Integrating Distributed Generation Technology into Demand Management Schemes

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Abstract – Recent developments in distributed generation technology brings extra flexibility into existing demand management schemes. Many utilities have implemented various demand management programs to help them in problematic times of the power system. This paper explains how existing demand management ideas can be supplemented by the use of distributed generation technology. More specifically it compares the economic aspects of using demand management contracts with the use of distributed generation. In some cases it is more beneficial to use distributed generation with demand management contracts.

Keywords: distributed generation, demand management, economic analysis, micro-grids, micro-sources

I. INTRODUCTION

During times of critical system loading it is necessary that customers shed load in return for some beneficent. Many demand management schemes offer lower rates of electricity for the customers who sign up for demand management, and also give them credit on the maximum demand charge depending on how much of their load they designate to be interrupted. The demand management contracts designed in [3] suggest the use of pay per curtailment method. Either way demand management requires a thorough economic analysis. The use of distributed generation through the micro-grids concept can be an effective alternative for load management in many cases.

Micro-grids provide a new paradigm for defining the operation of distributed generation. The micro-grid concept assumes a cluster of loads and micro-sources operating as a single controllable system. To the utility this cluster becomes a single dispatchable load, which can respond in seconds.

Electric utilities (or energy serving entities) try to provide reliable supply of electric power to their customers. Maximum benefit require both low cost and sufficient supply availability. At times, lower cost implies risk of potential unavailability of power. Customers willing to share in "availability risk" can derive benefit by participating in controlled outage programs. Whenever utilities foresee dangerous loading patterns, there is a need for a rapid reduction in demand either system-wide or at specific locations. The utility needs to get relief in order to solve its problems quickly and efficiently. This relief can come from customers who agree to curtail their loads upon request in exchange for an incentive fee. Reference [2] shows how utilities can get efficient load relief while maximizing their economic benefit. As an alternative a utility or a customer can install distributed generation units at the customer's site. This gives both the utility and customer additional flexibility during critical conditions. For the utility it provides a means for fast load reduction, while for the customer it can become a source of revenue or a tool for keeping critical loads online. This paper looks at potential revenues from demand management contracts to help defray the cost of distributed generation.

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II. DEMAND MANAGEMENT CONTRACTS

Reliable operation under conditions of uncertainty requires that loads be considered adjustable. In references [1,2] the authors assume that participation in demand management programs is voluntary and compensation for participation is an integral part of any demand management program. The incentives offered can be optimized if the utility can estimate the outage or substitution costs of its customers. Reference [3] illustrates how existing utility data can be used to predict customer demand management behavior. More specifically, it shows how estimated customer cost functions can be calibrated to help in designing efficient demand management contracts.

Demand management programs can help alleviate the stress brought on the system by events and contingencies. Some problems can be solved by system-wide load reduction, and other problems need location specific attention. If a utility has demand management contracts with customers at critical locations, most operational problems can be solved efficiently. Reference [2] also illustrates how locational attributes of customers incorporated into demand management contract design can have a significant impact in solving system problems. Having locational variance in demand management programs can help improve both the engineering and economic analyses of the system. Demand management contracts become more efficient economically, bringing more monetary benefits to the utility/customer, and system security issues are addressed more efficiently. Emerging distributed generation technology allows the utility/customer to consider installing distributed generation units at critical locations. The next section will discuss distributed generation types and how the current technology can be effectively used.

III. DISTRIBUTED GENERATION

Distributed power generation is any small-scale power generation technology that provides electric power at a site closer to customers than central station generation. Distributed generation provides a multitude of services to utilities and consumers, including standby generation, peak shaving capability, base load generation, or cogeneration[11]. In a deregulated power market, buyers and sellers of electricity will have to be responsive to market forces. A distributed power unit can be connected directly to the consumer or to a utility's transmission or distribution system to provide peaking services. Distributed power units varying in size from 30 kW to 40 MW could be located to alleviate transmission congestion or other circumstances that raise costs or threaten system integrity and reliability. Its ability to respond quickly to system problems could reduce investment in transmission, distribution and generation required to meet projected demand growth. In addition to increasing power system reliability, distributed generation also can reduce transmission losses, power wheeling cost and certain environmental emission costs.

Economic efficiency is one major concern of distributed generation customers. Various technologies are available for distributed generation, including turbine generators, internal combustion engine/generators, micro-turbines, photovoltaic/ solar panels, wind turbines, and fuel cells. Of special interest are small (~100kW) units with power electronic interfaces such as micro-turbines, photovoltaic panels and fuel cells. These technologies have the potential to be low cost, have high reliability, low emission and provide the opportunity to use waste heat making them ideal components of a micro-grid. Thanks to technology development, the installation cost of some of these distributed power units have dropped dramatically. Based on the data from DPCA (Distributed Power Coalition of America), the capital cost of micro-turbine ranges 450 to 1000 $/kW[11]. With electricity prices above the $4/kWh in recent months any doubt about the economics of distributed generation should be dispelled.

IV. IMPORTANCE OF LOCATION AND CHANGING SPOT PRICES

Some customers loads are at more critical locations than others. Existing demand management contracts usually offer rates depending on the size of the customer load, but these contracts tend to be uniform across all locations. The Game Theory formulation developed in [1,2] illustrates how customer location can be incorporated into demand management contract design. Once the formulation of contract design is developed, any power system can be analyzed to show the importance of location. This section reviews the locational attributes of the demand management contracts and distributed generation.

Sensitivity analysis can be used to determine the locational value of interruptible power contracts for the utility. It can also identify critical locations for distributed generation. In reference [4], the authors compute the sensitivity of the loading margin of a system with respect to arbitrary parameters. If loads are the parameters, sensitivity of the loading margin can be computed with respect to each load. Let:

$$g(x, \lambda, p) = 0 \qquad (1)$$

be the set of power balance equations, where x is the vector of state variables, λ is the vector of real and reactive power injections, and p is the vector of loads. If a pattern of load increase is specified with a unit vector k, the point of collapse method[3] can be applied to yield the left eigenvector w. The sensitivity of the loading margin to a change in any load is:

$$\frac{\partial L}{\partial p} = L_p = \frac{-w\, g_p}{w\, g_\lambda k} \qquad (2)$$

Once we have the sensitivity of the loading margin to a change in any load, we use it to rank loads. Let L be the loading margin of the system. The above formula lets us construct an expression relating changes in individual loads (Δp_1, Δp_2, etc) to changes in the security margin:

$$\Delta L = L_{p1}\Delta p_1 + L_{p2}\Delta p_2 + \cdots + L_{pm}\Delta p_m \qquad (3)$$

where m is the number of loads of interest. As equation (3) suggests, the load with the highest sensitivity would help increase the loading margin the most. By using these sensitivities and the dollars per kWh figures from the designed contracts, the utility can estimate how much it costs to increase system security:

$$\frac{\partial L}{\partial \$} = \frac{\partial L}{\partial p}\frac{\partial p}{\partial \$} \qquad (4)$$

where $\Delta\$$ is the amount the utility will spend. Equation (4) helps determine how much it costs to increase the loading margin by curtailing one of the loads. The same kind of analysis can be applied directly to figure out the cost of increasing the loading margin with the use of distributed generation. Other kinds of sensitivities can also be computed and combined with cost analysis to give the utility the cost of solving specific security problems. For example the same kind of analysis can be performed to relieve line overloads. In order to accomplish this the sensitivity of each constrained line flow ("flowgate") to each load in the system needs to be computed.

Whenever possible it is more efficient for markets to resolve congestion than to have side-markets for demand management. Locational Marginal Pricing (LMP) in various forms has been adopted by many markets as a means to resolve most congestion problems [2,4,5,6,7,8]. However, there are some situations where a pure market may be unable to resolve a serious security constraint. Real time markets might have a slow reaction time to some contingencies happening in the power system. In these cases the use of demand management or distributed generation may be effective. For these situations, the knowledge of margins and margin sensitivities is essential.

The key to using demand management contracts to improve the incentive to install and distributed generation is in the calculation of the power interruptibility value (□) at each location in the grid. Existing optimal power flow routines can be used to calculate this value for each location in the system. Critical locations have a high power interruptibility value that emphasize their importance and encourages prospective customers to create micro-grids at key locations.

V. DISTRIBUTED GENERATION VS. DEMAND MANAGEMENT CONTRACTS

One of the concerns of utilities (or energy serving companies) is to be able to meet the demand at peak times. Demand spikes during these times have been known to cause problems for utilities, and sometimes lead to complete or partial blackouts in the system. The use of effective demand management is one tool to help with peak loads. Another set of tools that has emerged are advanced distributed generation technologies.

Utilities and customers expect economic benefits when they install distributed generation units. Technology development and commercialization of distributed generation make the investment cost per kW very competitive. For example, based on the data from DPCA, the capital cost of installing micro-turbine generation units is about \$450-1000/kW. It is expected that this cost will reduce to as low as \$100/KW in the future with large volume manufacturing. If we assume the capital cost is recovered in a five-year period and the interest rate is about 7%. For 100 kW units, the current capital cost is \$80,000 (Assume \$800/kW). Then every year recovered capital cost is about \$20,000 (actually \$19510). If we assume the fuel price is \$0.03/kWh, and operational cost is \$0.006/kWh[11]. Then the variable cost of power production is \$0.036/kWh. If we assume the running time of the installed units is 1000 hours per year, we can have a cost function of production as shown in Figure 1. The jump in cost function will occur when a new unit is installed.

Power interruptibility value □

The power interruptibility value (□) depends on two things, one is system condition and the other is the location of the customer. As explained in the previous section □ value is highly dependent on the location of a customer in the power system grid. The cost of running a micro-turbine will not change greatly depending on location, however the contracts offered to the customers at different locations will vary. Hence the cost analysis of using demand management contracts vs. micro turbines needs to be done for each estimated □ value.

In times of peak load the cost of delivering power to the customers increases due to increased transmission costs, hence sometimes the utility can save money by not delivering to certain locations. This value in not delivering is reflected in the power interruptibility value (□). The □ values are calculated by using increased load conditions to simulate peak load conditions. However, these values can be much higher due to certain contingencies. Since the contingencies are less likely to occur than peak load conditions utilities may prefer to use demand management in case of contingencies. If peak loads are more likely to occur than contingencies distributed generation is a better way to go. This fact makes it critical to estimate the time of use of the distributed generation technology.

Once a utility determines the value of power interruptibility, it is possible to design demand management contracts to offer to its customers. In Figure1, three contracts are designed for three different values of □ to attract customers to participate in demand management program. This is similar and closely related to the concept of zonal price in current power market. Customers in the same zone will have one value of □.

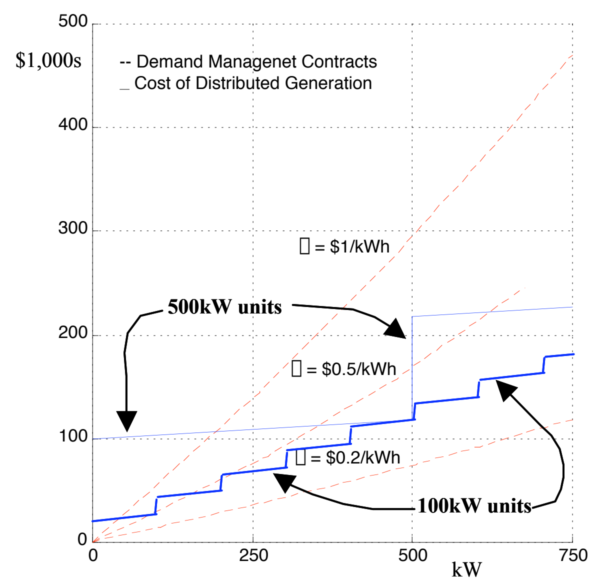

Figure 1: Comparison of costs of distributed generation and demand management contracts

The related cost of installing a micro turbine to interruption costs provides important planning information. It is easy to conclude that utility won't install micro turbine unit at the locations where customers' power interruptibility value □ is as low as \$0.2kWh. However when the power interruptibility value □ gets higher, micro-turbine become more attacrive.

For example when = $1/kWh, we can see that micro-turbine units become effective when the shed load is more that 100 kW. This concept becomes a bit more complicated for some values of . For example, if = $0.5/kWh, the break even load shedding value favors 100kW units over 500kW units.

Change of investment cost per kWh

Running time and capital cost of installing distributed generation units are very critical factors. In the previous case, we assumed the running time for a micro-turbine generator as 1000hours per year. However in reality the running time depends on the utility and or the customer needs. Large distributed generation units or micro-grids can be used as standby generation, peak shaving help, base load generation and dispatchable load. In most cases micro-grids are not the lowest cost source of electrical power, but they do provide many critical services to the customer. Such advantages are local voltage support, UPS services, premium power, and use of waste heat. From the utility perspective distributed generation is usually installed near transmission “bottlenecks”. When transmission prices are high, distributed generation can be run as base load. Based on the data from California ISO, the price of transmission goes up to $250/MWh. Utility or customer saves at least 25 c/kWh (equivalent to 250$/MWh). However typically price for congestion transmission lines is in the range of $20-80/MWh[12]. The value of power interruptibility is much higher.

Customer’s choice

Customers with critical loads find it too expensive to shed load. In situations of transmission congestion, or where system contingency exist, the load demand of these customers cannot be served sufficiently. These customers must work with the utility to increase transmission capability, which involves installing new transmission or distribution lines or create micro-grids. In reference [1], nonlinear cost function (quadratic or exponential) of load shedding is used in designing demand management contracts. If customers are willing to run distributed generation units to cover the unsatisfied power supply, they can get some compensation from the utility by taking the demand management contract. The benefit analysis should compare the cost of shedding critical load with the cost of installing distributed generation units. For example, this type of customers may have a quadratic cost function for load shedding as shown in Figure 2. In this case as more load is shed, the customer incurs higher losses. Although running time is only 200 hours per year, the customer will be better off with a micro-grid.

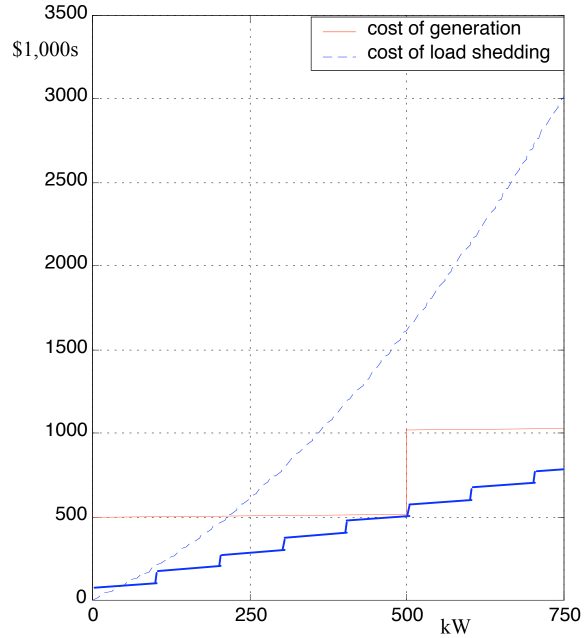

Figure 2. Comparison of cost of load shedding to cost of installing distributed generation units

Customers with high cost of load shedding will be willing to install distributed generation units and participate the utility’s demand management program. This will relieve transmission congestion and increase the reliability of power system. Meanwhile the customer will get the benefits of higher quality power and some compensation from utility for installing distributed generation units.

V. CONCLUSION

Micro-grids are an option in demand management program for most situations. In spite of their relatively high cost distributed generation near critical locations adds value for both the utility and the customers. In this paper we do the benefit analysis for both the utility and the customers for load shedding. The breakeven amount of load shedding is found by comparing the utility’s or the customers’ cost of shedding load to the cost of installing distributed generation units.

Distributed generation units providing power supply locally gives the utility and the customers more choices on demand management, which helps to increase the reliability of power supply and relieve the transmission congestion. It is expected that new development in distributed generation technology with higher volume will lower the investment cost of installing distributed generation units resulting in greater usage.

VI. REFERENCES

[1] Murat Fahrioglu. "*The Design of Optimal Electric Power Demand Management Contracts*." Ph.D. Dissertation, University of Wisconsin-Madison, Department of Electrical and Computer Engineering, 1999

2] Murat Fahriogluand and F. L. Alvarado "*Designing Incentive Compatible Contracts for Effective Demand Management,"* IEEE Transactions on Power Systems, Vol. 15, No.1, Nov 2000, pp1255-1260

3] Murat Fahriogluand and F. L. Alvarado "*Using Utility Information to Calibrite Customer Demand Behavior Models,"* IEEE Transactions on Power Systems, Vol. 16, No.2, Dec. 2000, pp317-322

[4] S. Greene; I. Dobson; F. L. Alvarado, "*Sensitivity of the loading margin to voltage collapse with respect to arbitrary parameters*", PWRS, Vol.12, No. 1, pp. 262-272, Feb. 1997

[5] C. A. Canizares; F. L. Alvarado, "*Point of Collapse and Continuation methods for large ac/dc systems*", PWRS, Vol.8, No.1, pp. 1-8, Feb. 1993

[6] F. C. Schweppe; M. C. Caramanis; R. D. Tabors and R. E. Bohn, "*Spot Pricing of Electricity*", Kluwer Academic Publishers, Boston, 1987

[7] R. E. Bohn; M. C. Caramanis; F. C. Schweppe, "*Optimal Pricing in Electrical Networks Over Space and Time*", Rand Journal of Economics, Vol.15,No.3, pp.360--376, Autumn, 1984

[8] H. P. Chao; S. Peck , "An Institutional Design for an Electricity Contract Market with Central Dispatch", Energy Journal, Vol.18, No.1, Jan. 1997

[9] H. P. Chao and S. Peck, "A market mechanism for electric power transmission", Journal of Regulatory Economics, Vol.10, pp.25--59, 1996

[10] William W. Hogan, "*Contract Networks for Electric Power Transmission*", Journal of Regulatory Economics, Vol.4, pp.211-242, 1992

[11] Homepage of *Distributed Power Coalition of America*, URL: http://www.dpc.org/

[12] Homepage of California ISO, URL: http://www.caiso.com

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