An overview of renewable energy resources and grid integration for commercial building applications

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Abstract

This paper presents an overview of the integration of renewable energy resources in the urban sector. The article also describes the current global energy demand and growth challenges that the world is currently facing. The literature survey on the global energy scenario and renewable energy integration, which mainly involves solar photovoltaic (PV) and battery energy storage systems (BESS), is presented. The paper also addresses the different contexts of using renewable energy resources (RERs) and grid-connected applications. It develops the concept of PV energy storage integration in commercial building applications. Since the common RERs such as wind and solar vary according to seasonal and geographic locations, an outline of the energy storage system that provides a platform for optimal use of RERs is also presented. This structure refers to their ability and dynamic structure that can combine with the renewable power generation to maximise the use of RERs and to ensure the total energy supply to the load. It was observed that the integration of distributed energy resources (DERs) which are connected to the grid is beneficial when the PV and energy storage system (ESS) are smartly mixed with the utility grid. The primary purpose of this energy mix is to assist in improving the dynamic performance of any electrical network operating in a commercial building setup. Thus, this research work analyses the possibility of designing dynamic behaviour for energy management for commercial building applications in Southern Africa.

Keywords: Battery energy storage system, building energy, energy efficiency, smart grid, solar energy, utility supply

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Nomenclature

Parameters and constants

BESS	Battery energy storage system
DGR	Distributed generation resources

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DER	Distributed energy resources
DG	Distributed generation
ESS	Energy storage system
EV	Electric vehicle
HDP	High demand period
LDP	Low demand period
NERSA	National energy regulator of South Africa
REFIT	Renewable energy feed-in tariff
RER	Renewable energy resources
RES	Renewable energy system
PV	Photovoltaic
Variables	
α	Elevation angle of module
β	Temperature coefficient of the cell efficiency
β_t	Tilt angle of module
Δt	Sampling time [hour]
E	Energy consumption [kWh]
E_c	Charging energy of the battery storage [kWh]
E_d	Discharging energy of the battery storage [kWh]
E_D	Energy demand [kWh]
E_{db}	Energy generated by the battery storage [kWh]
E_{max}	Maximum energy from battery [kWh]
E_{nom}	Nominal energy of the battery [kWh]
E_{pv}	Energy from photovoltaic array [kWh]
E_{re}	Remaining energy on the battery [kWh]
I	In-plane irradiance or the incident irradiance [W/m^2]
I_b	Current drawn from battery [A]
I_h	Horizontal irradiation [W/m^2]
I_i	Incident irradiation [W/m^2]
I_m	Module irradiation [W/m^2]
I_{pv}	Solar irradiation incident on the PV array [W/m^2]
$I_{pv,NT}$	Average of solar irradiation incident on the array at [NT (0.8kWh/m^2)]
k or (tT)	Sample of time or time interval [hour]
K	Ross coefficient [°C.m^2/W]
η_c	Battery charging efficiency
$\eta_{c/d}$	Charging or discharging coefficient
η_d	Battery discharging efficiency
η_{inv}	Efficiency of the inverter
η_{pv}	Efficiency of the PV array
S	PV array area [m^2]
SOC	State of charge of a battery
SOC_i	Initial state of charge of a battery
σ	Hourly self-discharge rate of battery

t	Time [hour]
T_m	Temperature of the module expressed in °C
T_{amb}	Ambient temperature expressed in °C

1. INTRODUCTION

Renewable energy has become an essential and sought after all over the world, with its uptake rapidly growing in the last decade in most developed and/or developing countries such as Australia, Canada, China, Denmark, France, Germany, India, Italy, Japan, Netherlands, Portugal, South Africa, Sweden, United Kingdom, USA, etc. Therefore, renewable energy resource (RER) has become more attractive in producing electricity. The power generation from the RERs is considered to be cleaner, cost-effective, environmentally friendly and sustainable, compared to the power from conventional or traditional power resources [1–8]. The deployment of RERs is one of the indicators that the implementation of sustainable energy generation is more suitable for the future power grid. The scientists who work on integrating renewable energy into the network argue that when more than one renewable resource is integrated into the generation mix, there are many advantages, for example, an increase in power generation efficiency [9–11]. Therefore, many countries have widely projected that hybrid renewable energy integrated systems will generate most of their electricity. This is also because the current power system has significantly relied on the depleting and environmentally unfriendly fossil fuel (coal).

The integration of RERs brings diverse challenges in the context of acceptable voltage variation and system frequency (in the alternative current configuration) into any given electrical network [12–25]. One of the most popular stresses on the operation process of renewable energy integration is the low and sparse density of resources to use for the generation of energy while the energy demand is growing. Currently, smart grid technology provides a diverse strategy to alleviate the challenges emanating from the instability and variability of the RERs. The essential methodology that assists in the effective use of the RERs is the implementation of microgrid system [10]. This technique consists of creating a peer to peer operation mode of the electrical system and maximising the system performance despite diverse operational challenges [26]. The energy storage system (ESS) is seen to be the solution to diverse RERs problems. In the urban sector, where energy demand needs and RERs implementation challenges are of concern, energy storage plays a damping rule between energy demand and generation.

Several research studies have been proposed and designed for optimal implementation of RERs in the urban sector where the use of ESS is the central conservation component of the energy and improvement of the system power flow in the presence of source variability from the RESs [27–47]. In most cases, it can be observed that the optimal energy system for a given electrical configuration efficiently operates when dynamic energy plays a damping rule of the energy generation. This strategy consists of charging the battery during the higher period of the RERs and/or lower demand or lower energy tariff from the utility grid, which can be discharged during a vital need to minimise the overall operation cost and maximise the system performance. The main scheme of those approaches aims to coordinate the dynamic behaviour of distributed energy resources (DERs), including both RES and ESS. Therefore, this research work presents an overview of photovoltaic (PV) and ESS implementation for the urban sector applications. This study is based on the dynamic performance of DERs and will analyse their diverse implementation for the energy management scheme.

The contributions of the research study can be listed as follows:

- Worldwide energy scenarios based on diverse challenges from the demand growth, pollution from the conventional energy generation systems and the implementation advantages and challenges of sustainable energy resources.
- Provides the best strategy for implementing the RER in urban areas based on diverse challenges that can be found in that sector. This scenario is specially focused on commercial building applications, and a detailed strategy of the Southern hemisphere context is also given.
- Describes different dynamic approaches to energy management strategy where the ESS is the central improving component of the dynamic performance of the system for power flow efficiency of the electrical grid.
- Details different strategies of designing DERs in the urban sector in Southern Africa.
- Presents the future perspective of implementing the ESS and PV system (or RERs) in the context of high storage ability, smart grid environment and technical-economic deployment.

The remaining part of this paper can be summarised as follows: section 2 presents the global energy scenario. Sections 3 and 4 provide energy demand growth and solar PV implementation in commercial building applications for Southern hemisphere. Section 5 details the diverse strategy of battery storage and their dynamic performance design. Sections 6 and 7 provide the future perspective of ESS and RER implementation in a smart grid environment and the conclusion of the paper.

2. GLOBAL ENERGY SCENARIOS

The electrical grid structure nowadays faces diverse challenges in terms of system reconfiguration for RERs integration, power quality and/or balancing power flow between the consumption and production of the energy [48–57]. From the demand side, the increase in energy demand is proportional to the actual population growth. At the same time, the energy production is facing several challenges due to resources allocation and sustainability of power generation system. Besides, approximately 87% of the world's total energy generation comes from burning oil, coal, and natural gas; about 6% of energy comes from nuclear; and the renewable energy resources, such as wind, solar PV and hydro, provide the remaining percentage of energy. China and India are the most populated countries in the world and generate 74% and 71% of the energy, respectively, with most of their electricity produced from coal causing 38% of the world's pollution [58–60]. The USA only makes up 5% of the world's population and 75% of their generated electricity come from coal (55%) and nuclear plants (20%) [58, 60].

The generation of electricity in Malaysia and South Africa depends on fossil fuels and coal, which make up about 93% and 90% respectively, of the total power generated in each country [61–63]. Renewable energy integration has introduced many advantages to the electricity grid. Therefore, renewable energy resources hold the fourth position of top five energy resources globally, after oil, coal and natural gas, in that order, while nuclear holds the fifth position. It is worth noting that the global fuel reserve is limited, and it has been projected that [58]:

- Natural uranium fuel is expected to last 50 years.
- Oil is expected to last approximately 100 years.
- Natural gas can last up to 150 years.
- Coal reserves will be depleted in 200 years' time.

The environmental and socio-economic impacts of the use of such fuels to produce electricity are negative [58]. Therefore, future power generation requires transition into sustainable and environmentally friendly alternatives that will protect the biophysical boundaries of the Earth.

2.1. Energy mix generation and renewable energy

Renewable energy is considered an environmentally-friendly energy resource for electric power generation [59, 64, 65]. Therefore, it is essential to explore and develop different RERs for power generation in a carbon-constrained world. This transition can protect the environment from global warming and other externalities associated with the extraction and exploitation of fossil fuels [59, 65–68].

The mixing of several RERs, namely hybrid system, can reduce the high dependency on fossil fuels all over the world. This integration of more than one RERs is called a hybrid power system, which can be operated in island mode or connected to the utility grid [64, 65, 68, 69]. A hybrid power system is more efficient than non-hybrid systems in cost and reliability [59, 64, 65, 69]. In general, hybridisation enhances energy security and reliability [59, 65, 69].

The current, commonly exploited renewable energy resources for hybrid integration are wind and solar PV [59, 65, 69]. The widely cited advantages include natural abundance, environmental friendliness and low energy production cost [65, 69]. Wind power was first used to produce electricity in the 19th Century. A new method of producing electricity from solar PV only started in 1954, but there was an increase in design and research after the oil crisis in 1974 [65].

However, it is also essential to note that due to the intermittent nature of RERs, their integration into the grid can cause the degradation of power quality. Therefore, power electronic devices are used to improve the efficiency of renewable conversion technology [58]. The conversion technologies that can be developed to exploit any renewable energy resource efficiently must consider the described factors, as detailed in Fig.1. This structure has seven steps which effectively analyse energy resources before implementation. The resource locations, as illustrated in Fig.1, constitute the first baseline of any renewable energy deployment and design. The dynamic performance of implementing renewable energy resources is defined based on these seven steps [2].

2.2. Advantages and disadvantages of renewable energy integration

Table 1 presents the main advantages and disadvantages of renewable energy resources [70]. Some specific renewable energy resources introduce many perceived problems that are caused by source conversion and applications. These can be listed as visual pollution and odour for biomass; large land requirement for solar energy conversion; perceived avian issues in wind resource plants and; brine from some geothermal systems.

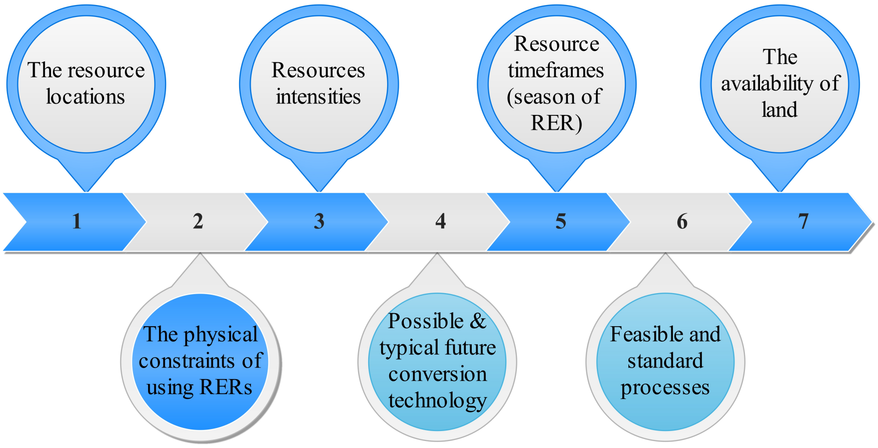

Figure 1: Seven steps of conversion implementation of RERs

Table 1: Advantages and disadvantages of RERs

Advantages	Disadvantages
Sustainability: it cannot be depleted	Variability
Ubiquity: it can be found everywhere in the world	Low density
Primarily carbon free and non-pollution	Higher starting cost of conversion hardware

3. ENERGY DEMAND IN SOUTH AFRICA

While there are various viable options for supplying electricity by use of a hybrid power system, there are still some zones without electricity in the world. In SADC countries about 80% of the population has no access to electricity and more than 25% of the people all over the world do not have access to grid electricity [28, 37, 71, 72]. South Africa has experienced a power supply crisis due to lack of research in the energy field [37, 73, 74]. Eskom, South Africa's national utility argued that building new power plants can solve the energy crisis [73]. Most of the energy produced in South Africa comes from coal [75]. The South African President said in the State of the Nation Address in February 2015 that one needs to switch on renewable energy resources to meet energy demand. This proposition compelled the Department of Energy to establish energy perspectives. This concept can ensure socio-economic development strategies which could guarantee the satisfaction of power requirements from the suppliers to consumers in all sectors [76].

Renewable energy resources, mainly solar and wind, are abundant in South Africa and thus viable for the exploitation of power generation [77, 78]. The Department of Energy has set carbon emission reduction targets and future power generation scenarios. These will be achieved only by the expansion of generation technologies to include a large scale of the renewable energy resources (solar, wind and hydro) with other energy supplies such as gas and imports, biomass and nuclear power plants [79]. RER is also considered as one of the vital energy generation solutions which can address the challenges of the energy demand growth [10, 80]. It is therefore essential to note that South Africa's energy supplies can be covered by the potential RERs that the country either has or that can be imported from nearby states. These energy resources are [80]: Solar, wind, hydro, biomass, geothermal, ocean wave and tidal and landfill gas.

3.1. Renewable energy integration

In South Africa, all government agencies and departments of energy support the integration of renewable energy resources in the national grid. In 2009, the National Energy Regulator (NERSA) developed a Renewable Energy Feed-in Tariff (REFIT) policy to provide a framework of reference regarding pricing and integration of renewable energy resources in the national grid. This policy focused on specifying renewable energy resources and individualised support cost. The potential target resources are the concentrated solar, small hydro, wind, and the landfill gas generation. The REFIT policy expects to enhance the uptake of renewable energy resources, thereby reducing the burden that is currently placed on the coal-fired power plants that provide the bulk of the grid power. This system will also introduce a fixed purchase price, a dynamic mechanism that can reflect both political and economic realities in the market, a scope for new projects on effects of cost reductions. It can also set a cap on the perspective of the yearly provision of resources and apply a willing seller and buyer approach [80].

However, the integration of renewable energy resources is constrained by inherent resource limitations regarding their functionality in different atmospheric and environmental conditions. Integration is also dependent on the ease of transfer of resources from rural to urban sectors. Besides, the type of combination to be used would depend on whether it is for private usage or public usage. In the cities, PV is the most sustainable and realistic resource that both the individual and the municipal sectors can use to produce electricity. Therefore, in this study, PV is the most effective option as the target is to integrate a renewable energy resource for optimising the energy supply in commercial buildings.

3.2. Solar energy resource

The Sun is a potential resource of renewable energy [2, 70, 76, 77, 79–81]. It can be observed directly by solar energy resources and indirectly by other energy resources such as biomass, fossil biomass fuels (coal), hydro power, natural gas, oil and wind [70]. This process produces solar energy which substantially sustains life on Earth for all living beings (human, flora, and fauna). The solar resource also addresses the needs of people by providing abundant sources of clean energy for the future [70]. In a conceptual framework of energy conversion, solar energy is the sum of three processes which are listed as [2]:

- The chemical process called "heliochemical". This is principally based on the photosynthesis process.
- The electrical process called "helioelectrical". The primary objective of this process is how to exploit solar cells or photovoltaics to produce electricity.
- The thermal process, well known as a "heliothermal". It consists of converting sunlight to thermal heat. This can be employed inside concentrating solar power plants.

The Sun is just one of the billions of stars in the universe. The universe, in the Milky Way or other galaxies, may have many stars that are incredibly powerful and bigger than the earth′s Sun. Still, the Sun generates a potentially potent nuclear energy which is based on the fusion process

[70, 81]. Besides, the Earth rotates around its axis in the plane of the equator in one day: or 23 hours, 56 minutes, and 4.1 seconds. The earth also revolves around the Sun in an ecliptic plane that describes the repartition of seasons. For the northern hemisphere, the season's repartitions are as follows [2, 81]:

- Winter which starts on the 21^{st} of December as the shortest day and longest night. It is also important to note that in winter, on the 4^{th} of January, the Earth is closest to the sun.
- Spring which begins on the 20^{th} of March with regular hours for the day.
- Summer which starts on the 21^{st} of June with the longest day and shortest night.
- Autumn which starts on the 23^{rd} of September with regular hours for day and night.

It is important to note that the seasonal repartition is different in South Africa, which is in the Southern hemisphere. Here winter starts in June and ends in September [77], and is considered as a period of high demand for electricity with high hourly electricity pricing. Other seasons have a lower demand with consequent lower electricity pricing [82].

The sun has a large diameter, and the earth can be contained in it more than ten billion times. Therefore, the solar radiation that the earth can receive is more than enough to provide for the annual energy consumption of the whole world's population [2]. Despite this, energy generation from solar resources only started in the middle of the twentieth century. The countries that implemented this type of generation to supply electricity by solar, argued that such energy production, installing a photovoltaic system, contributes to creating so-called "Green jobs", reducing emissions of a significant amount of CO_2 to the atmosphere and to developing a nation [83]. It is important to note that the sun provides more energy in one hour than all the countries on earth consume in one year [2].

With its essential sunshine average, South Africa is ranked as the third top solar energy resources country in the world. The Southern African country has annual average sunshine of more than 2500 hours, which can contain an average range of direct solar radiation intensities values between 4.5 and 6.5 kWh/m^2 per day [77]. The solar radiation in South Africa can reach a daily amount of more than eight kWh/m^2. It is necessary to note that the solar radiation depends on the type of array used in solar panel devices [84], and it can also be a function of location and/or station identification as well as the model and the specifications of the PV system. The power efficiency of solar PV, which aims to define the rating power or the electricity conversion from the PV also depends on these critical components, namely the electrical parameters, solar spectral, thermal, optical properties of the array and amount and direction of incident radiation [2].

The common solar energy conversion technologies that are used in South Africa are classified as follows [80]:

- Solar photovoltaic: this is mostly used in South Africa for telecommunication usage and households and in remote areas for supplying power to water pumps and rural institutions. This system can also be used in off-grid or grid-connected systems. All these applications are for the sustainability and the efficacy of the energy supply.
- Solar thermal electric: this uses thermal energy (heat) from the sun which can either power the Stirling engine or drive conventional steam turbines that drive power plants. This conversion system is used more in the medium term than the photovoltaic. The significant ad-

vantage of solar thermal is that it can be designed for a large-scale system from multi-mega to the gigawatt. It also has the potential to be a storage system that allows some specified solar thermal plants to run all day.
- Solar thermal heating: this is used in the domestic sector for space heating systems, water heaters and residential usages such as the solar cooker and process heaters. The solar thermal that is mostly used in South Africa and has a significant impact on development growth is the water heater.

For this study, the photovoltaic array will be considered as a relevant and useful system to be integrated into the electrical network of a commercial building.

4. PHOTOVOLTAIC ARRAY

Production and supply of clean energy are the solutions that the world seeks from technology. The solar photovoltaic therefore is considered as one of the essential energy conversion technologies to support the global transition to clean energy [85]. However, in the market nowadays, the solar PV modules that are commonly sold depend on the form of silicon in their manufacture. The PV modules can be categorised into three types: amorphous silicon modules, monocrystalline solar cells and polycrystalline solar cells [2]. In its deployment, the solar PV module is exposed to the possibility of adverse effects such as shading. Some techniques can be used to avoid these effects on the PV module by making it act as a load with less power output due to shading or darkness. This method entails connecting the combination of the PV array by by-passing and blocking diodes that can protect the modules and prevent the system from acting as a load [2]. The PV module has a lot of advantages concerning the variation of the application. Therefore, the PV can be used as microsystems to large systems that can power the load or the electrical grid directly [86].

4.1. Type of array

The conversion efficiency largely depends on the solar PV array type. It is characterised by solar power tracking, which depends on a detailed range model. In terms of a follow-up system, the PV device may be made with no tracking or monitoring system of the array type. The tracking system of PV array can either be a single axis tracker with a benefit of 20% or more or two-axis tracker with a benefit of about 25 to 30% or more [2]. PV array types are described as follows [83]:

- Open rack that has a fixed-axis.
- No tracking or roof mount: this is considered as a no-tracking system.
- One-axis tracking: this system tracks the solar direction.
- Back-tracking: this system has the main objective of avoiding the shadowing effects among the panels or trackers.
- Two-axis tracking: this tracks direction and season. It is important to note that the primary two-axis tracker system can be made with a back-tracking array type to increase the efficiency of the PV device [87].

Table 2 describes South Africa's annual difference of solar radiation measurement in Pretoria location with the weather data source of Johannesburg, latitude 26.13° South, and Longitude 28.23° East. These results are available online in [83]. Table 2 shows how the different kinds of array can play an indispensable role in the achievement of solar radiation. The tracking system helps to improve the rating power of the PV system. Measurement of the solar radiation of a specified location is considered as an essential factor that can be applied to the design of a PV module.

Table 2: Solar radiation of different array types [28]

Month	Solar Radiation of different (kWh/m^2/day)				
	Fixed (open rack)	Fixed (roof mount)	1-axis tracking	Back-tracking	2-axis tracking
January	6.19	6.19	6.91	7.05	7.66
February	6.00	6.00	6.83	6.95	7.34
March	6.10	6.10	7.24	7.36	7.58
April	5.68	5.68	6.86	6.98	7.15
May	5.65	5.65	7.12	7.22	7.71
June	5.36	5.36	6.84	6.93	7.61
July	5.61	5.61	7.08	7.17	7.79
August	6.05	6.05	7.44	7.55	7.87
September	6.22	6.22	7.46	7.58	7.69
October	6.25	6.25	7.15	7.28	7.46
November	6.07	6.07	6.47	6.87	7.31
December	6.34	6.34	7.07	7.20	7.90
Annual	5.96	5.96	7.06	7.18	7.59

4.2. Irradiance and cell temperature

The irradiance incident on a PV module, the spectrum difference between the beam and diffuse irradiance and the temperature of each cell play important roles in the performance of a PV system which can be affected by shading. However, the irradiance incident on the module of a PV is the composition of the component of shaded cell irradiance and the component of the unshaded cell [86]. The shaded cell constitutes two fractions which are the visible portion of the diffuse irradiance and the reflected irradiance. On the contrary, the beam irradiance is the whole part of the unshaded cell [2, 86]. All measuring irradiances on a PV module are the function of incident angle, azimuth angle, tilt angle, solar zenith and collector azimuth [88]. Therefore, it is imperative to clearly state that for a PV system application, the irradiance of a module is the transformation of the horizontal irradiance from the meteoroidal datasets to the in-plane irradiance. This derives from the horizontal beam irradiance to in-plane beam irradiance and from the horizontal diffuse irradiance to in-plane diffuse irradiance [86]. The solar irradiation of a PV module is described in (1) and (2) as a function of incident and horizontal irradiation as follows:

$$I_m = I_i sin(\alpha + \beta_t), \tag{1}$$

$$I_m = \frac{I_h sin(\alpha + \beta_t)}{sin\alpha}, \tag{2}$$

where I_m, I_i, I_h, α, and β_t are the module irradiation, incident irradiation, horizontal irradiation, the elevation angle and the tilt angle of the module respectively.

The mounting configuration of a PV module is an essential factor affecting cell temperature and solar radiation collection. The standard mounting configurations include a free-standing, flat roof, sloped roof, building attached PV and building integrated PV which can be in facades and/or roofs. The difference between each mounting configuration harms the operating temperature that affects the efficiency of a PV module [86]. Equation (3) describes the model of the temperature of a PV module developed by Ross [37, 86]. It is also important to note that the temperature of a PV module correlates with the environmental parameters. It introduces the nominal operating cell temperature, which is the function of wind speed, ambient temperature and incident irradiance [86].

$$T_m = T_{amb} + KI, \tag{3}$$

where T_m and T_{amb} are the temperature of the module and the ambient temperature respectively, expressed in °C, and I is the in-plane irradiance (W/m^2). The variable K denotes the Ross coefficient (°C.m^2/W). It is empirically determined by taking into consideration a given module temperature and the influence of the mounting configuration. Therefore, the Ross factor is between 0.021 to 0.056 °C.m^2/W as per the mounting type.

4.3. Energy rating of PV array

Equation (4) describes the daily energy generation from the PV system. This equation defines the hourly rating energy flow of a solar PV array per surface unit [28, 37]. This expression depends on the efficiency of the solar cell.

$$E_{pv_i}(k) = \Delta t \eta_{pv} S \sum_{K=1}^{N} I_{pv_i}(k), \tag{4}$$

where E_{pv}, k, Δt, η_{pv}, S, N, and I_{pv} are the hourly energy generated from the PV solar, sampling time, time variation, efficiency of the PV array, total surface of the PV array, system horizon of the time series, hourly solar irradiation incident on the PV array respectively. The sun temperature is characterised by its geometric and atmospheric conditions that define the rating power of PV array efficacy [2]. Therefore, the efficiency of a PV module is a function of tracking the geometric and atmospheric parameters of the sun. Equation (5) below determines the PV module efficiency as [6, 28, 37]

$$\eta_{pv}(k) = \left[1 - 0.9\beta\left(\frac{I_{pv}}{I_{pv,NT}}\right)(T_{c,NT} - T_{a,NT}) - \beta(T_a - T_R)\right], \tag{5}$$

with η_{pv} is measured at the standard condition and represents the efficiency at the reference temperature. β, $I_{pv,NT}$, $T_{c,NT}$ (45°C), $T_{a,NT}$ (25°C), T_a, T_R are the temperature coefficient of the cell efficiency, the average hourly solar irradiation incident on the array at NT (0.8kWh/m^2), the cell temperatures at NT test conditions, ambient temperatures at NT test conditions, ambient temperatures and reference temperature respectively.

The performance of solar cells and modules which are defined by (5) can introduce some loss into the conversion system. This is due to grid capacity, reflection loss, spurious absorption, quantum efficiency, absorption not near the junction, shading of the solar cell and some incoming solar radiation caused by the ejection of the energy of an electron from its electron shell. Figures 2 and 3 depict solar irradiance during the low demand period (LDP) and high demand period (HDP) of power consumption in the City of Tshwane (Pretoria) [83]. These show several daily solar irradiance measurements of different PV array tracking system in South Africa. The optimal setting of PV system consists of selecting the lowest daily solar irradiance during either the LDP or HDP.

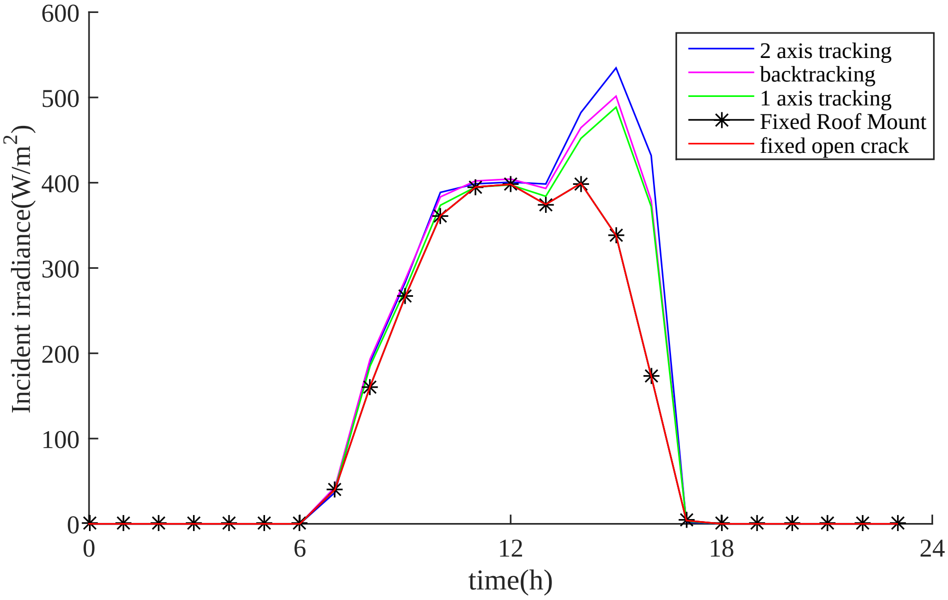

Figure 2: Daily solar irradiance in low demand season (LDP) [28]

4.4. *Solar photovoltaic system*

The solar PV system applications depend on the type of configuration used to supply energy to the load. There are two primary configuration methods of solar PV that are commonly applied in the standard electrical system. These may be connected to the utility grid and off-grid system.

4.4.1. *Off-grid PV system*

The off-grid configuration of a PV system is also known as a standalone system. This configuration often requires energy storage integration to mitigate against solar intermittency. The commonly used storage technology is the battery in solar PV-battery hybrid integration. The independent system can equate to a diesel generator and the grid energy cost. The operators of this system must devise precautions that can guarantee adequate performance. The main disadvantage of using an off-grid system is the daily inspection and high battery maintenance cost.

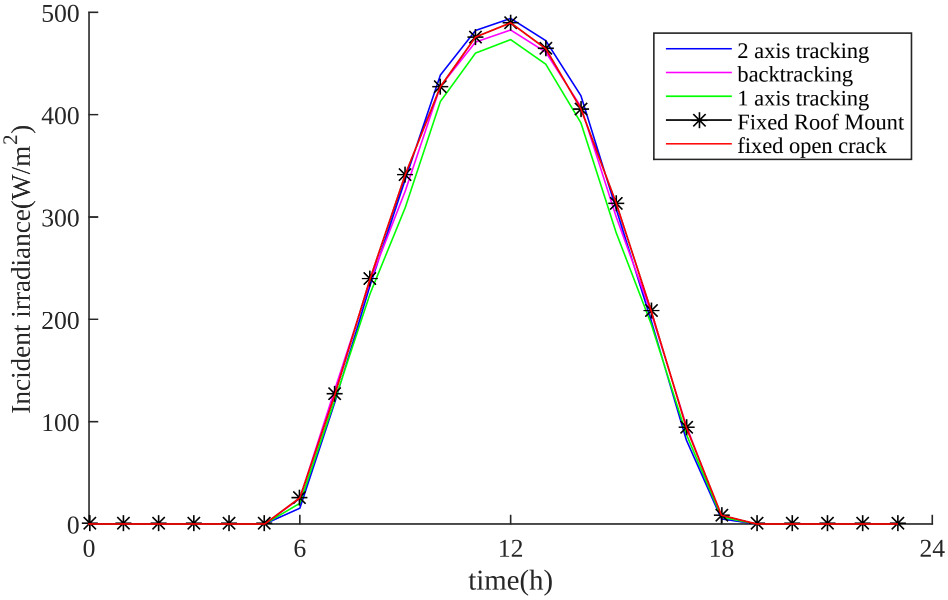

Figure 3: Daily solar irradiance in high demand season (HDP) [28]

4.4.2. Grid-interactive PV system

In a grid-connected or utility interfaced (UI) system, the advantage is that an energy storage device (mainly battery) is not often required and the utility grid provides the necessary backup energy supply. The UI system has a simple configuration when the battery storage is not incorporated into it. It is, however, essential to note that energy storage can be utilised in a grid-connected PV only if there are specific needs such as mitigation of outages and reduction of the cost of energy consumed from the utility grid [2].

5. ENERGY STORAGE SYSTEM

The energy storage system (ESS) is nowadays considered as a critical design requirement for high reliability and efficient grid. Although there being many ESS technologies, the commonly used device is the battery energy storage system (BESS) [89–91]. In practical applications, energy storage devices are used to regulate the rating frequency in the AC systems as well as support the voltage regulation and system stability in transmission and distribution lines. ESS can also improve the power quality and reliability of the electrical system, and act as a spinning reserve to cover the total energy supply. This advantage can enable the demand side to shave the peak as well as to stabilise the load demand. The ESS also permits the management of renewable generation for an optimal power supply [58, 91, 92].

All the coupling systems of battery storage to the electrical grid are supported by power electronic devices [89]. This is because of charging and discharging of battery storage as well as its rating voltage. It is worth noting that in future, through renewable energy development, the importance of energy storage is going to increase, providing more continuity and flexibility on the supply side [90]. The importance of ESS is expected to increase in future with increased integration of intermittent renewable resources in the grid. In such systems, the energy storage devices ensure high system reliability and availability despite seasonal variations.

From the supply to the demand side, the integration of energy storage system offers the possibility of maximising the use of renewable energy by minimising the use of fossil fuel and the development of a future smart grid system [92]. The ESS in the electrical grid can be described by different usages which depend on the frequency and the duration of the operation. Therefore, the ESS has two possibilities of technologies for its implementation. The first strategy consists of maintaining the acceptable voltage level into the network, which is based on the stability of the high cycle and rating output power supplied at short duration. Secondly, energy storage technology involves shifting, which is a function of long-term storage and the need for fewer cycles [92].

The technologies of energy storage application from suppliers to users offer the following advantages:

- Renewable energy generators must ensure that the time-shifting and the effectiveness of connection to the grid are mainly supplied at the average standard. This will provide more sustainability and flexibility of renewable energy supply. This implementation can allow energy suppliers to recover from losses and operate profitably.
- For the utility, isolated grids, emergency power supply for protection and control, efficient use of the network, time-shifting and power quality are principal roles to be covered for the amount of reliable and flexible power. This can give total satisfaction to the consumer as well as to the utility.
- For the consumers, time-shifting, which is a related function of the cost savings, electric vehicles and mobile appliances are the leading roles that can be covered to satisfy the consumer regarding the optimal cost of energy as well as power utilisation.

5.1. Types of energy storage systems

There are many types of electrical energy storage technologies. The common ones include mechanical, electrochemical, chemical, electrical, and thermal [92]. Some energy storage systems are not yet commercialised. There is also a biological energy storage form that uses glycogen and starch as a device to store the energy [93]. Moreover, some secondary forms, such as hydrogen and synthetic natural gas, are used to store electricity [92]. All storage systems are classified according to the following technical criteria [94]:

- The energy storage technology to be used is determined by the purpose of the stored energy (permanent or portable device).
- The energy storage duration which can be short term or long-term.
- The production types or characteristics to define the maximum power needed.

5.1.1. Mechanical storage systems

Mechanical storage systems use the mechanical principle to store energy in kinetic and potential forms [95] with ability to be re-converted back to electrical energy. Pumped hydro, compressed air and flywheel are the main mechanical storage systems [92, 93, 95]. Some secondary mechanical storage systems yet to be commercialised are classified as follows [93]:

1. Fireless locomotive
2. Gravitational potential energy (device)
3. Hydraulic accumulator
4. Liquid nitrogen

5.1.2. *Electrochemical storage systems*

Electrochemical storage uses electrochemical reactions which are electrically reversible. Two main groups divide the electrochemical storage. These are secondary and flow batteries [92]. Electrochemical storage systems can be classified as follows:

1. Rechargeable battery or secondary batteries
2. Flow battery
3. Super-capacitor
4. Ultra-battery

5.1.3. *Chemical storage system*

Chemical energy storage system offers several advantages as an energy storage device. Some of the chemical storage systems which are not yet commercialised can also be listed, such as hydrated salts, hydrogen peroxide and vanadium pentoxide. It is vital to note that chemical energy storage also includes both electrochemical energy storage systems and the thermochemical energy storage systems [95].

5.1.4. *Electrical storage system*

The conventional electrical storage systems are based on the effect of the passive components in electricity [92]. The first is constituted by a capacitor which is electrostatically used to store the energy and the second stores the energy in the magnetic field in magnetic/current form [92, 93, 95].

5.1.5. *Thermal storage system*

The thermal storage system is used in different applications, both industrial and residential. The main objective of using thermal storage is to store the available energy which can be used later for power generation, water supply, space heating or cooling system. The current thermal storage systems can be categorised according to the technologies used in absorption storage, latent heat storage, sensible heat storage and thermos-chemical storage [92]. These are devised in the form of low and high-temperature thermal options [95].

5.2. *Battery ESS*

The battery energy storage system (BESS) is a compact device which is based on electrochemical conversion. The BESS is devised to store the chemical energy that is later converted back to electrical power during the discharge process. The charging process reverses the mechanism of discharge [90, 96]. The battery is classified into two categories, which are primary batteries or non-rechargeable and secondary batteries or rechargeable [96]. The BESS, therefore, has batteries, a power conditioning system and control as well as a protection system that is mostly part of the electrical plant [90, 97]. Nowadays, all over the world, power system suppliers are investigating the development of a battery system technology that can store the energy produced. This can be designed for the application in small and large-scale energy storage systems [90, 96, 97].

BESS is also classified according to temperature; either low-temperature internal storage or high-temperature external storage [90]. BESS has many common forms namely, cobalt-based metal-organic frameworks, Li-ion battery, fuel cells, flow battery, lead-acid, Lithium-ion battery, nickel-cadmium, nickel hybrid, phosphate-based Li-ion battery and sodium-sulphur battery [90, 98, 99]. BESS or any ESS are integrated into a given electrical system based on the storage characteristics which are listed as follows: (i) Autonomy, (ii) Available energy, (iii) costs, (iv) depth of discharge or power transmission rate, (v) discharge time, (vi) durability (cycling capacity), (vii) efficiency (viii) feasibility and adaptation to the generating source, (ix) mass and volume densities of energy, (x) self-discharge, and (xi) storage capacity.

Other essential aspects that assist in maintaining the system operation of BESS include control equipment, environmental perspectives, monitoring equipment, operational constraints, reliability and other technical characteristics. The objective of all these aspects and features behaviour of BESS is to describe the capacity, design, flexibility and operation simplicity of realising the stored energy [94]. The BESS, therefore, provides a long-term integration of power storage for the renewable energy system. Additionally, the BESS can be fixed or mobile depending on a specific application. Figure 4 details the best strategy for selecting a BESS in the power sector. The selection defines all the characteristics that should be considered for the best choice of BESS [96, 100]. For the optimum design of a battery, all these performance characteristics must be respected.

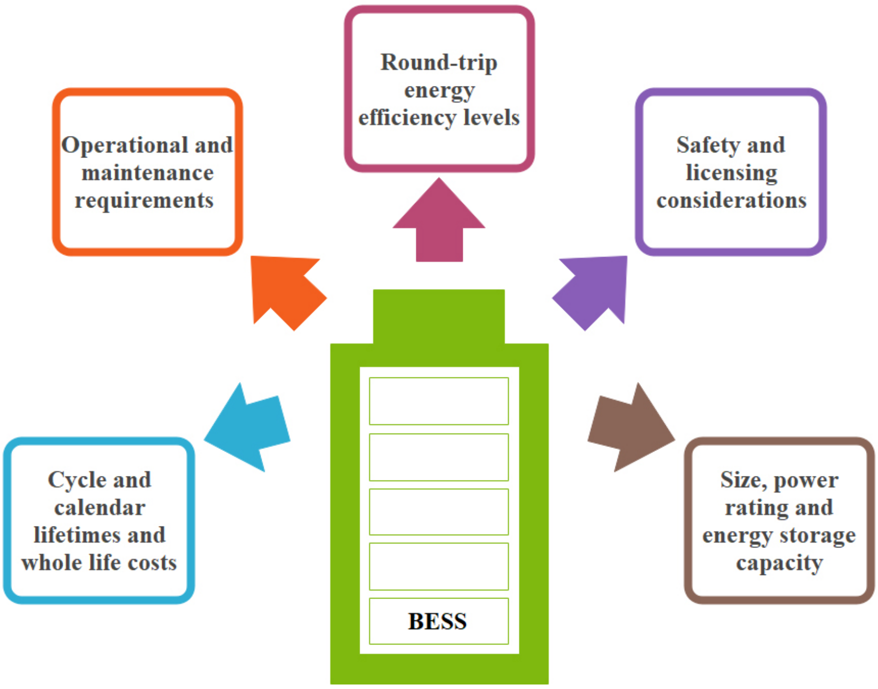

Figure 4: Performance characteristics of selecting BESS

5.3. Dynamic model of BESS

There are diverse manufacturers and different kinds of BESS in the energy storage market. The energy generated from chemical ESS is the most useful BESS that is employed for the PV system. This kind of ESS contains the chemical composition as the principal part of the device. Besides, as a part of chemical energy storage, a fuel cell is the primary component of the electrochemical BESS. The thermochemical energy storage, as a part of chemical energy storage, consists of solar ammonia, solar hydrogen, solar metal and solar methane as the primary devices [95].

The RERs (commonly wind and solar) are often implemented in hybrid mode with the BESS which works to cover all resource fluctuations due to the state of the wind and solar [2, 81]. The specific main objectives for the BESS operation are to store and discharge energy. These two principal objectives define the process operation of the battery. For the first objective, the system stores the energy (charging process) when the generated energy is more than the energy demand. The second objective is to use the stored energy to supply the load when the load demand increases and/or generated energy decreases. This process is called discharging process. These two process objectives are summarised in Eq. (6), which describes the process of charging and discharging [89, 101]. This expression is known as the battery dynamics model, and it is called the state of charge (SOC) of the battery.

$$\mathrm{SOC} = \frac{E_{re}}{E_{max}}, \tag{6}$$

where E_{re} is the remaining battery energy and E_{max} is the maximum energy from the battery. $E_{re} = E_{max} - E_{bd}$, and E_{bd} is the energy drawn from battery which is expressed as:

$$E_{bd} = \int V_b(t) I_b dt. \tag{7}$$

By combining (6) and (7) and the developed state of charge model in [102, 103], the dynamic model of the SOC in continuous time is a function of the charge and discharge process of the battery, which can be described as follows:

$$\mathrm{SOC}(t) = \mathrm{SOC}_i - \frac{1}{E_{nom}\eta_{c/d}} \int_0^N P_{db}(t) dt, \tag{8}$$

where N is the instant time in which the battery dynamic is considered, SOC_i is initial state of charge of a battery, E_{nom} is nominal energy of the battery, $\eta_{c/d}$ is charging or discharging coefficient and P_{db} is power flowing from the battery which can be detrimental in charging state and positive in discharging state. From the charging or discharging coefficient, the efficiency of battery storage can be defined as:

$$\eta_{c/d} = \frac{1}{\eta_c}, \tag{9a}$$

$$\eta_{c/d} = \eta_d, \tag{9b}$$

where η_c and η_d are the battery charging and battery discharging efficiency respectively. It is important to note that these two coefficients can be equalled or not, and they are a function of the design specification of each battery.

Furthermore, the dynamic model of the energy flow on the BESS during charging and discharging process is expressed in Eqs. (10) and (11) [104].

$$E_c(t+1) = E_c(t)(1-\sigma) + (E_{pv}(t) - E_D(t)/\eta_{inv})\eta_c, \tag{10}$$

$$E_d(t+1) = E_d(t)(1-\sigma) + (E_D(t) - E_{pv}(t))\eta_d, \tag{11}$$

where E_c is charging energy, E_d is discharging energy, E_D is energy demand, σ is hourly self-discharge rate which is fixed at 0.002, and η_{inv} is the inverter efficiency.

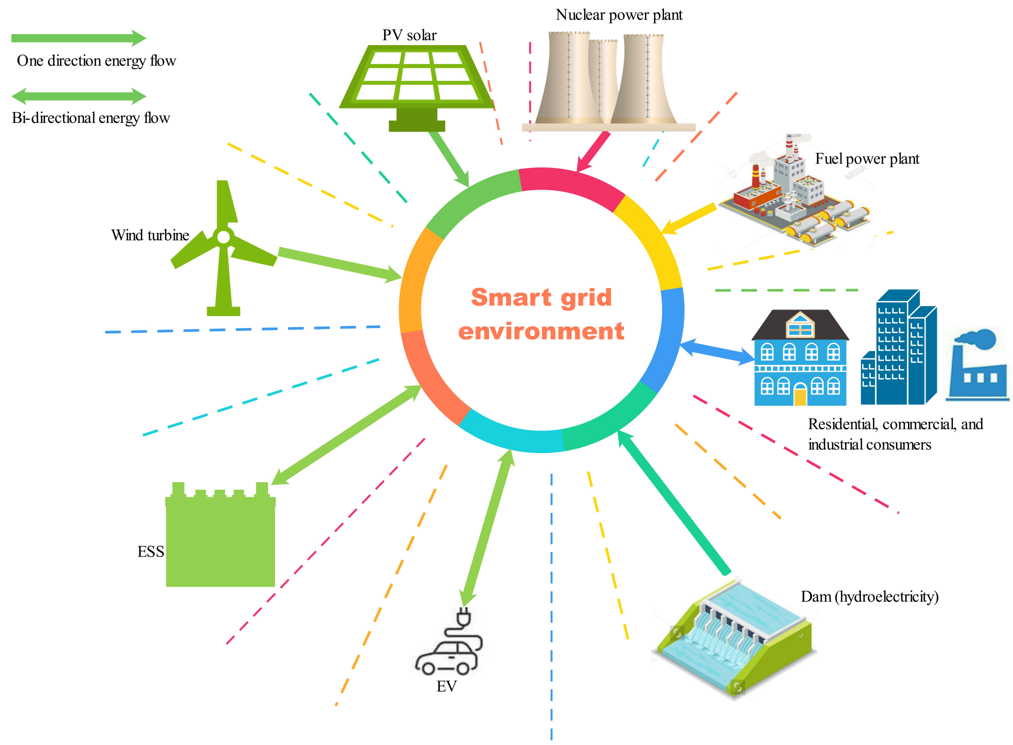

Figure 5: Overview of smart grid environment for the energy management system

6. DISCUSSION OF FUTURE TRENDS

The integration of RERs operates effectively on the electrical grid when it is working in an energy coordination manner [6, 105, 106]. It is therefore currently impossible to discuss RERs integration and energy management strategies without thinking about intelligent electrical grid technology [10]. The modern technologies that are based on the intelligent scheme introduce several approaches to coordinate the energy flow on any electrical system and an opportunity to optimally manage the ESS [107–111]. Alagoz et al. [112] have mentioned that the modern power grid can handle mechanisms for the efficient and reliable management of the energy system. This approach assists in the dynamism of the energy market that derives from the smart grid technologies which can be designed under several control schemes, such as model predictive control based real-time electricity pricing [113], closed-loop fractional-order as proportional control integrated through energy pricing scheme [114], closed-loop proportional-integral derivative-based price control mode [112] and any other optimal control strategy. Figure 5 presents a structure of smart grid environment based on DERs that are mostly used in the current intelligent electrical networks. It is important to note that the listed energy generations which are presented in the current smart grid environment, as described in Fig. 5, are not exhaustive. There are several types of either renewable or conventional energy resources systems which are not presented. However, this structure provides a model of the energy pattern in the smart grid environment. The most interesting components here, apart from the utility grid supplier that can generate the power from any conventional or renewable energy resources, are PV system [115] and ESS (and/or EV), which are accessible power resources to be integrated into commercial buildings [113]. The EV and ESS are based on the system dynamic behaviour as described in Eqs. 6 to 11. Both EV and ESS are battery storage system in the energy management manner.

For the implementation of the energy system in the commercial building, the future perspective consists of focusing on the smart grid technologies for a better energy coordination scheme. Due to the source stresses of RER (PV system) to be implemented in the commercial sector, ESS plays an important role in the energy coordination system that aims to optimise the system operation. Table 2 presents different profiles of yearly solar irradiation measured in the several PV panel systems implementation in a commercial building, as estimated in [83], for the Southern hemisphere. These solar irradiation systems are measured daily during the low and high demand period of energy consumption in Figs. 2 and 3. It shows that the combination of PV and ESS connected to the utility grid for the commercial building can optimise the operation stresses when implemented in smart energy coordination. The future perspective of the energy storage system can also be based on the deployment of ultra-capacitor BESS. The high capacitor storage system can boost the system operation when it is mixed with the PV system connected to the grid. Controversially, the ultra-capacitor is seen as an expensive storage system with low value discharging rate. This capacitor ESS model has a higher starting cost; thus, most design engineers avoid it. The advantage of using the ultra-capacitor, combined with the PV system connected to the utility grid, is more interesting during the high energy demand period when the solar irradiation is lower but for a short period of discharging.

Furthermore, the smart grid technologies can coordinate the energy mix strategy effectively even for high-efficiency ESS. It is therefore essential to note that before implementing the ultra-capacitor ESS, a more in-depth techno-economic analysis must be done. This kind of examination aims to provide the economic profile, which can define the need for using or not using ultra-capacitor ESS for a given electrical system.

7. CONCLUSION

The renewable energy resources can be efficiently incorporated into the electrical grid only if they are sized according to the network conditions and parameters. In the face of depleting fossil fuel reserves, renewable energy resources are considered a sustainable alternative solution to future electrical energy demand growth. Despite their high potential, renewable energy resources such as solar and wind are highly intermittent; their power output varies with the change in time of day and seasons. In practical applications, these downsides are mitigated by integrating them with energy storage systems in hybrid configurations. The solar power system is environmentally friendly and abundant in nature. Thus, it can be operated without any inconvenience in the commercial sector. Therefore, integration of solar PV array in a utility grid system can increase the flexibility and resilience of the electrical network. The sizing and seasonal variations of solar plays a significant role in their integration into a given system. The sizing parameters of the PV are optimally determined according to the demand. The dynamic variation of solar resources can only be resolved if it is set in the zone of sufficient resources and is combined with an energy storage system. The energy storage system will be charged during the high period of resources, and the same energy will be discharged when resources are insufficient or unavailable. This strategy constitutes coordinating an optimal control system to ensure the total energy supply.

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