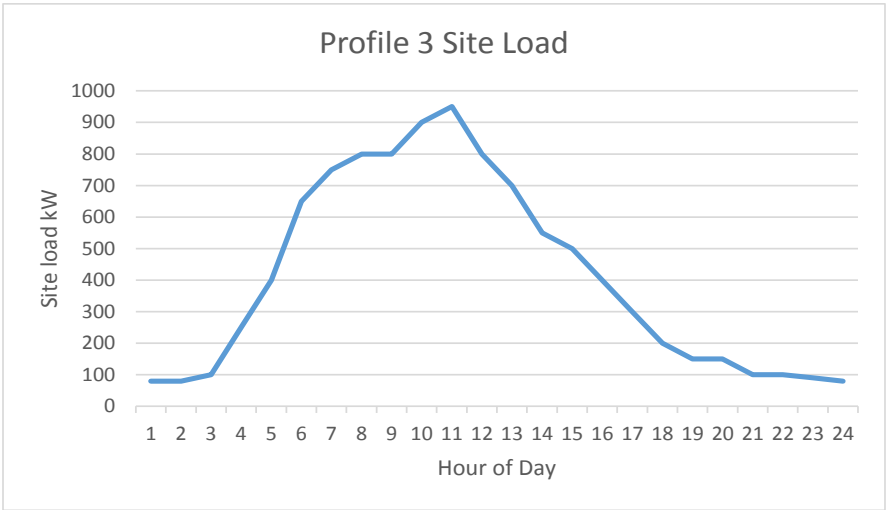
Seven Load Profiles Simulated

Simulations were run on several load profiles to validate the fuel savings potential with a multi generator set. The load profiles are generic with different peaks, valleys and ramp rates, they are intended to envelope various remote site profile possibilities. Profiles 1, 2 and 3 represent slow building long-term peaks that occur at various hours of the day. The peak to valley range is high and the profiles are similar to typical winter or summer profiles for bulk power systems. Profiles 4 and 7 have very high peaks with rapid transitions, while profiles 5 and 6 show very slow changing or non-changing loads.

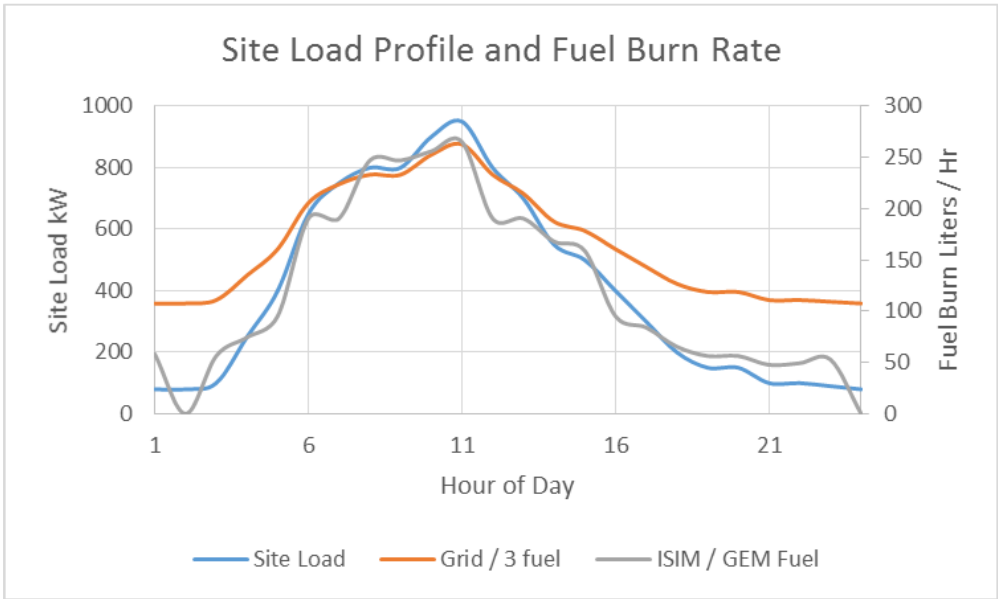


Results

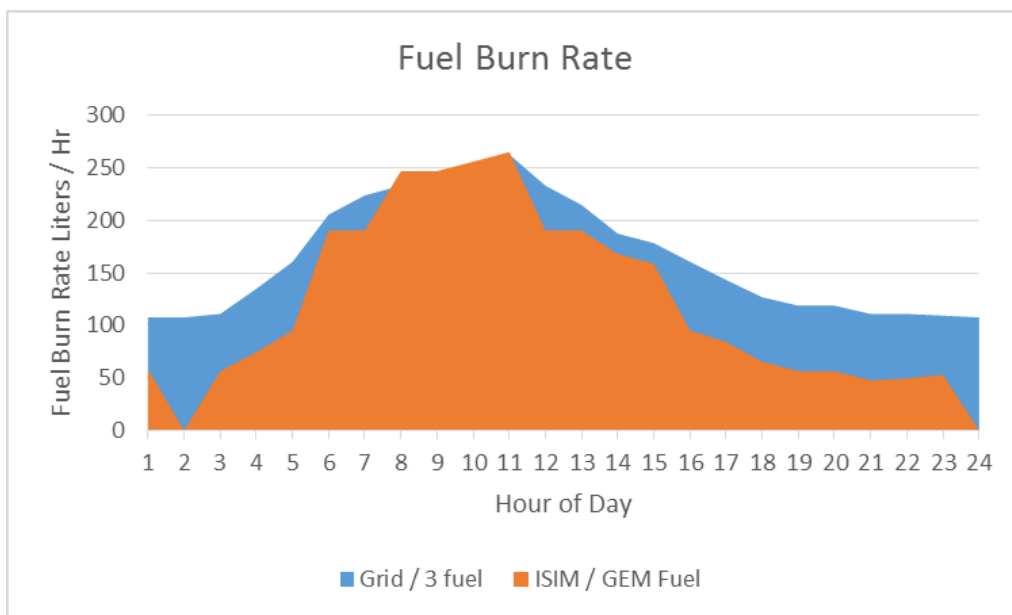
The following data is a more detailed examination of simulated load profile 3, a 24-hour site cycle ranging from an overnight low of 80kW to a mid-day peak of 950kW. The modeled site consists of three, 350kW diesel generators and one 250kW ISIM with 115kW-Hrs of storage and a GEM controller. The simulation was run once with pure load sharing and again with the GEM / ISIM optimization.



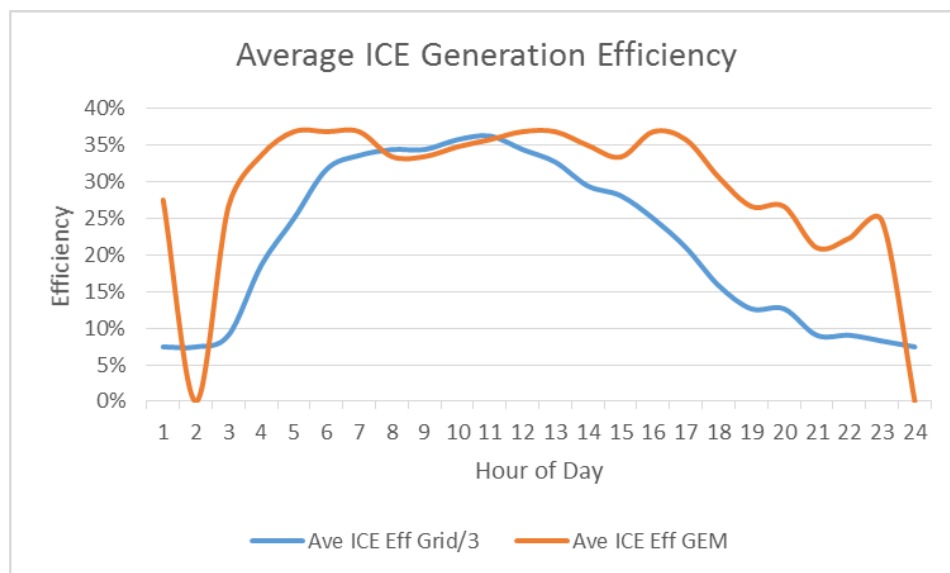
The graph below shows the fuel burn rate against the site load. The GEM / ISIM system, (grey line), has a much lower fuel burn rate than the pure shared load system does, (orange line). The GEM system actually turns off all thermal generation at two points, 0:00 hours and 02:00 hours as the loads are light enough to be carried safely by the ISIM alone.



The burn rate deltas are clearly seen in the chart below. During times of high generation, the GEM time shifting strategy is not operational as the thermal generators are running close to maximum efficiency. As the loads drop, and the generators fall in overall conversion efficiency, the GEM optimizes and balances the loads so that the efficiency is enhanced.



The key to the fuel savings lies in the increased conversion efficiency from the thermal generation. The chart shows the clear gains in efficiency using the GEM / ISIM system. The two locations where the efficiency curve goes to zero are the points where the ISIM is carrying the site load on battery power alone.



The load profile 3 results were compiled to evaluate the total fuel savings potential between the two control methods over the 24-hour profile. The theoretical Minimum estimated fuel required** was also calculated using an assumption that all required site electrical energy could be generated at the maximum fuel efficiency rate from the ICE generators. It is the minimum amount of fuel required to generate the site electrical energy. The comparison summary is listed below.

Load profile study 3 / Energy efficiency gains	
Total site electrical energy	9880 kW-Hrs
Fuel burn estimate with simple grid/3 load sharing	3955 liters Diesel
Fuel burn estimate with ISIM / GEM enhanced load sharing	2898 liters Diesel
Total 24 hour fuel savings	1057 liters Diesel
Minimum estimated fuel required**	2683 liters Diesel
Grid / 3 % of theoretical minimum	147%
GEM % of theoretical minimum	108%

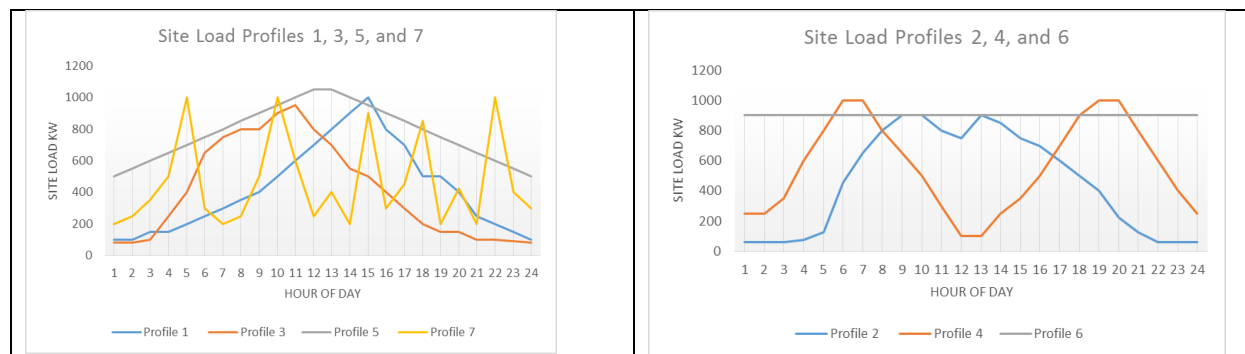
The GEM / ISIM system model saves 1057 liters of fuel in a 24-hour period, or about 26% of the 3955 liters required with the pure load share system. The GEM model show significant improvement over the load share model, operating at only 108% of the theoretical minimum fuel requirement.

The simulation was run on the other six load profiles with various results.

	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	Profile 6	Profile 7	
Electrical Energy	10100	10860	9880	13450	18600	21600	11025	kW-Hrs
Grid / 3	3984	4133	3955	4588	5516	6061	4147	Liters
ISIM / GEM	2899	3171	2898	3774	5238	6100	3161	Liters
Fuel Savings	1085	962	1057	814	278	N/A	986	Liters
Minimum estimated fuel required	2742	2949	2683	3652	5049	5863	2993	Liters
GEM % of theoretical minimum	105.7	107.5	108	103.3	104.6	104	105.6	

Profiles 1, 2, 3, 4, and 7 show significant improvement with the GEM system while profiles 5 and 6 show little to no improvement as expected. Steady state loads or very high loads tend to run towards the maximum end of generation efficiency so effectively no improvement can be made in conversion efficiency with time shifting strategies. Profile 5 is

slowly changing with a high load average and high total energy requirement, the GEM system only resulted in a 5% improvement. Profile 6 is a high constant load; the GEM system had no effect.



Profiles with the greatest max to min range tend to show the highest efficiency improvements Profile 1 is a typical afternoon high peak load with low overnight numbers, the GEM system resulted in a 27.2% improvement.

The maximum available site energy in 24 hours with all generators running is 25200kW-Hrs, (350kW x 3 x 24 hours). Profile 6 is close to this number, running a constant 900kW load for 24 hours. Profiles 1,2,3,4 and 7 however are typical where the total energy required is a relatively small percentage of the total possible.

Renewables Integrated In The Time Shifting Strategy

The addition of renewable energy to a remote site can provide substantial energy inputs to a site however, the site peak demands may require spinning reserve to accommodate rapidly shifting load requirements. The spinning reserve acts to decrease the value of renewable sources by consuming fuel with no energy output, acting only as a reserve source to maintain site stability.

The ISIM / GEM system accommodates variable renewable energy and balances fluctuating loads with fluctuating supplies, providing instantaneous sink and source capability with no fuel burn. Renewable inputs can also be time shifted with the storage to help optimize ICE efficiency thus increasing the renewable energy value.

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For more information on this case study and Go Electric micro grids, contact Alex Creviston at Alex@GoElectricInc.com