MULTIFUNCTIONAL PHOTOVOLTAIC INVERTERS – ECONOMIC POTENTIAL OF GRID-CONNECTED MULTIFUNCTIONAL PV-BATTERY-SYSTEMS IN INDUSTRIAL ENVIRONMENTS

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ABSTRACT: Power quality and reliability are two very important factors in electrical power supply, particularly for specific branches of industry. “Multifunctional Photovoltaic Inverters” with storage units at the direct current link of the photovoltaic inverter can substitute uninterruptible power supply systems. Installed in industrial facilities, this type of photovoltaic-battery-system can offer additional services such as energy management and peak shaving. This paper presents a thorough analysis of possible services under current German conditions. The most promising services are investigated with regard to the additionally generated profit for the stakeholders involved. With the presented analysis it is shown that this type of photovoltaic-battery-system can provide considerable added value in industrial facilities compared to conventionally available technologies.
Keywords: Multifunctional Photovoltaic Inverter, Peak Shaving, Uninterruptible Power Supply, Industrial Application

1 INTRODUCTION

Power quality and reliability are two very important factors in electrical power supply, not only for private households and public buildings but, particularly, for specific branches of industry. Photovoltaic (PV) systems with their inverters can contribute considerably to improve power quality and reliability without substantial additional costs.

The objective of the research and development project “Multifunctional Photovoltaic Inverter” (Multi-PV) is to develop a multifunctional PV inverter that connects not only the PV modules but also a battery unit (see also http://www.multi-pv.de) [1]. In addition to feeding in the active power from PV to the public grid, this type of inverter is also intended to be utilized to improve the local power quality and, in combination with storage units, ensure an uninterrupted power supply for a defined grid area, e.g. critical loads in industrial networks. Another goal is to use the storage units for energy management purposes, such as peak shaving, and to provide services for network operation, such as balancing power.

Figure 1: Industrial site of Hübner GmbH in Kassel with the 104 kWp PV generator

The Multi-PV project examines the general conditions for the operation of multifunctional PV inverters (from technological and economic perspectives) and develops the corresponding inverter technology. ISET e.V. and SMA Solar Technology AG in Kassel, Germany, are responsible for the content-related handling of various scientific, technical and economic issues as well as for setting up the 100 kVA prototype at the industrial site of the project partner Hübner GmbH in Kassel (see Figure 1).

Figure 2 gives a schematic overview of the Multi-PV concept. In addition to the PV generator, also a battery is connected via the DC/DC converter to the DC link of the PV inverter. Industrial loads with additional services, such as improved power quality, are decoupled from other loads and the public grid by an inductor as well as a fast circuit-breaker. The inductor is necessary to improve locally the power quality and provide uninterruptible power supply to critical industrial loads. These new components (battery, decoupling inductance, and fast circuit-breaker) enhance the capabilities of a standard PV inverter to a multifunctional device with many possibilities to provide additional services.

Against this background and given the worldwide efforts that are being made to give priority to renewable energy, there is a wide range of potential applications for multifunctional PV inverters to create grid areas with a high power quality, e.g. for industry, and integrate these systems effectively in the electrical power system operation and energy supply.

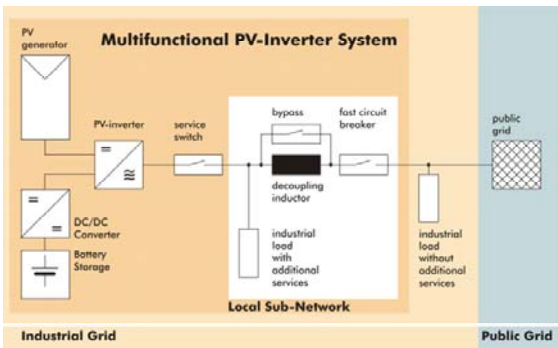


Figure 2: Schematic of Multi-PV system at an industrial site [3]

This paper presents the results of an investigation of the economic potential of multifunctional inverters under German conditions, such as feed-in tariff, European Energy Exchange (EEX), markets for ancillary services and power supply tariffs. In section 2, an initial assessment of possible Multi-PV services identifies and excludes those services that tend to be not attractive under current conditions in Germany. Relevant services are analyzed in section 3 by developing an algorithm to optimize their interaction and the power dispatch. The aim is to maximize the overall profitability and to quantify the additional monetary profit of each single service. The number of services delivered by the Multi-PV system is then reduced further on to the most beneficiary services. Finally, section 4 optimizes the reduced system's power dispatch in order to maximize the profit for three different examples of companies.

2 INITIAL ASSESMENT OF POSSIBLE MULTI-PV SERVICES

The economic assessment for the Multi-PV system starts with an evaluation of interesting services that are to be looked at in more detail. PV energy generation is assumed to be the basic functionality of the Multi-PV system. In addition, the services given in Table 1 and shortly discussed afterwards can be considered.

Table 1: Possible services by Multi-PV and their respective sources of benefit

Services	Benefits by
Improvement of Local Power Quality	Substitution of conventional devices or increased power quality
Compensation of Reactive Power	Substitution of conventional devices or reduction of reactive power purchase costs
Uninterruptible Power Supply (UPS)	Substitution of conventional devices or increased reliability
Peak Shaving	Reduction of capacity costs
Energy Management	Reduction of energy costs
Participation on Balancing Services Markets	Market prices for primary control, secondary control and tertiary reserve
Power Trading	Market prices on Day-Ahead or Intraday-Market of the EEX
Ancillary Services	Payments for providing active and reactive power control to the network operator

The first two services (improvement of power quality and compensation of reactive power) are already discussed in [2-4]. Their application has an interesting added value to the system but is neglected here because it can be considered as independent from the other services (in first approximation) and only has a small contribution to the overall profit of all services together.

The UPS functionality provides 15 minutes power at rated output fulfilling the qualification of the norm IEC 62040-3. 15 minutes or more (at part load) are sufficient to start an emergency diesel, stop critical processes or overcome the voltage sag or short outages.

Companies in Germany with an annual consumption of electricity of more than 100.000 kWh are considered as special tariff customers by energy supply companies. This means that these customers have to pay a capacity price [€/kW] for the maximum power demand measured in 15 minute mean values over the year. Shifting electrical energy from times with maximum energy demand to less energy intensive times allows reducing the annual peak power demand and thereby the capacity costs. Conventionally, this is done by corrective actions in the consumer's power demand (see Figure 3). Multi-PV can provide a more flexible storage-based peak shaving functionality.

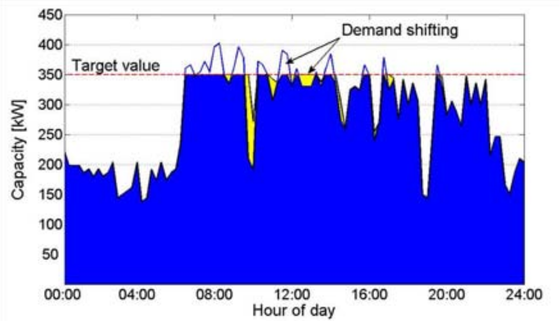


Figure 3: Principle of peak shaving by demand shifting

Energy management is another service that shifts demand, but from high-price to low-price periods. This reduces the energy costs when time-variable tariffs for power purchase need to be taken into account.

Balancing services are discussed in [5] and the grid code is provided in [6] with its annexes. Participation in primary frequency control in Germany is not attractive because a monthly tender (since Dec 2007) reduces flexibility and the control margin of ± 2 MW cannot be fulfilled with Multi-PV systems with sizes of about 100 kVA. Prequalification conditions for secondary frequency control allow the aggregation of many units to pools in order to fulfil the required control range but monthly tenders reduce the flexibility. Tertiary reserve that can be pooled as well is an attractive option because of its daily tenders with a timely resolution of 4 hour blocks and by far higher maximum prices compared to primary and secondary control. Both secondary control and tertiary reserve are separated in a positive and a negative control direction.

Not only the participation on balancing services markets but also trading on the power exchange market, e.g. EEX, may not be allowed to be provided by PV systems that participate in the feed-in tariff [7]. These questions are under discussion within the renewal process of the German feed-in tariff. At the EEX two markets are of interest: day-ahead and intraday. Pooling of many and diverse generators is considered as a valid option to participate with the Multi-PV system on the power exchange and the tertiary reserve market in Germany.

The combined application of these two services together with industry internal services is investigated in the next section. Industry internal services are Uninterruptible Power Supply (UPS), peak shaving and energy management.

3 OPTIMAL POWER DISPATCH FOR MULTIPLE SERVICES

Based on the initial assessment in the section before, the following services are considered for the Multi-PV system:

- PV energy generation
- Peak shaving
- Energy Management
- UPS
- Participation in pools on
  - the tertiary reserve market and
  - the EEX.

An optimal power dispatch for these possible services is investigated with the objective of maximizing the profit of the Multi-PV system. Firstly, the assumptions and conditions are described. Secondly, the results of the optimization algorithm are presented.

3.1 Assumptions

Generation profiles: A PV generation profile, measured in 2005 in steps of 15 minutes in Kassel (located at 51°N, 9°E, oriented to the south, with a tilt angle of 30°), Germany, serves as a basic assumption for the further investigations.

Feed-In Tariff: The feed-in payment for the PV energy is 48.74 c€/kWh for PV plants of or more than 100 kWp installed in 2007 [7]. The feed-in of PV power at times of battery usage is not possible because the battery is assumed to be charged from the public grid. Respective losses of feed-in tariff are considered as opportunity costs during battery usage.

Consumption profiles: In total, three different consumption profiles of real companies are used and analyzed. Company 1 (C1) comes from the metal-working industries and produces special electrical devices, such as components for transformers or bus bars. Company 2 (C2) processes scrap metal with support of energy intensive machines. Company 3 (C3) manufactures machines by individual production. The consumption profiles are available as mean values of 15 minutes for the year 2005 and assumed to be applicable in 2007 as well. Table 2 shows their respective characteristics. E_{el} is the energy consumption [MWh/a] within one year and P_{max} the maximum power consumption [kW]. The quotient of E_{el} and P_{max} are the corresponding full load hours [h/a].

Table 2: Characteristics of the investigated load profiles

	C 1	C 2	C 3
E_{el} [MWh/a]	1,205	12,876	758
P_{max} [kW]	402	6,144	194
E_{el}/P_{max} [h/a]	2,998	2,096	3,908

Power Purchase Tariff: The assumed energy tariff is correlated with the variability of the spot market prices at the EEX in Leipzig in the year 2006 (as a basis for 2007). The price is based on average power purchase prices in German industrial facilities [8] that include 2.75 c€/kWh network charges and 0.7 c€/kWh additional charges as fixed components. Figure 4 shows the assumed time-variable prices of the energy tariff that is of particular interest for the application of energy management.

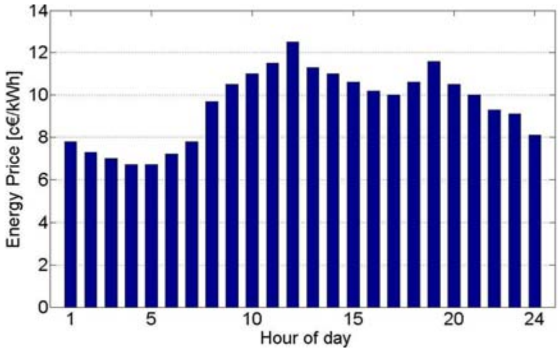


Figure 4: Assumed time-variable energy tariff

The analysis of the system usage fees of all German network operators with the ENET database [9] gives capacity prices at medium voltage level with statistics given in Table 3. In the following investigations, annual capacity prices in the range of 45 €/kW to 80 €/kW and an average of 62 €/kW are considered. These prices are decisive for the profit of the peak shaving function.

Table 3: Capacity prices of German network operators at medium voltage level for customers with full load hours of more than 2500 h/a.

	Capacity Price [€/kW/a]
Mean	62.14
Maximum	138.45
Minimum	23.90
Standard deviation	16.30

System components: The considered Multi-PV system comprises (see Figure 2):

- 110 kWp PV modules,
- an 100 kVA inverter,
- a 337 kWh (at I_{10}) lead acid battery (OPzS) coupled with DC/DC-converter to the DC link of the inverter, and
- a disconnection unit for UPS functionality with a decoupling inductance.

Battery: The maximum electrical output of the battery is 100 kW and its capacity is 337 kVAh at a continuous output of 34 kW [10]. For the lifetime of the battery 1500 cycles with a depth of discharge of 80% are assumed or a calendar life time of 20 years if less cycles are performed. The total efficiency (energy output over energy input at the AC connection) of the battery system is assumed to be 70%.

Costs of Multi-PV system components: The annuity *ic* of the investment costs *IC* is calculated by

$$ic = IC \cdot \frac{q^n \cdot (q-1)}{q^n - 1} \quad \text{with} \quad q = (1+i) \qquad (1)$$

with the discount rate i = 8% and the investment duration of n = 20 years.

The major advantage of Multi-PV is that there is just one DC/AC-Inverter that connects both: the PV generator and the battery. Only additional costs are looked at as well as only additional revenues.

Table 4 gives an overview of the assumed additional investment and operational costs that result from extending a standard PV system to a Multi-PV system with battery storage at the DC link. The investment costs of the lead acid battery (IC_{Batt}) depend on the capacity [kWh_C] and are assumed to be in the range of 80-120 €/kWh_C. Additional capacity-specific investment costs are caused by the DC/DC-converter and the disconnection unit and are assumed to be in the range of 80-120 €/kW. Fixed operational costs (OC_{fix}) consist of the annual maintenance costs including re-filling the battery acid. An average charge for loading of 6.9 c€/kWh during night times is assumed (compare Figure 4) leading to variable operational costs of approx. 10 c€/kWh for energy from the battery. Opportunity costs of lost feed-in tariff payments if used in parallel (register change of the meter) constitute the second component of the full variable operational costs (OC_{var}).

Table 4: Assumed range of additional investment and operational costs for the Multi-PV system.

Additional investment and operational costs	
Storage (IC_{Batt})	80-120 €/kWh_c
DC/DC-Converter incl. disconnection unit (IC_{misc})	80-120 €/kW
Additional fixed annual operational costs (OC_{fix})	1-2 €/kWh_c
Variable Operational Costs (excl. lost feed-in tariff payments)	0.099 €/kWh

Prices at the power exchange market: A comparison of the prices in the year 2007 on the Day-Ahead-Market and on the Intraday-Market shows in general more profits on the Day-Ahead-Market (see Figure 5) but more flexibility on the Intraday-Market where the pricing mechanism is hour-ahead instead of day-ahead. The higher Day-Ahead-Market prices on the EEX in the year 2007 are used here [11].

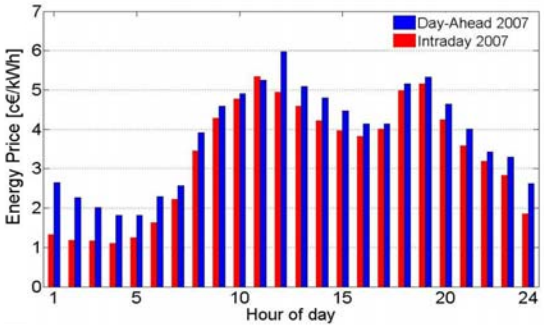


Figure 5: Prices [c€/kWh] in 2007 for trading power at the Intraday and Day-Ahead-Market (each hour as the average over one year)

Prices at the tertiary reserve market: The prices for positive and negative tertiary reserve are subdivided in six time slices of 4 hours each per day with tenders one day ahead. Here, the best price for the respective time slice is taken into account as the maximum possible revenue [12]. Figure 6 shows the resulting best prices as a mean over the year. The error bars show the range of capacity prices in which the 5% of the highest and 5% of the lowest values are excluded.

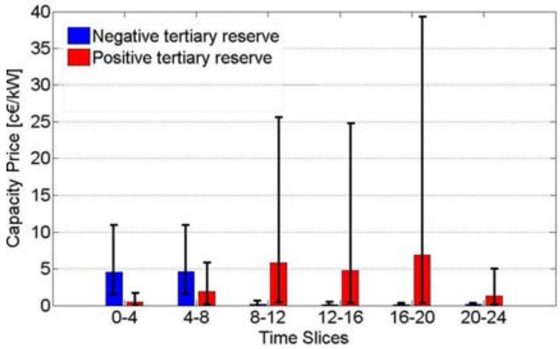


Figure 6: Example for capacity prices of positive and negative tertiary reserve over the year 2007 (the black error bar shows the full range excl. the 5% highest and 5% lowest prices)

Profit of the UPS function: A short market survey showed that an average annuity (same assumptions as for equation 1) of approx. 2000 €/a (+/- 20%) has to be paid for a conventional UPS unit with power supply of 15 minutes. The required capacity of the UPS battery C_{UPS} for 15 minutes (or effective energy E_{eff} = 25 kWh) autonomy in the Multi-PV system has to be at least

$$C_{UPS} = \frac{E_{eff}}{\eta_{dis} \cdot DOD} = \frac{25\ kWh}{0.85 \cdot 0.8} \approx 37\ kWh_C \qquad (2)$$

under consideration of the discharge efficiency (η_{dis} = 85%) and the allowed Depth of Discharge (DOD = 80%). Furthermore, it is assumed that a company only invests in a UPS unit if the benefit of such a system is at least as high as its total costs. In this situation, the Multi-PV system can generate additional benefit of 2000 €/a with a substituting UPS functionality.

3.2 Results of the Optimal Power Dispatch Algorithm

An algorithm was developed with Matlab® [13] in order to determine the optimal power dispatch to achieve maximum economic profit with the Multi-PV system taking into consideration the given assumptions. Three major constraints are taken into account:

- the maximum power transfer capacity of the inverter of 100 kVA
- the available battery capacity of 337 kWh (at I_{10}), and
- the effective energy of 25 kWh provided for the UPS function with a time-based availability of at least 99%.

The already described three companies (C1, C2 and C3) with their respective load profiles are analyzed. The optimal dispatch results and sensitivity analyses show that the achieved profit mainly depends on the characteristics of the load profile itself. As one example, the optimized power dispatch schedule is given in Figure 7 for C1 in the year 2007. In this case, one of the major restrictions is the inverter size that limits the sum of the two power flows from PV and battery.

Table 5 provides an overview on the results of the analyzed three companies with their respective load profiles. In this example, the investment costs for the battery are assumed to be 95 €/kWh$_C$ and 110 €/kW for the DC/DC-converter and the disconnection unit. A life time of 20 years for all components has been assumed because the cycle life time of the battery (75 cycles per year) is not reached with a total number of cycles in the range of 22 to 24 cycles per year.

It can be seen that the highest profits result from the peak shaving and the UPS functionality. The participation on the power exchange market and the tertiary reserve market contribute smaller margins. All together, the additional profit of the Multi-PV system is 1,100 €/a for C1 and 3,300 €/a for C2. Company 3, in contrast, has additional losses because peak shaving generates less revenue than in case of C1 and C2.

Assumed that only debit capital (8% interest rate over 20 years) is used for the additional investment costs IC of the Multi-PV system, the respective Return on Invest (ROI) is calculated by

$$ROI = \frac{Additional\ \ Annual\ \ Profit}{Additional\ \ Fixed\ \ Annual\ \ ic} \cdot 100\% \quad (3)$$

This leads to an annual ROI of 19.5% for C1 and 57.6% for C2.

The Internal Rate of Return (IRR) is an indicator that shows a company whether an investment is profitable or not. For example, if the IRR is higher then the current interest rate for debit capital, the investment can be profitable by making use of debit capital. If a company invests equity capital for the investment, the IRR should be higher than the equity yield rate resulting from alternative investment options. In this case, the IRR of company 1 and 2 is higher then the assumed interest rate of 8% for debit capital which underlines the profitability of the investment in a Multi-PV system. Company 3 is with an IRR of 7.7% below the reference value of 8%. However, the additional investments in a Multi-PV system can still be profitable if the equity yield rate is lower, e.g. 7%.

Table 5: Additional annual revenues, costs and resulting profit of the Multi-PV system in three companies (C1, C2, C3).

	C1	**C2**	**C3**
Contribution to Profit of…			
Peak Shaving [€/a]	4,029	6,210	2,025
Day-Ahead [€/a]	647	655	654
Pos. Reserve [€/a]	173	171	168
Neg. Reserve [€/a]	9	9	9
UPS	2,000	2,000	2,000
Sum of all Contributions to Profit [€/a]	6,858	9,045	4,856
Additional Fixed Annual Investment Cost [€/a]	5,739	5,739	5,739
Additional Annual Profit [€/a]	**1,119**	**3,306**	**- 883**
ROI [%]	**19.5**	**57.6**	**- 15.4**
IRR [%]	**13**	**18**	**7.7**

According to present German legal regulations [7], the participation on the power exchange market and the tertiary reserve market is not allowed. Moreover, the revenues given are optimal (maximum) revenues (assumption: full information). They are relatively small compared to not included costs for market participation and smaller sub-optimal revenues in real situations (with limited price predictability). Finally, these services also demand for larger battery capacity that may be reduced if only peak shaving and UPS functionalities are taken into account. Because of these reasons, market participation is not considered in the next iteration of the economic analyses.

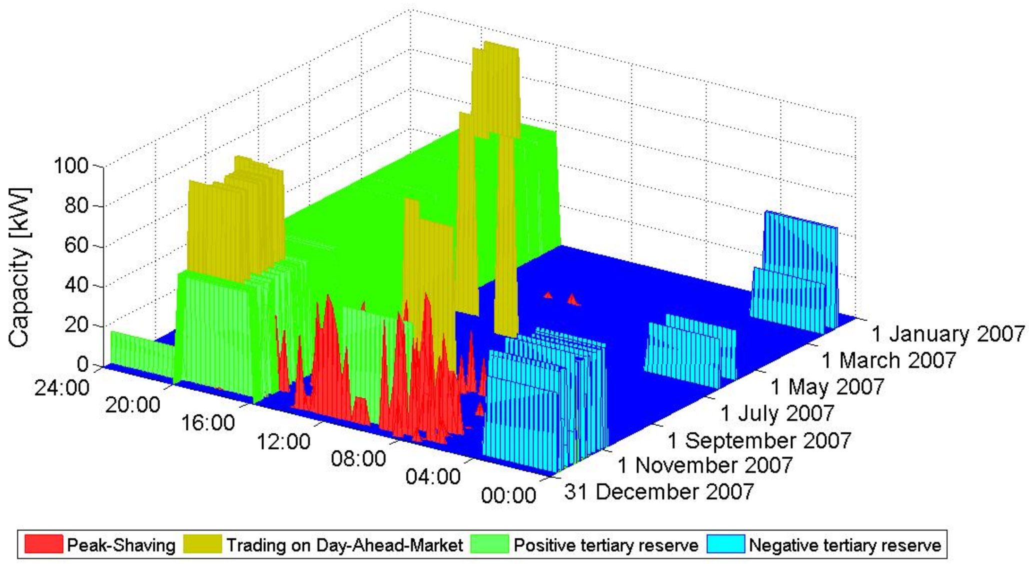


Figure 7: Optimized power dispatch schedule for company 1

3.3 Energy Management

Energy management may be another interesting feature of the Multi-PV system. Because of the 337 kWh_C battery of the Multi-PV system further revenues can possibly be achieved by shifting energy consumption from high-price to low-price periods of time. As already described in section 3.1, the costs of battery energy that is charged in low-price times at night are assumed be 9.9 c€/kWh. Provided that an average energy price in high-price times is about 11 c€/kWh (compare Figure 4) the profit margin is 1.1 c€/kWh for each shifted kWh. The assumed lifetime of the battery is limited by 1500 cycles with a depth of discharge of 80%. If we keep a system life time of 20 years, we can only use 50 cycles per year at 80% DOD (if about 25 cycles are reserved for the other functionalities). This would lead to maximum annual revenues of

$$337\frac{kWh}{cycle}\cdot 80\%\cdot 50\frac{cycles}{a}\cdot 1.1\frac{c€}{kWh}=148\frac{€}{a}\cdot \quad (4)$$

Because of this low revenue (compared to the other contributions to profit in Table 5) that is only available with time-variable tariffs, this function can be neglected as well in further investigations. To complete the consideration from another perspective: Daily energy management increases the investment costs for the battery because of its limited cycle lifetime but the additional revenues do not compensate the additional investment costs. Summing up these considerations, energy management becomes only of interest if the time-variable tariffs include margins between high and low price that are much higher than the given one of 6 c€/kWh.

The next section concentrates on the peak shaving and UPS functionality for industrial facilities and analyzes the added value of the Multi-PV system with these two functions.

4 REDUZED AND OPTIMIZED MULTI-PV SYSTEM

This section concentrates on the selected two main functions of the Multi-PV system: peak shaving and UPS. They generate the biggest revenue and demand for the smallest battery capacity. A sensitivity analysis showed potential to reduce the battery size whilst increasing the profitability [14]. An algorithm has been developed that determines the optimal power dispatch with the objective of generating the maximum profit with the Multi-PV system. The results from the application of this algorithm for the three companies are discussed in this section.

4.1 Optimal Battery Size for Maximum Benefit

Figure 8 shows the additional profit from peak shaving including UPS functionality by the Multi-PV system for company 1 depending on the battery capacity and the capacity price. The color of the map indicates the additional annual benefit with the given conditions and the black dotted line marks the maximum additional benefit. The maximum additional benefit defines the optimal battery size depending on the company-individual capacity price of power purchase. The resolution of 1 kWh in the calculations causes the discrete steps in the curve of maximum profit.

An optimal sizing of the battery is not realistic as the load profile is not exactly predictable and may change over the investment duration as well as other calculation parameters. Figure 8 clearly shows that the maximum is often shallow so that certain oversizing of the battery to include a security margin can be interesting because it does not change the benefit significantly.

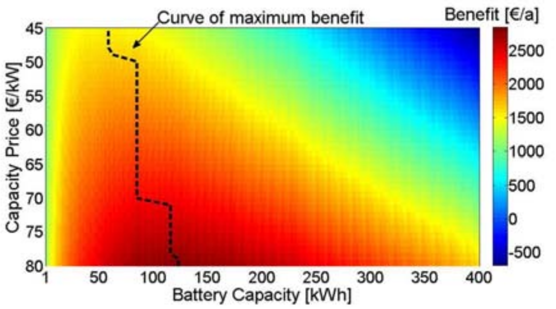


Figure 8: Additional profit for company 1 depending on the batteries capacity and the capacity price of power purchase.

Table 6 gives an overview on the range of the maximum profit provided by the Multi-PV system for all of the three investigated companies under the conditions mentioned above with the capacity price in the range of 45-80 €/kW/a. Different to the results of Table 5 with the extended Multi-PV system, the additional annual profit for the reduced and again optimized system is positive and higher for all three companies. The same can be stated for the ROI that is by far higher and clearly attractive.

Table 6: Maximum possible profit by Multi-PV under the mentioned framework conditions.

	C 1	C 2	C 3
Range of optimal battery size [kWh]	59-123	45	46-51
Additional Annual Revenues [€/a]	3,360-5,383	6,504-10,004	3,145 – 4,101
Additional Annual Costs [€/a]	1,805-2,544	1,631	1,699-1,755
Additional Annual Profit [€/a]	1,555-2,839	4,873-8,373	1,446-2,346
ROI [%]	86-112	299-513	85-134

The additional profit of the Multi-PV system with peak shaving and UPS function mainly depends on the characteristics of the companies' load profile. The rarer, the shorter and higher the load peaks are, the less energy is required from the battery. So, the battery size can be sized smaller. Also the opportunity costs from lost feed-in tariff payments decrease when the peak load occurs only shortly.

Sensitivity analyses show that the additional investment costs (due to battery and DC-DC-converter) only have little influence on the profit because of the generally small costs component.

4.2 Time-based Availability of the UPS function

As already described in section 3.1, the size of the battery has to be at least 37 kWh to provide the required minimum of 25 kWh of effective energy for the UPS function. Table 7 presents the time-based availability of the UPS function for all three investigated companies at their respective optimal battery size considering a capacity price of 62 €/kW/a. The time-based availability is above 99.8% and can even reach 100% if the produced PV power is used as well. These availability values are assumed to be sufficient to fulfill the criteria of a UPS unit.

Table 7: Time-based availability for the three companies at their respectively optimal battery size

	C 1	C 2	C 3
Optimal battery size	85 kWh	45 kWh	51 kWh
Time-based availability (without using PV power)	99.88%	99.81%	99.84%

5 COMPARISON OF THE INTEGRATED MULTI-PV CONCEPT WITH A MODULAR CONCEPT

A comparison of the additional costs of the Multi-PV system with two alternative system solutions underlines the attractive added value of Multi-PV system (see **Figure 9**). All of them provide a UPS function (25 kWh, 100 kW). Version 1 is a common UPS unit that consists of battery storage and an inverter. Version 2 is a system consisting of the same common UPS unit and a Multi-PV system that provides the peak shaving function and generates additional revenues compared to Version 1. The actual Multi-PV system under investigation is Version 3 that integrates all functions in only one Multi-PV inverter instead of two inverters in Version 2.

Table 8 compares three versions for company 1 from an economic point of view. Version 3 (Multi-PV) generates the highest additional annual profit, because of its smaller investment costs but similar high revenues compared to Version 2.

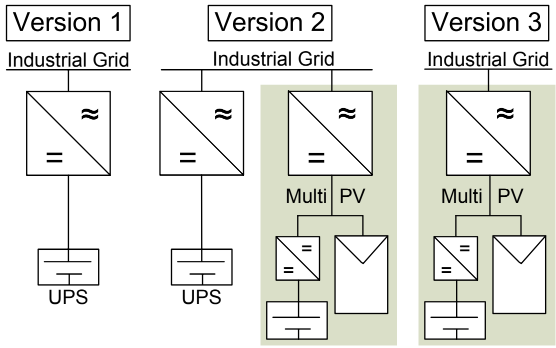


Figure 9: Distinguished versions

With 45..62..80 €/kW as the range of considered capacity prices, the added value of an optimized Multi-PV system is positive for all of the investigated companies. Figure 10 shows the additional profit of Version 2 and 3 for each company (compare with Table 8 for company 1). The figure clearly depicts that the integrated Multi-PV system is the most attractive solution from an economic perspective.

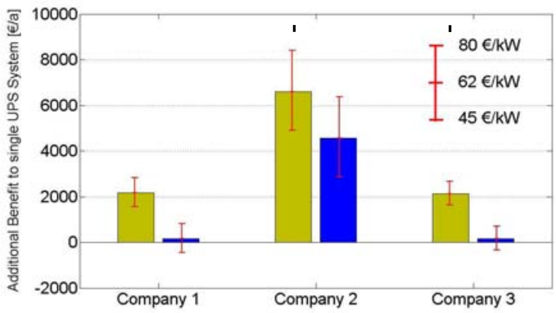


Figure 10: Additional profit of Version 3 (left yellow bar) and Version 2 (right blue bar) compared to single UPS unit (zero-baseline) for the three companies with the range of capacity prices

Table 8: Comparison of the three different versions for company 1

	Version 1 (UPS)	Version 2 (UPS+Multi-PV)	Version 3 (Multi-PV)
Investment Costs for Multi-PV Battery [€]	0	8,075	8,075
Investment Costs for DC/DC-converter and decoupling unit [€]	0	11,000	11,000
Investment Costs for Common UPS unit [€]	20,000	20,000	0
Total Investment Costs [€]	20,000	39,075	19,075
Total Annual Investment Costs [€/a]	2,037	3,980	1,943
Fixed Operational Costs [€/a]	0	128	128
Variable Operational Costs [€/a]	0	20	20
Revenue from UPS function [€/a]	2,037	2,037	2,037
Revenue from Peak Shaving function [€/a]	0	2,232	2,232
Additional Annual Profit [€/a]	**0**	**141**	**2,179**

6 CONCLUSIONS

The results of this investigation show that the developed Multi-PV system can provide additional economic profits for companies in Germany. Case studies have been performed for three different industrial sites. The results show that individual conditions strongly influence the profitability. Most interesting are peak shaving and uninterruptible power supply that are looked at in detail. The improvement of the local power quality and reactive power compensation can be beneficiary as well. Also functions such as participation on power exchange markets and balancing services markets may be of interest in the future when the legal framework allows more flexible participation than nowadays.

Four major factors influence the profit of the peak shaving function. The economic profit is bigger,

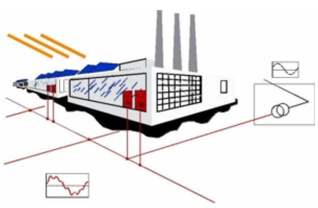
1. the bigger the ratio of the maximum peak load to the maximum output of the battery;
2. the shorter, rarer and higher the maximum peak load;
3. the bigger the grid capacity purchase price;
4. the smaller the feed-in tariff for PV energy.

These factors require optimizing the battery size according to the individual conditions of each company. It is shown that a certain security margin of the battery capacity can be included in order to be ready for future changes without jeopardizing the profit. Moreover, by usage of the Multi-PV system, corrective action to the company's workflow, as known from conventional peak shaving approaches, can be reduced or even substituted.

In summary, it can be said that the Multi-PV system is an innovative approach. It integrates a photovoltaic system within the emergency power supply strategy of companies. In many cases, the reliability and duration of the uninterruptible and emergency power supply can be increased significantly if the local photovoltaic power generation and the larger battery size are taken into account as well. The integration of photovoltaic-based local power generation and emergency power supply allows going one step further by using only one inverter instead of two separate ones. This integrated system with only one multifunctional inverter reduces considerably the investment costs and increases the overall profitability of the investment.

7 ACKNOWLEDGEMENT

The authors thank the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety for the support in the framework of the national project "Multifunktionale Photovoltaik-Stromrichter – Optimierung von Industrienetzen und öffentlichen Netzen" (FKZ 0329943, see http://www.multi-pv.de).



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