IEC TR 62933-2-200

Edition 1.0 2021-09

TECHNICAL REPORT

colour inside

Electrical energy storage (EES) systems –
Part 2-200: Unit parameters and testing methods – Case study of electrical energy storage (EES) systems located in EV charging station with PV

IEC TR 62933-2-200:2021-09(en)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
info@iec.ch
www.iec.ch

IEC TR 62933-2-200

Edition 1.0 2021-09

TECHNICAL REPORT

colour inside

Electrical energy storage (EES) systems – Part 2-200: Unit parameters and testing methods – Case study of electrical energy storage (EES) systems located in EV charging station with PV

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 13.020.30; 27.160; 43.120

ISBN 978-2-8322-1021-0

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD 5
1 Scope 7
2 Normative references 7
3 Terms, definitions and abbreviated terms 7
3.1 Terms and definitions 7
3.2 Abbreviated terms 7
4 Overview of EES systems located in EV charging stations with PV power generation 8
4.1 General 8
4.2 Application scenarios 8
4.3 System communication architecture 9
4.4 Duty cycle analysis 10
5 Project of commercial PV-EES-EV charging station based on common DC bus 11
5.1 Case project overview 11
5.2 System operation and control 12
5.2.1 Operation data analysis 12
5.2.2 Operation mode analysis 13
5.3 Summary 15
6 Project of commercial PV-EES-EV charging station based on common AC bus 17
6.1 Case project overview 17
6.2 System operation and control 18
6.2.1 Operation data analysis 18
6.2.2 Operation mode analysis 19
6.3 Summary 21
7 Project of business PV-EES-EV charging station based on common DC bus 23
7.1 Case project overview 23
7.2 System operation and control 24
7.2.1 Operation data analysis 24
7.2.2 Operation mode analysis 25
7.3 Summary 27
8 Project of business PV-EES-EV charging station based on common AC bus 29
8.1 Case project overview 29
8.2 System operation and control 29
8.2.1 Operation data analysis 29
8.2.2 Operation mode analysis 30
8.3 Summary 33
9 Recommendation for operation modes of EES systems located in EV charging station with PV panels 34
Annex A (informative) Duty cycles of the EES systems located in EV charging station with PV 36
A.1 General 36
A.2 Project of commercial PV-EES-EV charging station based on common DC bus 36
A.3 Project of commercial PV-EES-EV charging station based on common AC bus 38
A.4 Project of business PV-EES-EV charging station based on common DC bus 45
Bibliography 47

Figure 1 – Example of communication system architecture of PV-EES-EV charging station ... 10
Figure 2 – System structure of case commercial PV-EES-EV charging station based on common DC bus ... 11
Figure 3 – EV load and PV power for the case of a commercial charging station based on common DC bus ... 12
Figure 4 – TOU and charging service prices for the case of a commercial charging station based on common DC bus ... 12
Figure 5 – Operating power in low- and medium-price periods in the case of a commercial charging station based on common DC bus ... 14
Figure 6 – Operating power in high-price periods in the case of commercial charging station based on common DC bus ... 15
Figure 7 – EES system duty cycle in the case of a commercial charging station based on common DC bus ... 15
Figure 8 – Daily electricity flow for the case of a commercial charging station based on common DC bus ... 17
Figure 9 – System structure for the case of a commercial PV-EES-EV charging station based on common AC bus ... 18
Figure 10 – EV load and PV power for the case of a commercial charging station based on common AC bus ... 19
Figure 11 – Operating power in power smoothing mode for the case of a commercial charging station based on common AC bus ... 19
Figure 12 – Operating power in peak shaving mode for the case of a commercial charging station based on common AC bus ... 20
Figure 13 – Operating power in the TOU price arbitrage mode for the case of a commercial charging station based on common AC bus ... 21
Figure 14 – EES duty cycle for the case of a commercial charging station based on common AC bus ... 22
Figure 15 – Daily electricity flow of for the case of a commercial charging station based on common AC bus ... 22
Figure 16 – System structure for the case of a business PV-EES-EV charging station based on common DC bus ... 23
Figure 17 – PV power, EV load and output power for the case of a business charging station based on common DC bus ... 24
Figure 18 – TOU and charging service prices for the case of a business charging station based on common DC bus ... 24
Figure 19 – Operating power in equivalent load tracing mode for the case of a business charging station based on common DC bus ... 25
Figure 20 – Operating power in TOU price arbitrage mode for the case of a business charging station based on common DC bus ... 26
Figure 21 – Operating power in demand response mode for the case of a business charging station based on common DC bus ... 27
Figure 22 – Operating power involved in TOU arbitrage and demand response for the case of a business charging station based on common DC bus ... 27
Figure 23 – EES duty cycle for the case of a business charging station based on common DC bus ... 28
Figure 24 – Daily electricity flow for the case of a business charging station based on common DC bus ... 28
Figure 25 – System structure for the case of a business PV-EES-EV charging station based on common AC bus ... 29

Figure 26 – EV load and PV power for the case of a business charging station based on common AC bus 30
Figure 27 – Simulation results for operation strategy 1 for the case of a business charging station based on common AC bus 31
Figure 28 – Simulation results for operation strategy 2 for the case of a business charging station based on common AC bus 31
Figure 29 – Simulation results for operation strategy 3 for the case of a business charging station based on common AC bus 33
Figure 30 – Three operation strategies and resultant operation modes of the EES system for the case of a business charging station based on common AC bus 33

Table 1 – Time division of EES system's operation modes in the case of a commercial charging station based on common DC bus 16
Table 2 – Time division of the EES system's operation modes for the case of a commercial charging station based on common AC bus 21
Table 3 – Time division of EES operation modes for the case of a business charging station based on common AC bus 34
Table 4 – Recommended operation modes of the EES system in various installation scenarios of a PV-EES-EV charging station 35
Table A.1 – Charging-discharging power of EES system for the case of a commercial charging station based on common DC bus (per-unit value) 36
Table A.2 – Charging-discharging power of EES system for the case of a commercial charging station based on common AC bus (per-unit value) 38
Table A.3 – Charging-discharging power of EES system for the case of a business charging station based on common DC (per-unit value) 45

INTERNATIONAL ELECTROTECHNICAL COMMISSION

ELECTRICAL ENERGY STORAGE (EES) SYSTEMS –

Part 2-200: Unit parameters and testing methods – Case study of electrical energy storage (EES) systems located in EV charging station with PV

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

IEC 62933-2-200 has been prepared by IEC technical committee TC 120: Electrical Energy Storage (EES) Systems. It is a Technical Report.

The text of this Technical Report is based on the following documents:

Draft	Report on voting
120/231/DTR	120/238/RVDTR

Full information on the voting for its approval can be found in the report on voting indicated in the above table.

The language used for the development of this Technical Report is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/standardsdev/publications.

A list of all parts in the IEC 62933 series, published under the general title *Electrical energy storage (EES) systems*, can be found on the IEC website.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

IMPORTANT – The "colour inside" logo on the cover page of this document indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

ELECTRICAL ENERGY STORAGE (EES) SYSTEMS –

Part 2-200: Unit parameters and testing methods – Case study of electrical energy storage (EES) systems located in EV charging station with PV

1 Scope

This part of IEC 62933, which is a Technical Report, presents a case study of electrical energy storage (EES) systems located in electric vehicle (EV) charging stations with photovoltaic (PV) power generation (PV-EES-EV charging stations) with a voltage level of 20 kV and below. EES systems are highlighted in this document because they are a desired option to make the charging stations (especially the high-power fast charging stations) grid-friendly, improve the self-consumption of clean energy generation, and increase the revenue of stations. In this application, EES systems show excellent performance by running in a variety of available operating modes, such as peak shaving, power smoothing, load tracing, time-of-use (TOU) price arbitrage, and ancillary services. The general duty cycle is recommended based on the summary of the operation characteristics of the EES systems.

This document includes the following elements:

– overview of general PV-EES-EV charging stations;
– operational analysis of EES systems in typical project cases;
– summary and recommendation of EES systems' operation modes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62933-1, *Electrical energy storage (EES) systems – Part 1: Vocabulary*

3 Terms, definitions and abbreviated terms

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 62933-1 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- IEC Electropedia: available at http://www.electropedia.org/
- ISO Online browsing platform: available at http://www.iso.org/obp

3.2 Abbreviated terms

AC Alternating current
BAMS Battery array management system
BCMU Battery cluster measurement unit
BMU Battery measurement unit

CAN Controller area network

DC Direct current

EES Electrical energy storage

EMS Energy management system

EV Electric vehicle

EVSE Electric vehicle supply equipment

PCS Power conversion system

POC Point of connection

PV Photovoltaic

SOC State of charge

TOU Time-of-use

V2G Vehicle-to-grid

4 Overview of EES systems located in EV charging stations with PV power generation

4.1 General

The growing problems of climate change and environmental degradation on a global scale are the great challenges faced by people all over the world. Electric vehicles (EVs), which help reduce dependence on fossil fuels, are the key to advancing energy transition in the transportation sector. The convenience of charging has always been an important factor that affects whether consumers consider electric vehicles as an option. In recent years, EV charging infrastructures, especially the commercial charging stations and the business charging stations, have achieved rapid growth.

The integration of renewable power generation in the charging stations is conducive to further improving the use of clean energy while reducing the energy cost of the charging stations. Limited by the size of the site, PV power generation is often the primary choice for the charging stations. PV panels can be deployed on the roof of the station or integrated on the top of the charging infrastructure according to local conditions, which show significant advantages over wind turbines. However, both PV power and EV charging load are highly uncertain, and the charging demand of EV users during peak hours sometimes has a huge impact on the stable operation of the external power grid. EES systems can smooth the charging load of EV users and promote the local consumption of PV power generation. As for the operation of the charging station, EES systems can delay the expansion of the transformer at the charging station due to the rapidly increasing load, achieve peak-valley arbitrage according to TOU prices, and even assist the charging station to participate in ancillary service of the power grid.

The integration of PV and EES systems is the development trend of the EV charging stations. Many countries in the world, such as China, the United States, Germany, the United Kingdom, and Australia, have deployed the projects of EV charging stations integrated with PV and EES systems.

4.2 Application scenarios

Some PV-EES-EV charging stations are designed to operate off-grid, where the PV system provides the initial energy and the EES system serves as the storage place for electricity and timely power EVs. The entire station does not exchange energy with the external grid. At a charging station that operates in this mode, the capacity of EES systems is the key parameter that directly determines how many EVs can continue to serve.

Compared with the off-grid ones, the more common operation modes of charging stations are based on grid-connected operation. In this case, the charging needs of EV owners are always met even if the installed capacity of the EES system and PV is not sufficient. These kinds of charging facilities are widely deployed in residents' homes, parking lots, highway service areas and other places with high traffic flow.

In the grid-connected charging stations, EES systems can operate in a variety of modes, such as load tracing, peak shaving, power smoothing, TOU price arbitrage, and ancillary service, rather than simply balancing PV generation and charging load as in off-grid settings.

After investigating a large number of charging stations around the world, four typical application scenarios for the grid-connected PV-EES-EV charging stations from the perspective of electrical structure were found, namely commercial charging stations with common direct current (DC) bus, commercial charging stations with common alternating current (AC) bus, business charging stations with common DC bus, and business charging stations with common AC bus.

The main purpose of commercial charging stations is to provide charging services for general EV users and obtain economic revenues. In general, the commercial charging station is an independent interest subject and can be seen as a general load from the grid point of view due to the forbidden power feedback to the external grid in most cases. In this document, two practical cases are discussed in Clause 5 and Clause 6, respectively. In Clause 5, a DC common bus based PV-EES-EV charging station is introduced. The EES system in this station plays the role of load tracing and TOU price arbitrage. Alternatively, the PV-EES-EV charging station in Clause 6 is an AC common bus based station, and the EES system of this station mainly operates in power smoothing, peak shaving and TOU price arbitrage mode.

Business charging stations generally refer to charging stations built alongside commercial malls, office buildings, communities, campuses, which can not only provide services for EVs, but also power the surrounding load. In Clause 7, a common DC bus based PV-EES-EV charging station is analysed, where the EES system plays a comprehensive role in load tracing, TOU price arbitrage, and demand response. The entire charging station also undertakes the task of supplying power to a nearby shopping mall in the price peak time periods. At last, in Clause 8 a common AC bus based business charging project sponsored by the U.S. Department of Energy is introduced and the operation modes of one of the charging stations in this project are elaborated.

4.3 System communication architecture

Figure 1 shows a typical architecture of the communication system of a grid-connected EV charging station integrated with the PV and EES system in China. The battery energy management system is divided into three levels, namely the battery array management system (BAMS), battery cluster measurement unit (BCMU), and battery measurement unit (BMU). The controller area network (CAN) is used for information exchange between the upper and the lower management systems/measurement units. Only the highest level of BAMS communicates with the power conversion system (PCS) via RS 485. PV panels are linked to the PV controller through the convergence box. For unification, all components in the EV charging system communicate through CAN. The PV controller, battery PCS, and electric vehicle supply equipment (EVSE) are connected to the charging station's energy management system (station-EMS). The station-EMS responds to the commands of the external distribution network according to IEC 60870-5-104.

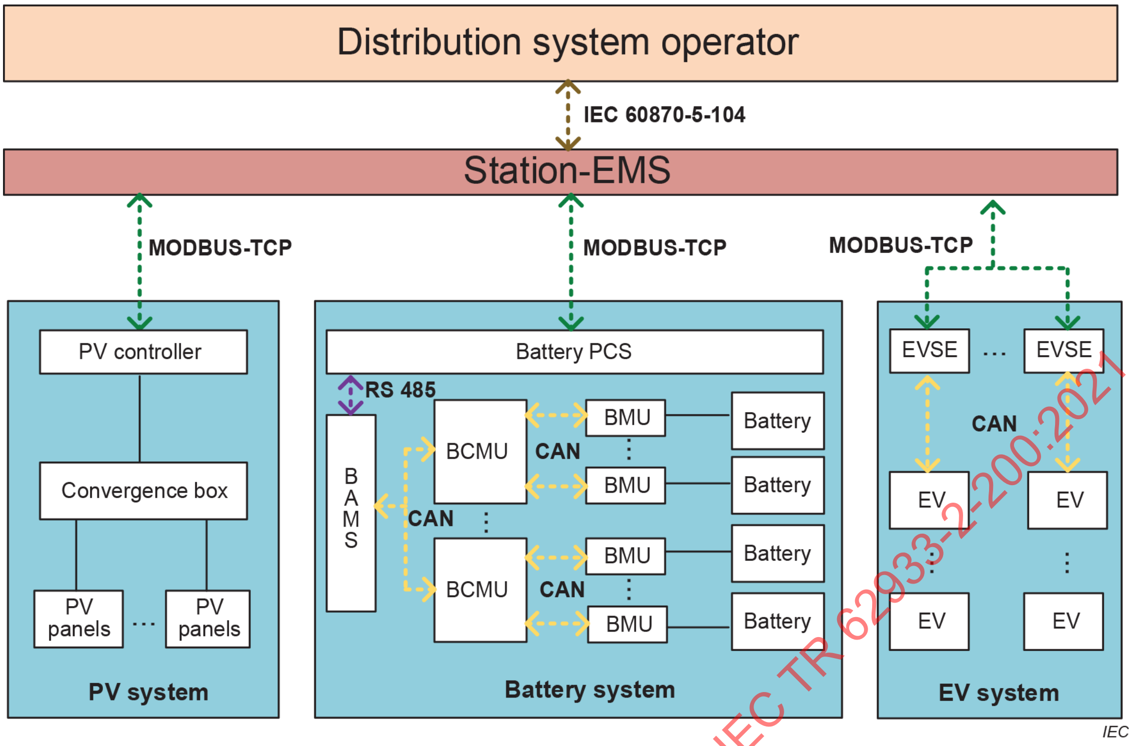


Figure 1 – Example of communication system architecture of PV-EES-EV charging station

Note that the above communication structure and protocols in Figure 1 are only intended as a typical demonstration for the cases practically adopted in China. In fact, some other open and interoperable protocols are also available. For example, IEC 61851 (all parts), ISO 15118 (all parts), CHAdeMO 2.0, and IEEE 2030.5 can be used as alternative protocols between EV and EVSE. In terms of the communication between the station-EMS and EV system, battery system, and PV system, IEC 61850 (all parts) is a good option to provide a higher level of security against unauthorized commands or interception of data.

4.4 Duty cycle analysis

A duty cycle is a charge/discharge profile that represents the demands placed on an EES system by a specific application. The duty cycle for the EES system in the EV charging station with PV panels will take into account how an EES system operates in a set cycle to make the charging station operate more efficiently.

Because the charging load of the charging station and PV power generation is random, and there are peak and valley periods, it is necessary to provide a 24 h duty cycle for the operation of the EES system to better provide energy for the charging station.

The following procedure is generally used to configure the duty cycle of an EES system in PV-EES-EV charging stations.

- Step 1: The charging stations are classified according to the collected data, which include PV data, EES system data, point of connection (POC) data, and load data.
- Step 2: The PV, EES system, POC, and load data are processed separately, which mainly includes filling in the missing data and making the sampling intervals of the four types of data the same.
- Step 3: The operation modes of the EES system in PV-EES-EV charging stations are analysed, and the corresponding operation curve is extracted according to different operation modes. Different methods are used for different operating modes to calculate their respective EES system operating curves.

- Step 4: The 24 h working curves under each operation mode are synthesized, and the typical duty cycle of the EES system is extracted.

5 Project of commercial PV-EES-EV charging station based on common DC bus

5.1 Case project overview

The electricity both generated by PV panels and required by EVs is in the form of direct current, and so are batteries. In order to reduce energy loss, many charging stations are deployed as DC systems. One of the typical representatives is the PV-EES-EV charging station. Figure 2 shows the electrical structure of a commercial PV-EES-EV charging station located in China.

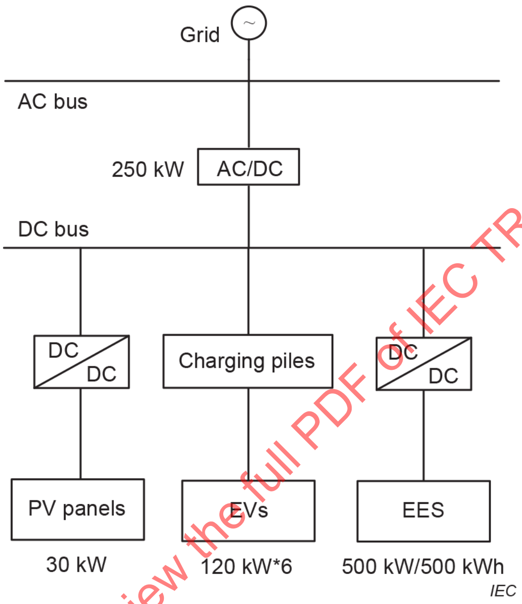


Figure 2 – System structure for the case of a commercial PV-EES-EV charging station based on common DC bus

This project is equipped with a DC bus to connect major in-station equipment, including 30 kW PV panels, 500 kW/500 kWh EES system and 6 DC fast charging piles. The maximum power of each pile can reach 120 kW. The charging station is connected to the AC bus with an AC/DC converter, through which it can purchase electricity from the external grid. However, the charging station is not allowed to inject power to the external power grid. In other words, the station is just a general load from the power grid view.

The main purpose for installing an EES system in this station is to meet the demand for fast charging and provide quality service without increasing the load demand on the external power grid of the charging station. If an EES system is not deployed, the service limit of the charging station is 250 kW based on the capacity of the AC/DC grid-connected converter in the case where the PV power output is zero. With the help of the EES system, the charging station can meet the charging demand up to 750 kW. In practice, the maximum power of the EES system is set to 250 kW (50 % of maximum output rating) under normal operating conditions to extend the service life of the batteries. In an emergency situation when the charging load exceeds the total power supply capacity of PV panels, EES, and the external grid, the EES system is allowed to run in the range of 250 kW to 500 kW.

5.2 System operation and control

5.2.1 Operation data analysis

The historical data of power generation and consumption on a typical day are illustrated in Figure 3. PV panels generate electricity mainly between 7:00 and 18:00. EV charging service is available 24 h a day. Figure 4 shows the TOU price and EV charging service tariffs for that day.

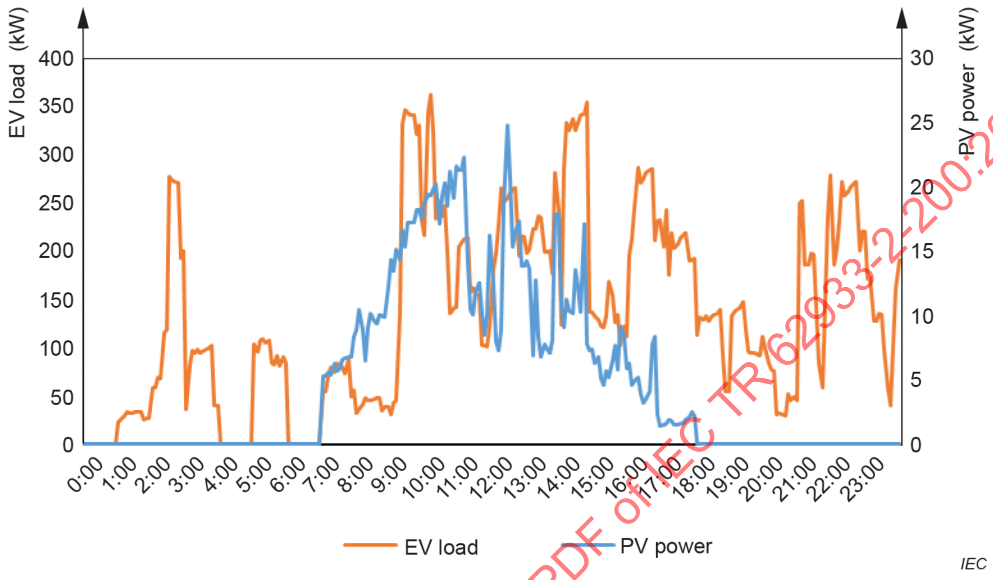


Figure 3 – EV load and PV power for the case of a commercial charging station based on common DC bus

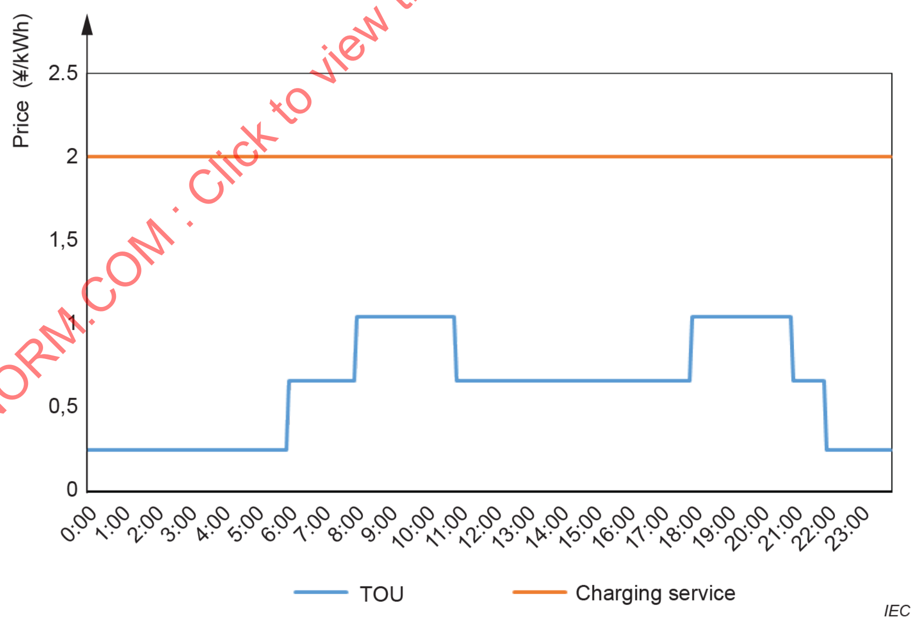


Figure 4 – TOU and charging service prices for the case of a commercial charging station based on common DC bus

5.2.2 Operation mode analysis

5.2.2.1 General

The EES system is able to absorb electricity from the external power grid during the low-price periods and release it when the price rises. Due to the fact that the EV charging load is unknown (this station is not equipped with a charging load prediction system); the reserve energy in the EES system has to be relatively large to avoid such a case as the state of charge (SOC) of EES falling below the allowable lowest when many cars are coming to charge at the same time. In this project, the minimal state of charge (SOC) of the EES system is set to 32 % for an unexpected charging situation. When the peak-price periods come, it is ensured that enough electricity (95 % of the rated capacity of EES system in this project) is already stored in the batteries.

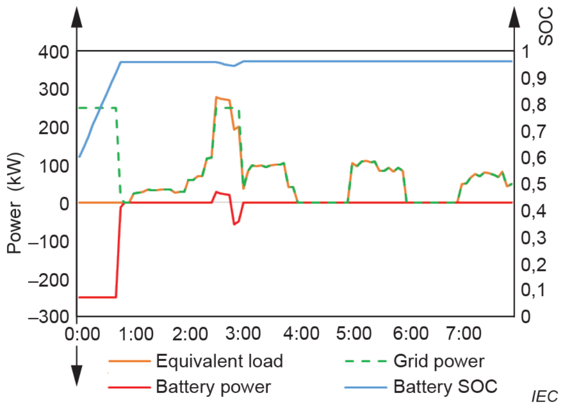
The EES system in this charging station plays the role of equivalent charging load tracing and TOU price arbitrage. Equivalent load is the difference between the EV charging load and PV power. In the low-price and medium-price periods, the charging load demand of electric vehicles is mainly satisfied by the external power grid, and the EES system is expected to supplement the stored electricity while the charging demand exceeds the sum of the capacity of the AC/DC grid-connected converter and the PV power. In the high-price periods, the EES system focuses on tracking the equivalent EV charging load. When the EES power is insufficient, the extra EV charging load is provided by the external power grid.

5.2.2.2 TOU price arbitrage mode

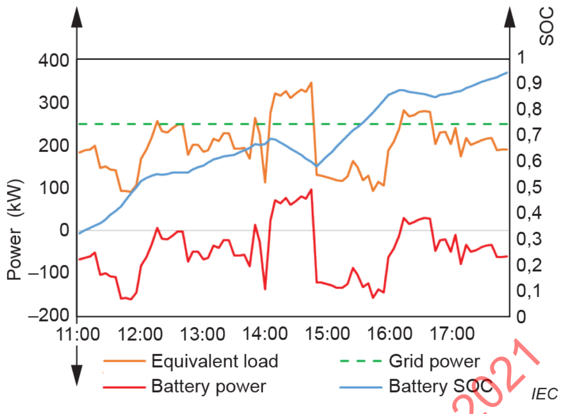
The TOU price arbitrage mode is mainly concentrated in low- and medium-price periods, i.e., 0:00 to 8:00, 11:00 to 18:00, and 21:00 to 24:00 (Figure 4). The equivalent load equals the EV charging load minus the PV output. The battery power is positive in the discharging mode and negative in the charging mode. The grid power is positive when the charging station gets power from the external power grid.

During these periods, the EES system is basically in the charging mode due to the relatively low price, and the external grid satisfies the equivalent EV charging load. When the equivalent load is below 250 kW, it is completely satisfied by the external power grid. At the same time, if the SOC of the EES system has not reached 95 %, it is in charging mode. The charging power of the EES system equals 250 kW (the capacity limit of the AC/DC grid-connected converter) minus the equivalent load. However, when the equivalent load demand exceeds 250 kW, for example, from 2:30 to 2:45 in Figure 5a), or from 14:05 to 14:45 in Figure 5b), the excess EV charging load is supplied by the EES system. In this case, the EES system is in discharging mode.

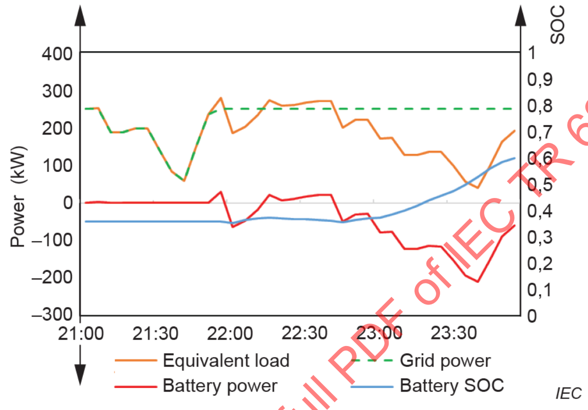
Note that the EES system is in the standby mode from 21:00 to 22:00 (as shown in Figure 5c)), in which the EES system does not charge and only discharges when the EV load exceeds the limit of 250 kW. The reason is that it achieves more cost savings to delay the charging behaviour of the EES system to a later low-price period (from 22:00 to 6:00 of the next day) than to charge during the medium-price period (from 21:00 to 22:00). However, during other medium-price periods, for example from 11:00 to 18:00, the EES system needs to charge in preparation for discharging at the later high-price period of the day.



a) **Operating power from 0:00 to 8:00**



b) **Operating power from 11:00 to 18:00**

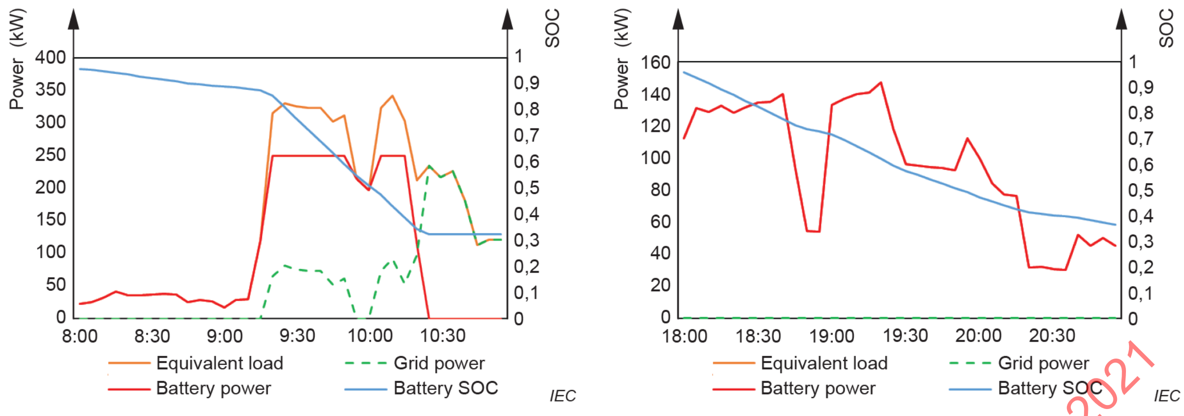


c) **Operating power from 21:00 to 24:00**

Figure 5 – Operating power in low- and medium-price periods for the case of a commercial charging station based on common DC bus

5.2.2.3 Equivalent load tracing mode

In high-price periods the EES system operates in the equivalent load tracing mode, as shown in Figure 6. Figure 6a) shows the operation power from 8:00 to 11:00, and Figure 6b) shows the operation power from 18:00 to 21:00. The EV charging load is first supplied by the EES system. In order to extend the service life of batteries, the discharging power of the EES system is limited to 250 kW. The part of the charging demand that exceeds this value is provided by the external grid, as shown in Figure 6a), for example between 9:20 and 9:50. If the charging load is large and exceeds 500 kW, then the EES system will supply the excess during the time period (this situation did not happen in this case). What needs to be pointed out is that when the SOC of the EES system reaches the lower limit of 32 %, the EES system stops discharging and the equivalent load is satisfied by the external power grid, for example between 10:25 and 11:00.

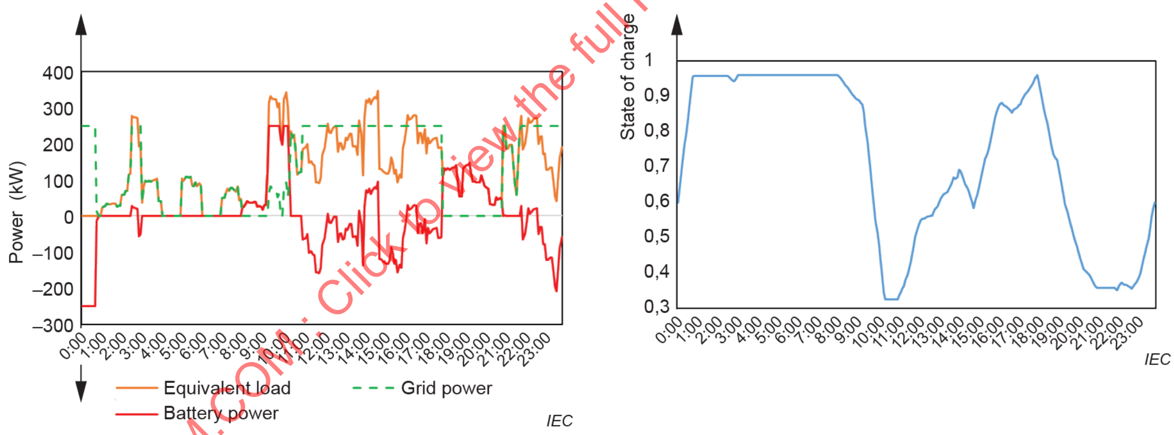


a) Operating power from 8:00 to 11:00 **b) Operating power from 18:00 to 21:00**

Figure 6 – Operating power in high-price periods for the case of a commercial charging station based on common DC bus

5.3 Summary

The resultant EES system duty cycle is the synthesis of the curves for each of the above two modes, as shown in Figure 7. It can be seen that the peak charging load is shaved due to the capacity constraint from the grid-connected converter. The EES system in the station satisfies the excess charging demand. In general, it can be seen that the EES system has gone through two big charging and discharging processes in the duty cycle of one day in Figure 7b). The time division of the EES system's duty cycle is tabulated in Table 1.



a) Comprehensive power **b) SOC of the EES system**

Figure 7 – EES system duty cycle for the case of a commercial charging station based on common DC bus

Table 1 – Time division of EES system's operation modes in the case of a commercial charging station based on common DC bus

Modes	Periods	Target	Remarks
TOU price arbitrage	0:00~8:00	The EES system is in charging mode until SOC reaches the upper limit of 95 % to prepare for discharging in the morning peak period.	– When the equivalent load is above the external grid input limit of 250 kW, the EES system is discharged to the excess load. – When the SOC of the EES system reaches 95 %, the charging mode is stopped. – The maximum charging power of the EES system is set as 250 kW.
	11:00~18:00	The EES system is in charging mode until SOC reaches the upper limit of 95 % to prepare for discharging in the evening peak period.	
	21:00~22:00	The EES system is in standby mode to wait for charging in the low price period.	
	22:00~24:00	The EES system is in charging mode until SOC reaches the upper limit of 95 % to prepare for discharging in the morning peak period.	
Equivalent load tracing	8:00~11:00	The EES system is in discharging mode to trace the equivalent load.	– The maximum discharging power of the EES system is set at 250 kW. When the equivalent load is above 250 kW, the excess load is satisfied by the external power grid. – When the SOC of the EES system reaches 32 %, the discharging mode is stopped.
	18:00~21:00		

In this practical project, the EES system is programmed to charge up to 95 % to prepare for the discharge during the high-price periods. If load forecasting is employed, the level of recharge will be optimized. For example, the SOC of the EES drops to 35 % after 21:00, but it is still above the set minimum threshold of 32 %. In other words, if the charging load for the rest of the day is known in advance, the EES system would not have to be charged to 95 % during the middle-price periods.

Figure 8 shows the daily electricity flow of the charging station (the value at the t time point means the total electricity from the t time point to the t+1 time point). The left axis shows the flow electricity of the power grid, PV and EV load for each hour. The right axis shows the stored electricity in the EES system. It can be seen that the utilization rate of the charging piles (the ratio of the charging power to the maximum power of charging piles) is considerable, reaching an average of 20 %/h. However, the PV capacity equipped with this charging station is relatively inadequate at only 30 kW. Better economic benefits are expected if more PV panels are installed.

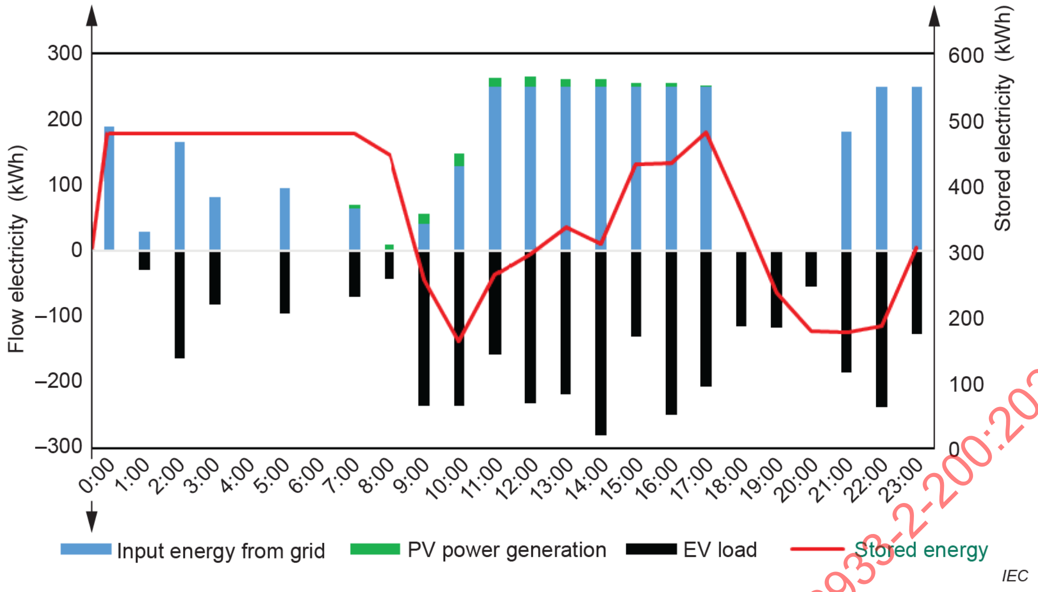


Figure 8 – Daily electricity flow for the case of a commercial charging station based on common DC bus

The duty-cycle data of the EES system in this station is provided in Clause A.2.

6 Project of commercial PV-EES-EV charging station based on common AC bus

6.1 Case project overview

The profiles of PV generation and EV load have fluctuation characteristics. High-power fast charging concentrated in the charging station will cause load spikes, which lead to undesirable transformer investments as well as a high demand charge. The EES system is able to shape the profiles by smoothing the output of equivalent load or shaving the peak.

Figure 9 shows the specific system structure of a PV-EES-EV charging station located in Shanghai, China. The entire station consists of 292 PV modules, which occupy an area of 530 m^2. The total installed capacity of the PV modules is 82 kW. The capacity of the EES system is 150 kW/150 kWh. As for the EV charging load, there are 14 AC charging piles, while the rated power of each charging pile is 3,5 kW, and 4 vehicle-to-grid (V2G) charging piles, while the rated power of each charging pile is 30 kW. All of those are connected to the electric network through the AC bus. The power flow on the AC bus is bilateral. If there is excess PV power, it can be fed back to the external power grid.

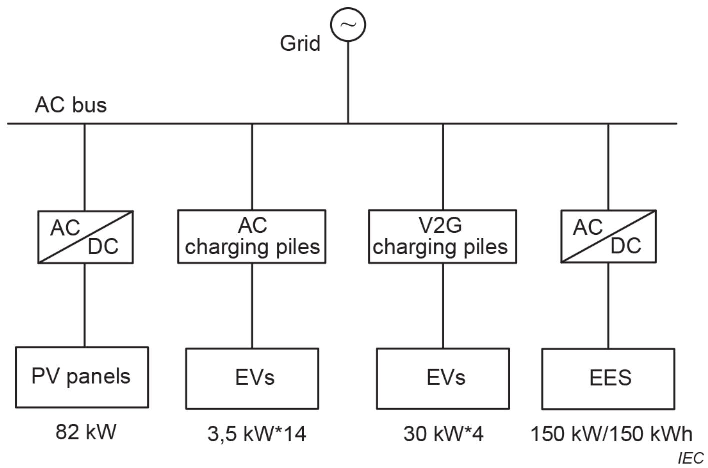


Figure 9 – System structure for the case of a commercial PV-EES-EV charging station based on common AC bus

The PV is used to provide low-carbon power. The EES system is used to absorb electrical energy during valley hours, and support fast charging load during peak hours, which effectively reduces load peak-valley difference, mitigates the impact of fast charging on the grid, and increases system operation efficiency.

According to the application of the EES system for the EV charging station with PV modules, there are three functional requirements for the EES system as follows:

1) power smoothing: buffering the sudden change of fast charging power for EVs, alleviating the impact of the charging load on the distribution network and smoothing the PV output;
2) load shaping: releasing the electrical energy at the peak load period and absorbing the electrical energy at the valley load period, reducing the peak-valley difference; meeting the peak load demand beyond the capacity of the distribution network, which delays the upgrading of the charging station and the network;
3) TOU price arbitrage: EES system charging in the valley price period, and discharging in the peak price period to obtain the price arbitrage.

6.2 System operation and control

6.2.1 Operation data analysis

The load power curve is obtained, as shown in Figure 10. The data sampling interval is 1 min. It can be seen that the maximum charging load power of daily EVs is about 150 kW. Also, the charging time is mostly distributed from 9:00 to 1:00 the next day and fluctuates greatly. In view of the intermittent characteristics of the charging load and PV power, they are synthesized into one (i.e., the equivalent load) for further analysis.

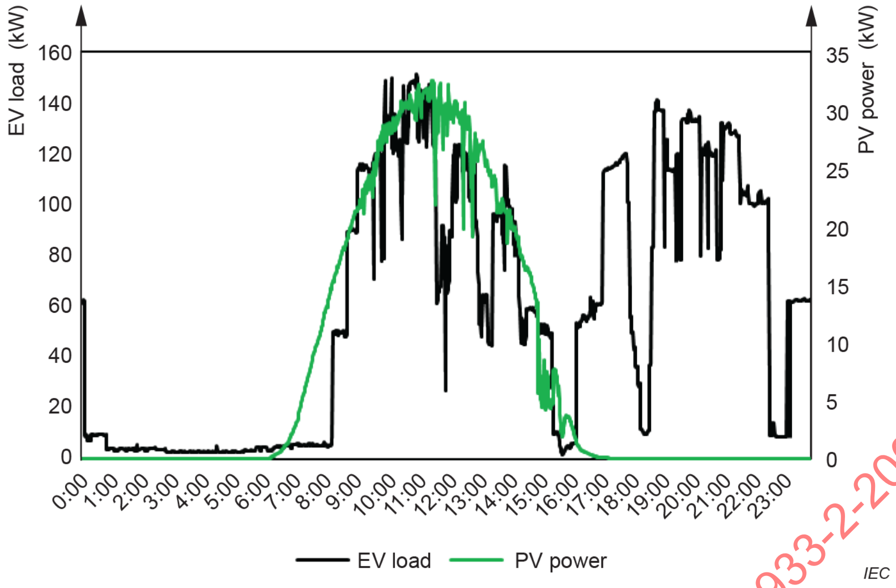


Figure 10 – EV load and PV power for the case of a commercial charging station based on common AC bus

6.2.2 Operation mode analysis

6.2.2.1 General

As the charging load fluctuates during 24 h, the EES system is divided into three operation modes, which include the power smoothing mode, the peak shaving mode, and the TOU price arbitrage mode.

6.2.2.2 Power smoothing mode

The power smoothing mode mainly uses the moving average method to smooth the power of the POC and describes the charge-discharge power characteristic of the EES system. The power curves obtained by applying the power smoothing mode alone within 24 h are shown in Figure 11. Figure 11a) shows the equivalent power and smoothing power, and Figure 11b) shows the EES system power.

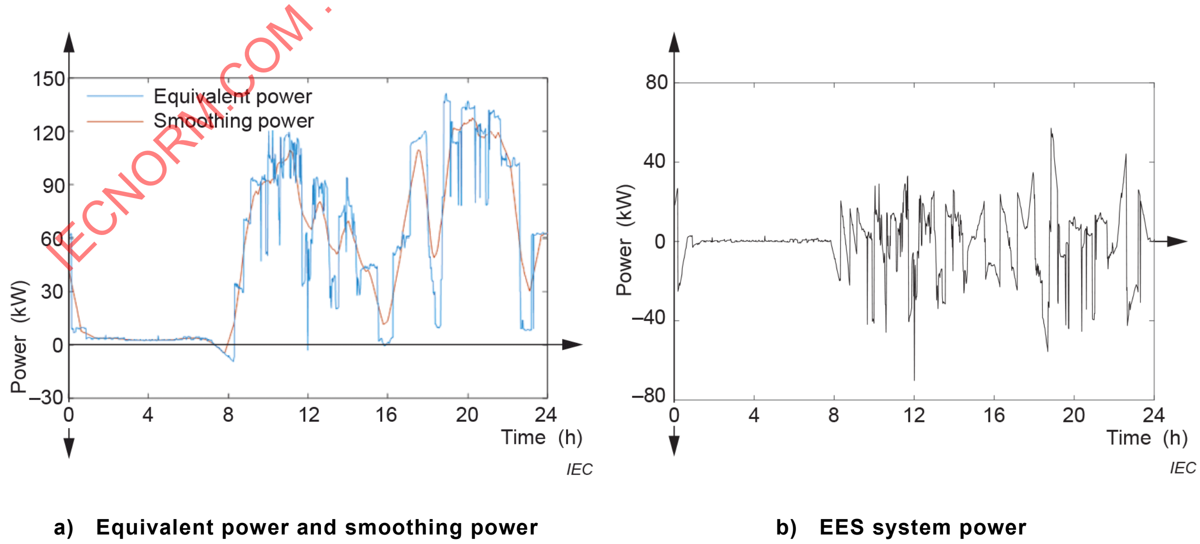
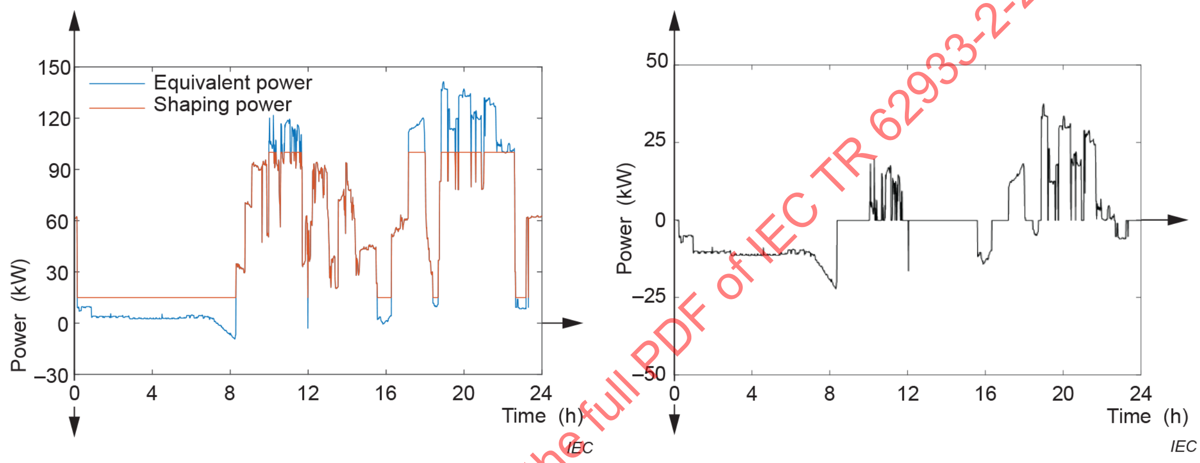


Figure 11 – Operating power in power smoothing mode for the case of a commercial charging station based on common AC bus

The power of the EES system is positive in the discharging mode and negative in the charging mode. The charge-discharge power of the EES system between 1:00 and 8:00 does not change much and tends towards a floating charge. Due to the surplus of PV power in the daytime, the EES system reaches the charging peak at around 12:00.

6.2.2.3 Peak shaving mode

In the peak shaving mode, the upper and lower limit power of the grid is set to 75 % and 10 % of the common transformer capacity, which is 112,5 kW and 15 kW respectively. The strategy is that the EES system will continuously increase its discharging power or decrease its charging power until the power at the POC is stable below 112,5 kW, and the EES system will increase its charging power or decrease its discharging power until the power at the POC is stable above 15 kW. The figure obtained by applying the peak shaving mode alone within 24 h is shown in Figure 12. Figure 12a) shows the equivalent power and smoothing power, and Figure 12b) shows the EES system power.



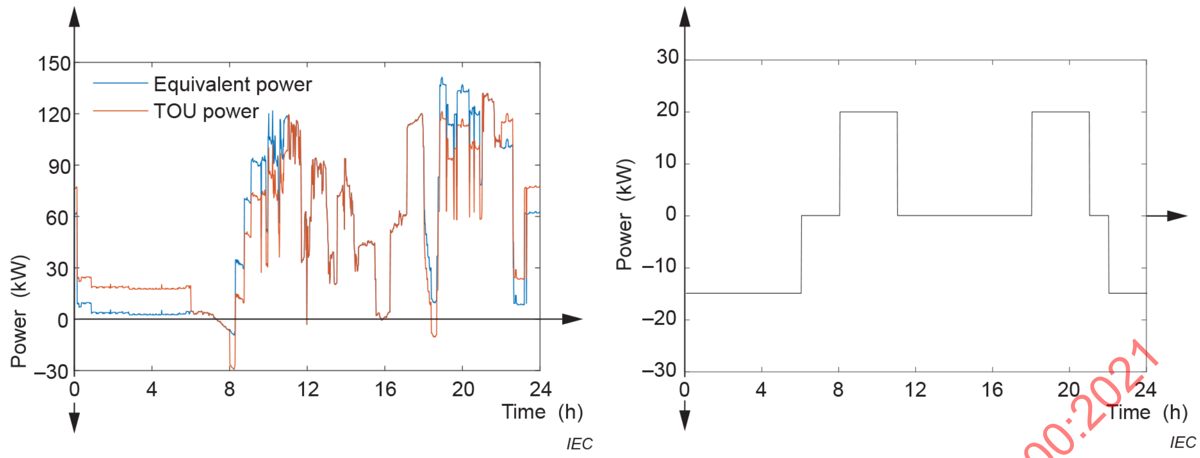
a) Equivalent power and shaving power b) EES system power

Figure 12 – Operating power in peak shaving mode for the case of a commercial charging station based on common AC bus

The EES system mainly charges between 1:00 and 8:00, discharges between10:00 and 12:00 and 17:00 and 22:00. During the rest of the time period, there are intermittent charging and discharging processes according to the change of load.

6.2.2.4 TOU price arbitrage mode

In the TOU price arbitrage mode, the strategy of "one charge and two discharges" which is charging at the low-price periods of 22:00 to 6:00 and discharging at the high-price periods of 8:00 to 11:00 and 18:00 to 21:00 according to the TOU price of Shanghai is adopted. The charging and discharging power is constant. The figure obtained by applying the TOU price arbitrage mode alone within 24 h is shown in Figure 13. Figure 13a) shows the equivalent power and smoothing power, and Figure 13b) shows the EES system power.



a) **Equivalent power and TOU power** b) **EES system power**

Figure 13 – Operating power in the TOU price arbitrage mode for the case of a commercial charging station based on common AC bus

The EES system can increase the valley load at night, but there will be intermittent valley load under the peak electricity price. Discharging at the fixed time will further lower the valley load that occurs during the high-price periods, which is not conducive to the stability of the grid. The EES system realizes the price arbitrage while reducing the network power stability.

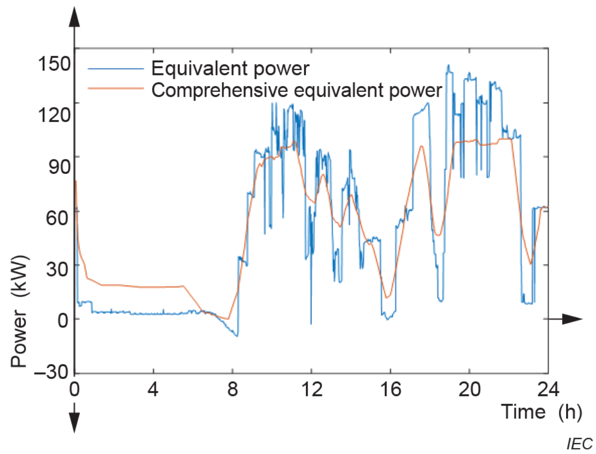
6.3 Summary

In view of the characteristics of the equivalent load in different time periods, the time division of the duty cycle, as shown in Table 2, is employed to coordinate multiple modes of the EES system.

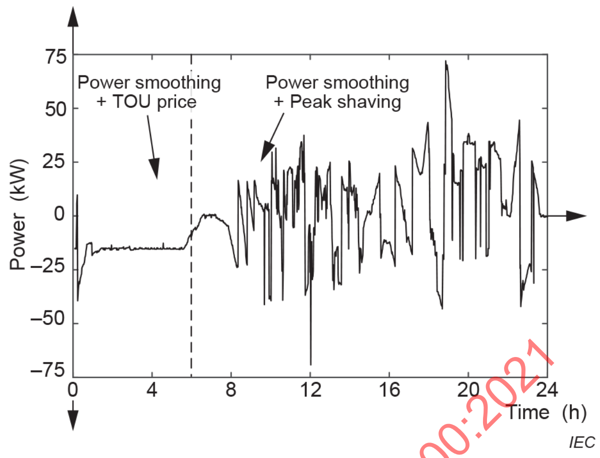
Table 2 – Time division of the EES system's operation modes for the case of a commercial charging station based on common AC bus

Modes	Periods	Targets
Power smoothing	0:00~24:00	Smoothing power fluctuation of the equivalent load throughout the day
Peak shaving	6:00~24:00	Reducing the difference between the load peak and valley
TOU price arbitrage	0:00~6:00	Storing power in the EES system at a low price

According to the division, the duty cycle is obtained and shown in Figure 14. Figure 14a) shows the equivalent power and the comprehensive equivalent power based on the power smoothing, peak shaving and TOU price arbitrage modes of the EES system. Figure 14b) shows the EES system's comprehensive power. It can be seen that the power smoothing is the main mode of the EES system. After that, the EES system will detect whether the smoothed power exceeds the capacity limit and further conduct peak shaving if the out-of-limit power is present. Finally, the EES system will be charged during the low-price periods for future operation.



a) Equivalent power and comprehensive power



b) EES system power

Figure 14 – EES duty cycle for the case of a commercial charging station based on common AC bus

Figure 15 shows the daily electricity flow of the charging station. The utilization rate of the charging piles reaches an average of 35 %/h. However, most of the electricity for EVs actually comes from the grid. The main function of the EES system in this case is power smoothing and peak shaving.

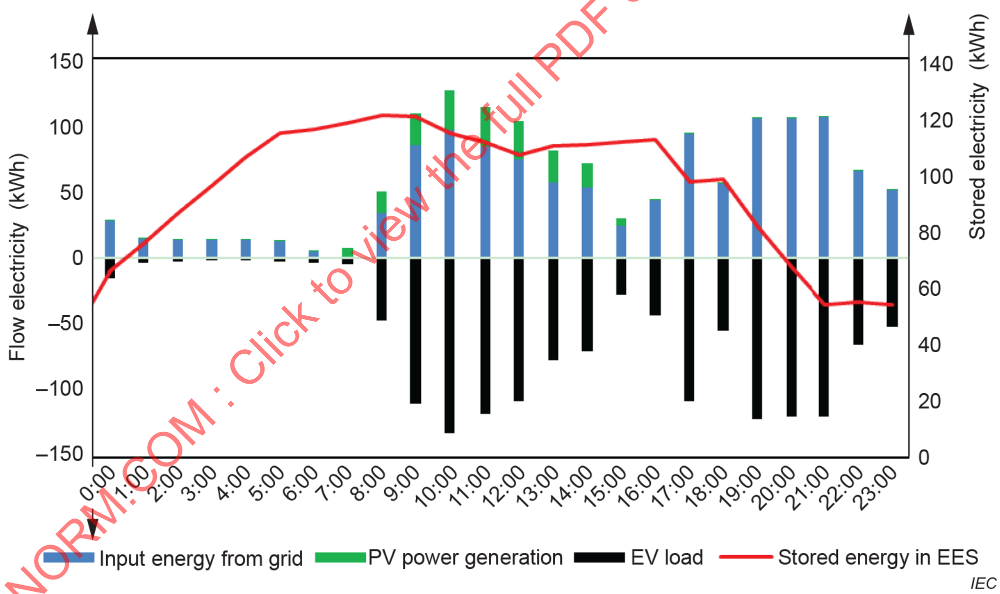


Figure 15 – Daily electricity flow for the case of a commercial charging station based on common AC bus

The duty-cycle data of the EES system in this station are provided in Table A.2.

7 Project of business PV-EES-EV charging station based on common DC bus

7.1 Case project overview

Another DC-based typical project of the EV charging station integrated with the PV and EES system is located in Beijing, China. Its specific system structure is shown in Figure 16. Different from the above two cases, it can be seen that there is a local AC load in this project, and the PV installed capacity is relatively large. The AC load denotes a shopping mall near the charging station in the real world. The charging station in this case is allowed to provide power to meet the needs of local loads. In other words, the charging station becomes a prosumer rather than just a load.

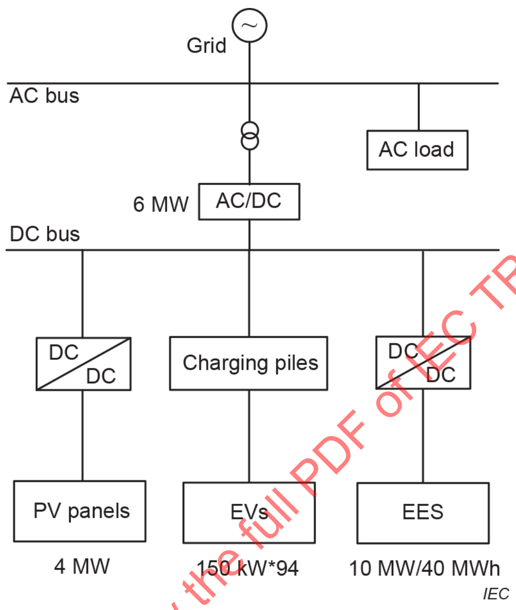


Figure 16 – System structure for the case of a business PV-EES-EV charging station based on common DC bus

This project case is equipped with a DC bus to connect major in-station equipment, including 4 MW PV, 10 MW/40 MWh lithium-ion batteries and 47 sets of DC fast charging piles. Every pile is an integrated equipment with double charging spots, whose maximum power can reach 150 kW. The charging station is connected to the AC bus with an AC/DC converter, through which it can purchase electricity from external grids or provide power to the nearby shopping mall.

There are four independent stakeholders in this project: the EV charging station integrated with the PV and EES system, the upstream power grid, the shopping mall, and EV users.

As a customer of the grid, this charging station pays electricity bills to the power grid based on the TOU electricity price in each billing cycle. PV power generation is 100 % consumed locally on the AC and DC bus, and it is not allowed to feed back to the upstream power grid. On the other hand, it is also a commercialized service provider independent of the power grid and end users. Especially with the help of the EES system, the charging station can buy electricity at low prices and sell it to users with high prices to arbitrage. It can be seen that the operation of the EES system is the key to maximize the benefits of the charging station. Based on different working conditions, the EES system has the following three operation modes:

1) equivalent load tracing;
2) TOU price arbitrage;
3) demand response.

7.2 System operation and control

7.2.1 Operation data analysis

The historical data of power generation and consumption on a typical day are illustrated in Figure 17. PV panels generate electricity mainly between 7:00 and 17:00. EV charging service is available 24 h a day. The mall owner (AC load) buys electricity from the charging station during peak loads. Figure 18 shows the TOU price and EV charging service tariffs for that day.

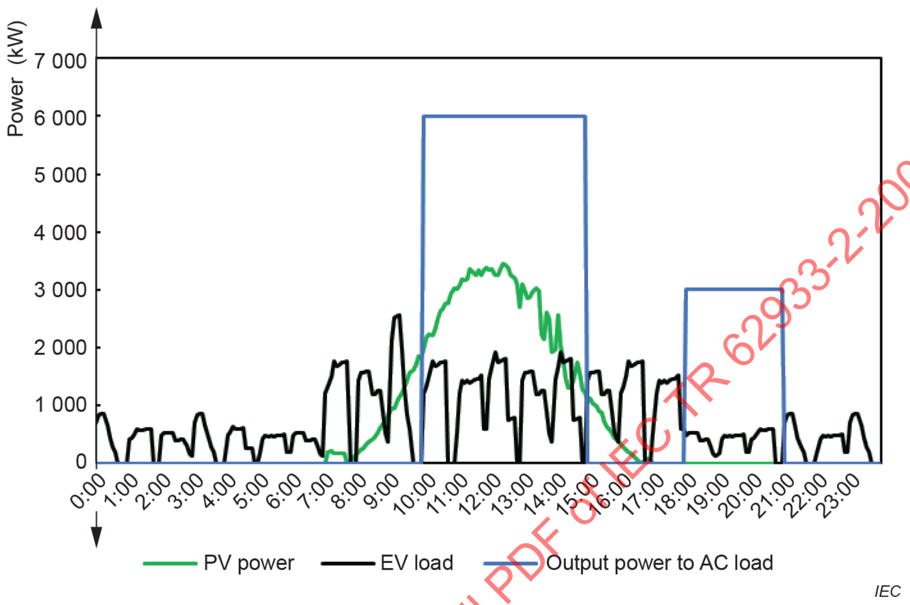


Figure 17 – PV power, EV load and output power for the case of a business charging station based on common DC bus

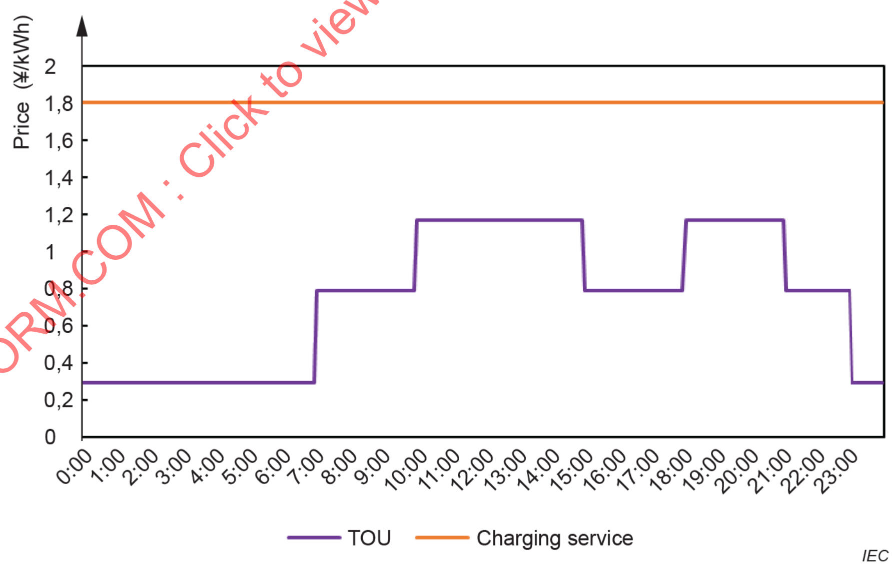


Figure 18 – TOU and charging service prices for the case of a business charging station based on common DC bus

The EES system is flexible and controllable with the dual properties of power supply and load, and is the key to maximizing the benefits of power stations. Reasonable operation duty cycle of the EES system is helpful to mitigate the impact of random PV and charging power on the grid and reduce load peak-valley difference.

7.2.2 Operation mode analysis

7.2.2.1 General

The typical operation modes of the EES system in this PV-EES-EV charging station include equivalent load tracing, TOU price arbitrage, and demand response. In Clause 5, an analysis method of dividing the operation mode according to time is adopted. Specifically, the EES system in Clause 5 operates in different modes at different times of day. However, in 7.2.2, a new analytical idea is tried, in which each operation mode of the EES system lasts for one day, and the final duty cycle is the superposition of the optimal power curves for its three operation modes.

7.2.2.2 Equivalent load tracing mode

PV power generation is highly volatile. The charging behaviour of EVs is random and can occur at any time of one day. In 7.2.2, equivalent load is still defined as the difference between the EV load and PV power. Because the rated power of the EES system on the DC bus is large enough (10 MW), by the use of the equivalent load tracing mode, the EES system completely neutralizes the PV power generation and EV charging demand, as shown in Figure 19, which eliminates power fluctuations and reduces the influence of high impact power on the grid. When the EV load is greater than the PV power, the EES system operates in the discharging mode. Conversely, if the PV power exceeds the EV charging demand, the excess self-generation electricity will be stored in EES system.

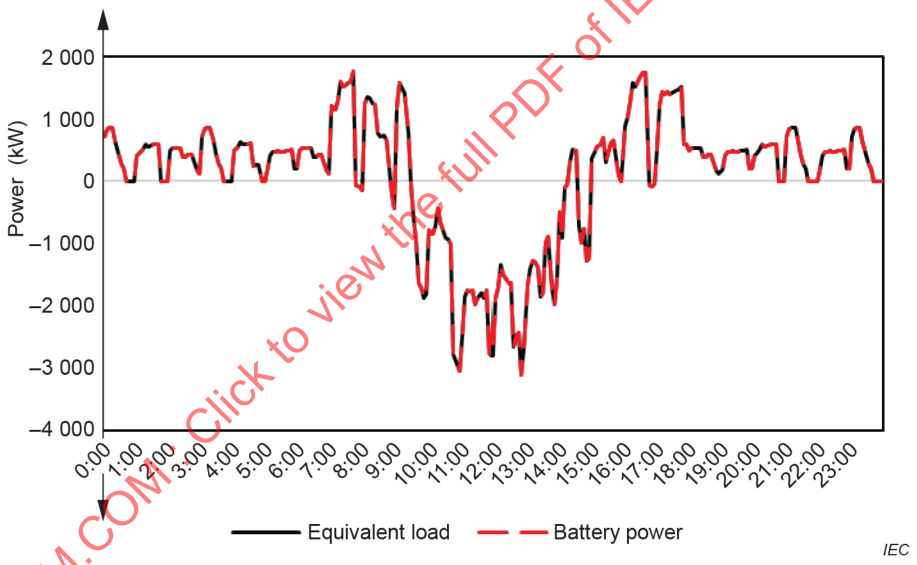


Figure 19 – Operating power in equivalent load tracing mode for the case of a business charging station based on common DC bus

7.2.2.3 TOU price arbitrage mode

The TOU prices create favourable conditions for increasing the revenue of charging stations with EES systems. Figure 20 shows the arbitrage action of batteries with the background of TOU prices. During the valley and flat price periods, the EES system stores energy from the external grid with the lower price. When the electricity price is at peak, the EES system can be discharged to the nearby shopping mall for high economic returns. The charging and discharging power of the EES system is limited by the capacity of the AC/DC converter, which is 6 MW. When the SOC of the EES system reaches its upper (SOC equals 90 %) or lower (SOC equals 10 %) limit, the charging or discharging process will be stopped. In this project, because there are some EV charging loads from 7:00 to 10:00, the SOC of the EES system decreases from 90 %, which triggers the charging process in this time period. The amount of discharging energy during peak time periods is based on historical shopping mall load data analysis and the capacity of the EES system. Generally the station will sell about 39 MWh of electricity to the shopping mall every day.

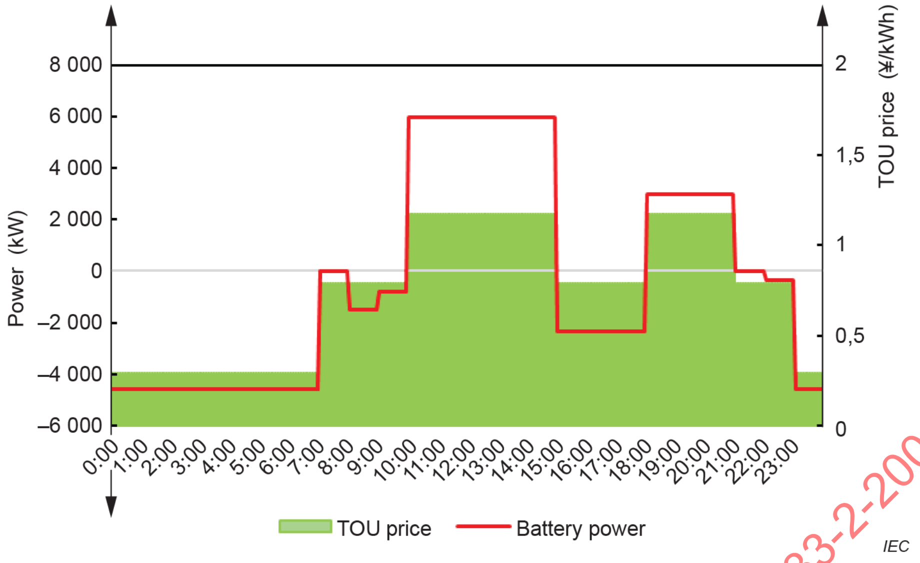


Figure 20 – Operating power in TOU price arbitrage mode for the case of a business charging station based on common DC bus

Another function of operating in the TOU price arbitrage mode is to maintain the balance of energy stored in batteries. The battery will release (e.g., partly to trace the EV load) as much power as it absorbs (e.g., partly to firm the PV generation) in a day. The mismatched energy is eliminated in the arbitrage mode considering the economic benefits over different periods of time caused by the TOU price. In other words, the amount of energy left in the battery by the end of the day returns to where it started.

7.2.2.4 Demand response mode

With the help of the controllable EES system, the charging station can take part in the demand response published by the grid operators and conduct flexibly the power schedule. In this project case, users who consume power between 2:00 and 6:00 will be offered by the grid attractive subsidies (the equivalent of the electricity bills being paid during that time are settled at a rate lower than the TOU price). As a result, the charging station makes an extra charging plan between 2:00 and 6:00, as shown in Figure 21. To maintain the balance of the charging and discharging power, the battery's operation schedule for other periods of time also has to be adjusted. The combined power of batteries participating in both TOU arbitrage and demand response is shown in Figure 22.

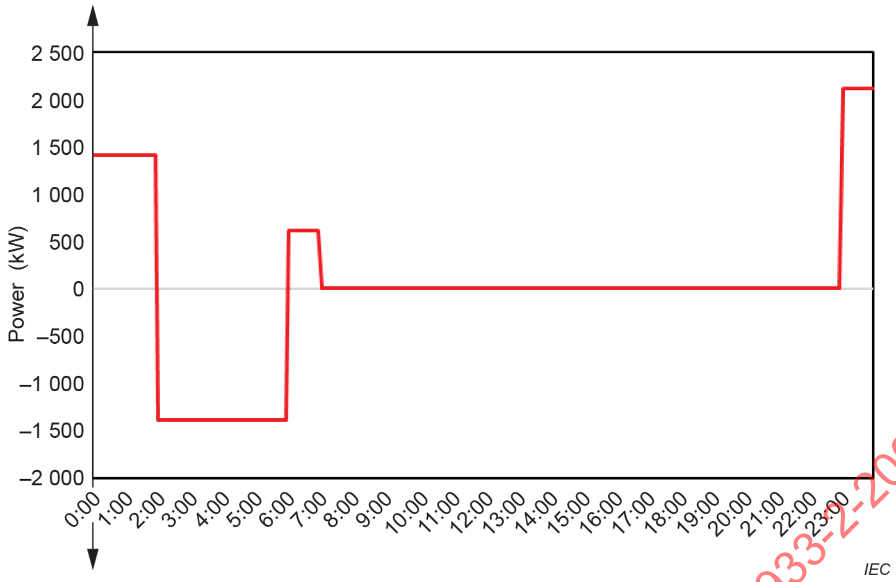


Figure 21 – Operating power in demand response mode for the case of a business charging station based on common DC bus

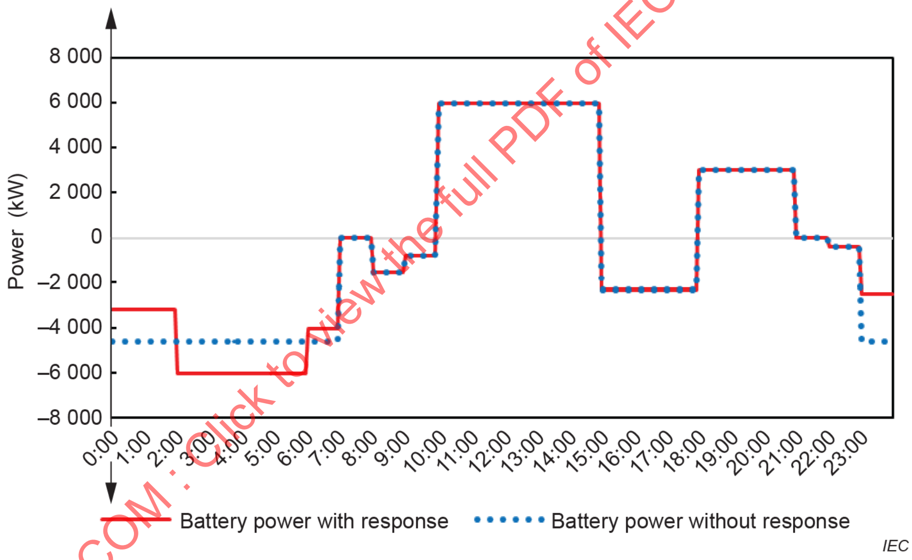


Figure 22 – Operating power involved in TOU arbitrage and demand response for the case of a business charging station based on common DC bus

7.3 Summary

The single mode cannot fully achieve the maximum benefits of the EV charging station integrated with the PV and EES system. The actual operating conditions of the EES system are the superposition of the above three modes, as shown in Figure 23.

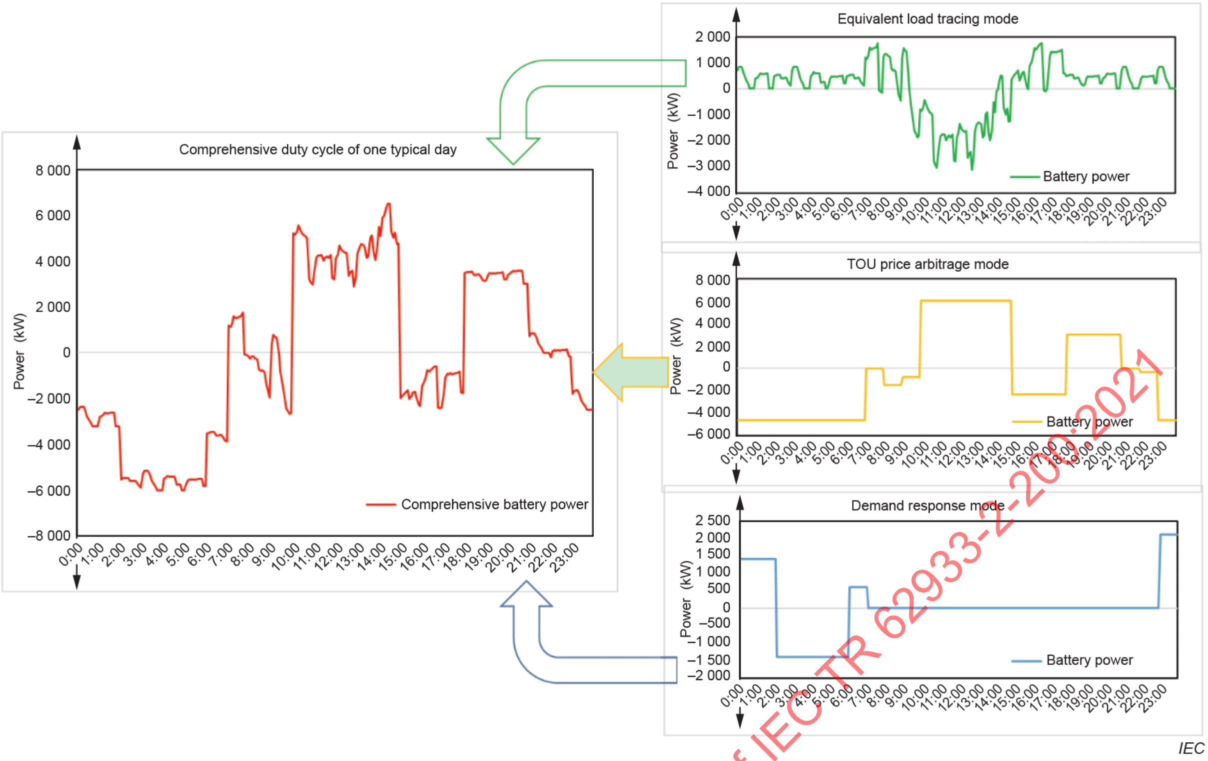


Figure 23 – EES duty cycle for the case of a business charging station based on common DC bus

The daily electricity flow of the charging station is shown in Figure 24. From that, the energy time-shifting function of the EES system can be recognized clearly. The electricity of the EES system at the end returns to the level at the beginning of the day, preparing for the next day's operation cycle. In addition, because this PV-EES-EV charging station has just been put into operation, the charging load is not very large. The average utilization rate of charging piles in 24 h is about 5,4 %. Most of the power is output to supply the AC load of the surrounding shopping mall. As EVs become more popular, revenue from providing charging services is expected to grow in the future.

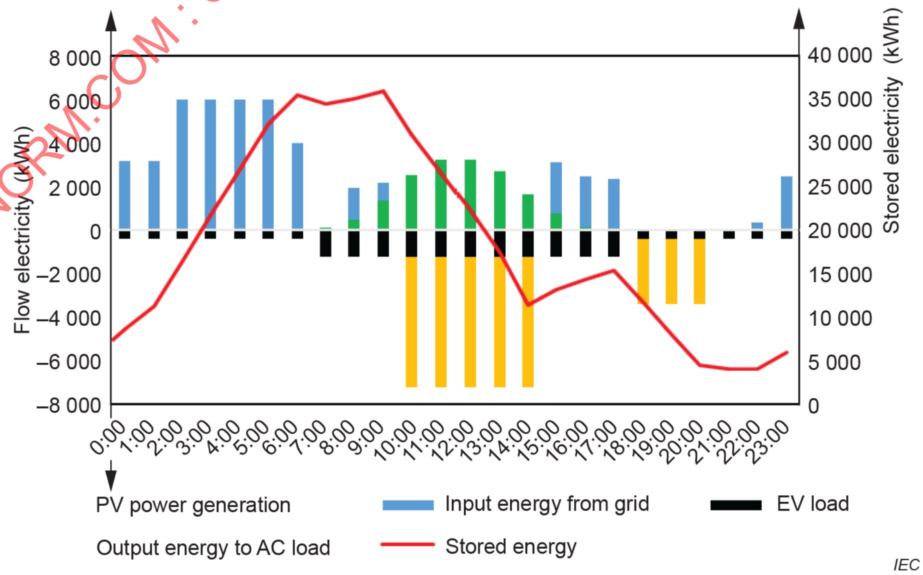


Figure 24 – Daily electricity flow for the case of a business charging station based on common DC bus

The duty-cycle data of the EES system in this station are provided in Table A.3.

8 Project of business PV-EES-EV charging station based on common AC bus

8.1 Case project overview

Oak Ridge National Laboratory (ORNL), located in Tennessee, US, received funding in 2009 from the American Recovery and Reinvestment Act (ARRA) through the Department of Energy (DOE). The funding was used to install 125 solar-assisted EV charging stations in cooperation with regional grant-matching partners. The goals of the project include researching the interaction between EV owners and equipment, using renewable energy and local storage to reduce the load of EV charging, and understanding the impact on the grid. Using these experiences will not only promote the construction of EV charging infrastructures, but also consolidate the lessons learned for widespread adoption of EVSE in the marketplace.

The 125 solar-assisted charging stations are partitioned into 15 sites. A number of EVSEs, a PV array, and an EES system which are all independently grid-tied are contained in each site. The solar generation capacity of each EVSE is about 2 kW. This document takes the Oak Ridge stations as the example, whose system structure is shown in Figure 25.

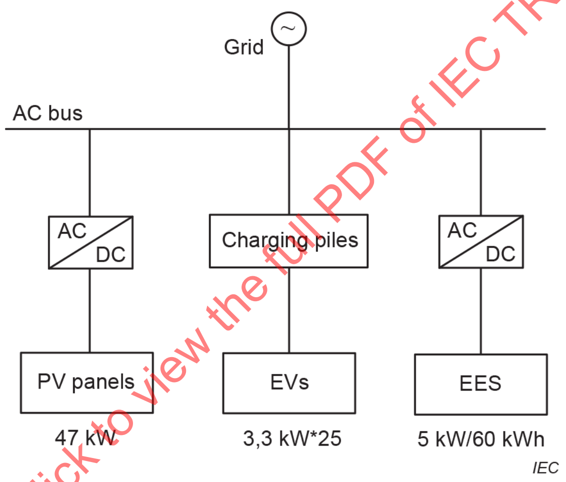


Figure 25 – System structure for the case of a business PV-EES-EV charging station based on common AC bus

The ORNL site represents a private site that is only used by employees and visitors of ORNL which can purchase electricity from the external grid or provide power to it conversely. The ORNL site has 25 EVSEs, a 47 kW solar PV array, and a 60 kWh EES system. A two-direction connection has been constructed between the EES system and the electricity grid through a 5 kW inverter/charger.

8.2 System operation and control

8.2.1 Operation data analysis

The historical data of PV power and EV load on a typical day are illustrated in Figure 26. The solar generation data for the ORNL PV-ESS-EV charging station are from the Advanced Energy website and the EV charging load data are from the Blink Network website. The PV panel generates electricity mainly between 9:00 and 20:00. As this private charging station provides charging services for the employees and visitors of ORNL, the charging events mainly take place between 7:00 and 14:00. The data sampling interval is 15 min.

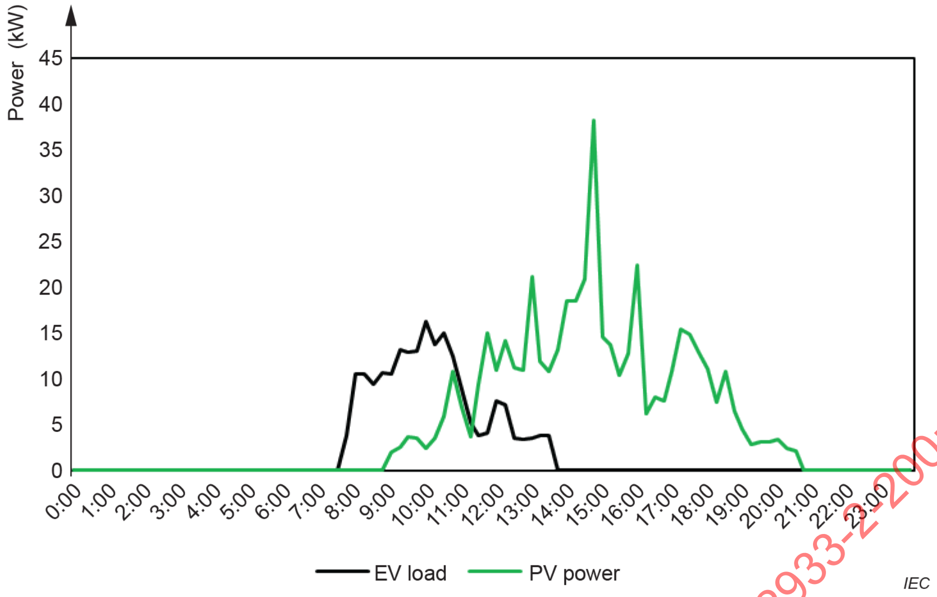


Figure 26 – EV load and PV power for the case of a business charging station based on common AC bus

8.2.2 Operation mode analysis

8.2.2.1 General

Three operation strategies are available for the EES system in the ORNL station at the Oak Ridge site. The operation strategy 1 has a fixed charge and discharge time regardless of the PV power and EV load. The EES system runs at the maximum power (5 kW) during operation. The charging mode of the operation strategy 2 is the same as the first one. However, at the level of discharge, the operation strategy 2 is determined based on the power limit of the EES and the number of EVs. The operating strategy 3 is more intelligent than the strategy 2. According to the gap between the PV power and EV load, the EES system can charge and discharge at different rates. Use of the excess PV power during the day to charge the ESS system can effectively reduce the charging time at night.

8.2.2.2 Operation strategy 1

The operation strategy 1 of the EES system is to set the EES running time and power in advance. Specifically, the start charging time and end charging time are chosen as 20:00 and 6:00, respectively, due to their being off-peak hours. The discharging periods are set as 7:00 to 13:00 of one day based on the historical usage statistics. The EES system runs at the maximum power (5 kW) during operation, regardless of charge and discharge.

Figure 27 shows the operation results under the first strategy. The "mode" in the figure denotes the operating state of batteries. Mode=1 means battery discharging, and mode=-1 means battery charging. In this strategy, the EES system is charged and discharged once a day and basically runs with the TOU price arbitrage mode. After 12:00, the battery is still discharging to the power grid even though it is not needed.

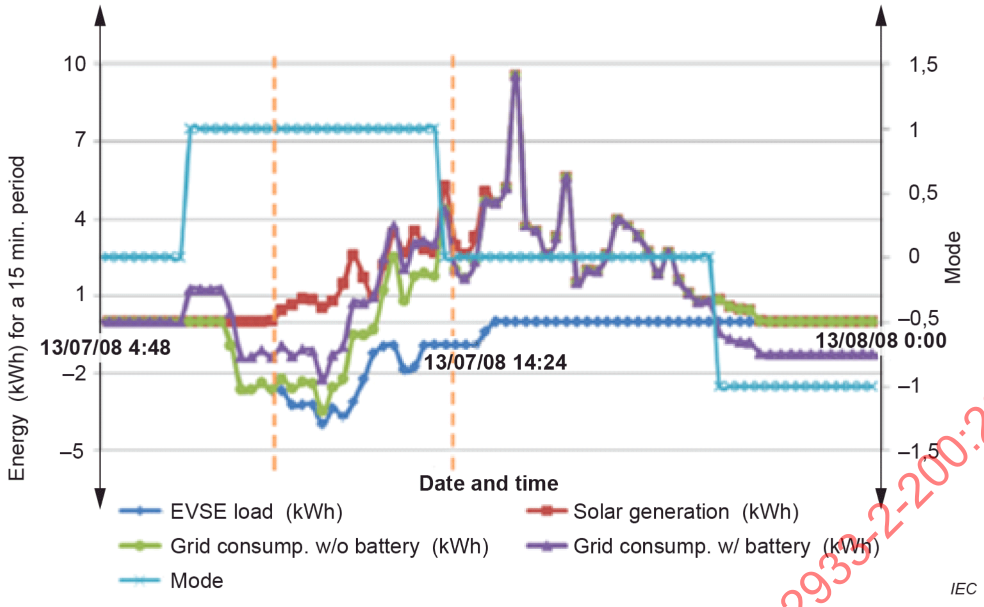


Figure 27 – Simulation results for operation strategy 1 for the case of a business charging station based on common AC bus

8.2.2.3 Operation strategy 2

In this operation strategy, PV power is used to charge EVs if it is available. If more power is needed, the EES system will supply part of the power according to the embedded algorithm, and the remaining power will be provided by the utility grid.

Figure 28 shows the operation results under the second strategy. As with the operation strategy 1, the charge events of the EES system with operation strategy 2 still follows the fixed periods and charging rates. At other times of the day, however, the EES system operates more intelligently. It can be noticed that the discharge actions of the EES system are triggered when the PV power is less than the EV charging load, and the discharging power of the EES system is determined based on the power limit of the EES and the number of EVs. Under this strategy, the EES system plays a TOU price arbitrage mode and equivalent load tracing mode.

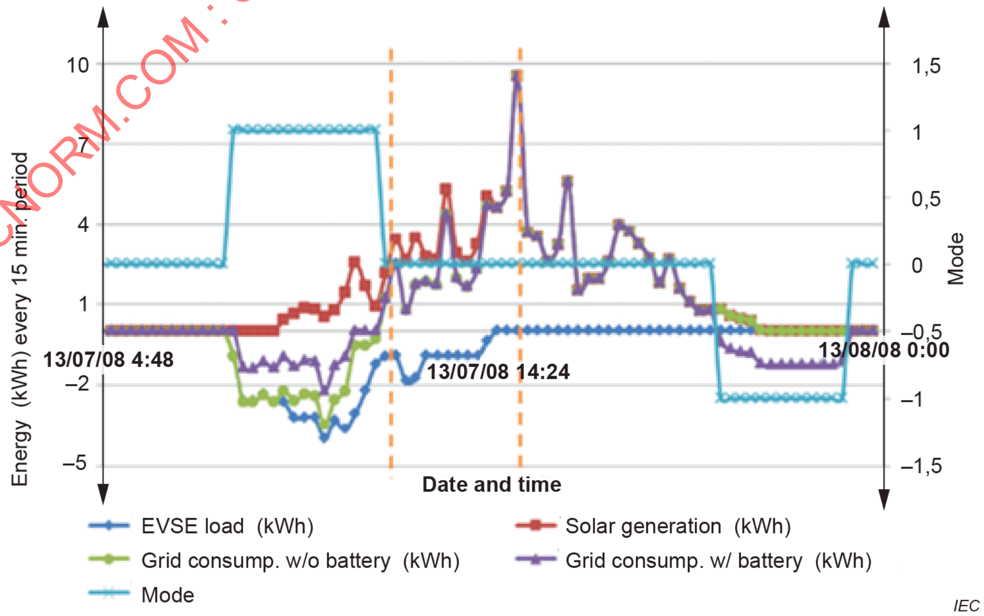


Figure 28 – Simulation results for operation strategy 2 for the case of a business charging station based on common AC bus

8.2.2.4 Operation strategy 3

Compared with the above operation strategy 2, the operation strategy 3 improves the PV self-consumption and more strictly limits the discharging power of the EES system.

First, when the PV power exceeds the EV charging load, which generally occurs between 8:00 and 20:00, the EES system is allowed to charge with the electricity from PV generation. Second, if the PV power is insufficient to meet the charging demand, a sigmoid function is introduced to determine the discharging power of the EES system. The sigmoid function is formulated as follows:

$$P_f\left(i_d\right)=\left(\frac{2}{1+e^{-\omega i_d}}-1\right)\times\left(P_l\right) \tag{1}$$

$$i_d = P_d / 120 \tag{2}$$

where

P_d is the equivalent load, equal to the EV load minus PV power;

i_d is the current of the equivalent load, which is calculated according to the equivalent load and the constant voltage (120 V in this project);

P_l is the power limit of the EES system;

P_f is the power of the EES system;

ω is the adjustable parameter, which is used to adjust the steepness of the sigmoid curve and control the response speed of the EES system.

The sigmoid function helps to prevent the EES system from discharging all of its energy too quickly, leaving no energy for later in the day.

Figure 29 shows the operation results under the third strategy. It is clear that the EES system uses the energy generated by PV panels during daytime to charge and promotes the on-site consumption of PV power. Because the current EV charging load of this station is relatively small, the EES system is fully charged only by the excess PV power during the day. Therefore, the EES system in Figure 29 does not run at night. If the EV charging load grows in the future, charging at night at low-price periods is still an option not to be ignored in this strategy.

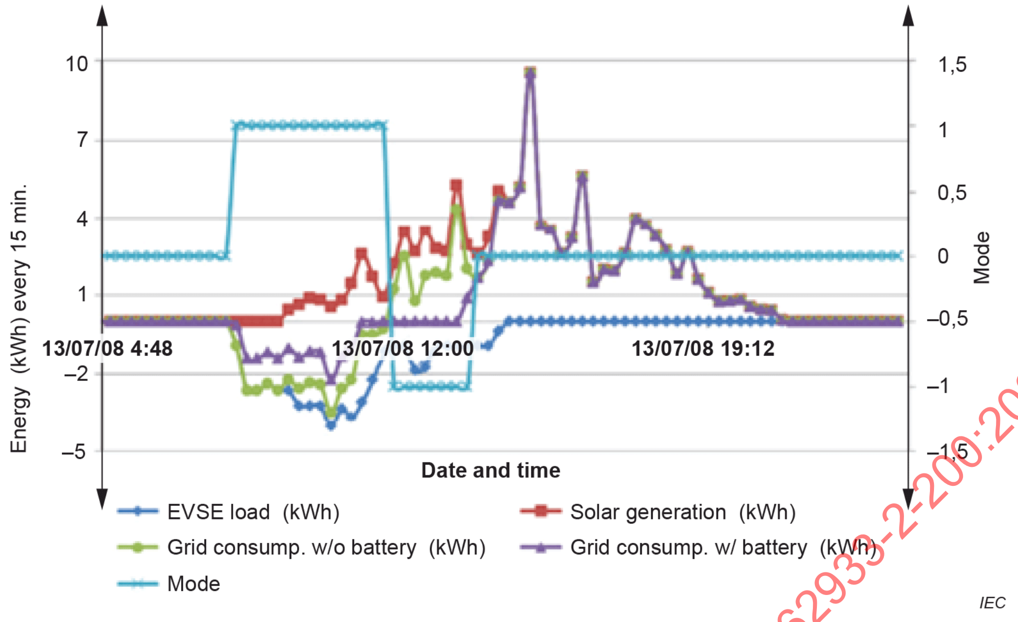


Figure 29 – Simulation results for operation strategy 3 for the case of a business charging station based on common AC bus

8.3 Summary

The summary of the three operation strategies is showed in Figure 30, from which the basic operation modes of the EES system can be extracted.

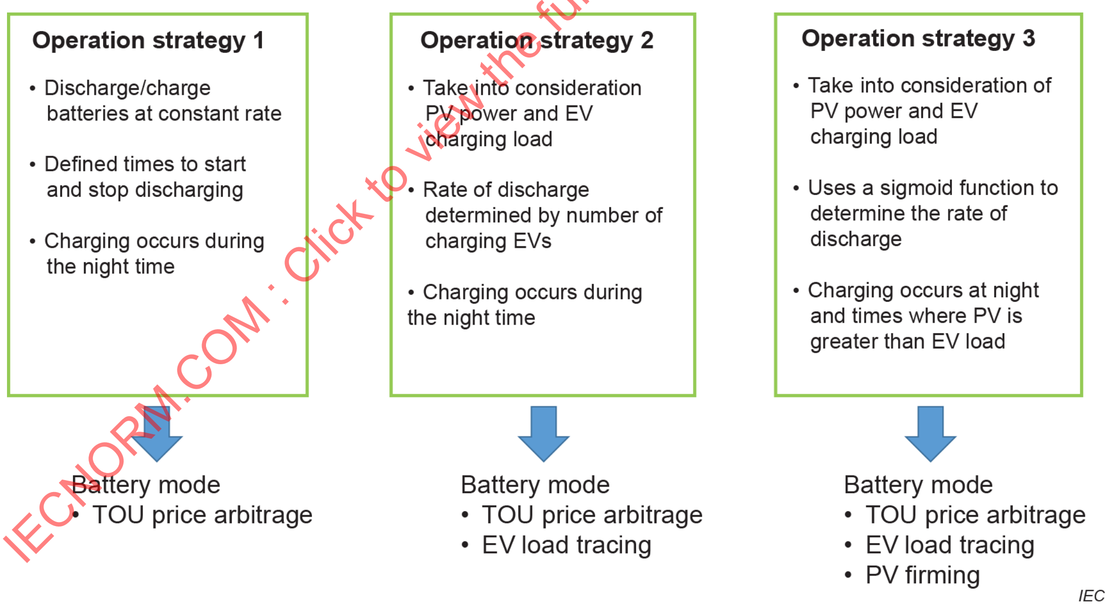


Figure 30 – Three operation strategies and resultant operation modes of the EES system for the case of a business charging station based on common AC bus

It can be noticed that the operation strategy 3 represents a more flexible strategy with significant advantages in promoting on-site PV consumption, reducing the dependence of EV charging load on the grid, and extending the discharge duration of the EES system. In view of the better recommendation value of the third strategy, further elaboration is provided and the basic operation modes behind the operation strategy 3 are extracted, as shown in Table 3.

Table 3 – Time division of EES operation modes for the case of a business charging station based on common AC bus

modes		triggers	targets
TOU price arbitrage		Timing (20:00~6:00)	Storing power in the EES system at a low price
Equivalent load tracing	PV power firming	Equivalent load is negative	Charging to absorb excess PV power
	EV load tracing	Equivalent load is positive	Discharging to reduce dependence on the power grid

9 Recommendation for operation modes of EES systems located in EV charging station with PV panels

The operation mode of the EES system in one charging station largely depends on the battery capacity compared to the charging load. From the economic point of view, the TOU price arbitrage is the basic operation mode. In addition, if the installed capacity of the EES system is relatively low, it is suitable for working in power shaping mode, for example, power smoothing and peak shaving. In addition, enough EES installed capacity allows the charging station to work in the load tracing mode and participate in some value-added ancillary service, such as the demand response.

With the popularity of EVs, it is expected that both the commercial charging stations that operate independently and the business charging stations that have interest relations with other business entities will achieve great development in the future. As analysed in this document, the single operation mode of the EES system cannot fully achieve the maximum benefits of the EV charging station. The typical duty cycle of the EES system is the combination of multiple operation modes. The optimal combination of EES operation modes generally varies with the application scenarios. Table 4 shows the recommendations given after the investigation of a large number of projects.

Table 4 – Recommended operation modes of the EES system in various installation scenarios of a PV-EES-EV charging station

	TOU pricing arbitrage	Equivalent load tracing	Peak shaving	Power smoothing	Ancillary service
Commercial charging station with high proportion of EES capacity compared with charging load and PV power	✓	✓	✓		
Commercial charging station with low proportion of EES capacity compared with charging load and PV power	✓		✓	✓	
Business charging station with high proportion of EES capacity compared with charging load and PV power	✓	✓	✓		✓
Business charging station with low proportion of EES capacity compared with charging load and PV power	✓	✓			

Commercial charging stations are generally aimed at regular EV users. For this kind of charging stations, reducing charging time means they can serve more users in the same time to gain greater profits, and help improve users' comfort. Therefore, in the commercial charging station, fast charging piles are the mainstream of charging facilities. The TOU price arbitrage is the basic operation mode of the EES system in the commercial fast charging station. Other choices of operating modes, for example, equivalent load tracing, power smoothing, and peak shaving, depend largely on the installed capacity of the EES system.

For the business charging stations, there are two main subtypes. One type of business charging station is equipped with fast charging piles to meet the short-term charging needs of EV users, such as those built alongside shopping malls (the Beijing case in this document). In this kind of charging stations, the EES system has the most flexible operation combination. Equivalent load tracing, TOU pricing arbitrage, peak shaving, and demand response are all perfectly suited to this application scenario. The other type of business charging station is equipped with only the common/slow charging piles because customers generally have plenty of time to wait for their EVs to be charged (e.g., the ORNL case in this document). Such business charging stations are typically located near the campus, office, and community, and the EES systems often operate in the modes of TOU pricing arbitrage and equivalent load tracing.

Note that the above recommendations are only the general expression of the operating modes in each scenario. The situation can change in practice as it can be affected by local policies or load levels.

Annex A
(informative)

Duty cycles of the EES systems located in EV charging station with PV

A.1 General

In Annex A, the recommended duty cycles of the EES systems in projects of PV-EES-EV charging stations are tabulated in Table A.1, Table A.2, and Table A.3, respectively. A positive value means the EES system is in discharging mode and a negative value means the EES system is in charging mode. In Table A.1, the power sampling interval is 5 min and the reference value is taken as 500 kW. In Table A.2, the power sampling interval is 1 min and the reference value is taken as 75 kW. In Table A.3, the power sampling interval is 5 min and the reference value is taken as 10 MW.

A.2 Project of commercial PV-EES-EV charging station based on common DC bus

Table A.1 – Charging-discharging power of EES system for the case of a commercial charging station based on common DC bus (per-unit value)

Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)
0:00	-0,500 0	4:50	0,000 0	9:40	0,500 0	14:30	0,141 4	19:20	0,294 9
0:05	-0,500 0	4:55	0,000 0	9:45	0,500 0	14:35	0,160 7	19:25	0,235 9
0:10	-0,500 0	5:00	0,000 0	9:50	0,500 0	14:40	0,150 5	19:30	0,192 5
0:15	-0,500 0	5:05	0,000 0	9:55	0,429 6	14:45	0,192 3	19:35	0,190 3
0:20	-0,500 0	5:10	0,000 0	10:00	0,394 6	14:50	-0,240 1	19:40	0,188 1
0:25	-0,500 0	5:15	0,000 0	10:05	0,500 0	14:55	-0,240 6	19:45	0,187 5
0:30	-0,500 0	5:20	0,000 0	10:10	0,500 0	15:00	-0,247 4	19:50	0,184 8
0:35	-0,500 0	5:25	0,000 0	10:15	0,500 0	15:05	-0,256 6	19:55	0,224 7
0:40	-0,500 0	5:30	0,000 0	10:20	0,229 6	15:10	-0,264 2	20:00	0,199 6
0:45	-0,026 3	5:35	0,000 0	10:25	0,000 0	15:15	-0,266 7	20:05	0,167 9
0:50	0,000 0	5:40	0,000 0	10:30	0,000 0	15:20	-0,246 3	20:10	0,154 3
0:55	0,000 0	5:45	0,000 0	10:35	0,000 0	15:25	-0,172 9	20:15	0,152 8
1:00	0,000 0	5:50	0,000 0	10:40	0,000 0	15:30	-0,203 9	20:20	0,062 8
1:05	0,000 0	5:55	0,000 0	10:45	0,000 0	15:35	-0,264 0	20:25	0,064 6
1:10	0,000 0	6:00	0,000 0	10:50	0,000 0	15:40	-0,242 8	20:30	0,061 0
1:15	0,000 0	6:05	0,000 0	10:55	0,000 0	15:45	-0,313 7	20:35	0,060 3
1:20	0,000 0	6:10	0,000 0	11:00	-0,132 8	15:50	-0,271 8	20:40	0,104 4
1:25	0,000 0	6:15	0,000 0	11:05	-0,124 8	15:55	-0,287 0	20:45	0,090 7
1:30	0,000 0	6:20	0,000 0	11:10	-0,120 0	16:00	-0,122 6	20:50	0,099 8
1:35	0,000 0	6:25	0,000 0	11:15	-0,100 9	16:05	-0,083 3	20:55	0,090 7
1:40	0,000 0	6:30	0,000 0	11:20	-0,204 3	16:10	-0,021 3	21:00	0,000 0
1:45	0,000 0	6:35	0,000 0	11:25	-0,197 1	16:15	0,061 6	21:05	0,004 2
1:50	0,000 0	6:40	0,000 0	11:30	-0,213 3	16:20	0,033 3	21:10	0,000 0
1:55	0,000 0	6:45	0,000 0	11:35	-0,217 1	16:25	0,042 7	21:15	0,000 0

Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)
2:00	0,000 0	6:50	0,000 0	11:40	-0,314 8	16:30	0,055 1	21:20	0,000 0
2:05	0,000 0	6:55	0,000 0	11:45	-0,312 0	16:35	0,060 2	21:25	0,000 0
2:10	0,000 0	7:00	0,000 0	11:50	-0,317 9	16:40	0,055 8	21:30	0,000 0
2:15	0,000 0	7:05	0,000 0	11:55	-0,286 7	16:45	-0,094 9	21:35	0,000 0
2:20	0,000 0	7:10	0,000 0	12:00	-0,163 3	16:50	-0,042 0	21:40	0,000 0
2:25	0,000 0	7:15	0,000 0	12:05	-0,121 0	16:55	-0,039 0	21:45	0,000 0
2:30	0,055 7	7:20	0,000 0	12:10	-0,061 7	17:00	-0,095 4	21:50	0,000 0
2:35	0,047 6	7:25	0,000 0	12:15	0,012 6	17:05	-0,017 9	21:55	0,057 0
2:40	0,044 5	7:30	0,000 0	12:20	-0,035 3	17:10	-0,153 3	22:00	-0,129 4
2:45	0,040 2	7:35	0,000 0	12:25	-0,040 4	17:15	-0,065 7	22:05	-0,095 3
2:50	-0,115 2	7:40	0,000 0	12:30	-0,020 1	17:20	-0,097 4	22:10	-0,035 9
2:55	-0,099 5	7:45	0,000 0	12:35	-0,003 6	17:25	-0,088 9	22:15	0,043 5
3:00	0,000 0	7:50	0,000 0	12:40	-0,003 0	17:30	-0,075 6	22:20	0,014 1
3:05	0,000 0	7:55	0,000 0	12:45	-0,143 6	17:35	-0,069 1	22:25	0,021 8
3:10	0,000 0	8:00	0,047 6	12:50	-0,098 6	17:40	-0,066 5	22:30	0,034 1
3:15	0,000 0	8:05	0,050 4	12:55	-0,097 6	17:45	-0,123 2	22:35	0,040 0
3:20	0,000 0	8:10	0,064 2	13:00	-0,131 7	17:50	-0,121 5	22:40	0,042 9
3:25	0,000 0	8:15	0,082 9	13:05	-0,124 4	17:55	-0,119 5	22:45	-0,099 2
3:30	0,000 0	8:20	0,072 5	13:10	-0,068 2	18:00	0,225 0	22:50	-0,060 4
3:35	0,000 0	8:25	0,071 6	13:15	-0,079 9	18:05	0,262 9	22:55	-0,059 3
3:40	0,000 0	8:30	0,075 0	13:20	-0,044 3	18:10	0,257 1	23:00	-0,158 4
3:45	0,000 0	8:35	0,076 5	13:25	-0,042 9	18:15	0,265 8	23:05	-0,154 9
3:50	0,000 0	8:40	0,075 7	13:30	-0,116 3	18:20	0,256 6	23:10	-0,244 9
3:55	0,000 0	8:45	0,050 7	13:35	-0,115 1	18:25	0,263 1	23:15	-0,244 9
4:00	0,000 0	8:50	0,057 8	13:40	-0,113 0	18:30	0,269 2	23:20	-0,229 5
4:05	0,000 0	8:55	0,053 2	13:45	-0,163 6	18:35	0,270 6	23:25	-0,230 6
4:10	0,000 0	9:00	0,034 4	13:50	0,028 2	18:40	0,279 7	23:30	-0,305 8
4:15	0,000 0	9:05	0,058 2	13:55	-0,049 7	18:45	0,187 5	23:35	-0,385 7
4:20	0,000 0	9:10	0,060 6	14:00	-0,274 1	18:50	0,108 5	23:40	-0,419 2
4:25	0,000 0	9:15	0,239 4	14:05	0,051 2	18:55	0,108 4	23:45	-0,298 2
4:30	0,000 0	9:20	0,500 0	14:10	0,142 7	19:00	0,266 2	23:50	-0,177 2
4:35	0,000 0	9:25	0,500 0	14:15	0,129 8	19:05	0,273 6	23:55	-0,118 7
4:40	0,000 0	9:30	0,500 0	14:20	0,152 4	19:10	0,279 8		
4:45	0,000 0	9:35	0,500 0	14:25	0,122 2	19:15	0,282 2		

A.3 Project of commercial PV-EES-EV charging station based on common AC bus

Table A.2 – Charging-discharging power of EES system for the case of a commercial charging station based on common AC bus (per-unit value)

Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)
0:00	-0,200 0	4:48	-0,196 8	9:36	0,045 5	14:24	-0,153 6	19:12	0,393 0
0:01	-0,201 3	4:49	-0,196 9	9:37	-0,548 0	14:25	-0,204 8	19:13	0,379 8
0:02	-0,198 4	4:50	-0,202 3	9:38	0,054 5	14:26	-0,206 8	19:14	0,380 0
0:03	-0,201 7	4:51	-0,202 2	9:39	0,051 5	14:27	-0,350 9	19:15	0,216 1
0:04	-0,124 6	4:52	-0,202 3	9:40	0,0780	14:28	-0,323 0	19:16	0,212 3
0:05	-0,002 9	4:53	-0,202 5	9:41	0,078 0	14:29	-0,197 3	19:17	0,207 1
0:06	0,079 0	4:54	-0,202 7	9:42	0,060 0	14:30	-0,202 7	19:18	0,208 6
0:07	0,134 6	4:55	-0,203 0	9:43	0,048 9	14:31	-0,200 6	19:19	0,207 3
0:08	-0,525 3	4:56	-0,203 2	9:44	0,048 5	14:32	-0,226 5	19:20	0,211 3
0:09	-0,488 4	4:57	-0,203 3	9:45	0,052 2	14:33	-0,261 2	19:21	0,205 9
0:10	-0,462 7	4:58	-0,203 4	9:46	0,041 2	14:34	-0,286 7	19:22	0,205 9
0:11	-0,435 4	4:59	-0,197 5	9:47	0,070 8	14:35	-0,274 8	19:23	0,207 3
0:12	-0,413 0	5:00	-0,197 5	9:48	0,081 6	14:36	-0,242 1	19:24	0,207 3
0:13	-0,404 0	5:01	-0,202 8	9:49	0,041 9	14:37	-0,209 4	19:25	0,195 3
0:14	-0,418 0	5:02	-0,202 9	9:50	0,032 1	14:38	-0,068 3	19:26	0,195 3
0:15	-0,402 0	5:03	-0,197 6	9:51	0,043 5	14:39	-0,065 2	19:27	0,208 6
0:16	-0,391 4	5:04	-0,197 7	9:52	-0,512 8	14:40	-0,049 8	19:28	0,211 3
0:17	-0,382 0	5:05	-0,197 7	9:53	-0,506 5	14:41	-0,040 2	19:29	0,207 3
0:18	-0,373 9	5:06	-0,197 8	9:54	-0,496 1	14:42	-0,030 4	19:30	0,209 9
0:19	-0,365 3	5:07	-0,203 2	9:55	-0,505 6	14:43	-0,027 1	19:31	0,209 9
0:20	-0,358 8	5:08	-0,203 4	9:56	-0,513 9	14:44	-0,022 3	19:32	-0,102 1
0:21	-0,322 3	5:09	-0,203 4	9:57	-0,525 9	14:45	-0,014 8	19:33	-0,264 7
0:22	-0,316 9	5:10	-0,203 5	9:58	0,223 1	14:46	-0,008 3	19:34	0,283 3
0:23	-0,312 0	5:11	-0,203 5	9:59	0,223 1	14:47	-0,003 1	19:35	0,288 6
0:24	-0,307 2	5:12	-0,203 6	10:00	0,400 9	14:48	0,006 0	19:36	0,289 9
0:25	-0,302 9	5:13	-0,203 7	10:01	0,214 3	14:49	0,008 8	19:37	0,285 9
0:26	-0,297 3	5:14	-0,203 9	10:02	0,208 2	14:50	0,016 3	19:38	0,285 9
0:27	-0,297 5	5:15	-0,204 0	10:03	0,207 4	14:51	0,033 7	19:39	0,282 1
0:28	-0,291 7	5:16	-0,204 4	10:04	0,239 0	14:52	0,021 5	19:40	0,283 6
0:29	-0,286 3	5:17	-0,204 7	10:05	0,217 4	14:53	0,025 5	19:41	-0,275 0
0:30	-0,268 1	5:18	-0,198 4	10:06	0,212 9	14:54	0,025 9	19:42	-0,275 0
0:31	-0,255 2	5:19	-0,198 7	10:07	0,195 8	14:55	0,025 2	19:43	0,452 9
0:32	-0,248 9	5:20	-0,205 8	10:08	0,171 3	14:56	0,024 4	19:44	0,454 3
0:33	-0,235 9	5:21	-0,202 2	10:09	0,168 1	14:57	0,032 8	19:45	0,462 3
0:34	-0,217 6	5:22	-0,197 3	10:10	0,187 2	14:58	0,029 4	19:46	0,464 9
0:35	-0,204 5	5:23	-0,193 8	10:11	0,218 7	14:59	0,012 0	19:47	0,462 3
0:36	-0,187 3	5:24	-0,194 2	10:12	0,426 2	15:00	0,011 1	19:48	0,463 6
0:37	-0,174 1	5:25	-0,194 3	10:13	0,205 9	15:01	0,015 4	19:49	0,463 6

Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)	Time	Power (p.u.)
0:38	-0,172 8	5:26	-0,202 4	10:14	0,049 6	15:02	0,017 7	19:50	0,463 6
0:39	-0,171 5	5:27	-0,202 6	10:15	0,194 9	15:03	0,022 8	19:51	0,463 6
0:40	-0,170 4	5:28	-0,203 1	10:16	0,013 2	15:04	0,028 7	19:52	0,468 2
0:41	-0,169 2	5:29	-0,203 4	10:17	0,024 0	15:05	0,061 2	19:53	0,466 9
0:42	-0,167 8	5:30	-0,203 8	10:18	0,085 7	15:06	0,076 9	19:54	0,449 5
0:43	-0,166 5	5:31	-0,200 9	10:19	0,226 7	15:07	0,074 1	19:55	0,449 5
0:44	-0,165 6	5:32	-0,198 0	10:20	0,215 5	15:08	0,082 9	19:56	0,500 2
0:45	-0,164 9	5:33	-0,195 0	10:21	0,044 6	15:09	0,105 1	19:57	0,496 2
0:46	-0,164 1	5:34	-0,191 9	10:22	0,028 3	15:10	0,104 8	19:58	0,514 9
0:47	-0,169 9	5:35	-0,188 9	10:23	0,008 1	15:11	0,110 7	19:59	0,516 2
0:48	-0,169 2	5:36	-0,185 8	10:24	-0,006 6	15:12	0,114 3	20:00	0,505 5
0:49	-0,168 5	5:37	-0,177 5	10:25	-0,026 8	15:13	0,123 3	20:01	0,501 5
0:50	-0,162 4	5:38	-0,179 9	10:26	-0,069 9	15:14	0,136 6	20:02	0,458 1
0:51	-0,169 1	5:39	-0,176 6	10:27	-0,056 5	15:15	0,146 0	20:03	0,455 8
0:52	-0,242 5	5:40	-0,173 3	10:28	0,001 6	15:16	0,165 0	20:04	0,450 5
0:53	-0,241 3	5:41	-0,1700	10:29	-0,018 4	15:17	0,174 3	20:05	0,454 5
0:54	-0,234 7	5:42	-0,162 7	10:30	-0,244 4	15:18	0,175 1	20:06	0,454 4
0:55	-0,233 4	5:43	-0,159 4	10:31	-0,339 7	15:19	0,188 7	20:07	0,454 4
0:56	-0,228 1	5:44	-0,156 1	10:32	-0,339 5	15:20	0,179 8	20:08	0,457 1
0:57	-0,226 8	5:45	-0,138 3	10:33	-0,521 1	15:21	0,190 0	20:09	0,457 1
0:58	-0,225 6	5:46	-0,133 6	10:34	-0,285 1	15:22	0,203 9	20:10	0,455 8
0:59	-0,224 4	5:47	-0,130 3	10:35	0,285 5	15:23	0,209 7	20:11	0,458 8
1:00	-0,223 1	5:48	-0,126 9	10:36	0,287 0	15:24	0,211 5	20:12	0,447 2
1:01	-0,221 7	5:49	-0,123 6	10:37	0,265 8	15:25	0,221 3	20:13	0,447 2
1:02	-0,220 4	5:50	-0,120 5	10:38	0,062 0	15:26	0,240 4	20:14	0,445 9
1:03	-0,219 1	5:51	-0,117 2	10:39	0,128 7	15:27	0,254 3	20:15	0,452 5
1:04	-0,217 9	5:52	-0,113 9	10:40	0,026 0	15:28	0,268 1	20:16	0,448 5
1:05	-0,218 0	5:53	-0,110 7	10:41	0,010 0	15:29	-0,006 4	20:17	0,452 5
1:06	-0,216 7	5:54	-0,126 2	10:42	-0,010 0	15:30	0,002 9	20:18	0,463 2
1:07	-0,224 7	5:55	-0,123 0	10:43	-0,015 3	15:31	0,016 4	20:19	0,467 2
1:08	-0,223 4	5:56	-0,113 2	10:44	-0,022 1	15:32	-0,259 6	20:20	0,111 2
1:09	-0,215 4	5:57	-0,098 2	10:45	0,136 5	15:33	-0,250 3	20:21	-0,262 1
1:10	-0,214 0	5:58	-0,095 1	10:46	0,074 5	15:34	-0,236 8	20:22	0,293 9
1:11	-0,220 7	5:59	-0,092 0	10:47	0,277 7	15:35	-0,226 9	20:23	0,300 5
1:12	-0,218 0	6:00	-0,084 9	10:48	0,256 9	15:36	-0,210 2	20:24	0,290 8
1:13	-0,216 7	6:01	-0,081 8	10:49	0,279 6	15:37	-0,204 7	20:25	0,293 0
1:14	-0,210 1	6:02	-0,078 7	10:50	0,288 1	15:38	-0,181 8	20:26	0,293 9
1:15	-0,208 8	6:03	-0,079 7	10:51	0,290 2	15:39	-0,172 1	20:27	0,292 1
1:16	-0,207 5	6:04	-0,076 7	10:52	0,294 8	15:40	-0,162 6	20:28	0,290 2
1:17	-0,202 3	6:05	-0,073 6	10:53	0,299 0	15:41	-0,153 3	20:29	0,327 0
1:18	-0,200 9	6:06	-0,070 5	10:54	0,297 1	15:42	-0,144 1	20:30	0,356 4
1:19	-0,199 7	6:07	-0,066 9	10:55	0,306 5	15:43	-0,160 3	20:31	0,351 2
1:20	-0,198 3	6:08	-0,083 6	10:56	0,306 2	15:44	-0,156 5	20:32	0,355 2