Energy Sufficiency Arbitrage

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ABSTRACT

Arbitrage is the exploitation of a commodity price differential in two or more markets. Energy Sufficiency is an element of an energy portfolio that makes use of just-in-time electrical or thermal generation or conversion. Energy Sufficiency Arbitrage requires the use of a sufficiency-inclusive private energy portfolio, characterized by a non-zero Energy Index (ENDX™) [2].

A sufficiency-inclusive energy portfolio for consumers of large amounts of energy, specifically with high energy density (>70W/m2, for example), can be implemented using a private micro-grid, which creates a local energy market: a microgrid converts one form of energy into a more useful one at a certain cost. Arbitrage pricing opportunities are created in the pricing differential between microgrids and macrogrids, with a resulting cost reduction, often significant, for the portfolio owner.

We discuss in this paper how a Sufficiency Arbitrage advantages are created and managed as part of the Sufficiency Kaizen continuous improvement process [3].

Keywords: Arbitrage, Energy Sufficiency, Energy Portfolio, Kaizen, Macrogrid, Microgrid, Pricing Differential

INTRODUCTION

Electrical energy markets in the US are a patchwork of advanced markets and regulated regions. Businesses in rural areas enjoy some of the lowest electrical commodity costs in the country, partially due to taxpayer subsidies, partially due to low population growth rates and aging generation fleets.

The higher density population centers have migrated toward a market organization for electricity, managed by regional Independent System Operators (ISO). These include the ERCOT region in Texas—as a pioneer, followed by the PJM, ISO New York, ISO New England, Midwest ISO (MISO), and the California ISO. The PJM is often cited as one of the most advanced nodal pricing electrical markets, e.g. [4], [5], [1].

The ISOs operate markets that are characterized by a demand-supply relationship that result in a price accord. There are typically two electrical markets to set prices: a real time and day-ahead market. In the former, buyers and sellers engage in 15-minute or 1-hour contracts to produce or consume energy. The latter, a contract is made for a block of Megawatthours one day ahead. In this discussion we concentrate primarily on the real-time market, although these concepts are valid for the day-ahead markets as well, with some changed conditions.

Over a 24-hour period the price of electrical energy moves up and down, depending on the demand-supply relationship. A well-structured ENDX™ portfolio will offer generation capability that remains at a fixed price for certain time periods. The resulting price differential between these two markets can be exploited to limit costs when markets offer low pricing, and produce revenue when markets demand higher pricing, as shown in Figure 1.

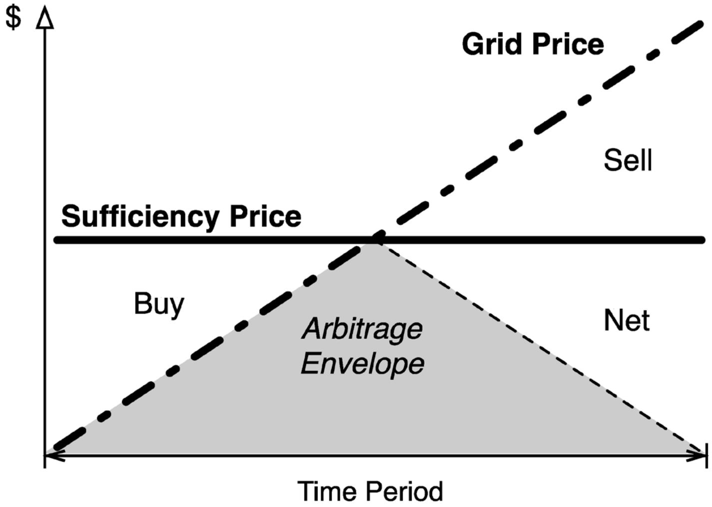


Figure 1. Arbitrage Envelope Definition

Market prices bottom out during low demand times, such as during cool weather nights, holidays, etc. Since Sufficiency Cost is less elastic, during these times onsite generation is either turned off or not utilized, as the nature of the resource requires. Required energy is purchased on the market (CM). As the market cost increases over the day, it will eventually exceed sufficiency cost (CS), and excess energy, resulting from a difference between generation and onsite demand, can be sold. The resulting revenue is offset from the sufficiency cost, yielding the energy arbitrage cost envelope, described as:

$$C_{AE} = \int_{0}^{t} C_M(t) - \int_{l}^{k} C_S(t) \ \left\{ \begin{matrix} C_M(t_l) = C_S(t_l), \\ t \geq k \geq l \end{matrix} \right.$$

and its resulting Energy Index effect as

$$Ex = O\left({}^{\Gamma}\!/_{C_{AE}\,D}\right)$$

Under the right circumstances, the area of the arbitrage envelope can be half or less of the area under the market cost curve.

STRUCTURAL REQUIREMENTS FOR ELECTRICAL ENERGY ARBITRAGE

Markets require the communication of pricing information between buyer and seller, as well as the satisfactory transference of the traded commodity from seller to buyer.

As discussed above, electricity markets are created and managed by ISOs (Independent System Operators), which connect buyers and sellers in both real-time and day-ahead markets. See Figure 2. An ISO control center collects buy & sell offers and transmits this information over secure Internet as a Pricing Signal to registered buyers and sellers. The actual transference of electrical energy is via an installed grid connection point, which is designed to accommodate up to a certain amount of electrical energy transfer for both load and generation.

In order to participate in this market, an industrial user must register their sufficiency capability with the ISO as a ‘generating entity’.

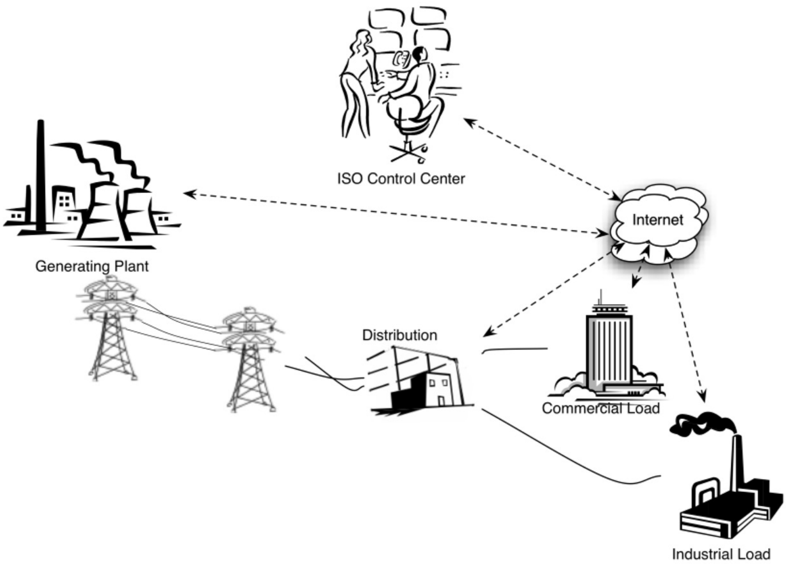


Figure 2. Typical ISO simplified network profile

The satisfactory completion of this process ensures the properly sized grid connection, as well as the receipt and transmission of suitable pricing and capacity signals. In effect, the owner of a sufficiency-inclusive private energy portfolio is known to the ISO as a generating entity.

Not every sufficiency technology is suitable for grid exposure. Usually only systems that can supply uninterrupted, sustained blocks of Megawatthours of electrical energy are suitable for industrial use, in the absence of subsidies. The selection and supply of this capacity requires sophisticated digital controls on a microgrid.

Microgrids

A Microgrid is an organizing network for energy sufficiency resources; a network of onsite energy producers and consumers. Microgrids are similar to data networks: they have a gateway to a larger network—the (macro)grid—and internally have a variety of devices, producing (generation) and consuming (load), connected to it. The installation of any sufficiency resource will require the installation of a microgrid.

Onsite Demand and Location Based Marginal Pricing (LMP)

Sufficiency resources are intended to meet onsite electrical and thermal demand. This demand is imperative, and can fluctuate independently of Location Marginal Price (LMP) of electricity: demand peaks can coincide with grid demand peaks, or loads can be constant throughout the day for many days at a time. The LMP is a regional electricity price in an ISO nodal area, adjusted for congestion or other local circumstances that affect distribution price.

Figure 3 shows the LMP histogram distribution of the 2010 year for a node in the mid-Atlantic region. This dataset has an average value of $48.81, a median of $40.20, and a standard deviation of $27.74 for the year (values are $/MWh). Note the long tail on the high side, and the relatively rapid dropoff from the peaks toward the low side. Most snapshots of RT LMP data from these markets have this same graphical pattern.

Consider the hourly graphs depicted in Figure 4 of LMP superimposed on electrical demand of an industrial facility for two different months. In Figure 4, electrical demand, shown as gray area, evidences significant differences in demand from month to month. In fact, August is nearly the inverse of January, showing a steady demand peaking at near 4 MW. For most industrial and commercial facilities this has nothing to do with energy markets; this is driven by demand for products or services.

The hourly LMP signals, in black, show pronounced regular spike patterns for cost when daily demand is high—these spikes in Figure 4 correspond to the long histogram tail ‘in action’ of Figure 3. Changes or interruption in supply can cause dramatic increases in real-time cost, as shown in the January chart. Extraordinarily high ambient temperatures are reflected in the LMP pricing patterns of the August chart.

CAPACITY CONSIDERATIONS IN ENERGY ARBITRAGE

In this section, we examine the relative Arbitrage volume opportunities for different generating capacities: 2, 3, or 4 MW continuous electrical generating potential. In addition we consider the effect of thermal demand on cogeneration technologies.

Thermal demand has a dramatic influence on what kind of co- or trigeneration technology is installed. The quantification and stratification of thermal demand is one of the first steps in sufficiency design. The nature and constraints of thermal demand and supply can have an

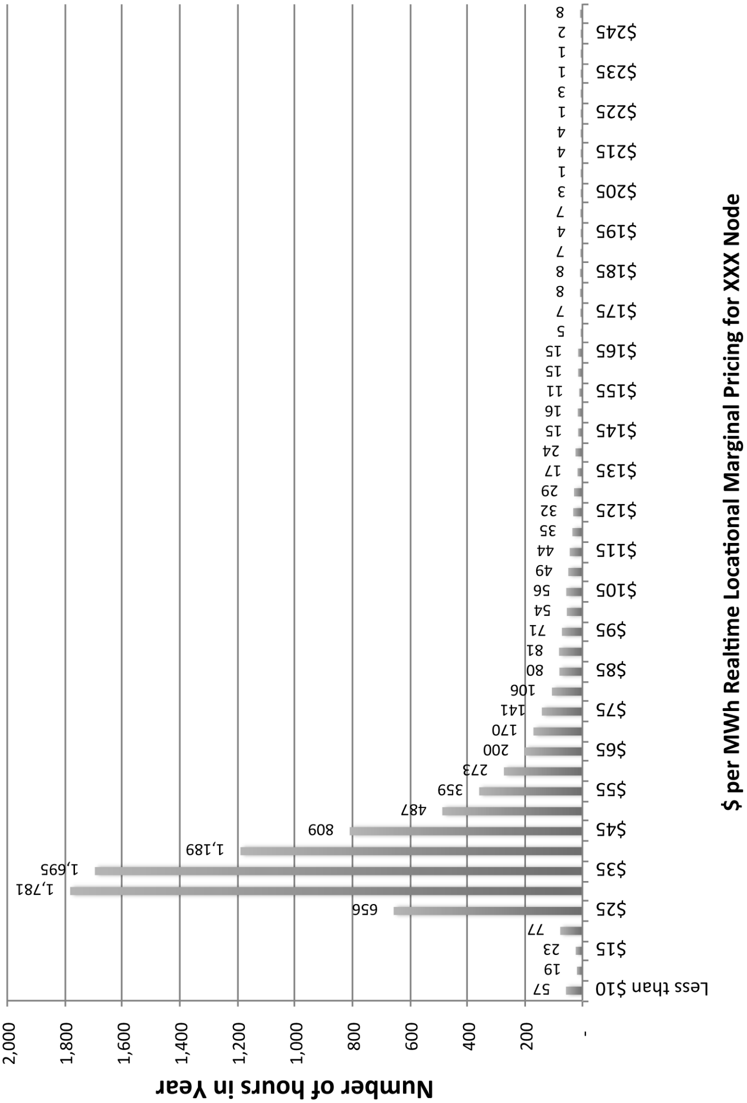
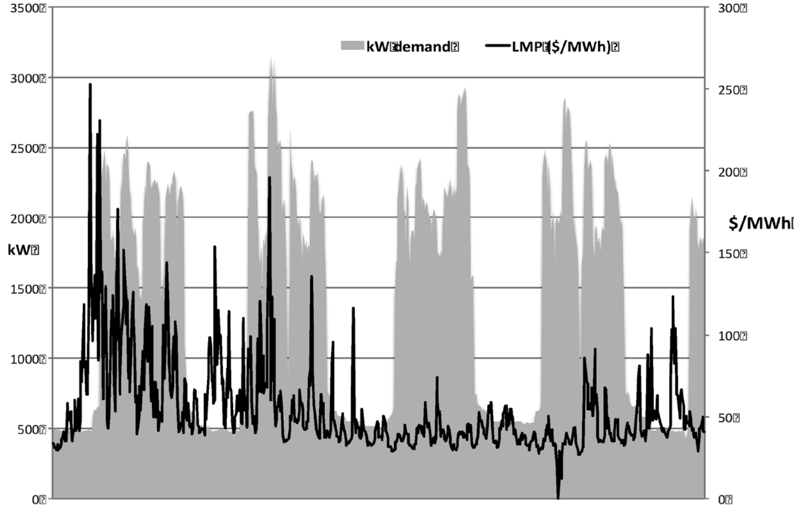
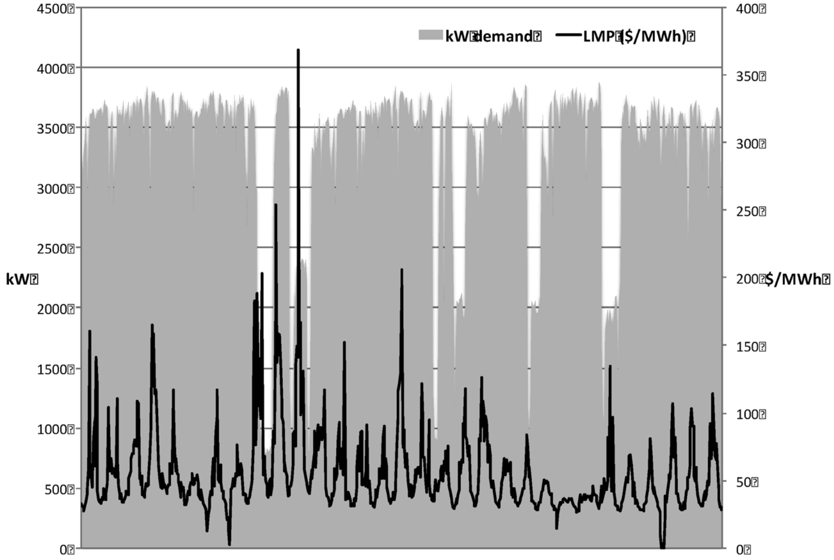


Figure 3. LMP distribution for a node in the Mid-Atlantic Region (2010)



January



August

Figure 4. LMP and electrical demand for an industrial facility and two different months.

attenuating impact on Sufficiency Arbitrage if not properly considered. However, for purposes of this discussion we will assume that thermal demand is an exogenous factor, i.e., the sufficiency design provides a decoupled thermal supply option, and relegates thermal management exogenous to electrical markets.

We would like to install sufficiency capacity at the facility described above. However, the continuous change in demand characteristics, as well as historically low overnight LMP prices, create uncertainty whether the capacity should meet 50%, 75% or 100% of peak demand, measured at 4 MW in this case. The continuous cost of central generation from coal, hydroelectric, or nuclear power plants is very low. By fixing the natural gas price into longer term contract, we determine that we are able to generate electricity at approximately $55 per MWh, significantly higher that that of a nuclear plant, for example.

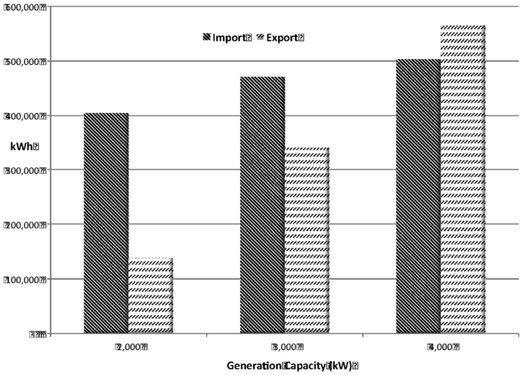
Cursory review of the LMP histogram above tells us that historically the LMP price has exceeded our Sufficiency price by 1,600 hours per year, or 18% runtime. At first blush, this apparent low runtime would not justify the expense. The alternative, however, purchasing on the wholesale market, would fix electrical prices at $75/MWh or higher, and would therefore run counter to the objectives of Sufficiency Kaizen.

The following two charts, Figure 5, show the relationship of bought and sold kWh for the differing capacities for the two months discussed above. The darker bars show the market purchase volume; the lighter bars show the sell volume. Due to the variant nature of January's demand, we are able to exploit LMP pricing spikes with a large Arbitrage envelope, shown in the January buy/sell chart.

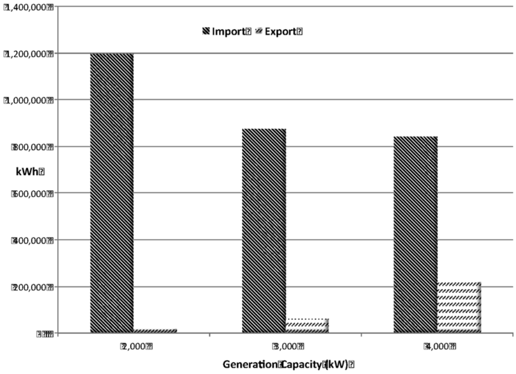
Conversely, the high continuous load in August narrows the Arbitrage value considerably. To illustrate the aggregate effect, the following table shows the financial buy & sell results of Arbitrage for the whole year, for different capacities:

Input costs actually produce a positive cash flow—$74,249—for the 4MW option at 100% Sufficiency. Notice the variance in sell revenue for the different capacities in the August-October timeframe compared to other months. Please note these are simply the market transactions, not the fully loaded sufficiency costs.

As we saw in the above data for January, the standard deviation for demand is high in the early months of the year. We examine the role of both demand and market volatilities in this dynamic.



January buy/sell



August buy/sell

Figure 5. Relationship of bought (dark bars) and sold (light bars) energy (kWh) for the differing capacities for the two months discussed above and depicted in Figure 4.

CORRELATION TO DEMAND AND MARKET FACTORS

Market volatility is a key consideration when deciding what generating capacity should be installed. Thus, we show in Table 2 a correlation analysis for both demand and LMP fluctuations against Buy and Sell volumes under different capacity constraints. Recall peak

Table 1. Financial buy & sell results of Arbitrage for the whole year

	2MW		3MW		4MW	
Month	***Buy***	***Sell***	***Buy***	***Sell***	***Buy***	***Sell***
Jan	$ 17,505	$ 11,887	$ 18,015	$ 28,922	$ 19,264	$ 48,751
Feb	$ 15,677	$ 5,085	$ 18,443	$ 14,814	$ 18,060	$ 22,925
Mar	$ 20,279	$ 2,201	$ 23,210	$ 7,402	$ 23,269	$ 12,829
Apr	$ 20,364	$ 1,414	$ 22,573	$ 6,032	$ 22,686	$ 11,818
May	$ 17,039	$ 9,128	$ 19,137	$ 20,443	$ 17,473	$ 28,423
Jun	$ 17,734	$ 10,701	$ 16,824	$ 26,423	$ 19,704	$ 43,137
Jul	$ 26,563	$ 19,852	$ 18,698	$ 44,573	$ 16,277	$ 72,888
Aug	$ 61,860	$ 1,818	$ 37,260	$ 5,924	$ 28,636	$ 18,021
Sep	$ 35,379	$ 612	$ 33,470	$ 6,453	$ 32,036	$ 14,137
Oct	$ 30,007	$ 1,186	$ 32,073	$ 4,818	$ 37,763	$ 9,271
Nov	$ 21,797	$ 2,841	$ 23,748	$ 7,790	$ 27,636	$ 13,361
Dec	$ 15,974	$ 10,906	$ 15,150	$ 34,181	$ 15,726	$ 57,219
Total	$ 300,176	$ 77,629	$ 278,602	$ 207,774	$ 278,531	$ 352,780
Net		**$ (222,547)**		**$ (70,828)**		**$ 74,249**

Table 2. Correlations of Buy and Sell Dollar Amounts with LMP, Demand Volatility and Monthly Demand Average under differing Sufficiency capacities. A positive correlation indicates that high Buy or Sell Dollar amounts correspond to high values of the row labels.

	2MW		3MW		4MW	
	Buy	**Sell**	**Buy**	**Sell**	**Buy**	**Sell**
LMP*Pricing*Volatility	0.194	0.737	(0.226	0.786	(0.484	0.845
LMP*Average*Price	0.104	0.797	(0.359	0.839	(0.607	0.895
Demand*Volatility	0.131	0.282	0.169	0.256	0.271	0.289
Demand*Monthly*Average	0.986	(0.337	0.858	(0.345	0.583	(0.233

demand for this facility is 4 MW. We find that buy and sell decisions are sensitive to different influences.

Note sell revenue has a strong positive relationship with not only LMP pricing average, but also volatility, albeit to slightly lesser degree. Unsurprisingly, purchasing cost is strongly correlated to the average monthly demand. However, the strength of Buy correlation slows as capacity nears or exceeds demand peaks.

We conclude that an important step in Energy Sufficiency design is to carefully examine LMP average pricing and volatility. If volatility is high (high standard deviation), and is expected to remain high, optimal sufficiency system design capacity is characterized primarily to meet thermal demand, as the Arbitrage benefit will offset electrical consumption costs.

THE EFFECT ON EQUIPMENT RELIABILITY

Most energy generating equipment, such as reciprocating engines or turbines, whether aero-derivative or not, is designed for an expected amount of start/stop cycles. Energy pricing arbitrage could expose equipment to rapid and frequent starts and stops, thereby reducing the mean time to failure (MTTF) and accelerating the time to rebuild. We discuss how this risk is reduced.

In nodal pricing markets we distinguish between the LMP price, which is the contractual price for that zone/node for a give time, and the dispatch signal from the ISO itself. These two data have different semantics for our microgrid and macrogrid pricing relationship. The ISO dispatch signal is sent every five minutes by the ISO control center to certain registered entities.

The ISO dispatch signal is a balancing tool that grid managers use to align production with demand. As such, it is highly volatile, for understandable reasons.

The hourly LMP is a contract basis, used for reconciliation, and is therefore not operationally meaningful. Our approach has been to use a smoothing algorithm on the 5 minute ISO Pricing Signal to ensure that start/stop cycle do not occur more than two times daily. Figure 7 demonstrates this response smoothing effect for the above time period.

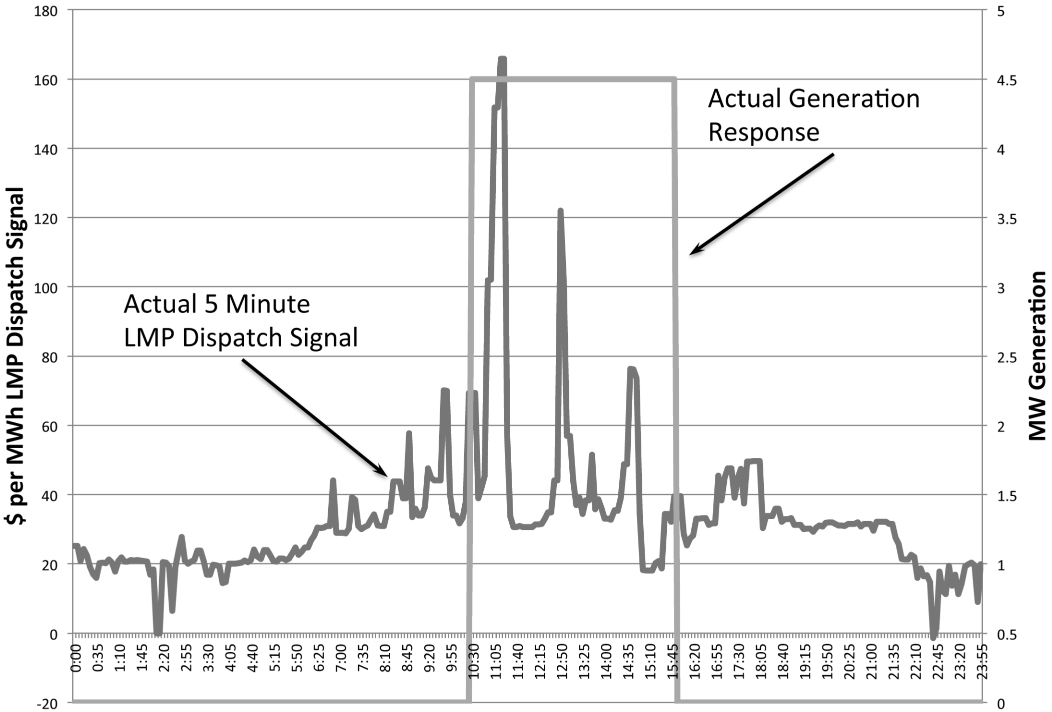


Figure 7. Superposition of Generator Response to LMP Dispatch Signal

SUFFICIENCY ARBITRAGE AND ENERGY STORAGE

Energy can be stored for later use. While electrical energy storage is expensive and is not often done in large capacities, thermal energy storage is commonplace. Chilled water storage is the most common for low temperature storage; Paraffin, molten salt, or other low cost materials can be used for higher temperature storage.

We model energy storage mechanisms as an options contract. The capacity of the storage system represents the maximum forward value of the contract. The options base price is cost of charging energy storage, which is essentially an implicit call option: the right to buy a block of energy at an agreed upon price. The right is implicit in that it is subsumed in normal operating demand. See Figure 8.

That price is set heuristically, as one has to study the daily fluctuations to determine what an advantageous future value is.

Our system recognizes when the LMP has crossed the price threshold downward, and then starts charging the energy storage facility as long as the LMP price remains below the expected future prices and that storage system has available capacity.

As the market rises each day there will be a point where the value of the storage is equal to the current market price (At the Money). The system reverses, and then starts drawing energy from storage while the market price is above and capacity is not exhausted.

This has the effect of reducing the Arbitrage Envelope even further, as is shown in Figure 9. The Sell Volume is improved by the

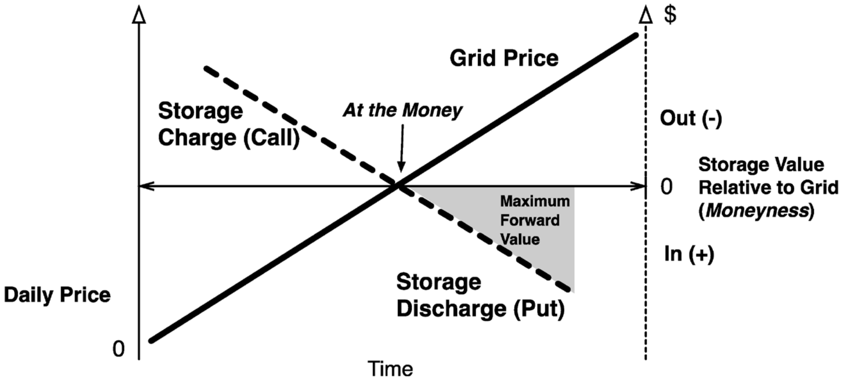


Figure 8. Arbitrage options-contract model with energy storage charge/discharge

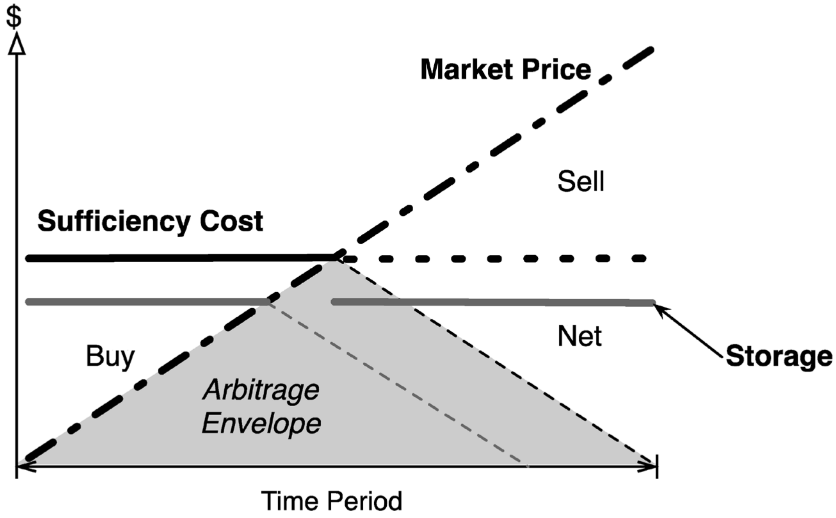


Figure 9. Energy Arbitrage with Sufficiency including Energy Storage

increased amount of Sufficiency sold, minus the amount purchased (Option Cost).

Fuel Flexibility

Fuel flexibility is a characteristic that allows the operator of a sufficiency system to use fuel from different markets. A simple example might be a dual-fuel boiler allowing the combustion of either natural gas or fuel oil. Another is combusting different types of biomass for a steam turbine system, or combining wind, solar, and biomass and natural gas combustion into a microgrid.

Economically, Fuel Flexibility is the similar to Storage by creating a shift of the Sufficiency Cost curve (Figure 10). Next, consider two fuel sources: A and B, where A has a fixed cost but virtually unlimited supply, and B has a limited supply, but very low cost. The effective employment of this fuel supply strategy under Sufficiency Arbitrage rules reduces the Arbitrage envelope even further. This result requires JIT logistics management of the supply chain and fuel changeover mechanisms.

Fuel and Storage mechanisms differ in the nature of the Call Option. The fuel price option must be explicit and time independent, i.e., the Call option may be purchased at any time, and is Put at any time.

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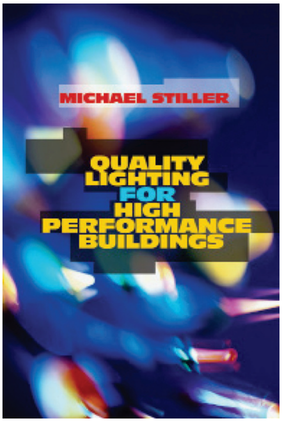

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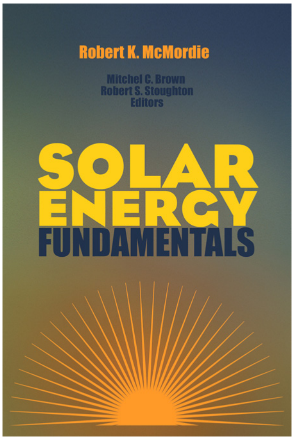

This book is a compilation of decades of knowledge that spanned the author's career as a mechanical engineer specializing in heat transfer and thermodynamics in the solar and aerospace industries. It was written with the goal of providing a comprehensive understanding of solar energy to readers of varying backgrounds and experience, in a manner which allows the information to be readily applied to real world projects. Beginning with an enlightening discussion of the relationship of the sun and the earth and the impact of sunlight on the earth, Dr. McMordie proceeds to explain in clear terms the basics of heat transfer, how solar collectors work, and how solar energy is absorbed. Specific technologies detailed include solar domestic hot water systems, solar photovoltaic systems, solar space heating, solar power towers, Stirling engine solar power systems, passive solar energy, and greenhouse solar collectors. Appendices provide mathematical techniques for solving heat transfer problems and case studies. The book also includes an Excel® based companion CD of computations to enable the reader to readily put the information in the book to practical use.

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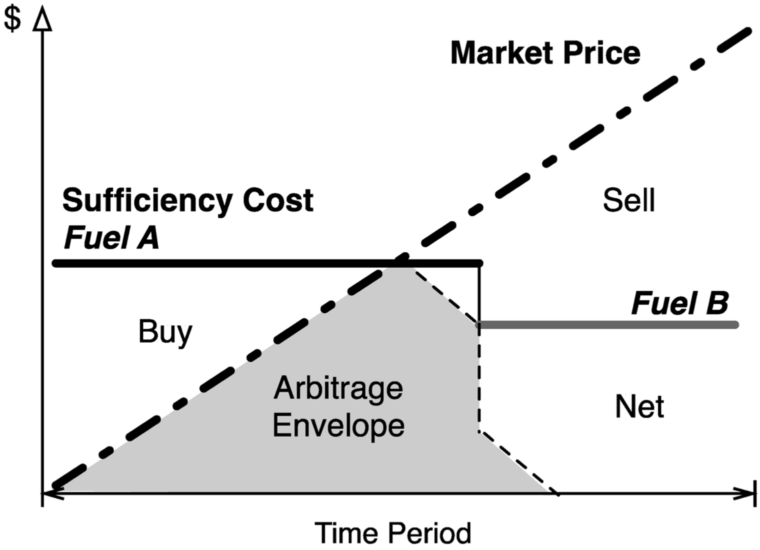

Figure 10. Arbitrage effect of dual fuels under varying conditions

Storage merely depends on the balance of prices and capacity, and the Call must immediately precede the Put.

AN OPERATING EXAMPLE

A 9MW dual turbine cogeneration powerplant designed and constructed by our team supplies a hospital with electrical power and 53,000 lbs/hr of high quality steam. The hospital's electrical demand peaks at 9.9 MW; the steam supplies direct thermal supply needs such as laundry and steam-driven chillers for cooling in the summer.

The facility is grid connected via a high voltage grid line, is registered as a generating entity with the ISO, and receives hourly LMP pricing signals. The facility went into operation in July 2011 and has been operating continuously, and unattended (lights out) since.

Net electrical prices in the region (landed costs including all fees) have dropped since 2009, and are now at approximately $85/MWh.

After some installation testing the system went live on July 19th. Figures 11 and 12 show the production balances in terms of energy and expense, respectively, for a ten-day period.

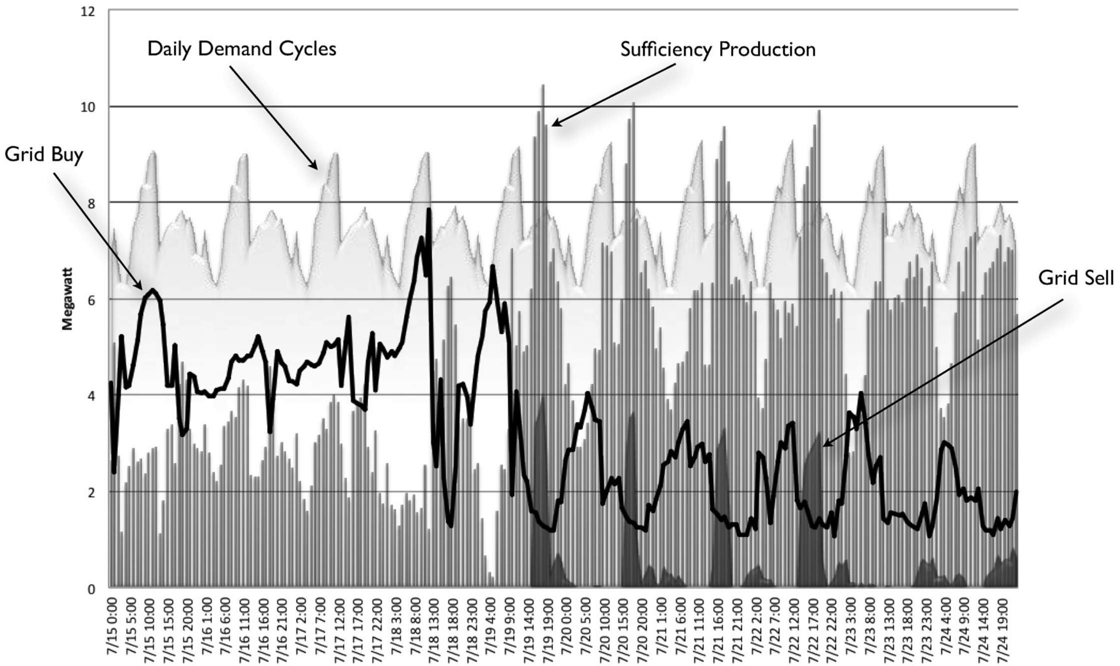

Figure 11. 9MW Production Startup Sequence vs. Energy Demand

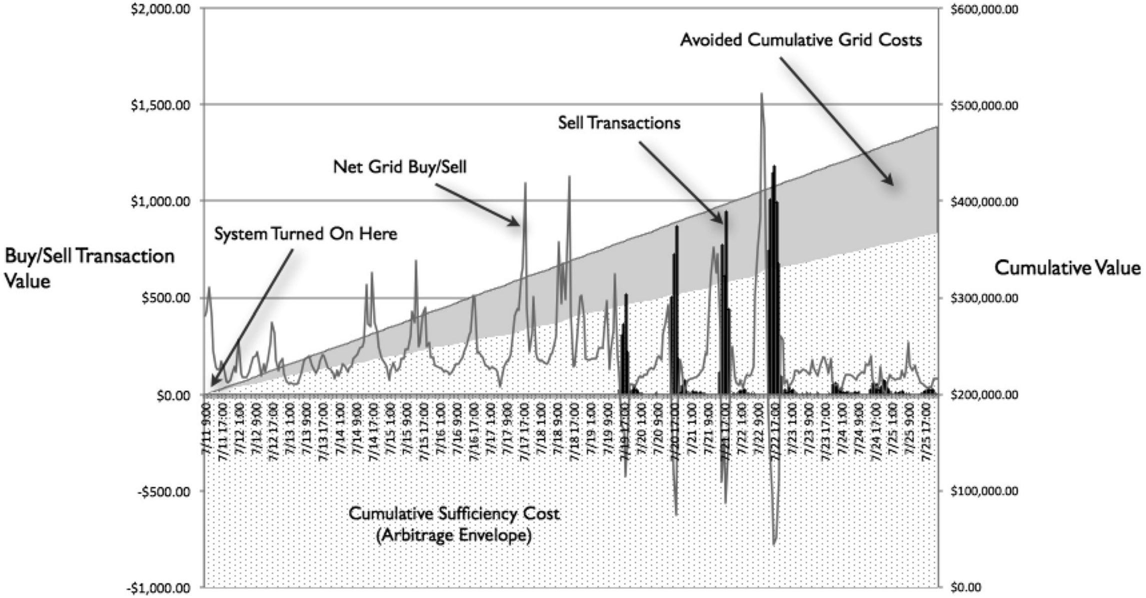

Figure 12. Arbitrage Cost Dynamic

The background area graph shows daily demand cycles ranging from 6 to approximately 8.5 Megawatts each day. The thin bar graph shows hourly Sufficiency Production. You can see 'live' production tests for several days before July 19th. The system is started in autonomous 'lights out' mode and the arbitrage software starts economic dispatch on July 19 at 13:00 with the first Grid Sell transactions. You can see grid power is sold during evening periods when onsite demand is low and LMP prices are high. The Sufficiency system does not shut down completely due to grid failure response standby requirements.

Over this two week period the economic impact of this shift has a significant impact on net energy costs—a little over $100,000 saved. The reader should bear in mind that the cost of turbine operation is not considered here, but it is a fraction of the variance between grid and production cost.

The gray area shows the grid-only cost computed as the normal landed cost of electricity and gas. The green area shows the cumulative total cost of turbine gas consumption plus LMP buy/sell transactions for the facility after it was turned on. The blue line shows the transactional energy charges of purchases minus sales. The red lines show the excess energy sales from the generating turbines.

Two factors account for the large divergence between the grid-only cost line and the cumulative net cost line: (a) once the turbine starts, only unit values below sufficiency cost are purchased, and (b) grid sales produce positive cash-flow after accounting for demand. Figure 10 is Figure 1 put into practice. Overall energy costs for this facility are now approximately 65% of the original cost.

CONCLUSION

We have shown the use of Sufficiency Arbitrage as a management strategy deployed in the Portfolio Execution step of the Sufficiency Kaizen lifecycle. Arbitrage of electrical and thermal energy from sufficiency resources can significantly offset the cost of onsite energy conversion, reducing net input costs anywhere between 25% and 75% of baseline, depending on context and configuration.

PATENT NOTICE: The Energy Index description and method is protected under USPTO US61/472,539.

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