Energy Management and Optimization Control for Building Energy Systems under extremely hot climate conditions-Qatar Case Study

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- TII has 10 Research Centers in Abu Dhabi
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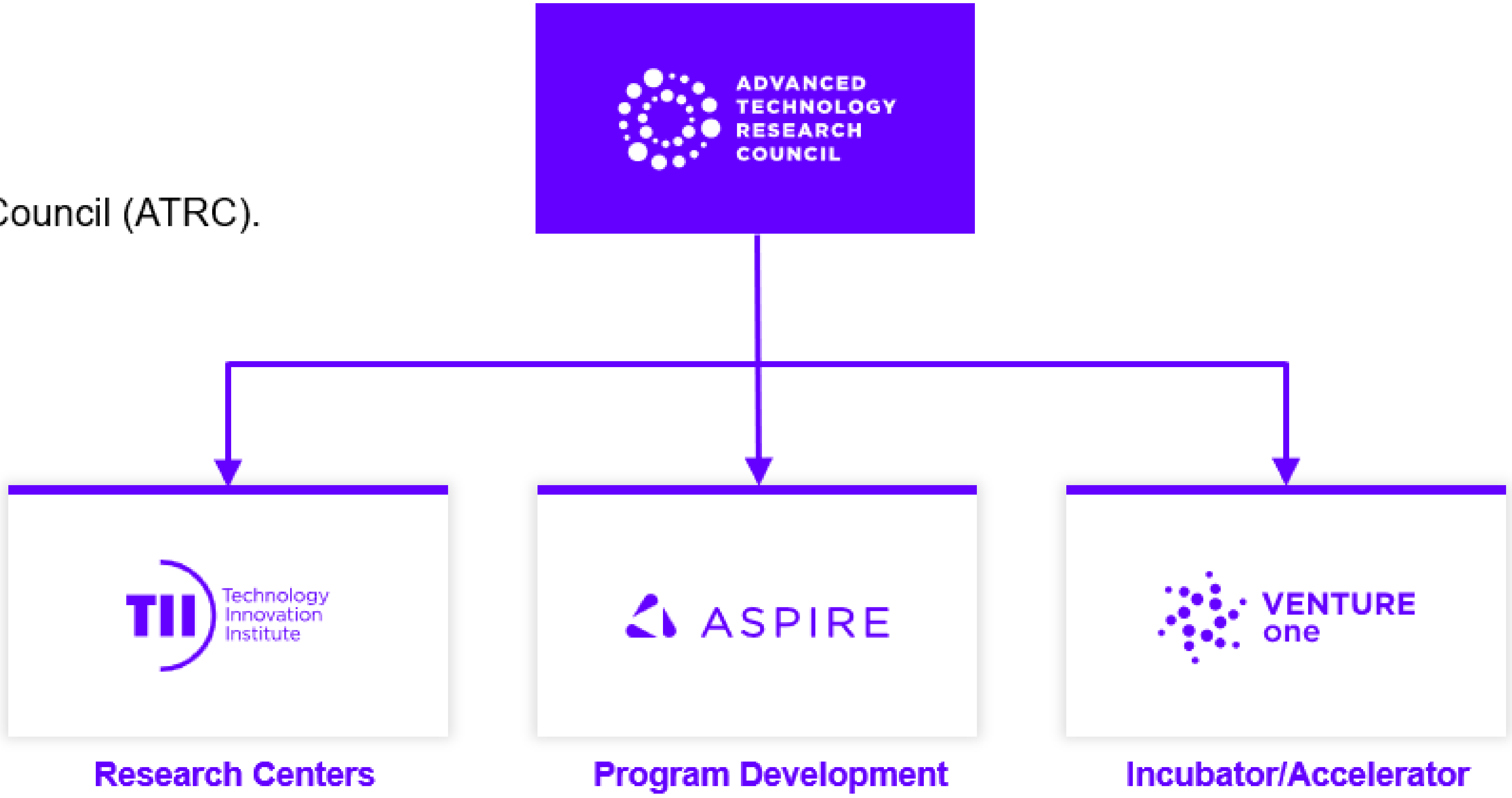
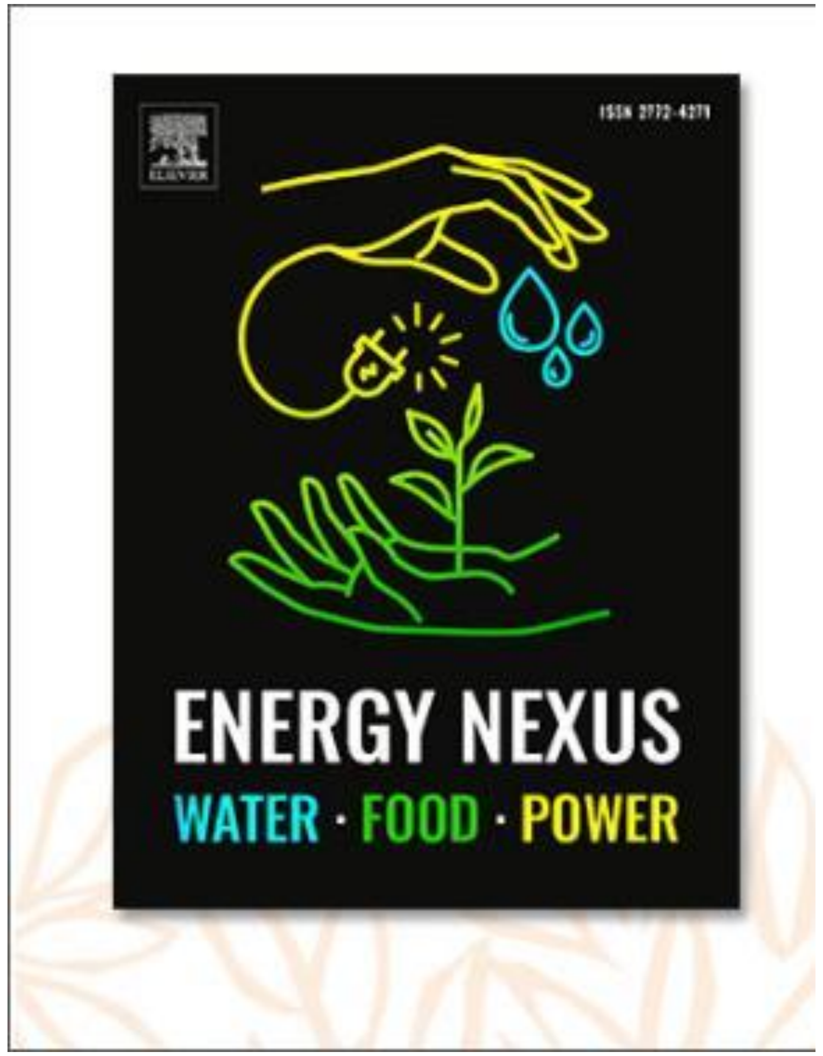
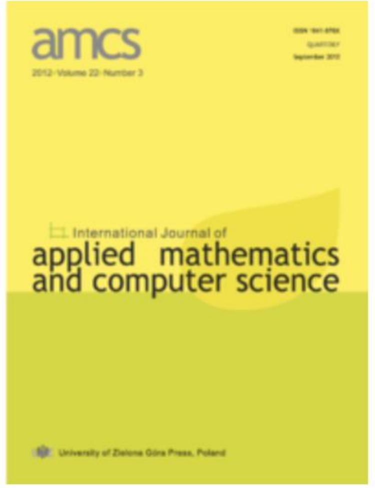


- Advanced Materials
- AI and Digital Science
- Autonomous Robotics
- Biotechnology
- Cryptography
- Directed energy
- Propulsion and Space
  - Electric (battery, fuel cell) long endurance drones
  - Heavy lift electric/hybrid cargo drones
  - SAF based Advanced Air Mobility
- Quantum Computing
- Renewable and Sustainable Energy
- Secure Systems

Qatar Environment & Energy Research Institute (QEERI)

- Vision: To become the reference national research, development and innovation (RDI) institution in the fields of energy, water and the environment in Qatar and in arid regions
- Key stats: 160+ headcount / 120+ permanent staff; > 4000 m² laboratory space





SUBMISSION OPEN

Recent Research Advances on Solar Energy Digitalization and Automation

Zhaohui Cen · Luis Martin Pomares · Awad Bin Saud Alquaity · Yukun Hu

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CALLS FOR SUBMISSIONS

Contents

PV-Battery Storage

- large-scale PV-storage system for building energy system
- Maintenance work for the 500kWh BESS.

Air-Conditioner

- AC cooling optimization control for mitigating power fluctuations
- AC cooling optimization control for absorbing Solar PV power
- AC cooling optimization control for AC performance enhancement

AC cooling as alterative storage

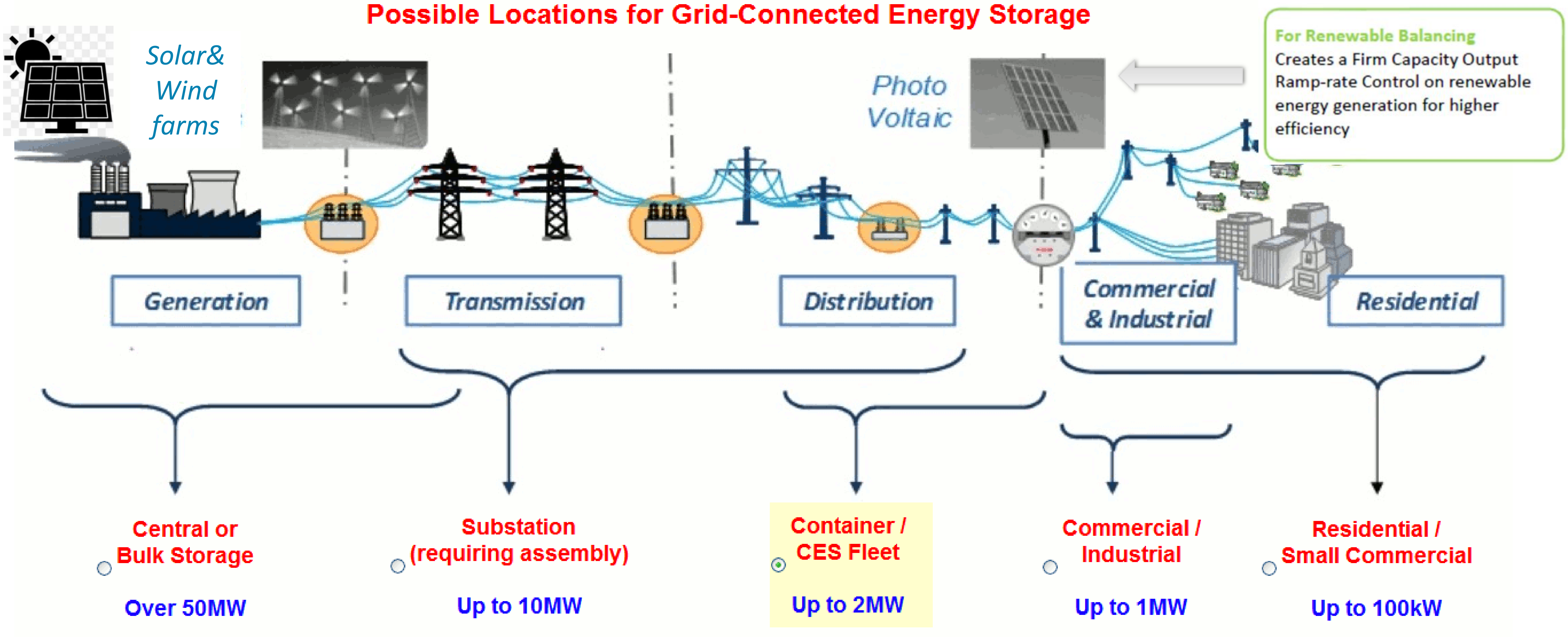
Solar PV

HVAC

Energy Storage

Background of Lithium-ion Battery Energy Storage System

ESS roles for grid



Bulk Energy Services
Electric Energy Time-Shift (Arbitrage)
Electric Supply Capacity
Ancillary Services
Regulation
Spinning, Non-Spinning and Supplemental Reserves
Voltage Support
Black Start
Other Related Uses

Transmission Infrastructure Services
Transmission Upgrade Deferral
Transmission Congestion Relief

Distribution Infrastructure Services
Distribution Upgrade Deferral
Voltage Support

Customer Energy Management Services
Power Quality
Power Reliability
Retail Electric Energy Time-Shift
Demand Charge Management

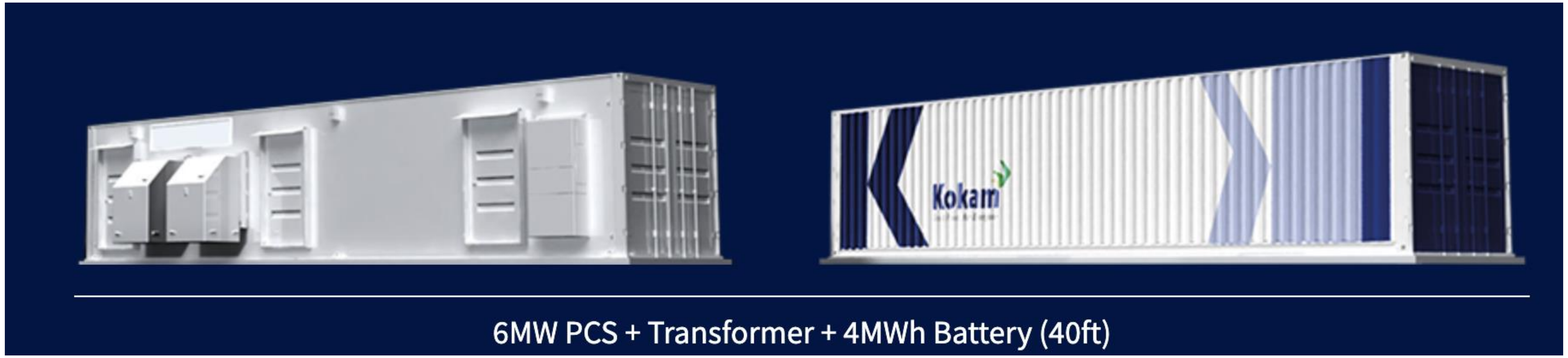
Largest lithium-ion battery energy storage system (In total and single container)

largest ESS project in Total capacity

Name	Type	Capacity			Country	Location	Year
		MWh	MW	hrs			
Oss Landing Energy Storage Facility	Battery, lithium-ion	1,200	300	4	United States	Moss Landing, California	2020
Red Sea Project	**Battery, lithium-ion**	**1300**	**400**	**3**	**Saudi**	**NEOM**	On-going
Mohammed bin Rashid Al Maktoum Solar Park by DEWA	Battery, lithium-ion	8.61	1.21	7	UAE	Abu Dhabi	On-going
11 kV Nuaija station	Battery, lithium-ion	4	1	4	Qatar	Doha	2020

largest BESS in single container

It can store 250kWh-**5.4MWh** of energy in transferable 20ft / 40ft / 53ft ISO containers

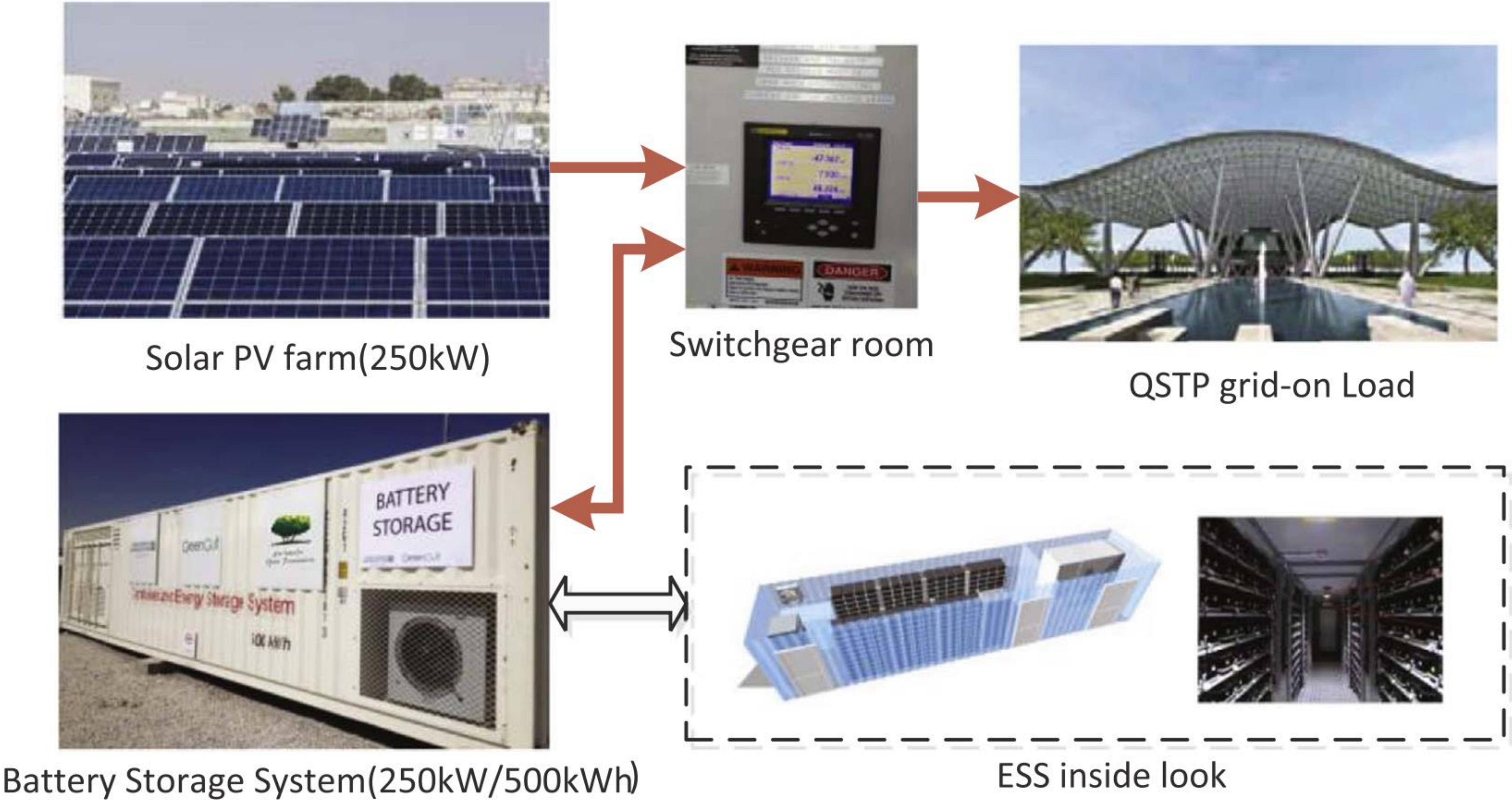


Qatar demonstration study on large-scale PV-storage system

Reference: Cen Z, Kubiak P, López C M, et al. Demonstration study of hybrid solar power generation/storage micro-grid system under Qatar climate conditions[J]. Solar Energy Materials and Solar Cells, 2018, 180: 280-288.

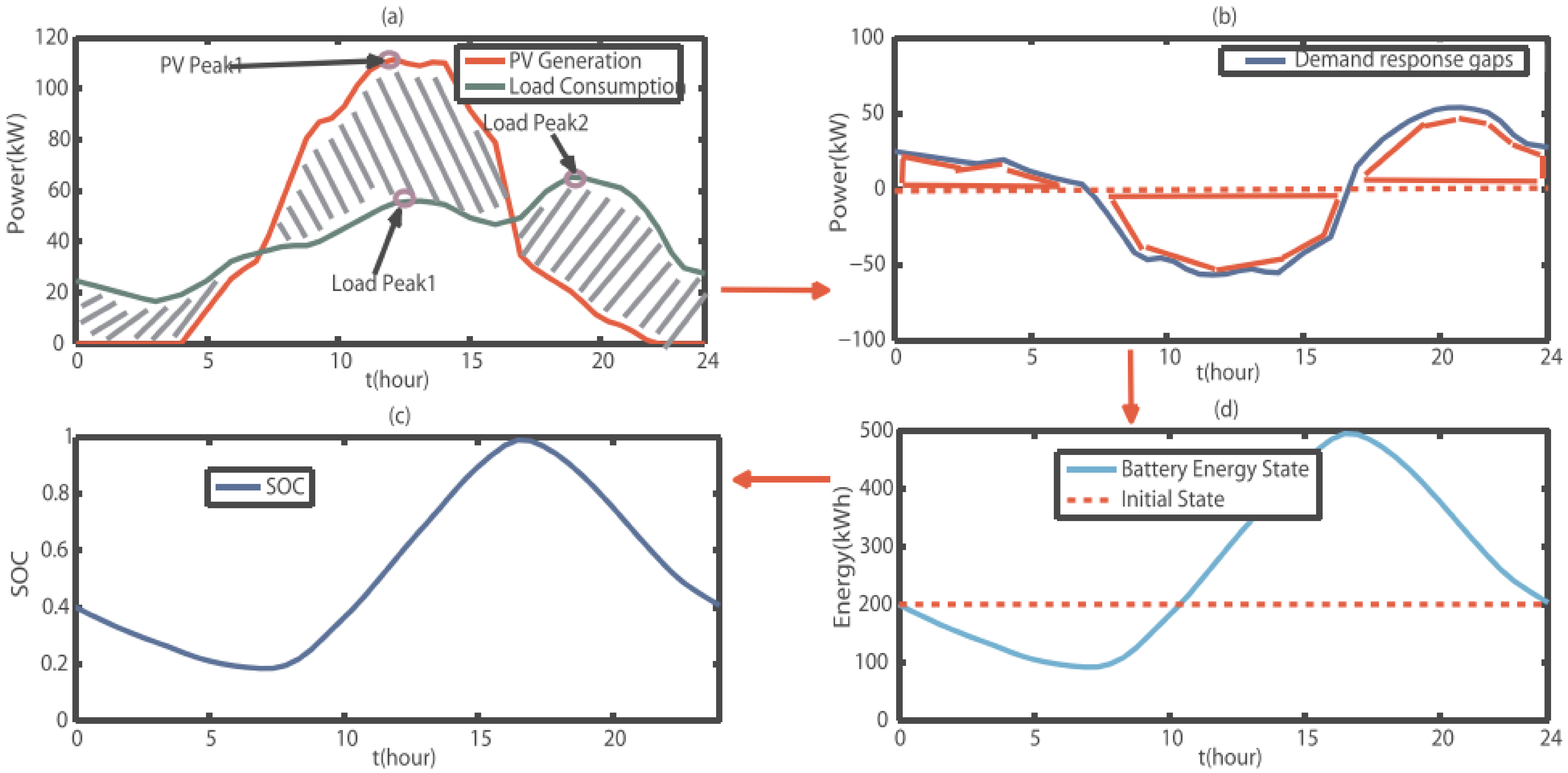
QEERI Outdoor facilities

250 kW/500 kWh Li-ion battery at the OTF



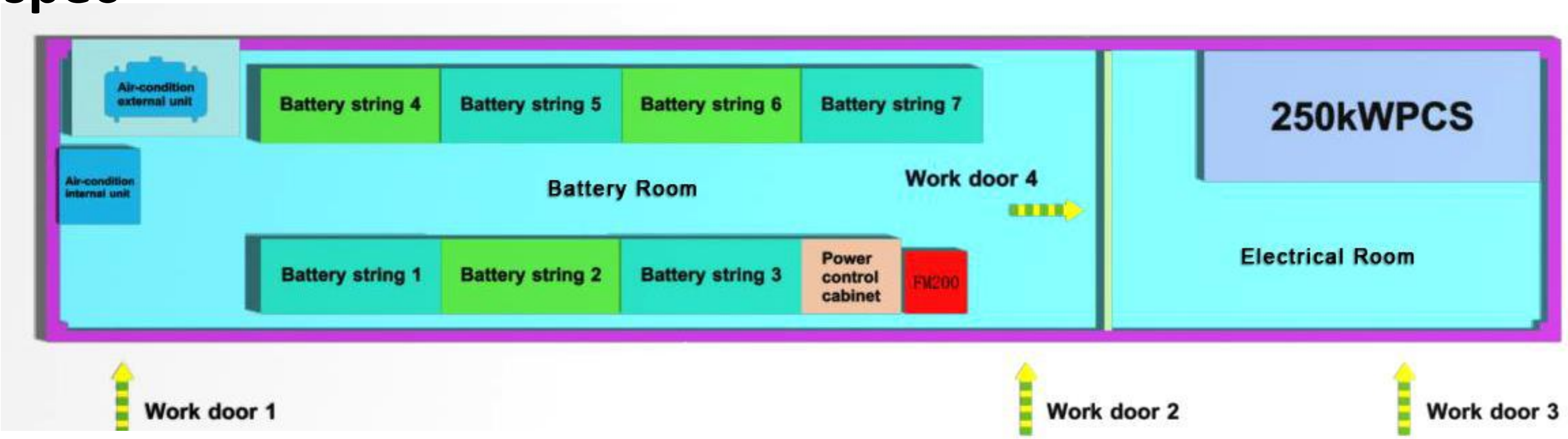
QEERI Outdoor facilities

OTF BESS Time-Shift User Case Simulation



500kWh Lithium-ion BESS

250 kW/500 kWh Li-ion BESS spec



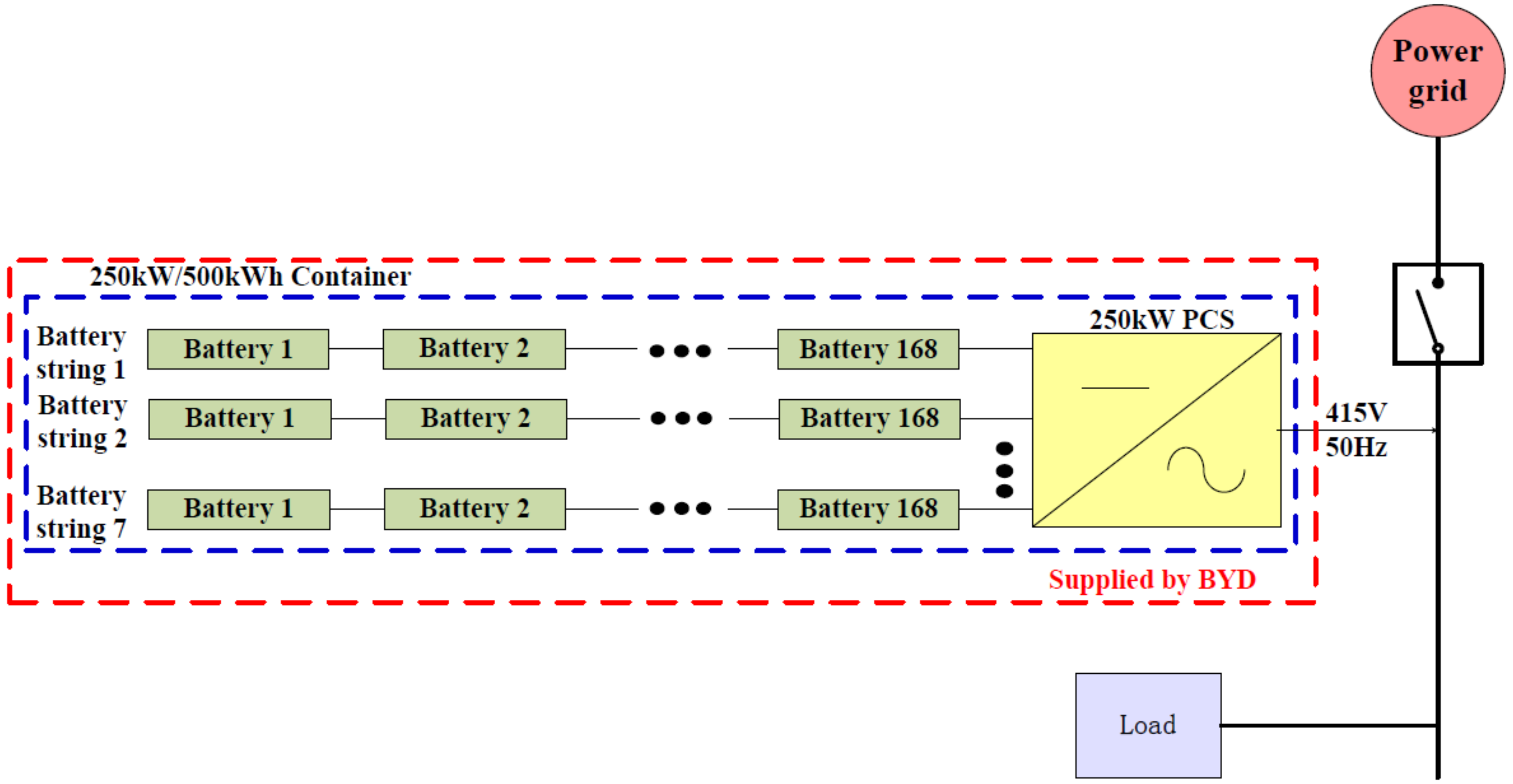


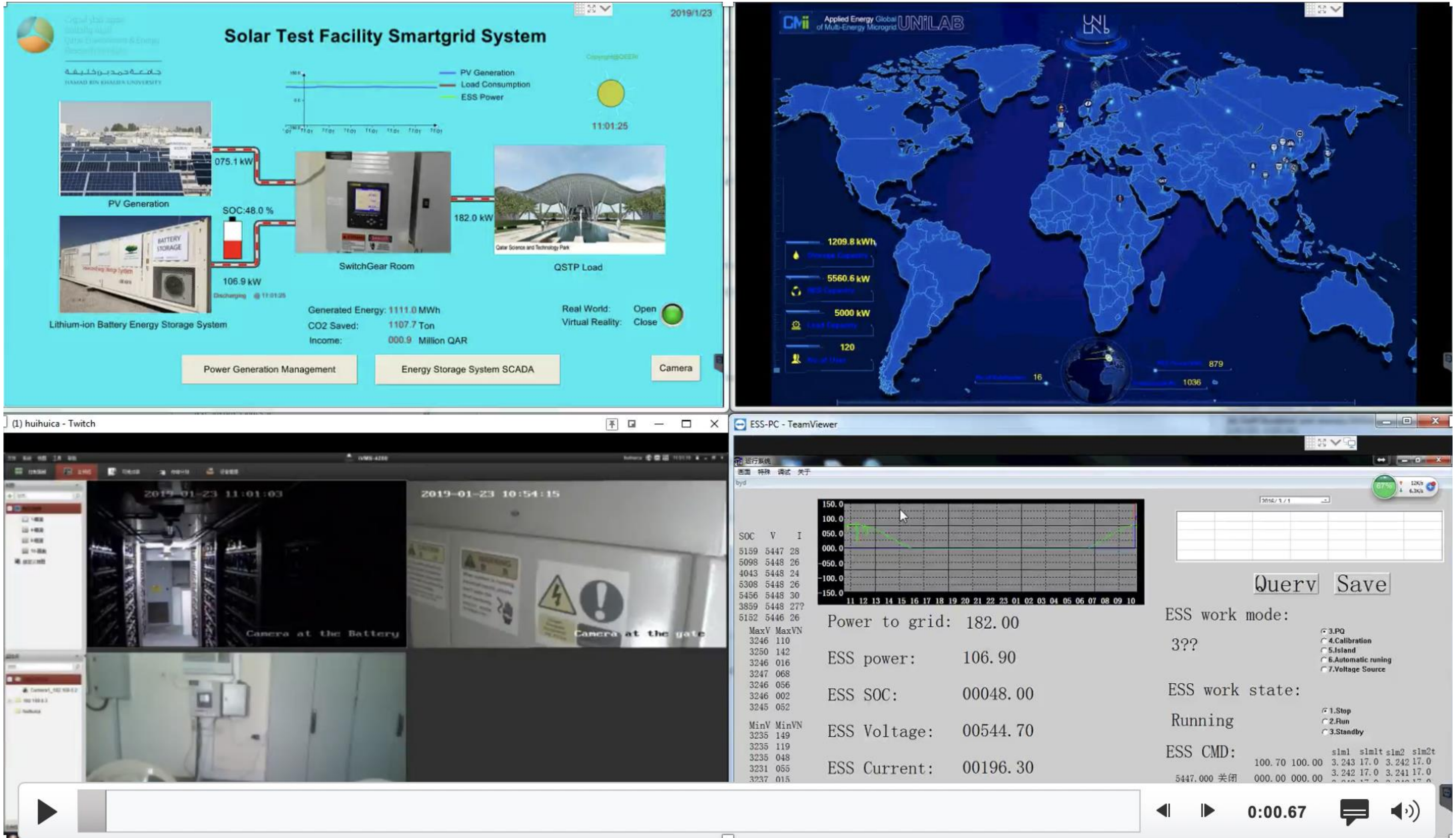
Figure 3.4-1 Topology of 250kW/500kWh ESS

- **Cell chemistry**: $LiFePO_4$ cathode, Graphite anode
- **Cell nominal voltage**: 3.2 V
- **Cell charge cut-off voltage**: 3.8 V
- **Cell discharge cut-off voltage**: 2.0 V
- **Cell nominal capacity**: 195 Ah
- **Cell nominal energy**: 614 Wh

Maximal capacity: 722 kWh

Nominal capacity: 500 kWh

Remote Control Center View for 500kW/500kWh PV-storage System



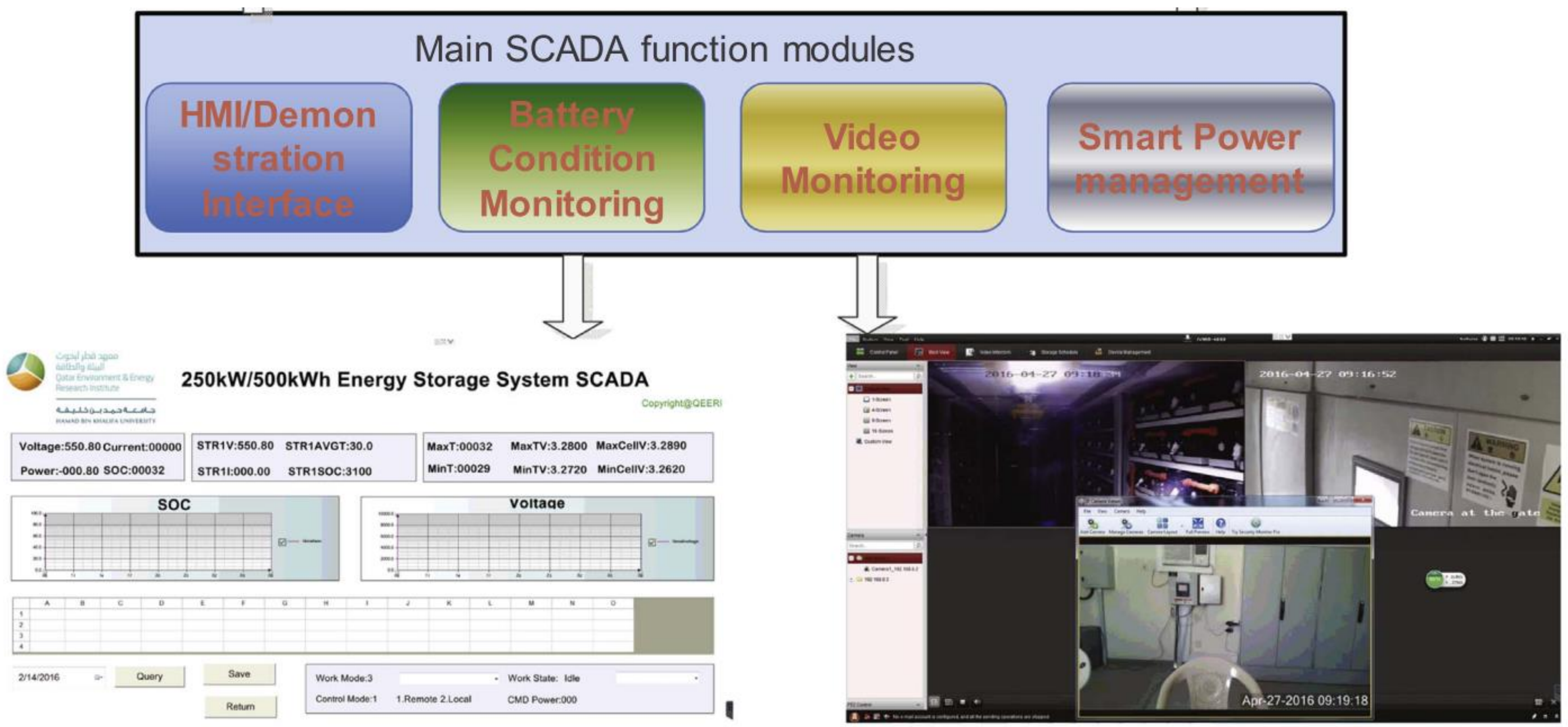
Key technology 1 - Online monitoring for BESS battery and PV parameters

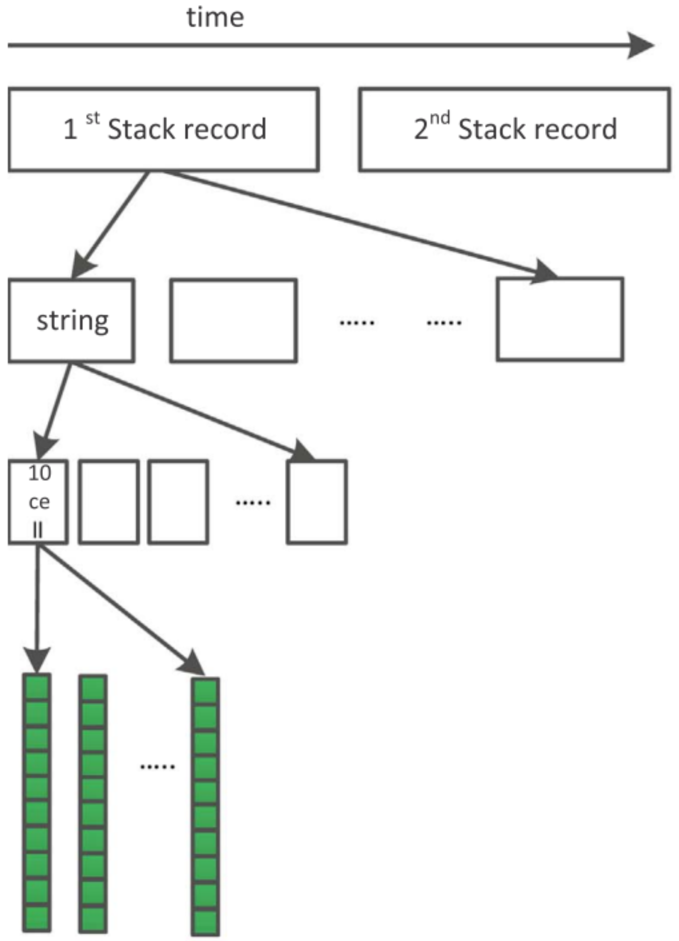
Technical Challenges:

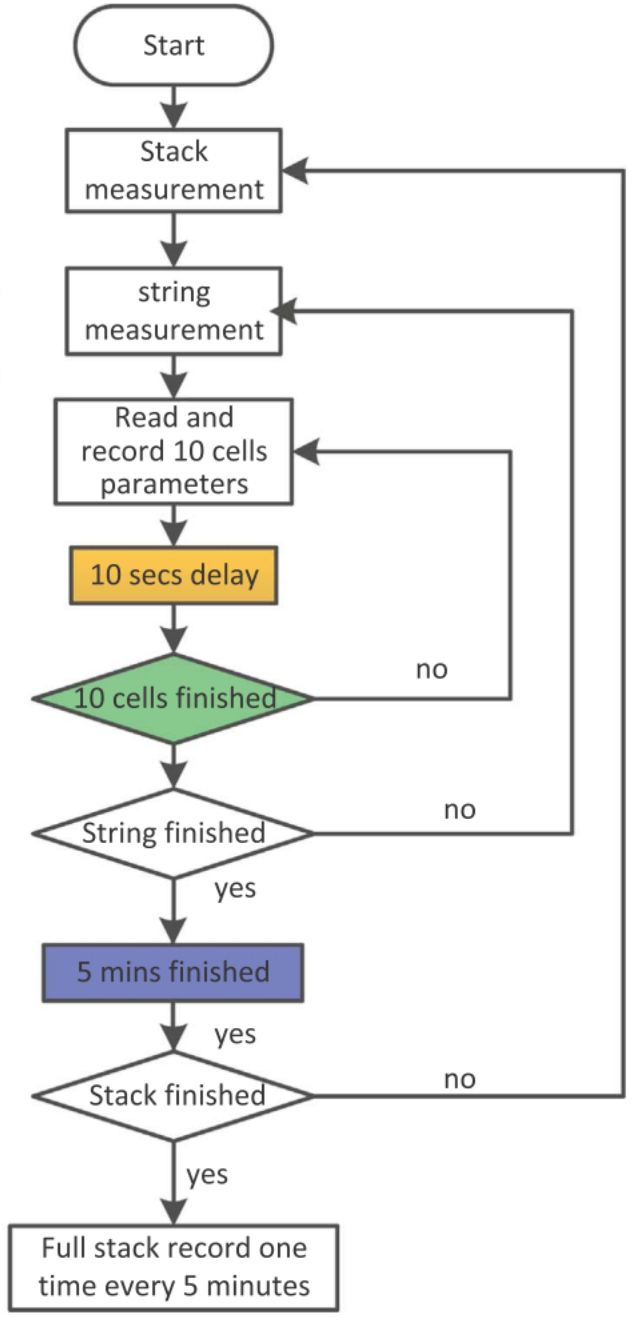
1)1176 cells unit(electrical and thermal parameters) need to be measured;

2)Industrial measurement devices capability limit(step time interval>1s, Max 100 channels);

3)7*24 Continuous data recording and the data can be exported as excel file in different resolution for research.







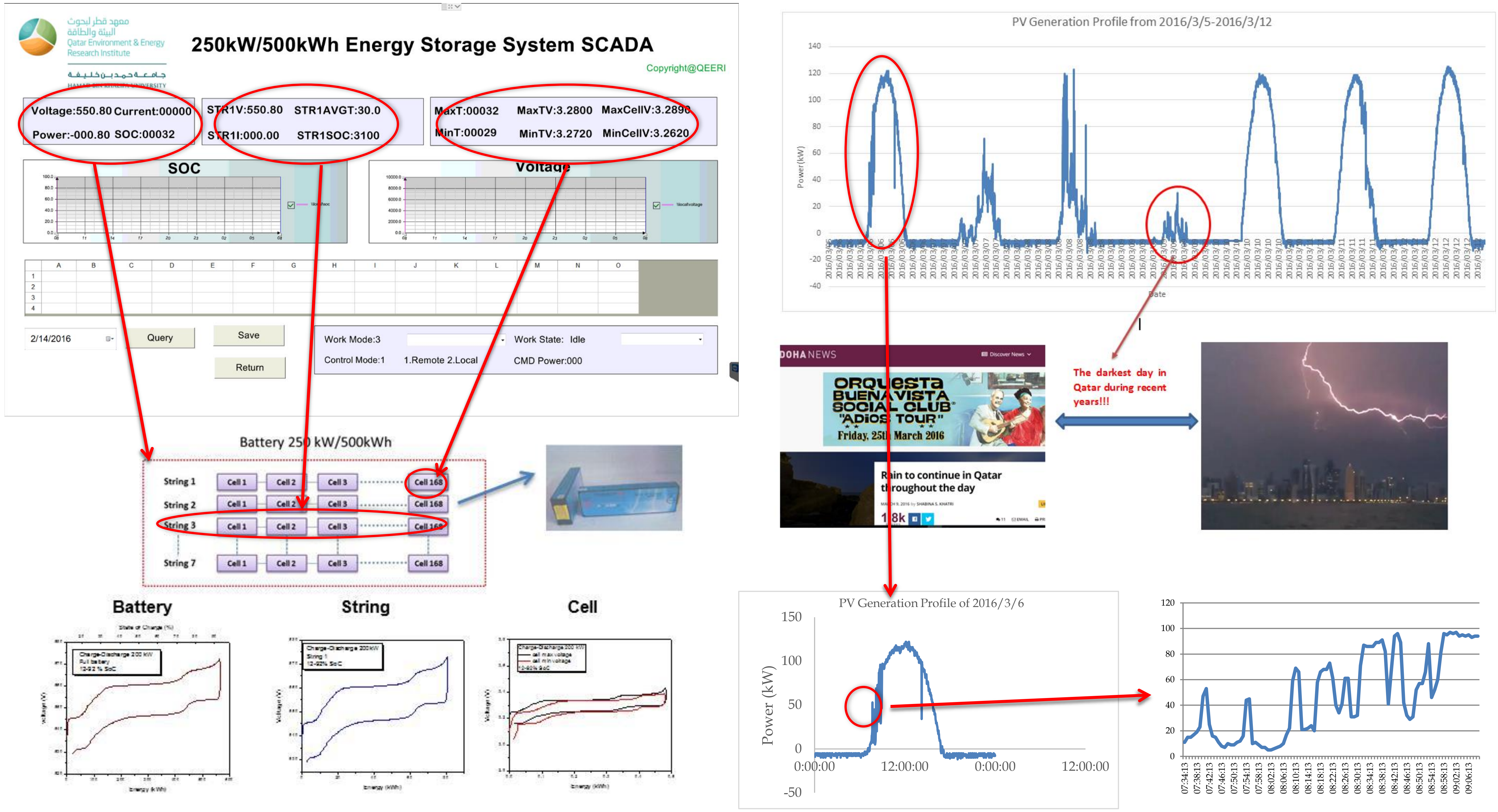
Key technology 1 - Online monitoring for BESS battery and PV parameters

Technology merits:

1) Solution for massive and high-resolution data acquisition in all levels;

2) low-latency for BESS sensing and control;

3) Support historical data storage and export



Time-interval=1s

Key technology 2 - Safety control and remote surveillance system

Risks:

High-current, High-voltage, danger of leaking components, risk of fire and/or explosion.

Solutions:

Safety management policy/procedure + state of the art unmanned surveillance based on both SCADA and video surveillance

Safety control system

- Safety access procedure
- Video surveillance
- SCADA emergency control

Safety Warning

This equipment is a Li-ion Battery container. The battery is under maintenance & test, and it has potential safety risks due to high-current

& high-voltage, danger of leaking components, risk of fire and / or explosion

NO ENTRY IS ALLOWED

Please contact the following staff for approvals:

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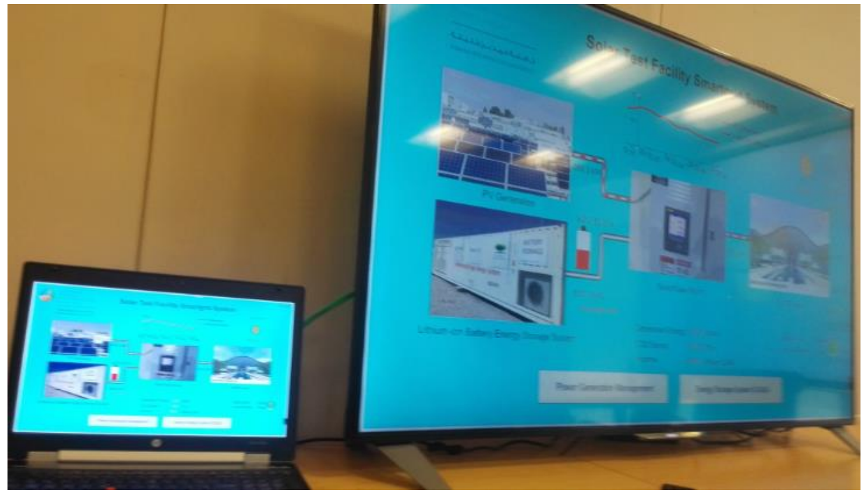
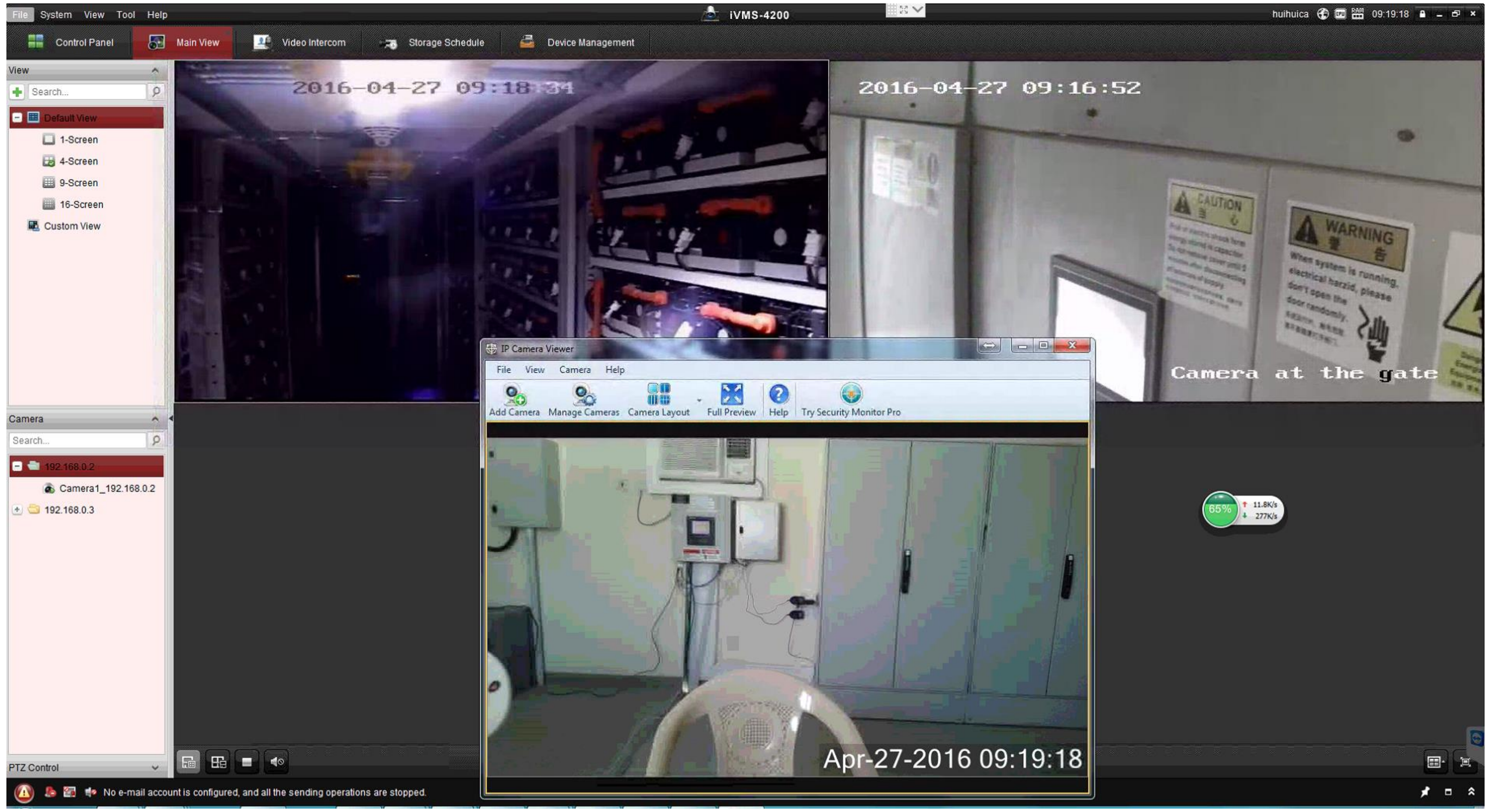
Dr. Zhaohui Cen (Cell. 3373 0488)/ Dr. Ilias Belharouak (Cell. 3388 3219)



SCADA Safety automatic control logic:

If(SOC>95% or SOC< 10% or Cell Max T>35 C or THD>10%)

{ /////==========shutdown ESS=========== ///// }

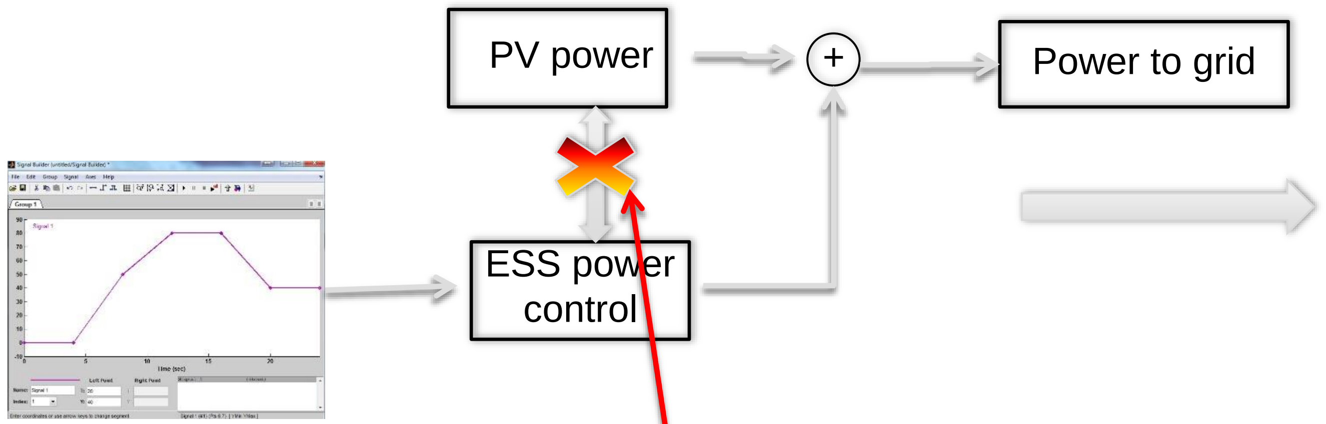


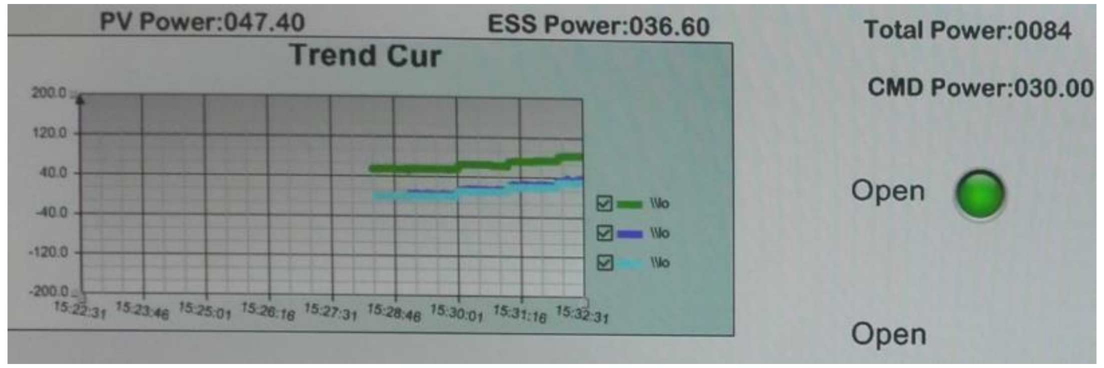
Key technology 3 - Smart power generation/storage management

1**. Open-Loop power control**-programed ESS automatic charging/discharging;

Contributions:

1) Unmanned control and remote monitoring; 2) control step time interval <sec; 3) control power error<1kW

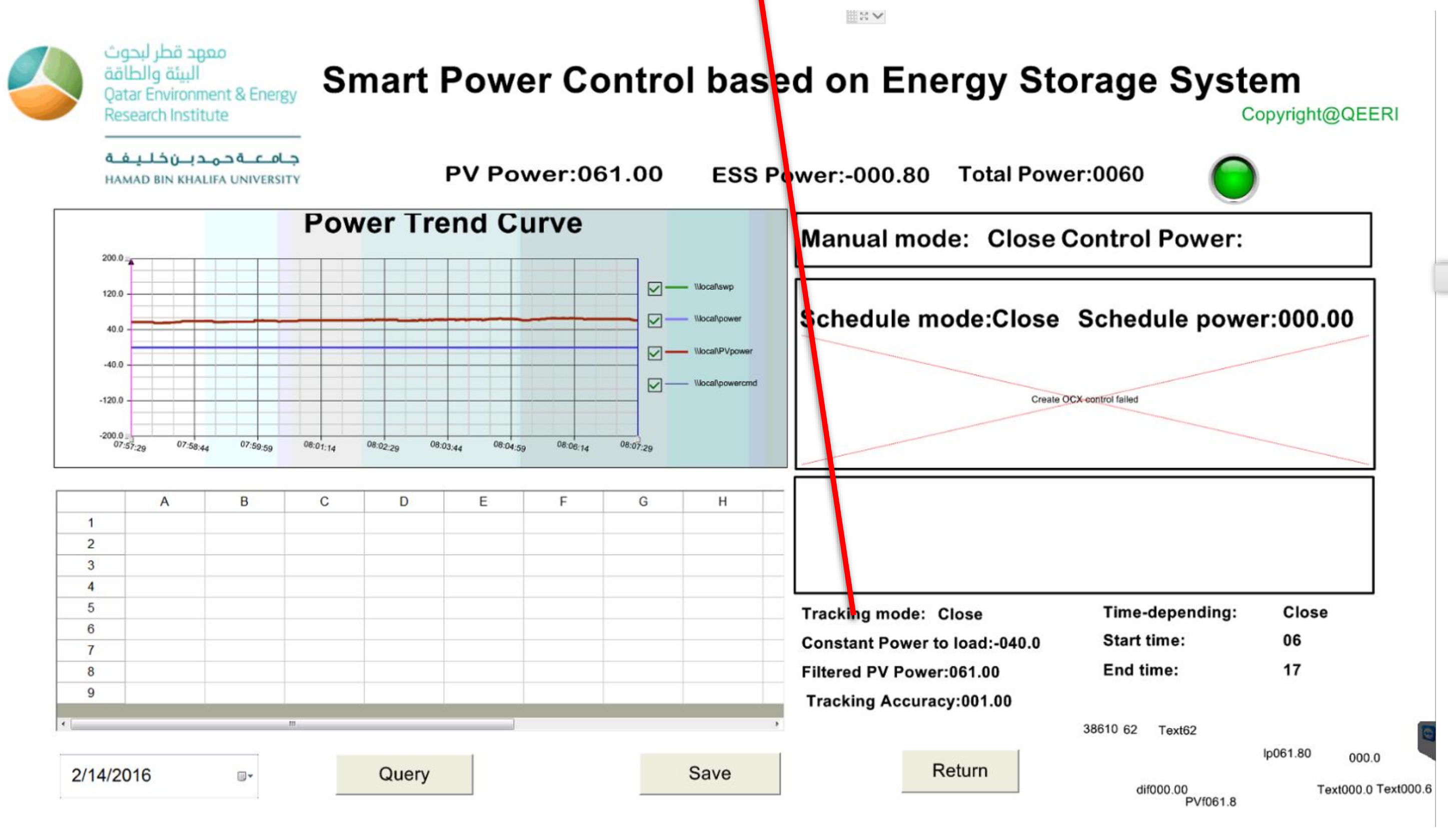


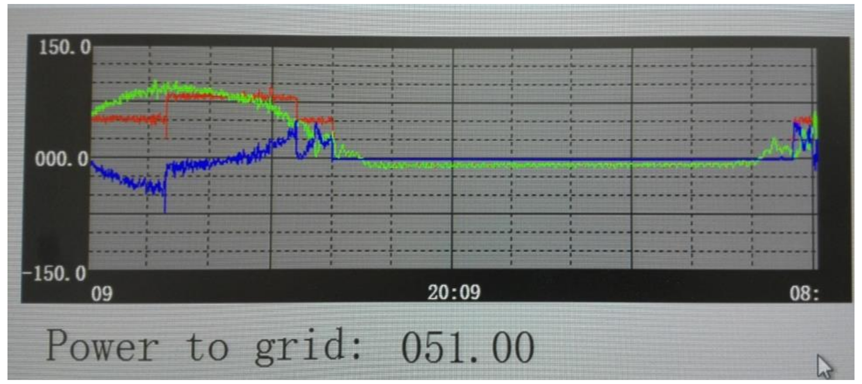


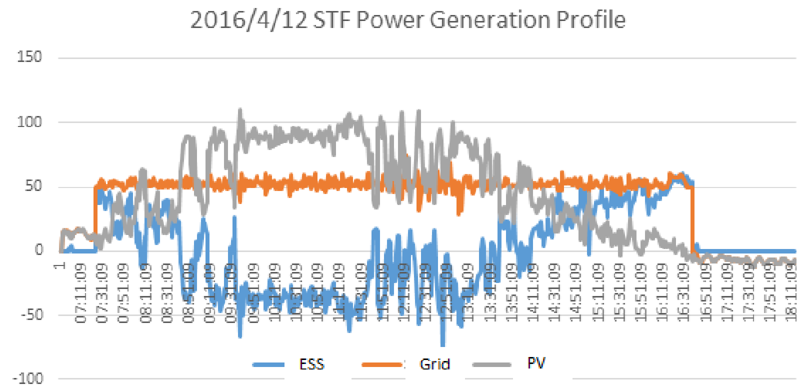
2. **Close-Loop power control**-Constant power feeding to grid against PV generation variations

Challenges:

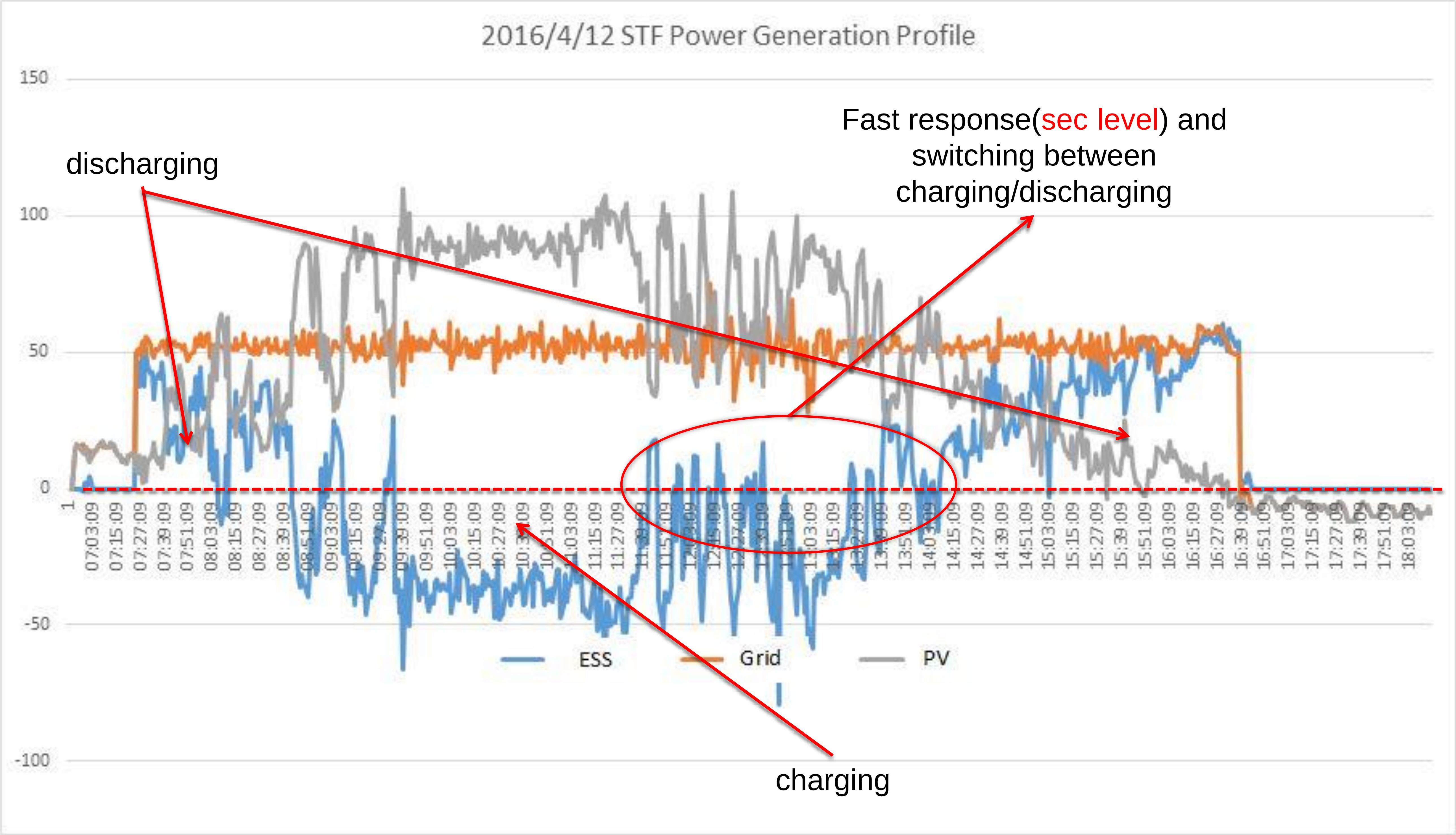
1) measurement error and latency against controller stability and accuracy; 2) effective robust and fault-tolerant control





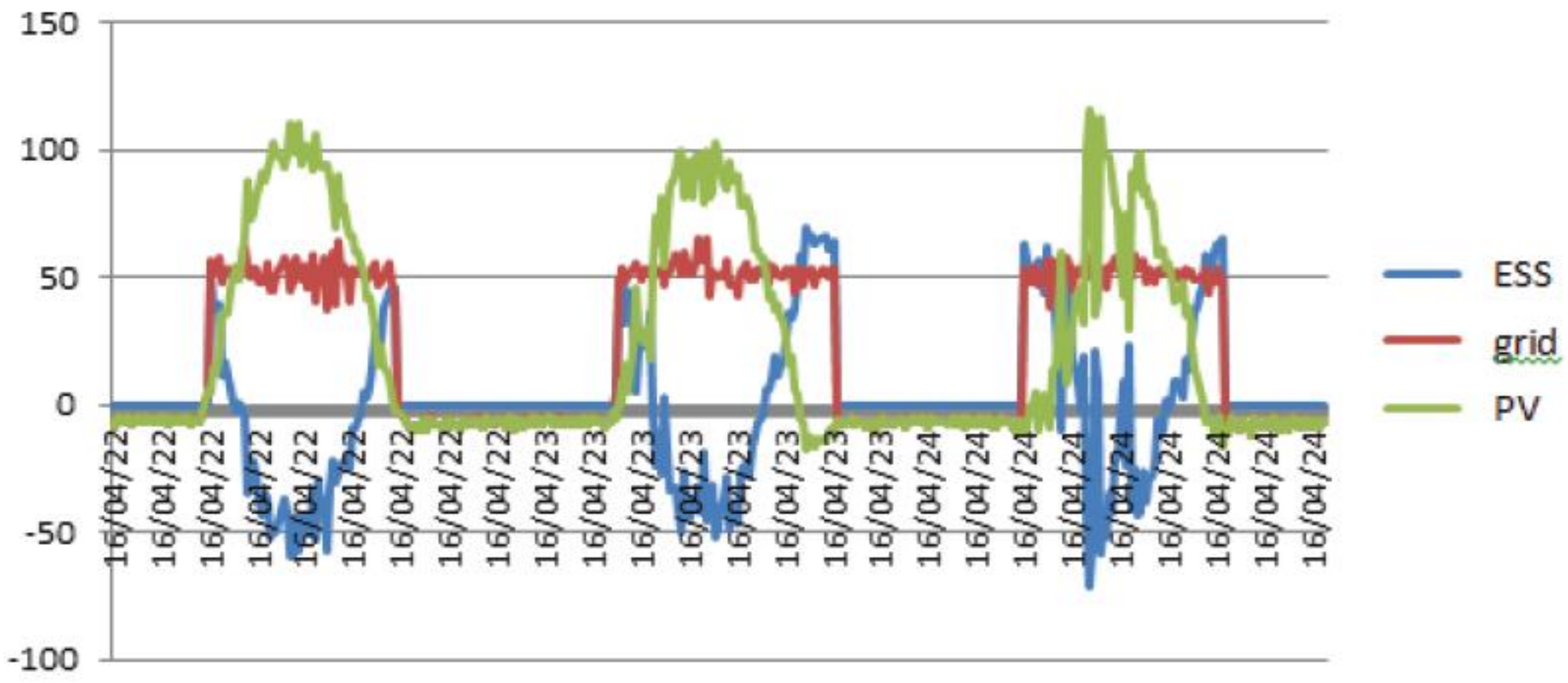


Key technology 3 - Results for BESS fast response use case

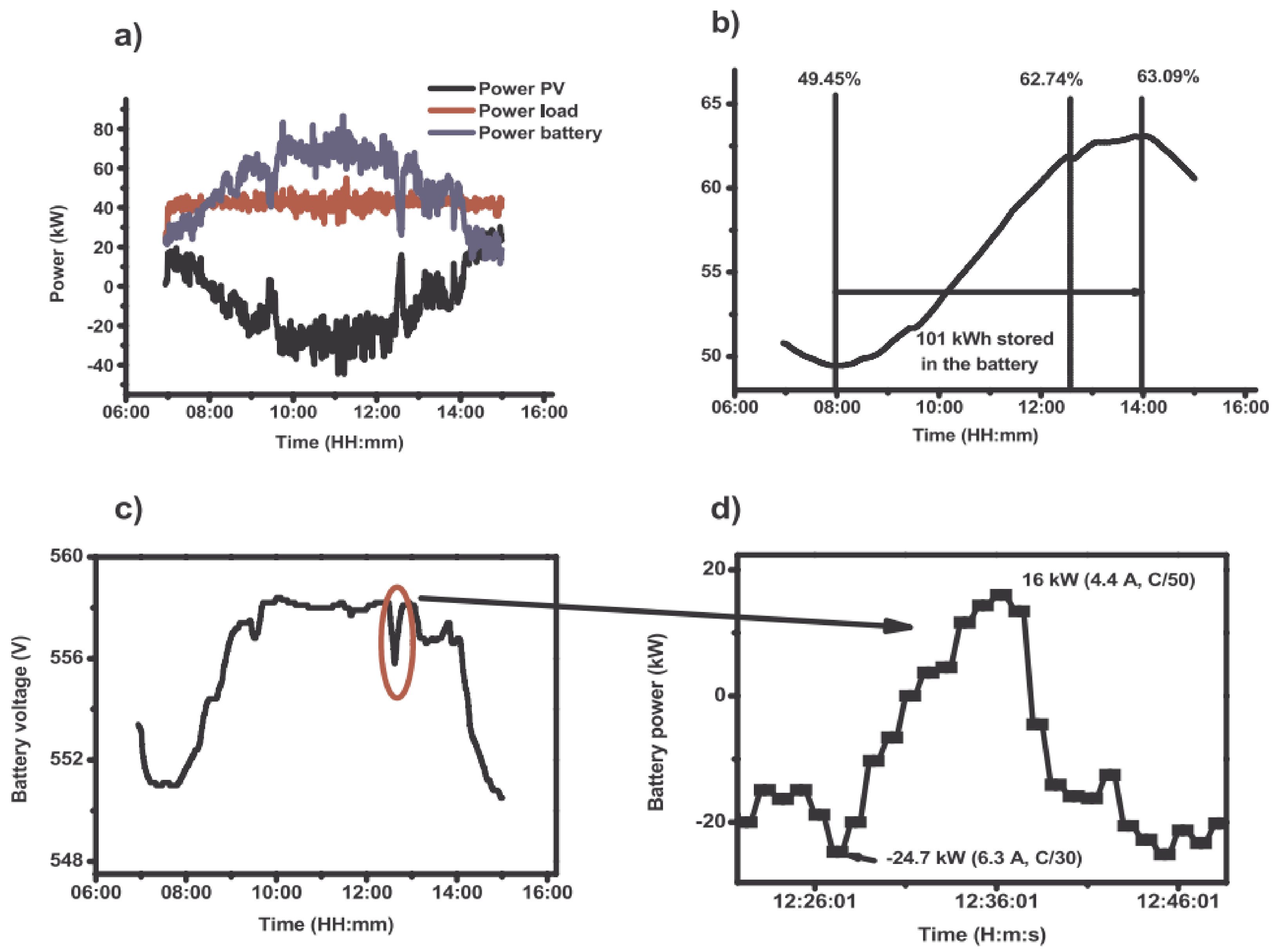


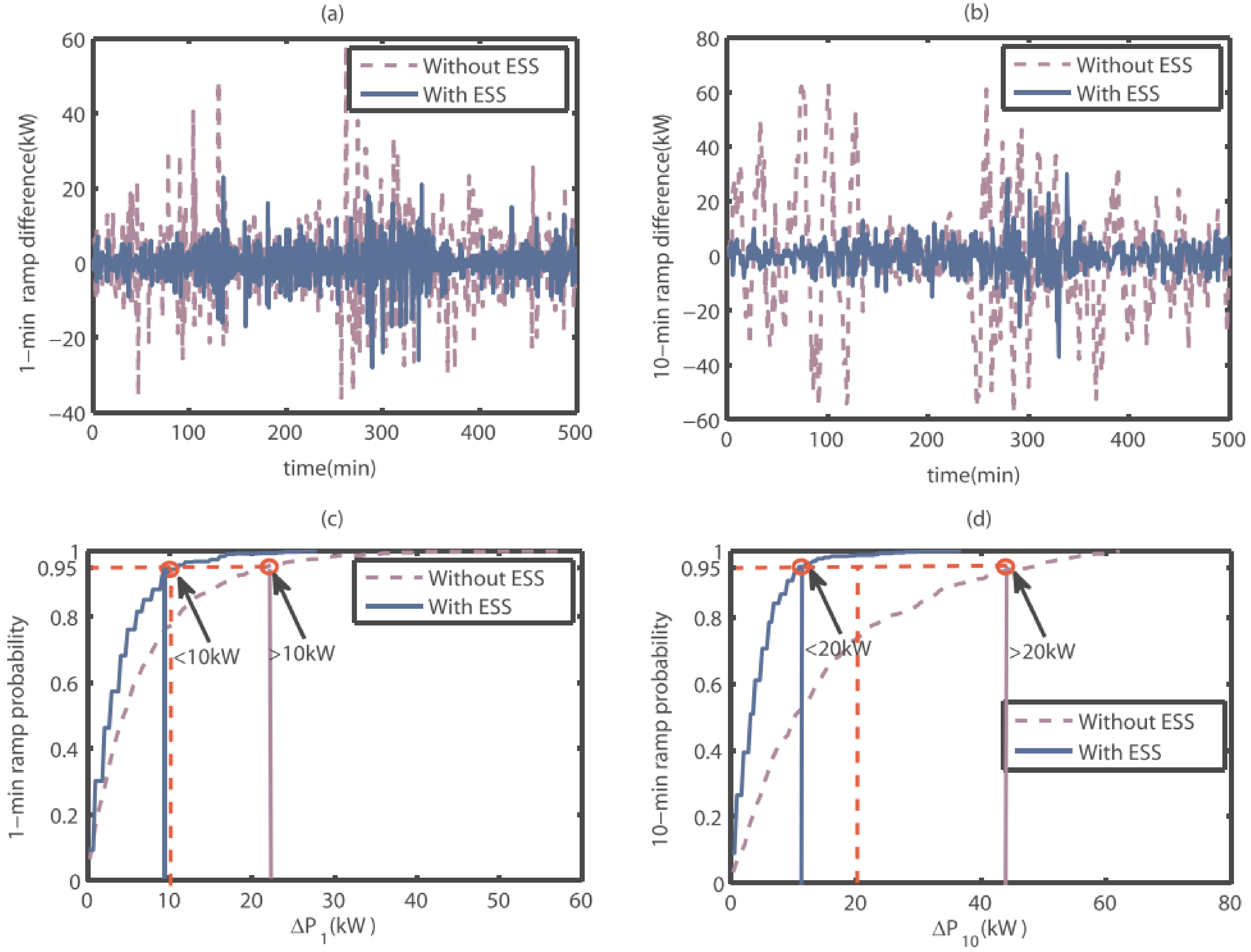
Key technology 3 – Results for BESS fast response use case

250 kW/500 kWh Li-ion battery at the OTF 3 consecutive days interaction with PV
Constant power (50kW) to load



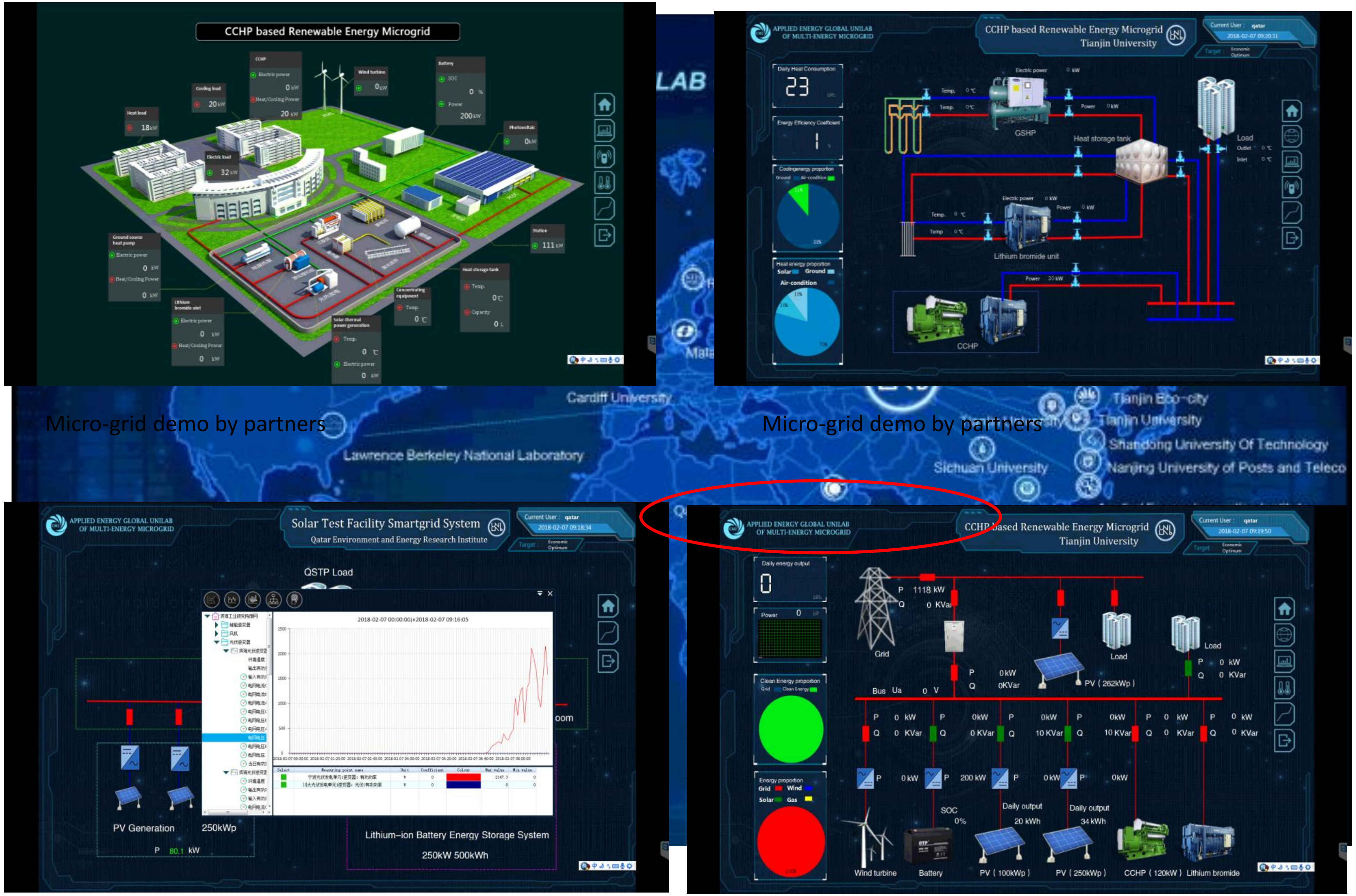
Key technology 3 - Results





Key technology 4 – Remote-Integration with World-Wide Unilab Multi-Energy Micro-grid

PV integrated Smart-grid Worldwide Multi-Energy Micro-grid



Micro-grid demo by partners

Micro-grid demo by partners

QEERI integrated Micro-grid

Full functional Micro-grid by partners

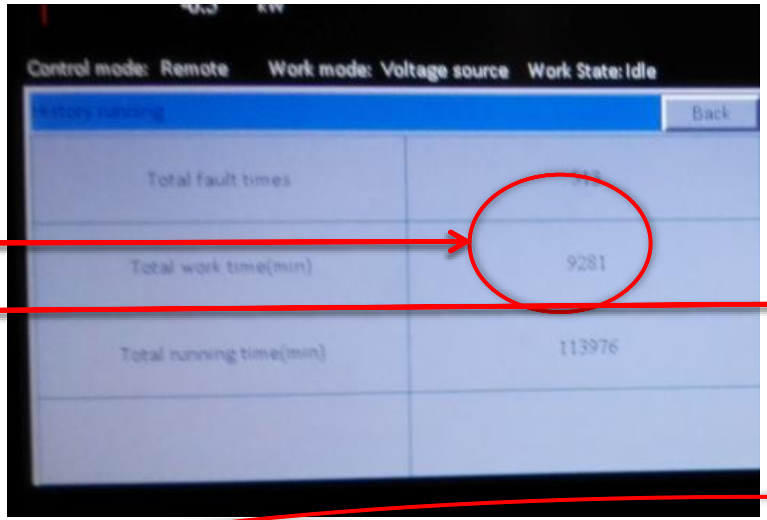
Reliability Study on the 500kWh BESS

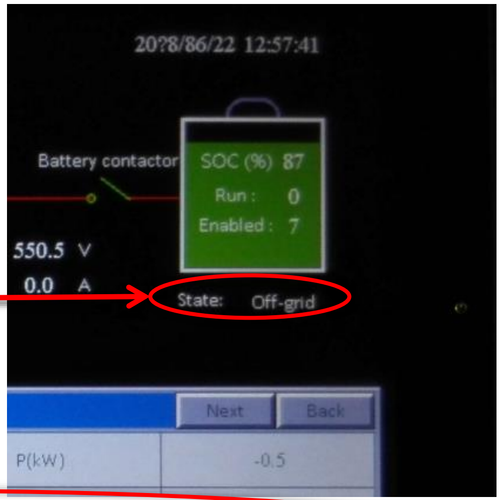
Reference:
1. Kubiak P, Cen Z, López C M, et al. Calendar aging of a 250 kW/500 kWh Li-ion battery deployed for the grid storage application[J]. Journal of Power Sources, 2017, 372: 16-23.
2. Cen Z, Kubiak P. Lithium-ion battery SOC/SOH adaptive estimation via simplified single particle model[J]. International Journal of Energy Research, 2020, 44(15): 12444-12459.

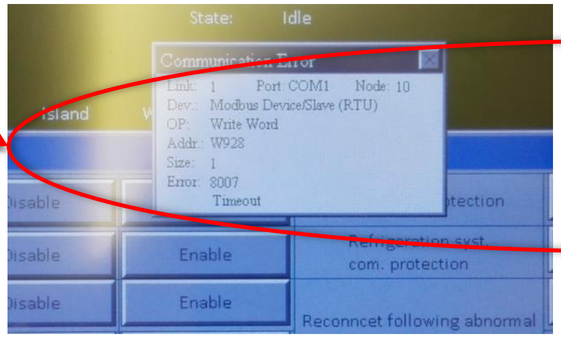
Repair, training and setup maintenance program

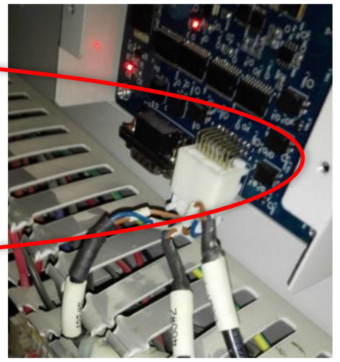
ESS **fatal problems** before QEERI team access:

1) never be used (One week running only), grid-on mode is dead;
2) key parts such as AC, UPS, cooling pump, fan, and Alarm system are not working;
3) ESS Communication and grid integration functions are missing and unfinished by green-gulf.



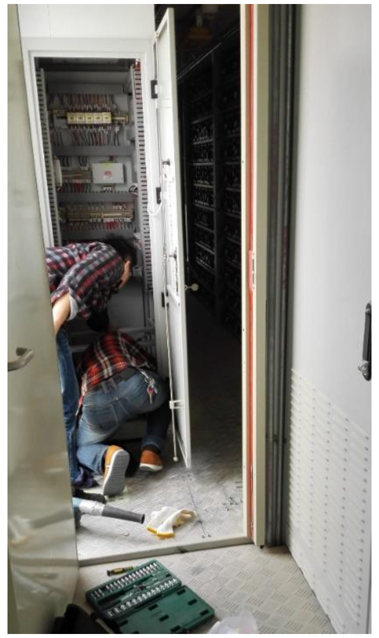


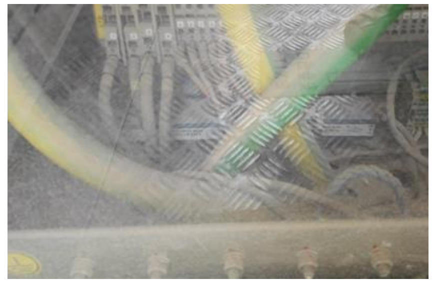


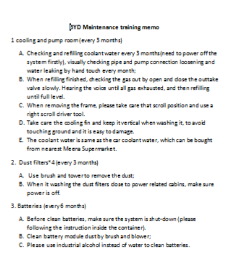


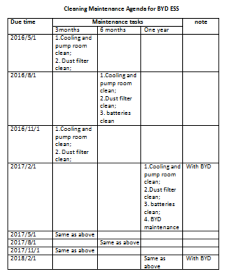
Contribution by QEERI Team for recovery of the ESS

1) Trouble-shooting
2) Repairing and make it work in grid-on mode;
3) Fully maintenance and cleaning
4) practical operations and training for staffs and technicians









Dust issue

(a) (b)

Dust on PV module in comparison

Dust jamming the ventilation filter in comparison

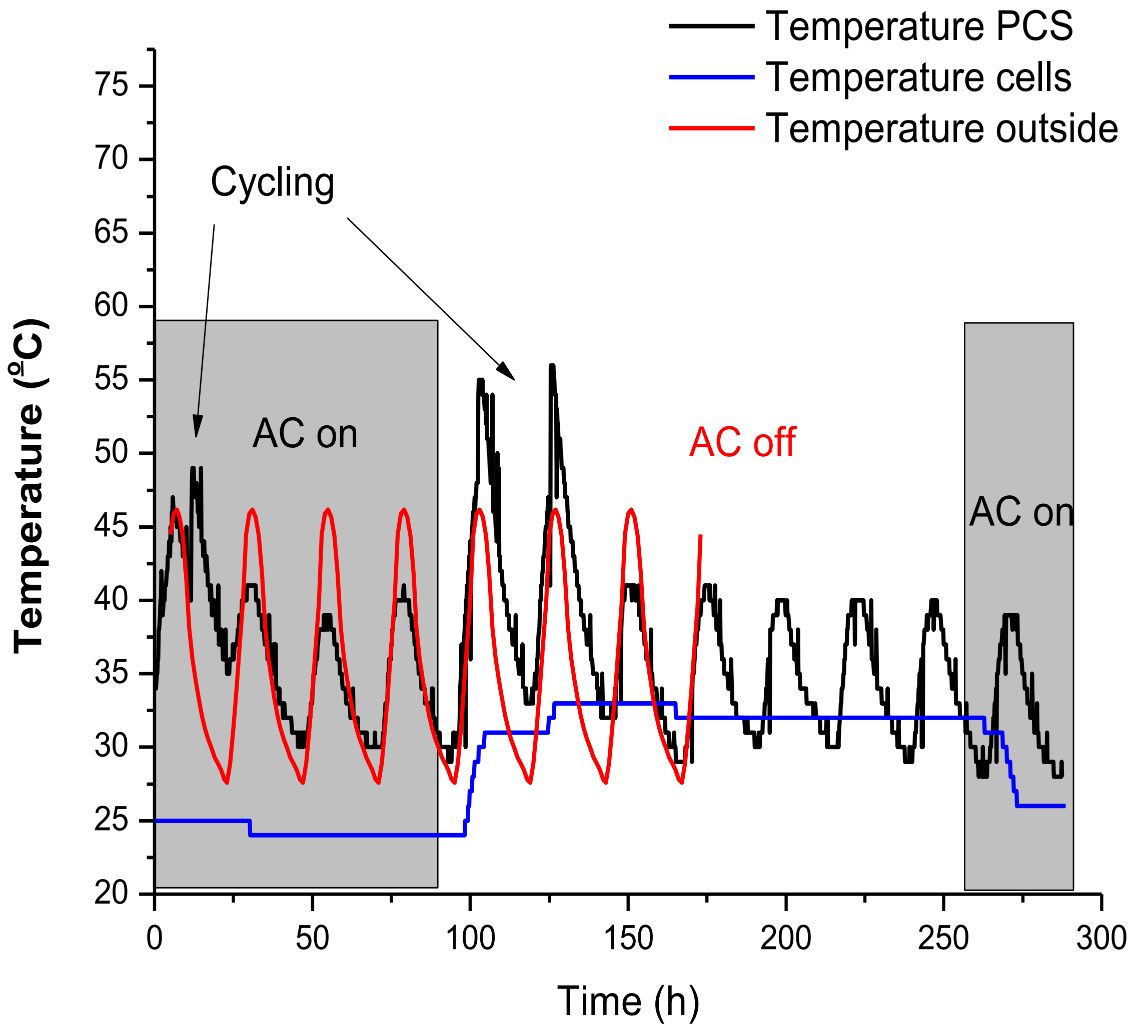
Dust over cable and UPS

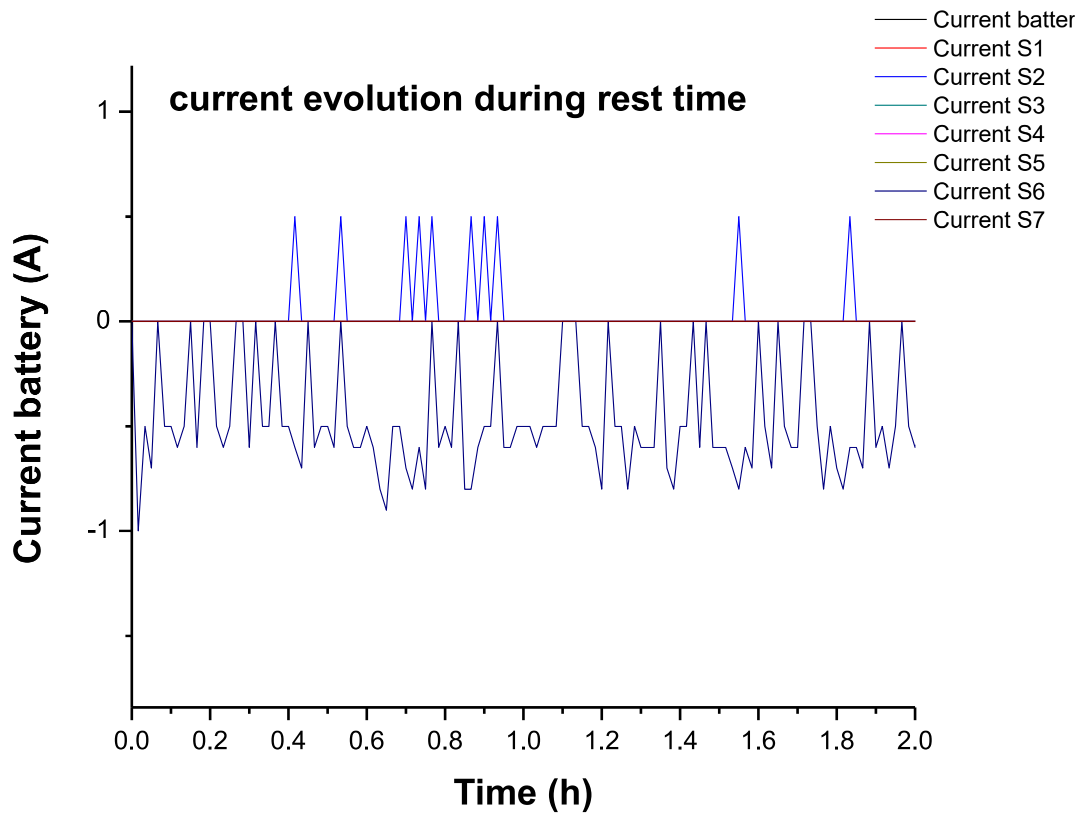
Dust over cooling pipe and IGBT devices

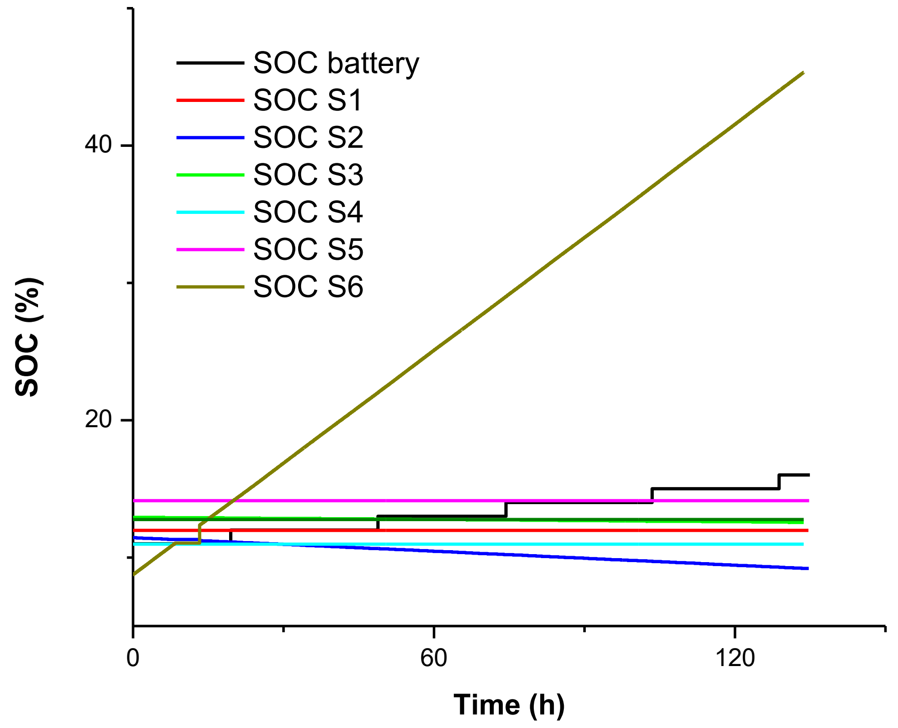
Dust over battery module connector

Qatar Climate challenges of heat and dust

250 kW/500 kWh Li-ion battery at OTF Challenge







High temperatures and dust affect the PCS than the cells leading to errors, fatigue and premature failure of the electronic system

Soiling impact on PV-Storage Sizing

Soiling and PV performance fading

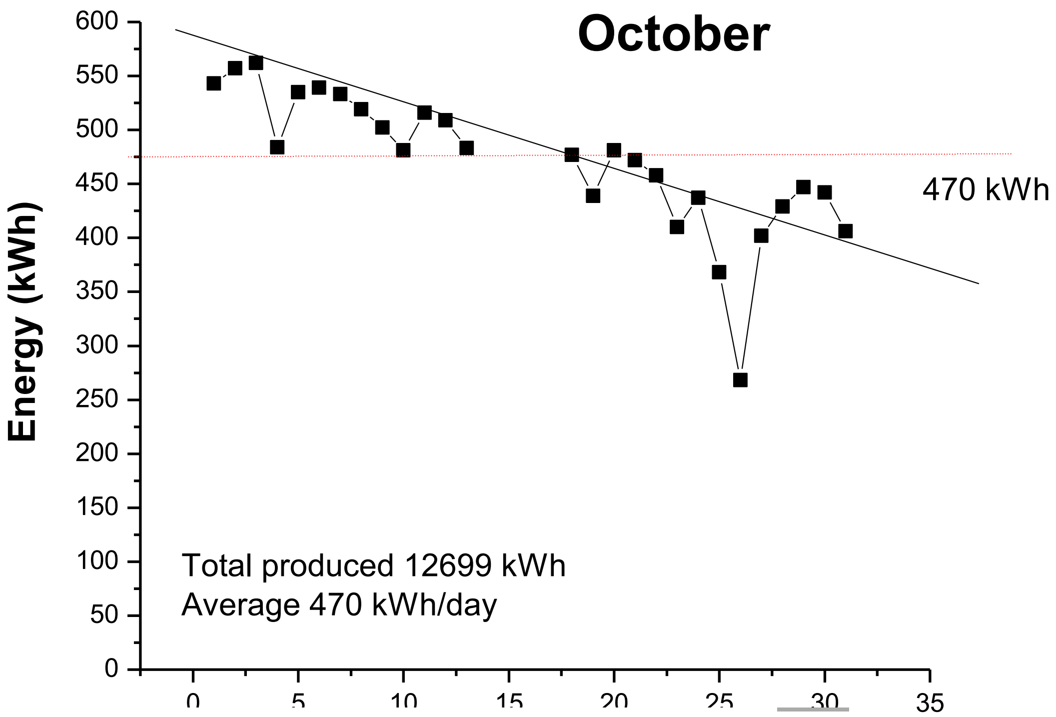
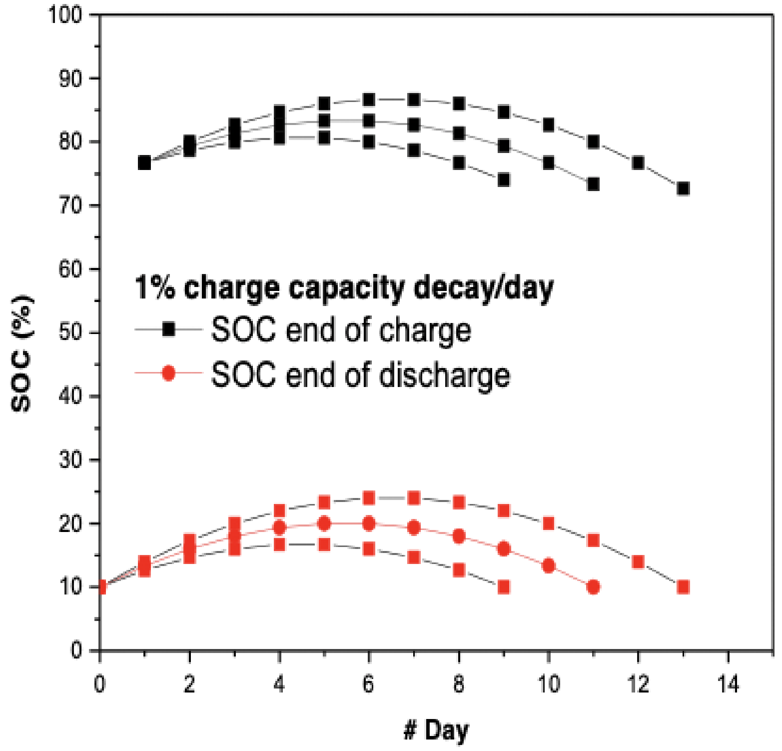
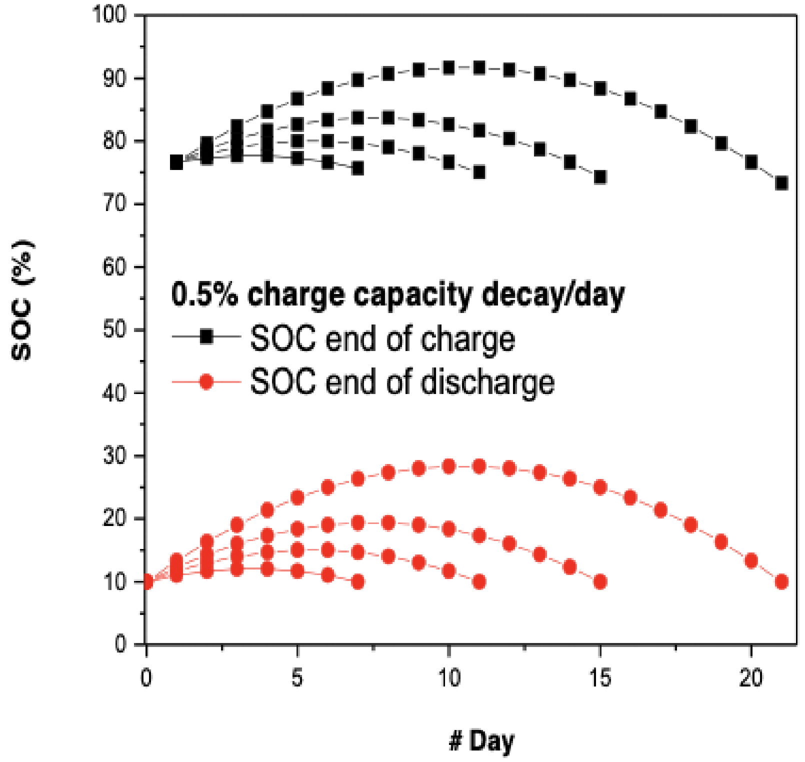


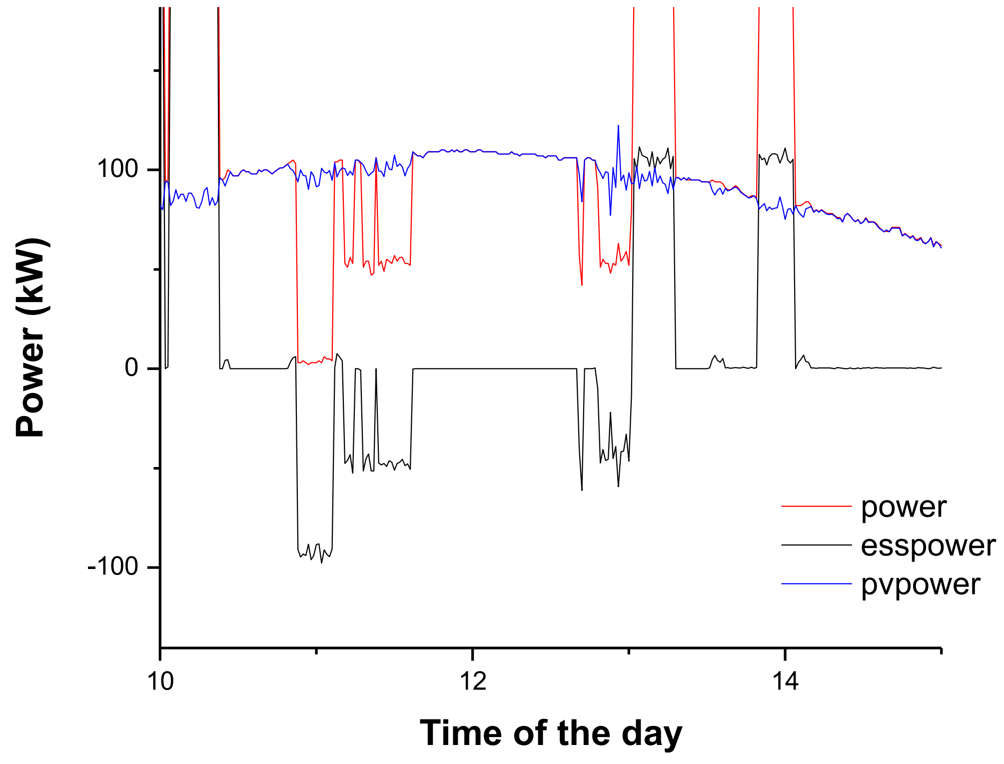
Figure 14: Calculations of battery oversize due to soiling





Impact on Automatic Circuit Breaker(ACB) tripping faults

Battery breaker tripping



- Grid AC power phase unbalance and disturbance (it could from grid or local disturbance)
- Total Harmonic Distortion issue due to PV fluctuations.
- Wrong protection action from breaker or connector due to inefficient insulation by sand particles in air.
- PV Inverter degradation due to dust and cooling.
- Battery Inverter degradation due to dust and cooling

Battery ACB intermittent tripping fault troubleshooting

Fig.7 fault tree analysis for intermittent trip fault

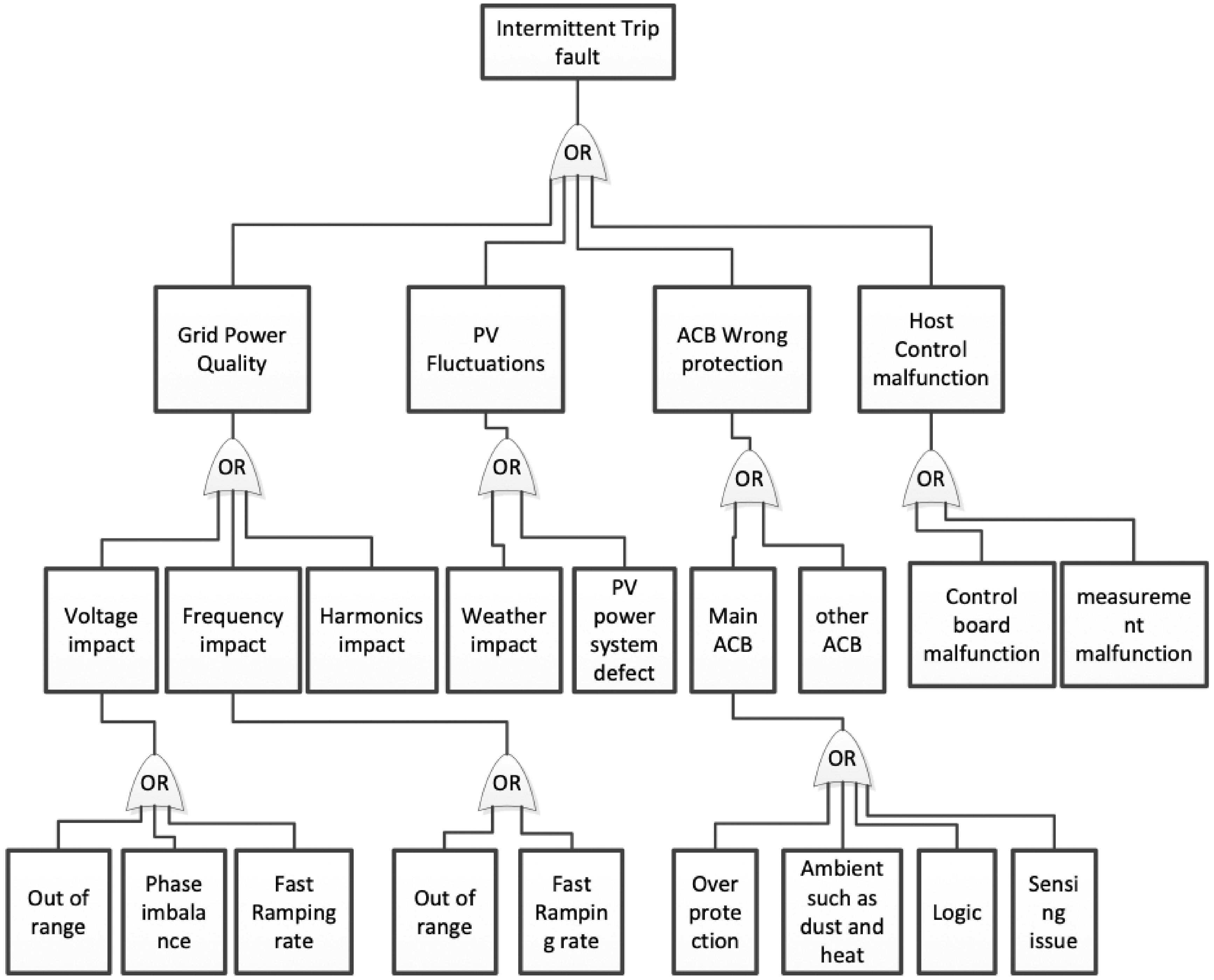
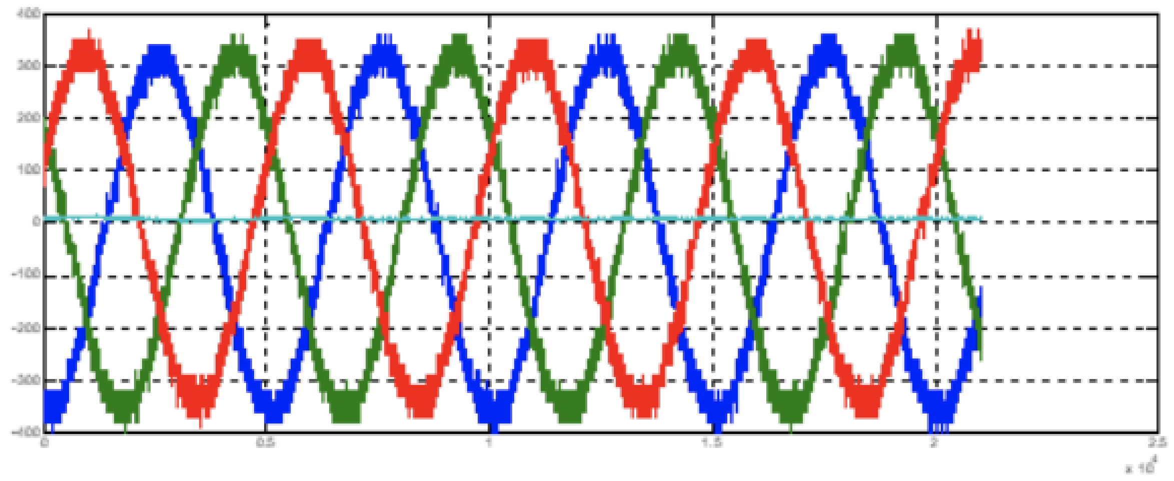
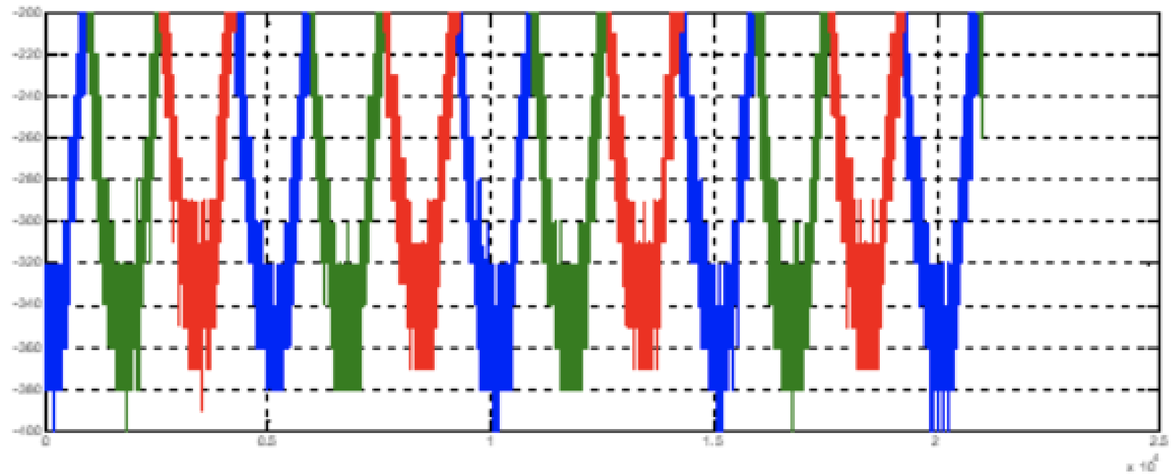


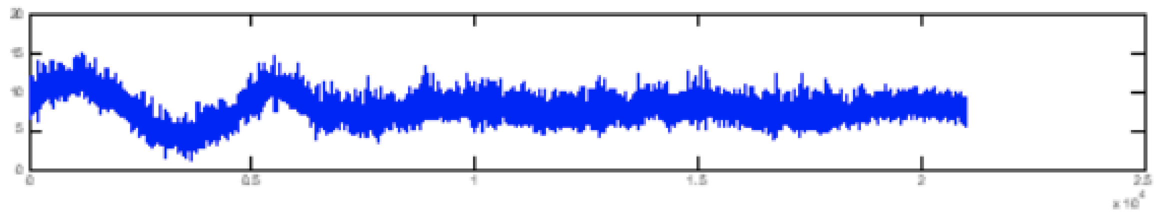
Fig.8 phase voltages and currents during trip occurrence duration



(a) phase voltage and current during a trip failure



(b) phase voltage drops within the acceptable range defined by Qatar gird regulations

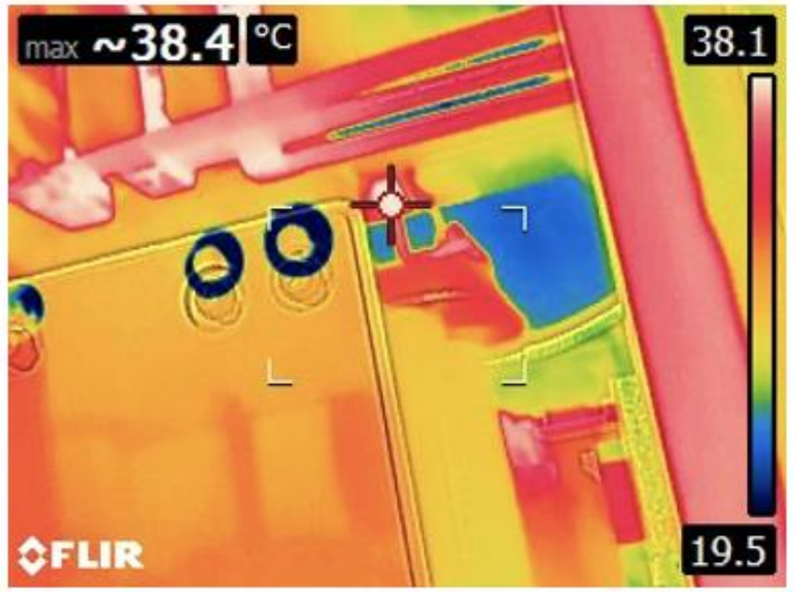


(c) current failure due to trip failure

Battery ACB tripping failure trouble-shooting

Fig.9 THD indicator measurement by power quality metering

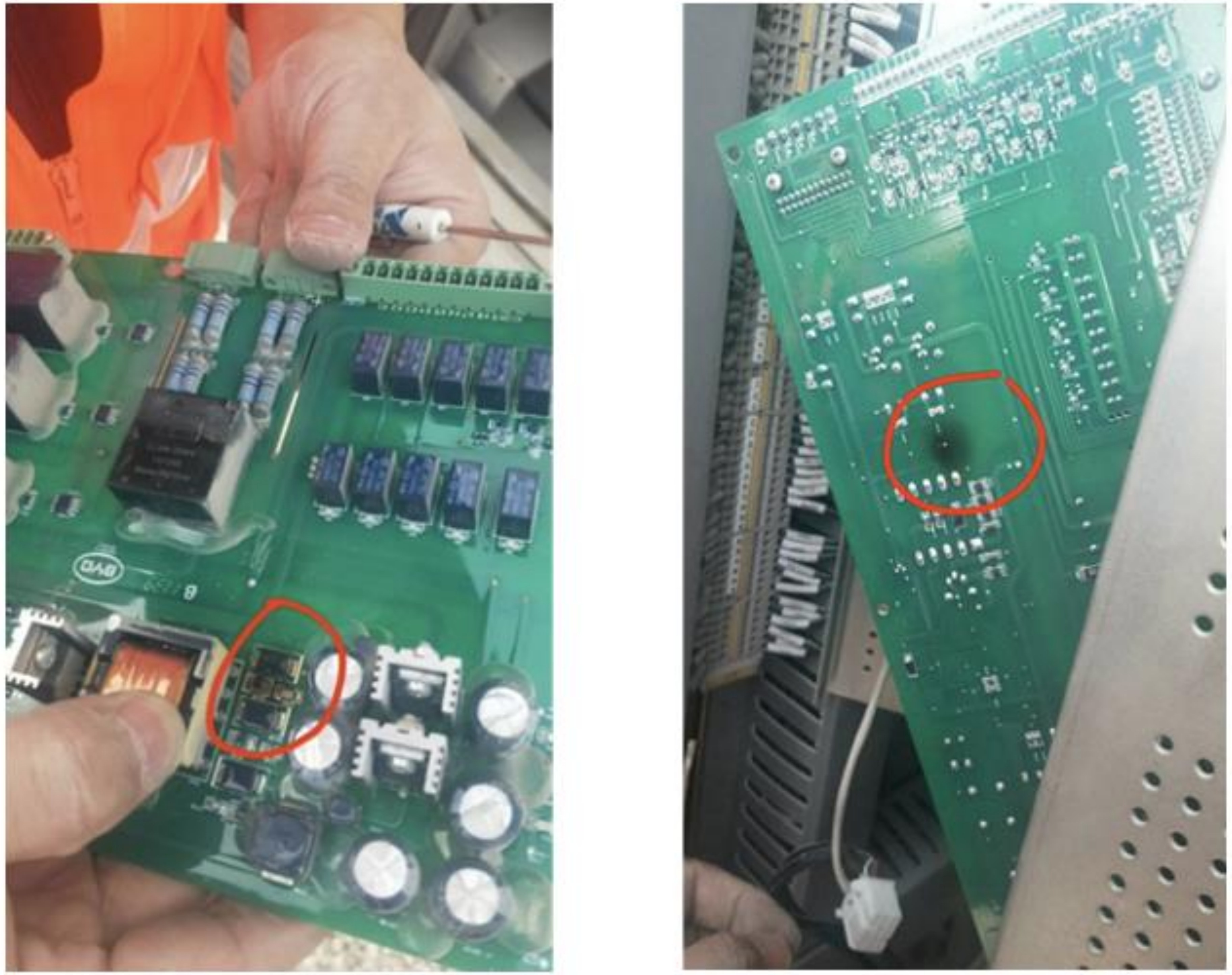
Fig. 11 IR image detection for abnormal temperatures



(a) PCS cabinet rear side(close to broken PCB board) (b) PCS cabinet front side

Battery breaker stripping failure trouble-shooting

Fig.12 identified faulty component due to electronic burning failure



Temprature measurement failure due to power-supply IC burned

Experience and lessons

- High temperature needs high-efficient cooling system for power converter-Water cooling is not suitable for Qatar weather conditions;
- Air conditioning for the battery container need to be strengthened;
- Dust cleaning is mandatory, and cleaning program need to be optimized based on Qatar weather conditions;
- Annual maintenance is mandatory for BESS safety;
- Trouble-shootings rely on powerful SCADA system and site investigation

Research On Air-Conditioner Cooling Optimization Control

Reference:
1.Al-Azba, Mohammed, et al. "Air-Conditioner Group Power Control Optimization for PV integrated Micro-grid Peak-shaving." Journal of Industrial and Management Optimization 17.6 (2020): 3165-3181.
2. Al-Azba, M., Cen, Z., Remond, Y., & Ahzi, S. (2020). An optimal air-conditioner on-off control scheme under extremely hot weather conditions. Energies, 13(5), 1021.

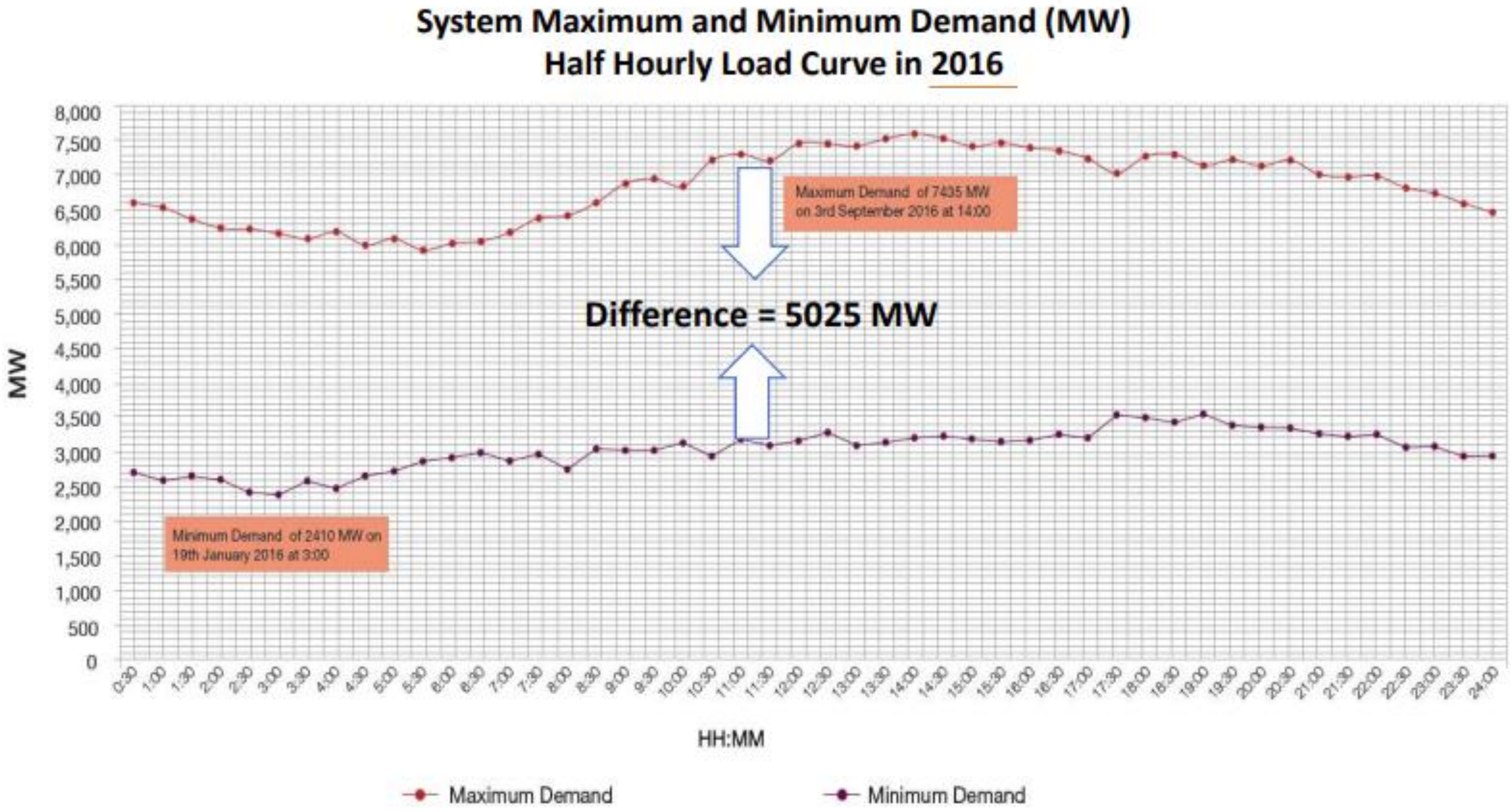
Introduction

- In the middle east and Gulf countries in particular (eg. Qatar) there is a huge demand for cooling due to the harsh desert environment (heat, humidity & dust) which approximately accounts for 60 – 70 % of total energy consumption.
- There have been numerous studies and ideas trying to address such energy challenge through state-of-the-art technology, energy efficiency and the use of renewables.
- While some have shown great success, many of the measures/ solutions or ideas are region or country specific, meaning that local energy policy, regulations and culture can have an impact on expected results.
- In this study, an engineering approach is proposed to assist in addressing the high-power consumption for cooling and address peak demand issues. The target will be the development of a suitable control scheme for buildings' ACs to effectively respond to space cooling demand while maintaining peak load at minimum.

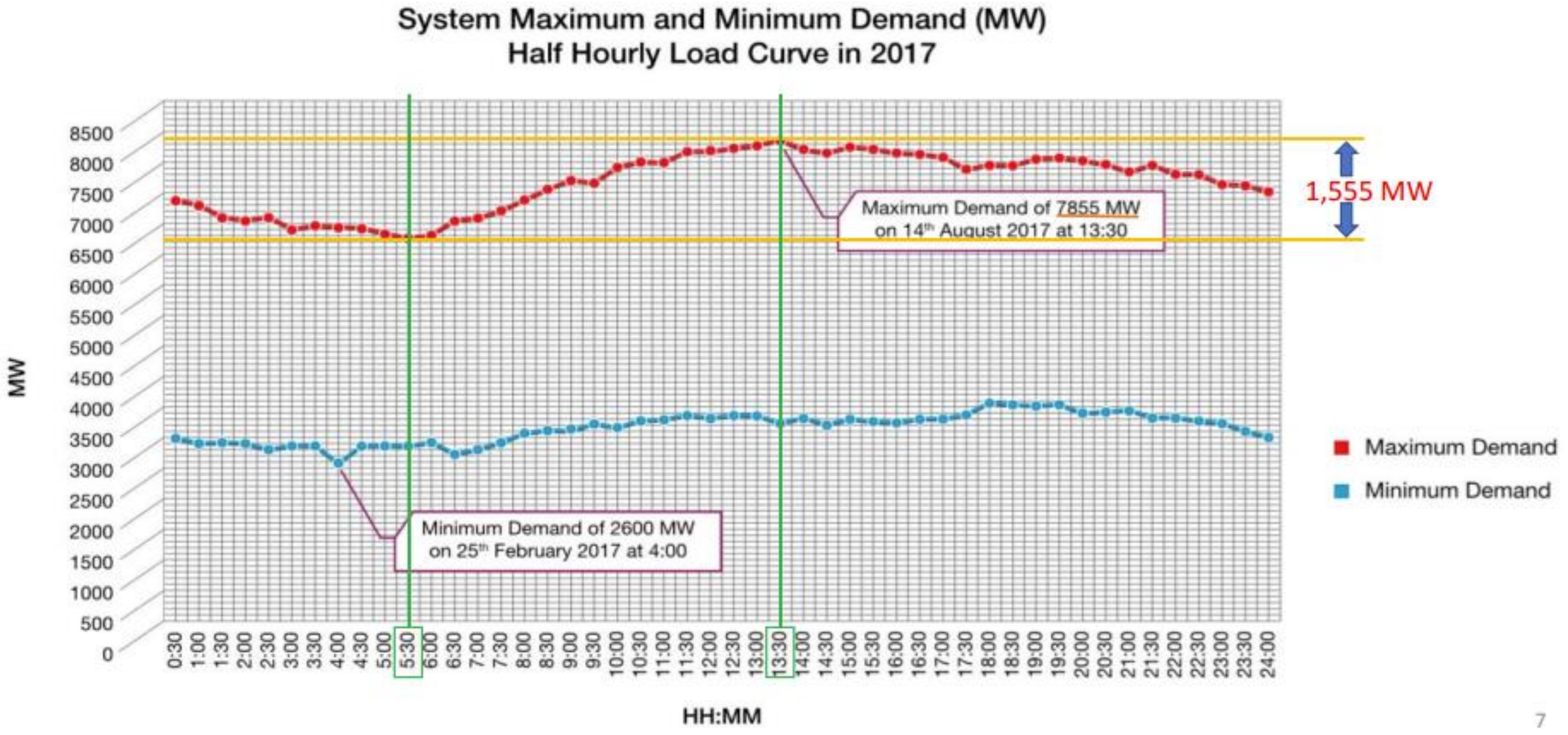
Background

- Governments and utility providers are facing another energy related challenge which is peak demand.
- We do not necessarily suffer lack of energy resources, but certainly have issues in managing the growing demand for electric power especially during summer seasons.
- Lack of stringent environmental & Energy policies and energy subsidies add complexity to the above challenge.
- The focus is on domestic sector (residential, commercial and government buildings) makes about 80% of energy use in Qatar.

Problem/Significance



Problem/Significance



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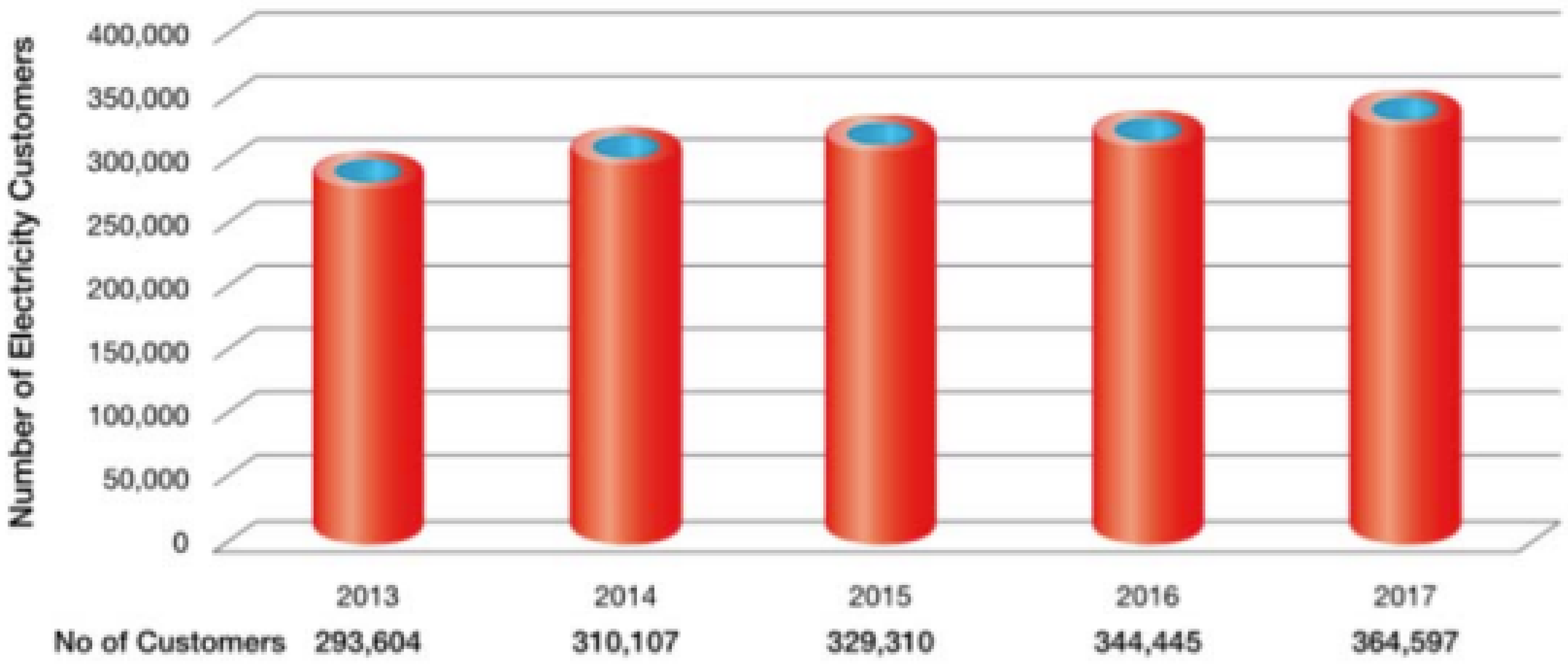
Problem/Significance

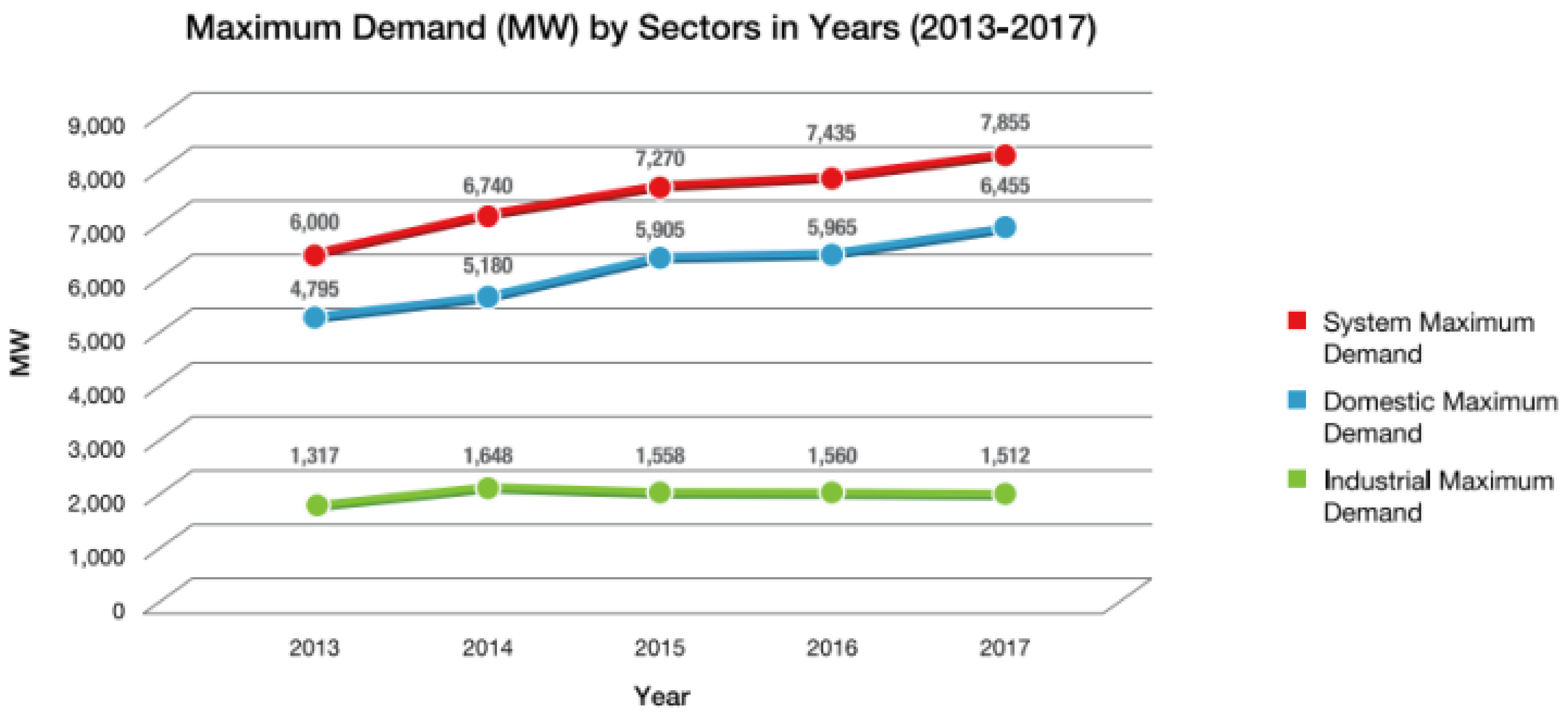
Year	2013	2014	2015	2016	2017
No of Customers	293,604	310,107	329,310	344,445	364,597
Annual Growth (%)	1.6%	5.6%	6.2%	4.6%	5.9%

Number of Electricity Customers in Years (2013-2017)



Total Capacity	10,170 GW

Why buildings?

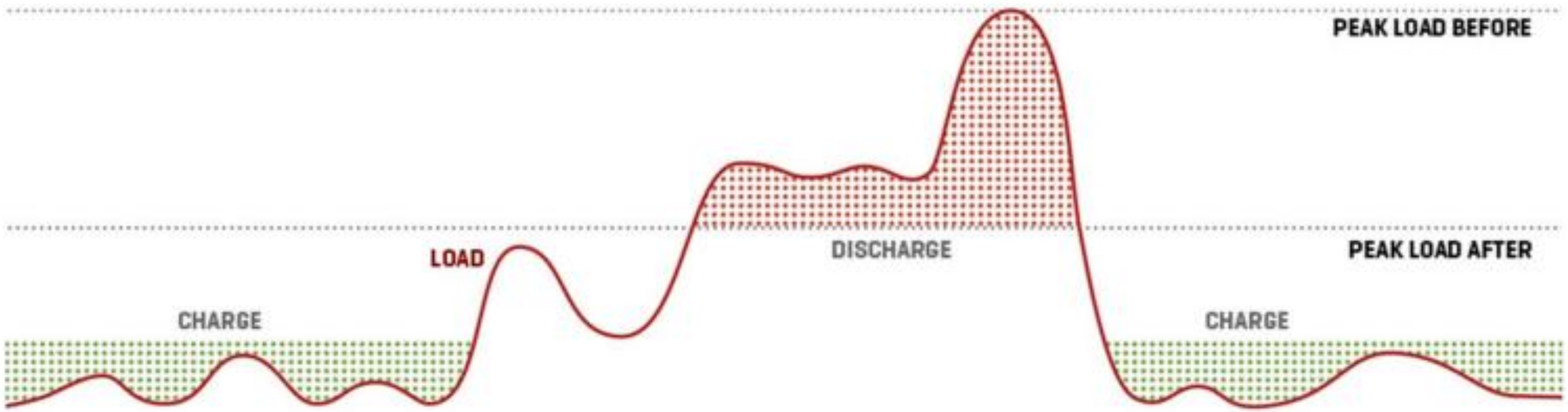


Domestic sector = residential + commercial +government buildings

Prior Art

Existing ways to address peak load issues:

- Peak load shaving using Energy (*or thermal*) storage

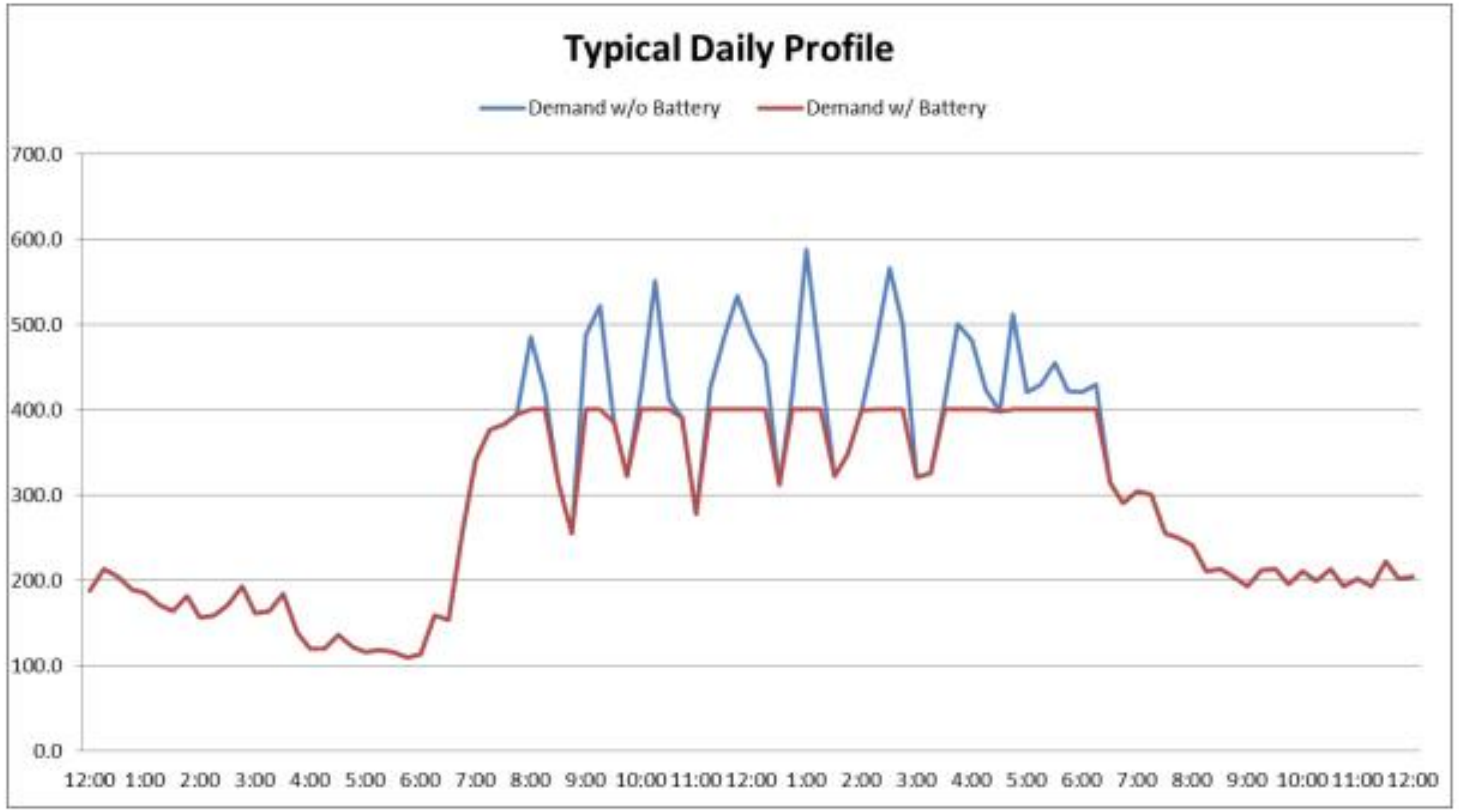


* greenspherecleantech.in

Prior Art

Existing ways to address peak load issues:

- **Peak load shaving using Energy storage**



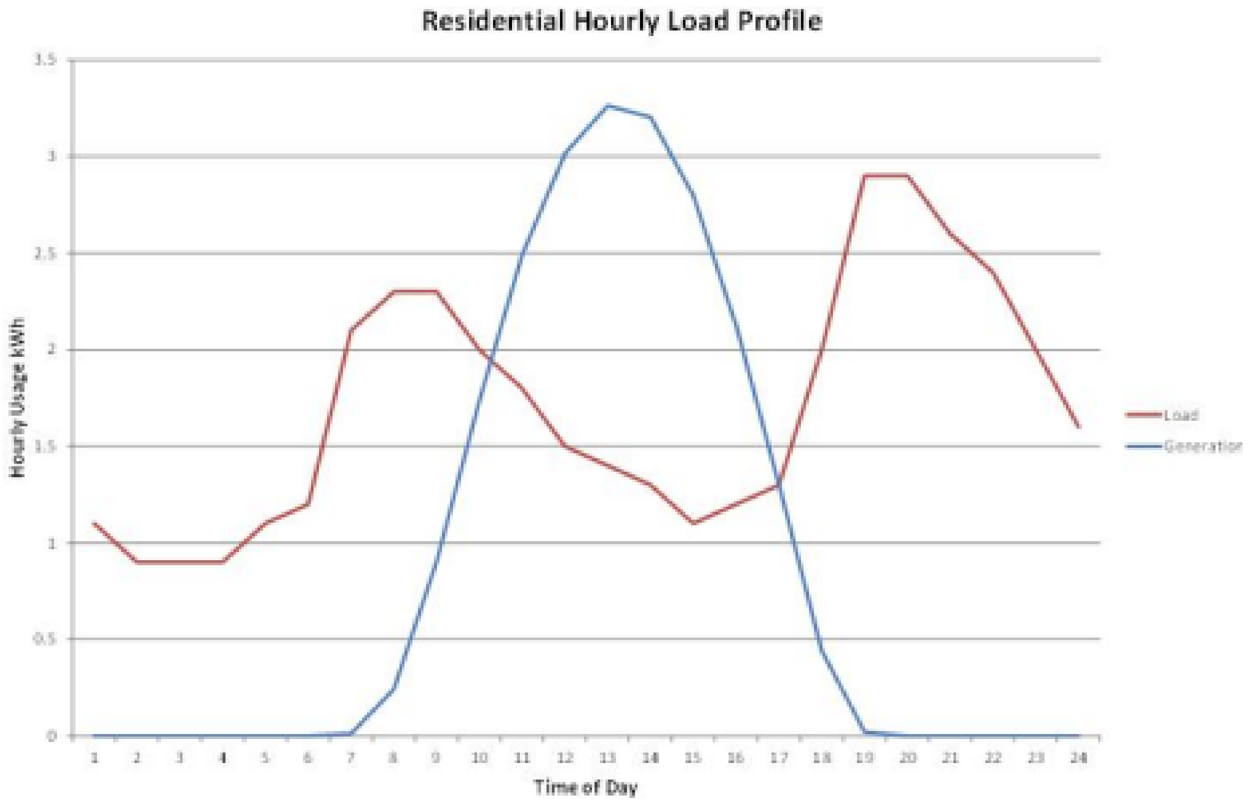
Tesla Powerwall

*brilliantharvest.com

Prior Art

Existing ways to address peak load issues:

- Peak load shaving using Energy storage
- **Peak load shaving using direct PV energy supply**



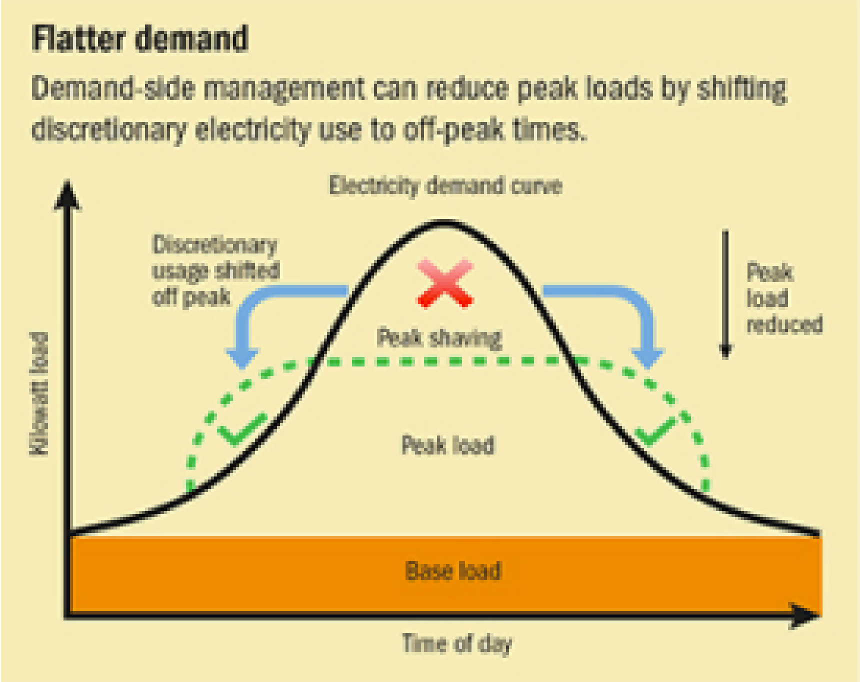
*segensolar.co.za

Prior Art

Existing ways to address peak load issues:

- Peak load shaving using Energy storage
- Peak load shaving using direct PV energy supply
- Demand Response and Demand Side Management (DSR/DSM)
- Policy (Energy conservation and efficiency)

  Example: Tariff, Tax, regulations, incentive programs, compensation schemes



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- Build more power plants!

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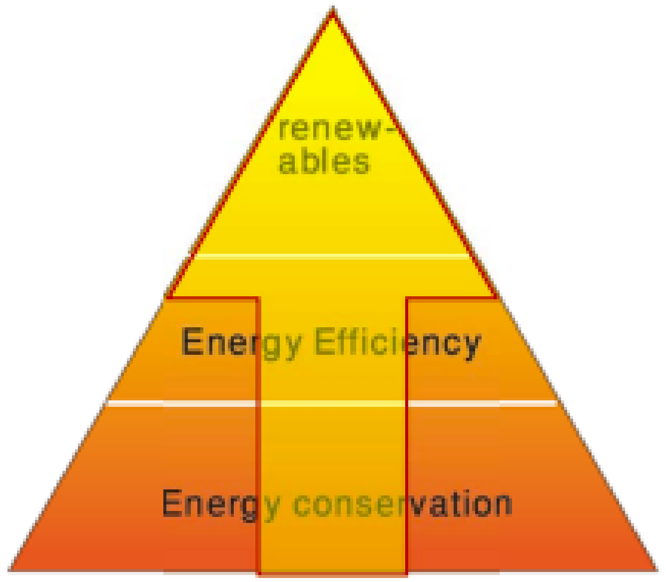

<u>Saving 1 kW is better than producing it even from renewable sources</u>

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Scope and limitations

- The focus is on targeting peak load reduction in residential buildings
- Conventional Air conditioning systems are only considered
- Typical small-size residential house with average insulation conditions
- Minimum of 4 AC units is considered in this study
- Investigation of performance during peak hours is initially targeted
- Some assumptions are made & factors are neglected for simplicity purposes (eg: room size, neglect humidity & disturbance effects)

Objective and Methodology

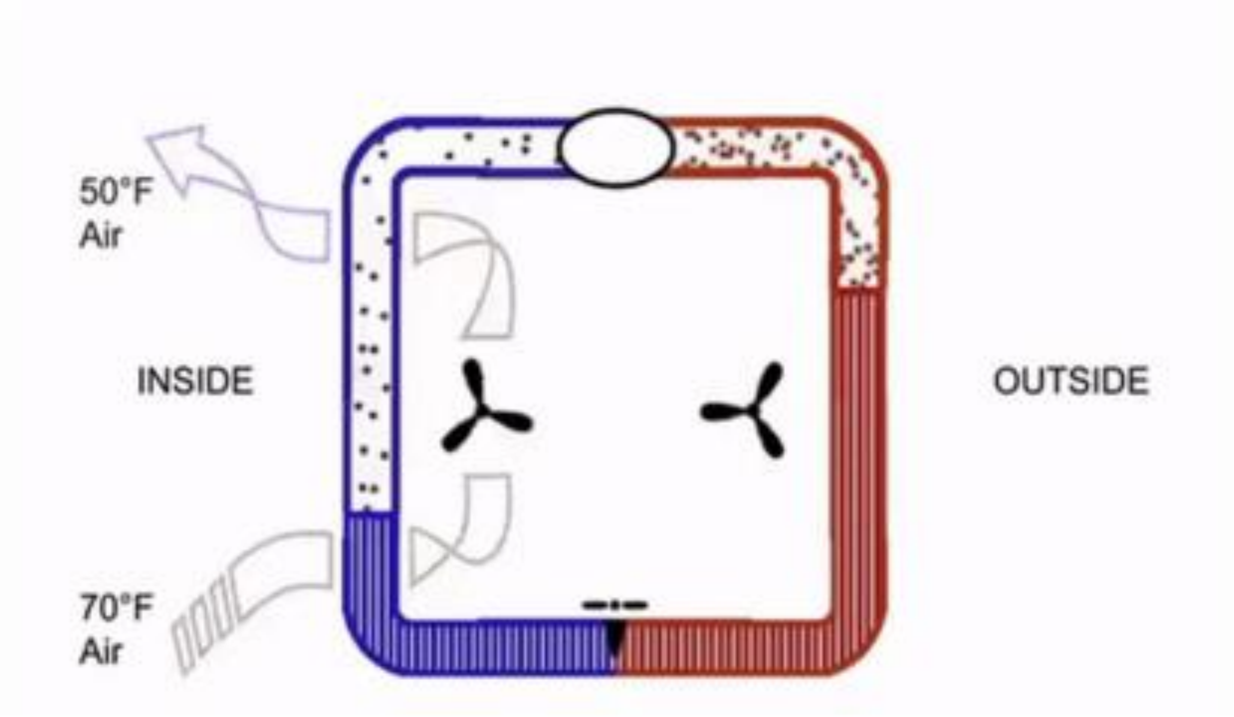
Objective

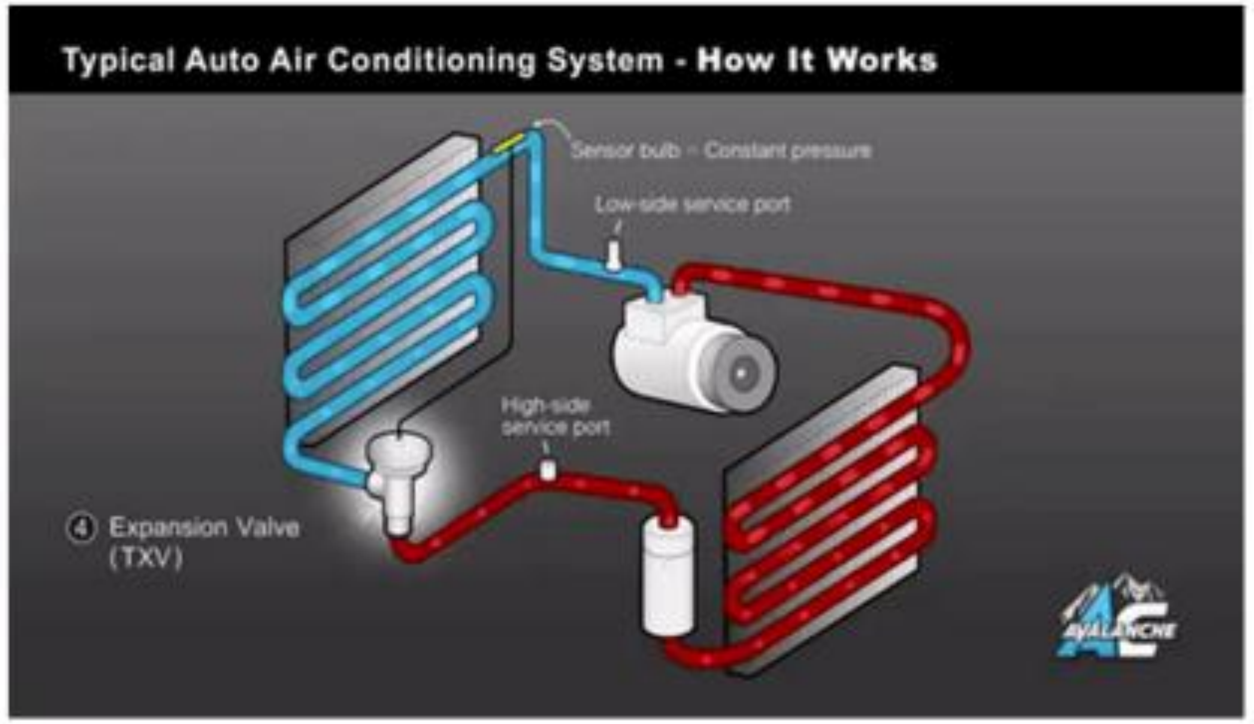
- Develop a control algorithm to minimize power spikes caused by running multiple AC units within a typical house while maintaining optimum cooling performance and comfort.

Methodology:

- Literature review
- Build mathematical models to analyze and simulate a complete house cooling system using Matlab / Simulink
- Develop control logic for optimum performance
- Validate models and results

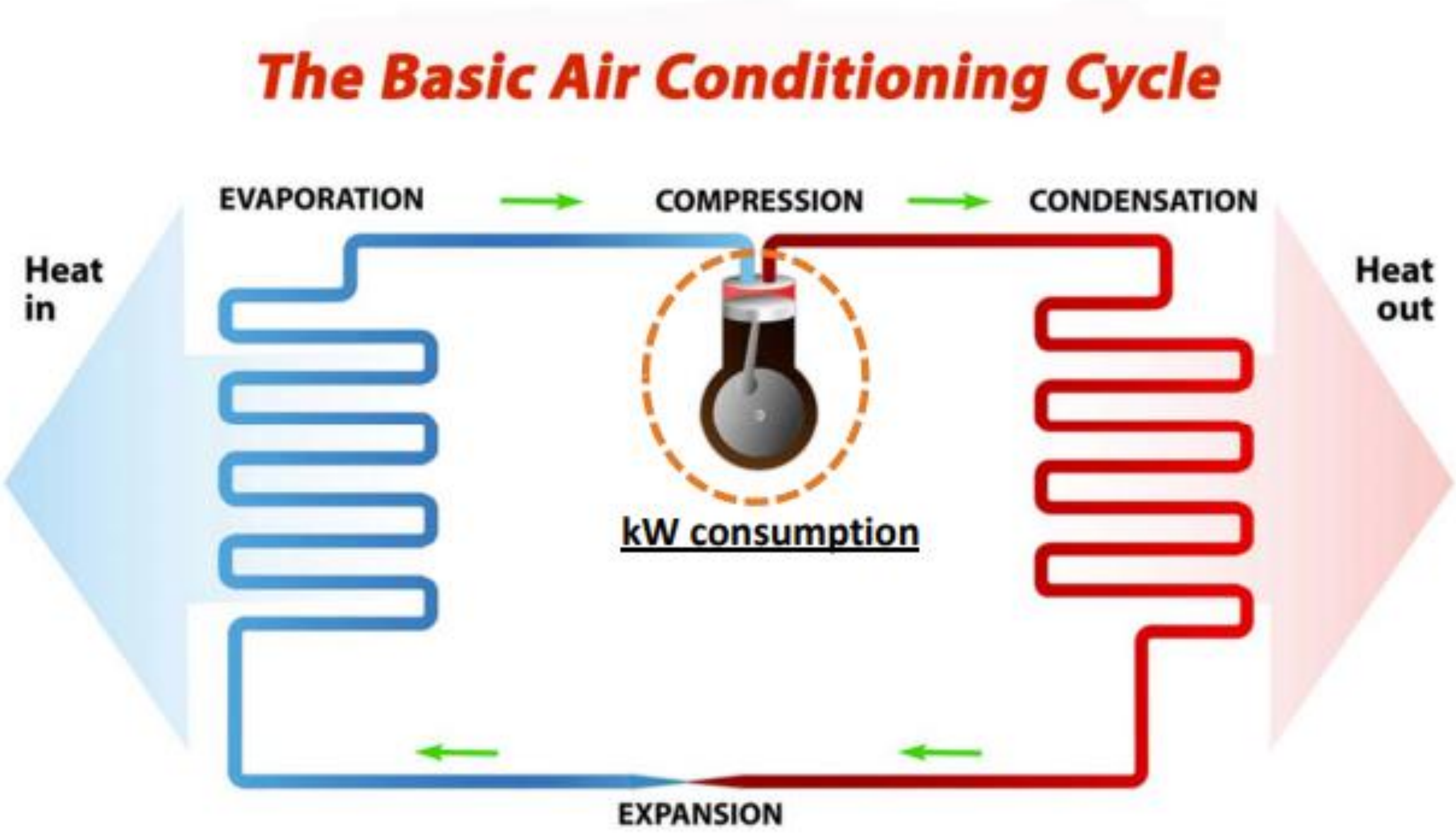
Basic Air conditioning System



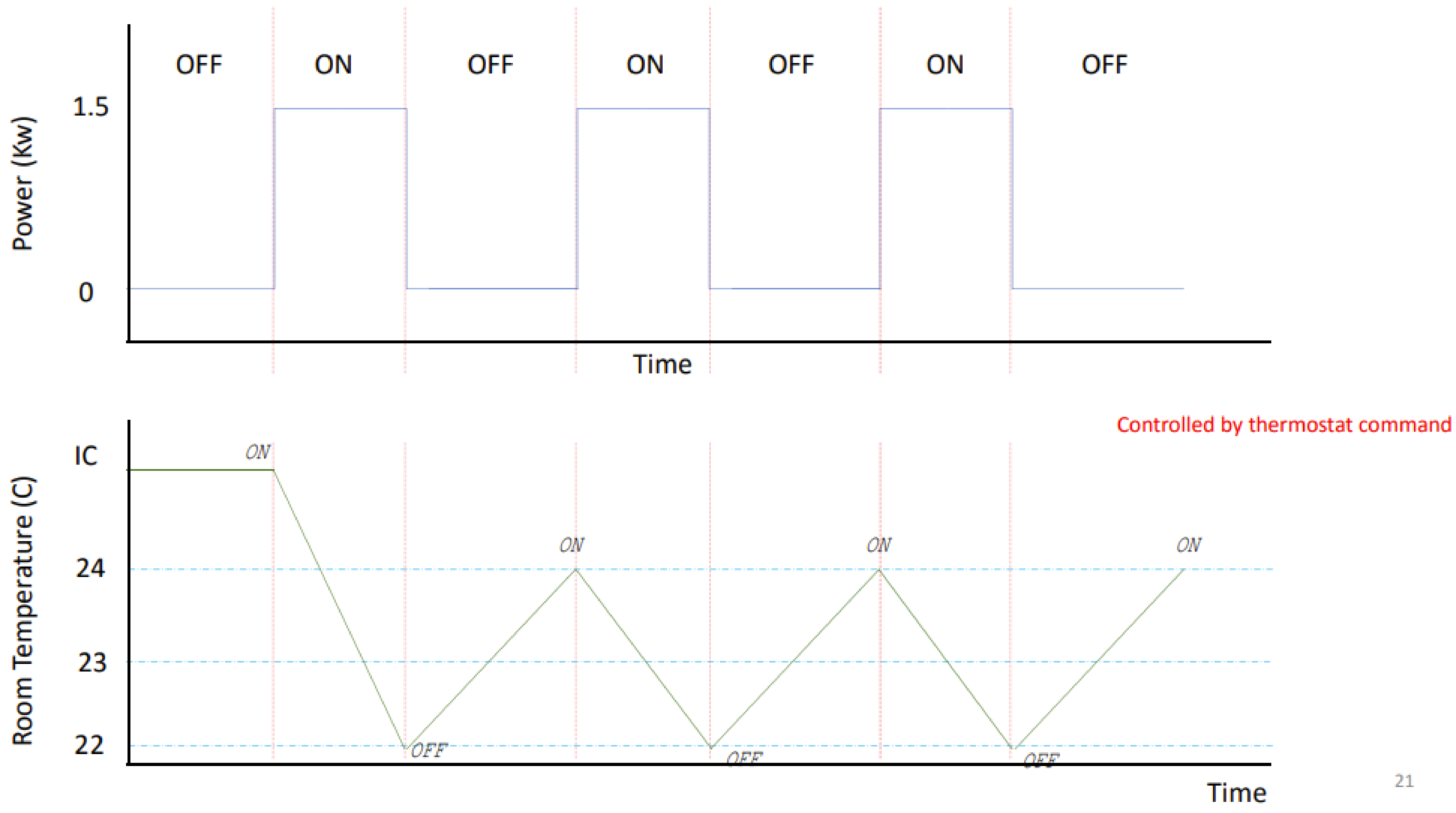


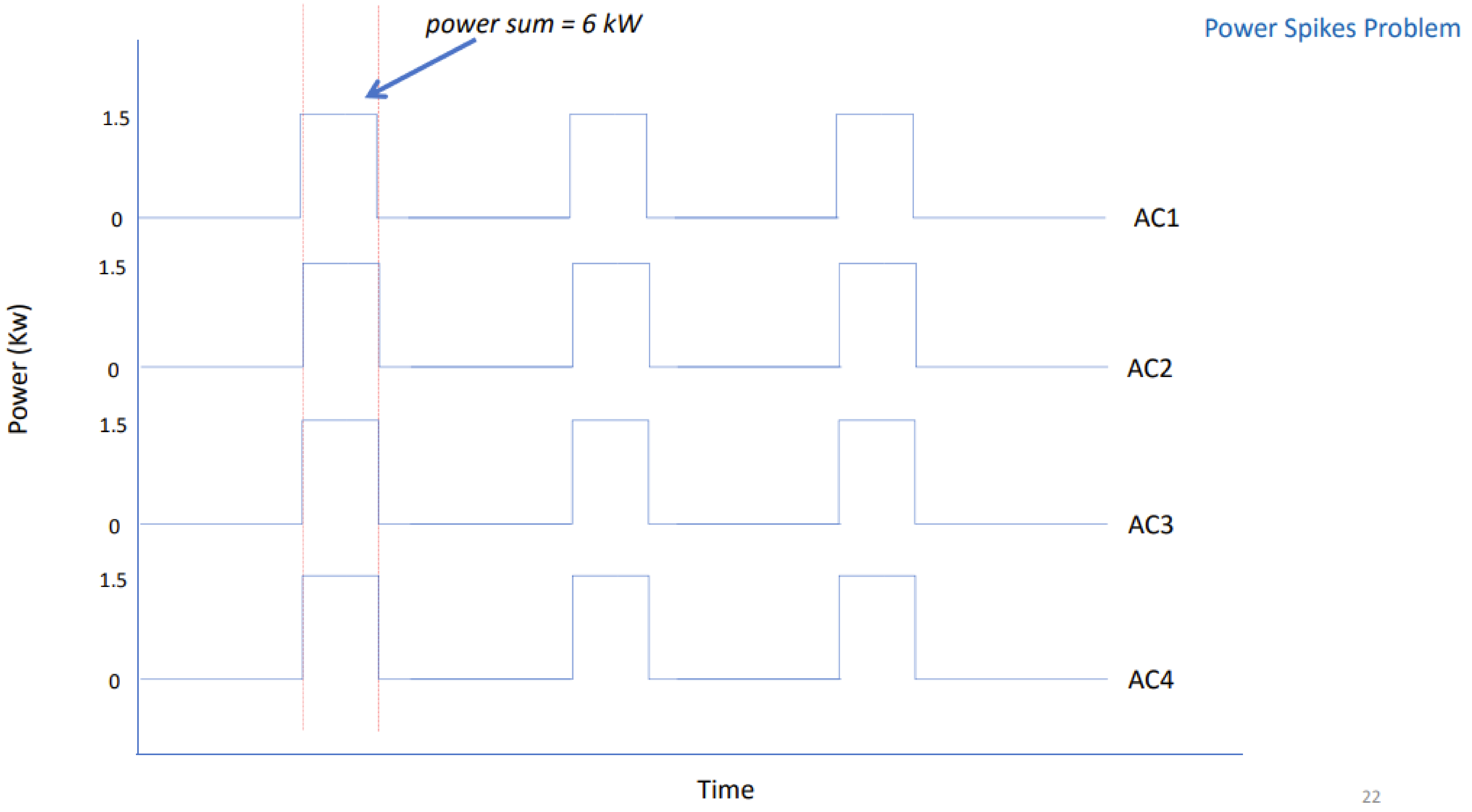
- AC units are used for removing heat and humidity from the interior by relying on standard refrigeration cycle.
- This is basically a continuous process of compression and expansion of certain refrigerant which eventually gives the cooling effect.

Basic Air conditioning System



https://energyair.com/4-signs-ac-small/


OFF
ON
OFF
ON
OFF
ON
OFF
Power (Kw)
1.5
0
Time
Controlled by thermostat command
IC
24
23
22
Room Temperature (C)
ON
OFF
ON
OFF
ON
OFF
ON
Time
21


power sum = 6 kW
Power Spikes Problem
Power (Kw)
1.5
0
AC1
1.5
0
AC2
1.5
0
AC3
1.5
0
AC4
Time
22

Building a house cooling model

The cold air flow into the room is expressed by Equation 1 below:

$$\frac{dQ}{dt} = (T_{room} - T_{aircon}) \cdot Mdot \cdot c \quad \ldots\ldots\ldots\ldots\ (1)$$

$$\left(\frac{dQ}{dt}\right)_{losses} = \frac{T_{room} - T_{out}}{Req}$$

Heat losses, temperature time derivative:

$$\frac{dT_{room}}{dt} = \frac{1}{M_{air} \cdot c} \cdot \left(\frac{dQ_{losses}}{dt} - \frac{dQ_{aircon}}{dt}\right) \quad \ldots\ldots\ldots\ldots (2)$$

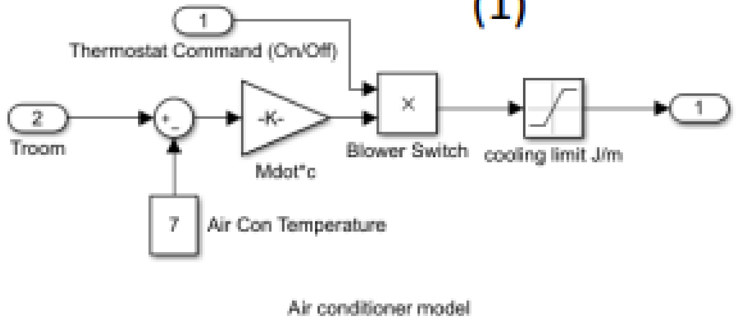
Where,

dQ/dt ➔ the heat removal rate (J/h) ***T_{room}*** ➔ indoor temperature (°C) T_{aircon} ➔ cold air supply from AC (°C)

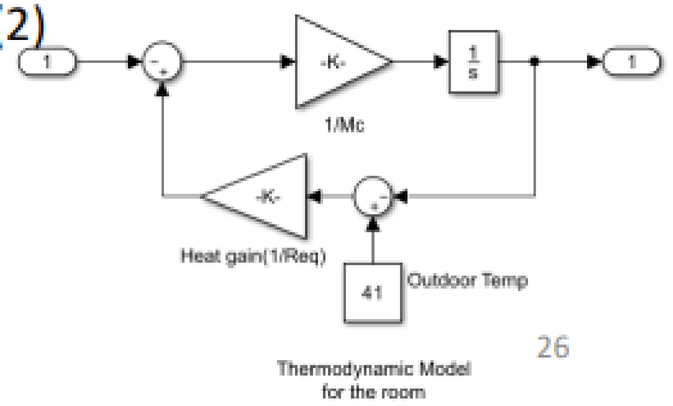
Mdot ➔ air mass flow rate kg/h ***c*** ➔ heat capacity of air at constant pressure (J/kg.k)

T_{out} ➔ outdoors temperature (°C) ***M_{air}*** ➔ room air mass (kg) ***Req*** ➔ room equivalent thermal resistance (K/W)

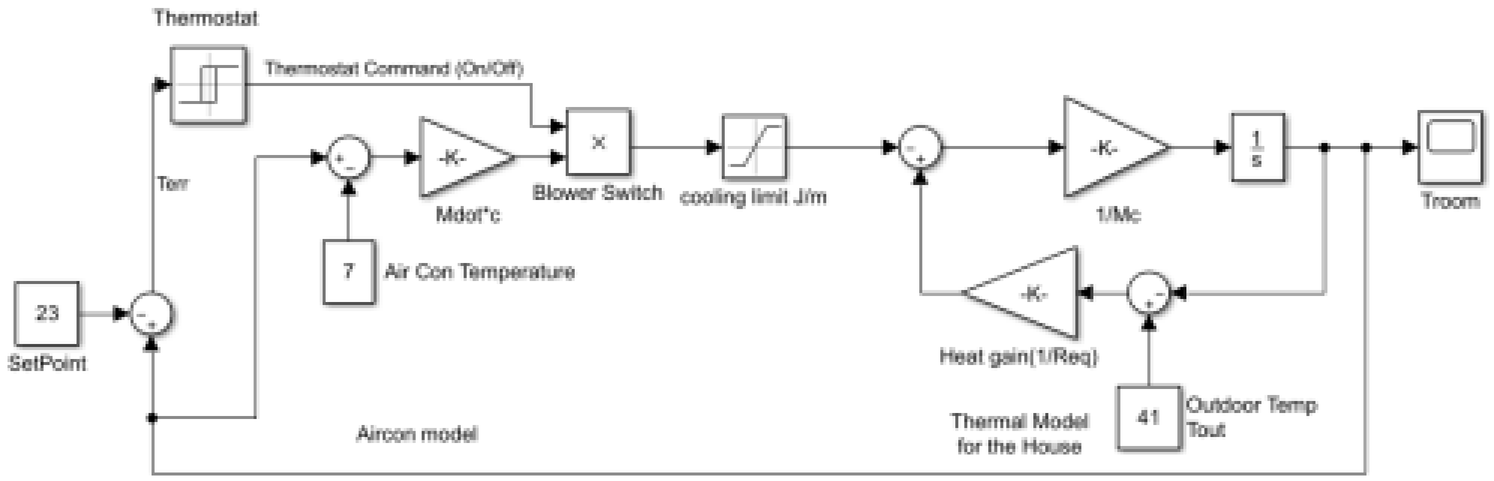
(1)



(2)



Building a house cooling model



Model parameters:

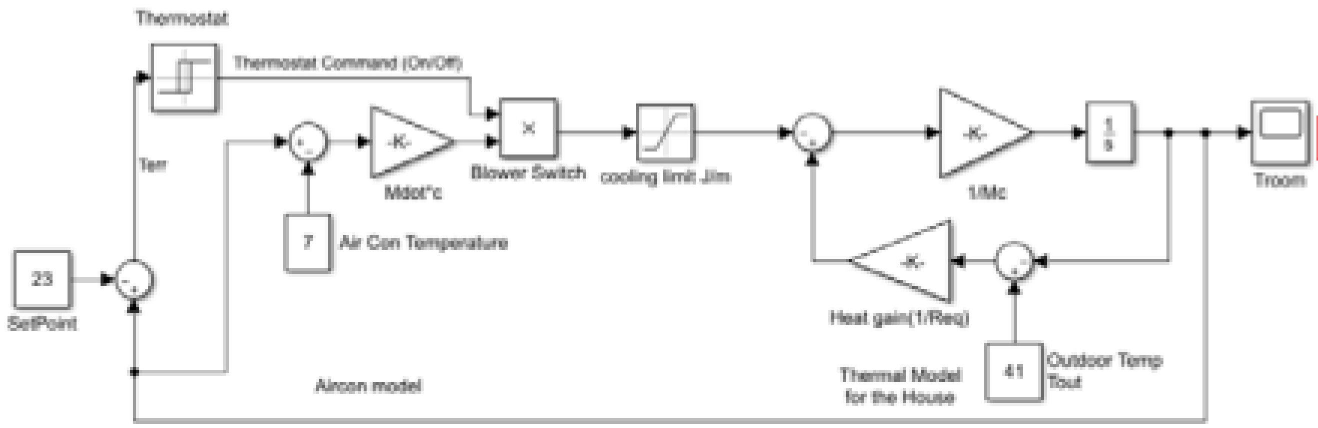
•Room size /dimensions
•Insulation level & thermal characteristics
•AC sizing (cooling capacity)

Building a house cooling model

Model parameters:

a) Room

Parameter	value	unit	
lenRoom	6	m	
widRoom	8	m	
htRoom	4	m	
numWindows	2		
htWindows	1	m	
widWindows	1	m	
WindowsArea	2	m^2	numWindows*htWindows*widWindows
wallArea>>>	158	m^2	2*lenHouse*htHouse + 2*widHouse*htHouse +RoofArea - windowArea
Kvalue(wall)	0.055	J/min/m/C	
kWall (m)	3.3	J/min/m/C	
Lwall	0.3	m	
Rwall	5.75E-04		RWall = LWall/(kWall*wallArea)
kWindow	84	J/min/m/C	
Lwindow	0.06	m	
RWindow	7.14E-04	$(m^2C)/W$	RWindow = LWindow/(kWindow*windowArea)
Req	3.19E-04	$(m^2C)/W$	
c	1005.4	J/kg-K	
densAir	1.225	kg/m^3	
T_{aircon}	7	°C	AC temp
Mdot	22.45833333	kg/min	Air flow rate
M	235.2	kg	total internal air mass



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Building a house cooling model

Model parameters:

b) Air conditioner

Fixed Speed Models

Model	Indoor Unit		6800121	6800131	6800141	6800151
	Outdoor Unit		6800120	6800130	6800140	6800150
			Indoor Unit			
	Power Supply	V-ph-Hz	240-1-50	240-1-50	240-1-50	240-1-50
Cooling	Rated Capacity	kW	2.7	3.3	5.0	7.0
Heating	Rated Capacity	kW	2.7	3.3	5.0	7.0
Cooling	Rated Input	W	720	860	1500	2100
Heating	Rated Input	W	700	860	1500	2100
	AEER	W/W	3.66	3.68	3.3	3.25
	ACOP	W/W	3.94	3.74	3.27	3.33
	Airflow H/M/L	m^3/hr	750/700/650	750/700/650	1100/1000/900	1200/1100/1000
	Unit Dimensions WxDxH		900x280x202	900x280x202	1033x313x202	1240x325x250
			Outdoor unit			
	Power Supply	V-ph-Hz	240-1-50	240-1-50	240-1-50	240-1-50
	Refrigerant		R410-A	R410-A	R410-A	R410-A
	Compressor		Rotary	Rotary	Rotary	Rotary
	Sound Pressure Level	dB(a)	53	56	57	59
	Refrigerant Pipe Sizes (Suc/Liq)	Dia. mm	6.35/9.52 (1/4"- 3/8")	6.35/12.7 (1/4"- 1/2")	6.35/12.7 (1/4"- 1/2")	9.52/15.88 (3/8"- 5/8")
	Refrigerant pre charge length	M	5	5	5	5
	Unit Dimensions WxDxH		760x256x552	820x300x605	902x307x650	900x360x805

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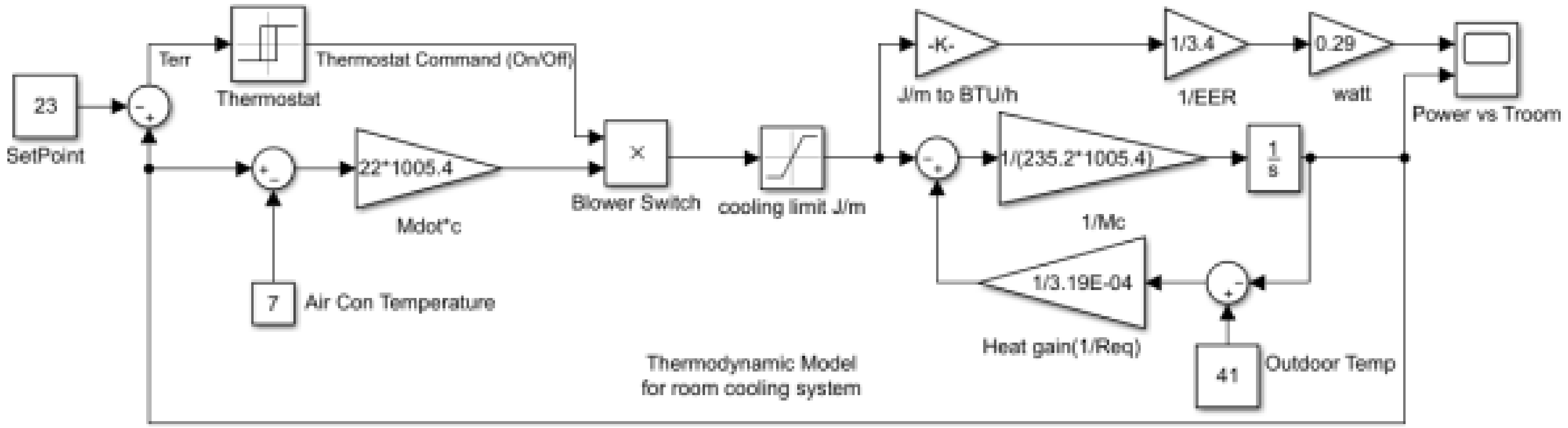
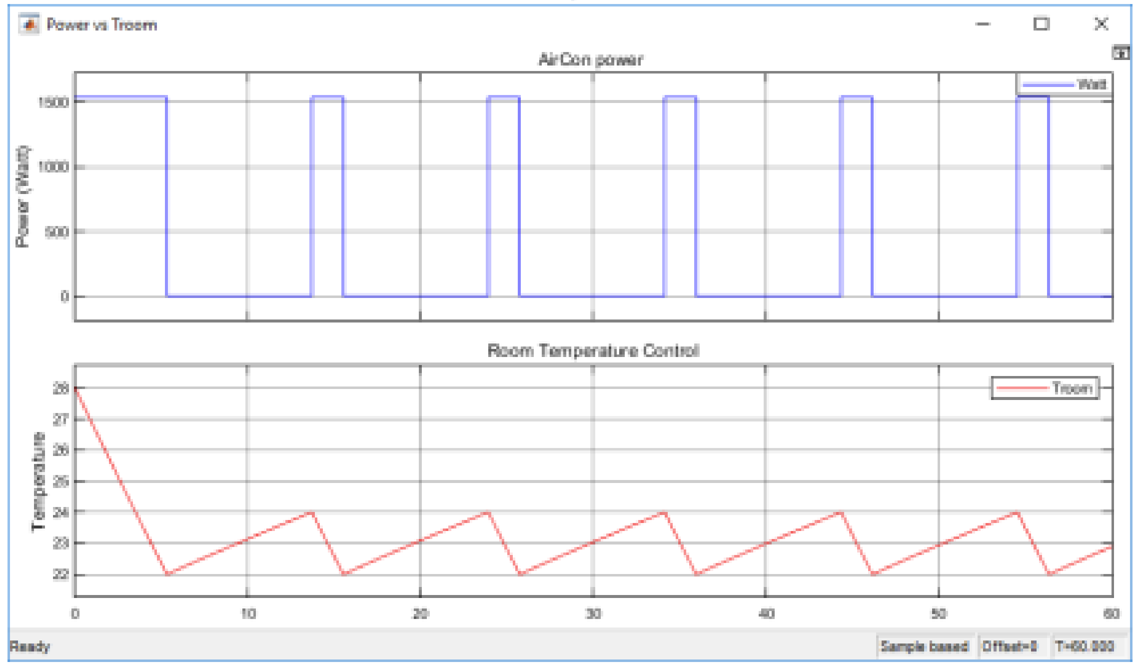
Modeling and simulation





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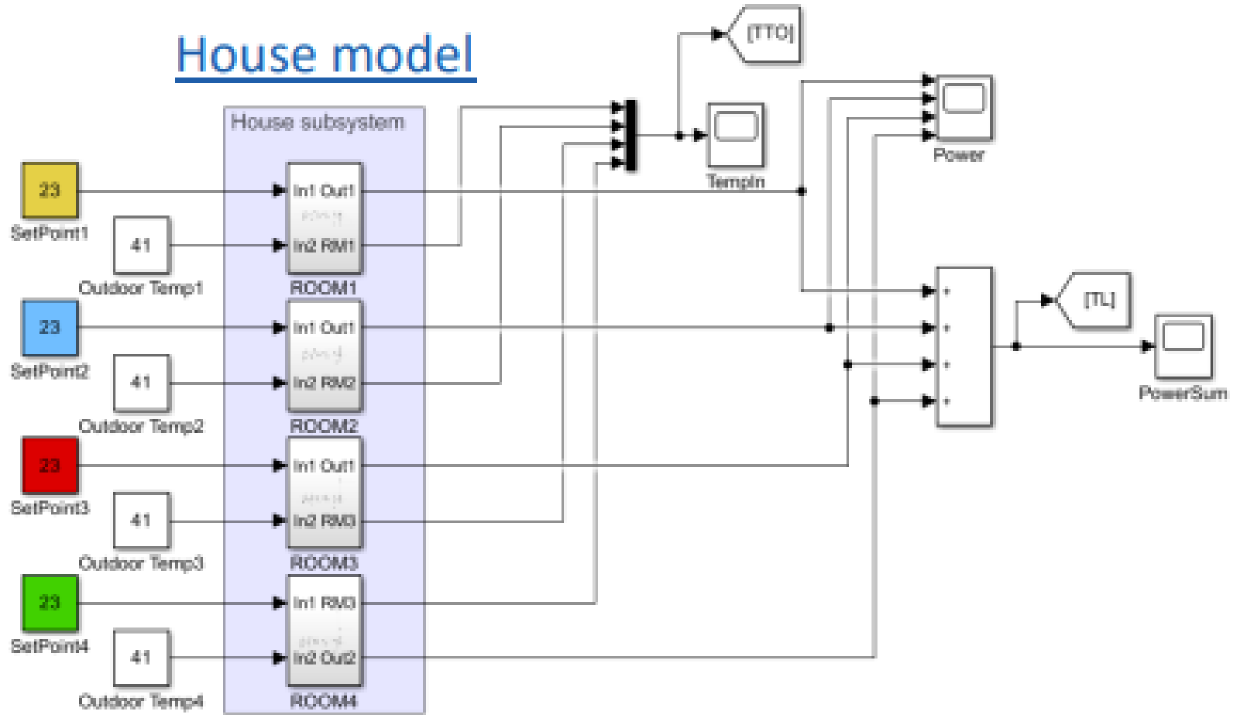
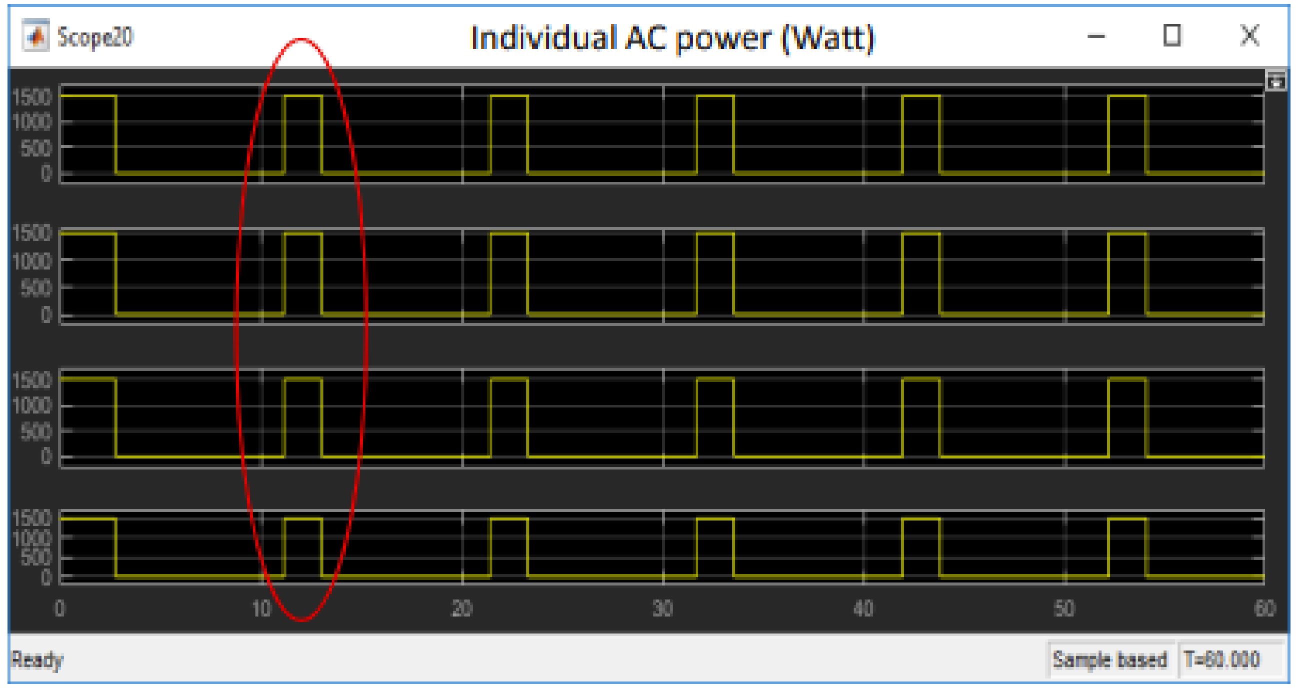
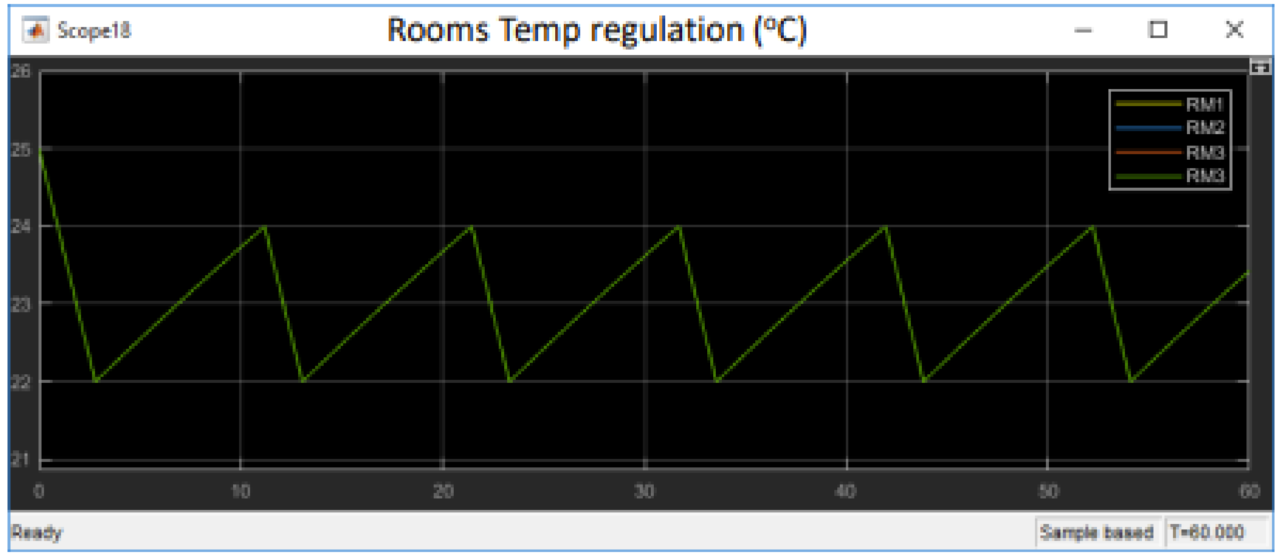
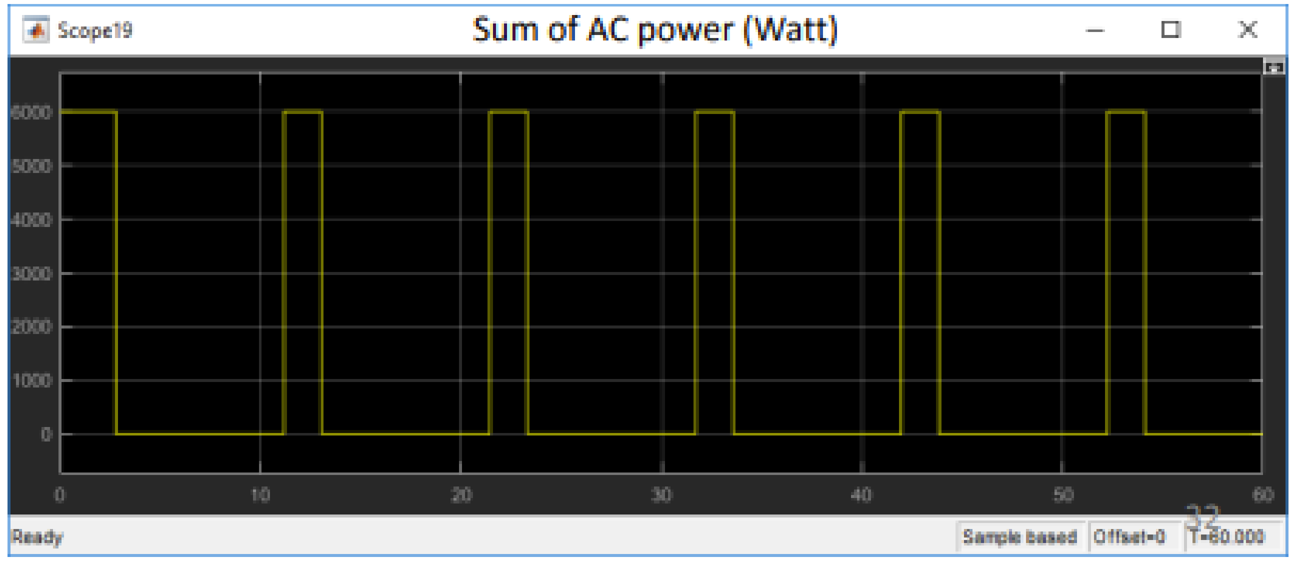
Modeling and simulation

House model





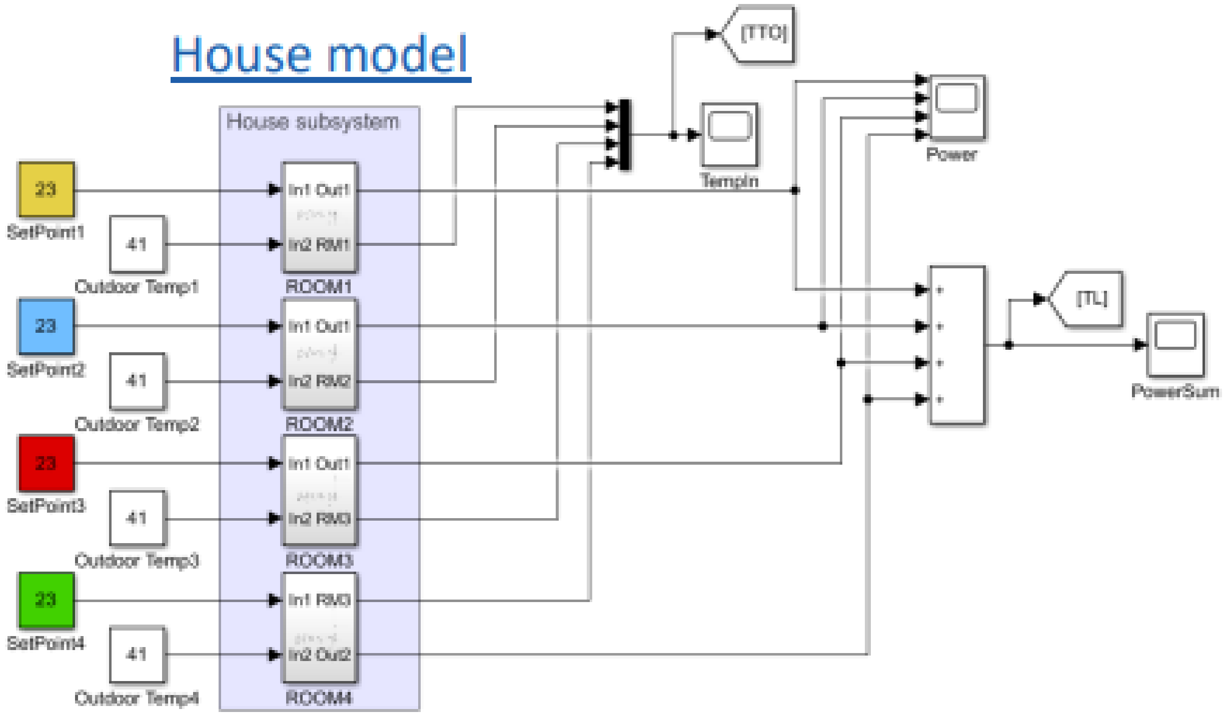


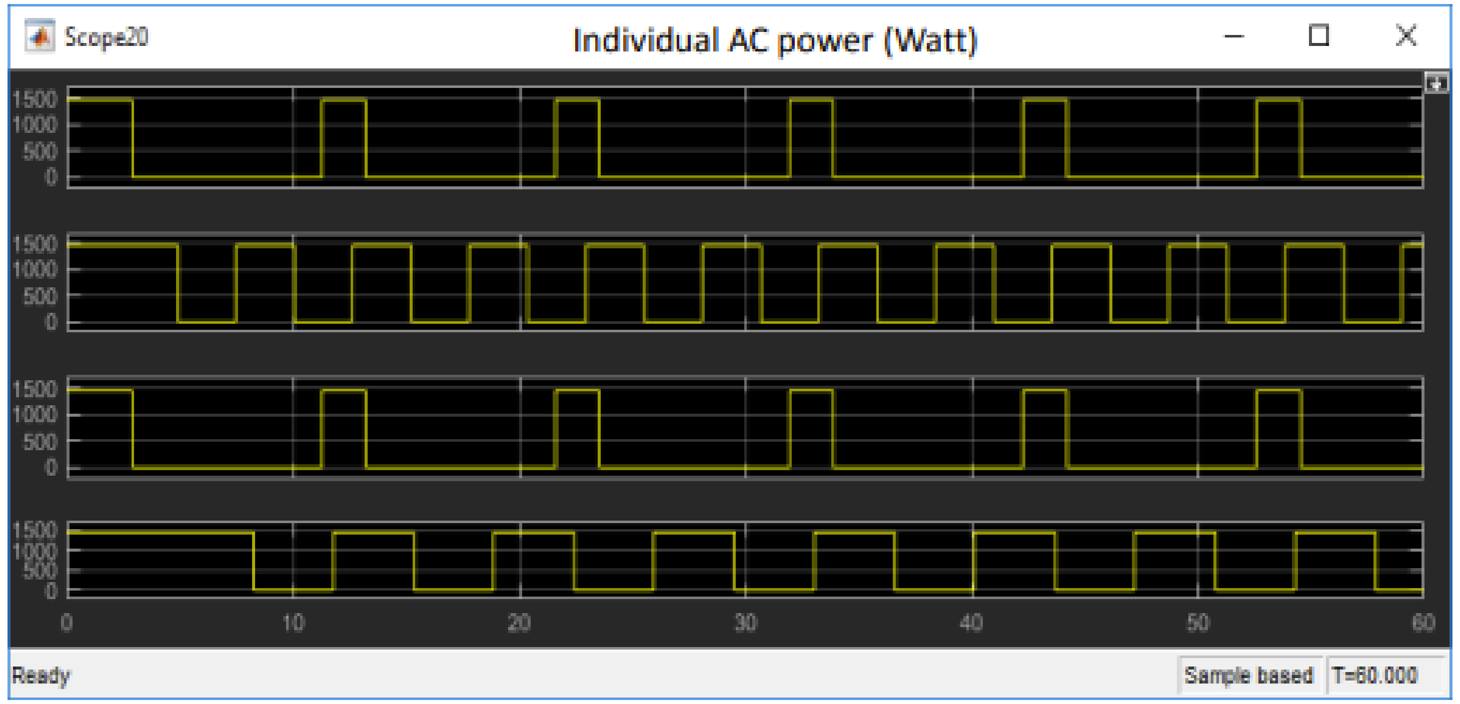


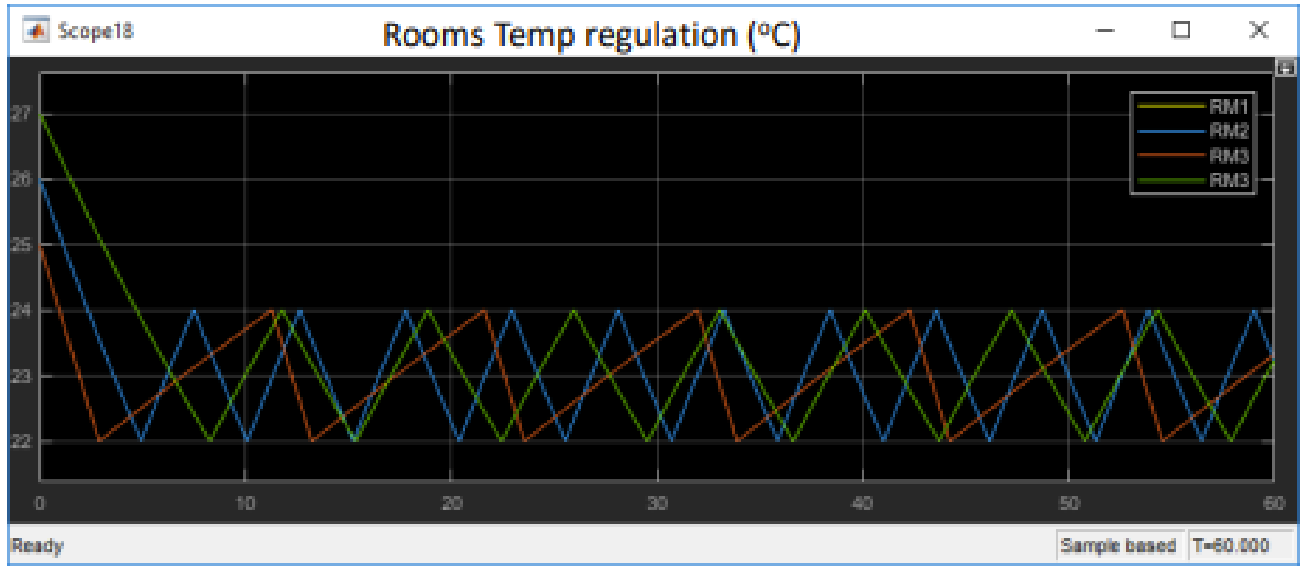
Modeling and simulation

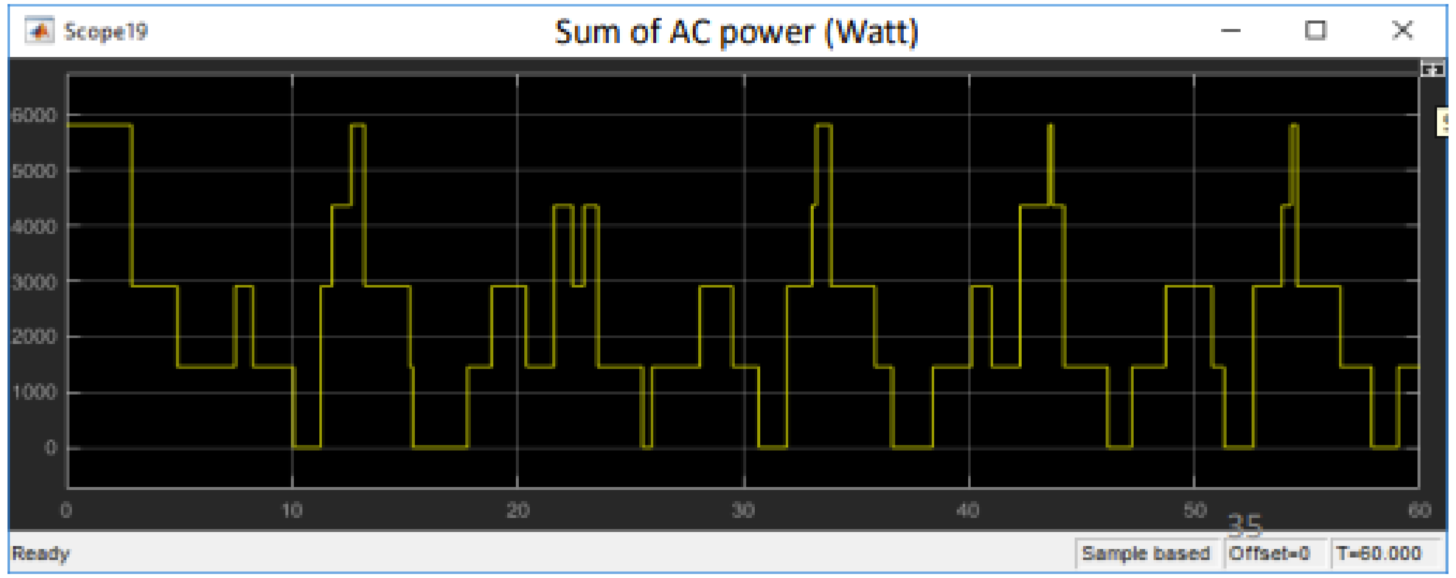
Slightly varied IC & Req

House model





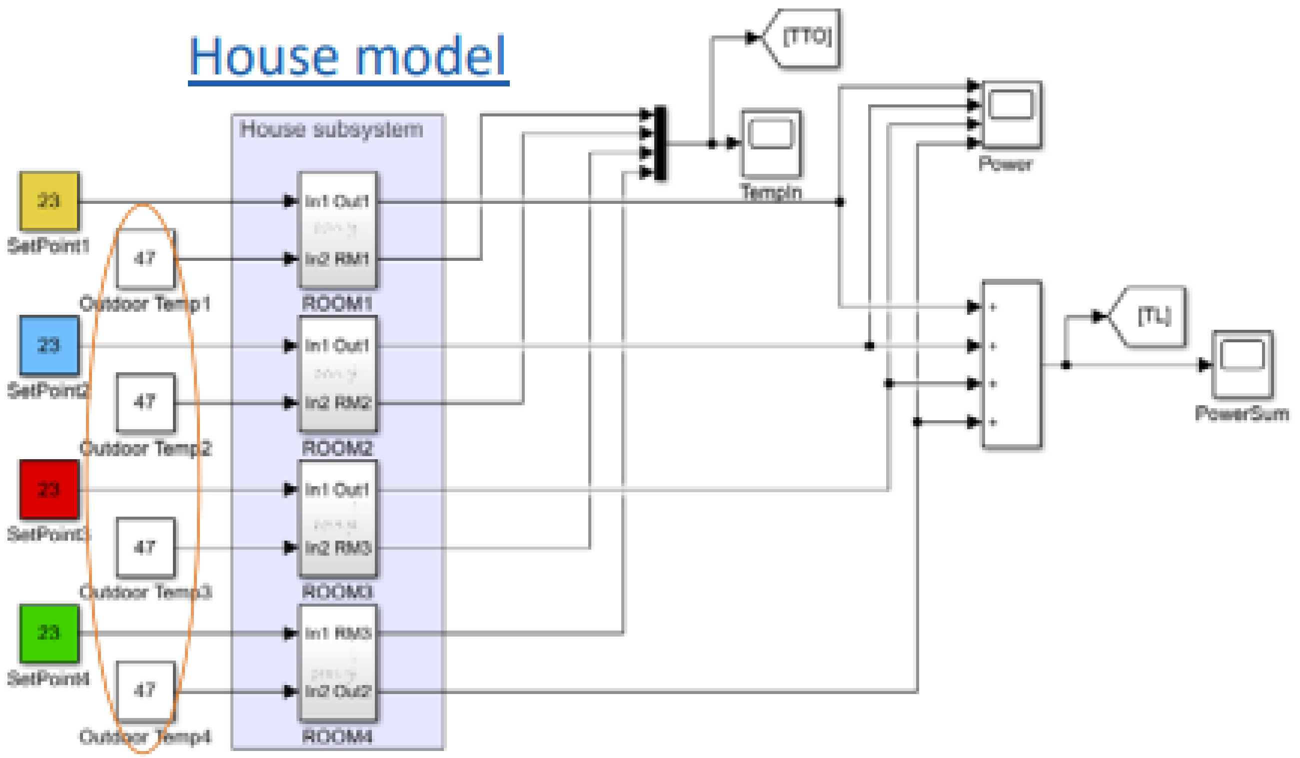


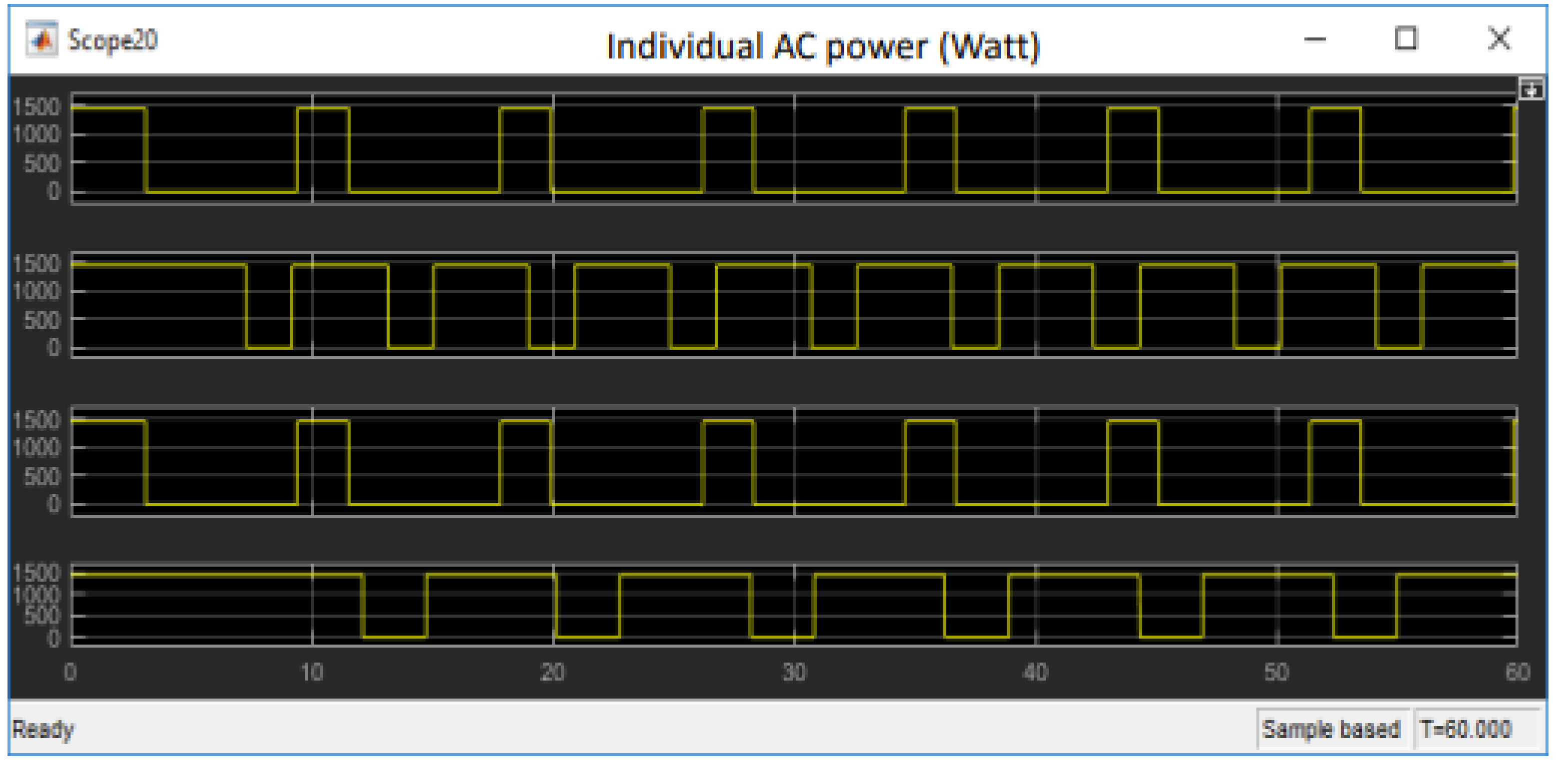


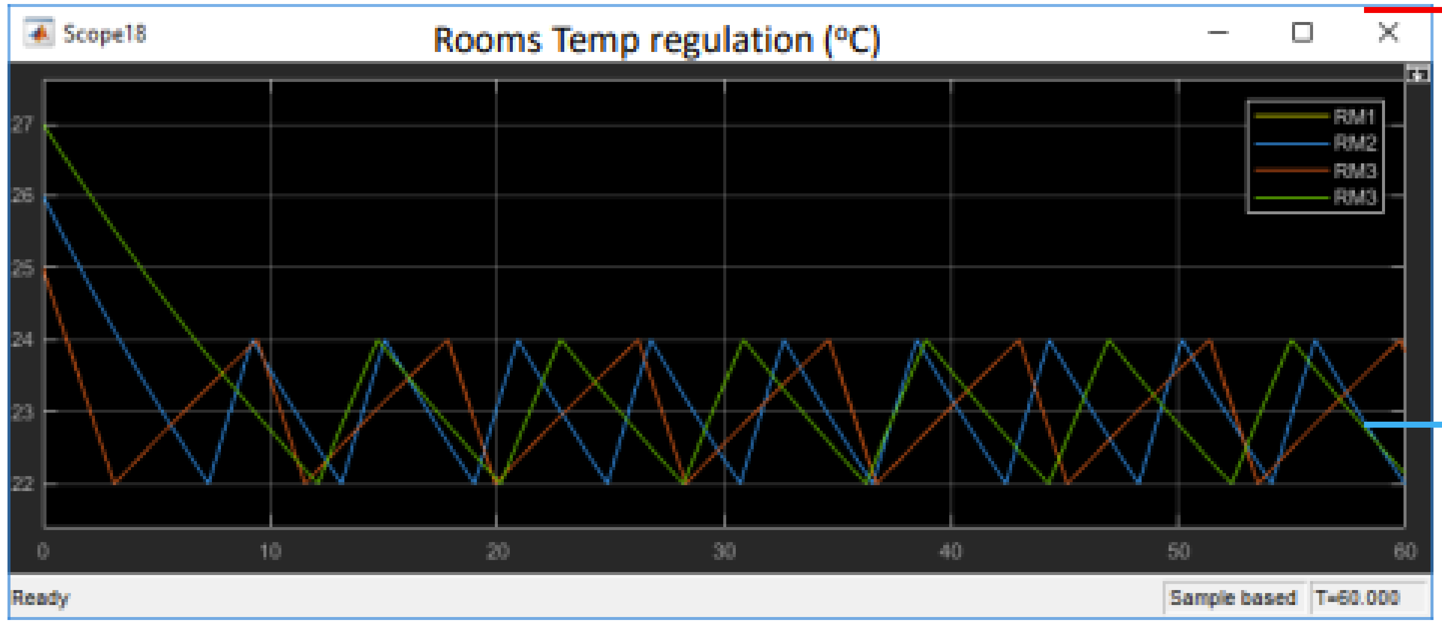
Simulation results

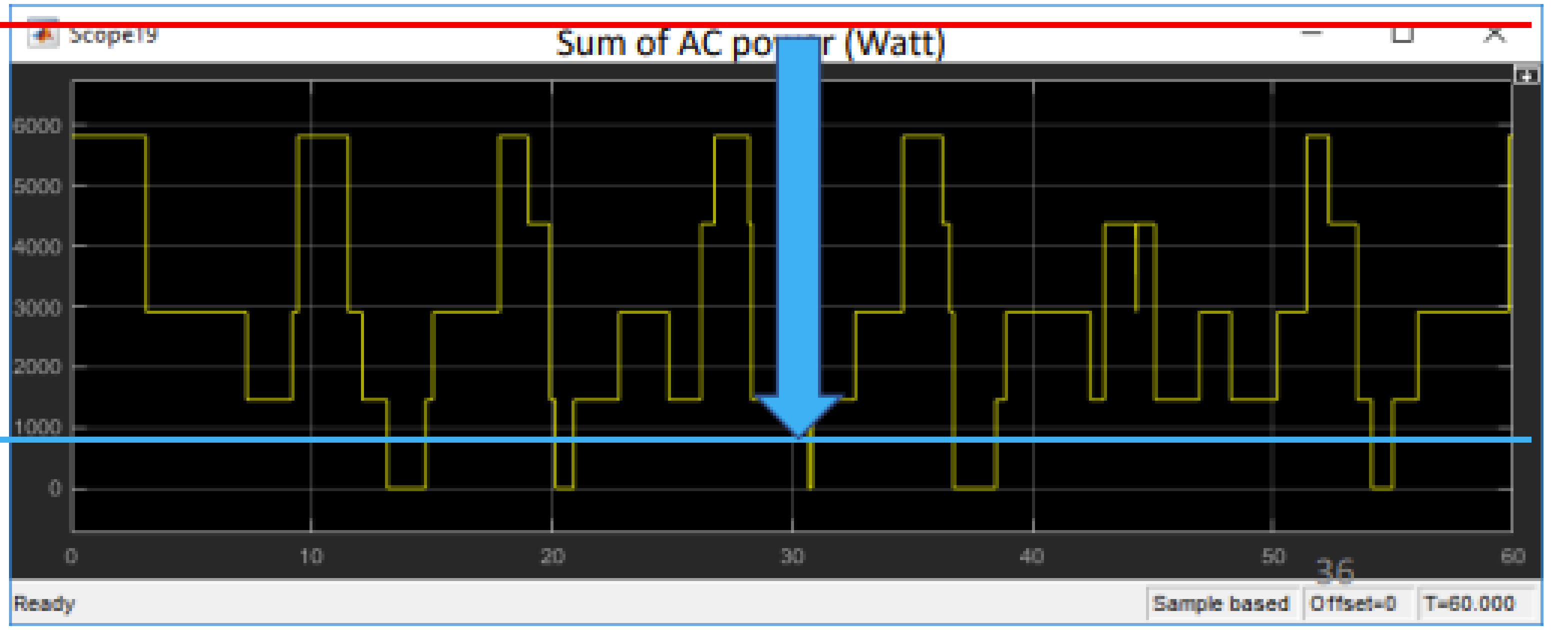
Outdoor temp raised from 41 to 47

House model

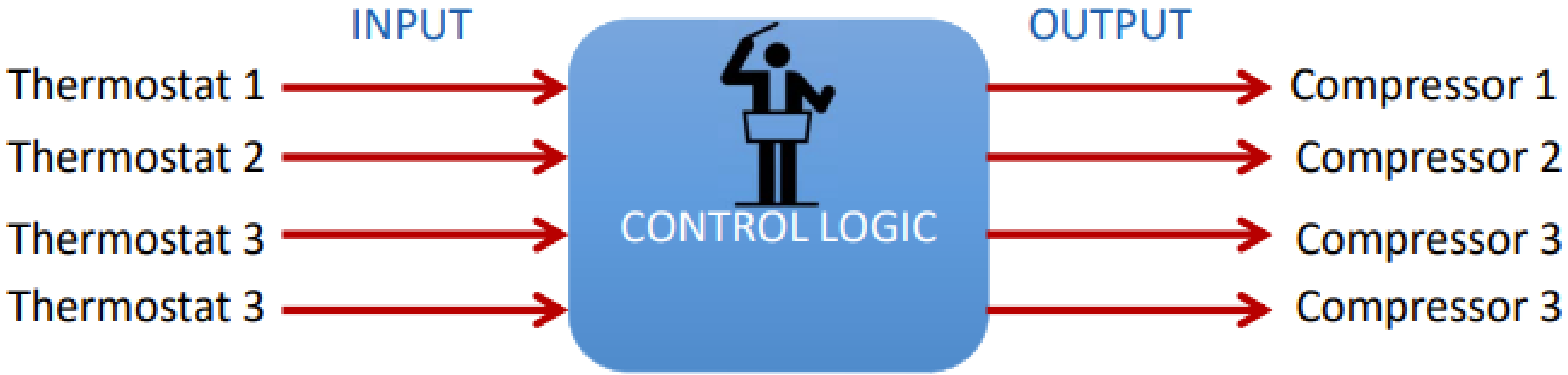








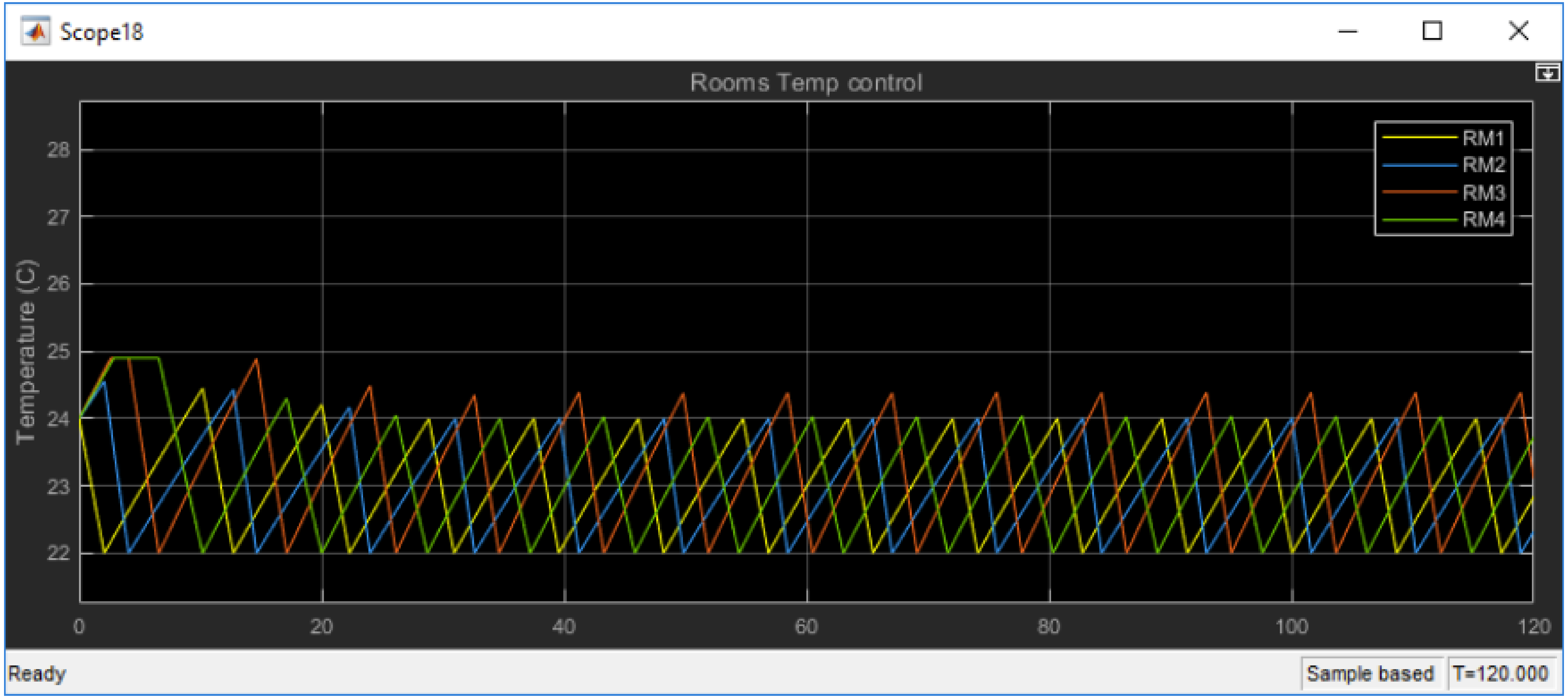
Building the AC control system



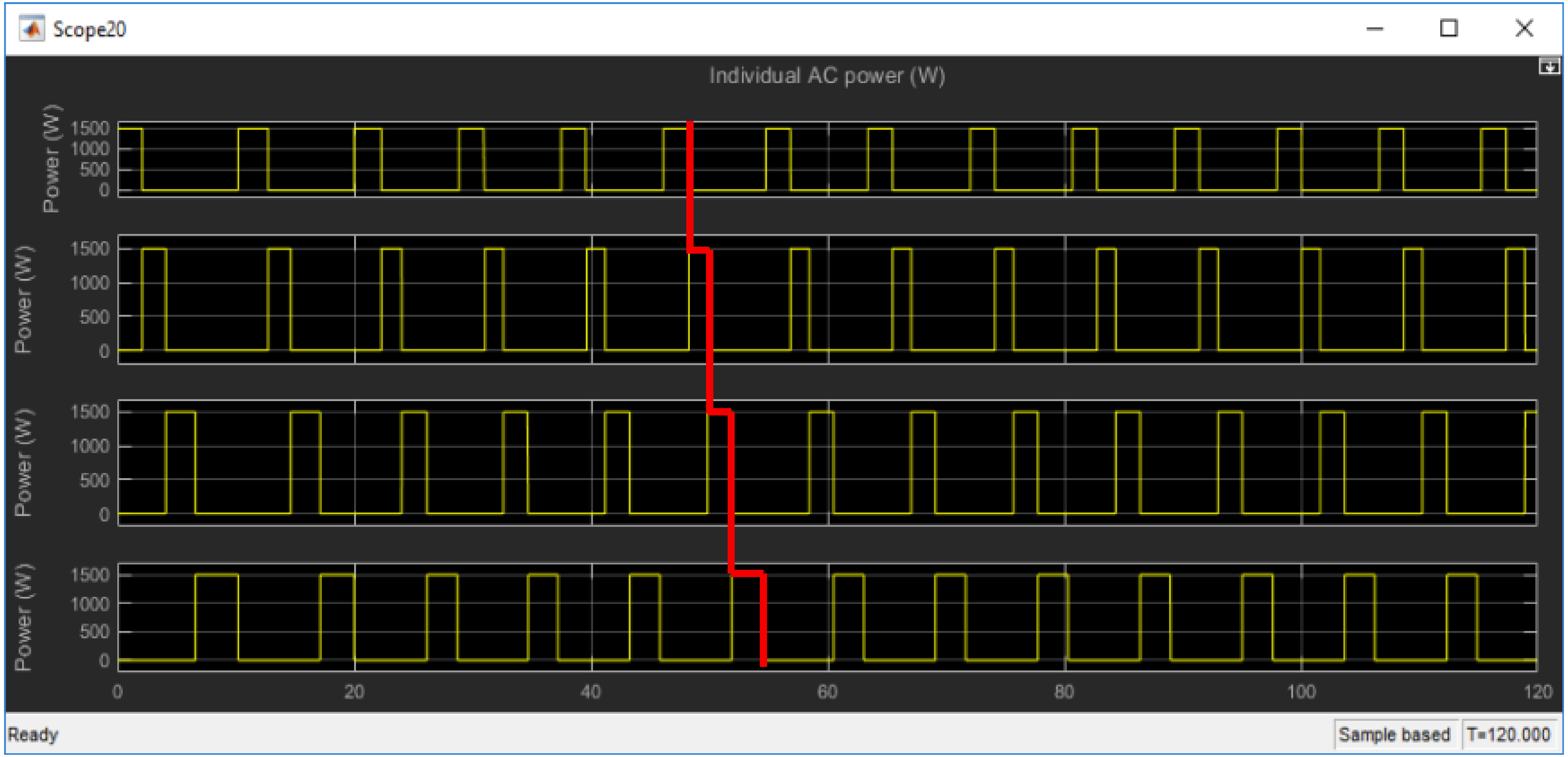
- A control logic has been developed to minimize excessive power consumption
- The control system receives cooling demand (input) from individual AC thermostats and sends output command (on/off) to multiple compressors
- The control logic is built using Matlab Stateflow® toolbox

Stateflow® is an environment for modeling and simulating combinatorial and sequential decision logic based on state machines and flow charts.

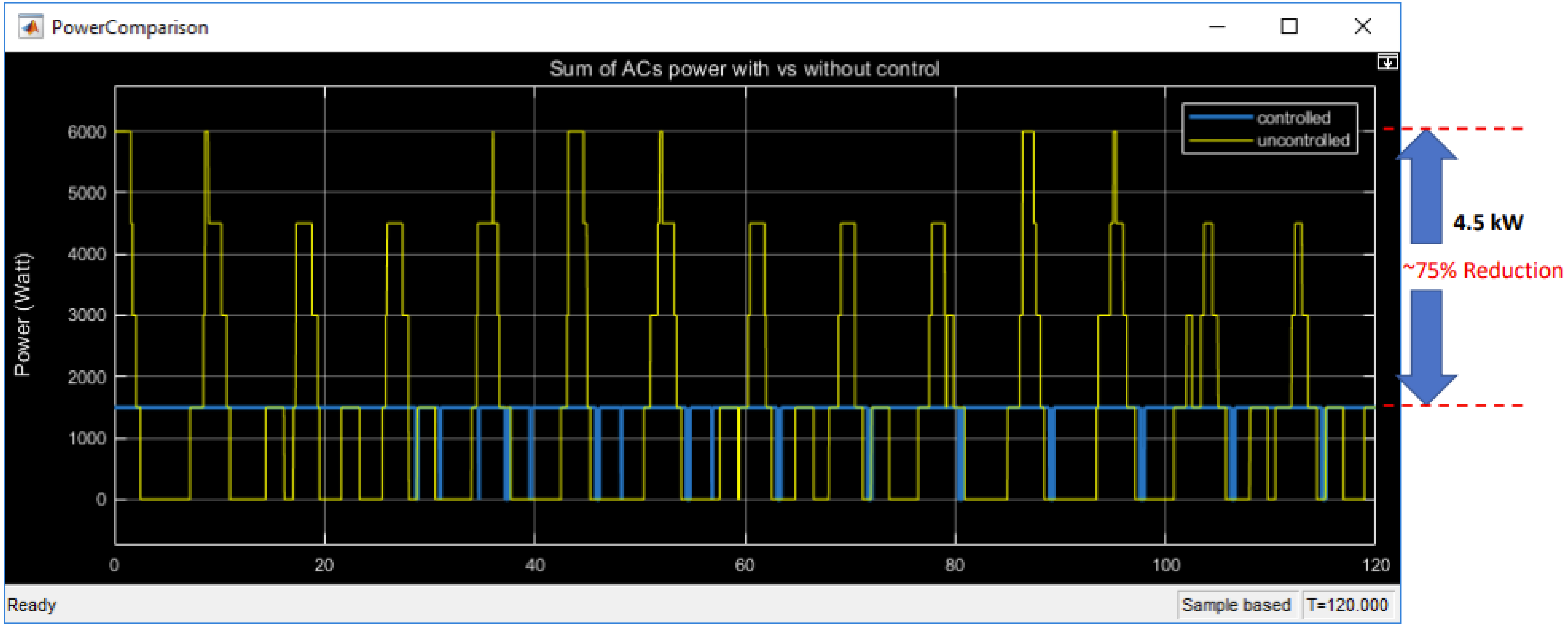
Results1: Temperature control



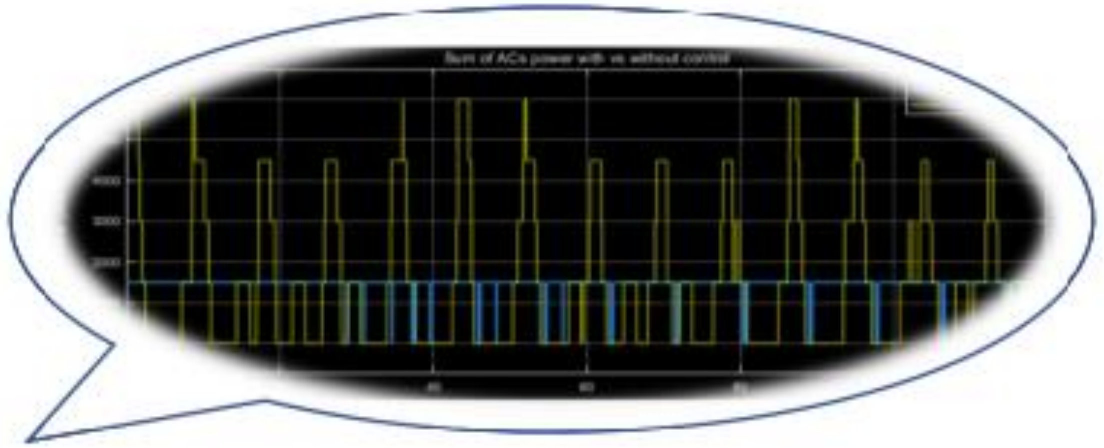
Results2: Load shifting



Results3: Power control



Findings



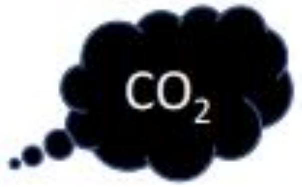
Up to ~75% reduction in peak power

~ 4.5 kW for a small 4-room house/flat (4x1.5 Acs)

Assuming 500k residential units to be targeted

4.5 kW x 500,000 houses = 2,250,000 kW = **2,250 MW**

- Amount of CO2 emission avoided ?



0.572Kg CO2/kWh → 0.572x2,250,000 =**1,287** tonne CO2/kWh per 1 hour

= 30.888 tonne per day → **11,274,120** tonne CO2 per year

- Number of new power plants avoided ?

- minimum of two big power plants OR >4 typical size plants (~300-500MW)
- capital and operational costs

-Other benefits?

Reduced transmission losses and grid stability

Part2: Group AC power control for mitigating power fluctuations

Problem to be addressed:

- Targeting the control of much more than 8 ACs
- Stabilizing the Power consumption profile to be as smooth as possible for grid stability.
- The use of thermodynamic of the building as a means of thermal storage.

In this work, the focus is on smoothing out the power curve profile with more flexibility with the indoor temp ~±2.5°C

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Part2: Group AC power control for mitigating power fluctuations

Proposed solution; design a control system based on Quadratic programming technique and use of outdoor temp forecasting

Discretized AC Group model

For controller design, the thermal model of the house can be represented as a state-space model format as follows

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) + E \\ y(t) = Cx(t) \end{cases}$$

$$\dot{\tilde{x}}(t) = A\tilde{x}(t) + Bu(t) \quad \tilde{x} = x - T_{amb}$$

Standard SS

$$\tilde{x}_{k+1,j} = A_j \tilde{x}_{k,j} + B_j u_{k,j} \qquad A_j = e^{A\Delta T}$$

$$j \in [1, N_{AC}], k \in [0, N_T - 1] \qquad B_j = \left(\int_0^T e^{A\sigma} d\sigma\right) B$$

discrete

if we consider the time interval as $\Delta T = 2h$, so the time step number $N_T = 24/2 = 12$

$$P(k) = \sum_{j=1}^{N_{AC}} u_j(k) \approx const$$

(target for optimization)

Constraints

Solve for best power curve and acceptable in door temp range

$$x_{k,j} \in [20^\circ C, 25^\circ C]$$
$$j \in [1, N_{AC}], k \in [0, N_T - 1]$$

$$u_{k,j} \in \{0, 1\} * P_{AC}$$
$$j \in [1, N_{AC}], k \in [0, N_T - 1]$$

Cost function

$$J_u(k) = \left(\sum_{j=1}^{N_{AC}} u_j(k) - P_C(k)\right)' R \left(\sum_{j=1}^{N_{AC}} u_j(k) - P_C(k)\right)$$

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Part2: Group AC power control for mitigating power fluctuations

```
yalmip('clear')
clear all
nac=40;
nw=12;
P = intvar(nac,nw);
T = sdpvar(nac,nw);
Tout=[27.1;26.8;26.7;26.9;27.2;27.9;28.9;29.9;30.9;31.6;31.8;31.7;31.3;30.6
Tout=Tout(1:2:24);
 Ppv=3*ones(1,2*nw);
Ppv2=Ppv(1:2:24)+20*ones(1,12);
i=1:(nw-1);
s=1:nw;
F = [];
 F = [1>P>=0];
for g=1:nac
F = [F, 25>T(g,s)>20];
F = [F, T(g,i+1)==0.95*(T(g,i)-Tout(1,i))-1.0093*P(g,i)+Tout(1,i+1)];
end
obj=0;
a=0.59;
optimize(F,obj);
bbb=value(P);
eee=repmat(2*[1:nac]',1,nw)+bbb;
ttt=value(T);
ccc=sum(bbb);
plot(ttt');
figure;
stairs(eee');
figure;
plot(ccc,'-r');
hold on
plot(Ppv2*a);
save data;
```

Yalmip

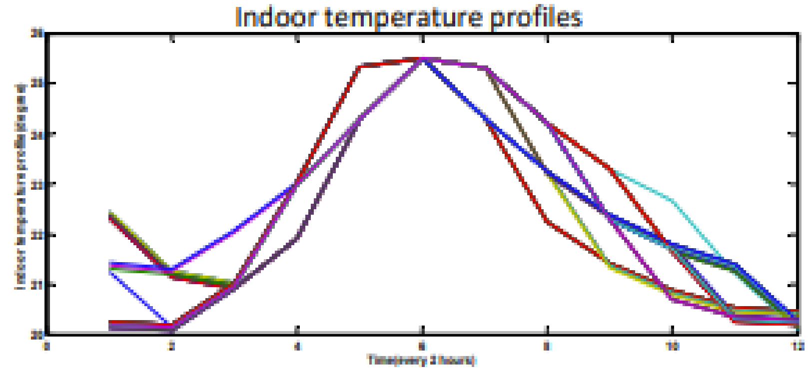
IBM CPLEX

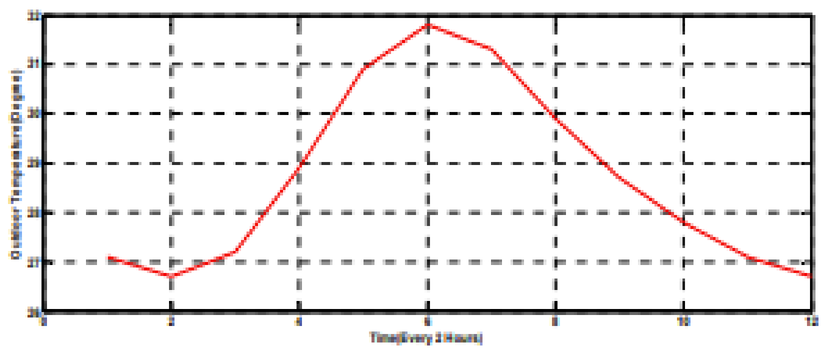
GUROBI OPTIMIZATION

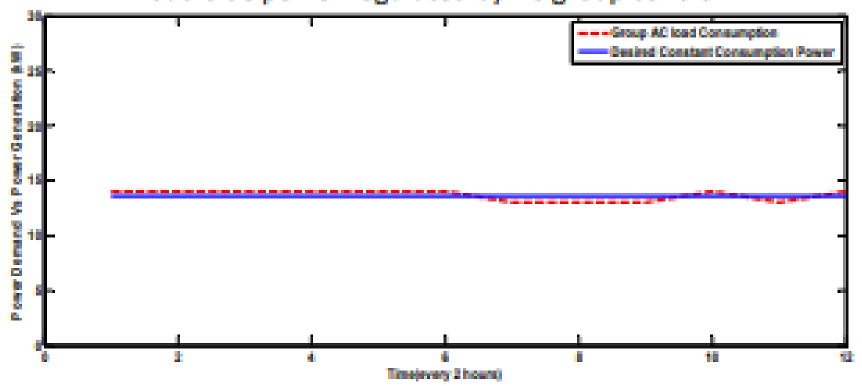
Part2:Group Power AC Control for mitigating power fluctuations

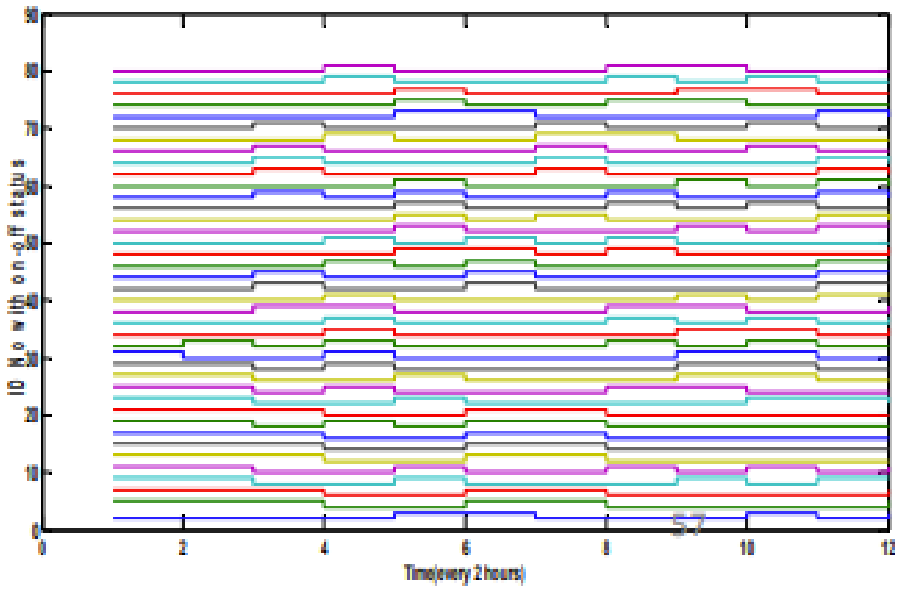
Summary & Results

- Novel group control strategy is able to regulate indoor temp within acceptable range.
- Based on the local ambient temperature profile, the AC group control optimization is performed as Mixed-Integer Quadratic Programming (MIQP) problem on a daily basis with constraints by an acceptable range of target indoor temperatures,
- The AC power consumption is controlled to maintain desired profile.
- The simulation results demonstrates effectiveness of the proposed control strategy to minimize power peaks and smooth out the load.

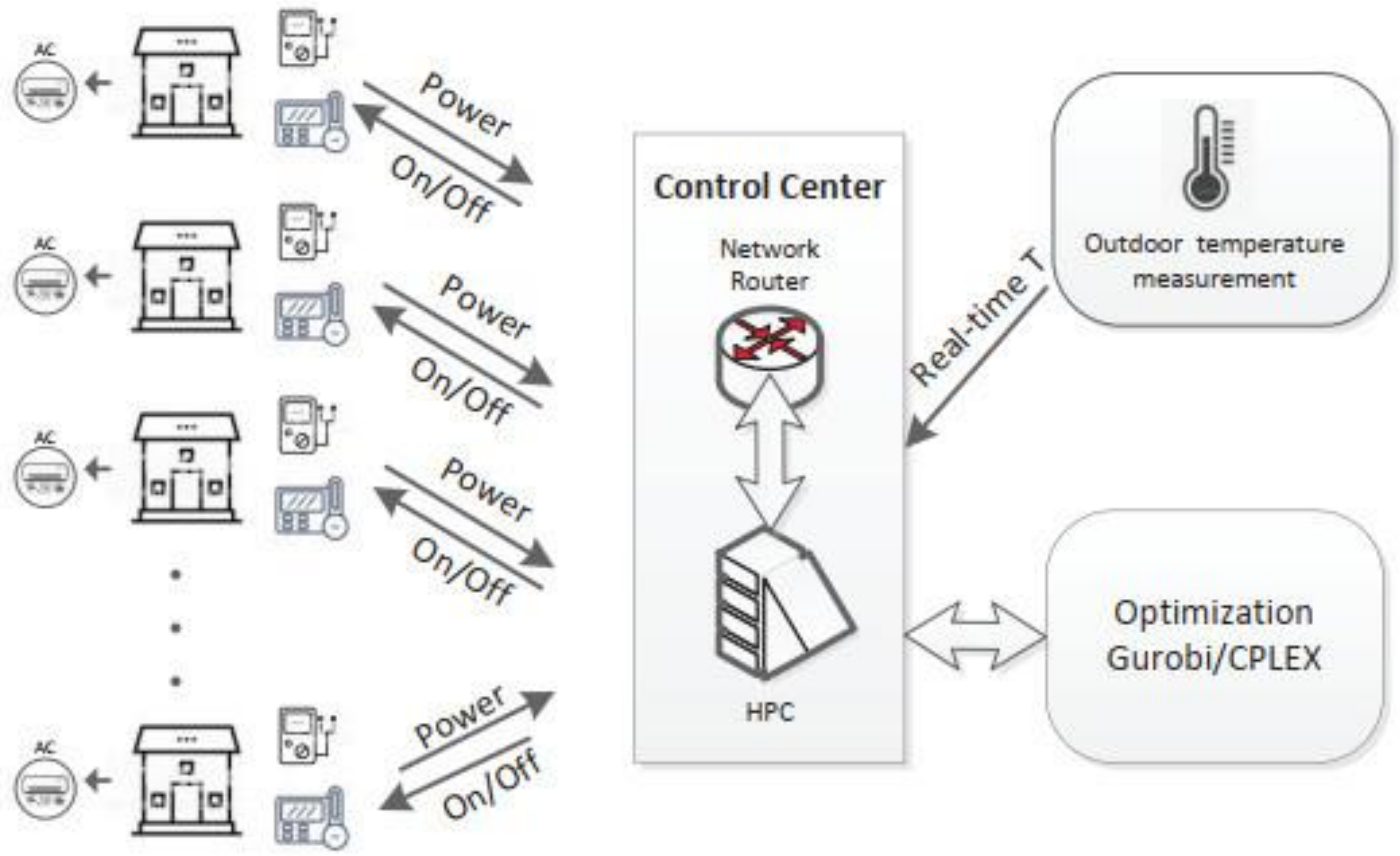






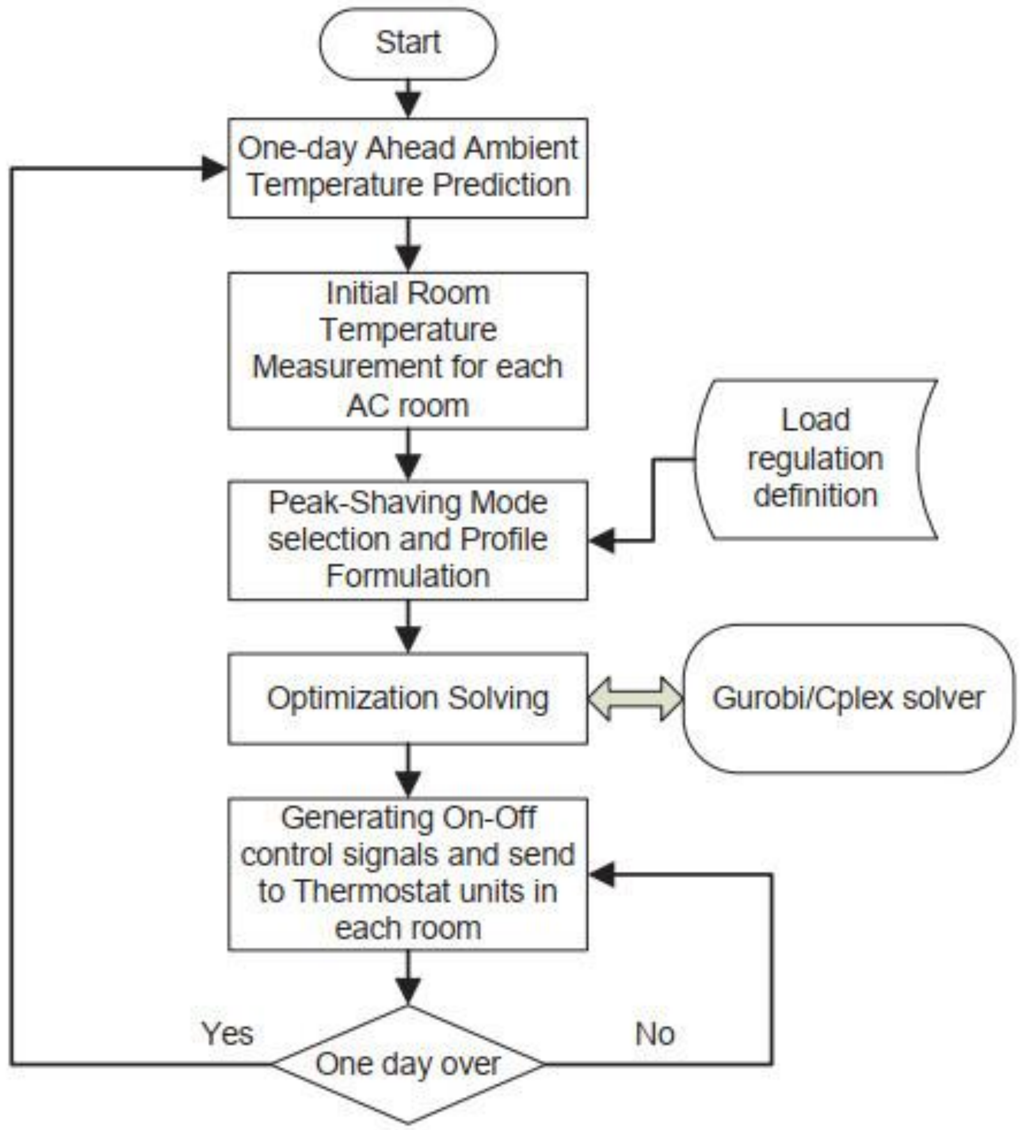


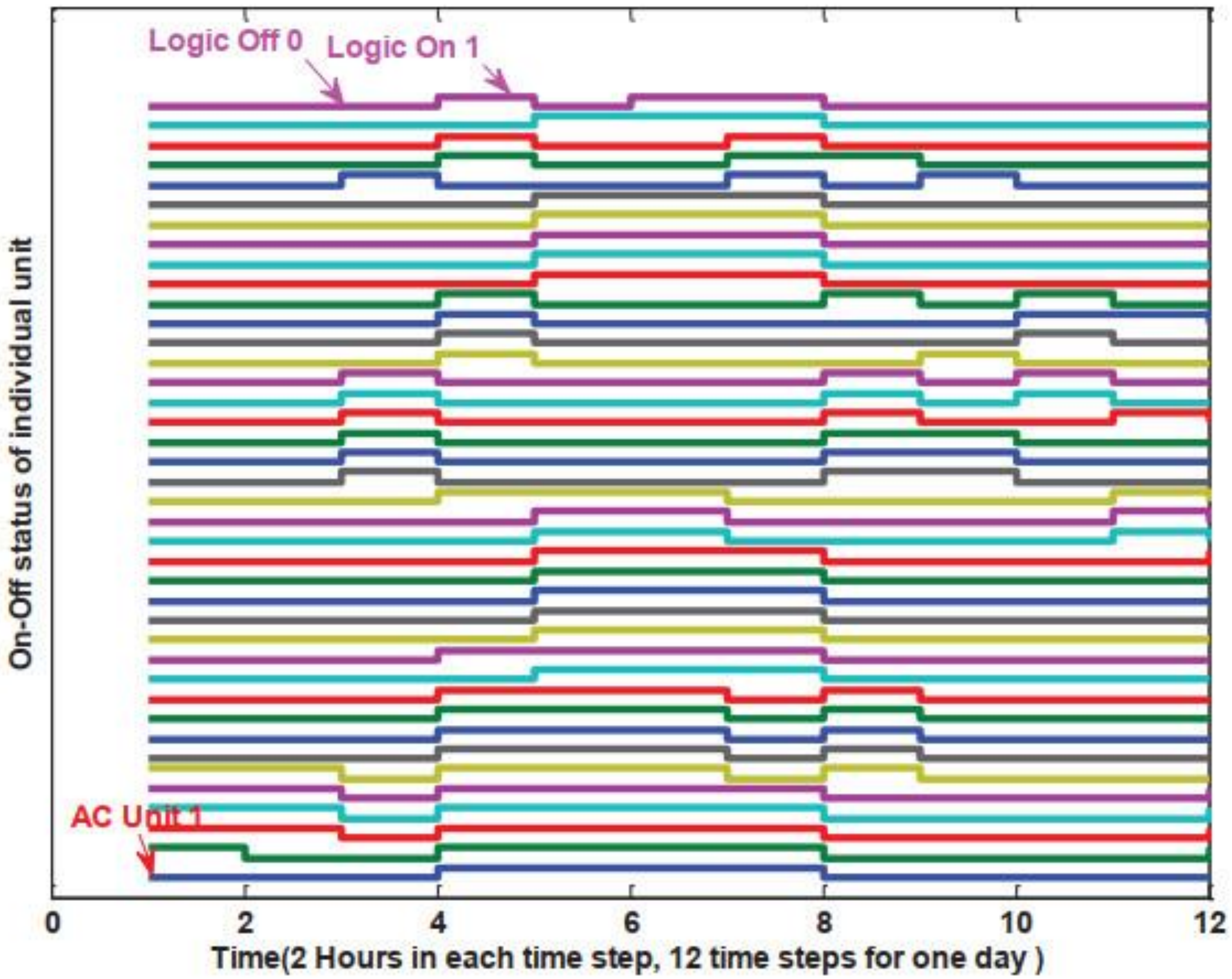
Alterative Storage Solution for Grid-connected PV-Storage-Air Conditioning System



40 AC Units

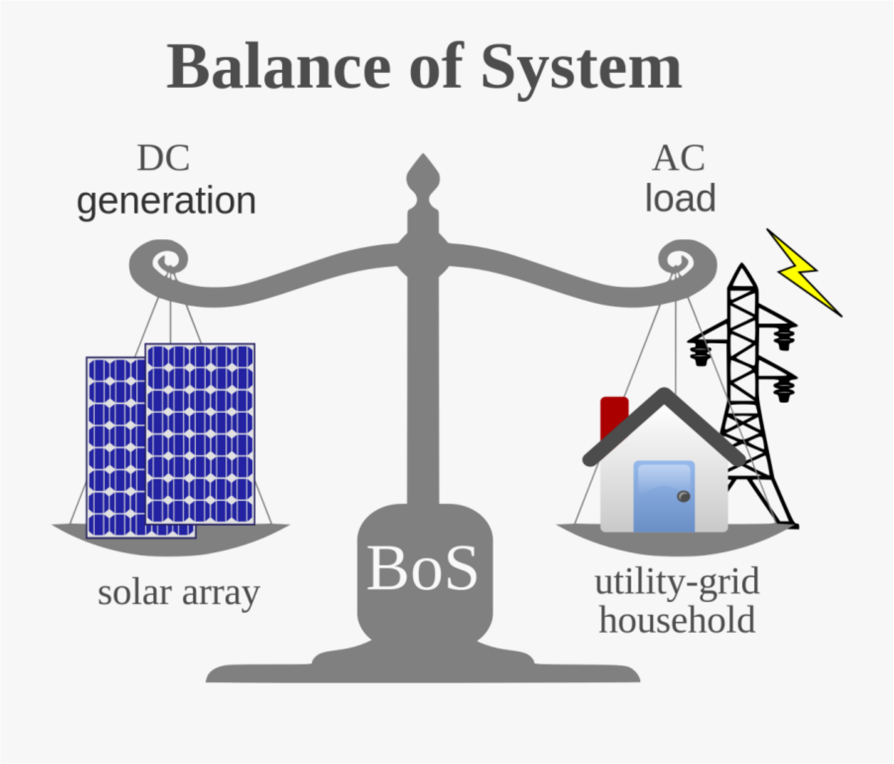
Alterative Storage Solution for Grid-connected PV-Storage-Air Conditioning System

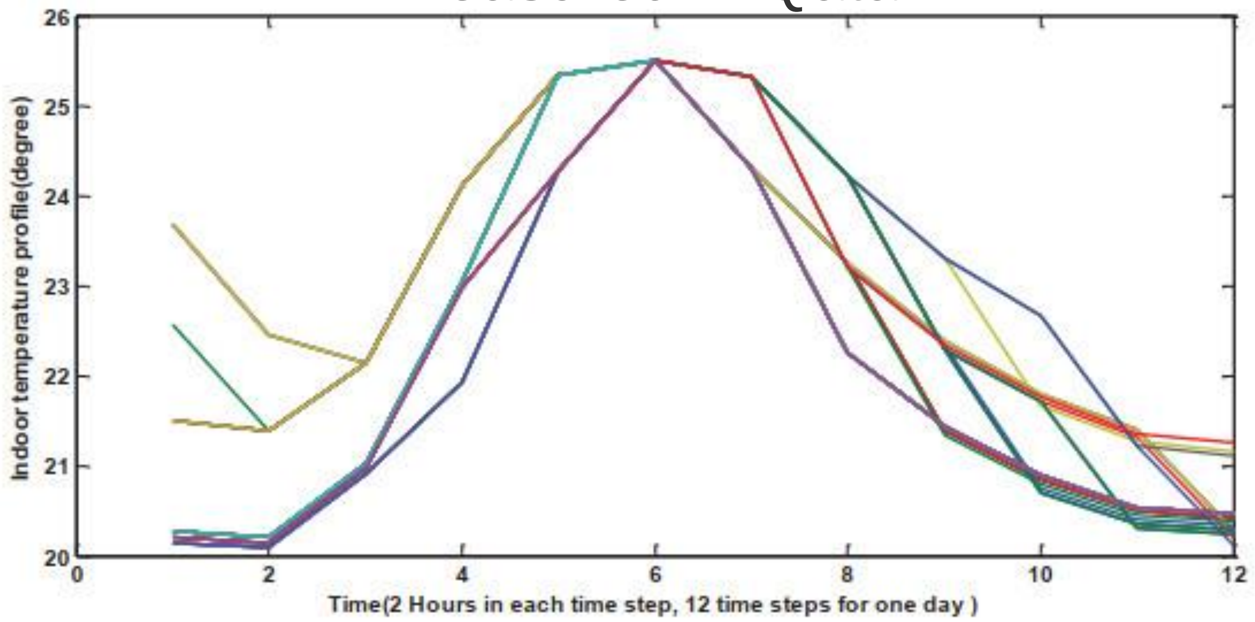




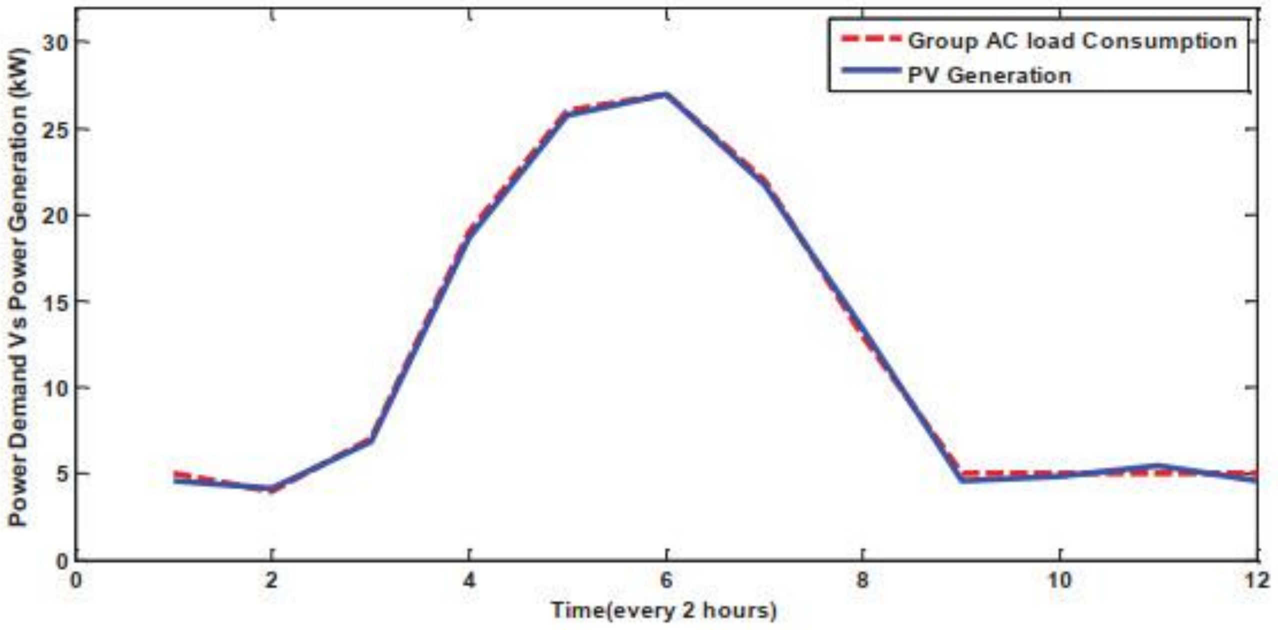
Air-Conditioner Group Control as virtual storage

Outdoor Temperature in One day measured in Qatar





Indoor temperature profiles under On-off Control

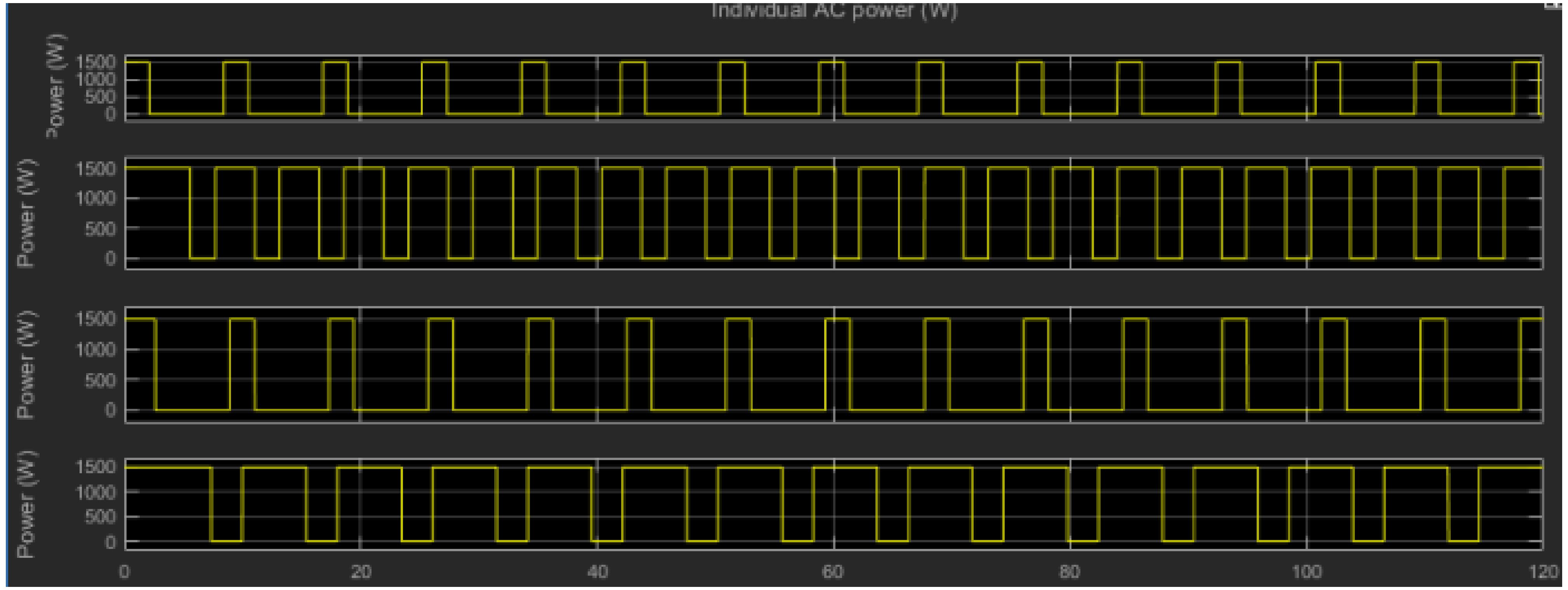


PV side Peak-shaving

Part3: Optimal On-Off Control for enhanced AC performance

Problem to be addressed: Control oscillation for optimum performance and maximum lifetime of AC

Which oscillation performance is ideal ?



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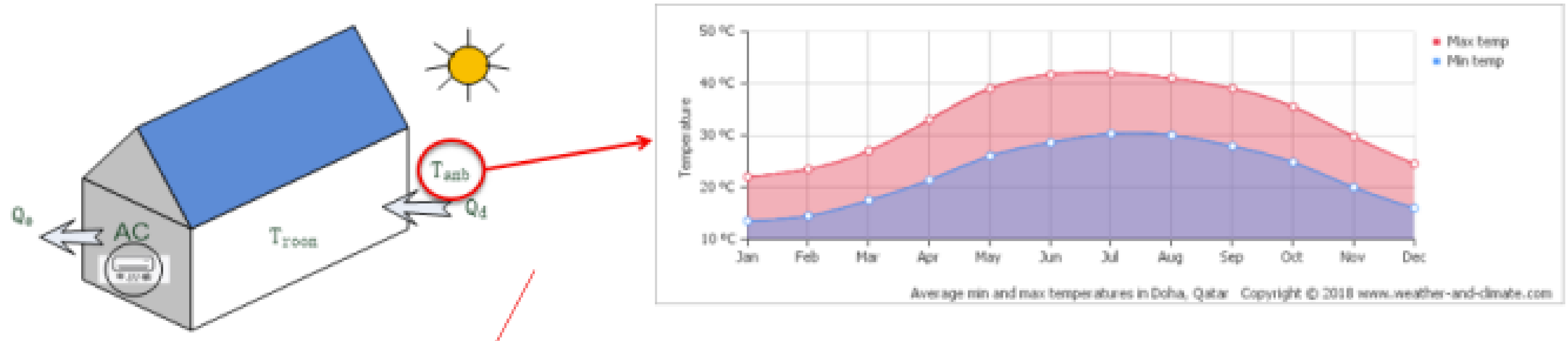
Part3: Optimal On-Off Control for enhanced AC performance

- Proposed solution



$$\frac{dT_{indoor}}{dt} = \frac{-1}{C_p mR} T_{indoor} + \frac{-1}{C_p m}\dot{Q}_e + \frac{1}{C_p mR} T_{amb}$$

$$\begin{cases} \dot{x}(t) = Ax(t) + Bu(t) + E \\ y(t) = Cx(t) \end{cases}$$

$$u = \begin{cases} P_{AC} & t \in T_{on} \\ 0 & t \in T_{off} \end{cases}$$

$$A = \frac{-1}{C_p mR_t} \quad B = \frac{-1}{C_p m} \quad E = \frac{1}{C_p mR_t} T_{amb}$$

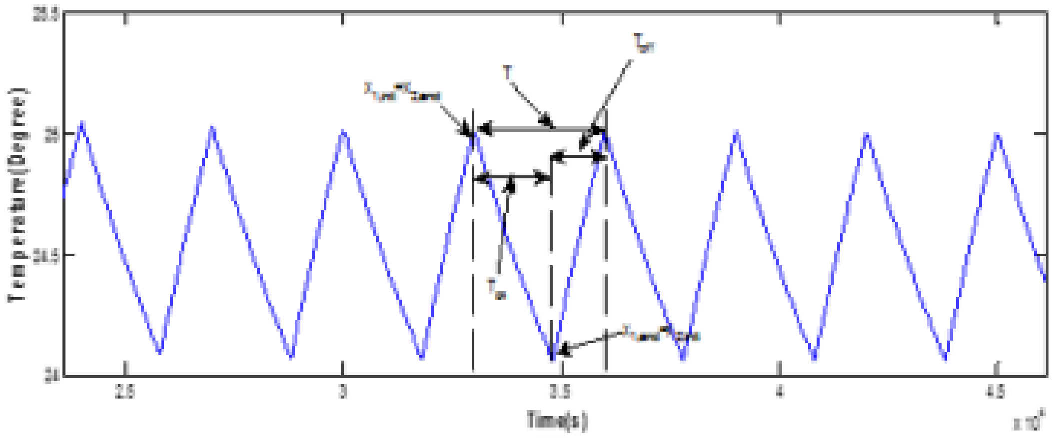
T_{indoor}	Indoor temperature of the house.
T_{amb}	Outdoor temperature of the house
$\dot{Q}_d$	Heat flow from outdoor to the house
$\dot{Q}_e$	Heat removed by AC system
R_t	Thermal resistance from outdoor to the house
m	Mass of the indoor air
C_p	Heat capacities of the room air

$$\begin{cases} x_1(t) = \dfrac{Bu_{on}(t)+E}{-A} + (x_{1,init} + \dfrac{Bu_{on}(t)+E}{A})e^{At} \\ x_2(t) = \dfrac{Bu_{off}(t)+E}{-A} + (x_{1,end} + \dfrac{Bu_{off}(t)+E}{A})e^{A(t-\alpha T)} \end{cases}$$

Part3: Optimal On-Off Control for enhanced AC performance

- Proposed solution

On-off Thermal Dynamics



$$\begin{cases} x_{1,end} = x_{2,init} \\ x_{1,init} = x_{2,end} \\ T = T_{on} + T_{off} \\ T_{on} = \alpha T \end{cases}$$

Duty ratio

constraint equation

Solution to dynamic equation

$$\begin{cases} x_{1,init} = \dfrac{\dfrac{Bu_{on}+E}{-A} + \dfrac{Bu_{on}-Bu_{off}}{-A} e^{A \cdot T_{off}} + \dfrac{Bu_{on}+E}{A} e^{A \cdot T}}{1-e^{A \cdot T}} \\ x_{1,end} = \dfrac{\dfrac{Bu_{on}+E}{-A} + \dfrac{Bu_{off}+E}{A} e^{A \cdot T} + \dfrac{Bu_{on}-Bu_{off}}{A} \cdot e^{A \cdot T_{on}}}{1-e^{A \cdot T}} \end{cases}$$

Cost function for multiple-objective optimization

On-time Cost | Off-time Cost | switching Cost

$$J(T_{on}, T_{off}) = \frac{Q \cdot \int_0^{T_{on}} (x_1 - x_{ref})^2 \, dt}{T_{on} + T_{off}} + \frac{Q \cdot \int_{T_{on}}^{T_{on}+T_{off}} (x_1 - x_{ref})^2 \, dt + RJ_{sw}}{T_{on} + T_{off}}$$

Here, J denotes the cost of one period of oscillation when the on-off control is stabilized, and J_{sw} denotes the switching cost due to weariness and set to be constant for the sake of simplicity; Q and R denote the weight coefficients of COP cost and switching cost, respectively; x_{ref} denotes the target house temperature, which is set to a constant value in this case.

Convex Optimization Problem

$$\begin{cases} T \in [100, 10000] \\ \alpha \in [0,1] \end{cases}$$

Sec

Optimization variables

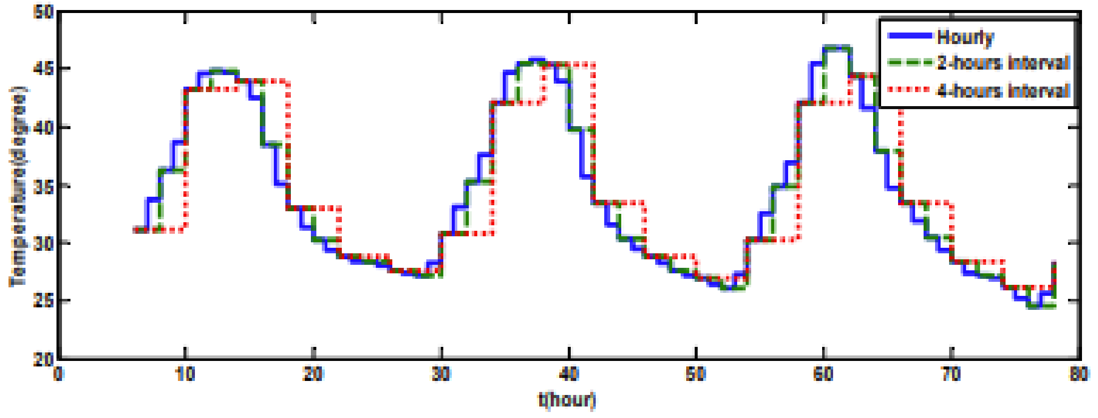
$$[T_{opt}, \alpha_{opt}] = \arg\min_{T,\alpha} J$$

Solution space to solve for minimum

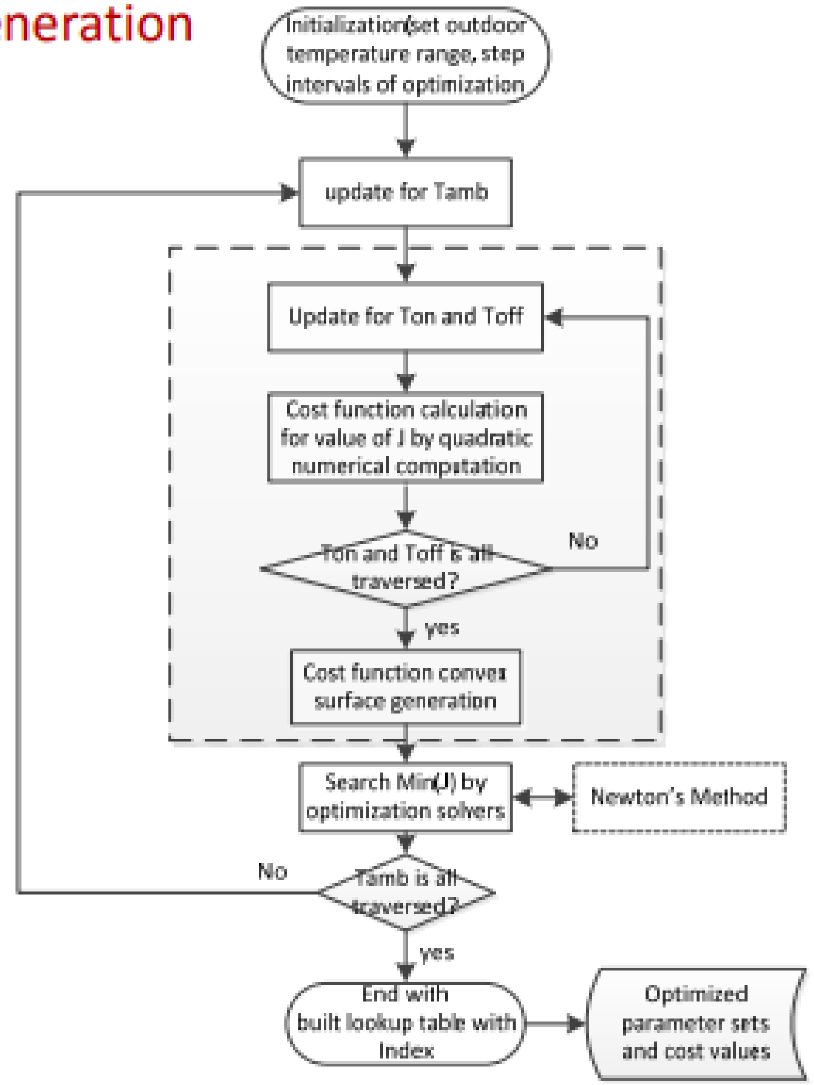
Part3: Optimal On-Off Control for enhanced AC performance

- Proposed solution

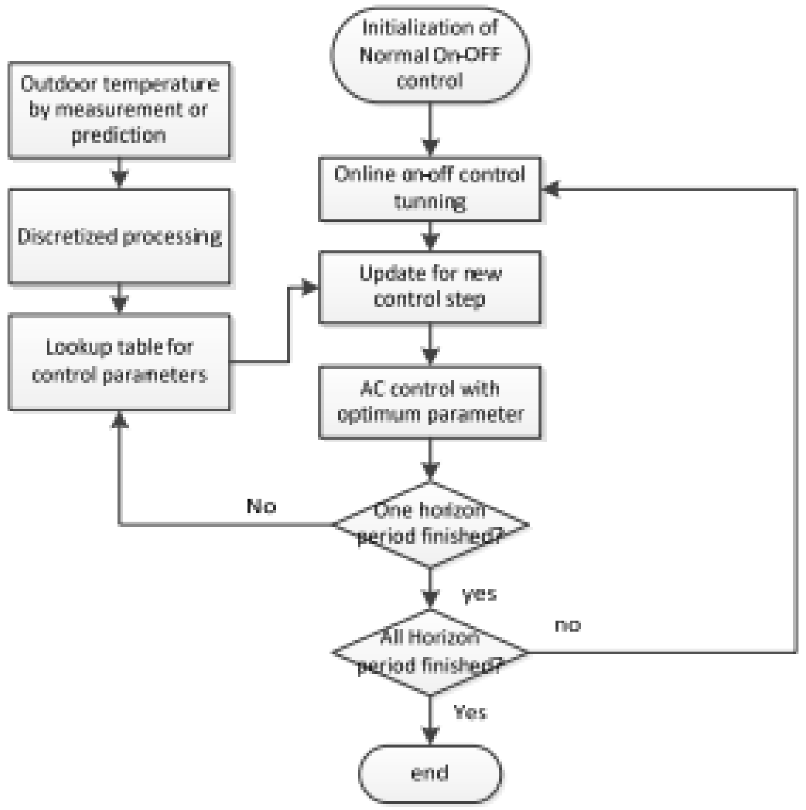
1) Temperature profile discretization



2) Offline Optimization & lookup table generation



3) Online adaptive control scheme



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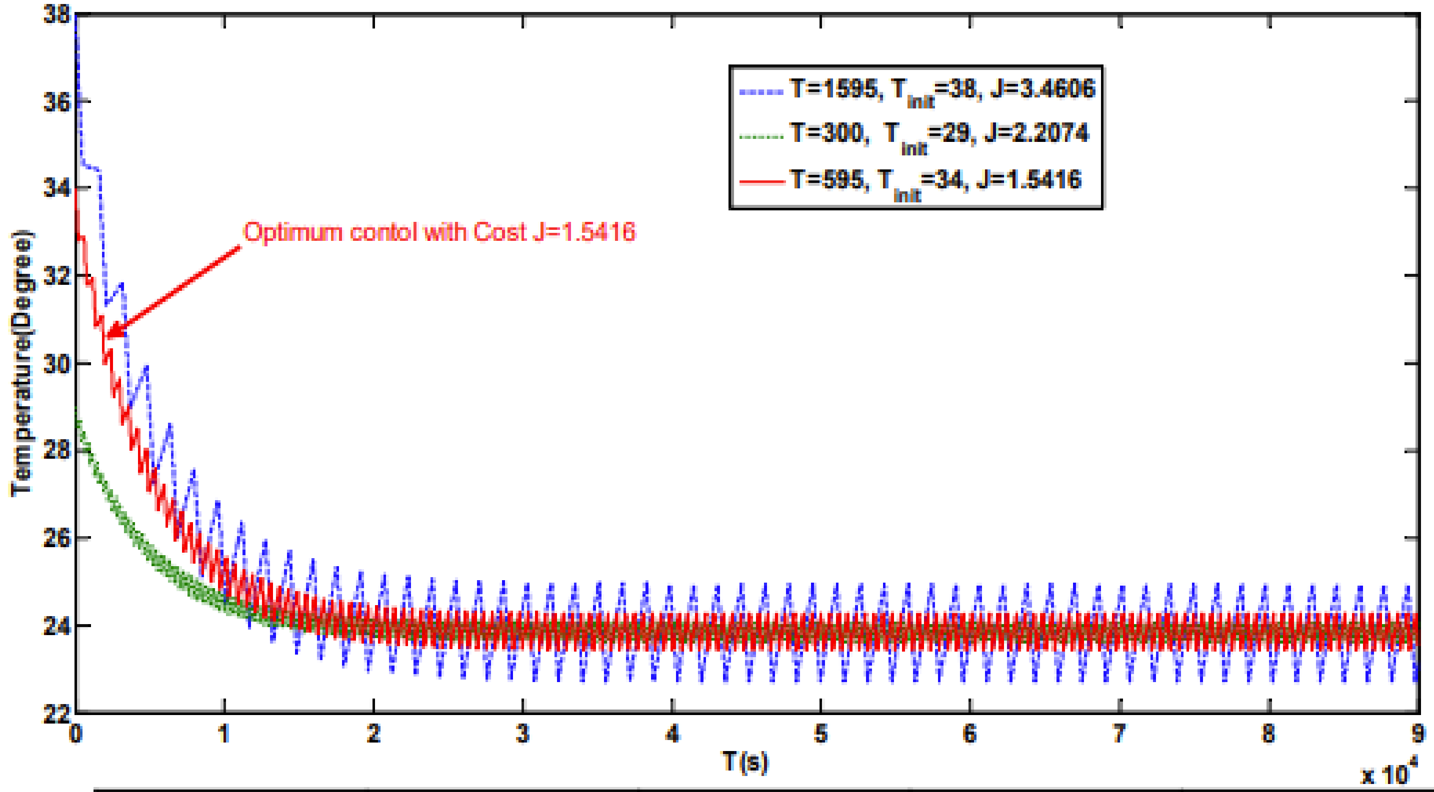
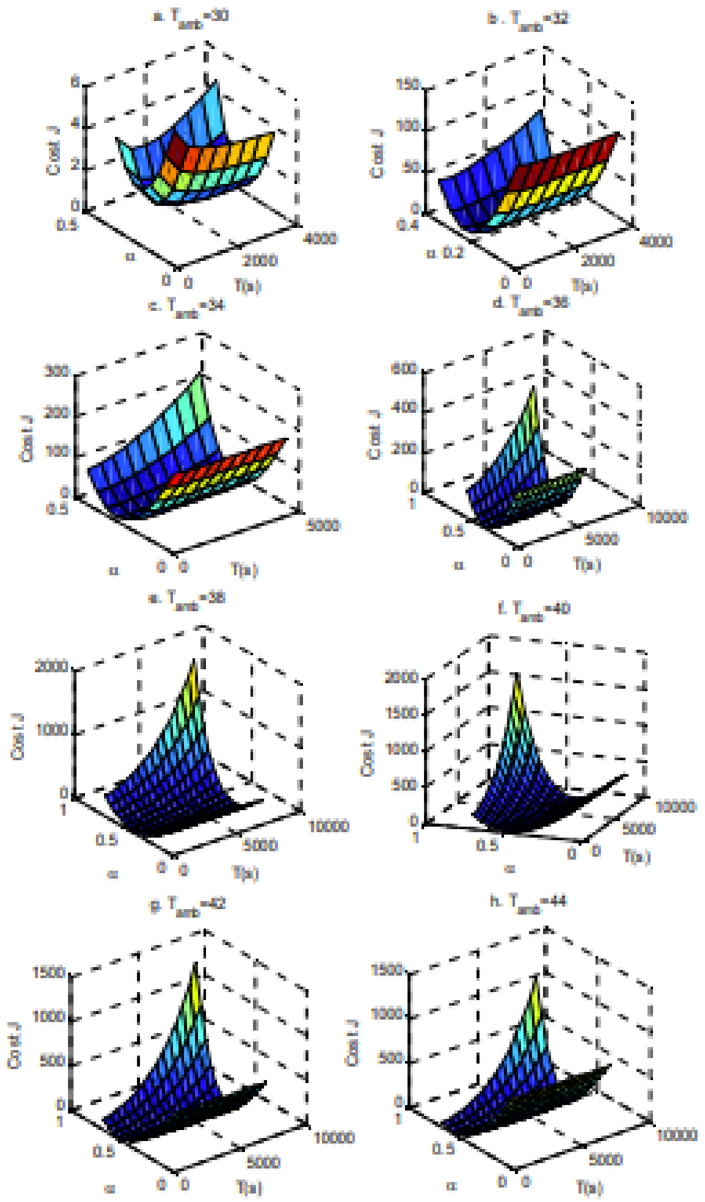
Part3: Optimal On-Off Control for enhanced AC performance

Offline optimization results

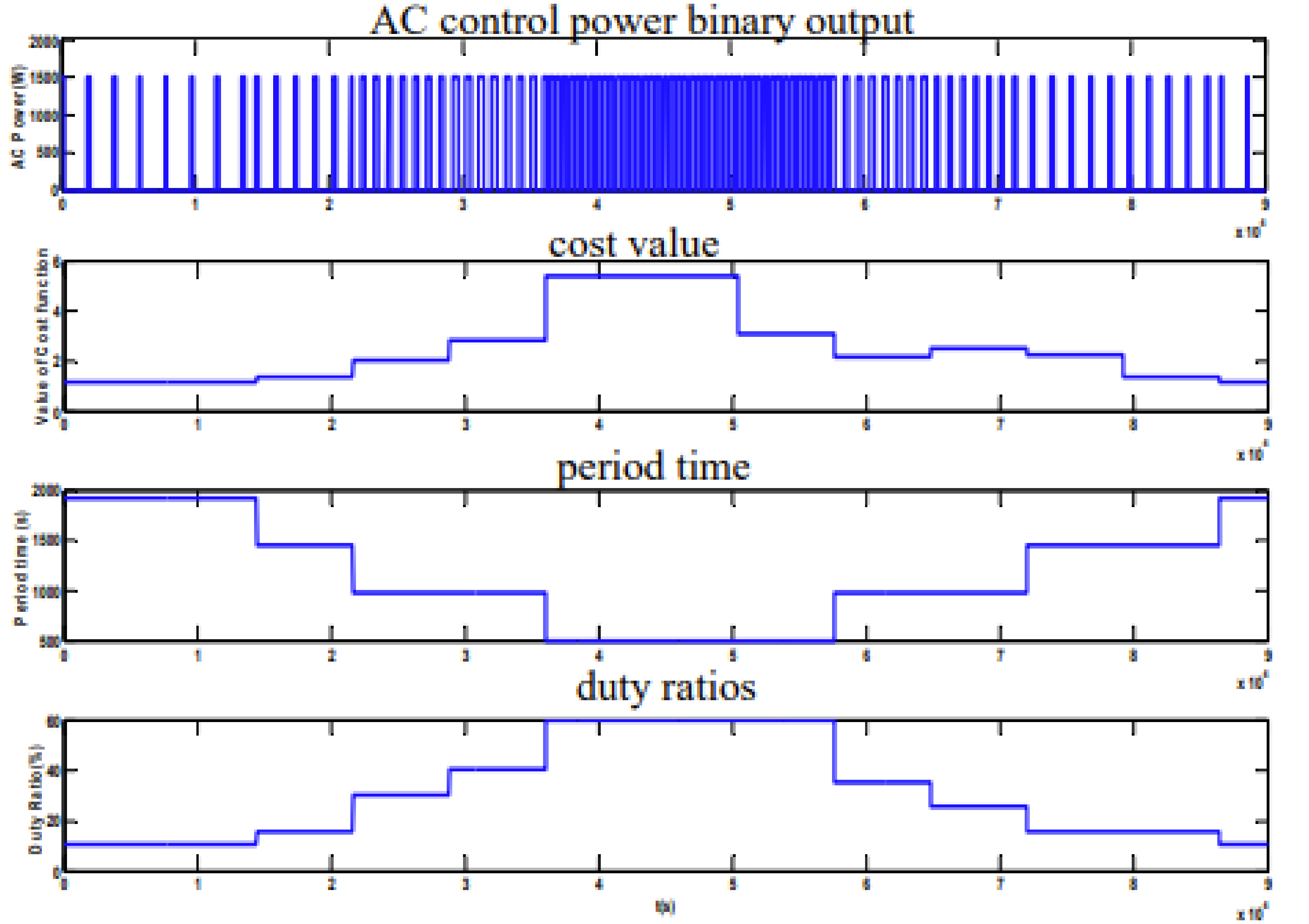


AC Cooling control strategies	Initial room temperature	Period	Cost value	Cost can be saved
Case1	38	1595	3.4606	55.45%
Case2	29	300	2.2074	30.16%
Optimum Case	34	595	1.5416	N/A

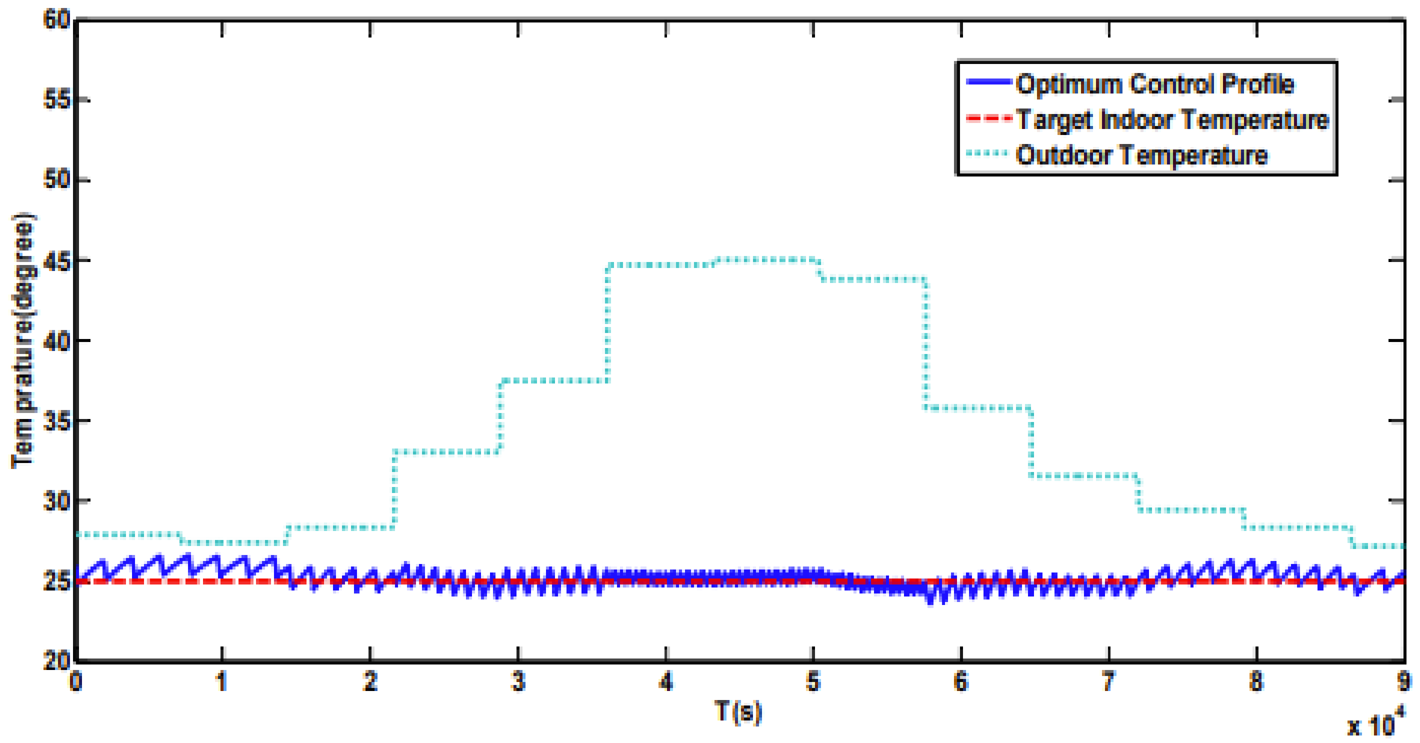


Part3: Optimal On-Off Control for enhanced AC performance

Online optimization results



The plots demonstrate that the control process can track the ambient temperature change in a real-time manner.



- The control system is successful in regulating indoor temperature within acceptable limits of the desired value.
- Slightly sluggish control at lower temperatures.
- it demonstrates the controller is optimal based on a cost function with consideration of COP, switching frequencies, and variable outdoor temperature.

Conclusions

- Advanced control scheme to control multiple conventional AC units is proposed. The result of implementing such controller can result in significant peak load reduction.
- Novel group AC Control system is proposed to address power fluctuation and smooth out power curve.
- Optimal adaptive on-off AC control is proposed to lower the cost of wear and fatigue due to AC on-off switching while maintaining adequate level of comfort under wide-range ambient temperature variations.

Research for alterative energy storage solutions and Qatar ESS market opportunities

Reference:

Qatar Solar Development Status

Qatar Solar PV development is blooming, BESS opportunities is on the way.

[Source: QP twitter]

Lusail bus depot to have solar panels on parking canopies generating 4MW electricity per day

07 Mar 2021 - 18:24

[Source: The Peninsula]

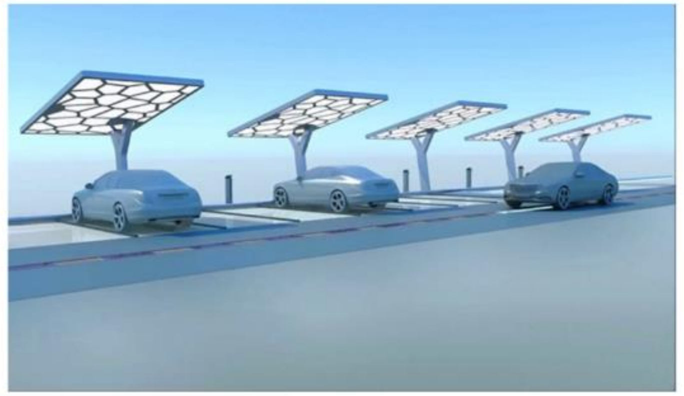
[Source: Google map]

Qatar to house region's largest solar-powered electric charging station

26 May 2021

Ashghal will build an electric charging stations that operates on solar energy, which will be the largest electric charging station in the region, controlling the operation of all sites involved.

As part of the strategy to shift to clean energy within Qatar National Vision 2030, the Public Works Authority (Ashghal) has begun installing 653 electric chargers and 713 inverters in 41 charging sites that are under construction for the Public Bus Infrastructure Program to serve the fleet of electric buses to operate as per the plan set by Ministry of Transport and Communication.



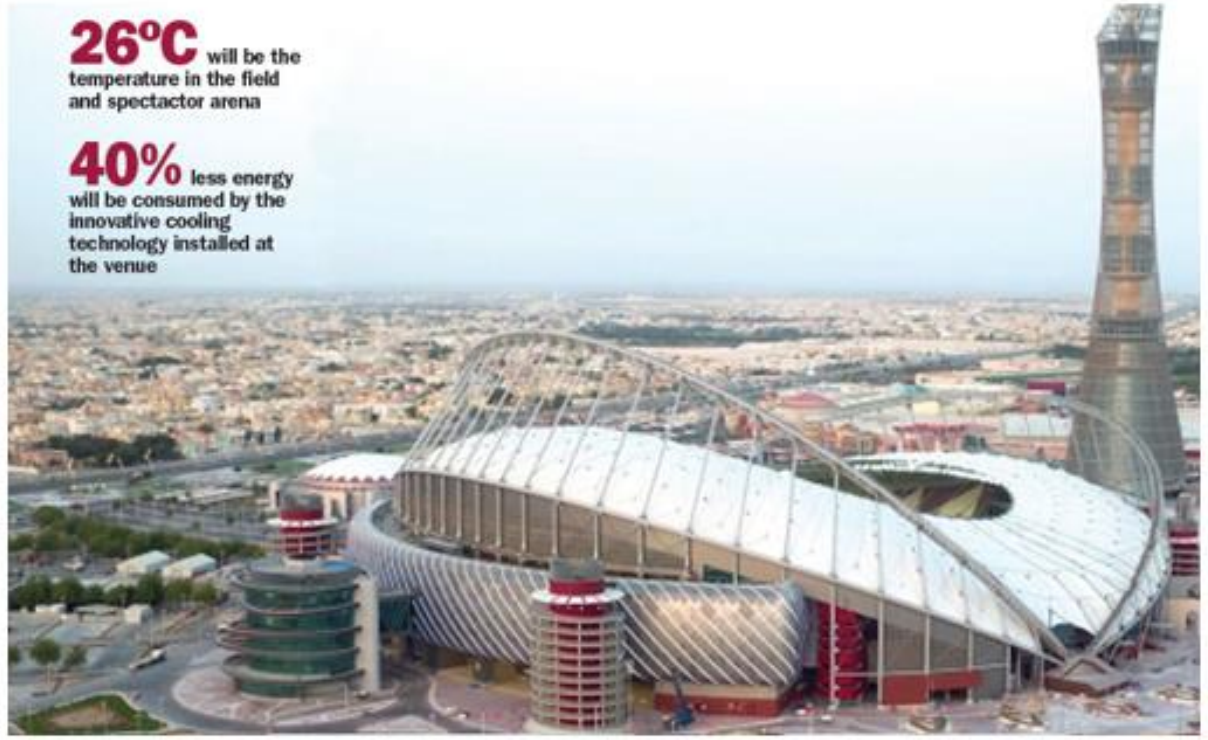
[Source: OnlineQatar]

Solar PV development in Qatar

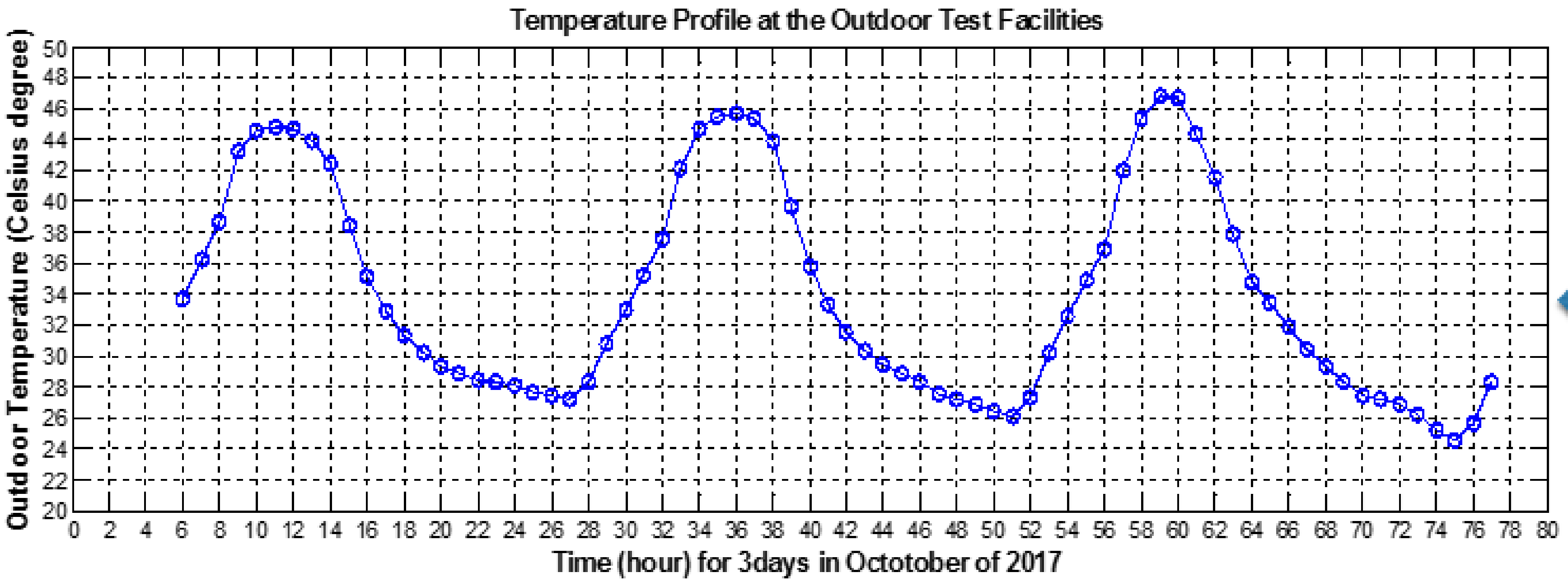
800MW Al Kharsaah solar farm(on-going)

Background for Alterative storage solution research

- Qatar has desert area climate with high temperature, humidity, and dust storms
- 60% of the energy consumed in the residential area is from Air Conditioning (AC) systems.



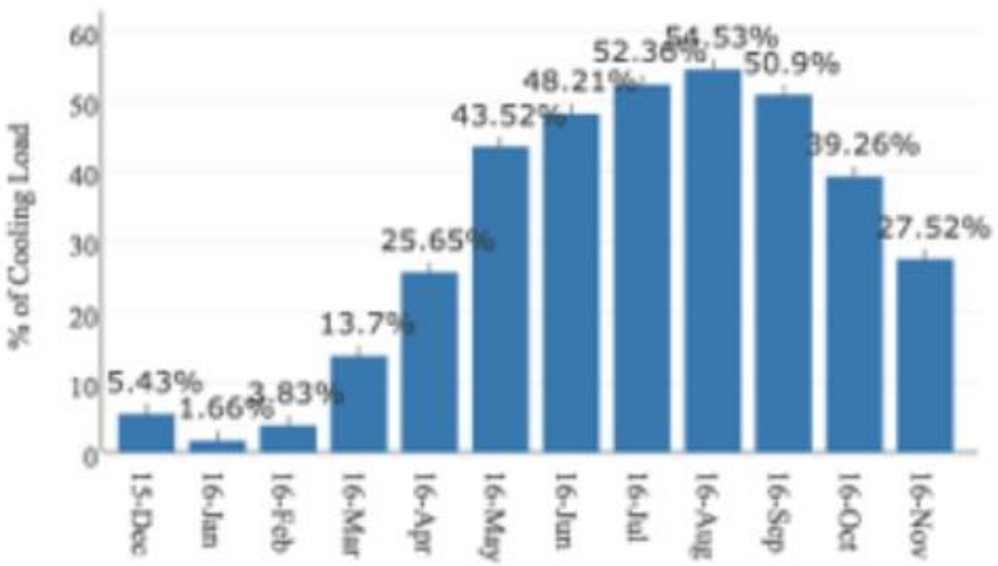
KHALIFA STADIUM THE COOLEST OPEN-AIR VENUE IN THE WORLD



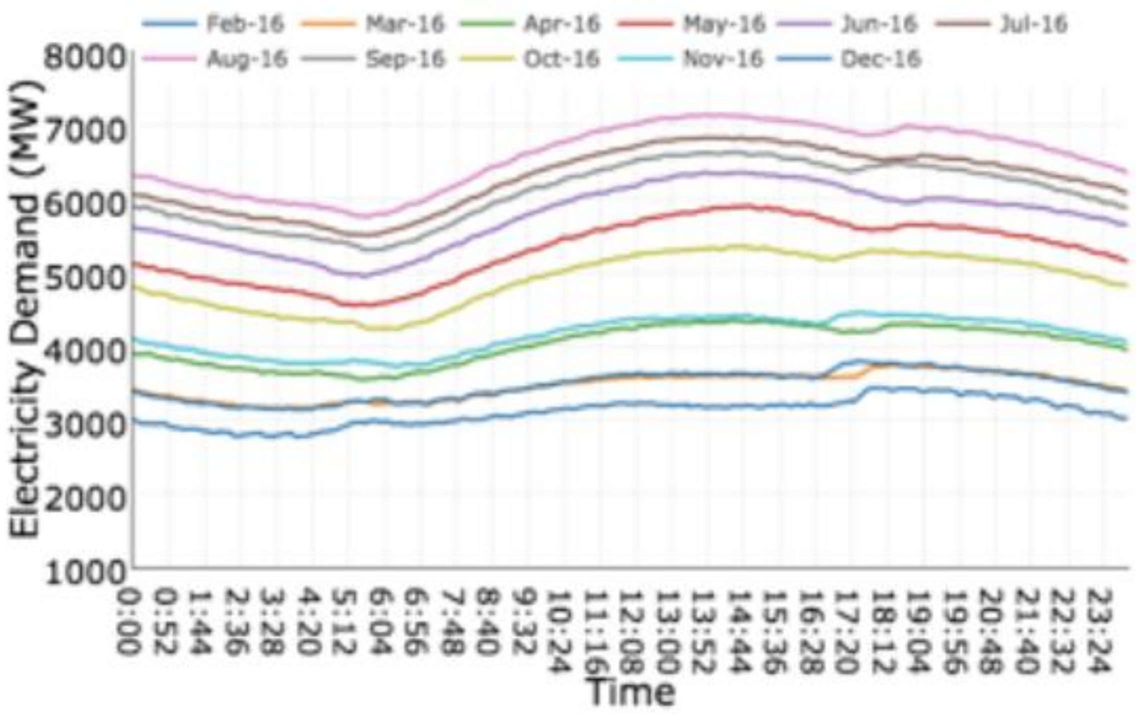
Qatar Demand Profile

------Highlights------

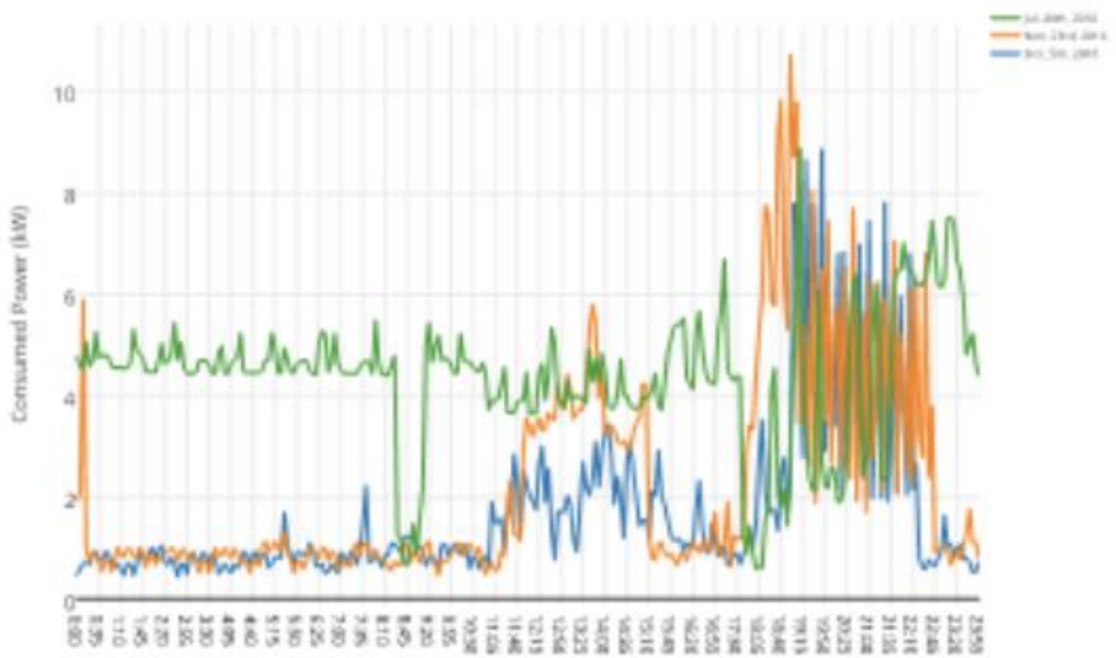
Annual cooling load: 14 TWh



Average Load Profiles

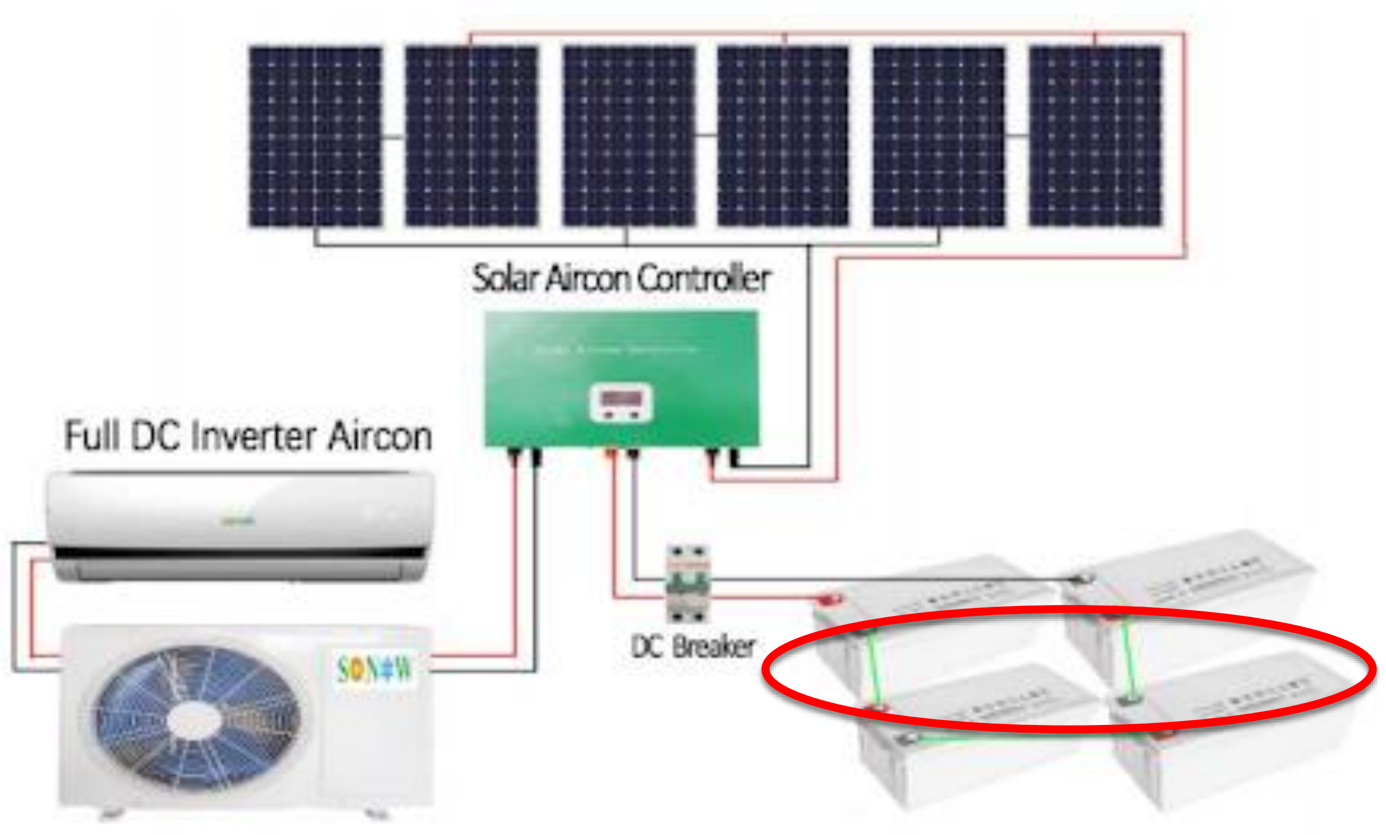


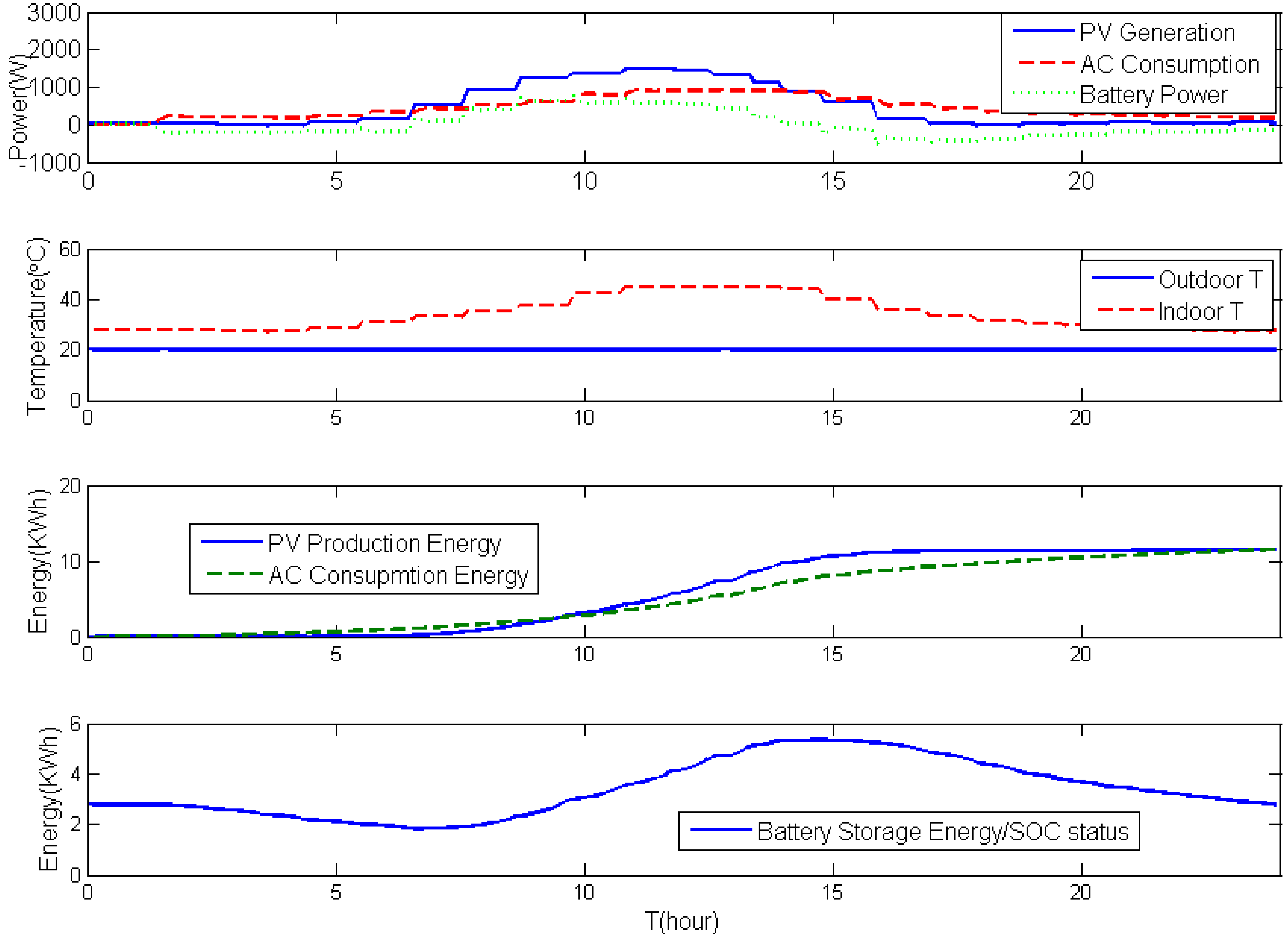
Household consumption



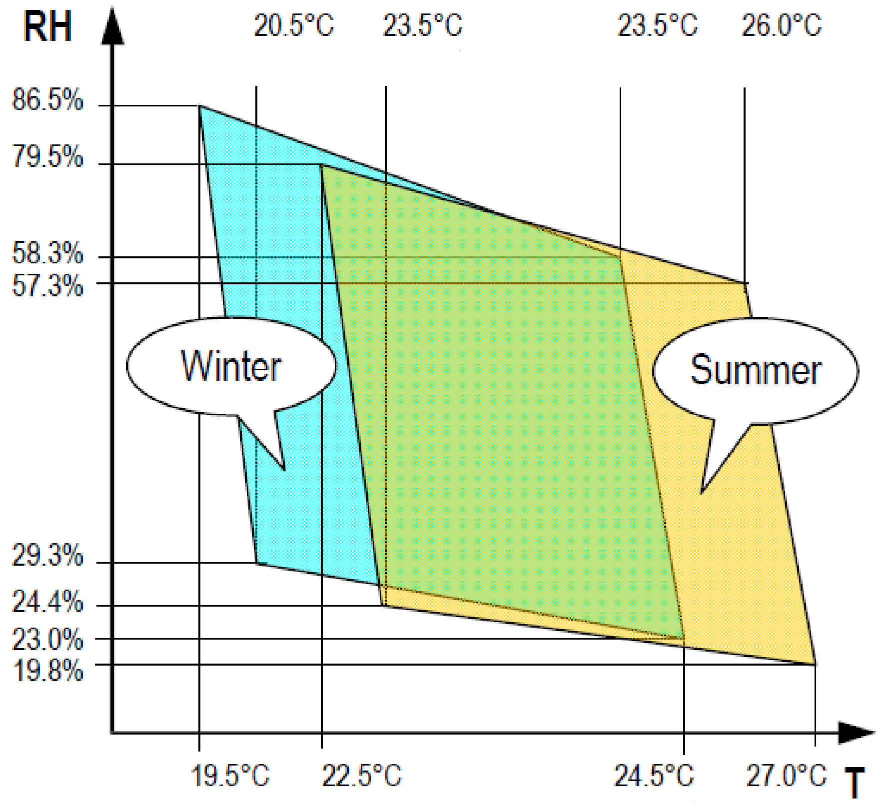
Bayram, Islam Safak. "Smart grids and load profiles in the gcc region." *EAI Endorsed Transactions on Smart Cities* 2.5 (2017).

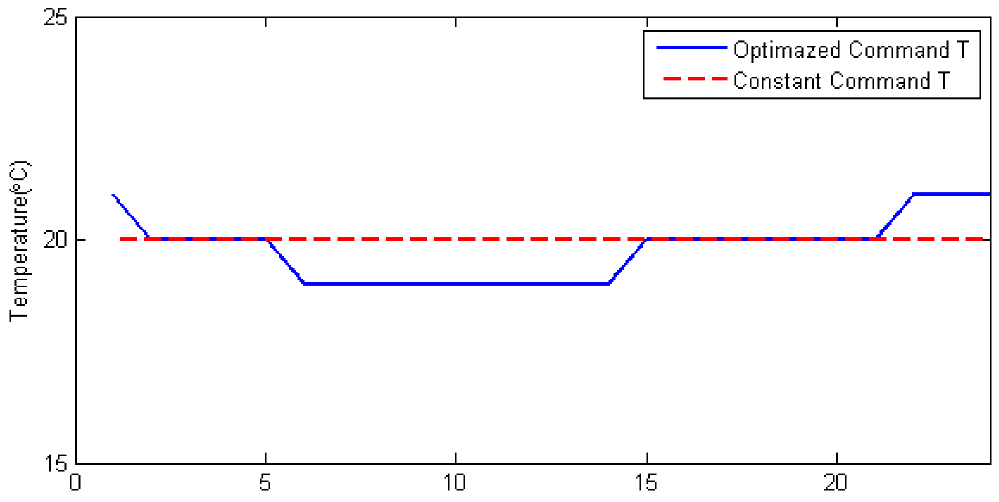
Standalone Solar-Storage-Air Conditioner system

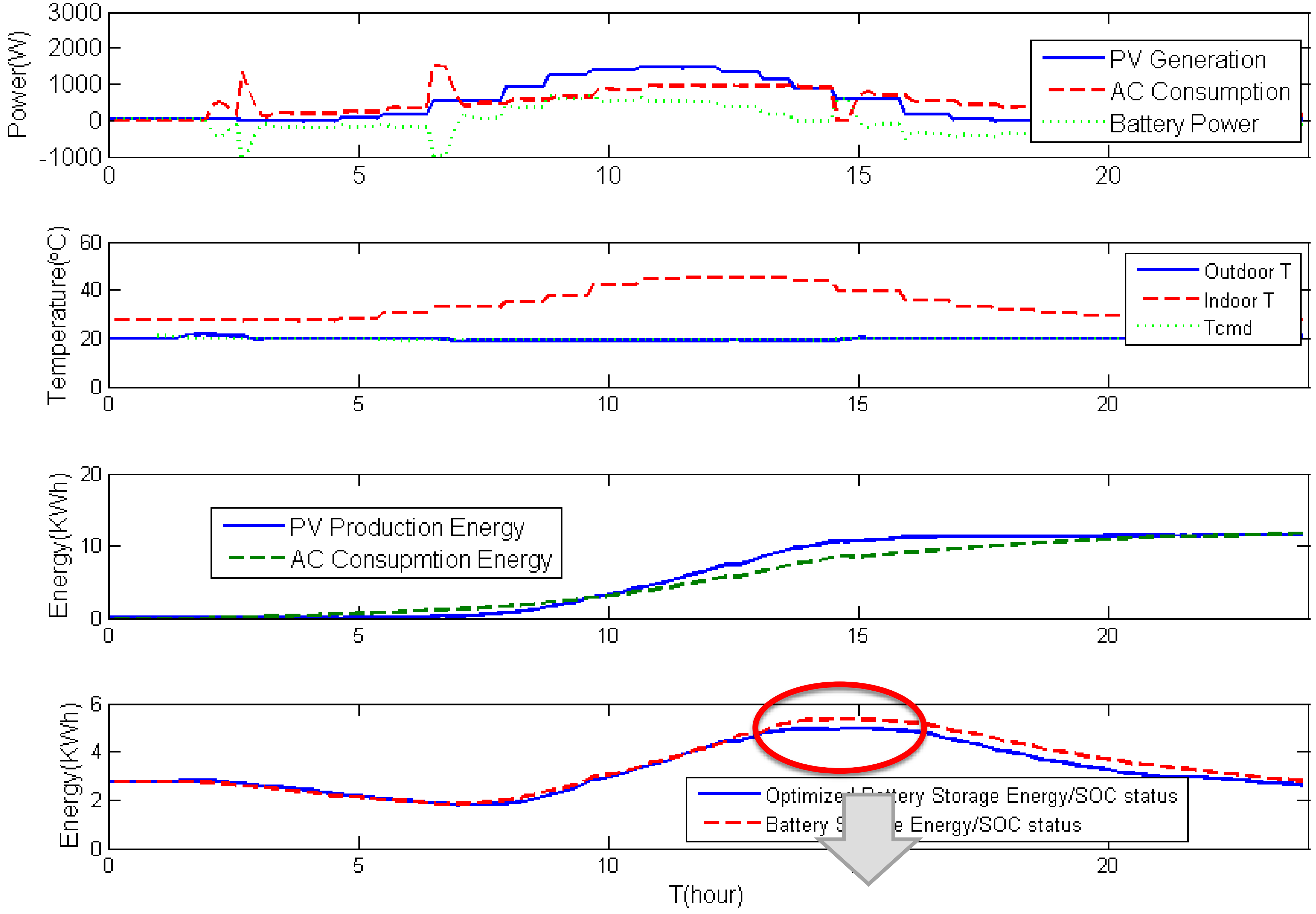




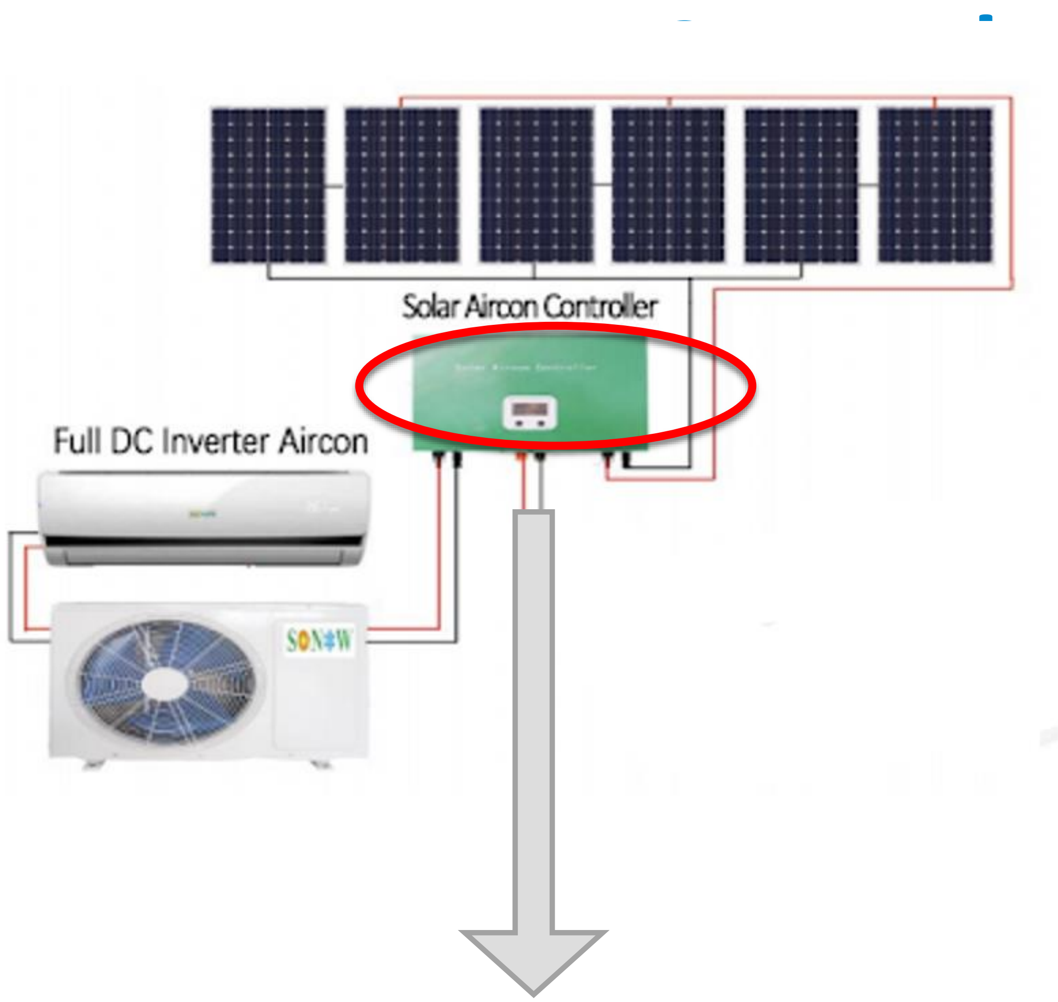
Optimization-1 for Battery Storage Size reduction

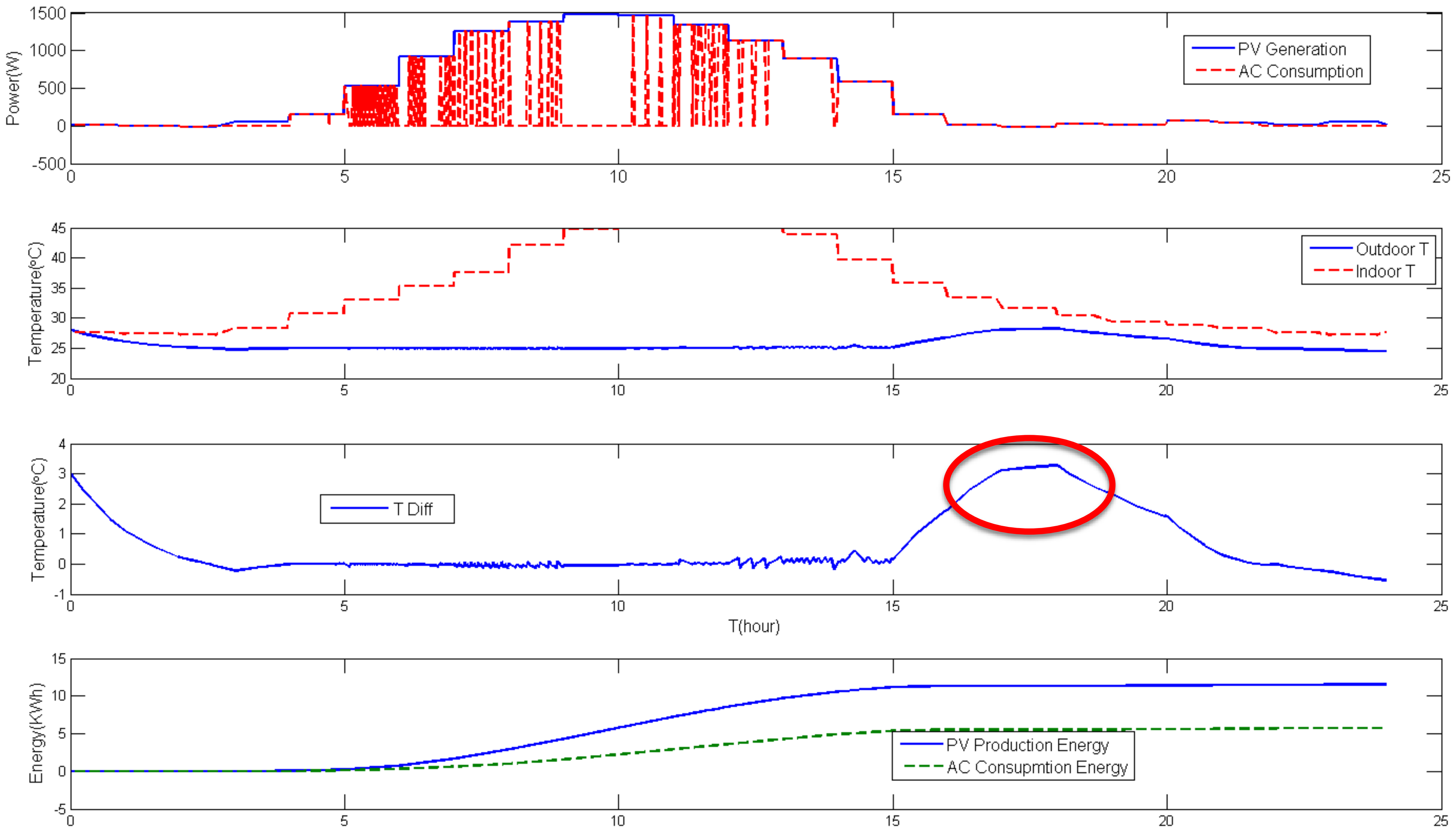






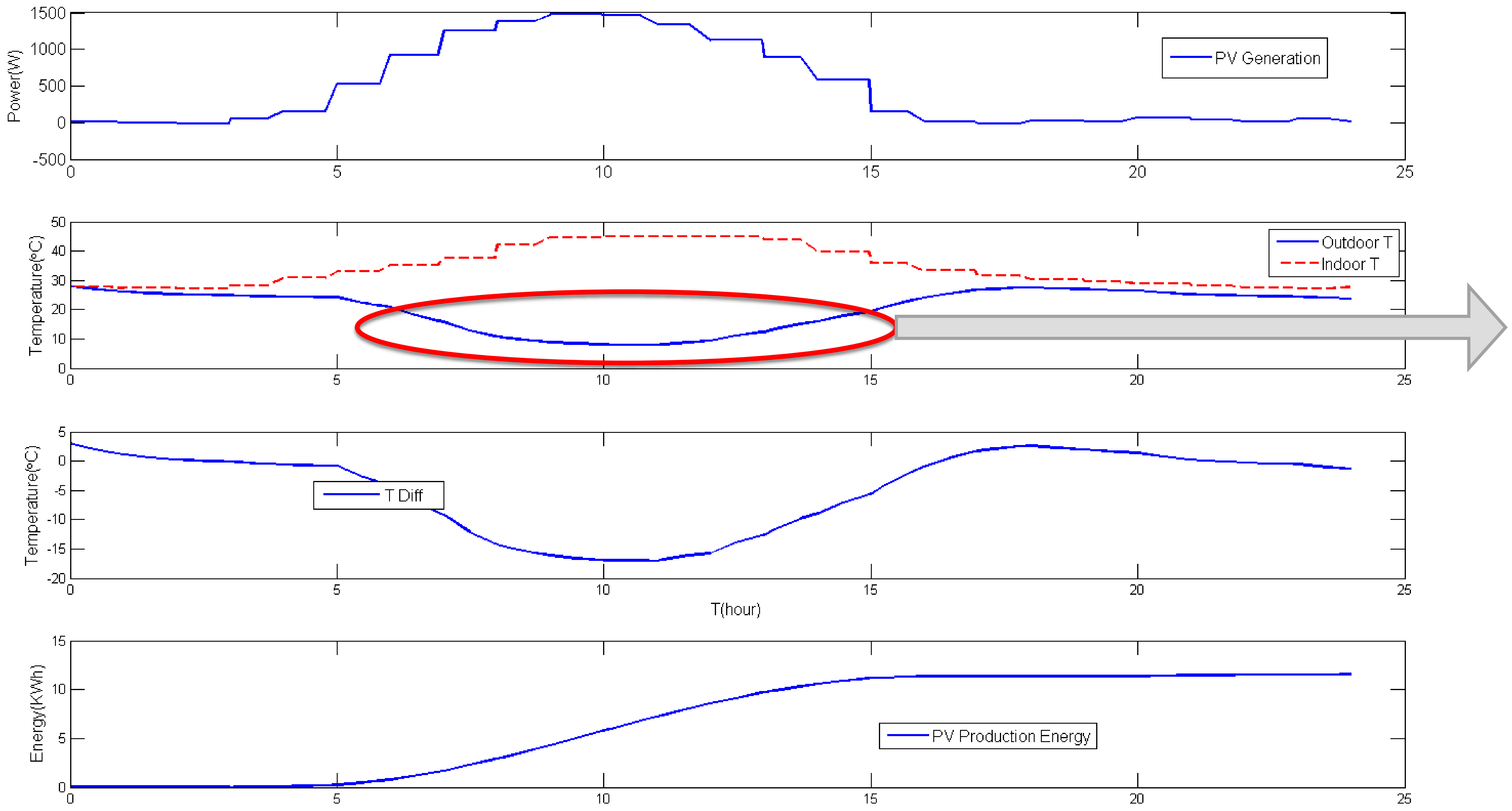
Optimization-2 for Battery Storage Size reduction





PV Inverter based P control for generation output

Optimization-2 for Battery Storage Size reduction



Possible solutions:

1)Water based cooling storage and control

2)Ice based cooling storage and control

Alterative Storage Solution Benefit

1. Qatar climate conditions require storage and other storage solutions for PV-AC cooling balance issue, while battery storage is still costive ;
2. AC can work as virtual storage roles and support reactive power control by efficient converter control, which is promising for Qatar Air-Conditioning application use-cases;
3. By On-OFF control of PV output, day-time cooling demand can be meet in Autumn and Spring with acceptable COP
4. Water storage cooling or Ice cooling storage could be future solutions

Thanks for your attention !

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