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Analysis and comparison of premium power park performances

Maurizio Delfanti[a], Stefano Quaia[b,*]

[a] Politecnico di Milano, Department of Energy, Via Lambruschini 4, 20156 Milano, Italy
[b] Universita' di Trieste, Department of Industrial Engineering and Information Technology, Via Valerio 10, 34127 Trieste, Italy

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ABSTRACT

Premium power parks (PPP) are one possible answer to the need for high quality power supply for sensitive users. A few pilot plants based on Custom Power devices have been realized, but their cost and complexity are so high that they have not been widely adopted. However, the quality of the power supply can be improved with simpler solutions. This paper compares the performances of different PPPs by calculating the annual number of production process halts (PPH) due to the most impacting power quality (PQ) disturbances (interruptions and voltage dips, the latter classified according to the latest edition of EN 50160). The calculations are based on a large data set from Italian Medium Voltage (MV) networks. Aiming to look for practical PPP solutions, suitable assumptions are used to point out the efficacy of a relatively simple solution arrangement.

1. Introduction

Since the 1980s, the increasing diffusion of electronic loads that are sensitive to the quality of the power supply has dramatically increased PQ concerns and the importance of PQ. The technical quality of the power supply includes voltage continuity (related to supply interruptions) and voltage quality (related to voltage disturbances, e.g. dips, swells, flicker, harmonics). Of all the categories of PQ disturbances, interruptions and voltage dips have by far the greatest impact on customers. Accordingly, this paper addresses these two main categories of disturbances.

Only a low percentage (10%) of customers are sensitive to voltage dips and to transient interruptions (hereinafter referred to with the term "microinterruptions"), but these customers have significant influence; in Italy, these customers (hereinafter, sensitive customers) represent 17% of the national sales [1]. Two basic approaches are possible to mitigate the impact of PQ disturbances on sensitive customers:

(1) installation of mitigation equipment (for example, UPS) in the customer plant;
(2) supply quality improvement through special arrangements on the public distribution net.

Costs involved by the two approaches cannot be directly compared: in the first case, they are charged to the customer, and in the second case, they are charged to the Distribution System Operator (DSO). Nevertheless, it can be stated that the first approach is usually simpler and cheaper: the mitigation equipment, adjusted on the sole sensitive loads, can be low-power; on the contrary, trying to put in place the same equipment to manage the MV distribution network (feeding customers with rated powers of 1 MW or above) could be questionable. In particular, using UPS for this power size has to be considered with caution; possible faults on the network downstream from the conditioning system can frustrate the investments made in the conditioning system itself. The same consideration applies to DC preferential sources. The usual (and technically sound) application of such techniques is limited to small power supplies (less than several hundred kW).

Since 1990, the Electric Power Research Institute (EPRI) of Palo Alto, CA, has developed custom power devices based on power electronics. These devices, which mainly include DVRs (dynamic voltage restorers), STSs (static transfer switches) and D-STATCOMs (distribution static compensators), can be installed at MV level either inside a customer plant or on a public distribution network to improve the supply quality for all the MV and LV customers connected downstream.

The availability of custom power devices and the demand for high quality power supply from sensitive customers led to quality contracts and PPPs, which are both classified in the second approach above listed. Even if quality contracts (i.e. individual contracts between the network operator and a single user, customised

Abbreviations: PPP, premium power park; PPH, production process halt; PQ, power quality; UPS, uninterruptible power supply; DSO, distribution system operator; DVR, dynamic voltage restorer; STS, static transfer switch; D-STATCOM, distribution static compensator; HSMTS, high-speed mechanical transfer switch; ASVC, Advanced Static var Compensator; SB, separation breaker; WSC, worst-served customer; SAIFI, system average interruption frequency index; MAIFI, momentary average interruption frequency index.

* Corresponding author. Tel.: +39 40 5583552; fax: +39 40 5583460.
E-mail address: quaias@units.it (S. Quaia).

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based on the user needs) are allowed in several countries, few have existed world-wide until today.

A PPP can be defined as a limited area where some customers are supplied, typically at the MV level, with a high quality power supply (at a price that should be related to the supply quality), obtained through proper solutions adopted on the public distribution network. However, until now, few PPPs have been realized because of the high cost for the DSO, that turns into high energy price for the PPP customers.

This paper evaluates and compares the performances of the main PPP solutions schemes to identify the most practical solutions. In particular, the goal is to evaluate the expected annual number of PPHs a sensitive MV customer will experience because of PQ events when the customer is supplied by a standard distribution system (i.e. with standard quality level) and by a PPP (i.e. with specific premium quality levels).

The paper is organised as follows: Section 2 provides a short description of the main PPP solutions, including the relevant PQ levels guaranteed downstream. Section 3 addresses the load immunity curves to be used for PPH calculation. Section 4 reports the annual PQ disturbances (interruptions and voltage dips recorded on the Italian system). Detailed calculations to determine the number of PQ events that result in a process halt for each individual PPP solution are performed in Section 5. Finally, a more sophisticated PPH calculation is performed in Section 6 with reference to the most effective PPP solution.

2. Main PPP solutions

The Futuroscope, which is located in France near Poitiers, can be considered the first example of a PPP. Its operation, based on a now obsolete technology, began in 1986. The first example of a modern PPP is the Delaware PPP (OH, USA) which employs different coordinated custom power devices. The Delaware PPP was developed in 1999 to supply about ten MV industrial users with an overall load close to 15 MW [2,3]. An almost identical solution has been adopted for the Korea Custom Power Plaza (Korea), which was initially used as a test plant and has been available to customers since 2006 [4]. A different, complex solution was developed for the PPP in Sendai, Japan in 2004 (a city hit hard by the earthquake on 3/11/2011) and has recently begun operating [5–7]. A simpler approach, which is mainly based on local generation, is proposed by the Consortium for Electric Reliability Technology Solutions (CERTS) [8].

We report a short description of the Delaware and Sendai PPPs, along with a discussion concerning the CERTS proposal. For a more detailed review, the reader can refer to the literature cited.

2.1. Delaware PPP

The Delaware PPP (Fig. 1), which operates at a voltage level of 13.2 kV, is supplied by two MV feeders (derived from two separate 138 kV HV/MV stations) and uses one DVR rated 2 MVA, 13.2 kV, with 40% max voltage compensation and capacitors for energy storage; one 13.2 kV High-Speed Mechanical Transfer Switch (HSMTS) with an opening time of approximately 30 ms; and one Advanced Static var Compensator (ASVC, essentially a thyristor-controlled reactor), which is rated 1.5 Mvar per phase.

The system control activates the DVR during voltage dips with a residual voltage of at least 62%. Table 1 reports the ideal voltage dip compensation capability of the DVR according to its design characteristics. Compensation for interruptions and more severe dips is assigned to the Transfer Switch.

In the Korea Custom Power Plaza, an STS was installed instead of the HSMTS, and a D-STATCOM was installed instead of the ASVC. The performances and power ratings of the two PPPs are similar.

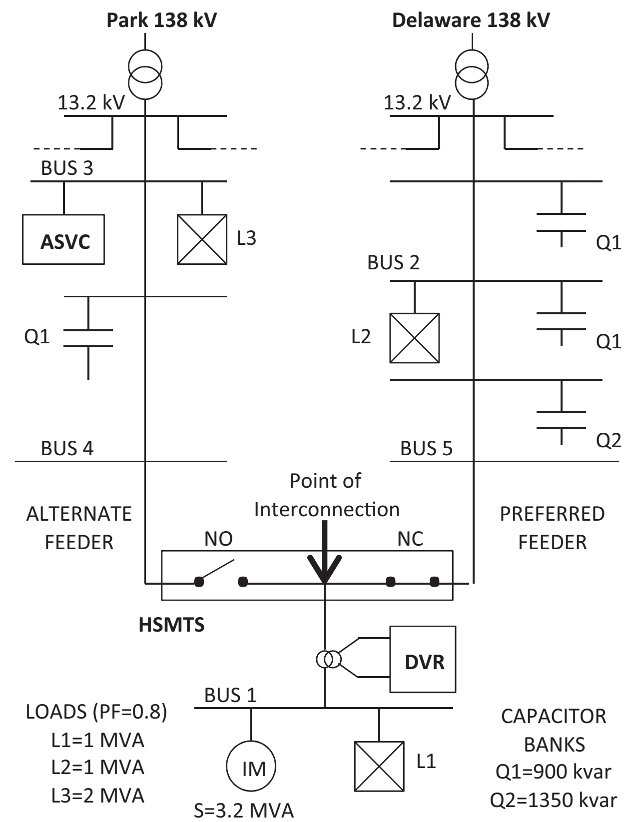

Fig. 1. One-line diagram of the Delaware PPP.

2.2. Sendai PPP

The PPP realized in Sendai covers a 300,000 m^2 area that includes part of the local university and a small area of the city. The PPP is connected to a 6.6 kV public distribution system and supplies a 1.6 MW maximum load through different busbars. In the university zone, the PPP supplies clinical laboratories, servers, a nursing home and nursing facilities. In the city zone, the PPP supplies a high school and a water plant. Clearly, the PPP was not built for industrial users.

The Sendai PPP, which is more complex than the Delaware PPP, integrates the public power supply with local generation (using both traditional and renewable energy sources), uses Custom Power devices and includes a 300 V DC distribution (Figs. 2 and 3). More specifically, the PPP includes two DVRs rated 6.6 kV (600 kVA and 200 kVA), one 400 V static breaker, one 50 kWp PV generator, two turbo-gas generators rated 350 kW each, fuel cells rated 250 kW (for 1 MW total local generation), DC/DC and AC/DC power converters, batteries and other traditional components. Table 2 shows the ideal voltage dip compensation capability of the two DVRs, according to their design data.

The Sendai PPP provides five different high-quality power supply levels:

Table 1
Delaware PPP: DVR ideal voltage dip compensation capability at the rated power.

Dip duration [ms]	Max voltage compensation [%]
200	40
300	26.7
400	20
500	16
600	13.3