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New opportunities for fuel cells in the restructured power systems of the United States

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Abstract

Conventionally, the fuel-cell power system (FPS) is used mainly to provide electric power, the product. This paper demonstrates that the FPS can also be used to enhance the delivery of electric power – an important service in the new competitive environment in the USA. There are many new applications (and new markets) for the FPS that can provide service as well as power. Some of the new applications may be economical at current prices. Design changes for these new applications involve mainly changes in the power conditioning subsystem and its control. © 1998 Elsevier Science S.A.

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1. Introduction

Electric power systems in the United States are undergoing significant changes due to the 1992 Energy Policy Act and the new orders (Order Nos. 888 and 889) issued by the Federal Energy Regulatory Commission (FERC) in 1996 to open up the power transmission networks to encourage competition among power producers with the goal of reducing costs for the customers. Although the new federal orders initially target only the wholesale power market, more and more states are pursuing the implementation of competition at the retail level in the near future. This new environment creates many new opportunities for flexible power technologies such as the fuel-cell power system (FPS). The objective of this paper is to provide an overview of the new applications (and new markets) for the FPS in the new environment and the necessary changes in the design of the FPS for its new roles.

For the restructured power systems in the United States, electric power is viewed as a product that is decoupled from the service – the delivery of power. Conventionally, the FPS is used mainly to provide electric power, the product. This paper demonstrates that the FPS can also be used to enhance the delivery of electric power – an important service in the new competitive environment. A major concern for power producers, customers and utilities in the deregulated environment is the transmission systems' capability to support frequent and significant levels of power transactions. Open access by various parties to the transmission facilities which was designed and built many years ago without this foresight can create so much traffic on the transmission network that not only the amount of power transactions will be limited, but the transmission-system-owner's (TSO) basic operation may also be jeopardized. In view of the difficulties in building new transmission lines, there is a market demand for technologies that can enhance the utilization of existing transmission networks. This paper demonstrates that FPS can provide significant impact in this regard. Power transactions that are not feasible because of transmission bottleneck can be made feasible through the use of properly designed and optimally located FPSs. In addition, the FPS can also be used to provide the ancillary services specified by the new FERC order. An overview of these new opportunities is presented in Section 3. The necessary changes in the design of the FPS to meet the new challenges are presented in Section 4.

2. New environment

The 1992 Energy Policy Act and FERC Order No. 888 and No. 889 are creating a new environment for electric power systems in the United States. The basic intent of these federal legislations is to encourage competition at

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the wholesale level with the goal of reducing electricity costs. In many states, further government actions are shaping up to allow customers at the retail level to have their own choices of electricity supplier. The power systems in the US are undergoing major restructuring to adapt to this new environment. Three major aspects of this new environment that have significant impact on the applications of FPS are discussed in this section.

2.1. Product separated from service

In the conventional power systems, the generation, transmission and distribution of electric power are bundled together and electric utilities are vertically integrated. In the new competitive environment, electric power is viewed as a product that customers should have the right to decide from whom they purchase. The delivery of electric power is considered to be a service. The company that provides the service of power transmission and distribution may or may not be the same company that supplies the power. In the new environment, vertically integrated companies are encouraged to separate their power generation business from their transmission and distribution business. To facilitate fair competition, the FERC orders require that transmission system owners (TSOs) charge both their own generation enterprises and generation enterprises from outside their companies the same tariffs for using their transmission facilities.

2.2. Need for new power supply

The load demand in the US is growing at a steady 2% per year in recent years. However, the combined effect of high costs, regulatory hurdles, community hostility, uncertainty associated with deregulation, and downsizing to prepare for competition have provided very little incentive for electric utilities in the US to invest in the construction of new generation facilities. In recent years, the independent power producers (IPP) have provided most of the new generation capacity. The reserve margin has shrunk from 23% in July 1987 to 17% in July 1997 [1]. The situation is even more serious in certain parts of the country.

2.3. Need for more transmission capacities

While the growing environmental concerns and other economic and regulatory factors make it very difficult for utilities to build new transmission lines, the need for new transmission facilities is compounded by the trend to deregulate the electric power industry. Table 1 shows the projected need for new transmission lines at four major transmission voltage levels [2].

The need to build new lines may be lessened if existing transmission lines can be more effectively utilized. Appropriate devices can be installed and appropriate strategies can be implemented to deal with each of the factors that restrain the power transfer capacity of a transmission line from reaching the full potential (the thermal limit of the conductors) [3]. Table 2 lists the major methods to increase the level of power that can be transmitted through existing systems.

3. New applications of FPS

Conventionally, the FPS is used mainly to provide electric power, the product. The new environment creates many new opportunities for FPS because of the flexibility FPS offers. An FPS is flexible in its size because of its modular design. An FPS is also flexible in its location because of its benign impact to its environment. These attributes enable FPS to be used in a dispersed generation framework as well as in the conventional centralized generation framework.

This paper asserts that there will be many new applications (and new markets) for FPS if FPS can be used to enhance the delivery of electric power – an important service in the new competitive environment. An FPS is flexible in providing control in two major ways. Firstly, the fuel cells themselves are capable of changing its power output significantly in a relatively short time. Phosphoric-acid FPS developed about two decades ago can match a load demand that varies by more than half their rated output within 0.1 s [4]. The more advanced FPS developed since then is expected to perform at least as well in this aspect. Using advanced power electronic components, the power conditioning subsystem (PCS) is also capable of fast dynamic responses. A study shows that the dynamic response of FPS is fast enough so that an FPS can be used to compensate for the variable and intermittent power produced by photovoltaics such that the hybrid photovoltaics/fuel-cell system can be used to perform load following service [5].

Another way FPS is flexible in providing control is that the PCS can be used to provide a variety of control characteristics. For example, an FPS may be designed to perform voltage/reactive power control while simultaneously supplying real power at various levels. FPS's flexibility in providing control enables FPS to be used as a versatile service provider. For example, an FPS can be designed to

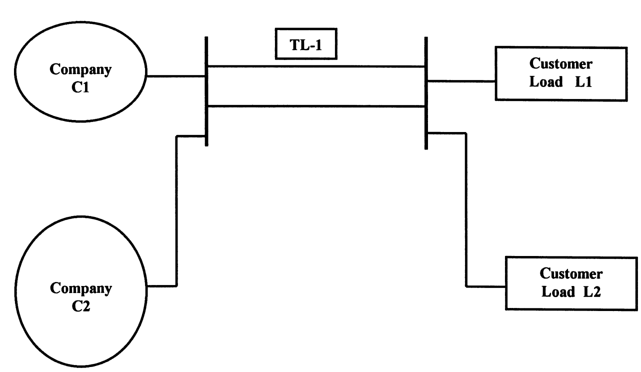

Fig. 1. Power transmission in a competitive environment.

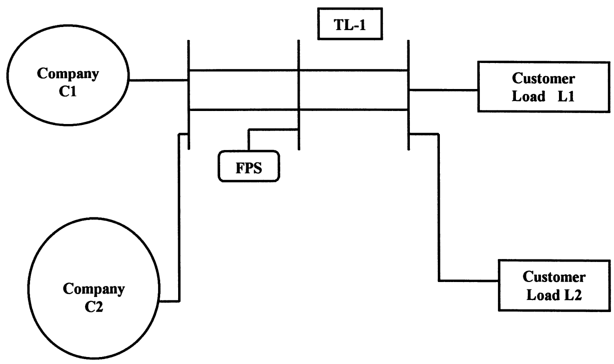

Fig. 2. Facilitation of power transaction through the installation of an FPS.

function as a static volt-ampere-reactive (var) compensator or as other devices stated in Table 2 while providing real power at the same time.

Under the FERC order, the transmission customer or the transmission provider may contract for one or more of the ancillary services as listed in Table 3. Ancillary services are services that are needed to support the transmission of electric power so that the operation of the transmission system remains reliable in accordance with good utility practice. With design changes discussed in Section 4, an FPS can be used to provide the ancillary services shown in Table 3.

Potentially there are numerous new applications for the FPS to function as service provider, as product provider or as both. The following example illustrates one particular new application of FPS that has promising potential in the new environment.

3.1. Example

As shown in Fig. 1, a transmission line TL-1 (in this case, a 345-kV double-circuit line with the same line data as that used in Ref. [3]) serves to transmit electric power generated by company C1 to the customer load L1. L1 is located within the territory of company C1 and company C1 owns TL-1. This situation is typical of the conventional power systems.

In the new competitive environment, customer L2 wants to buy cheaper power from another company C2. Both L2 and C2 are not physically within the traditional territory of C1. However, this transaction cannot take place because transmission line TL-1, which was designed many years ago to transmit power from C1 to L1, has already been loaded up to its limit due to the power transfer between C1 and L1.

Power transaction between C2 and L2 can be made possible if an FPS is installed at the midpoint of TL-1 and functions as a static var compensator (SVC) to regulate the midpoint voltage of TL-1. This arrangement, shown in Fig. 2, can raise the power transfer limit of TL-1 significantly to provide room for additional power transmission through TL-1 [3]. In addition to functioning as an SVC, the FPS also provides a load-regulating service that compensates for the moment to moment variations of L2.

An economic analysis has been performed on this application from three perspectives. Economic data common to all three perspectives are listed in Table 4. The power transaction between C2 and L2 is 600 MW for 8 h per day, 5 days per week and 52 weeks per year for a period of 20 years. The FPS installed has a rating of 30 MW with an additional PCS capacity of 415 MVA to perform SVC and load regulation services. The FPS will compensate for load variation within ±15 MW, allowing for 5% load fluctuation in the 600-MW transaction.

3.1.1. Perspective 1: perspective of company C2

It is assumed that company C2, being able to provide cheap power, can earn a levelized profit of US$0.015/kWh (including the cost of transmission losses) on this transaction. Based on published data on the difference in electricity prices [6], this assumption can be justified. To make the power transaction possible, the company C2 pays for the installation, operation and maintenance of the FPS. The rate of return for C2 (before tax) is 13% over 20 years.

In the USA, the merging of electric and gas utilities is becoming an emerging trend. This new application of FPS can be very attractive to a merged company. The company can use FPSs as service providers to facilitate more sales of

Table 1

Miles of proposed line additions

Year	230 kV	345 kV	500 kV	756 kV
1997	496	41	0	0
1998	445	24	12	0
1999	455	323	85	115
2000	388	21	969	0

Table 2

Ways to increase power transmission capacity through existing transmission networks

Static var compensator[a]
Static series compensator[a]
Static phase shifter
Uniform power flow controller[a]
Energy storage system
Demand-side management

[a]Can be replaced by FPS.

Table 3

Ancillary services

Loss compensation[a]
Load following service[a]
Backup service[a]
Energy imbalance service[a]
Reactive power/voltage control service[a]
Scheduling and dispatching service

[a]Can be provided by FPS.

Table 4

Data for economic analysis (in 1997 US dollars)

Inflation rate	3%
Interest rate	7.5%
Cost of FPS	2000 $/kW
Cost of PCS	100 $/kW
FPS O and M cost	0.02 $/kWh
Cost of natural gas	2.5 $/MBTU
Efficiency of FPS	45%
Service life of FPS	41 600 h

electric power. More sales of electric power in turn increase the amount of natural gas used by the FPSs.

3.1.2. Perspective 2: perspective of customer L2

It is assumed that customer L2, by purchasing cheaper power from company C2, can save itself $0.018/kWh (including the cost of transmission losses) on a levelized basis relative to other alternatives. Based on published data on the difference in electricity prices [6], this assumption can also be justified. To make the power transaction possible, customer L2 pays for (or contracts out) the installation, operation and maintenance of the FPS. The rate of return for L2 (before tax) is 16% over 20 years.

3.1.3. Perspective 3: perspective of the owner of the transmission line TL-1

The owner of the transmission line TL-1 also has economic incentive to upgrade the transmission capability of TL-1 and then charge other parties for using it. It is assumed that the owner of TL-1 charges a transmission tariff of $2.5/kW/month and a service fee of $0.062/kW/h for the load regulation service. This assumption can also be justified by published data [7]. To make the power transaction possible, the owner of TL-1 pays for the installation, operation and maintenance of the FPS and receives a rate of return (before tax) of 15% over 20 years for its investment.

This example shows that some new applications of FPS may be economical even at current prices. Although the potential of FPS in these new applications can be established in general, the benefits provided by an FPS for a specific situation depends on how the FPS is used in that situation, the economic factors involved and the general economic environment (such as inflation rate, interest rate, etc.).

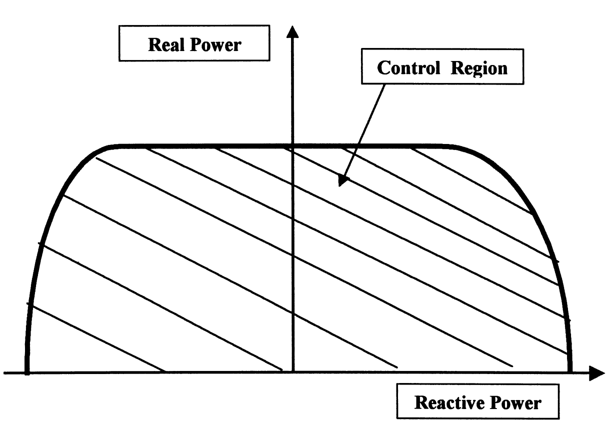

Fig. 3. Independent real and reactive power control.

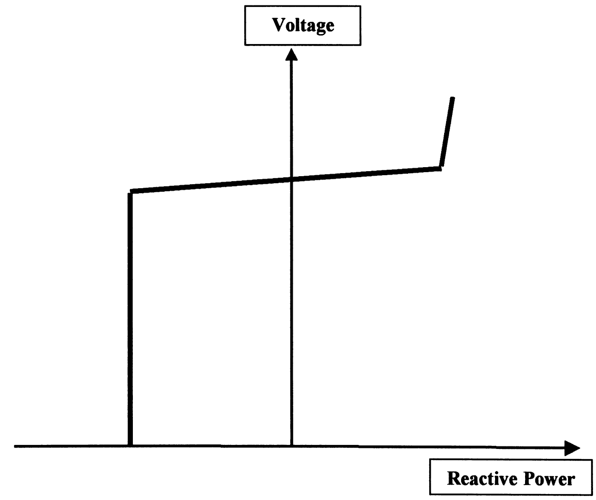

Fig. 4. Characteristics of a static var compensator.

For the new application presented in the example, the FPS supplies at most 30 MW in a power transaction that involves 600 MW. The role of FPS as a service provider is very different from the role of FPS as a product provider, although an FPS can be designed to play both roles simultaneously.

4. Design changes

If an FPS is to function as a service provider, major design changes are needed for the PCS and the control system. The role of the PCS needs to be expanded beyond DC/AC inversion. An important new requirement for the PCS is its ability to perform independent real and reactive power control within the control region, as shown in Fig. 3. The control region indicates that at any level of real power output, the reactive power output can assume any value within a range bounded by the boundary of the control region, the size of which is determined by the rating of the PCS. For an FPS functioning as both a service provider and a power producer, the rating of the PCS alone will be larger than the rating of the fuel cell stack.

Depending on the service the FPS is designed to provide, the reactive power control may be used for various functions such as voltage regulation, power factor correction, etc. In many new applications (e.g. the one mentioned in the example in Section 3), it is useful for the FPS to function as a static var compensator that has characteristics as shown in Fig. 4.

The control and monitoring capability also needs to be expanded. Depending on the service the FPS is designed for, more pertinent parameters in the power system may need to be monitored, and these measurements need to be processed by the FPS control unit as inputs to its control actions. Depending on the application, the FPS control unit may need to be coordinated with the overall power system control to optimize the performance of the entire power system.

5. Conclusions

Conventionally, the FPS system is used mainly to provide electric power, the product. This paper demonstrates that the FPS can also be used to enhance the delivery of electric power – an important service in the new competitive environment in the US. There are many new applications (and new markets) for the FPS that can provide service as well as power. Some of the new applications may be economical at current prices. Design changes for these new applications involve mainly changes in the power conditioning subsystem and its control.

An FPS can be used simultaneously for the new applications and for supplying clean power. From the user's viewpoint, the cost effectiveness of a multi-purpose FPS that simultaneously meets several needs can be significantly higher than that of the conventional FPS. The new applications and the improved cost-effectiveness also provide new appeal for FPS as a viable option for the transmission system owners, the wholesale power buyers and sellers, utilities and various kinds of customers. Many benefits of a multi-purpose FPS are also applicable to electric power systems outside the US. Opportunities for new applications of FPS are even more interesting for companies formed by the merging of electric utilities and gas companies, a trend that is emerging in the United States.

References

[1] *USA Today*, August 11, 1997, p. 3A.
[2] *Electric Power and Light*, May 1997, p. 18.
[3] K.-S. Tam, *Electric Power Systems Res., 41 (2)* (1997) 133.
[4] R. Noyes, *Fuel Cells for Public Utility and Industrial Power*, Noyes Data Corp., Park Ridge, NJ, 1977, p. 203.
[5] S. Rahman and K.-S. Tam, *IEEE Trans. Energy Conv., 3 (1)* (1988) 50.
[6] *Wall Street Journal*, August 13, 1997, p. A2.
[7] *Electric Power and Light*, October 1995, p. 1.