Micro-Grids and Financial Affairs

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Creating a value based real time price for electricity and thermal products

The drive for improved efficiency has led to an advocacy of distributed energy resources and the concept of micro-girds for electricity and steam systems. But for these micro-grids to be financially feasible, there must be a way for the participants to pay each other as peers and for the micro-grid to interact with any larger grid as a peer. Further, the payment mechanism needs to be consistent with how the system operates, providing incentives for buyers and sellers to do the right thing. Real time pricing can achieve that peer relation if the prices are allowed to change on a wide open load following basis.

A micro-grid is a localized, nominally self-sufficient group of consumers and producers. Though the micro-grid concept is most commonly used in relation to electricity, micro-grid can also be used in regard to other flowing systems. Most commonly the term micro-grid is applied to steam or hot water systems, but also can be applied to nitrogen pipelines, natural gas pipelines, and water systems. In this paper I will primarily relate micro-grids to electricity.

I used the term "nominally self-sufficient" in regard to micro-grids to allow for the possibility that some participants are both consumers of electricity and producers of electricity. Such participants might be self-sufficient with but a minor interchange with the micro-grid. Further, the micro-grid sometimes buys electricity from a larger grid, and perhaps, sometimes the micro-grid will sell electricity to the larger grid. Though some micro-grids are indeed isolated from larger grids, most have some sort of interconnection.

The concept of a micro-grid raises numerous issues

- What is a micro-grid? What should be included in the definition? What should be excluded?
- How should the participants on a micro-grid compensate each other?
- What should be the financial interface between the micro-grid and the larger grid? For when the micro-grid is a buyer? For when the micro-grid is delivering electricity to the larger grid? How can there be a peer to peer relation?

There may not be unique answers to these questions. Indeed, the answers will depend on local legislation and regulation. But an initial exploration of these issues might lead to a productive discussion of these questions, and, perhaps might even lead to a consensus that will allow us to improve the efficiency of the network.

WHAT IS A MICRO-GRID

I generally take an expansive view in regard to defining a micro-grid, allowing the concept to range from as small as a homeowner supplying electricity to her neighbor to as large as a distribution utility interconnected to the wider grid. Indeed, I would allow the concept to include any utility interconnecting with another utility.

Perhaps the most important micro-grid will be chemical plants or paper mills, which can be self sufficient, but desire to establish a peer relation with the local utility. On the small side, the homeowner with self generation could be considered to be a micro-grid, with her interaction with the grid being a necessary peer relationship subject to wide open load following pricing.

Each country, state, and region entity will have its own laws as to how producers and consumers can interact, generally with the intention of protecting the consumer. Occasionally the laws can be viewed as protecting the incumbent utility. These laws will restrict how micro-grids can be structured in each jurisdiction.

Many consumers have installed their own generating equipment, from the environmentally conscious owner of a wind mill or solar cell to the owner of an uninterruptible power supply (UPS) system who supplements the UPS with a small generator in his back yard. Sometimes there is a surplus and the owner of the generator is willing to share that surplus with his neighbor. The shared emergency generator in the back yard is but a step away from office buildings, hotels, and hospitals having standby generation that can feed their electricity to their neighbors, or to the larger grid itself.

In war-torn Baghdad, some entrepreneurs have gone so far as to buy small generators in order to sell electricity to their neighbors during the frequent power outages Baghdad experiences. These power providers are able to make a living through being a backup power supply for their neighbors. Many magazines and newspapers have included articles with a spider web of wires belonging to each of the backup power providers. However, these micro-grids generally have not established a peer relation with the larger grid, limiting themselves to being sellers of electricity in small isolated grids.

On an even larger basis, many industrial complexes, such as chemical complexes or paper mills, can be considered to be micro-grids. Often the steam load on their cogeneration plants exceeds the electricity needed by the complex, allowing the industrial complex to export power to the grid. Indeed, some industrial complexes are equivalent to a major utility. For instance, the tar sands projects in Northern Alberta has several thousand megawatts of cogeneration capacity in a relatively small geographic area, effectively forming its own micro-grid.

There have been many legal limitations on micro-grids. Some states regulate any sale of electricity, no matter how minor. Thus, selling surplus electricity from the solar cell on my roof to my neighbor might nominally require me to register as a utility with the state public service commission. Some states take a less restrictive view, allowing neighbors, including industrial neighbors, to sell to each other so long as the wires connecting the properties do not cross public land, such as a street. Clearly, the spider web complex of wires that I described in Baghdad would not pass muster with most states, forcing the Baghdad entrepreneur to register and function as a utility.

Some limitations on micro-grids have been federal issues in the US. For over 40 years, the Pubic Utility Holding Company Act (PUHCA) specified that any sale of electricity for resale in interstate commerce would turn the seller into a public utility, requiring filings with the Securities and Exchange Commission (SEC) and the Federal Power Commission (FPC the predecessor to the Federal Energy Regulatory Commission or FERC.)

Some industrial complexes were so acutely aware of the PUHCA implication in regard to a delivery of electricity to the utility that at least one industrial complex had a contract with its local utility specifying that any delivery of electricity to the utility was a permanent, no cost gift to the utility, not a sale. Another industrial complex went so far as installing relays that physically opened the normally closed interconnection with the utility whenever electricity starting to flow from the industrial complex to the utility. Fortunately, the Public Utilities Regulatory Policy Act (PURPA) ended this farce in 1978, at least in the US.

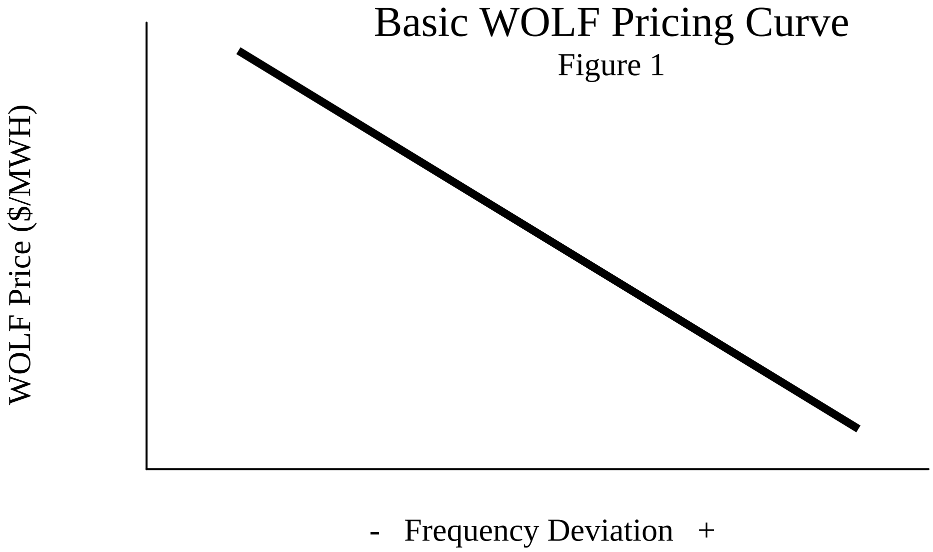
STARTING SIMPLY

The simplest micro-grid might consist of me and my neighbor. Considering my neighbor is eco-friendly, we can assume that she has installed a wind generator and solar panels, both potentially many times the size of her own need. I, on the other hand, am a troglodyte, preferring to install a gasoline engine sized to twice my own needs, thus large enough for both homes when the sun isn't shining and the wind isn't blowing.

With wires connecting our homes, the control system is simple, at least my part is. Whenever there isn't enough electricity for our homes, I run the gasoline generator to meet the shortfall. The payment scheme is relatively simple. She pays me for any electricity I deliver to her at the current cost of gasoline and a heat rate of 50,000 BTU/KWH. (I know it doesn't have a great heat rate, I am a troglodyte, remember.)

Though this pricing and control system is simple and works for our small micro-grid, the pricing and control system doesn't work very well when we get hook up our small micro-grid to a bigger micro-grid. For that we need a slightly more sophisticated pricing and control system, one that I call Wide Open Load Following or WOLF.

WOLF sets the price for unscheduled flows of electricity using a formula with the independent variable (X for those whose experience with algebra is as ancient as my experience with algebra) being the frequency of the grid (including its calcula such as time error.) The general concept is expressed in Figure 1. When the frequency is low, the price is high. When the frequency is high, the price is low. The calcula of frequency shifts the curve up and down.



When my neighbor and I are hooked into the larger micro-grid, I can change the way that I operate my gasoline generator. Instead of meeting any joint deficiency that neighbor and I have, I now operate my gasoline generator full bore, but only when the price of electricity is expected to exceed my cost of fuel. Notice that I said "expected to exceed", in that I won't know the actual price during any time period until after the end of the time period, when the WOLF formula produces a price based on actual operating conditions. Notice also that I now operate my generator full bore, since I sell I can sell its full output to the grid at what I hope is a profitable price.

When I operate my gasoline generator while connected to the larger grid, my neighbor and I are fairly sure that our electricity costs will be limited to my cost of gasoline, because that is the side deal that my neighbor and I have, she gets my generation unless the grid is less expensive. I have some risk in this deal, in that I am not always sure that I can predict when the frequency for the micro-grid will produce a threshold price, but I come close.

Though Exhibit 1 presents a WOLF pricing curve, it is also indirectly an operating curve. Some of my more distant neighbors are more progressive than I am and have installed more efficient gasoline generators. Some have even installed diesel generators, gas turbines, and even fuel cells. Their heat rates are much lower than my heat rate. Of course, they had higher front end costs. Just as I use the pricing curve to decide when I want to operate my inefficient gasoline generator in order to limit my exposure to high costs, or make a profit, so my more distant neighbors have decided to use the pricing curve as the basis for operating their small generators.

WOLF can also effectively deal with reliability and capacity issues. The WOLF pricing period is short, much less than the hourly settlement period used by utilities in regard to their normal interaction with each other. Some reliability agreements require participants to have 5-minute or 10-minute spinning reserves. By pricing unscheduled flows every 5 or 10 minutes, WOLF can effectively provide a payment for capacity. When frequency drops and my gasoline generator starts a few seconds later, the payment I receive is in excess of the my fuel cost, or the fuel cost of any other generator. The excess can be considered to be a capacity payment.

Unbeknownst to most people on the larger micro-grid, I have installed a computerized operating system that controls my water heater, my air conditioner, and my refrigerator, three significant thermal storage devices. When I anticipate the price to be very low, I change the thermal settings, allowing the water heater to operate at the upper end of the allowed temperature range. Conversely, when I anticipate the price to be very high, I allow the water heater to discharge and its temperature to drop, denying electricity to the water heater, electricity that might be many times the bargain basement prices that I prefer to incur.

My neighbor is impressed with the cost savings I have achieved and had me wire her appliances to receive a signal from my computerized system. My neighbor compensates me for my efforts by sharing with me the savings she earns. We are discussing a fixed payment for my load control services.

My neighbor also installed a flywheel in her garage, using the device to store electricity when electricity is cheap and then to produce electricity when electricity is very expensive.

- Initially she used the flywheel to back up her wind generator and solar cell.
- Later she used the flywheel for our small micro-grid, discharging the flywheel whenever I would otherwise be operating my gasoline engine.
- As part of the larger micro-grid, my neighbor discharges the flywheel every day during the period she expects the price to be highest and charges the flywheel every day during the period she expects the price to be the lowest.

My neighbor’s flywheel sometimes makes two or three round trips a day, buying cheap electricity and selling expensive electricity.

My neighbor has found that her operating income from the operation of the flywheel is significantly more than the carrying costs on the bank loan she used to buy the flywheel. She is looking at buying more flywheels (over a megawatt) to be placed in her garage.

OTHER OPERATING ISSUES

The above story about me and my neighbor is fictional. But it shows how a good pricing system can allow many participants to interact with a micro-grid using distributed financial intelligence for the operation of local facilities. However, Figure 1 ignores at least two operating issues, transmission constraints and voltage constraints, both of which other parts of WOLF pricing can handle.

Transmission

The price for electricity needs to be geographically differentiated. Geographic differentiation provides some compensation for the owners of the wires. Geographic differentiation will also end the lunacy of my neighbor who wants to put a megawatt of flywheels in her garage. A megawatt will overload local facilities.

- When my neighbor is drawing a megawatt in the middle of a windy night, the central price might only be $10/MWH, but geographic differentiation could result in a price at my neighbor’s meter of $200/MWH.
- Conversely, when my neighbor is discharging a megawatt on a hot becalmed summer afternoon, the central price might be $300/MWH, but geographic differentiation could result in a price at my neighbor’s meter of only $5/MWH.

Accordingly, my neighbor will operate her megawatt of flywheels in ways that maximize her profitability. She limits her nighttime changing operations to levels that do not overly increase the local price of electricity and her daytime discharging operations to levels that do not overly depress the local price of electricity.

These self imposed limitations on the operation of my neighbor’s flywheels can cause legal issues, at least in the US when she is discharging the flywheel. The complaint is that she is withholding capacity in an effort to manipulate the market, the same issue that was raised in the California 2000/2001 debacle.

However, my neighbor and the operator of the micro-grid have reached a non-standard contract that reflects her size and her ability to influence the micro-grid. The non-standard contract gives the micro-grid operator rights to a prescribed output of the flywheel at a fixed price. My neighbor still has operational control of the flywheel, but has markedly less ability to manipulate the market price and her profitability.

Voltage

Magnetic and electric fields contain energy. Alternating Current (AC) systems create and extinguish those fields twice each cycle. Reactive power is the amount of energy that enters and then leaves the system each cycle, creating and extinguishing the magnetic and electric fields. Reactive power can congest the transmission and distribution system, incur active power losses, and affect the voltage at the customer's meter. Another aspect of WOLF prices reactive power based jointly on (1) the local (geographically differentiated) price of active power and (2) the local voltage.

The heavy draws on the distribution system created by my neighbor's flywheels dramatically changes the local voltage. However, as with many electronically controlled systems, she can control the amount of reactive power produced or absorbed by her flywheels in an effort to regulate local voltage. Because of the concern about economic withholding of reactive power capacity, the local grid operator has a non-standard contract to allow the grid operator to specify reactive power levels, though actual control remains with my neighbor.

REAL SYSTEMS

South Africa

I mentioned above that I operated my gasoline fired generator based on an expectation that the WOLF price would be high enough for long enough to make it worthwhile. I first saw the ability to connect financial models with control models in Johannesburg, South Africa, in 1983/1984. ESKOM did not operate its very expensive combustion turbines until system frequency was below 49.5 Hertz and was expected to stay below that level for at least two hours. The combustion turbines had a fuel cost of 20 to 30 times the cost of base load generation, much as I hypothesized that my gasoline engine had a very high heat rate and fuel cost.

In the context of Figure 1, the 49.5 Hertz is to the left of the graph and the 20 to 30 times multiple is to the top of the graph. Similarly, 50.0 Hertz is in the center of the graph, as is the cost of base load generation. To some extent, the graph in Figure 1 can be considered to be connecting the dots I saw 25 years ago, creating a continuous function from almost nothing, where almost nothing refers to the two dots associated with normal operations of based load generation versus the abnormal operation of ESKOM's combustion turbines. My first article on WOLF was "Tie Riding Freeloaders--The True Impediment to Transmission Access," *Public Utilities Fortnightly,* 1989 December 21. I mentioned this operating consideration and connecting the dots in a later article, "WOLF Pricing," *Public Utilities Fortnightly,* 1994 October 1.

India

In 1999, Bhanu Bhushan of India contacted me about his idea to price Unscheduled Interchange (UI) under the proposed Availability Based Tariff (ABT). We had both been participating on the Power Globe list server and my comments seemed consistent with his approach to pricing. We met that summer and exchanged papers, and again in 2001.

India implemented the ABT in 2002 and 2003, introducing it region by region. Though I dwell on the UI pricing provision, the ABT primarily transformed the payment provisions for central station power plants into a form similar to unit power contracts, with the State Electricity Boards buying the bulk of their power under such provisions. Thus, India implemented the equivalent of a series of bilateral contracts for generation by their central power plants. In some respects, these power provisions are similar to the non-standard contracts I said my neighbor had with the grid operator. UI pricing, like WOLF pricing, only applies to the non-scheduled portion of the flow of electricity.

The ABT pricing of UI is shown on Figure 2. After implementation in 2002 and 2003, the UI pricing chart was modified as of April 2004 and October 2004. The first two pricing curves are smooth ramps between 49.0 Hertz and 50.5 Hertz. The third pricing curve has a kink at 49.8 Hertz. Below 49.0 Hertz, each curve has a constant price. Above 50.5 Hertz, the price is zero. I overlay a WOLF pricing curve to show that the WOLF price continues to increase as frequency declines, instead of reaching a maximum.

One problem with the ABT pricing of UI is that ABT doesn't have a way to handle systems when the cost of generation is excessively high, currently above about $120/MWH. Thus, my preference for WOLF and the ability to adjust the WOLF curve for time error. Despite the limitation associated with price cap, ABT pricing of UI had a remarkable achievement upon its introduction. System frequency improved to almost the nominal level of 50 Hertz, as is shown in the histograms of Figure 3.

For January 2002, a year prior to the implementation of ABT pricing of UI, the average frequency was 48.69 Hertz in the Southern Region of India. As shown in Figure 3, the frequency was in a 0.05 Hertz band around 48 Hertz for over 16% of the minutes during the month.[1] A year later, in January 2003, the first month of operation of ABT pricing of UI in the Southern Region, the average frequency jumped to 49.91 Hertz in the Southern Region. In August 2004, the average frequency in the Southern Region was effectively the nominal level for India.[2] However, the run up in petroleum prices in 2005 and 2006 pushed up the cost of generation and lowered the resulting average frequency in each month.

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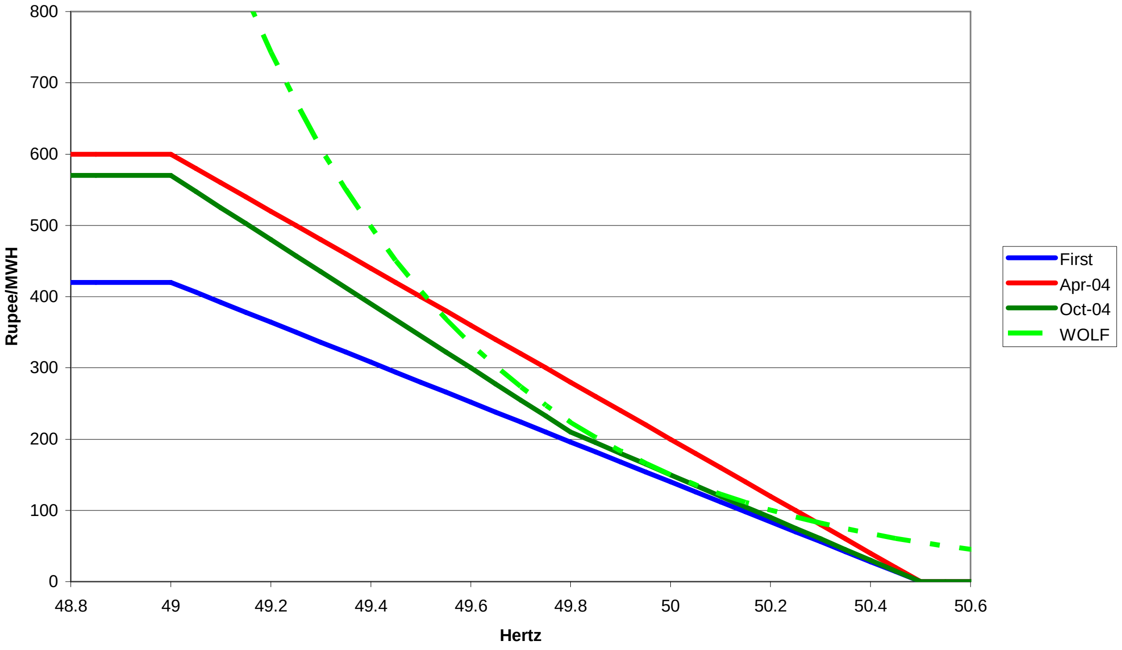
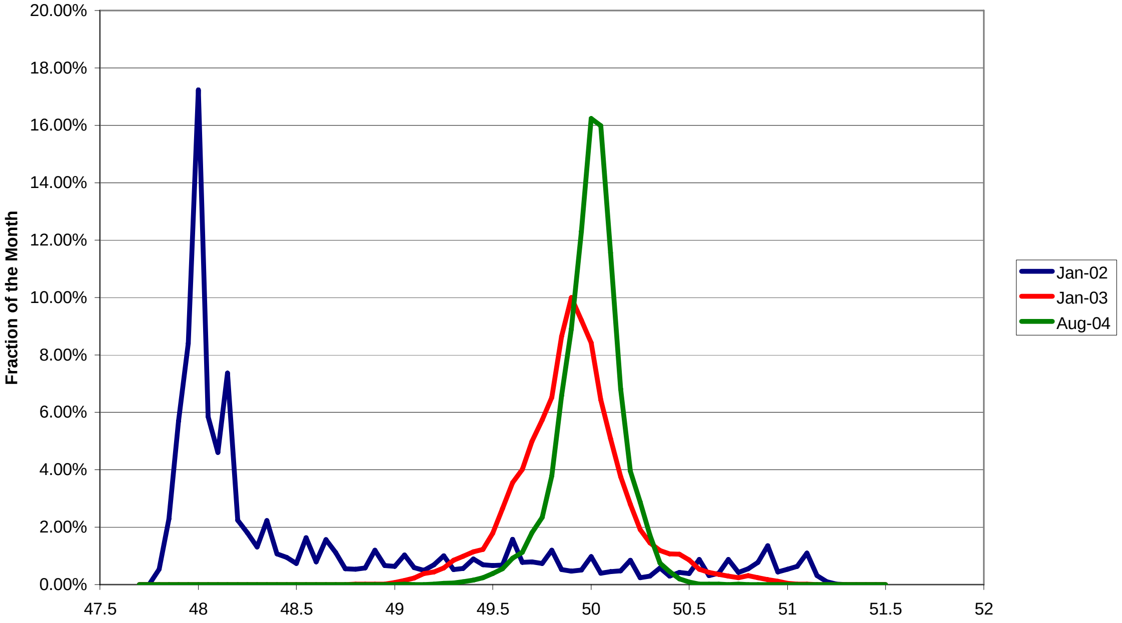
[1] Though Figure 3 presents data summarized from each minute of the reported month, UI pricing is actually based on 15 minute average frequency measurements.

[2] The average for the month was 49.9963 Hertz, which, rounding to two decimal places, is 50.00 Hertz.

ABT UI Pricing Chart
Figure 2



India Southern Region Frequency Distribution
0.050 Hertz Bucket Size
Figure 3



WOLF POTENTIAL

Alberta Tar Sands

WOLF has its greatest potential on grids where there is a history of strong competition and thus poor communication and cooperation. For instance, the tar sands area of Northern Alberta is being developed by several of the largest petroleum companies in the world. The petroleum companies are highly competitive with each other. Further, their market dominance imposes legal issues in negotiating economic deals with each other.

WOLF pricing would allow each developer to operate semi-autonomously in the tar sands area of Northern Alberta, with the unscheduled flows of electricity between and among the developers being priced on a real time basis in relation to operating conditions. Thus, no one party or pair of parties would be setting the price.

Currently, each tar sands developer nominally operates a balanced electric system, having roughly the same amount of electrical production as it has electrical consumption. This near balance between each operator's supply and demand will change the dynamics of economic withholding, the issue my neighbor faced when installing flywheels with the purpose of participating in the market.

Much of the electrical production in the tar sands area is cogeneration, with the steam being used to process the tar. The WOLF pricing concept can also be applied to any steam exchanged among the parties, with the price reflecting the concurrent scarcity or surplus of steam, as measured by the enthalpy in the resulting steam balance.

Developing Countries

A different form of competition exists for industrial firms in areas with small or poorly developed electric utilities. Most utilities see industrial interconnections as new revenue sources, not as the potential for new supplies of electricity. WOLF provides a peer relation, allowing the industrial firm to sell electricity at times and to buy electricity at other times, with the price varying based on system frequency. Under such a peer relation, there would be no obligation on the part of either party to supply electricity to the other, but the WOLF price makes such supply a potentially lucrative concept.

Middle East

The tar sands area of Northern Alberta has its counterpart in the Middle East. Many of the petroleum companies operating in the tar sands area of Northern Alberta are also operating in the Middle East. The competition between these petroleum companies is fiercely matched by the various political factions in the area. The Gulf Coast Council Interconnection Authority is examining a transmission system connecting the various systems. WOLF pricing could provide an operating and pricing solution while other deals are being negotiated.

A substantial part of the generation in the Middle East is also cogeneration. Thus, there is some potential for steam networks among closely spaced plants. Further, some of the thermal value is being used for desalinization plants. WOLF pricing of the thermal process could depend on the current balance between (1) consumption of water and (2) the production of water, including the calcula of that balance, as mentioned above in regard to time error.

Spider Networks

Several communities around the world have entrepreneurs who install generators with the purpose of selling electricity to their neighbors when the grid is down, as was previously mentioned in regard to Baghdad. Under WOLF, these entrepreneurs could also sell electricity to the grid when the grid is marginally functional, as is indicated in the previous discussion of micro-grid, using WOLF to dispatch disparately owned generators.

CONCLUSIONS

The benefits of micro-grids can be obtained by installing a plug-and-play pricing mechanism, a pricing mechanism that allows any participant (1) to supply electricity or (2) to use electricity, doing either without negotiating a complex interconnection contract. The prices should go up and down to reflect shortages and surpluses. Such a pricing mechanism must be flexible enough to address wires constraints and reactive power issues on a real time basis. WOLF provides one such pricing mechanism and can be adapted to handle other flowing commodities such as steam, natural gas, and water.