Proceedings of the Nineteenth Annual North American Power Symposium

FOREWORD

These Proceedings record the information presented at the 19th Annual North American Power Symposium.

For copies of previous North American Power Symposium or Midwest Power Symposium proceedings, please write to:

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Cover photo courtesy of City of Edmonton Power.
Top: Genessee Coal-fired Power Plant and Switchyard - 1986
Center: Cloverbar Gas-fired Generator Unit 4 Low Pressure Turbine Blades - 1976
Bottom: Rossdale Coal-fired Power Plant - 1918

Proceedings of

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NAPS '87

CHAIRMAN'S MESSAGE

Welcome to the 19th Annual North American Power Symposium. The purpose of the Symposium is to stimulate scholarly work through presentation of new and innovative ideas in the field of electric power engineering and to provide a forum for industry, utility, research institutes, governmental agencies and university representatives to actively discuss the benefits and limitations of theoretical models applied to practical power engineering problems and to define future research needs of the power industry. This conference will feature for the first time a limited number of conference exhibitors who will display "state of the art" technologies (e.g., computer software packages and power system measuring instruments). In addition, all sessions will be chaired by utility, governmental and industrial specialists selected from the North American continent.

It is an honour to present the proceedings of the 19th Annual North American Power Symposium (NAPS '87) on behalf of the following sponsoring agencies: IEEE Power Engineering Society, IEEE Region 7 Canada, IEEE Northern Canada Section and The University of Alberta. These agencies provided the initial "seed" money which was essential for advertising the conference throughout North America. Their enthusiastic volunteer members spent many months behind the scenes working on the activities necessary for this successful conference. The core of dedicated supporters of the North American Power Symposium (i.e., formerly the Midwest Power Symposium) have strongly promoted it in the form of advertising, presenting technical papers and bringing their students to the conference. The utilities of the Province of Alberta (i.e., Alberta Power Limited, Edmonton Power, TransAlta Utilities Corporation and The City of Calgary Electric System), Canadian Utilities (e.g., Hydro Quebec, Saskatchewan Power Corporation, Ontario Hydro) and American Utilities (e.g., N.E. Utilities) have promoted the conference by allowing their representatives to attend and actively participate in the conference activities.

Over sixty technical papers will be presented during the two day symposium in three parallel sessions. The subjects presented cover the following areas of utility operation: generation and co-generation, power electronics, modeling, generation dispatch and commitment, probabilistic methods and reliability analysis, advanced analysis methods and state estimation, rotating machines, computer applications, systems analysis, stability and control, distribution systems, transmission lines, HVDC and high voltage.

The success of this 19th North American Power Symposium is due to the enthusiastic and dedicated support of the authors, session chairpersons, exhibitors and attendees and particularly their institutions and supporting agencies for allowing them to participate. On behalf of the supporting agencies, it has been my pleasure to be associated with all the NAPS attendees and to thank them for their enthusiastic participation.

Don O. Koval
Conference Co-Chairman

Message from the Honourable Les Young, Minister of Technology, Research and Telecommunications Government of Alberta

Dear Friends:

Welcome to Alberta.

On behalf of the Government of Alberta, I am delighted to extend greetings to participants in the 19th Annual North American Power Symposium (NAPS '87).

Over the next few days, there will be presentations from experts on the most current research available in your field. I know you will find each session informative and rewarding. I commend your organization for providing a forum for industry and university representatives to share views on the benefits and future direction of electric power engineering.

May I offer you a warm Alberta welcome and my personal wishes for a productive symposium. I invite you to enjoy your visit to our magnificent province and return in February to Alberta for Winter Olympics '88.

Yours truly,

Leslie G. Young
Minister

NORTH AMERICAN POWER SYMPOSIUM

MIDWEST POWER SYMPOSIUM (1969 - 1985)

SCHEDULE

1969 -	University of Minnesota
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1971 -	University of Michigan
1972 -	University of Missouri at Columbia
1973 -	University of Cincinnati
1974 -	University of Missouri at Rolla
1975 -	University of Akron
1976 -	Kansas State University
1977 -	West Virginia University
1978 -	University of Nebraska
1979 -	Ohio State University
1980 -	Purdue University
1981 -	University of Illinois
1982 -	University of Wisconsin
1983 -	Iowa State University
1984 -	Drexel University
1985 -	Michigan Technological University
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1990 -	Auburn University

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Jim Beckett - Alberta Power Limited

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H. Baird - Edmonton Power

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GUIDELINES FOR PROSPECTIVE COGENERATORS/SMALL POWER PRODUCERS

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ABSTRACT

This paper is intended to assist prospective cogenerator/small power producers. Issues that should be considered in undertaking an installation are described in non-technical terms. Legal, economic, equipment, installation and operation considerations are presented.

1. INTRODUCTION

The Federal Public Utility Regulatory Act of 1978, Federal and State tax credits and higher energy costs have produced an incentive for customers, investors and small businesses to develop small power production and cogeneration facilities. In a number of instances, facilities have been planned and installed without considering the system to which they will be connected and without negotiating a contract for the interconnection and sale of generated energy. This lack of coordinated planning between the cogenerator/small power producers and the utility has resulted in additional costs for equipment modifications, lost generation and excessive time expended by consulting and utility engineers.

Through an assignment with the Arizona Public Service Company, this document has been developed to reduce or eliminate problem areas. It is intended to explain in non-technical terms, the things that a prospective cogenerator/small power producer should consider in undertaking an installation so that the objectives of both the cogenerator/small power producer and the utility will be met. Legal, economic, equipment, installation and operation considerations are presented.

2. OPERATION OF AN ELECTRIC COMPANY

It is essential that a prospective cogenerators/small power producer be acquainted with the operation of an electric company since a cogenerator/small power producer will not be allowed to degrade the quality of power using substandard equipment or unacceptable operating procedures.

2.1 What Keeps the Lights On?

The utility companies go through many different techniques and strategies to maintain a reliable source of power. For example, in order to maintain service continuity, additional transmission lines are built between two points such that if one of the line fails to operate other lines will carry the loads.

The "Operation" and "Load Dispatching Centers" of a utility company are departments that operate 24 hours each day to ensure normal operation of the system and to re-route the flow of electric power to load center in case the normal flow is disrupted. The full time job of "Planning" or "Distribution" department engineers is to analyze the system behavior under various operating conditions and contingencies before the problem occurs. After extensive study of various contingencies, these engineers propose solutions to the problem and provide the operators and dispatchers with various tables that list solution for each problem. This arrangement facilitates restoration of service following an abnormal condition during any time of the day. The net result, as General Electric describes, is that: "Modern electric power systems are remarkably dependable, standing ready night and day to deliver their energy without interruption" [1].

2.2 Quality of Power

A utility company has to strive to achieve the following goals regarding the quality of power:

1. The electrical power should be continuously available.
2. The electrical frequency must be 60 Hz.
3. Maximum allowable variations in the voltage level is approximately 5% within the city and 10% in the rural areas.

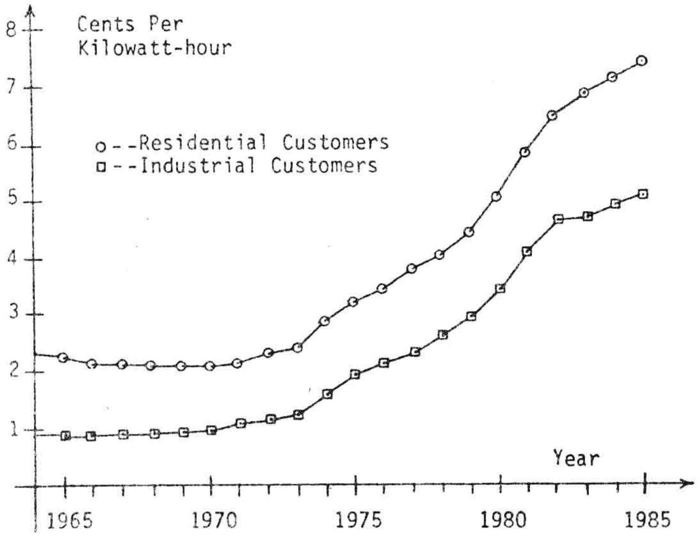
Since violation of the above requirements may result in undesirable performance or in some cases collapse of various systems within our society, a utility company will make every effort to satisfy these requirements. This includes not allowing a cogenerator/small power producer to degrade the quality of its power.

3. MOTIVATIONS FOR CUSTOMER OWNED GENERATION

The emergence of customer owned generation stems from (1) the rising price of electrical energy and (2) the Public Utility Regulatory Act (PURPA) of 1978. These topics are discussed in more detail in the following sections.

3.1 Rising Cost of Electrical Energy

Electric rates have steadily been increasing during the last decade. Rising prices of gas, oil, and coal, escalating costs of building central generating plants, and general inflation are major reasons for this increase. Fig. A shows charts of electric utility rates for industrial and residential customers in the United States since 1965 [2]. An industrial customer with a monthly load of 2000 kilowatt-hour that has paid $19.00 monthly in 1970, paid $38.40 in 1975, $68.80 in 1980, and $93.60 in 1983. Although compared with other commodities, electrical energy is still relatively inexpensive, the mere rise in the rate is a disturbing factor to many customers. The net result is that customers may seek a way of producing their own electricity and selling the excess energy to the local utility.



Source: Edison Electric Institute

Fig. A Average Price of Electrical Energy for Residential and Industrial Services in the United States Since 1965

3.2 PURPA

In an article titled "Renewable Power Sparks Financial Interest", Mr. Colin Norman of the Science magazine describes PURPA in the following manner [3]:

> PURPA Forces Utilities
> to Buy Power
>
> Congress passed the Public Utility Regulatory Policies Act (PURPA) in 1978 to encourage the production of electricity from renewable resources and from cogeneration systems. Cogeneration is the combined production of electricity and useful thermal energy. A cogeneration plant, for example, may be an industrial boiler that produces steam which is run through a turbine to generate electricity and then used to provide heat for an industrial process. Because the thermal energy is usually discarded in a central power plant, a cogeneration system makes much more efficient use of primary fuels.
>
> Before PURPA came into force, cogenerators and small power producers faced many barriers in selling their surplus electricity. Utilities were not obliged to buy power from them, and owners of even a single wind machine were subject to a maze of regulations if they wanted to sell a few kilowatt-hours of power. PURPA set out policies to remove some of the barriers, and in March last year the Federal Energy Regulatory Commission (FERC) published detailed regulations to implement the law.
>
> The heart of the law is a requirement that utilities must buy electricity from cogenerators or small power producers at a price equal to what it would have cost them to generate the power themselves. This rate, called the avoided cost rate, includes the cost of fuel that the utility would have to burn to generate an equivalent amount of electricity, together with any capital costs that the utility can avoid by buying power rather than building its own new plants. The State Utility Commissions were given until 20 March 1981 to draw up avoided cost rates for the utilities under their purview, but few have met the deadline. Among those that have, the rates vary from about 3 cents per kilowatt-hour in states where the purchased power would displace nuclear or coal-generated electricity to more than 8 cents in states such as New Hampshire where oil-generated electricity would be displaced.
>
> Another key provision is that the utilities must provide backup power to cogenerators or small power producers at their average rates, which are usually lower than avoided cost rates. Utilities, moreover, can bill decentralized power producers only for the actual costs of hooking them up to the gird. These provisions are designed to prevent the utilities from charging discriminatory rates to cogenerators and small power producers.
>
> To qualify for the benefits of PURPA, small power producers are limited to a capacity of 80 megawatts at any one site, and they must use renewable energy resources or waste products. There is no size limit for cogeneration facilities, but those that burn oil or natural gas must meet efficiency standards to qualify.

Finally, PURPA stipulates that qualifying facilities can not be owned by utilities: a utility's share of the investment in a qualifying small power plant or cogeneration facility must be less than 50 percent. Facilities that meet these conditions are exempted from most of the regulations that now govern the electricity supply industry. In other words, the owner of a small hydroelectric plant would no longer be treated like Con Ed.

Note that PURPA distinguishes cogeneration from small power production in the following manner:

3.3 Cogeneration-vs-Small Power Production

The terms cogeneration and small power producers are mistakenly interchanged at times. Cogeneration is the simultaneous production of electrical and thermal energy. There is no fuel requirement for a cogeneration facility but those that burn oil or natural gas must meet certain efficiency requirements [4]. A small power producer generates electrical energy by using (as primary energy source) biomass, waste, or renewable resources such as solar, water, or wind energy.

3.4 Firm and Non-Firm Power Producers

If a qualifying facility (as defined in section 3.2) can deliver electrical energy with reliability acceptable to the utility and with reasonable guarantee, then it is referred to as a firm power producer. Facilities that use geothermal or biomass may qualify as firm power producers. A non-firm power producer can deliver electricity, but can not guarantee when or how much. Facilities that use solar or wind energy are examples of non-firm power producers.

The distinction between a firm and a non-firm power producer is important because only a firm power producer can allow the utility company to defer adding capacity. The electricity that a non-firm producer generates is useful but the company has to have the capacity in reserve to pick up the load if the non-firm producer stops generating. Because of this, the rate for the purchase of energy from a firm power producer will be higher because it reflects avoided capacity cost as well as avoided energy costs. The rate for a non-firm power producer will be lower because it only reflects avoided energy cost.

4. CHARACTERISTIC OF VARIOUS GENERATORS

Electric power can be generated using synchronous, induction or DC generators. These devices which have totally different properties and operating characteristics are described in an excellent article titled "Making Interconnection Work" [5].

5. PROJECT EVALUATION

5.1 Economic Consideration

Decision regarding installation of cogeneration/small power production facilities is a business decision and requires careful planning and intelligent thinking. The following is a set of questions that any prospective cogenerator/small power producer should ask before making any commitments:

A. What will be the total cost of the project?

1. What kind of assurance do you have that actual cost will be the same as projected cost?

2. Remember that total cost should include utility interfacing cost. These costs include the cost of connection, switching, metering, distribution, transmission, and safety provisions.

B. What is the annual operation and maintenance cost?

1. As a cogenerator/small power producer you are liable for damages to properties or injuries to persons. Thus, to ensure proper operation of various devices, maintenance is absolutely necessary for your facility.

2. Will you be able to insure the facility? If so, insurance cost should be included.

3. Do not forget to include the utility monthly service charges for a customer with parallel operation.

C. What is the useful life of the proposed installation?

Is there a facility similar to the one that you will have. If so, arrange for a visit and an interview with the owner of that facility. The visit could prove to be quite valuable.

D. What are the tax advantages?

If you qualify as a cogenerator/small power producer, then you are entitled to some tax benefits. Find out exactly what these benefits are. Also, check to see if this information is up to date. Some of the laws that pertain to cogeneration/small power production facilities are being challenged by various organizations at the present time [6].

E. What is the utility purchase rate?

As mentioned in section 3.2 avoided costs for various utilities are different. It is totally wrong to think that because a facility is profitable at one state, it would also be profitable in another state.

F. What will be the duration of your contract with the utility company and how negotiable will it be?

Depending on the type of generation, i.e., solar, wind, geothermal, etc., the utility company will grant you different contracts. The type of contract that you will be able to have with the utility should be a good indication of the merits of your proposed project.

G. Will the overall project provide you with your minimum acceptable rate of return?

5.2 Problems From the Utility Standpoint

The addition of customer owned generation on utility network can cause deterioration of electric service quality. Since electric power must satisfy the requirements of section 2.2, the utility company is faced with technical and operational problems because of customer owned generation. These topics are briefly described below:

A. Technical Problems

Technical problems include harmonic distortion, voltage variation, phase imbalance, voltage flicker, power factor reduction, and system protection.

B. Operational Problems

Operational problems include unit commitment and safety hazards. In a paper titled "Customer Generation on the Distribution System", R. H. Moffatt of Houston Lighting and Power Company (HL&P) describes the safety problems as follows [7]:

> The distribution system of HL&P is designed as a radial system, with the power transformer at the distribution substation acting as the power source and with relaying designed to sense and isolate fault currents flowing from this source. Customer generation will act as a new source of electrical energy that can not only feed faults but also can unexpectedly energize the distribution system. Faults are a common occurrence and are caused by a variety of reasons: lightning, trees and wind, ice, animal, construction work, and human error. Most of these faults however are momentary in nature. Over 92.5% of the faults in 1980 on the HL&P distribution system were momentary. Therefore, our relaying scheme is designed to clear system faults by tripping the feeder breaker and to attempt to restore service by instantaneously reclosing the feeder breaker. This reclosing is extremely important to service reliability. Any other source on the system would continue to feed the fault and prevent the reclosing system from proper operation.
>
> It is very important that a customer not be allowed to energize a "dead" circuit. System dispatchers and linemen will assume a line is dead when all utility power sources have tripped off. To have an unknown customer generating power on a supposedly dead circuit would be hazardous to both utility personnel as well as bystanders and equipment.

5.3 Problems From The Owner/Operator Standpoint

The requirements of a utility company regarding customer owned generation and normal operation of a utility system introduces various problems for prospective cogenerators/small power producers. These problems, which can generally be solved using more expensive and/or additional equipment, are briefly described below:

A. Customer owned generation facilities must meet utility requirements regarding harmonic distortion, voltage variation, phase imbalance, voltage flicker, power factor, system protection, and safety requirements as mentioned in section 5.2.

B. Customer owned generation facilities must be equipped with proper synchronization devices to monitor correct closing of the generator breaker. Accurate operation of these devices is essential since out-of-phase closing of the generator breaker may severly damage customer's equipment.

C. Utility companies normally apply automatic reclosing to overhead distribution circuits. When the utility source breaker trips, the customer must ensure that his generator is disconnected from the utility circuit prior to automatic reclosure by the utility. Otherwise, reclosing action of the breaker may severely damage customer equipment.

5.4 Typical Owner/Operator Complaints

Some of the typical comments and complaints that are made by a "unhappy" owner or operator of cogeneration/small power production facility will be discussed in this section.

Complaint:

"Utility company does not really want to have parallel operation of customer owned generation on its system."

Response:

This is probably a true statement for the majority of the utility companies. However, as indicated in section 5.2, the reason is mainly due to technical and operating problems and the fact that a typical small power producer does not have an adequate knowledge of power system operation.

Complaint:

"Utility company does not pay as much as it charges."

Response:

This is probably a true statement for the majority of the utility companies. As