Technical–economic sustainability of premium power parks

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ABSTRACT

This paper evaluates the economic sustainability of different premium power park (PPP) solutions – derived from two prototypes and a theoretical solution – and completes a previous technical analysis of the same PPP solutions. All of these are utility-provided solutions that improve the quality of the electricity delivered at medium voltage (MV) level.

We calibrate the study on the potential customers of a PPP, which are MV users sensitive to power quality (PQ) events and badly served. As to PQ events, accidental interruptions and voltage dips are concerned. We evaluate the direct costs caused by PQ events through original and simple cost models developed using different approaches. Even though until today PPPs have not proved to be a winning idea, the results prospect possible future applications of this idea as a consequence of the increasing penetration of dispersed generation, maturation of renewables and developments of energy storage technologies.

1. Introduction

The idea of PPP – an utility-provided solution to improve electrical service quality in a limited area of a public distribution system – had a strong impulse in the 1990s following the development of power electronics and the availability of new 'custom power' devices such as, for example, dynamic voltage restorers (DVRs). In this paper, a PPP is a solution that allows to improve the quality of the electrical supply at MV level by means of one or more devices connected to the Distribution System Operator (DSO) side of a distribution network.

A PPP should be tailored for one or more users who need a 'premium quality' power supply. Such 'sensitive' users are not satisfied by the standard quality level and could accept a higher energy cost for a higher quality power supply.

The technical performances of different PPPs, in terms of annual number of productive process halts (PPH) caused by PQ events, were analyzed in the previous work [1]. The work examined the following PPPs, whose principle solutions are illustrated in Fig. 1:

- Delaware Industrial Park PPP (Ohio, US, in operation since 2002);
- Sendai PPP (Japan, 2010), concerning the quality levels B2 and B3 at MV level[1];
- 'CERTS[2] solution' (theoretical solution).

Addressing the reader to [1–7] for further details, we list here in short the main devices used in these PPPs. The Delaware PPP (13.2 kV nominal voltage) includes one DVR (rated 2 MVA, 40% maximum voltage compensation capability for 0.2 s) and one high-speed mechanical transfer switch (1.5 cycle opening time) between two independent MV feeders.

The Sendai PPP includes, for the quality level B2 (6.6 kV nominal voltage), one DVR (rated 0.6 MVA, 100% maximum voltage compensation capability for 0.2 s) and two 350 kW local generators in stand-by. For the quality level B3 (6.6 kV nominal voltage), one DVR (rated 0.2 MVA, 100% maximum voltage compensation capability for 0.2 s).

As to the CERTS solution, it can be divided into two main cases, depending on the state of the local generator which can either run in parallel with the network (CERTS-1) or be kept in stand-by (CERTS-2). The first case includes one Low Voltage (LV) generator set with

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[1] The Delaware PPP was realized in an existing industrial park to feed one industrial user of ~4 MW. On the contrary, the Sendai PPP is not designed for industrial users; through a complex arrangement, it provides five different quality levels – three of which at LV and two at MV – better than the standard one.

[2] Consortium for Electric Reliability Technology Solutions, instituted in the USA in 1999 to research, develop and publicize novel methods, tools and technologies to improve distribution electricity reliability.

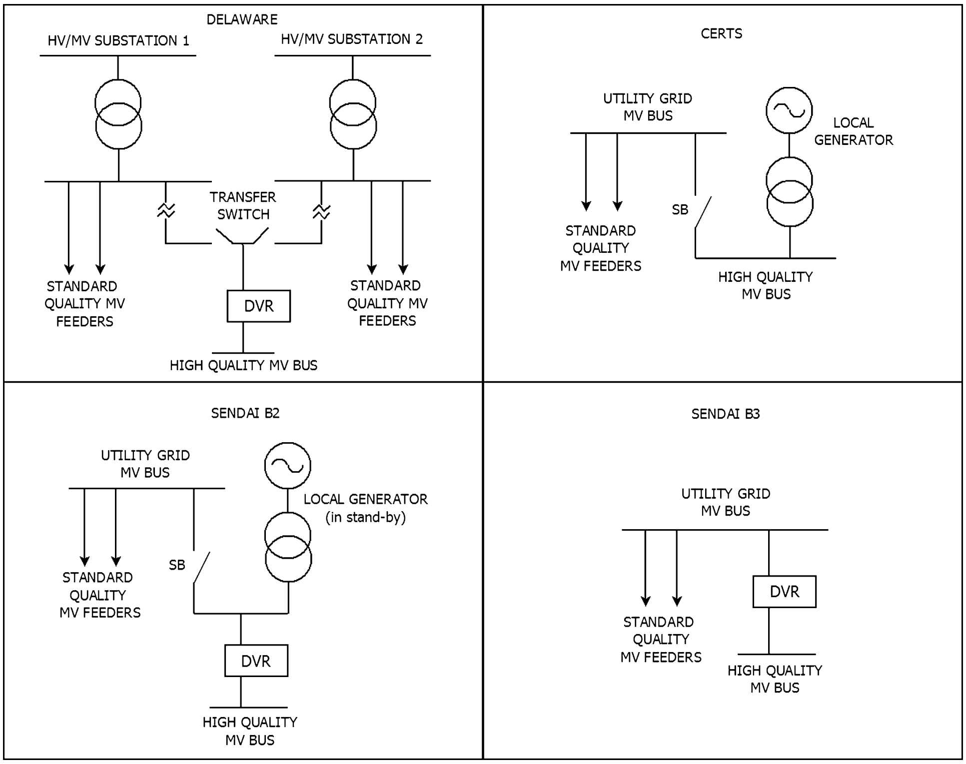

Fig. 1. Principle schemes of the PPP solutions under investigation:. Delaware, Sendai B2, Sendai B3, CERTS. (SB: Separation Breaker).

the related LV/MV transformer, one MV static circuit breaker (the SB in Fig. 1) and the related power panel with synchronization devices. The case CERTS-2 includes the generator, the transformer, and one MV traditional circuit breaker (SB in Fig. 1). Clearly, the CERTS solution is not based upon custom power devices but exploits local generation. Notice that, inside customer plants with electricity production, this principle solution is widely used to improve the supply reliability of critical loads.

Previous works have already analyzed the operation of each of these PPP solutions. The innovation brought by this work consists in providing a homogeneous comparison among them. This is obtained by using the same power, PQ data and cost models for the technical and economic analyses.

The study [1] shows that, from an exclusively technical point of view, the most effective solution is the CERTS-1. This paper completes the technical analysis [1] evaluating and comparing the economic sustainability of these PPP solutions.

To this aim, both the PPP costs (capital and operative) and benefits (reduction of the PQ direct costs) must be evaluated and compared[3].

Since a PPP cannot be justified for an ‘average’ user, we calibrate calculations on a small minority of MV users, sensitive to PQ events and badly served (*worst-served customers*—WSC). We work under the assumption that these users are sensitive to both voltage dips and interruptions and we perform calculations using the annual number of PQ events that is not exceeded by 95% of the MV users. In the following sections of this paper, we will refer to these users as “WSC 95%”. In addition, to make the results comparable, we will refer to a reference load power (1 MW), equal for all the PPP solutions.

The analysis performed in [1] is fully revised here – in Section 2 all data are updated and the PPHs computation is repeated – maintaining the general frame and thus considering, as PQ events, long, short, transient (less than 1 s long) accidental interruptions and voltage dips, and working in coherence with the standard EN 50160 for voltage dip classification [8].

As to the immunity of loads/industrial processes, necessary to perform the PPH calculation, as already made in [1] we refer to the Class 2 and Class 3 curves defined in the European Standard EN 61000-4-11 [9][4]. In addition, calculations are performed here also with reference to the R-DFI[5] (*regulated dip frequency index*), which is a middle course between the Class 2 and Class 3 immunity levels.

This way we calculate the annual (expected) number of PPHs avoided, which is equal to the difference between the PPHs expected with a standard supply and the residual PPHs expected with each different PPP solution.

In Sections 3 and 4 we perform specific cost analyses in order to evaluate:

1. the economic benefit for the PPP customers (Section 3). To this aim, a cost is associated with each type of PQ event (voltage dip, long interruption and so on). The annual benefit is obtained as the product, for each type of PQ event, of the expected PPHs avoided and the associated cost;
2. the PPP costs, both capital and operative (Section 4).

Finally, in Section 5 we calculate widespread economic indexes for each different PPP solution. In Section 5, we also compare the results and provide a short discussion that takes into account the effect of PPP removal costs as well.

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[3] Notice that the costs are for the DSO and the benefits are for the users. Therefore, the relationship between the DSO and the PPP customers should be governed by quality contracts, through which the premium quality energy delivered can be evaluated case by case to justify the PPP costs.

[4] These are equipment test curves, according to the product standards. We use them here as equipment immunity curves.

[5] The R-DFI is got weighting 1 each voltage dip below the Class 3 curve, 0 each voltage dip over the Class 2 curve and 0.5 each voltage dip between the two curves.

2. PQ statistical data and PPH calculation

In this paper, we use statistical data of interruptions and voltage dips recorded in Italy. The annual numbers of long, short and transient interruptions derive from the 2009–2010 data provided by AEEGSI, the Italian National Regulatory Authority [10–13]. Interruption data represent exhaustively the continuity levels in Italy, because the DSOs must keep track of all interruptions recorded by SCADA systems. From these data, the following annual figures are derived for WSC 95%:

- 5 long interruptions;
- 13 short interruptions;
- 30 transient interruptions[6].

Voltage dip data are drawn from QuEEN, the Italian MV PQ monitoring system, which has been operating since 2006 with 400 voltage-quality recorders installed on 10% of the total MV busbars in the HV/MV stations[7]. Although these data refer to a subset of the Italian MV distribution systems, they can be accepted as representative of the whole territory since the 400 MV busbars monitored are well distributed over the country and the MV networks subtended are well diversified for feeders type and length, station short-circuit power, neuter connection and so on.

Table 1 reports the "expected annual number of voltage dips" for WSC 95%, obtained from the three years period 2010–2012. In Table 1, the Class 2 and Class 3 curves are chromatically evidenced[8] (light-grey cells for Class 2, grey and light-grey cells for Class 3).

We work under the assumption that the standard supply for WSC 95%, i.e. the power supply without a PPP, is characterized by the above interruptions and voltage dips data.

In order to calculate the annual number of PPHs due to PQ events, we assume that each interruption causes a PPH. As to voltage dips, Table 1 allows a fast PPH calculation for the standard power supply. Error! Reference source not found. For example, with reference to the Class 3 immunity, each voltage dip more severe than the Class 3 curve (i.e. the dips in the white cells) causes a PPH. This leads to 61 annual PPHs.

Finally, for each of the three immunity levels considered, Table 2 reports the annual number of PPHs caused by the expected PQ events.

These figures are lower by about 20% than those used in [1], but they still look quite high. In particular, one could object that, probably, most real industrial processes have an overall immunity better than the Class 2 (and even the Class 3) curve. To this regard, it is interesting to note the results of a monitoring period over 3 months that involved an ensemble of 16 MV industrial users [14], according to which:

- all of the 35 transient interruptions recorded caused a PPH
- 41 out of 45 (91%) voltage dips below the Class 2 curve caused a PPH
- 44 out of 278 (16%) voltage dips over the Class 2 curve caused a PPH.

Thus, the 'average' immunity of these users is close to the Class 2 curve. In addition, these results further justify the choice to assume as reference immunity levels the Class 2 and Class 3 curves, and the R-DFI.

It must be also pointed out that the WSC 95% relevant to interruptions and the WSC 95% relevant to voltage dips are not the same set of users. Thus, by directly adding the relevant PPHs, as simply made in Table 2, the annual number of PPHs is overestimated.

3. Economic analysis: annual benefits for the PPP users

We assume the annual benefits for the PPP users to be equal to the direct PQ costs avoided over one year. Since these costs depend on the technical performances of each PPP, the first step for benefits evaluation is to calculate the residual PPHs for each PPP. Second, for each PPP, the PPHs avoided are obtained subtracting the residual PPHs from the PPHs expected with a standard supply (Table 2). This was already done in [1], to which the reader can refer for the methodology adopted and computation details. In this paper, calculations were repeated using:

1. the updated PQ data presented in Section 2, and
2. introducing a new parameter k_S to account for the asymmetry of most real voltage dips. The parameter k_S is equal to the ratio between the energy (stored in the DVRs) required to compensate an ideal symmetrical three-phase voltage dip and the energy required to compensate a real dip, with same depth and duration, but which is often not symmetrical. On average, we assumed $k_S = 1.5$.

The results are reported in Table 3. The differences with respect to the calculations made in [1] have opposite effect on the number of PPHs. Thus, they tend to balance each other out, and the performances of the different PPPs are not much modified[9].

The annual PQ direct costs for a WSC 95% are obtained as the PPHs reported in Table 3 multiplied by the relevant costs, which were estimated as follows.

3.1. Short and long interruptions cost models

For short and long interruptions, we estimate the direct costs using an original cost model developed starting from two different approaches:

(1) using the results of surveys on PQ costs;
(2) using the present Italian regulation on the continuity of supply.

As to the first approach, the main reference adopted in this work is a wide survey performed in the US, on behalf of the Electric Power Research Institute (EPRI), by the Consortium for Electric Infrastructure to Support a Digital Society (CEIDS), whose results were published in 2001 [15]. They indicate average rounded costs of 5000 €/long interruption and 1750 €/short interruption. However, sensitive users should bear costs higher than the average. Concerning this, in [15] it is reported that 5% of the users (in some industrial sectors) bear costs ≥15 k€ in case of a 1-h interruption. This datum is very useful as it refers to the same percentage of WSC considered in this paper. Keeping in mind all this, we choose to increase the above reported average costs by a (prudential)

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[6] Statistics of the year 2009 were used in [1], leading to 5.5 long, 13.5 short and 35 transient interruptions.

[7] https://queen.rse-web.it. The voltage dips recorded on the MV busbars of the HV/MV stations can be considered a good approximation of those seen by the MV customers connected downstream.

[8] Overall, voltage dips are a little less than those considered in [1] and derived from the year 2009 data.

[9] As made in [1], the PPHs are computed starting from the design data of the two PPP prototypes. For example, in the Delaware PPP, the DVR compensates for dips with residual voltage higher than 62% and the transfer switch operates in case of more severe dips. Of course, adopting the same PPP solution elsewhere, the threshold value 62% as well as the DVR design data can be modified according to the specific local situations.

Table 1
Expected annual number of voltage dips (MV) for WSC 95%.

Residual voltage [%]	Duration				
	20–200 [ms]	200–500 [ms]	0.5–1 [s]	1–5 [s]	5–60 [s]
80–90	89	28	5	2	0
70–80	44	19	2	0	0
40–70	63	22	2	1	0
5–40	25	8	1	0	0
0–5	0	0	0	0	0

Table 2
Expected annual number of PPHs for WSC 95% with standard supply.

	Voltage dips	Transient interruptions	Short interruptions	Long interruptions	Total
Class 2	131	30	13	5	179
Class 3	61	30	13	5	109
R-DFI	96	30	13	5	144

factor 2.5, obtaining a simplified cost model of 12.500 €/long interruption and 4375 €/short interruption.

A different approach is allowed by the current Italian regulation on the continuity of supply. This regulation provides incentives and penalties for DSOs and individual continuity standards for MV users [16]. Using the figures set for the conventional compensations that a DSO must pay to its MV customers if the individual continuity standards are exceeded, it is possible to evaluate the cost associated to an interruption. For the period 2014–2015 we can derive a cost/interruption (independent from its duration) of 2.7 k€/MW, referred to the contractual power of the customer. Again, this has the meaning of an average cost, because it concerns all MV users. Therefore, adopting the same factor 2.5 used above and considering the 18 annual interruptions expected (13 short and 5 long), an annual cost of about 120 k€/MW is obtained.

Clearly, the two approaches cannot be directly compared. The first gives cost figures not related to the customer power and diversified for long and short interruptions, whereas the second gives costs per unit power independent from the interruption duration. However, both approaches give practically the same cost – about 120 k€/year – for a 1 MW user (the reference user, or reference PPP power, that will be considered in the following sections).

Once verified the consistency of the costs obtained through these two approaches, we have finally adopted the simple cost model reported above (12.500 €/long interruption and 4375 €/short interruption).

3.2. Transient interruptions and voltage dips cost models

We can regard transient interruptions as severe voltage dips with roughly zero residual voltage on all the phase voltages[10]. Therefore, in agreement with [1], for the evaluation of PQ direct costs we will group together transient interruptions and voltage dips and call them 'microinterruptions'.

The scientific literature clearly points out that the costs due to a microinterruption can vary in a very wide range, depending on the industrial sector and the individual user. There is full accordance in singling out the semiconductor industry as the most penalized sector, with very high costs that can reach 15–45 k€/MW per transient interruption [17]. In this paper, also considering the high number of PPHs caused by microinterruptions (Table 2), we adopt a conservative cost of 2 k€/MW per microinterruption.

For the 1 MW reference WSC 95% here considered, these costs per event lead to the annual costs reported in Table 4.

The annual benefits (direct costs avoided) for the reference customer are, finally, those reported in Table 5[11]. These figures are the difference between the annual costs relevant to the standard supply (reported in Table 4, first column) and those relevant to the various PPP solutions (Table 4, columns 2–6).

4. Economic analysis: costs of the PPP solutions

We evaluate the PPP costs – both capital (CAPEX) and operative (OPEX) – using data found in the literature and information provided by manufacturers and operators of the electrical sector.

In particular, as to the CAPEX, we assume the following rounded figures for the main apparatus:

- DVRs: 500 k€/MVA (that means 250 k€/MVA referred to the load power, in case of a DVR designed for 50% voltage compensation capability)
- MV high-speed mechanical transfer switch (Delaware PPP): <100 k€
- MV static circuit breaker (15–20 kV nominal voltage, nominal current < 1 kA): 100 k€
- MV static transfer switch (transfer time < 1 cycle and nominal current < 1 kA): ≥ 200 k€
- 1 MVA generator set, with LV/MV transformer and synchronization devices: 130 k€.

Table 6 shows the rounded costs evaluated for the different PPP solutions, all referred to the same reference power.

Clearly, the solution CERTS-1, with the generator running in parallel with the network, is characterized by high OPEX due to the fuel consumption. For a 1 MVA diesel fueled generator set the fuel cost can be assumed not lower than 250 €/MW h times the energy generated in one year. On the other hand, the energy not purchased from the network represents a saving up to about 150 €/MW h (including taxes), with a difference not lower than 100 €/MW h. Even if the generator is normally operated only at 50% power, relying upon a high load acceptance (this hypothesis appears quite optimistic when the voltage disturbance must be strictly limited to avoid voltage dips), this difference leads to OPEX higher than

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[10] More precisely, interruptions happen when all the phase voltages fall below 0.05 p.u. On the contrary, a voltage dip can exhibit a reduction on just one phase voltage.

[11] We assume here that the PPP apparatus are always available. In order to account, more realistically, for the real availability of equipment, one should introduce the relevant fault rates and perform FMEA analyses. This way, the PPP would be a little less performing and the annual benefits would result a little lower than those reported in Table 5.

Table 3
Expected annual number of PPHs for the different PPP solutions.

		Standard	Delaware	Sendai B2	Sendai B3	CERTS-1	CERTS-2
Voltage dips	Class 2	131	30.4	15	15	0	131
	Class 3	61	16.9	14	14	0	61
	R-DFI	96	24.3	14.5	14.5	0	96
Transient interrupt.		30	3	27	27	0	30
Short interruptions		13	0	13	13	0	13
Long interruptions		5	0	5	5	0	5
All PQ events	Class 2	179	33.4	60	60	0	179
	Class 3	109	19.9	59	59	0	109
	R-DFI	144	27.3	59.5	59.5	0	144

Table 4
Expected annual PQ direct costs for the reference 1 MW WSC 95% [k€].

		Standard	Delaware	Sendai B2	Sendai B3	CERTS-1	CERTS-2
Microinterruptions	Class 2	322	66.8	84	84	0	322
	Class 3	182	39.9	82	82	0	182
	R-DFI	252	54.7	83	83	0	252
Short interruptions		56.9	0	56.9	56.9	0	56.9
Long interruptions		62.5	0	21.9	62.5	0	21.9
All PQ events	Class 2	441.4	66.8	162.8	203.4	0	400.8
	Class 3	301.4	39.9	160.8	201.4	0	260.8
	R-DFI	371.4	54.7	161.8	202.4	0	330.8

Table 5
Annual benefits for the reference 1 MW WSC 95% [k€].

		Delaware	Sendai B2	Sendai B3	CERTS-1	CERTS-2
Microinterruptions	Class 2	255.2	238.0	238.0	322.0	0
	Class 3	142.1	100.0	100.0	182.0	0
	R-DFI	197.4	169.0	169.0	252.0	0
Short interruptions		56.9	0	0	56.9	0
Long interruptions		62.5	40.6	0	62.5	40.6
All PQ events	Class 2	374.5	278.6	238.0	441.4	40.6
	Class 3	261.5	140.6	100.0	301.4	40.6
	R-DFI	316.7	209.6	169.0	371.4	40.6

Table 6
Rounded CAPEX and OPEX assumed for a 1 MW reference load.

PPP	CAPEX [k€]	OPEX [k€]
Delaware—Ohio	500	36
Sendai B2	630	56
Sendai B3	500	40
CERTS-1a	230	400
CERTS-1b	230	200
CERTS-2	130	10

400 k€/year for an average delivered power close to 1 MW. Thus, since OPEX are higher than or similar to the benefits, this solution cannot be regarded as sustainable.

However, this conclusion would change if the cost of the energy generated locally could be reduced so as to drive the OPEX well below the annual benefits: i.e. less than 400 k€/year in case of Class 2 immunity, and less than 300 k€/year in case of Class 3 immunity. For instance, this objective could be pursued resorting to renewable energy sources (RES) and/or cogeneration. In the following section, we consider two sample values for OPEX: 400 k€/year (CERTS-1a) and 200 k€/year (CERTS-1b).

5. Economic indexes

Some economic indexes referred to the different PPP solutions are easy to compute starting from the relevant CAPEX and OPEX (Table 6) and the benefits, in terms of avoided direct costs (Table 5). In this section, we will compute the pay-back time (PBT) and the net present value (NPV), according to the following definitions:

$$\mathrm{PBT} = \mathrm{CAPEX}/\mathrm{Annual\,Saving}[\mathrm{years}] \quad (1)$$

where the Annual Saving is the difference between avoided costs and OPEX[12];

$$\mathrm{NPV} = \sum_{k=1}^{n} \frac{C_k}{(1+c)^k} [\mathrm{monetary\,unit}] \quad (2)$$

where k are the cash flow terms (we assume one term each year during the lifetime); n is the PPP lifetime (years); C_k is the cash flow (positive or negative) at year k; and c is the weighted average cost of capital (WACC)[13].

We assume prudentially a ten years lifetime for all PPPs ($n = 10$ years, $k = 0, \ldots, 10$) and WACC = 7% ($c = 0.07$).

Table 7 reports the PBT and NPV calculated for the different PPP solutions. Negative NPV values mean that the incoming cash flows cannot compensate the outgoing flows.

The results show that the Delaware solution has the lowest PBTs, unless the cost of the energy generated locally is very low (CERTS-1b). These values are well in line with those estimated by EPRI, which reports a PBT of about 1–2 years for the Delaware PPP [18].

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[12] The PBT allows a simple comparison of different investments. This index does not bring to actual time the cash flows. As we compare solutions characterized by the same lifetime, this limit can be accepted.

[13] The NPV is widely used to evaluate investment projects; generally a valid project should have positive NPV.

Table 7
PBTs and NPVs for the different PPP solutions.

	Class 2	Class 3	R-DFI
PBT [years]			
Delaware	1.48	2.22	1.78
Sendai B2	2.83	7.45	4.10
Sendai B3	2.53	8.33	3.88
CERTS-1a	5.56	–	–
CERTS-1b	0.95	2.27	1.34
CERTS-2	4.25	4.25	4.25
NPV [M€]			
Delaware	1.88	1.08	1.47
Sendai B2	0.93	−0.04	0.45
Sendai B3	0.89	−0.08	0.41
CERTS-1a	0.06	−0.92	−0.43
CERTS-1b	1.47	0.48	0.97
CERTS-2	0.08	0.08	0.08

Table 8
NPVs [M€] including removal costs equal to 50% of CAPEX.

	Class 2	Class 3	R-DFI
Delaware	1.75	0.96	1.35
Sendai B2	0.77	−0.20	0.29
Sendai B3	0.76	−0.21	0.28
CERTS-1b	1.41	0.42	0.92
CERTS-2	0.05	0.05	0.05

The solution CERTS-1, which under a merely technical perspective can be considered the best solution among those compared here, becomes economically valid if OPEX are well lower than 400 k€/year. With OPEX as low as ~200 k€/year, the solution CERTS-1 becomes comparable (as to the PBT and NPV values) to the Delaware one, compared to which it has lower CAPEX – and so can be more easily realized – but higher OPEX.

Regarding the Delaware solution, some further comments are necessary. Its effectiveness depends on the efficacy of the supply transfer between the two MV feeders – which improves with the "independence" on the HV side of the two HV/MV substations – and on the DVR design. In fact, since most of the expected PPHs are caused by dips with residual voltage under the threshold for the DVR operation, the PPHs number could be reduced through a more burdensome DVR design. However, this would also improve the PPP capital cost. By comparison, in the Sendai PPP, the DVRs are sized for 100% voltage compensation capability and the quality levels B2 and B3 allow effective voltage dip compensation.

Finally, we repeat the last calculations including also PPP removal costs at the end of its lifetime. Since reliable information about these costs is not available, we assume them equal to 50% of the CAPEX. This way, adding removal costs to CAPEX, PBTs simply increase by 50%, without modifying the comparison among the different PPP solutions. Conversely, NPVs are reduced – not proportionally – as reported in Table 8. In spite of the different conservative assumptions made, NPVs are still positive with the exception of the two Sendai solutions for the Class 3 immunity level. The Delaware solution still has the highest NPVs.

6. Discussion

A PPP should be tailored on both customers and local distribution system features (as made in the exemplary case of the Delaware PPP [19]). The former are essential and include both technical (immunity to the PQ events) and economic aspects (PQ direct costs). The latter include the standard supply quality level (annual number and characteristics of PQ events) and network-related features (for example, the availability of two independent MV feeders, as in the case of the Delaware PPP). Nevertheless, some solutions (as the two Sendai and the CERTS solutions) can be singled out as generally effective for sensitive users.

This being said, the present technical–economic analysis shows that the Delaware solution can really be effective for badly served users sensitive to voltage dips.

The solution CERTS-2 is not suitable for sensitive users but, since it can be implemented and operated with relatively low costs, it may be interesting for customers damaged (only) by interruptions.

The solution CERTS-1 is not economically sustainable with a traditional gas or diesel fueled generator set, but it could become competitive by a drastic reduction of the operative costs. This goal can be pursued exploiting RES, cogeneration, low cost fuels.

Connecting this last result with some of the main current trends in power systems – increasing penetration of distributed generation, maturation of RES technologies, and development of new energy storage systems – we can try to sketch a historical synthesis of PPPs. During time and exploiting different technologies, just a few PPP prototypes have been realized—the old Futuroscope (France, 1986), then the Delaware PPP (2002) and the similar Korea Custom Power Plaza (South Korea, 2006), more recently the Sendai PPP (2010). The harsh conclusion is that, until today, the idea to improve the quality of electricity supply through utility-provided solutions substantially failed. The main reason is the excessive costs, which dramatically reduce the number of potential PPP customers and, thus, make it very unlikely to find two or more of them located in the same small area (industrial park). This way, the installation of PQ mitigation devices on the customer side becomes more convenient and actually is the worldwide adopted solution to improve PQ.

Nonetheless, the PPP idea might find future application in the frame of the micro-grid concept, when the developments mentioned above could justify solutions such as the CERTS-1, whose implementation is sufficiently simple, and quickly and easily realizable. Indeed, this solution matches well with the micro-grid concept, as this includes local generation and allows isolated operation. In addition, aiming to be energy-independent, micro-grids should include energy storage systems in order to exploit better the local non-predictable generation (typically PV generation). This provides a double advantage: first, the possibility to use the energy storage systems also to improve the PQ (notice that the energy required for PQ improvement is extremely low compared to the energy required for a better exploitation of the local generation, thus this goal does not increase the energy storage costs); second, the main goal of local generation is to feed local loads, and thus its costs should not be ascribed to PQ improvement. In conclusion, a micro-grid can be designed – or used – also to provide customers with high quality power supply, thus working like a PPP, with low additional costs.

7. Conclusions

In this paper, we performed a technical–economic evaluation of different PPP solutions, completing a previous merely technical analysis. We worked assuming that the potential PPP customers are badly served (i.e., they have low quality standard supply) and sensitive to both interruptions and voltage dips (as to the latter, we considered three different immunity levels).

We based the economic evaluation on original cost models for the computation of PQ direct costs, and on the evaluation of the PPP investment and operative costs. The results show interesting values of the economic indexes calculated (PBT and NPV). Apparently, this is in contrast with the concrete experience, since at present PPPs have not gone beyond a few prototypal realizations. It must be remembered, however, that the results apply only to a small number of users (the potential PPP customers), and when the power delivered by the PPP is not too low. These constraints dramatically reduce the possibilities of application.

Giving a look into the future, a new chance to the PPP idea (utility-provided solutions for PQ improvement) can be given by micro-grids. In particular, the CERTS solution looks very interesting since it is consistent with the micro-grid concept, which includes dispersed generation and energy storage systems, both required for different goals but that could be used for PQ improvement as well.

Finally, we point out that this work used a general methodology for cost-benefit analysis that includes both technical and economic aspects, and can be applied to any other network configuration. Since the analysis is carried-out using the same power, PQ data and cost models, it allows a homogeneous comparison among different PPP solutions.

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