Annotated Confirmation Report

Study on Standalone Hybrid Renewable Energy Systems with Pumped Hydro Storage for Remote Areas

The Hong Kong Polytechnic University

CONFIRMATION REPORT

Study on Standalone Hybrid Renewable Energy Systems with Pumped Hydro Storage for Remote Areas

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Date: 2012

Include:

i. An abstract

ii Acknowledgements

iii. A list of tables and charts

iv. A list of abbreviations

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1. INTRODUCTION

Energy is an essential component for all social activities and required for the production of all goods and the provision of all services [l]. Currently, the majority of the energy used on earth comes from conventional fossil fuel oil, gas and coal. The conventional energy, however, will be exhausted in 50-100 years based on the recent exploring and consuming rates [2]. And also, the world energy consumption will increase up 53% by 2035 [3]. Therefore, energy will be the biggest crisis to humanity in the near future. In addition, the combustion of depleting fossil fuels for power generation has detrimental impact on human life and environment especially global warming and climate change. In view of this, renewable solar energy sources, like solar, wind, and biomass energy, are being increasingly exploited to meet the energy needs regarded as potential routine to cope with serious energy dilemma and environmental concerns [4, 5]. As for China, the share of renewable energy sources (16% by 2020) for energy supply is relatively low compared with European countries, though the trend of development is positive [6].

✓ Describes importance of field

💡 Avoid overusing linking words to connect ideas, e.g. "and also", "therefore", "in addition", "in view of this" and "as for China"

💡 Avoid using time adverbs at start of sentence, place it next to verb, avoid use of "nowadays". State "5 million people in China currently lack access"

Nowadays, more than 1.5 billion inhabitants worldwide including 5 million people in China still lack access to electricity, most living in small remote villages or isolated islands far away from the national utility grid [7, 8]. In such remote areas the population is dispersed and the terrain rugged, hence utility grid extension to these locations is not only impractical for these reasons but also because of the prohibitive capital cost. Constructing long transmission and distribution lines to such comparatively inaccessible places is thus both impractical and uneconomical [9-12]. As a result, the electrical demand is commonly powered by diesel generators or even no power is supplied [13-15]. The significant rise in diesel price and subsequent environment pollution since the oil crises of the 1970s [16], however, make further employment of these systems expensive and hence less favourable. Additionally, the negative environmental effects resulting from the employment of diesel, noise and water, soil and air pollution, damages the local ecological system [11].

Faced with problems originating from diesel, power supply for remote areas with limited access has drawn extensive public attention, they are beginning to consider the locally available renewable energy (RE) to provide power[17]. With technical renovation and the rapid development of renewable energy system (RES), the initial cost of renewable energy technologies (RETs) have declined rapidly, which is no longer the key barrier to their usage and suggest that the comparative economics of RE are likely to get better and hence motivates the remote communities to transfer from diesel toward a greater reliance on more local and sustainable renewable energies.

✓ Uses present perfect tense to describe recent developments in field, e.g." has drawn" and "have declined"

Avoid spoken language, e.g. "get better" when rest of the report uses formal language. 'Improve' is a better option.

However, the common disadvantages of RE sources are their power generation discontinuity (intermittent and unpredictable characteristics), as well as the fact that its energy generation is not controlled by the system operator thus making it more difficult to integrate these plants in the generation pool than in the case of conventional plants[18]. A suitable energy storage system (ESS), with great potential and capability to solve the problems described above, must be introduced to make the remote area power supply become fully reliable and economically viable. At present, this is the most challenging and crucial task for remote renewable energy applications.

Currently, the majority of stand-alone renewable energy systems use lead acid batteries for electricity storage, while the high initial capital cost, frequent replacements and ultimate disposal remain the enormous challenges for the battery storage. In some cases, for system simplification, some stand-alone renewable energy supply systems might discard energy storage devices and apply the dispatchable generators (eg. diesels) instead, which are supplemented by intermittent renewables suppliers, if available. However, this approach results in a substantial waste of energy and investments in renewables, the environmental benefits are also greatly affected.

✓ Explains current situation
✓ Outlines current solution
✓ Explains drawbacks with current solution

An awareness of the limitations of the batteries, a conventional and novel energy storage technology, i.e. pumped storage, is introduced in this research. The pumped storage is widely employed for conventional coal-fired and nuclear power stations. However, until now, not much research has been conducted on pumped water storage for RESs, especially for the standalone systems on remote areas. Without enough theoretical and experimental investigations, the concept of pumped storage is therefore not widely adopted in the renewable energy power supply systems.

In this study, the standalone hybrid RESs with combined pumped hydro storage (PHS) and batteries storage are introduced, its performance will be investigated in greater detail in the future work. The research framework is listed in Fig. I and the major objectives of this research are briefly summarized as follows:

✓ Develops introduction from more general worldwide problem
✓ Then, narrows focus to China.
✓ Explains current problems with existing solutions
✓ Introduces research 'gap' with phrase "However, until now not much research has been…"
✓ Explains how this project will fill research gap

- To investigate the technical feasibility of standalone hybrid renewable energy systems with combined pumped hydro storage and batteries storage on remote areas;
- To evaluate the economic performance of the pumped storage and battery storage subsystem for standalone RESs;
- To develop an overall mathematic model for various components in the hybrid systems;
- To design/size, simulate and optimize the hybrid renewable energy systems with combined pumped hydro storage and batteries storage using some novel algorithms;
- To set up an experiment test system and evaluate the operating performance of a standalone solar photovoltaic (PV) powered pumped storage system under real conditions;

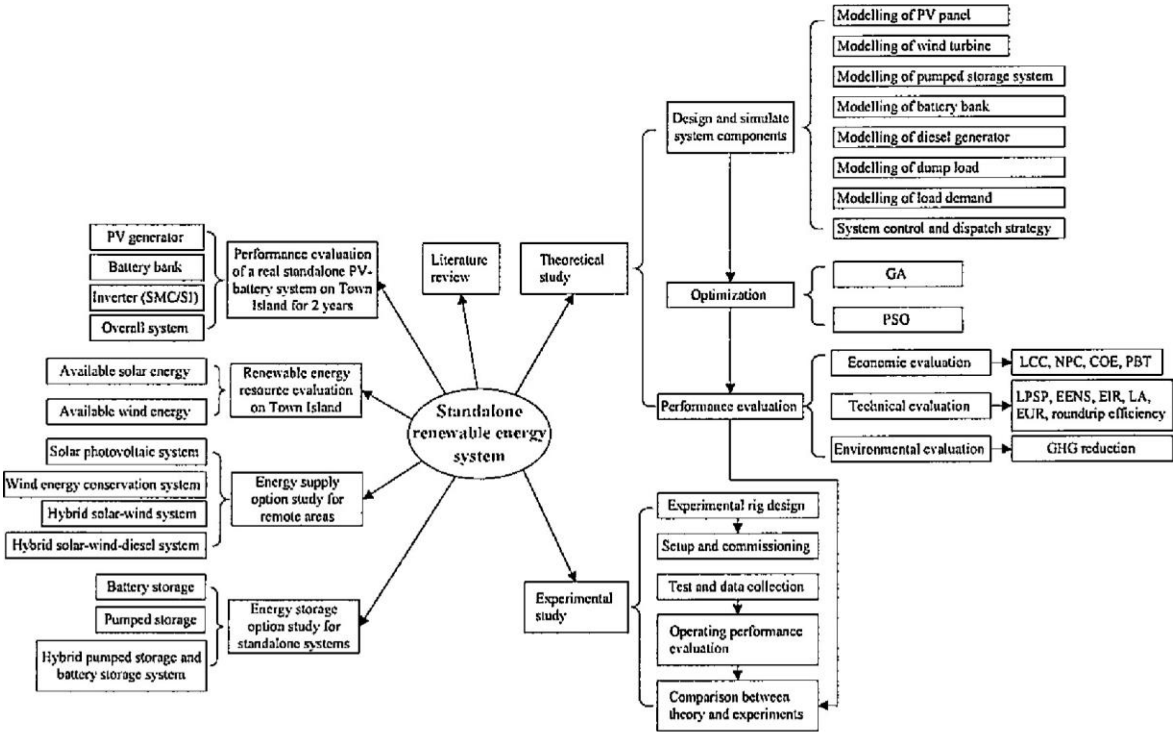


Fig. 1 The framework of the proposed study

2. LITERATURE REVIEW

A few studies on the hybrid renewable energy and pumped storage systems have been found in literature. The literature review is divided into four parts. The first part is about the RESs for the remotes island. The energy storage system (ESSs) for standalone RESs are reviewed in the second part, following by a detailed investigation on the pumped storage. The fourth part focuses on the design and simulation methodologies and optimization algorithm. Finally, previous studies about computer tools for performance evaluation of hybrid RESs are reported.

Avoid "a few". Write "Few studies…" or "Little research…"

✓ Explains outline of contents of whole paper

2.1. Standalone renewable energy systems (RESs) for remote areas

2.1.1. Economic considerations

Renewable energy technologies (RETs) have become competitive with conventional resources in many areas of the world, most notably in remote areas, over the last five to ten years. This is primarily attributable to two key factors: the rising cost of diesel generation and the rapidly declining cost of RETs[17]. These increases in fuel price have caused the price of diesel electricity to more than double in the last decade. On an unsubsidized basis, RE now can be broadly competitive with electricity from diesel generators at current fuel prices (depending on location and application) [19, 20]. This trend has dramatically expanded the portfolio of diesel energy alternatives for RE transition, particularly when coupled with the fact that RETs have come down rapidly in cost. PV represents the most dramatic illustration of RE cost declines and the potential for renewables to compete with diesel. PV panel prices, for example, declined by 40% in 2009/2010, and are projected to continue to decline significantly in 2011/2012 [21]. Recent evidence from India, for example, suggests that PV is already significantly cheaper than diesel electricity in many areas, prompting major industrial customers to begin increasing their use of PV in off-grid applications[22]. The competitive position of renewable energy can provide additional economic benefits to local communities and utilities beyond direct savings. In addition, the cost of renewable

✓ Uses adverbs to highlight the importance of this topic, e.g. "notably", "dramatically", "rapidly", "significantly"
✓ Places the adverbs next to the main verb.

energy technologies continues to come down globally, which suggests that the comparative economics in the years ahead are likely to get much better than present.

2.1.2. Advantages of renewable energy systems (RESs) for remote places

For the islands, remote regions and national borders where the national grid is not available or too costly to be implemented, the most practical and cost-effective energy future is the renewable energy power supply systems. These systems are installed for a range of reasons, including: expensive grid connection or diesel fuel cost[23]; desire to use renewable energy[24]; desire for independence and low running costs; avoidance of overhead line or undersea cable in environmentally sensitive areas[24]. Therefore the remote areas around the world are at the forefront of the transition toward a more sustainable energy future[17], particularly after investigation the viability of RESs, such as PV, wind, micro hydro, biomass and their hybrids.

Better to place the main idea first in topic sentences, i.e. "The most practical and cost-effective...supply systems, for the islands ... implemented.

The stand-alone renewable energy systems (RES) have a reputation for being inexhaustible, environmentally benign, reliable, efficient, and with cost-effective characteristics, which are hence seen to be the most likely viable and practical energy future for such remotes areas [25-27]. In addition, renewable energy is a promising key to solve the problems of global environmental pollution and hence reduce the subsequent negative impact on worldwide prosperity due to the depletion of such as nonrenewable resources and also the negative impact on human health caused by the ensuing atmospheric degradation[28, 29]. Furthermore, renewable energies avoid the safety problems derived from atomic power [30], which is why, from the social point of view, it has become more desirable to adopt renewable energy power plants[31]. An awareness of the above has caused the last decade to witness a dramatic expansion in the use of RES as replacements for fossil-based energy. As renewable energy costs come down worldwide, the economic, financial and ecological case for beginning to transition away from fossil fuels to a greater reliance on more local and sustainable forms of energy is increasingly compelling[17].

Better to discuss studies in more detail and highlight strengths and weaknesses of studies, i.e. "discuss" the safety question of atomic power and compare with renewable energies.

✓ Summarizes main idea of the paragraph with the last sentence.

Due to wide deployment of the renewable energies, remote areas, remote communities can unlock a number of both monetary and non-monetary benefits from the development of local renewable energy resources. These benefits include enhanced energy security, decreased environmental impact, improved local residents' life quality, climate mitigation, greater self-reliance, as well as lower electricity, transportation and heating/cooling costs [28, 29], Finally, the lessons learned from transitioning remote areas to higher levels of renewable energy penetration, such as innovative storage and demand side technologies, can help mainland areas and real world better understand the technical, financial, operational challenges and can help them harness a greater share of their locally available energy resources as well.

Better to divide the information into clearer paragraphs. Better to have one main advantage in one paragraph.

Of the renewable sources given above, the solar PV system is regarded as the most promising candidate[32]. Solar energy is expected to be the foundation of a sustainable energy economy, because sunlight is the most abundant renewable energy resource[33]. One major advantage of PV versus wind power is that typically solar energy matches the time distribution of load profiles better than wind energy [34]. The initial cost of PV systems might be higher than other RESs, but solar power is superior to other RES as it is produced silently with little O&M inputs, no direct pollution or depletion of resources as reliance is solely on inexhaustible solar irradiation. In addition, PV systems hold good promise for worldwide electrical energy generation, for instance the study[l] estimated that a PV station of area 250 x 250 km^2 would be enough to meet the electricity requirements throughout the world for the year 2020. With this in mind, the specific share for renewable energy and PV power for the whole energy structure of the world would be 80% and 60%, respectively, at the end of 21st century[2]. The increased global popularity of the PV system is also due to increased investment which has resulted in greater reliability and also making it more cost-competitive in meeting energy demands.

Better to explain in which section something was discussed if it is in a different section i.e. "Of the renewable resources discussed in Section 1…".

✓Discusses advantages, should also cite sources and discuss at further length any disadvantages, i.e. compare and discuss relative costs.

Better to not to use "would" to discuss future. Better to use "is expected to be" or "could be".

2.1.3. Hybrid renewable energy system (RES)

It is evident that neither a standalone PV nor a single wind energy system is able to provide a continuous power supply because of seasonal and periodical fluctuations [35]. The independent use of any single technology usually leads to a considerably oversized generation system and energy storage subsystem for power supply reliability, which in turn requires a higher operating and life cycle costs [16, 26, 36, 37].

✓ Explains problem

To meet the challenges stated above, the renewable energy resources either integrated or used in combination with the backup storage subsystem, called hybrid systems, are propounded. The integrated multi-source RESs can leverage the strengths of each technology to provide a more reliable and less costly power generation than the systems rely on a single source of energy[13, 17, 29, 38, 39], since the renewables can complement each other component capacities are better utilized, improve load factors of generators and better exploitation of renewable. The economic benefits of these combined RETs are sufficiently promising and becoming popular now for developing the power supply systems for remote areas [40].

✓ Discusses possible solution

✓ Evaluates possible solution.

Hybrid power systems, various combinations of solar, wind, hydro, and biomass with/without rechargeable batteries, are currently being researched and widely considered as a cost-effective and ecologically sound solution in a long run [28, 41, 42].

✓ Describes current situation in general.

Amongst various configurations proposed, the hybrid solar and wind systems with battery storage is becoming increasingly attractive and being widely used as an alternative to fossil-fuel energy[43]. The main reason behind that is the complementary nature exhibited from wind and solar energy in daily and seasonal patterns [44, 45]. Hybrid solar and wind energy can attenuate variations in power produced, thereby significantly reducing energy storage requirements[16, 46]. A great deal of research has reported the hybrid solar and wind system [40, 47-50]. The hybrid solar-wind system optimization Sizing (HSWSO) model [51, 52] was developed for the hybrid solar-wind power generation systems with batteries.

✓ Describes current situation more specifically.

In addition, the renewable sources can also be used in combination with the conventional energy system to provide a more reliable electricity 24-hour-a-day and 7 days a week, such as hybrid PV-wind-diesel-battery systems[53, 54], or wind-diesel system[39, 55, 56], or PV-diesel system[15, 28, 57] or PV-wind-hydro-diesel system[58].

2.2. Energy storage system (ESS) for renewable energy supply system

2.2.1. Motivation of energy storage system

Energy storage is recently in vogue because of concerns about climate change and peak oil. Many studies discussed the future 100% RE scenarios at the national level, such as 55% wind and 45% solar power generation for Germany and Denmark[59], 100% RE systems for Denmark in years 2030 and 2050[60], and 100% renewable electricity for Australia[61]. One study[62] showed that a PV-wind-hydro-biomass system could supply 100% electricity for Japan by 2100. At the project level, the book[63] described the efforts of the Los Angeles Community College District to implement a 100% RES for its nine college campuses. Almost all studies above identified that the energy storage was a key barrier to a fully renewable powered world due to the intermittency of renewable energies.

💡Better to avoid "many". "Numerous" or a "large number of" are better options.

✓ Gives examples to highlight feasibility of the system.

Recently the large-scale development of wind and solar power generation inevitably brings remarkable influence upon the power grid peaking and system safe operation because of their unpredictable and intermittent characteristics [64, 65], To a large extent, ESS is considered as a prominent solution for the problem as it provides an inventory for the unexpected surplus or deficit from random renewable generation. On the one hand, it can flat the fluctuating output power of the new energy generation, improve power quality, maintain stable system, and on the other hand, it can adjust the changes of grid voltage, frequency and phrase caused by new energy generation, and enable the large-scale wind turbine (WT) and solar power penetration.

💡Better to use recently with the present perfect when discussing background, i.e. "has recently brought a remarkable…".

✓ Lists the advantages of the system.

💡Better to discuss both sides of the issue highlighting weaknesses as well as strengths that have been shown in previous studies.

For the stand alone systems in remote areas, RESs have the inherent characteristics of intermittency and non-controllability, threatening the reliable operation of electricity supplies of public utilities. Such disadvantages have become major hurdles to the extensive utility of the RE[66]. A suitable EES could obviously provide an important (even crucial) approach to dealing with the intermittency of renewable sources and the unpredictability of their output as the surplus could be stored during the periods when intermittent generation exceeds the demand and then be used to cover periods when the load is greater than the generation[6]. Therefore, storage technology is a critical component to ensure sustainable growth of clean energy [67].

2.2.2. The role of energy storage

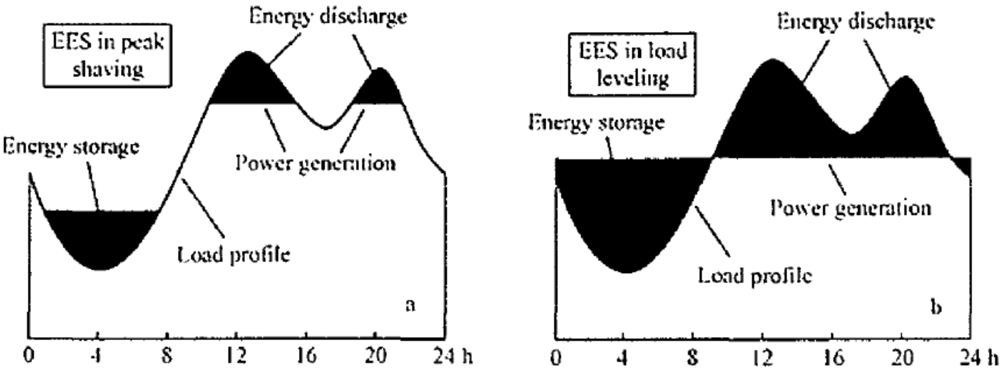


Fig. 2 Load profile of a large-scale electricity storage system. (a) EES in Peak Shaving; (b) EES in load levelling

Energy Energy Storage (EES) refers to a process of converting electrical energy from a power network into a form that can be stored for converting back to electrical energy when needed[68]. EES systems are critically important to intermittent renewable energy supply systems [69-71]. They can provide substantial benefits including load following, peaking power shift, providing dispatch power and spinning reserve, improving power supply stability and quality [6, 69]. As shown in Fig. 2, the following two functions of EES for standalone RES are the most common:

✓ Defines and describes key concepts.
✓ Refers to figures in text, e.g. "As shown in Fig 2,

- *Ramping (Peak Shaving).* As indicated, solar energy to a large extent fluctuates intermittently due to its stochastic nature. Because of this unpredictability, it does not produce usable energy for a considerable portion of the year, and even when it does produce power there may be no demand for that power at the time. Therefore storage devices are necessary to compensate for the inherent defects of solar energy and ensure power produced from PV can be released and dispatched reliably to better fit demand.

- *Load leveling and time shifting (balancing the production and load).* An energy storage system enables the produced energy to be held in reverse when demand is low, ready for discharge during peak demand, hence alleviating the mismatch between peak load occurrence time and the periods when maximum power is generated. It is obviously prudent for electricity to be stored when the excess is produced and to be released only when needed.

2.2.3. ESS classification

Research to build more reliable and cost-effective energy storage technologies is now on the rise. As a result, many new technologies and applications are evolving and competing[67]. The principal EESs are summarized in Fig. 3, which are classified into the following four main categories by the form of storage: (l) Mechanical process, (2) Electrochemical process, (3) Electromagnetic process and (4) Thermal processes. Electrical energy storage usually includes only the first three types. The EESs also have been divided into two kinds based on the function of storage: energy management, power quality and reliability[6]. The characteristics and performance of these storage technologies have been widely studied [72-75].

Better to have a short introductory paragraph including the background sentence 1 and a sentence summarizing the section, i.e. There are four principal methods of…".

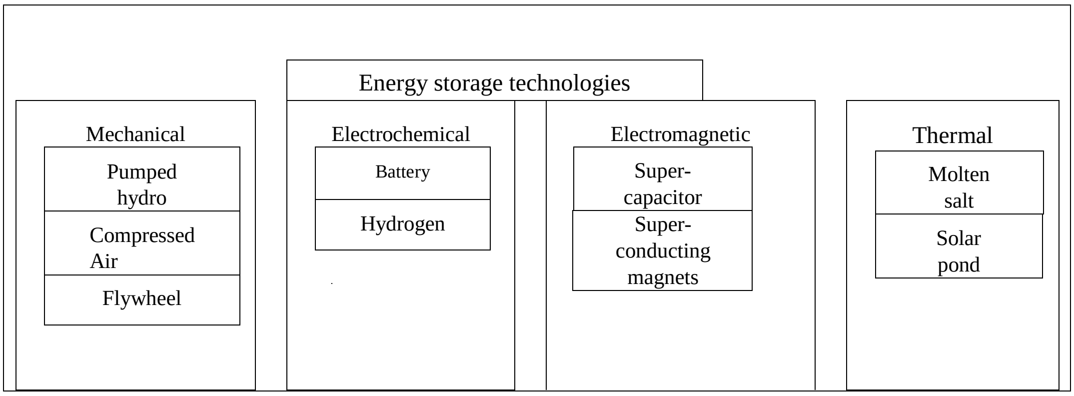


Fig. 3 Classification of energy storage systems

Energy storage is rapidly gaining more interest from industry leaders, policymakers and academic researchers. Currently, the majority of stand-alone renewable energy systems use lead acid batteries for electricity storage. Possible storage technologies for renewable energy have been extensively investigated by many researchers in recent years. An overview of six popular energy storage alternatives for a medium scale renewable energy system, 100 kW PV plant, was contrasted in [18]. One study[76] suggested that batteries, compressed air and pumped storage were three promising technologies worthy of exploration for grid-independent medium sized electricity storage. Andreas[77] stated that pumped hydro storage was the only proven system of energy storage for medium and larger size renewable systems, whereas energy storage for small power systems is usually performed by batteries. Some researches on the power generation and load balance, system regulation of the isolated grid dominated by wind and solar power were carried out in recent years[78]. Besides, the optimal energy storage capacity for PV and wind hybrid system was studied in [79] based on stochastic simulation in order to minimize the investment cost of storage cell.

Avoid repeating background with the first sentence of this paragraph. Use a topic sentence that outlines the main point of the paragraph, i.e. 'Six popular energy storage alternatives...have been proposed'.

Use "research" as an uncountable noun, do not use the form "researches".

Avoid 'vague' comments, e.g. Some research on power...were carried out in recent years. Comment on the findings of the studies and their strengths and weaknesses.

2.2.4. Lead-acid battery

Currently, the majority of standalone RESs usually employ rechargeable lead-acid batteries to store the excess electricity from the renewable energy. The study[80] shows that for very low energy storage system contribution and very short period of autonomy, the lead-acid batteries show a lower cost than the pumped storage. As the autonomy values and energy storage contributions increase, however, the pumped storage gradually become more attractive. On the other hand, batteries have well known limitations:

- The initial investment is too high, especially for large-scale and high capacity systems;
- They have a relatively low lifetime (Usually 2 - 8 years). Frequent replacement imposes an additional financial burden.
- They incur particular environmental problems in containing toxic substances such as lead, which can cause problems during shipment, installation, and particularly in ultimate disposal.

- They tend to be dangerous with sulfuric acid and in the possibility of explosion;

2.3. Pumped hydro storage (PHS) system for renewable energy

2.3.1. Introduction of pumped hydro storage

Pumped hydro storage (PHS) was first used in Italy and Switzerland in the 1890s[81] and the first large-scale commercial application was in the USA in 1929 (Rocky River, Hartford). It remains the most commonly used and commercially viable electricity storage technology[82] due to its low cost and maturity with over 127 GW installed worldwide, accounting for 99% of the total storage capacity[73].

Introduce the new section, outline the contents and link it to what has been discussed previously, i.e. "Having given an overview of ...in section 2.2, this section..."

In the past, pumped storage, the only market-proofed technology for large scale energy storage, was used as a tool to contain surplus energy during non-peak or low market price periods so that it could be used later in peak periods or as a resource during periods when high market prices prevailed. In Europe, for instance, Switzerland with its extensive network of river and reservoirs has allowed to import cheap excess nuclear power from France and Germany to pump water uphill and store it in vast reservoirs. The energy could then be sold back to these countries during peak-priced periods, or sold to Italy, Europe's largest electricity-importing nation.

Limit the background details to what is relevant to the current project. The details of the history and pumped storage could be summarized in one short paragraph.

Currently, the pumped storage is more relevant to renewables integration (solar and wind), is deployment in those countries with the most renewables: Japan, Western Europe and US [83].

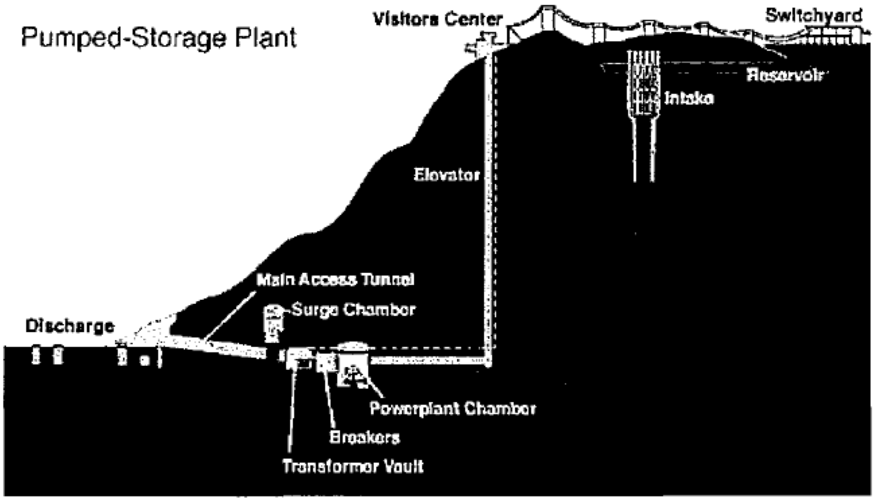


Fig. 4 Pumped hydroelectric storage plant

As shown schematically in Fig. 4, such a system normally consists of (l) two vertically-separated water reservoirs, (2) a pump to elevate water to the high elevation (to store electricity in the form of hydraulic potential energy during off-peak hours), and (3) a turbine to generate electricity with the water returning to the low elevation (converting the potential energy to electricity during peak hours). Clearly, the amount of stored energy is proportional to the height difference between the two reservoirs and the volume of water stored.

✓Describes key features of figure

💡Avoid absolute words, e.g. "clearly" and "obviously".

PHS is a mature technology with large volume, long storage period, high efficiency and relatively low capital cost per unit of energy. Taking into account the evaporation and conversion losses, at present its efficiency in the world is about 70-85% [6, 73, 84], The lifetime will be 40-60 years and the total installed capital cost is about \$1500-4300/kW or \$250-430/kWh[73, 85].

💡Include more technical background and less historical background".

2.3.2. Increase renewables penetration in grid connected system

As stated earlier, at present the pumped storage is more relevant to renewables integration. The Eagle Mountain pumped storage project in US [86], as an engineering example, represents a sustainable renewable energy dependable solution, which can provide integrated, reliable and clean electricity generation. In Japan and Germany, which are putting full blast on renewable energy particularly after the nuclear accident, the number of pumped hydro cycles could be doubled from one to two times per day due to the excess and cheap solar energy during the afternoon peaks[87]. George's study[88] showed that wind energy with hydro pumped storage is considered as the most suitable storage technology for allowing high wind penetration levels in medium and large autonomous power systems. Substantial research also demonstrated that pumped-storage hydro is an ideal option and is being applied to confirm the variability of renewable power sources, such as wind and solar[89].

Avoid spoken expressions, e.g. “full blast” better to use “considerable resources”.

2.3.3. Standalone renewables based/powered PHS

Wind energy based/powered pumped storage power stations have been the subject of many publications in recent years and being considered for implementation in isolated power systems such as remote islands [90-105], most of which focus on stabilizing the output from the wind power, peak clipping and valley filling of the power demand, increasing the penetration level of wind power. In addition, the combination system of wind and hydro energy assisted by the pumped water storage was studied by [106-110].

Highlight key results of studies that relate directly to this research project.

PHS complements with solar and wind energy. Their respective characteristic determines the complementary operation can get more benefit[111]. However, there are just a few reports on standalone solar or hybrid solar and wind system powered pumped storage system.

In order to decrease significantly diesel consumption for an isolated island grid, additional energy storage and sufficient power regulating capability are needed when fluctuating renewable energy is to be integrated into it. Among several kinds of energy storage technologies, PHS can be the technically more mature and economically viable alternative [112].

Reference[113] developed a calculation model of the capacity of PHS in hybrid wind-solar system to explore the economic rationality according to the principle of that price of electricity cost and investment cost per kilowatt is the lowest. In [114], the

Use the name of the study’s authors as the subject, rather than “Reference [113], i.e. Xin et al, (2007 developed…”.

determination of PHS capacity for hybrid wind and pumped storage system was demonstrated with genetic algorithm method to get the maximum benefit of the wind farm.

Some literatures introduce a wind-solar-hydro combined generation system that utilizes both wind and solar complementary resources to generate, and then uses a PHS station and battery storage to store energy [113, 115]. The PHS plant was proposed for a PV system to mitigate the imbalance between renewable energy production and load demand [116, 117], which can effectively solve the power supply reliability problems associated with excess power. With the same objective, a wind-solar and pumped-storage hybrid power supply system has also been studied [111, 118]. In addition, the papers [91, 119] have preliminarily established simple models of the main components of a hybrid wind-solar-pumped-storage power system.

Do not use the term "literatures" in the text, use "research" or "studies".

State clearly the findings of the studies rather than just report they have been done.

To date there is little literature reporting real applications of pumped storage in small to medium sized RESs, even though the subject has attracted the attention of many scholars. A small scale PHS system was established in the energy park of Budapest Tech campus for demonstration and education purpose [120]. Manolakos et al. [121] implemented a PHS system to partially replace the battery system for a stand-alone 18 kWp PV plant in Greece. The results demonstrated that the efficiency of the micro PHS system was only 28%, while the social impacts, such as both electricity and water supply, would be increasingly significant.

✓ Highlights research gap, i.e. what needs to be studied

✓ Reports key findings and methods of studies directly relevant to this research project

2.3.4. Future outlook of PHS

Currently reversible pump-turbines and adjustable speed machines are widely used to improve efficiency[122]. While development of PHS is limited due to the lack of suitable sites, there is continued interest in developing new PHS systems using less land disrupting schemes, such as underground or sea based reservoirs[69]. The open sea can be used as the lower

Start section with a clear topic sentence.

Do not use "not enough", "insufficient" or "lack" are more appropriate options.

reservoir for some remote islands which characterize with special topographical condition and not enough fresh water[123]. The pumped-storage system using seawater presents good potential for renewable energy storage, which was first examined by Japan in 1981[111]. A pilot seawater pumped storage plant was then constructed on Okinawa with 400 MWh storage capacity, and the resultant roundtrip efficiency is 77%[124]. In addition, the economic performance of seawater pumped storage system was investigated in [125]. In addition, underground PHS which uses flooded mine shafts or other cavities, currently being researched, is also proofed technically possible[6, 126].

The PHS is the only way of the large-scale energy storage and also presents its great potential in the medium and micro sized system. The only market-proofed technology for large scale energy storage, PHS will remain a dominant EES system at least in the very near future[6]. However, some key challenges should be overcome, creating opportunities for further improvement of the technology and its promotion for renewables:

✓ Lists key challenges in point for using italics to highlight key terms

💡 Introduce the list in text, i.e." which are listed below..."

- *Site availability:* the presence of appropriate geography for two large reservoirs is a critical factor for decision.
- *Water availability*: an adequate water supply should be guaranteed. for the seawater pumped storage, some technical problems should be assessed such as the corrosive effects of salt water and possible leakage into the ground water.
- *Water availability*: an adequate water supply should be guaranteed. for the seawater pumped storage, some technical problems should be assessed such as the corrosive effects of salt water and possible leakage into the ground water.
- *Technical viability:* the operation of renewables has not been widely realized in real applications. As some unknowns and technical issues remain to be solved, providing a challenge for many future researchers in this field.
- *Environmental issues:* ecological problems, removing trees and vegetation from the large amounts of land prior to the reservoir being flooded [69, 127].

2.4. Design and simulate the hybrid renewable energy system

The performance of a hybrid system depends upon proper sizing of the system. Design and simulation followed by optimization are main steps involved in sizing an isolated hybrid system. The size of a system, that can supply the required power

✓ Outlines content of section, .e.g. "This section reviews..."

demand, can be determined by simulating the entire system using the resource and the demand data. This section reviews the state-of-art of hybrid system sizing approaches and optimal sizing methods.

2.4.1. Basic design approaches

There are primarily two different approaches to basically design and simulate a hybrid system: deterministic and probabilistic [40, 45]. The evaluation of the mentioned approaches is given in following subsections.

Avoid the following:
"basically" is better "the basic design",
"mentioned" is better "these approaches"

1) Deterministic approaches

In this approaches, the RE resources and the demand are considered as deterministic quantities and their variation with respect to time is assumed to be known. Usually, time for which the system has to be analyzed (time horizon), is divided into smaller time periods, during which the resources availability and load are assumed to be constant. In deterministic methods, the chronological sequence of the data is extremely important. Sometimes the calculation based on the worst case scenario, say worst month, can also be used in designing of the system [128-130]. Typical weather year (TWY) for a particular location can also be used to design a renewable power system[131]. However, the TWY data for more than one renewable resource are difficult to obtain. The synthetically simulated weather data was used to simulate a hybrid system[132]. These approaches are either computationally intensive (if it uses data for a long time period, say many years) or produce sub-optimal results (if it uses the worst month scenario).

Use present tense to describe standard approaches but to use past tense for individual studies, i.e. NOT "data was used" rather "data is used".

2) Probability-based approaches

Probabilistic approaches may be very simple sizing methodologies. Results obtained by these techniques, however, are not the most suitable to find out the best solution. Usually, they take into account one or two system performance indicators to be optimized in order to size components of the studied system[133]. These methods involve the development of appropriate models for generation and/or load followed by a combination of these models to create a risk model. Some methods did not consider the chronological sequence of the data, which makes them less accurate. In this method, energy generated by power sources, and load demand in some cases, are considered as random variables[45].

✓ Critically evaluates probability-based approaches using evaluative language, e,g, “are not the most suitable”, “did not consider”

A probabilistic approach based on convolution technique using probability density function (PDF) in order to evaluate the performance of hybrid PV-wind systems was proposed in [134-136]. A three-event probability density approximation was employed in [37], which is based on the two state process, proposed by [137].

3) *Hybrid approaches*

As presented in the literature[45], deterministic and probabilistic approaches for system design and simulation have their own merits and demerits. Design methodology utilizing deterministic methods are either computationally intensive or produce sub-optimal results depending upon the type and amount of data used. Whereas, design methodologies based on stochastic methods are simple. However, deterministic methods take into account the chronological sequence of data, and hence, can produce accurate results compared to that of stochastic methods. In order to overcome the limitation of inaccuracy in stochastic methods reported in the literature (e.g.[137]), a new stochastic method to optimally size a renewable hybrid system with more than one power source and to determine the cost of energy produced is proposed in this paper. The method combines the advantages of both the deterministic and probabilistic approaches while retaining inherent simplicity of stochastic method.

Better to avoid starting topic sentences with “As presented in literature [45],...Better start with a subject, i.e. “Deterministic...”.

2.4.2. Optimum design/sizing

The recent trends about optimum sizing of hybrid RESs are reviewed in this subsection. The optimum design of hybrid renewable energy systems is a hot topic and there is a rich literature dedicated to this topic[138]. Therefore, substantial optimization techniques have been applied by many researchers for the sizing of hybrid RES, which will be discussed in greater detail in the following section.

✓Outlines content of the subsection.
💡Better to avoid clichés, e.g."hot topic".

1) Analytical methods

In analytical approaches, hybrid RESs are usually represented by means of computational models which describe hybrid system size as function of its feasibility[133]. Consequently, system's performance can be assessed for a set of possible system architecture and/or a particular size of components. Best configuration of a hybrid energy system is determined due to a single or a multiple performance index of the systems analyzed. This kind of methodologies allows the designer to simulate the performance of several hybrid system configurations; nevertheless, they need long time series, usually 1 year, of weather variables (solar, and wind) for the simulations. The performance assessment of hybrid system can be carried out by computational models (i.e. commercial software tools and/or numerical approximations of system components). Recently, several computer tools have been developed in order to assess hybrid energy performance, which aids the designer to analyze the integration of renewable sources. Many studies have employed the analytical approaches to optimize the standalone RESs [139, 140].

✓Explains a key term.
✓Highlights advantages of approach.
✓Highlights disadvantages of approach.

2) Iterative methods

Performance assessment of hybrid energy systems in iterative methodologies is done by means of a recursive process which stops when the best configuration is reached according to design specifications[133]. An iterative method is reported by [141] where an optimal hybrid system was obtained among different renewable energy combinations for a rural community, minimizing the

✓Provides a strong topic sentence with a clear subject, explaining approach.
✓Gives example.

total life cycle cost, ensuring system's reliability. In this work, a numerical algorithm based on Quasi Newton method was used to solve the optimization problem[142].

GA and PSO are iterative methods, which are reviewed in the following section in detailed.

3) *Hybrid methods/approaches*

Due to multidimensional nature in optimization problem, a suitable methodology to deal this problem will be one able to solve multi-objective optimizing. The objective can be twofold (techno-economical) or threefold (technical, economical, and environmental). The multi-objective optimization is also reviewed in the following subsection.

✓Provides a link at the end of the subsection to the next section. E.g. "in the following subsection".

2.5. Optimization techniques for RESs sizing

Due to the discontinuity and being climate-dependent, renewable energy supply requires complex design, simulation and optimization methods to ensure a reliable energy supply [87]. Fortunately, the continuous advances in computer hardware and software are allowing researchers to deal with these optimization problems using computational resources, as can be seen in the large number of optimization methods that have been applied to the renewable and sustainable energy field. The population-based meta-heuristics optimization algorithms mainly include: genetic algorithms (GA) and evolutionary algorithms (EA), scatter search (SS), path relinking (PR), memetic algorithms (MA), ant colony optimization (ACO)), particle swarm optimization (PSO), estimation of distribution algorithm (EDA), differential evolution (DE), artificial neural network (ANN), artificial bee colony optimization (ABCO), etc.[143] .

Better not to use long lists and etc. Here the list is introduced with "mainly include". Therefore, "etc." is not required.

The optimization algorithms constitute a suitable tool for solving complex problems in the field of renewable energy. Optimization of the entire system may be performed to arrive at a sizing which satisfies certain cost and reliability criteria. This is typically achieved by minimizing the net present cost of the system or the levelized cost of generated energy[45].

✓Gives a clear topic sentence.

✓Develops topic by detailing how it is used, e.g. "This is typically achieved".

Based on Scopus database, Fig. 5 illustrates an exponential evolution in the number of research papers that use optimization algorithms in the study of RES.

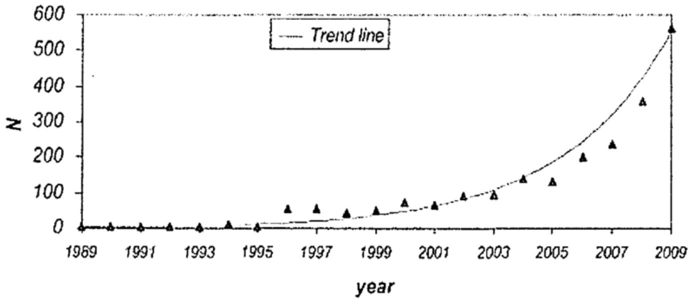


Fig. 5 Number of papers using optimization algorithms applied to renewable energies in the last 20 years

Different optimization algorithms have been employed for the different types of models in the study [144]. A review of the optimization methods for hybrid renewable energy systems demonstrated that the most popular applied methods were genetic algorithm and particle swarm optimization [145]. Many researchers are continuously proposing and applying new methods in the field of renewable energy, these commonly used optimization methods are briefly reviewed as follows:

2.5.1. Multi-objective optimization formulation

To date the most popular computational optimization methods only have focused on solving single-objective problems [87], including constraints in some cases. However, there are many shortcomings in studies of single-objective methods, which are formulated as a problem whose goal is to find the "best" solution, corresponding to the minimum or maximum value of a single objective function that group all different objectives into one[146]. On the other hand, for the realistic problem, there exist a large number of applications that require the simultaneous optimization of several objectives, which are generally in conflict, preventing simultaneous optimization of each objective. Many, or even most, real engineering problems actually do have multiple-objectives, i.e. cost, system performance, reliability (days of autonomy, loss of load probability, loss of power supply probability, unmet load), etc. These combined objectives are difficult but realistic problems [147-

✓ Highlights drawbacks with single-objective methods, but better to include a strong topic sentence at the start, i.e. Multi-objective approaches are preferable".

✓ Contrasts two approaches and highlights differences.

💡 Better not to use "On the other hand" to show differences and opposites, better to use "In contrast".

149], allowing decision-makers to think about the trade-offs between different benefits of different objects and choose the prior one.

✓Becomes more specific in the second paragraph after a more general first paragraph.

Generally these multi-objective approaches are often divided into two main categories, One is aggregate weight functions which combine the individual objective functions into a single composite, where the relative importance of each objective is adjusted according to relative weights[150]. The other general approach is Pareto-based optimization method, which establishes relationships among solutions according to the Pareto-dominance concept[151].

✓Gives examples of studies with supporting ideas discussed in paragraph 3.

A reasonable solution to a multi-objective problem is to investigate a set of solutions, each of which satisfies the objectives at an acceptable level without being dominated by any other solution[148]. With the aim of optimizing the mix of the renewable system maximizing its contribution to the peak load, while minimizing the combined intermittence, at a minimum cost, some multi-objective algorithms have been proposed [152]. A multi-objective algorithm which aims to minimize the energy cost of the system, while the total greenhouse gas emissions of the system during its lifetime are also minimized[153]. A multi-objective optimization of load dispatch of power systems including renewable energy and CO_2 capture and storage technologies was conducted in [154].

2.5.2. Evolutionary algorithm (EA)

✓Gives a clear progression in this subsection, e.g. paragraph 1 explaining general concept with examples and evaluative comments. Paragraph 2 and 3 are more specific

The evolutionary algorithm was effectively employed to design and optimize a complex hybrid photovoltaic-wind-diesel-batteries-hydrogen system[155]. The results obtained show that the EA was able to obtain good solutions with low computational effort. The EA was combined with an automated optimization software for optimum sizing of the various components of a reversible hydraulic system, i.e. turbine size, the size and the number of the pumps, the penstock diameter and thickness, the capacity of the reservoirs and some financial parameters [156].

In addition, the multiple-objective evolutionary algorithm (MOEA) was also popularly used in the references. A good overview of multi-objective methods by using evolutionary algorithms for hybrid renewable energy systems was proposed and reviewed in [145]. The MOEA for evaluating wind turbine performance was implemented in [157], where the objectives are to maximize the wind power output and minimize the vibration of the drive train and the tower. The MOEA was also proposed in [158] for wind turbine placement based on wind resource distribution.

✓ Evaluates the quality of studies discussed, e.g. "A good review".

In addition, the MOEA was used in designing a PV-wind-diesel system[159], where the objectives are to minimize are the total cost throughout the useful life of the installation and the pollutant emissions. This methods was later applied to in a three-objective problems[160], where the unmet load was also considered.

2.5.3. Genetic algorithm (GA)

The concept of GA, inspired by the evolutionist theory explaining the origin of species, was developed by Holland and his colleagues in the 1960s and 1970s[161]. GA is a global optimization method based on the principle of survival of the fittest (Darwin's hypothesis of evolution) and thus simulate the phenomena of reproduction, selection, crossing and mutation that are observed in nature using a computer program[27]. The basic principles of the GA are attributed to [162] and further developed for engineering applications by [151, 163].

✓ Describes the theoretical background and development of the approach. However, the Literature Review should aim to comment on those aspects of previous research that is relevant to the current study.

Substantial publications have been employed GA to optimize sizing, configuration or operational control renewable energy systems: PV-diesel system [27, 57, 159, 164]; PV-wind-diesel system [165]; Hybrid solar and wind system [51, 165-167]; PV-battery-full cell system [168]; PV-wind-diesel-battery system [169]. GA was also used to identify the electrical parameters of solar cells and PV modules, aiming at determining the corresponding maximum power point based on I-V curve[170].

✓ Gives specific examples of the approach that has been used.

In addition, a good overview was presented in [148] to describe the GA developed specifically for problems with multiple objectives. A multi-objective GA was adopted in [48] as well for sizing a hybrid solar—wind-battery system with the aim of minimizing the annualized cost system and the loss of power supply probability.

💡 Better to comment critically on the successes and problems with this study.

2.5.4. Particle Swarm Optimization (PSO)

Apart from GA, POS is also considered as one of the most popular optimization methods[145]. This algorithm was represented by Kennedy and Eberhart for the first time and since then, it has been widely used to solve a broad range of optimization problems[171, 172]. The basic idea of the algorithm was to seek the optimal solution through collaboration and information sharing among individuals in group.

💡 Better not to link subsections using "Apart from…" better to use "As well as GA, POS is considered".

Niknam et al. [173] proposed a hybrid method that combines non-linear programming and PSO, whose results outperformed those obtained by other population-based algorithms such as GA, ANN, and ACO. The authors [174] also presented a fuzzy adaptive PSO algorithm to solve the optimal operation management of distribution networks including fuel cells power plants.

✓ Comments on the effectiveness of previous study, e.g. "outperformed"

PSO was also applied to optimize PV grid-connected systems in [175], to determine the optimal tilt angle of photovoltaic modules in [176], to solve the wind-photovoltaic capacity coordination in [177], to optimize sizing a hybrid wind-PV-fuel cell generation system in [178], to process economic dispatch problems in [179] and concluded that its performance was better than conventional optimization techniques. In addition, both GA and PSO were implemented for solving a planning problem for thermal units integrated with wind and solar energy systems[180].

✓ Comments on the key finding of previous study, e.g. "concluded that its performance was better."

2.5.5. Design space

The design space based approach which can generate the sizing curve for RESs was also widely employed in this field. The set of feasible configurations that can meet the given load demand forms the design space[45]. The concept of design space was introduced for optimized sizing of solar hot water systems by[181]. For standalone power supply systems, the design space approach was used for diesel-battery systems[182], PV-battery systems[183-185], wind-battery systems [186, 187] and hybrid PV-wind systems [188-191], hybrid RESs[45].

Better not simply report the uses but to comment on its effectiveness.

2.5.6. Artificial neural network (ANN) and neuro-fuzzy theory

Intelligent solutions, based on artificial intelligence (AI) technologies to solve complicated practical problems in various sectors are becoming more and more popular nowadays[144]. An ANN is a collection of small individually interconnected processing units. Information is passed through these units along interconnections[192]. ANNs are based on our present understanding of the brain and its associated nervous systems. An ANN was applied to the operation control of PV-Diesel systems[193]. Both ANN and GA were used to maximize the economic benefits of a solar system[194].

Better not use the key word as the subject of every sentence, better to also use alternatives, i.e. "They", "These networks"

Neuro-fuzzy theory is to mimic the aspect of human cognition that can be called approximate reasoning, with many applications in the field of engineering. A neuro-fuzzy controller for a wind-diesel system was developed in [195]. Daily management of the household PV panel generation without using storage equipment was also optimized in [196] by a neuro-fuzzy algorithm. The fuzzy logic was also employed for estimation the wind turbine power curve[197]. The energy consumption in residential sector was modeled using a neural network[198]. An artificial neural network model was also developed to predict the regional peak load of Taiwan [199].

2.5.7. Other optimization techniques

Apart from above optimization techniques, other approaches such as linear programming [200-202], simplex algorithm[168, 203], dynamic programming[204], response surface

Better to use "In addition to" to link subsections rather than "Apart from".

methodology[205, 206], matrix approach[207], quasi-Newton algorithm[141], and "Energy hub" concept[208] have been utilized by researchers to design hybrid renewable energy systems in a cost effective way. Several more algorithms also seem promising to enrich the literature dedicated to hybrid energy system sizing.

2.6. Simulation by computer tools software

The computation power of modern computers is increasing dramatically and hence the computer-based simulation and optimization have received more and more attention, and becoming an important tool for the design of the power systems requiring a detailed analysis[209]. There are some programs that simulate hybrid systems, such as HOMER, Hybrid2, PV *SOL, and RETScreen. In a recent and extensive review[210], 37 different computational simulation tools used for hybrid RESs were analyzed and compared. Another study briefly reviewed the simulation tools can be seen in [138]. It is evident that there is no energy tool that addresses all issues related to integrating renewable energy, but instead the ideal energy tool is highly dependent on the specific objectives that must be fulfilled.

Better to use "increasing amounts" than use "more and more".

Better to use a more academic word than "some", i.e."A number of"".

According to literature reviewed, a simulation tool broadly used in performance assessment of hybrid RESs is the Hybrid Optimization Model for Electric Renewable (HOMER) [210]. HOMER is a computer model originally developed by the U.S. National Renewable Energy Laboratory, to assist in the design of micropower systems and facilitate the comparison of power generation technologies across a wide range of applications [211], with over 70,000 users in 193 countries. HOMER, the public domain modeling software, is widely investigated by substantial scholars for both standalone and grid-tied micropower RESs in respect of case feasibility study, simulation, optimization, sensitivity analysis and validation.

Better to include reference when using "According to", i.e. "According to [210], a simulation...".

Better to also highlight the advantages this tool has over others.

For the purpose of hybrid systems optimization, HOMER is considered as the most widely-used one[38]. The following are some examples about HOMER application in extensive research:

HOMER has been previously employed to investigate the standalone PV-diesel system in Malaysia[15], in Saudi Arabia[28, 212, 213], in Cameroon[214], in northern Brazil[215], and in Jordan[216]. It was used to size a PV system to power a remote health clinic in southern Iraq [42] and a homestead in West Australia [217], hybrid solar-wind system for a small community in Bangladesh [218]. The diesel was coupled into the hybrid RES for a remote village in Saudi Arabia [41] and in the rural areas of Bangladesh[219] using HOMER. HOMER was also used to evaluate the potential wind energy in Ethiopia [220], available solar and wind resources in Maldives[221], and various renewable energy resources (solar, wind, hydro and biomass) in Bangladesh[222].

Better to present long lists of data in a table form if there are no evaluative comments on the success of these uses of the system.

HOMER has been used extensively to perform the feasibility study of a stand-alone wind-diesel hybrid in Saudi Arabia[55, 223], in Algeria[29] and in Alaska[56], of a wind energy conversion system to achieve a zero energy home in Newfoundland [224], of a small Hydro/PV/Wind hybrid system for off-grid rural electrification in Ethiopia[14], and of a hybrid microhydro-PV system for rural electrification in developing countries of Africa [225].

The researchers developed some models for microgrid system with hybrid energy sources, the results obtained are validated with HOMER[226]. The genetic algorithms for optimization of hybrid system was developed in [13]and also validated with HOMER.

In addition, The stand-alone hybrid RES with hydrogen energy storage was also studied in Newfoundland[227] and in Greece [228]. The feasibility of hybrid RES-diesel and RES-gird energy system in Iran was evaluated using HOMER[229].

The Literature Review should end with a summary subsection of the major points discussed. It should also include a discussion of what has not been studied or done in previous research and how the current study will add to the existing scientific knowledge that has been discussed.

3. RESEARCH METHODOLOGY

3.1. System description

After a thorough literature review, the standalone hybrid solar and wind system with pumped storage is proposed. The system schematic is illustrated in Fig. 6. In this hybrid system, the PV array and wind turbine are used to convert sunlight and wind power for power generation. An inverter transforms the output DC to supply 220V AC load via the power distribution network while any surplus power is used to charge the energy storage subsystem. A pump/turbine set is used as the energy storage device, usually operated in pumping mode in the daytime and in generating mode at night. On the other hand, a micro battery bank and diesel generator can also be introduced in this system to form the hybrid solar-wind-diesel- PHS-battery system, with the aim to reduce the pumped storage capacity and cater for peak load demand. The entire system would be regulated by a control centre to manage the whole microgrid system: ramping intermittent renewables outputs and balancing supply and demand.

Better to have a short introductory paragraph that includes the outline of the section.

Better to avoid using "would" unless you are describing things that are not real.

Better not to mix tenses when describing the process, i.e. use present tense and avoid "will".

The operating principle of hybrid power supply system can be briefly described as follows: The pumped storage system elevates water to the upper reservoir using pumps when renewable power is available and greater than the load demand. The stored water is then allowed to flow back to the lower reservoir enabling the production of electricity by the turbine during periods of high electrical demand and low or no solar energy availability. In this way, a sustained energy supply would be guaranteed throughout day and night. This activity will suffer some conversion losses but the electric network can be stabilized and the related environmental problems from batteries can be solved. Once the reversible pump-turbine set were be available for the renewables powered pumped storage systems, the overall efficiency will be greatly enhanced.

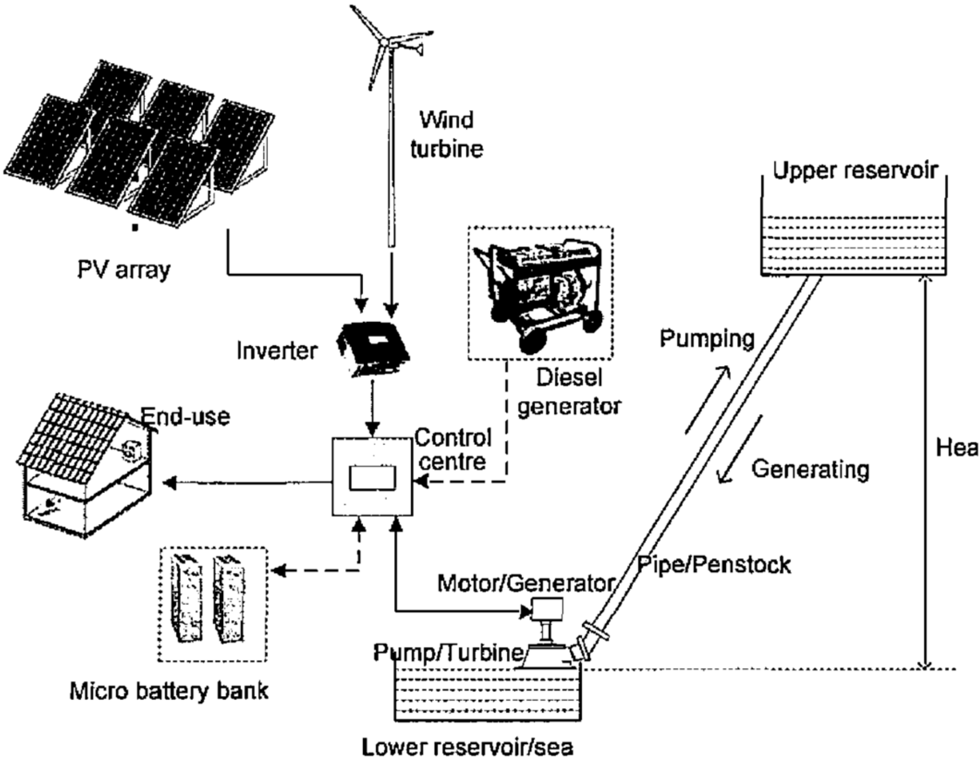


Fig. 6 System schematic of the stand-alone hybrid solar-wind pumped storage system

This hybrid power system combines the tradition hydropower, renewable solar energy and wind energy, and uses the differences of three sources of energy in the space-time distribution to realize the complementary operation, to achieve a stable supply of electricity[111]. Therefore, the pumped storage, the alternative to batteries, is considered as the most ideal partner for utilization intermittent renewables, which enables the renewables to remain renewable. At the same time, the combination of pumped storage and agricultural irrigation or village drinking water supply are also a promising solution for remote regions[2]. Another possible benefit is that a pumped storage system can be integrated with a conventional micro hydroelectric station through natural stream-flow, making good use of a combination of solar and

✓ Links ideas well within paragraphs, e.g. “At the same time” and “Another possible benefit” hydro power sources. Rain water can also be collected to offset evaporation and leakage in the upper reservoir. Many advantages of this system will be put forward and analyzed in detail in the following study.

This kind of hybrid system with combined storage technologies reflects the trend of development of new energy, demonstrating a very good market prospect for remote areas where network coverage is impractical.

✓ Links to the next sections.

💡 Better not to include a discussion of the future economic benefits in the methods section, this should be in the Literature Review or the conclusion.

3.2. Mathematic models establishment for simulation study

To predict system operating performance and optimize system design, individual components should be modeled first and their combinations can then be better evaluated.

Various modeling techniques are developed by researchers to model components of HRES. Performance of individual component is either modeled by deterministic or probabilistic approaches in [136]. The modelling of PV, wind turbine (WT), diesel, batteries were developed in [40]. The researchers reviewed different types of models such as renewable energy models, emission reduction models, energy planning models, energy supply-demand models, forecasting models, and control models in [144]. The PV/WT system with battery storage is modeled in [165, 230]. Reference [98] also provided a comprehensive literature review on system modelling.

💡 Better not to mix the past and present tenses when reviewing studies, e.g. "techniques are developed" and "batteries were developed". Better to use past for specific studies and present perfect for more general research, i.e. "modeling techniques have been developed".

General methodology for modeling the components in the study such as PV, WT, diesel generator, pumped hydro storage (PHS), and battery bank are described below:

3.2.1. Modelling of photovoltaic (PV) panels

Modeling PV arrays is one of the key components in the analysis of PV systems' performance. There are several mathematical models describing PV behavior under external influences, such as temperature and solar irradiance. Hence it is necessary to classify the existing models to simplify the study of PV arrays. Broadly these models can be categorized as electrical and thermal models. The literatures related to two models are summarized in Table 1.

Better not to use the word "literatures" use "research".

Table 1 Classification of solar PV models

Electrical models	Thermal models
• Single diode model [231]	• Model based on U_L (overall heat loss coefficient) [231, 232]
• Two diode model [233-235]	
• Three diode model [236]	
• Models considering only R_S [237]	• Model based on U_L and C_t, (thermal capacitance) [232]
• Models considering only R_{sh} [238]	

Each PV array consists of N_p PV modules connected in parallel and N_s PV modules connected in series. In this study, the maximum output power of each PV array on the day i (1≤i≤365) and at hour t (1≤t≤24) is determined based on the specifications of the PV module under Standard Test Conditions (STC, cell temperature 25 °C, irradiance=1000 W/m2, Spectral distribution AM 1.5), as well as the ambient temperature and solar irradiation conditions. The following equations are used to model the performance of a PV pant [165, 230]:

1) PV array output:

$$P_A^i(t) = N_s \cdot N_p \cdot V_{oc}^i(t) \cdot I_{sc}^i(t,\beta) \cdot FF^i(t) \tag{1}$$

where $P_A^i(t)$ is the output power of the PV array, $I_{se}^i(t,\beta)$ is the PV module short-circuit current (A), $V_{oc}^i(t)$ is the open-circuit voltage (V) and $FF^i(t)$ is the fill factor.

✓ Numbers and centers formula.

2) Cell operating temperature

The normal operating cell temperature (NOCT) is defined as the cell temperature when the module operates under the following conditions at open circuit:

✓ Uses present tense and passive voice to explain calculations, e.g. "is usually assumed".

irradiance: 800kw/m2; Spectral distribution: AM 1.5; Ambient temperature: 20℃ and wind speed: 1.5 m/s

NOCT, which is provided by manufactory and usually between 42 and 46℃, is used to determine the solar cell temperature $T_c^i(t)$ during module operation. It is usually assumed that the difference between $T_c^i(t)$ and $T_a^i(t)$ depends linearly on the solar radiation $G^i(t,\beta)$ in the following manner:

$$T_c^i(t) = T_a^i(t) + \frac{NOCT - 20°C}{800\ (W/m^2)} \times G^i(t,\beta) \tag{2}$$

where $T_c^i(t)$ is the cell operating temperature (℃),$T_A^i(t)$ is the ambient temperature (℃), and $G^i(t,\beta)$ is the global irradiance (W/m2) incident on the PV module placed at tilt angle β (^{0}).

3) *PV module short circuit current under arbitrary operating conditions*

To accurately predict the output of PV array, it is important to understand module's behavior under any operating conditions of irradiance $G^i(t,\beta)$ and ambient temperature $T_a^i(t)$. There, a good balance between simplicity and exactitude is obtained through the following additional assumptions:

Sometime, the effect of the temperature on short circuit current is neglected due to the fact that this implies an error of less than 0.5% under real operating conditions[122]. On the other hand, the short circuit current of a module is proportional to the irradiance[239]. In this study, both impact of irradiance and that of temperature on $I_{se}^i(t,\beta)$ are considered and they are expressed by:

Better not to use "In this study" as an introductory phrase, better to use it as a subject, i.e. "This study considers both…".

$$I_{sc}^i(t,\beta) = \{I_{sc0} + K_I[T_c^i(t) - T_0]\}\frac{G^i(t,\beta)}{G_{STC}} \tag{3}$$

where I_{se0} is the short-circuit current under STC, T_0 is the cell temperature under STC (25°C), and K_I is the linear short-circuit current temperature coefficient (A/°C). This coefficient is a positive and small Value (about +0.06A/°C) for a square metre of the module area[239]). In this study, the temperature coefficient of $I_{se}^{i}(t,\beta)$ for the specified PV module from Suntech is +0.045%/°C. Therefore K_V is 0.00375A/°C.

4) PV module open circuit voltage under arbitrary operating conditions

Since the voltage is a logarithmic of the current, thus the open circuit voltage $V_{oc}^{i}(t)$ of a module will also depends logarithmically function of the irradiance. During the day, the voltage will therefore vary less than the current, making the effect of illumination relatively unimportant. In the design of PV generator, it is customary to neglect the effects of illumination on voltage variation [239]. Therefore, the open circuit voltage $V_{oc}^{i}(t)$ of a module depends exclusively on the temperature of the solar cells $T_c^{i}(t)$. In the range of operating conditions encountered:

Better not to use "will" to describe processes, better to use the present simple, i.e. "the voltage therefore varies less…".

$$V_{oc}^{i}(t) = V_{oc0} + K_V[T_c^{i}(t) - T_0] \tag{4}$$

where V_{oc0} is the open-circuit voltage under STC (V), and K_V is the linear open-circuit voltage temperature coefficient (V/°C), which is is approximately equal to -2.3mV/°C for an individual cell [122, 239].

$$\frac{dV_{oc}}{dT_c} = -2.3\text{mV}/°\text{C} \tag{5}$$

In this study, the temperature coefficient of $V_{oc}^{i}(t)$ for the specified PV module from Suntech is -0.34%/°C, that is, 0.114V/°C for the module or 2.12mV/°C for one solar cell (54 cells connected in series). So that K_V is -0.11424.

5) Serial resistance

It is well acknowledged that the ideality factor *n* is irradiance intensity and temperature dependent, and their effects are very complicated. However, the ideality factor can be determined by calculating first the series resistance which is a property of the solar cells and dependent of the module conditions[239].

About 20 methods of evaluating the solar cell series resistance are reviewed in [240]. One method proposed in [241], based on one-diode model, is very simple and accurate to find the series resistance of a solar cell because no more complicated testing steps or calculations are required except the module characteristic

✓ Refers to source of the method used, This is often done by the phrase, "Following from [52] and [242], the series …"

parameters. In this method, the ideality factor was supposed as an output current dependent variable under illumination with an infinite shunt-resistance value. This method has been employed in the studies [52, 242]. The series resistance R_S is expressed in the following equation:

$$R_s = \frac{V_m}{I_m} \cdot \frac{(1/V_t)\cdot(I_{sc}-I_m)\cdot[V_{oc}+V_t\cdot\ln(1-I_m/I_{sc})]-I_m}{(1/V_t)\cdot(I_{sc}-I_m)\cdot[V_{oc}+V_t\cdot\ln(1-I_m/I_{sc})]+I_m} \tag{6}$$

where $V_t = kT_0/q$ is the thermal voltage.

One study stated that the shunt resistance also cannot be ignored for more detailed and accurate calculation of ideality factor[243].

6) Ideality factor under the maximum power point status

Instead of the two-diode model[244], an empirical ideality factor *n* can be introduced in the single-diode that usually lies between 1 and 2. Some studies assumed that the diode ideality factor is constant along the entire I-V output characteristic[240], but this assumption is inaccurate at whole irradiance distribution and can lead to erroneous results[245]. Yordanov et al.[246] demonstrated that the ideality factor varied with the cell voltage and considered this factor as variable in their research.

✓ Uses evaluative language when discussing previous studies, e,g, "inaccurate" and "lead to erroneous results".

This ideality factor under the maximum power point can be determined after finding the series resistance, which is also followed the method in [241].

$$n = \frac{V_m + I_m \cdot R_s}{V_{oc} + V_t \cdot \ln(1 - \frac{I_m}{I_{sc}})} \tag{7}$$

7) Fill factor

Fill factor is a dimensionless parameter. It is a measure of the deviation of the real I-V characteristic from the ideal one. In a simplified calculation, the fill factor can be assumed constant [239] as equal to the ideal value under the STC. It is convenient to define the fill factor *FF* by:

$$FF = \frac{V_m \cdot I_m}{V_{oc} \cdot I_{sc}} = \frac{P_m}{V_{oc} \cdot I_{sc}} \tag{8}$$

Solar cells usually have a parasitic series and shunt resistance associated with them. Both types of parasitic resistances act to reduce the fill factor. An infinite shunt resistance is assumed in this study. And the magnitude of the effect of R_S, on the fill factor can be found by comparing their values to the characteristic resistance of a solar cell defined as:

$$R_{CH} = \frac{V_{oc}}{I_{sc}} \tag{9}$$

After defining the normalized resistance r_s as R_S/R_{CH} or $R_S \bullet I_{SC}/V_{OC}$, a satisfactory empirical expression for this relationship can be written as:

$$FF = FF_0(1 - r_s) \tag{10}$$

The fill factor FF of a solar cell with the ideal characteristic will be furnished by the subscript 0, i.e.FF_0, representing an ideal and maximum fill factor value of a solar cell. An empirical expression describing the relationship between FF_0 and normalized voltage $v_{oc} = \frac{V_{ov}}{nV_t}$, to an excellent accuracy of about two significant digits for v_{oc} > 10 and r_s < 0.4, can be seen below[247]:

$$FF_0 = \frac{v_{oc} - \ln(v_{oc} + 0.72)}{v_{oc} + 1} \tag{11}$$

3.2.2. Modelling of wind energy conservation system (WECS)

The available power in the wind passing through an area perpendicular can be expressed as:

$$\overline{P_w}(v) = \frac{1}{2}\rho A\bar{v}^3 = \frac{1}{2}\rho A\int_0^\infty v^3 f(v)dv \tag{12}$$

The detailed procedures for estimation the wind energy potential has been included in the second part of the final report for CLP.

Wind turbine performance is generally presented in a power vs. wind-speed graph. Different types of wind turbines usually have different power output performance curves, Consequently, the model used to describe their performance should also differ. There are several existing models for the estimation of wind turbine power, such as the linear model [51, 131, 135, 167], and the quadratic model [140, 248]. In most literature [191, 249-252], the following equation based on Weibull distribution is used to simulate power output of a wind turbine:

Better to use the following forms with "estimate";

a. The estimation of the...
b. For estimat<u>ing</u> the ...

$$P_w(v)=\begin{cases} P_R\dfrac{v^k-v_c^k}{v_R^k-v_c^k} & (v_c\le v\le v_R)\\ P_R & (v_R\le v\le v_F)\\ 0 & (v<v_c\ and\ v>v_R)\end{cases} \tag{13}$$

where $P_R$is the rated electrical power; v_c is the cut-in wind speed (the wind speed at which the turbine starts to generate usable power); v_R is the rated wind speed; v_F is the cut-off wind speed; k is the Weibull shape parameter.

This model is simplified when the wind speed is higher than rated speed. In studies [253, 254], a quadratic function was used for simulation, i.e.

Better not to use the form "In studies [253], [254],...." It's better to use the study as the subject if it is an important study or at the end of the sentence as a general reference: i.e. {253}, [254] used the following...

$$P_w(v)=av^2+bv+c \tag{14}$$

Another method is to use the cubic spline interpolation functions to model the wind turbine output by dividing the power curve into several segments [49, 189]. The power output between the cut-in and cut-off speed can be expressed as:

$$P_w(v)=av^3+bv^2+cv+d \tag{15}$$

3.2.3. Modelling of pumped hydro storage unit (PHS)

The pump-turbine set is most important part of PHS, which consists of the pump-motor unit and turbine-generator unit. The water pumping coefficient (m^3/kWh) and turbine generating coefficient (kWh/m^3) are two key parameters. The models and calculation procedures are as follows:

The water flow rate sucked from the lower reservoir by the pumps is expressed in Eq.(16), which is directly supplied by the renewable energy, This flow rate can be compared to the battery charging rate.

$$q_{PTS_P}(t) = \frac{\eta_P \cdot P_{PV_P}(t)}{\rho g h} = c_P \cdot P_{PV_P}(t) \tag{16}$$

Where $P_{PV_p}(t)$ is the input power to the pumps; c_p is the water pumping coefficient of the pump motor unit; h is the elevating head, the available static head for this island can be conservatively assumed as 80m; Q is the average volumetric flow rate (100 m^3/h); g is the acceleration due to gravity (9.8 m/s^2); ρ is the density of water (1000 kg/m^3);

Therefore, the water pumping coefficient is determined by the following Eq.(17).

$$c_P = \frac{\eta_P}{\rho g h} = \frac{\eta_{array-motor} \cdot \eta_{motor-pump} \cdot \eta_{pipe}}{\rho g h} = \frac{Q}{P_{pump}} \tag{17}$$

✓ Refers to the equation in text, e.g "by the following…"

The output from the water turbine generator unit is derived from the Eq.(18).

$$P_{PTS_T}(t) = \eta_T \rho g h \cdot q_{PTS_T}(t) = c_T \cdot q_{PTS_T}(t) \tag{18}$$

where η_γ is the overall efficiency of the turbine generator unit; $q_{RPT_T}(t)$ is the water volumetric flow rate input into the turbine; c_γ is the turbine generating coefficient, expressed as follows.

$$C_\gamma = \eta_\gamma \rho g h \tag{19}$$

The volume of water in the upper reservoir (UR) storing gravitational potential energy should be adequate to meet the power consumption of this island for the several expected days of autonomy. The potential energy released from the upper pond can be derived from the following Eq.(20):

Better not to use "should be adequate, better to use "is theoretically adequate"

$$E_c = n_{day} \cdot E_{load} = \eta_t \cdot \rho \cdot V \cdot g \cdot h \tag{20}$$

where E_c is the energy storage capacity of a water reservoir (Joules); n_{day} is the number of days of autonomy (5 days); E_{load} is the daily energy consumed by the load (250 kWh); V is the volume or storage capacity of the water reservoir (m^3).

The volume of UR can be calculated by Eq.(21):

$$V = \frac{E_c}{\eta_t \cdot \rho \cdot g \cdot h} \tag{21}$$

If E_c is expressed in kWh, the formula can be rewritten as Eq.(22):

$$V = \frac{3.6 \times E_c}{\eta_t \cdot \rho \cdot g \cdot h} \times 10^6 \tag{22}$$

Based on Eqs. (21) and (22), the theoretical volume of UR is worked out to be 9,454m^3 . For easy calculation, this number was rounded to 10,000m^3. This is a quantity roughly equivalent to seven Olympic swimming pools (50 meters long, 20 meters wide and 1.4 meters deep).

Better to avoid giving reasons informally, i.e. "In order to simplify calculation" rather than "For easy…"

✓ Gives equivalent to aid readers understanding.

The total quantity of water stored in the upper reservoir is determined by:

$$Q_{HR}(t) = Q_{HR}(t-1)(1-\alpha) + \int_{t-1}^{t} q_{PTS_p}(t)dt - \int_{t-1}^{t} q_{PTS_r}(t)dt \tag{23}$$

where α is the evaporation and leakage loss. It can be compared to the self-discharge of a battery bank. For simplification, this study has ignored these losses in the above four equations.

The water quantity of upper reservoir is subject to the following constraints:

$$Q_{UR_{\min}} \le Q_{UR} \le Q_{UR_{\max}} = V \tag{24}$$

In this study, the minimum storage of UR $Q_{UR_{min}}$ was set at zero.

3.2.4. Modelling of battery bank (BB)

Battery bank is a conventional energy storage device and widely used in today's standalone systems. In this study, a micro or small battery bank will be introduced in the hybrid RESs to assist the PHS. Several functions can be forecasted as follows:

Better not to use the form to ensure key words that refer to general processes have an article or plural form in text i.e. "Battery Banks" or "A battery bank"

l) Balancing demand and supply in turbine/generator mode

The consumption load is unsteady since residents turn their electrical appliances on and off as they see fit. In the traditional hydro turbine powered village, the surplus energy when demand is lower than production is transferred into a load resistor. This is a simple but wasteful approach involving converting the excess electricity into waste heat and hence lowering system efficiency. This solution is not appropriate for consideration.

A small battery bank, which is employed to match demand at all times, can maintain output voltage and frequency at allowable levels that do not damage appliances. The bidirectional inverter such as the SI5048 from SMA can also be utilized to deliver any excess to battery bank and to convert the DC output from batteries to serve the AC load. The detailed operating conditions of a small battery bank in a RES can be divided into several cases:

- When the load demand falls below the levels at which the battery bank (fully or partial charged) is able to supply that load, the controller should turn off the turbine completely and switches to battery bank supplying the minimal loads as a bridge until the maximum depth of discharge is reached or load rises. At that point the turbine turns back on again and the process cycle repeated. This action can avoid frequent starts and stops the turbine/generator

✓States each bullet point item with the same grammatical word.

✓Links ideas using grammar, e.g. "This action ..."

- When the load demand is low but still larger than the existing energy stored in the battery bank, the turbine/generator should start. To ensure reasonable "partial load" efficiency, the turbine should keep operating at its minimum load ratio of 50%. If the required power is 30%, for instance, the turbine operates at its 50% capacity, with the 20% surplus power charging the battery bank. In this way, the inefficient and life-shortening "partial load" operation for the turbine can be avoided.
- When the electric load suddenly increases and an extreme peak load occurs, the controller combines outputs from both turbine and batteries to meet the load. This action can cater for a brief period of peak demand while avoiding the need to size a turbine big enough to meet that peak demand.

2) Balancing renewable sources and water pumps in pumping model

The presence of a small battery bank can also be used to balance intermittent renewable generation, interposing between the stochastic renewable energy sources and motors/pumps to provide a stable voltage and current for driving these machines. This approach is popular with traditional PV water pumping systems and can also be adopted in pumped storage system for renewables. The roles of the batteries are as follows:

✓ Introduces subsection with clear topic sentence.

✓ Content introduced by bullet points.

- When system surplus renewable energy output is a slight insufficient to start up the pumps, the batteries release some power to fill the gap in launching the pumps;
- When system surplus renewable energy output is far below the launching power of pumps, then the available energy is directly fed into battery bank through SI5048, avoiding frequent starting and stopping of the motors/pumps unit and ensuring the pumps efficiencies;
- When system surplus renewable energy output is greater than rated power of pumps, the excess can be stored in the batteries, which can cut the peak renewable energy output and absorb the energy to avoid excessive pump/motor sizing;
- When the UR reaches its maximum capacity, the battery bank might also absorb the renewable energy production if not already fully charged, thus the wasted energy can be minimized and a high energy utilization rate ensured.
- The batteries act to better distribute the times spent water pumping and battery charging and discharging. The pumps are therefore operated more steadily and lifting efficiency further improved.

These multiple effects of the small battery bank play a vital role in the scheduling of energy dispatch, managing the remote microgrid renewables powered pumped storage scheme, reducing dumped energy and ensuring high efficiency for the pump and turbine. An effective controller is also necessary to manage the energy distribution between renewables supply, the pump/motor unit, the turbine/generator unit, the batteries and the load side. Settings and operating principles need to be developed such as turbine minimum load ratio, pump and turbine rated capacity and battery bank capacity.

Modeling of the lead-acid batteries in RESs must account for the following parameters: (i) state of charge (SOC) or depth of discharge (DOD), (ii) storage capacity, (iii) rate of charge/discharge, (iv)ambient temperature, (v) lifespan and other internal phenomenon, such as self-discharge.

In the area of modelling BB, the kinetic battery model [242, 255] was employed in HOMER software, which treats the battery as a two tank system. In combined ESS with battery bank and pumped storage, the mode of operation of battery (i.e. charging or discharging) is dependent on the RE source availability, load demand and operation of diesel and pump-turbine set. During any hour, the excess power generated by the PV and wind generators can be utilized for charging the batteries if the pumped storage is full or the excess power cannot start the pumps, whereas the stored energy can be discharged whenever there is a deficiency in power generation. When both the wind generator, the PV array and water turbine are insufficient, and thus the BB discharges power to serve the load demand until it is depleted. The model required for sizing and economic study is based on an energy balance of BB, the difference between total energy generated and load demand energy, which can determine whether BB is in charging or discharging state. The SOC at any instant *(t + Δt)* is widely used as follows [49, 51, 140, 167, 256, 257].

Better to use exact time expressions i.e. "At any time" is better "than during any hour" or if it is a unit of measure give the technical term for the hourly unit.

✓ Gives multiple references e.g. "widely used as follows [49, 51, 140, 167,256, 257].

$$SOC(t+\Delta t) = SOC(t)(1-\delta) + I_{bat}(t)\cdot \Delta t \cdot \eta_{bat} \tag{25}$$

where δ is the self-discharge coefficient, $I_{bat}$is the battery current (positive value for charge process and negative for discharge) and η_{bat} is the battery efficiency.

On addition, the SOC is also subjected to maximum-minimum bounds on the storage state variable to prevent gassing and over-discharging: $SOC_{min} \leq SOC(t) \leq SOC_{max}$

The current of the BB can be expressed as (apply to charge or discharge process):

$$I_{bat}(t) = \frac{P_{PV,BB}(t) + P_{WT,BB}(t) + P_{Diesel,BB}(t) - P_{BB,L}(t)}{V_B(t)} \tag{26}$$

3.2.5. Modelling of inverter

The conversion efficiency of the inverter is defined as the ratio of the output power, P_{out}, to the input power, P_{in} and is given by the following equation[140]:

$$\eta_{inv} = \frac{P_{out}}{P_{in}} \tag{27}$$

3.2.6. Modelling of diesel generator

To attenuate shortfalls in energy production during periods of poor renewable energy availability and peak load requirement. The HRESs require a backup diesel for improving system power supply reliability and minimum storage and power generator requirements. The published studies has demonstrated that it is more cost-effective and viable to employ a diesel than to increase the size of the ESS or WT or PV array, even with high diesel fuel costs [25, 43, 53].

💡 Better not to use "for ___ing" to express purpose. A better option is "diesel to improve…".

Diesel generators supply energy in two ways [258]. Either they generate only the power for covering the load (load following), or they generate at nominal power and the surplus energy (if any) is used to charge the ESS (cycle charging). Both dispatch/control strategies will be considered and compared in the study, but the second kind can be predicted to work better.

✓ Gives a clear topic sentence

✓ Explains ideas, e.g. "Either, or".

The modelling of diesel generator is based on its fuel curve and efficiency curve, which are usually provided by the manufactory. On the other hand, another important factor is the minimum load ratio if it is under the load-following dispatch strategy. The minimum threshold is generally set at 30% of its rated capacity[25], meaning that the generator was not allowed to operate at less than that. If the deficit of power is at 20% of diesel capacity, for instance, it will run at 30%, with surplus power either charging ESS or being dumped.

3.2.7. Modelling of dump load

A dump load is an alternative place to dissipate the excess renewable energy when the load does not need the energy meanwhile the energy storage system (ESS) has reached its maximum capacity [259]. The PHS system should be stopped when the upper reservoir is full, and the batteries need to be protected from overcharging which will shorten their life span. Therefore this part of excess energy which should be dissipated is called as the dumped energy[49]. Simply the dump load absorbs the power when the charge controller senses that the ESS is full [36]. Once the power has been diverted, the dump load uses the power for something productive such as conventional electric water heater, or loses it directly into the ground and transfers it to waste heat, such as resistance[258]. Therefore, the spilled energy can be recovered into electricity. The hourly dumped energy is modeled as follows:

✓Defines key terminology.
✓Details how and why it is used.

✓Summarizes the main points with a conclusion at the end of the paragraph, e.g. "Therefore, the …".spilled…"

$$E_{dump} = E_{ess,in} - E_{ess,out} / \eta_{ess} \tag{28}$$

where $E_{ess,in}$ is the energy charged into the ESS, including the PHS and BB, $E_{ess,in}$ is the energy discharged from the ESS, and η_{ess} is the ESS discharging efficiency. In the above equation, negative results are assumed as zero dump energy.

3.2.8. Modelling of load demand

The load demand is mainly provided by two sources and expressed as follows:

$$P_L^i(t) = P_{WT_L}(t) + P_{PV_L}(t) + P_{diesel_L}(t) + P_{PTS_L}(t) + P_{BB_L} \tag{29}$$

where $P_{PV_L}(t)$, $P_{WT_L}(t)$, $P_{diesel_L}(t)$ is the power directly delivered from the PV array, wind turbine and diesel generator; $P_{PTS_L}(t)$ and P_{BB_L} is the power produced by turbine-generator unit and battery bank. When the net load is negative, no energy is required from ESS, and thus $P_{PTS_L}(t)$ and P_{BB_L} is zero; When the net load is positive, the ESS will be launch and discharge the power.

3.2.9. Dispatch strategy and system control

The dispatch strategies are a set of rules that controls how a system charges the ESS [159]. The dispatch strategies described in [57, 260, 261] are used by the HOMER program and widely used in other studies involving the backup diesel. The two simple dispatch strategies to govern the operation of the diesel and ESS are: load-following (LF) and cycle-charging (CC). Under the LF strategy, a generator produces only enough power to meet the load demand, never to charge the battery bank for which the renewable energy output is the only supplement. Under the CC strategy, whenever a generator is needed, it operates at its maximum rated capacity, or as close as possible to reach the maximum efficiency, and charges the ESS with the surplus power [260].

The combined cycle charging and load following strategy is employed in this study. If the net load is lower than the critical charge load (mini load ratio of the diesel such as 30%), the CC strategy is applied, and thus the excess energy after the load is charged into the ESS to avoid waste. If the net load is higher than the mini load ratio, the LF strategy is applied.

The hybrid controller for energy flow and management using the conventional approach and expert system has been reviewed in [43]. The control strategy is of vital importance for hybrid systems with more than one dispatchable component. The determination of how to control dispatchable components each hour is the most complex part of simulation logic of the system since the dispatchable sources must be able to match supply and demand properly, to cover the operating reserve enough, and to compensate for the intermittency of the RE sources. The goal of this section is to design an effective power control and dispatch system for a renewable based hybrid power system.

Fig. 7 illustrates the flow chart of the operating strategies for the proposed solar-wind-diesel-PHS-battery system comprising three dispatchable power sources, i.e. PHS, diesel generator and battery bank. The control logic of dispatchable power sources is also shown in the diagram. Whenever the net load, which is the difference between the actual load and

✓ Explains cause/effect relationship, e.g. "meaning that the"

the renewable power output, is negative, meaning that the renewables are sufficient to serve the load, thus the excess power will charge the battery bank and more surplus power will transfer to the dump load. Whenever the net load is positive, the system will have six options: launch the pump-turbine set, battery bank or diesel, or combinations by two of three, or all, to serve the load deficit.

In the beginning of the study, the diesel would not be included in this study to simplify the simulation process, and thus there are only three options, either PHS, battery bank or both. If all these alternatives are capable of supplying the net load and the operating reserve, which to use is based on a fundamental principle, minimizing the system cost by two values: a fix and a marginal cost of energy. The cost-based dispatch logic will be employed in the study for the whole simulation process. When a system including more than one dispatchable source, the one that can fulfill load demand and operating reserve with cheapest cost will be chosen.

Better to refer back by stating section numbers, .i.e. "In section 1.2 it was stated …".

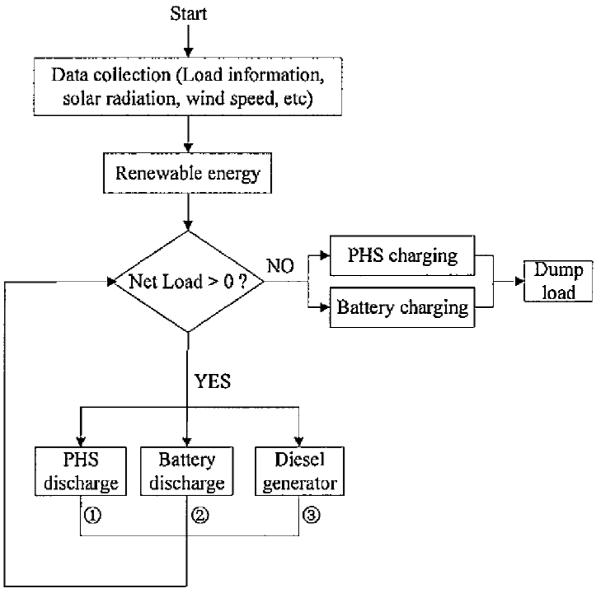


Fig. 7 Control of dispatchable system components

Fig. 8 shows the block diagram of the system controller. The controller monitors the real time input data for deciding the system operation (outputs). For this controller, the complicated controller logic should be used to formulate the system dispatch criteria. In addition, the set points for all dispatchable components starts and stops should be determined first.

✓ Uses a range of vocabulary to refer to figures, e.g. “shows”, illustrates”, “demonstrates”, ”is presented".

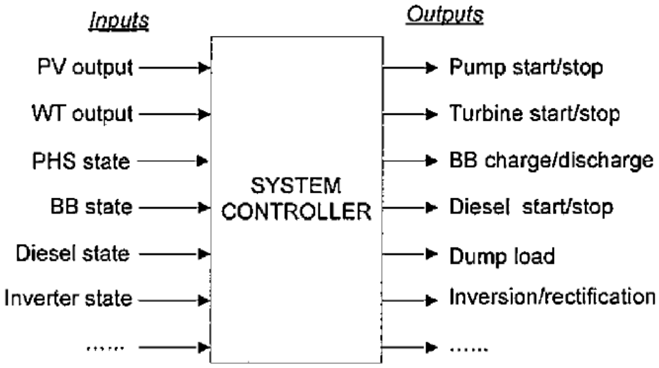


Fig. 8 Block diagram of a hybrid system controller

3.3. Optimization

After simulation and initial sizing, the optimization process of the entire system is the main step involved in designing an isolated hybrid system, which will be very important to achieve some certain cost and reliability criteria. The economic indicators are typically achieved by minimizing the net present cost of the system or the levelized cost of generated energy. The system reliability is also generally either in the form of constrains (such as load requirement, level of autonomy) or as another variable to be maximized, in which a multi-objective optimization routine might be needed. Sometime, the GHG reduction is also introduced in this hybrid RES optimization to maximize its environmental benefits.

✓ Explains the scope of the key concepts involved in the optimization process.

A general block diagram outlining the proposed optimization methodology is presented in Fig. 9. The most important step of the methodology is the optimization algorithm employed. Based on literature review, the most popular technique GA will be employed in this study, which dynamically searches for the system configuration. In addition, the PSO will also be conducted and compared with GA. After all device type combinations have been optimally sized as described above, the combination with the lowest cost and the corresponding devices mixture are displayed as the overall optimal system configuration.

Better to avoid vague terms, e.g. “Based on literature review” better “Having established the rationale for the use of…in section 2.4,….”.

The set of all configurations, which can meet the load, forms the design space and it can be used to select the optimum configuration based on the specified objective[45]. The objective function, used in this study, is to minimize the net present cost (NPC) or cost of energy (COE) produced by the hybrid system. The COE and NPC depend upon the capital cost, operation and maintenance cost and the amount of energy delivered. The constrains for the optimization objective function are subjective to the technical criteria and/or environmental restrictions, such as operating reserve. The multi-objective in technical, economic and environmental terms will be discussed in detail in next section.

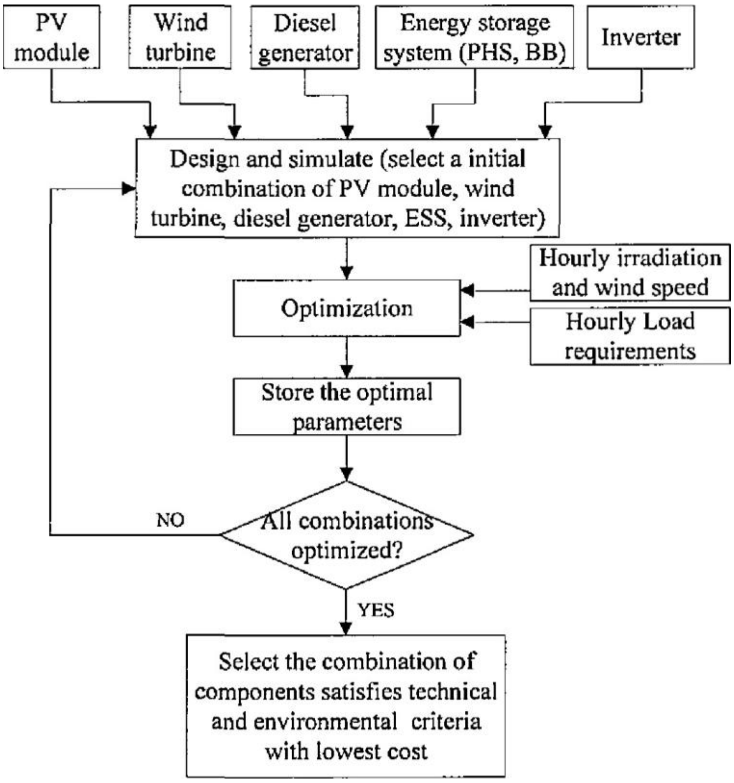


Fig. 9 Flowchart of the basic optimization methodology

3.4. Multi-objective optimization model and system performance evaluation model

Well recognized indicators are usually employed to help to assess the performance of RESs in technical, economic and environmental terms[133]. On the other hand, these indicators are also the design criteria in the process of system optimization. In the following sections, the indicator for system performance analysis will be proposed in detail, which will be employed in the whole study for sizing optimization and performance evaluation.

✓ Introduces the main idea of the section and outlines the content.

3.4.1. Technical evaluation models

The typical criteria adopted in this study are evaluated from the technical point of view and are briefly described below.

The loss of load probability (LPSP) [51, 131], defined as the total power supply failure hours divided by the number of sample hours over the reporting period, is used to evaluate whether a system is able to cater for the load demand and what is the time percentage with insufficient power. The LPSP is given by the equation below, followed by the load models in Eq.(30).

$$LPSP = \frac{\sum_{t=1}^{8760} hours[(P_{PV_L}(t) + P_{RPT_L}(t)) < P_L(t)]}{8760} \tag{30}$$

The LPSP technique can help to size the renewable energy generators and ESS capacity and also to assess the reliability of a specific system.

On the basis of Eq. (30), the excepted energy not supplied (EENS) [135], also known as the loss quality of load power supply or unmet load, can be calculated:

$$EENS = \sum_{t=1}^{8760} P_{PV_L}(t) + P_{RPT_L}(t) - P_L(t) \tag{31}$$

The energy index of reliability (EIR) [135, 201] on an hourly basis is then given by:

$$EIR = 1 - \frac{EENS}{\sum_{t=1}^{8760} P_L(t)} \tag{32}$$

Another indicator, the level of autonomy (LA)[128, 129] is given as 'one' minus the ratio of the number of hours in which power supply failure occurs to the total number of sample hours.

$$LA = 1\text{-}LPSP \tag{33}$$

In addition, the ratios of renewable energy supplied directly to the load, to the dump load and to the pump-turbine set are discussed in relations to the utilization performance of renewable energy power generated (e.g. energy utilization rate). The final water level of UR and SOC of BB is worked out as an indicator of the stored energy, and the differences between the maximum and minimum level of UR over the whole year are studied. Finally, the overall efficiency of the hybrid system is examined.

For the hybrid system with the diesel generator, renewable fraction (RF) should be also discussed. The definition of renewable fraction is the proportion of the system's total energy production generated by RE sources (WT and PV), divided by the total energy production. The equation for RF is presented below:

$$RF = \frac{E_{ren}}{E_{tot\_production}} \tag{34}$$

where E_{ren} is the renewable electrical production (kWh/yr) and $E_{tot\_production}$ is the total electric production (kWh/yr). The RF will influence greatly on the system configuration, economic performance and environmental benefits. To get a reasonable renewable energy contribution, the RF is usually set at higher than 80%.

💡Better not use "get" rather use "achieve".

3.4.2. Economic performance evaluation models

Life Cycle Cost (LCC) is the total cost of ownership of machinery and equipment, it takes into account costs of acquisition, operation, maintenance, replacement, and/or decommission. LCC analysis is the most straightforward and easy-to-interpreted measure of cost estimation and economic analysis. In the optimization process, a great variety of system configurations involving different amounts of renewable or nonrenewable energy sources could fulfill the same performance requirements but differ with respect to LCC, they can be compared and the most cost-effective one will be chosen based on the LCC analysis results.

✓Defines key terminology.
✓Explains its level of difficulty using evaluative language.
✓Explains its role in the model

In this study, the total net present cost (NPC) is employed to represent the LCC of a system. The total NPC condenses all the costs (positive) and revenues (negative) that occur within the project lifetime into one lump sum in today's dollars, the future cash flows will be discounted back to the present value using the discount rate. Virtually the net present cost is different from net present value only in sign.

💡Better to avoid "will" when describing processes.

The NPC includes the cost of initial investment for equipment procurement, transportation, installation, which occurs in year zero, the replacement cost, which occurs each time the component needs replacement at the end of its lifetime, the O&M cost, which occurs each year of the project lifetime, and miscellaneous costs such as penalties resulting from pollutant emissions.

✓Separates explanation into short clear paragraphs.

The revenues include salvage value (also called residual values or disposal costs) of a system and/or a component that occurs at the end of the study period. It can be calculated by linearly depreciating its initial or replacement costs, as shown in Eq.(35):

$$S = C_{rep} \frac{N_{rem}}{N_{comp}} \tag{35}$$

where S is the salvage value, C_{rep} the initial or replacement cost of the component (\$),N_{rem} is the remaining life of the component (years), and N_{comp} the lifetime of the component (years).

The annual real interest rate, which is also called the real interest rate or just interest rate, is the discount rate used to convert between one-time costs and annualized costs. It is related to the nominal interest rate by the Eq.(36) given below[54].

$$i = \frac{i' - f}{1 + f} \tag{36}$$

where i is the interest rate, i' nominal interest rate, and f is the annual inflation rate.

The total net present cost (NPC) can be calculated according to the Eq.(36) and (37):

$$NPC = \frac{TAC}{CRF(i,n)} \tag{37}$$

where *TAC* is the total annualized cost (\$/year), which is sum of annualized cost of individual system component, *CRF(i,n)* is the capital recovery factor, given by the equation, *i* is the annual real interest rate (the discount rate), and *n* is the project lifetime (years).

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{38}$$

Beside NPC, the levelized cost of energy (COE) is also considered as one principal economic figure of merit for the system. It is the average cost per kilowatt-hour of useful electrical energy produced by the system, which is expressed as below Eq.(39):

$$COE = \frac{TAC}{E_{Load}} \tag{39}$$

where TAC is the total annualized cost (\$/year), E_{Load} is the total amounts of electrical load that the system serves per year (kWh).

The COE index is often a convenient metric with which to evaluate the cost effective of different system options. However, the total NPC is employed as the primary economic figure of merit since the definition of COE is ambiguous in a way but that of the total NPC is not. The formula of COE just considers the actual electrical load served rather than the total electrical demand, which may be not equal if the some unmet load is allowed. Therefore during the optimization process, system configurations are ranked based on NPC rather than COE.

✓ Explains choice of metric. However, avoid imprecise statements, e.g. "in a way" better "can be ambiguous".

3.4.3. Environmental evaluation model (GHG emission reduction)

Also examined in this paper are the pollutants emissions particularly the greenhouse gas (GHG), since the utilization of the diesel will cause serious environmental pollution. Currently, the emission factor from coal fired power station in Hong Kong is 0.7-0.91kgC02/kWh. The pollutants and emission factors in diesel power generation are simplified and summarized in **Table 2.**

Table 2 Emission factor from diesel power generation

Pollutant	Emissions factor (g/L diesel)
Carbon dioxide (CO2)	2,633
Carbon monoxide (CO)	6.5
Unburned hydrocarbons (CHx)	0.72
Particulate matter (PM)	0.49
Sulfur dioxide (S02)	5.28
Nitrogen oxides (NOx)	58

3.4.4. Payback time (PBT)

The payback time (PBT) is also an important index for evaluating the system performance. Currently the majority of the published researches only focus on payback times of the - renewable energy system. Just limited studies have been conducted on the payback time of the stand-alone RESs [262-264].

💡 Better not to use "limited studies" better is "a limited number of studies"

PBT is the number of years to make the cumulative annualized savings of RESs, compared to the diesel-only system, to become positive [264]. That means during that year the sum of the renewable system cost under study is equal to that of diesel only configuration [265]. Annual savings is expressed subtracting the annualized costs of the RES from the diesel-only system, and thus the overall saving can be simply expressed as:

✓ Defines and then explains definition, e,g, "That means…".

$$\sum_{j=0}^{PBT}(NCF_{RES} - NCF_{Diesel}) \geq 0 \tag{40}$$

where j is the year number, PBT is the calculated payback time (years); NCF represents the nominal cash flow, the outflow is recorded as negative such as the initial cost, fuel expenditure, equipment replacements, or O&M. The salvage value of equipment at the end of the project lifetime is taken as income and recorded as positive value.

It is evident that the shorter the PBT is, the better the investment. This is a criterion which values the availability more than the profitability. It also does not take into account the cash flow generated after the recuperation period [265].

3.5. Sensitivity analysis

The sensitivity analyses on hourly data sets such as the electric load and the RE resource will be the one of most powerful feature of this study. Sensitivity analysis can help the designers understand the effects of uncertainty and make good design decisions despite uncertainty. It can also help the modelers to determine the effect that variations in these inputs on the behavior, feasibility, and economics of a particular system configuration.

In the sensitivity analysis, a range of values for a single input variable can be input to the software to test its effect of the results, this variable for which the user has entered multiple values is called a sensitivity variable. Actually, almost every numerical input variable that is not a decision variable can be a sensitivity variable. However, this study just focuses on several variables: electric load; capacity shortage; solar radiation; wind speed; renewable fraction and diesel price.

💡 Better not to use "actually at the start of a sentence. "In fact" is better or place "actually next to the verb.

The sensitivity analyses is to utilize a corresponding scaling variable to scale the entire hourly data set up or down, the scaling process just changes the magnitude of the load data set without affecting the daily load shape, the seasonal pattern, or any other statistical properties.

3.6. Experiment study

To date, there are only two application examples reported about the renewables based pumped storage in the world [120, 121]. However, only two project examples cannot fully reflect all possible operating conditions and more experiments and real demonstration projects are of great importance, which will be carried out in my future PhD study.

Better to also highlight limitations in the two previous studies, i.e. limited scope, or perhaps different environmental factors

A small scale pumped storage device for solar and wind power supply system can be setup in Hong Kong for demonstration and preliminary research purpose. The main elements of the system are: PV array and wind turbine (roof); upper water tank (rooftop); turbine-generator set (1st floor); lower water tank and a small battery bank (1st floor); remote control panel (1st floor). The diesel generator would not be considered in the experiments.

The structure and construction of the different elements of the system should be investigated, such as the turbines, pumps, water level sensors, remote control, storage containers, valves, pipes. The system operating performance will be evaluated in the following aspects: overall efficiency, energy and water balance, energy index of reliability, level of autonomy.

Better not to use "should". It does not express certainty, better to use "will".

On the other hand, the successful pumped storage engineering examples in Budapest and Greece[121] can be referenced for my future experiment tests.

Better not to use "on the other hand", better to delete the phrase.

4. FINISHED WORK.

Based on the research framework in Fig. l, the left four parts have been finished. The work was majorly conducted based on a collaborative research with China Light & Power (CLP), which began from the December in 2010. The finished work is briefly discussed as follows.

✓ Outlines the content of the following section.

4.1. A real standalone PV system operating performance evaluation

This part of the work mainly focused on the performance evaluation of a standalone PV system on a remote island (Town Island), located in the southeastern part of the Sai Kung District in Hong Kong. During Stage 1 of the renewable energy supply scheme which began in 2008, CLP tentatively installed a PV plant, comprising 20.8kWp PV arrays, associated balance of system (BOS) components and distribution facilities.

The system schematic diagram of the PV system on Town Island is illustrated in Fig. 10. The PV array has two subarrays, consisting of 99 non-reflective solar panels from Suntech. The PV array is connected to a plant room containing of 96 batteries, 5 bidirectional inverters SI5048, 2 PV inverters SMC10000TL; data loggers, cut-out boxes, meters, fans, switches and a power conditioning system.

✓Describes the main features of the system, using key figures to further illustrate the figure.

To better understand the system operating characteristics of Stage 1 and to facilitate the system design of Stage 2, the system operating data and environmental data from Jan 2010 to March 2010 were collected. This work was based on the onsite collected data and evaluated the long term system operating performance in respect of the PV array, inverters, that battery bank and the entire PV system performance was analyzed in terms of daily energy balance, normalized parameters (array yield, reference yield, final yield, and losses), performance ratios, production factors, usage factors, and capacity factors.

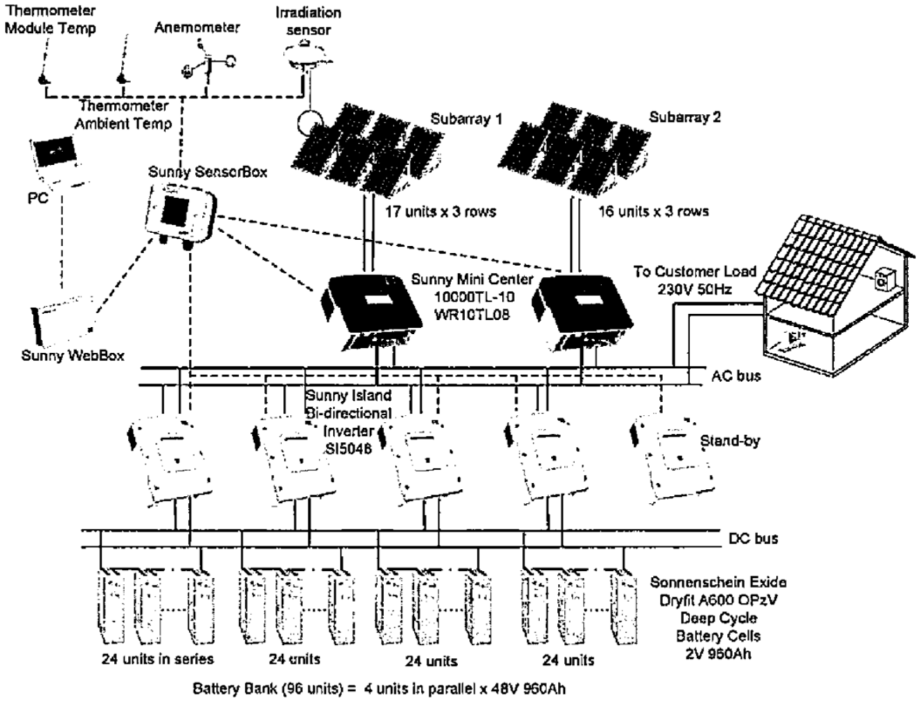


Fig. 10 Schematic diagram of the standalone PV system on Town Island

The detailed evaluation methodology and procedures can be seen in the first part of final report for CLP. Some typical results are demonstrated as follows.

4.1.1. PV panel performance analysis

The energy production from this PV plant in the year of 2011 is presented in Fig. 11. The gross electricity generation during the year 2011 was 22,322 kWh with a daily average value at 61.2 kWh. The production in winter and spring months (November-April) was very limited and most, particularly in January and February, below the average line. Production in the summer months was considerable owing to the good solar radiation resources. The results indicate that the existing PV system performs better and produces more power in summer than in winter.

Fig. 12 shows the daily mean temperatures over the reporting period. The variations in module, battery and environment temperature show a similar trend.

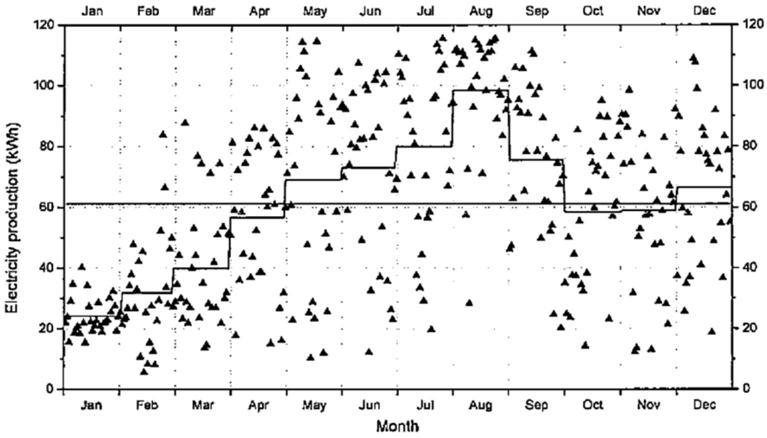


Fig. 11 Electricity generation profile in 2011

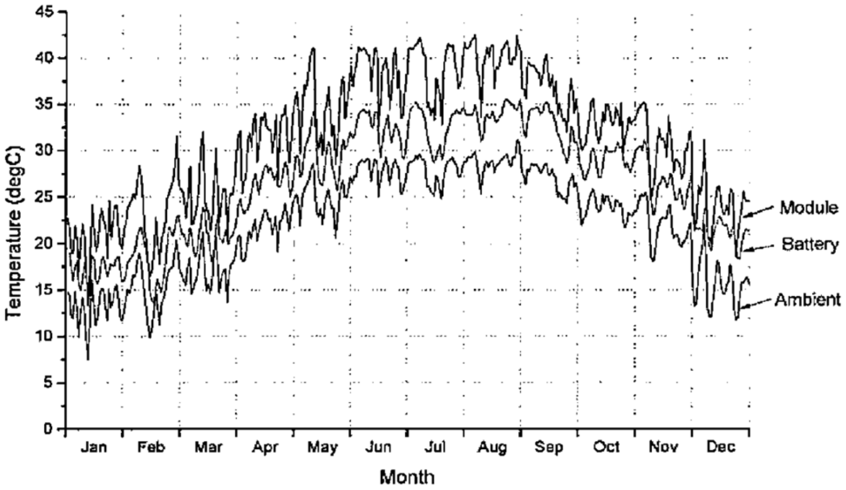


Fig. 12 Daily average temperatures of ambient, battery and PV module

4.1.2. SMC inverter and SI inverter performance analysis

Fig. 13 shows that the SMC operates well with higher efficiency from 95% to 100% if the solar radiation is greater than 100 W/m^2. The mean efficiency over whole solar radiation range is 97.1%, very close to the value of 97.5 % provided by the manufacturer.

The master SI bidirectional inverter performance is presented in Fig. 14 which demonstrates that the two functional modes behave differently. In the charging mode, the average efficiency was 87.2%. In the discharging mode, the average efficiency was 89.4%.

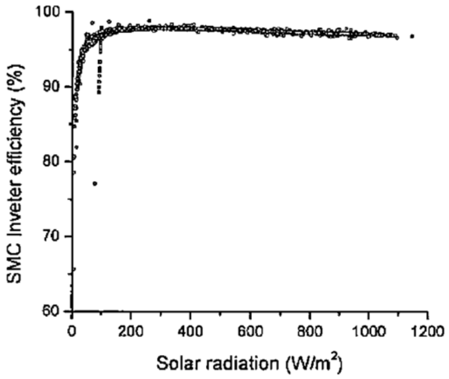


Fig. 13 SMC inverter efficiency from 1st to 10th May 2011

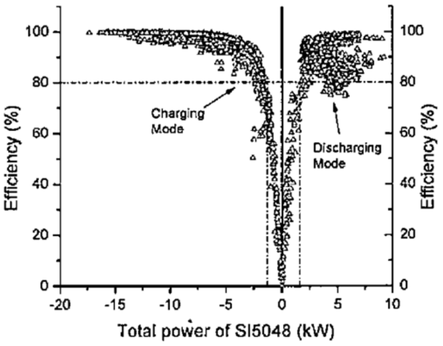


Fig. 14 SI bi-directional inverter efficiency from 1st to 10th May 2011

4.1.3. Battery bank performance analysis

✓ Defines key terminology.

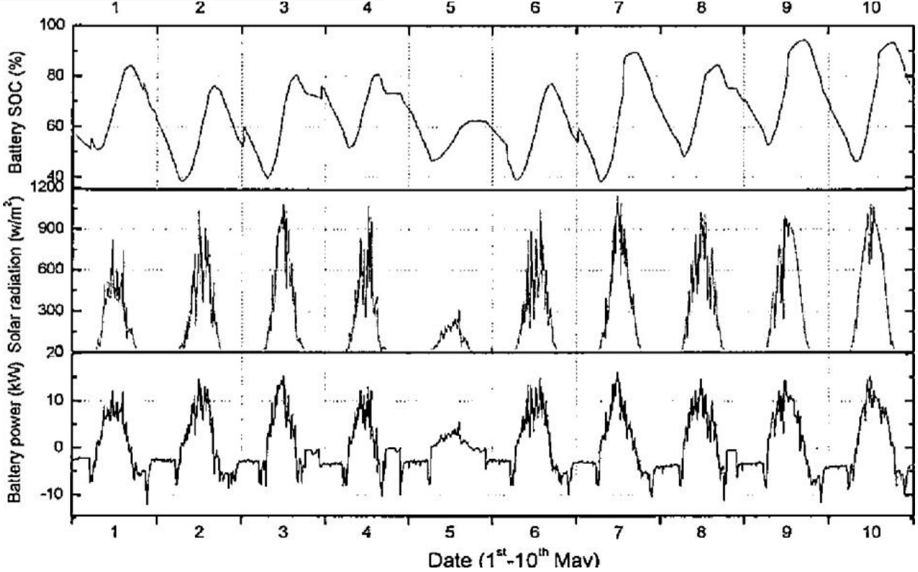


Fig. 15 The status of battery bank from 1st to 10th May 2011

Fig. 15 illustrates battery status in detail including the battery SOC and battery charging and discharging power. During this period, the SOC ranged from 40% to 100%. The lowest SOC occurred during early morning of each day after several continuous hours of discharging, and the peak SOC appeared in the afternoon lagging a couple of hours behind the peak solar radiation. The increase in SOC indicates the battery bank storing surplus energy from PV after supplying the load. The maximum battery bank charging and discharging power was found to be 16.2kW and 13.4kW, respectively. The charging rate was lower than 10kW for most of time except for the peak value at noontime under bright sunlight. For most of time, the discharging power was under 10kW, and the stable value was around 4 kW, which closely related to the load demand.

✓ Describes the key trends from the results and only uses key numbers, i.e. highest and lowest.

✓ Uses past tense and passive voice to report the findings of this study, e.g. "was found".

The monthly SOC distribution is statistically presented in Fig. 16 which demonstrates that the SOC seasonal changes were well marked. The smallest SOC occurred in the summer from May to Sep when the monthly averages were lower than 70%. The main reason behind that is that the cooling load during summer is high even though solar

✓ Describes the key trends.
✓ Gives only key numbers.
✓ Explains key data.

resource is good during this period. The monthly average values from Jan to Apr and from Oct to Dec were relative higher.

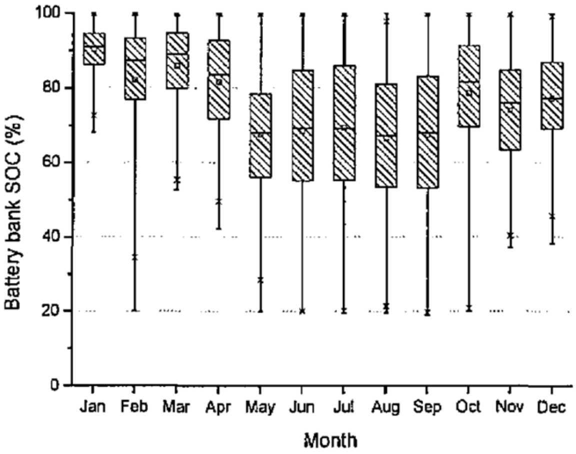


Fig. 16 Monthly battery SOC profile during the year of 2011

The net energy stored into the battery bank was 21.1kWh. Throughout the year in total 16,308 kWh were input to the battery bank and only 12,090 kWh output from it. Therefore about 4,239kWh were dissipated during the charging, discharging and storing periods. As a result, the battery bank roundtrip efficiency is calculated to be approximately 74.3% on an annual basis.

4.1.4. Entire system performance analysis

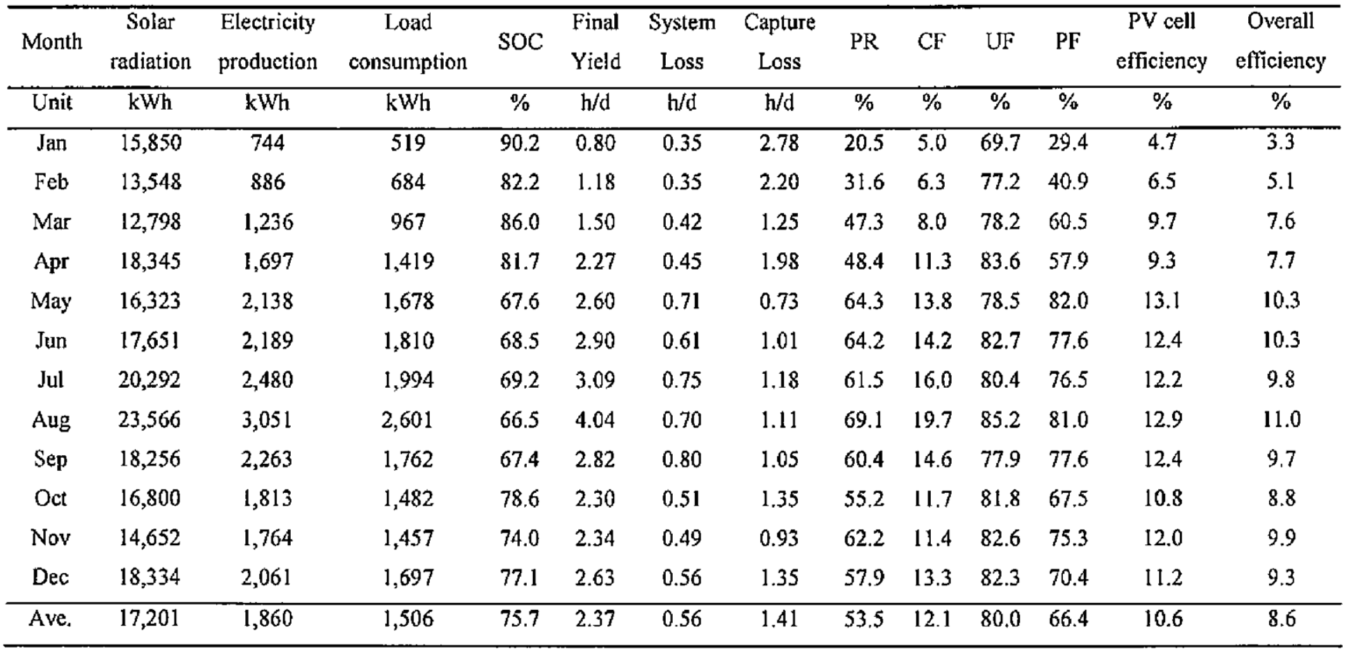
The whole set of system performance parameters and indicators by month are summarized in Table 3, including annual incident solar radiation on PV array, solar electricity production, load consumption, normalized parameters, performance ratios, usage factors, production factors, capacity factors, PV cell efficiencies and whole system efficiencies. The values in the last row are monthly averaged values. Some parameters have not been illustrated due to limited table space.Due to the space limited, these parameters are not discussed in detail.

✓ Explains how to interpret the chart, e.g. "The values in the last row are…".

From this study, the following conclusions are summarized: The average electricity production from the PV system was 61.2kWh/day and the electricity consumption on the island was 49.5kWh/day. The available solar radiation incident on the PV array was 4.34kWh/m2/day so that the average efficiencies of PV cells and entire system were 10.6% and 8.6% in that year; the roundtrip efficiency of the battery bank during the year was 74.3%, with the SOC values above 50% for 88% of the year; the annual yield, system losses and capture losses were 2.37h/d, 0.56h/d and 1.41h/d, respectively.

Better to sometimes give approximations of numbers within the text, if the exact number is clear from the table.i.e."Just over 61Wh/day...".

Table 3 Summary of the system performance indices



Month	Solar radiation	Electricity production	Load consumption	SOC	Final Yield	System Loss	Capture Loss	PR	CF	UF	PF	PV cell efficiency	Overall efficiency
Unit	kWh	kWh	kWh	%	h/d	h/d	h/d	%	%	%	%	%	%
Jan	15,850	744	519	90.2	0.80	0.35	2.78	20.5	5.0	69.7	29.4	4.7	3.3
Feb	13,548	886	684	82.2	1.18	0.35	2.20	31.6	6.3	77.2	40.9	6.5	5.1
Mar	12,798	1,236	967	86.0	1.50	0.42	1.25	47.3	8.0	78.2	60.5	9.7	7.6
Apr	18,345	1,697	1,419	81.7	2.27	0.45	1.98	48.4	11.3	83.6	57.9	9.3	7.7
May	16,323	2,138	1,678	67.6	2.60	0.71	0.73	64.3	13.8	78.5	82.0	13.1	10.3
Jun	17,651	2,189	1,810	68.5	2.90	0.61	1.01	64.2	14.2	82.7	77.6	12.4	10.3
Jul	20,292	2,480	1,994	69.2	3.09	0.75	1.18	61.5	16.0	80.4	76.5	12.2	9.8
Aug	23,566	3,051	2,601	66.5	4.04	0.70	1.11	69.1	19.7	85.2	81.0	12.9	11.0
Sep	18,256	2,263	1,762	67.4	2.82	0.80	1.05	60.4	14.6	77.9	77.6	12.4	9.7
Oct	16,800	1,813	1,482	78.6	2.30	0.51	1.35	55.2	11.7	81.8	67.5	10.8	8.8
Nov	14,652	1,764	1,457	74.0	2.34	0.49	0.93	62.2	11.4	82.6	75.3	12.0	9.9
Dec	18,334	2,061	1,697	77.1	2.63	0.56	1.35	57.9	13.3	82.3	70.4	11.2	9.3
Ave.	17,201	1,860	1,506	75.7	2.37	0.56	1.41	53.5	12.1	80.0	66.4	10.6	8.6

In summary, the long term system monitoring and evaluation enables a detailed understanding of the system operating performance from the technical point of view. It also provides useful reference information for future PV system design and operation. This study is also a useful case study relevance to future applications of RE supply on remote islands.

4.2. Available renewable energy resource assessment

In order to efficiently utilize RE, an analysis of the characteristics of solar irradiance and wind conditions on Town Island was conducted. This work mainly focused on the evaluating the available RE resources on this island, to provide a foundation for designing. a hybrid solar and wind system in Stage 2.

✓ Summarizes the subsection with a clear subheading.

4.2.1. Solar energy resource evaluation

The solar radiation from different database are illustrated in Fig. 17 which shows that the solar radiation in horizontal surface from HK Observatory and RETscreen is a little lower than that from NASA database but they have the consistent tendency. Compared to the real data recorded on the Town Island, however, the differences in either magnitude or pattern are obvious, particularly in April and August. To accurately evaluate the solar energy potential on Town island and in Hong Kong, the data in Kau Sai Chau was employed.

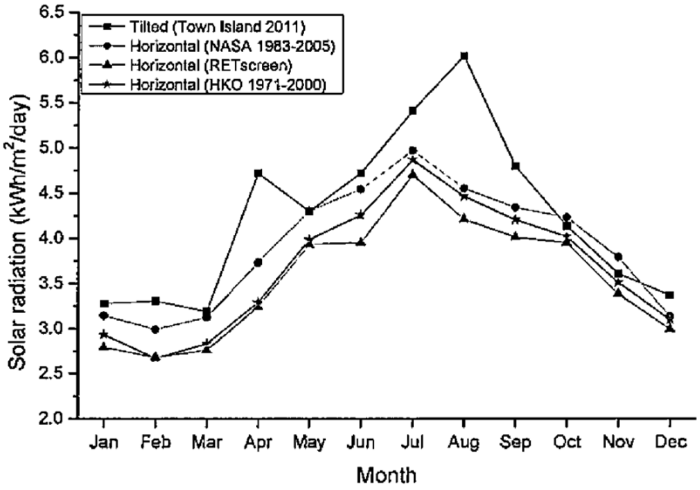


Fig. 17 Daily averaged radiation recorded by Town Island, NASA database, RETscreen and HKO

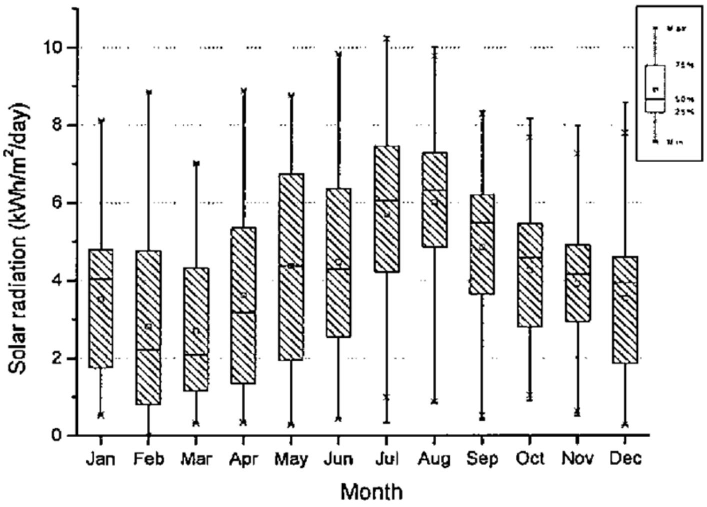


Fig. 18 Mean daily global solar radiation on a horizontal surface (kWh/m^2/day)

The average daily global solar radiation on a horizontal surface for each month of the year is shown in Fig. 18. The average daily total values range from 0 to 10.3kWh/m^2/day. The yearly average value is 4.23kWh/m^2/day. The season distribution is consistent with the typical subtropical climate in Southern Asia.

Fig. 19 shows that the annual curves of the occurrence frequency when compared to the daily solar radiation with a specified value level. In the winter months of December and January, more than 60% of days receive less than 4.0kWh/m^2/day. However, in the summer months between May and September, at least 40% of the days are above 5.0kWh/m^2/day and of these a small number of days exceed 8.0kWh/m^2/day. It can also be seen that the yearly frequency distribution is quite symmetrical with respect to the mid-summer month of July.

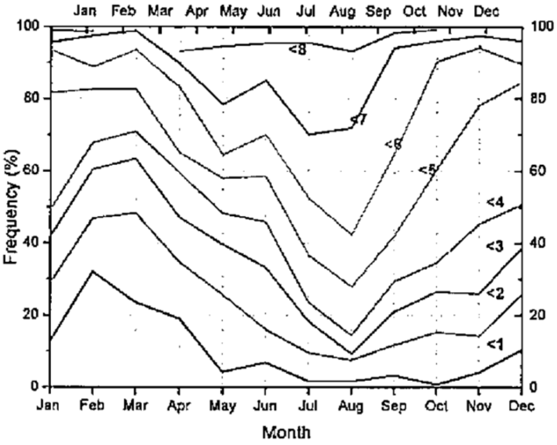


Fig. 19 Frequency distribution of daily average irradiation (kWh/m^2/day)

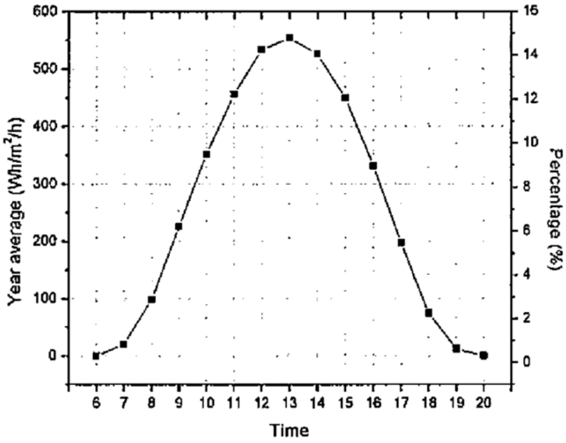


Fig.20 Yearly average solar radiation at a given hourly interval

Fig. 20 gives the yearly average solar radiation distribution at a given hourly interval. They show that the hourly peak value occurs at 1:00pm and the solar radiation profile has a symmetrical distribution from 6:00am to 8:00pm.

4.2.2. Wind energy resource evaluation

It is widely acknowledged that wind power is one of the most potential RE resources for Hong Kong, because it is characterized by a long coastline and numerous islands for such a relatively small territory. However, the potential for wind power has been somewhat neglected and just a few large-scale wind farms have been built on Lantau Island. According to the schedule in Stage 2, CLP will install two 6 kW Proven 11 wind turbines.

In this section, the wind data from Waglan Island was purchased from the HKO for evaluation. The research methodology reported in one of the research group's published paper[249] was adopted in this study to assess the wind power potential on this island.

Better to state why the methodology used was chosen.

The detailed evaluation procedures are not included in this report, but some results are presented as follows:

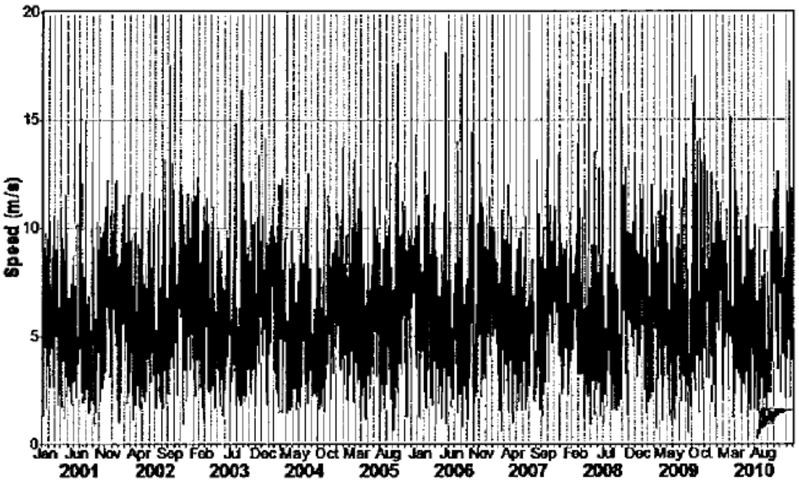


Fig. 21 Daily mean wind speed during the 10 years (2001-2010)

The daily mean wind speed data in the 10 years are illustrated in Fig. 21 as an example to show the wind speed profile.

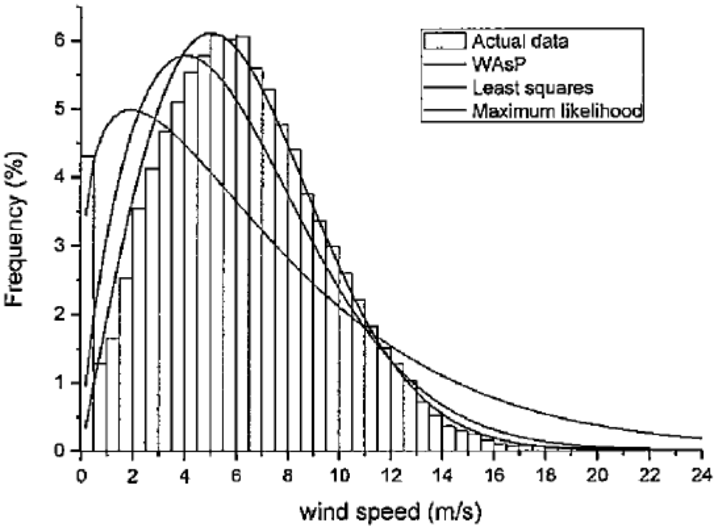


Fig. 22 Wind speed frequency distribution fitted by three different algorithms (10 years data)

The frequency distribution of 10-year wind speed data is presented in Fig. 22, which is then fitted by three different algorithms to model the Weibull distribution. The figure demonstrates that the WAsP methods meet well with the actual data with acceptable accuracy. Based on the 86,145 valid wind data recordings, the overall shape factor is calculated as 2.02 and the overall scale parameter is 7.05 m/s, indicating satisfying wind energy potential on that island.

The monthly mean wind speed and theoretical wind power density (W/m^2) by 10 years average are given in Fig. 23. The yearly average power density is calculated at 283 W/m^2.

Fig. 23 Monthly (and yearly) average wind power density and average wind speed

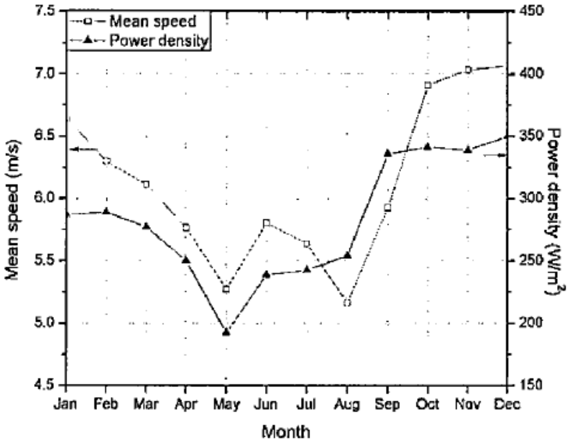
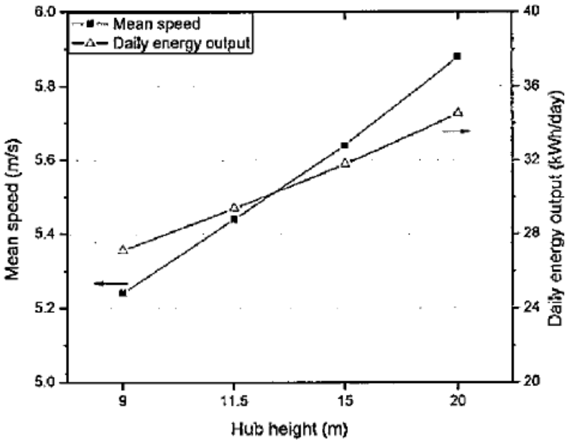


Fig. 24 Annual power density versus mean wind speed for different hub height



In addition, the wind turbine performance at different hub height was compared. The results are summarized in Fig. 24. When the hub height changes from 9m to 20m, the mean wind speed and daily energy output increase by 12.2% and 27.3%, respectively.

4.2.3. Complementary characteristic of solar and wind energy

A drawback, common to wind and solar options, is their unpredictable nature and dependence on weather and climatic changes. Fortunately, the problems can be partially overcome by integrating the two resources in a proper combination to form a hybrid system which uses the strengths of one source to overcome the weakness of the other. In this section, the complementary effect of the solar radiation and wind speed was briefly analyzed.

✓States a problem.
✓Suggests solution
✓Details how this approach applies to the current study (in the second paragraph).

The average solar and wind potential on Town Island in 2009 is presented in Fig. 25 which displays their inherent complementary nature. The summer provides a relative good solar energy resource but poor wind condition, while the winter has a crosscurrent. Usually, the wind speed is higher during seasons of low insolation and low for high insolation. In addition, the daily distribution, shown in Fig. 26, also demonstrates a complementary characteristic that the wind often blows when the sun does not shine and vice versa. In brief, the above figures show that solar and wind energy resources exhibit complementary daily and seasonal patterns. Therefore, the solar and wind together can provide greater value than either alone: a better utilization factor for the available energy and thus less energy storage capacity is needed.

✓ Gives a clear concluding sentence based on the observations reported.

Fig. 25 Monthly solar radiation and wind speed distribution in 2009

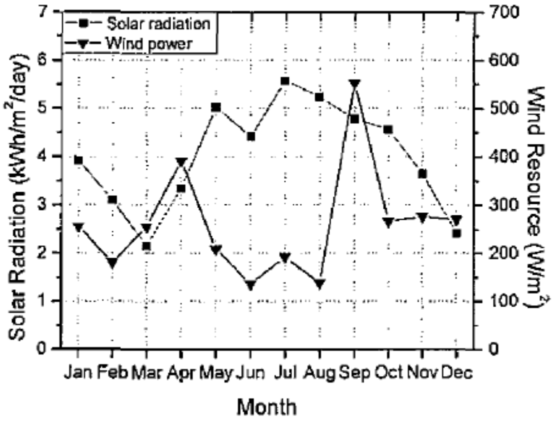
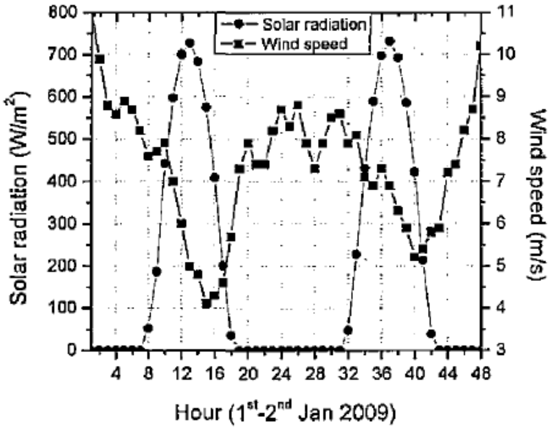


Fig. 26 Daily solar radiation and wind speed distribution in 1^{st}-2^{nd} January in 2009



4.3. Feasibility study and economic comparison of pumped hydro storage and battery storage for powered by renewable energy

This work mainly focused on the energy storage options for a remote island. Pumped hydro storage was proposed and the investigation was described in this study. The feasibilities and economic comparisons between battery and pumped storage schemes were examined in terms of life cycle cost (LCC) and technical viability. The two potential alternatives are divided into 5 subcategories, as summarized in Table 4. The electricity consumption was estimated as 250kWh/day, and the desired number of autonomy days was 5.

The methodology employed for these five options study is not included in this report, some typical results are presented as follows.

Table 4 Summary of potential energy storage options

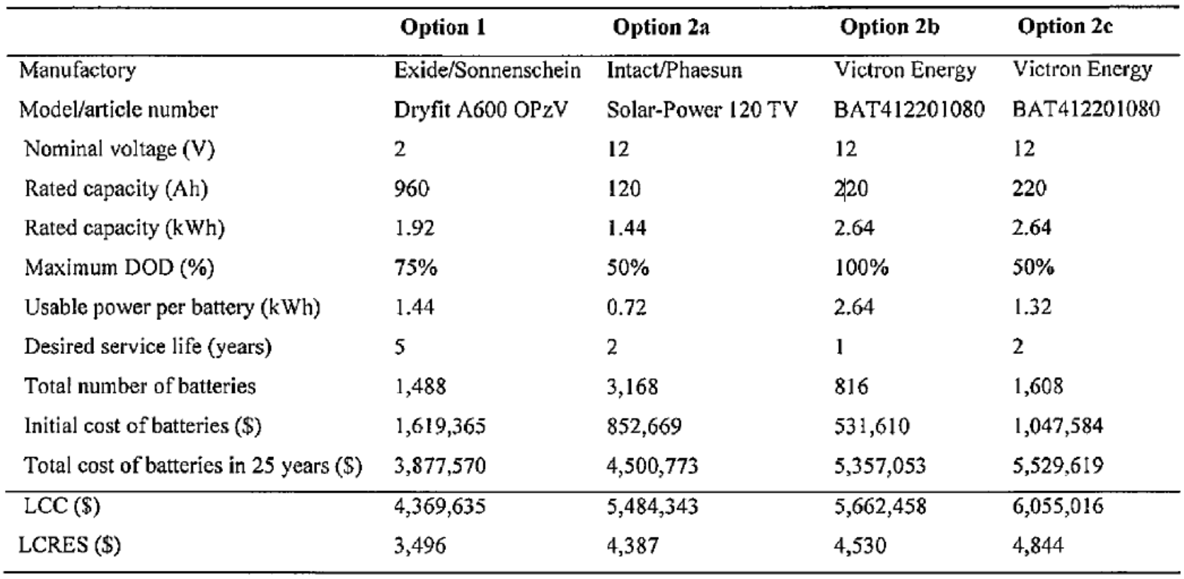
Options	Description

Option 1	Advanced deep cycle lead acid battery
Option 2	Conventional battery
Option 3	Pumped storage combined with battery bank
Option 4	Pumped storage (no battery)
Option 5	Pumped storage (reversible pump-turbine)

4.3.1. LCC&COE results for all options

The total LCC of Option I (deep cycle battery), at approximately $4.37millon (LCRES: $3,496), is mainly shared by the two key components, batteries and inverters. The cost of batteries and inverters accounts for 89% and 11%, respectively.

Table 5 Battery storage option comparison (Option I & Option 2)



	Option 1	**Option 2a**	**Option 2b**	**Option 2c**
Manufactory	Exide/Sonnenschein	Intact/Phaesun	Victron Energy	Victron Energy
Model/article number	Dryfit A600 OPzV	Solar-Power 120 TV	BAT412201080	BAT412201080
Nominal voltage (V)	2	12	12	12
Rated capacity (Ah)	960	120	220	220
Rated capacity (kWh)	1.92	1.44	2.64	2.64
Maximum DOD (%)	75%	50%	100%	50%
Usable power per battery (kWh)	1.44	0.72	2.64	1.32
Desired service life (years)	5	2	1	2
Total number of batteries	1,488	3,168	816	1,608
Initial cost of batteries ($)	1,619,365	852,669	531,610	1,047,584
Total cost of batteries in 25 years ($)	3,877,570	4,500,773	5,357,053	5,529,619
LCC ($)	4,369,635	5,484,343	5,662,458	6,055,016
LCRES ($)	3,496	4,387	4,530	4,844

The LCC results for the conventional battery solution of Option 2 are summarized in Table 5. It should be noted that the discrepancies between three options (2a & 2b & 2c) are obvious. Compared with Option l, the Levelized cost for renewable energy storage system (LCRES) results for all Option 2 cases are considerably higher, indicating that the advanced deep cycle batteries perform better than the conventional one for long term operation. The findings in Table 5 also reveal that the increase of initial costs incurred in adopting advanced technology can effectively decrease running and maintenance costs.

✓ Highlights clear trend in table

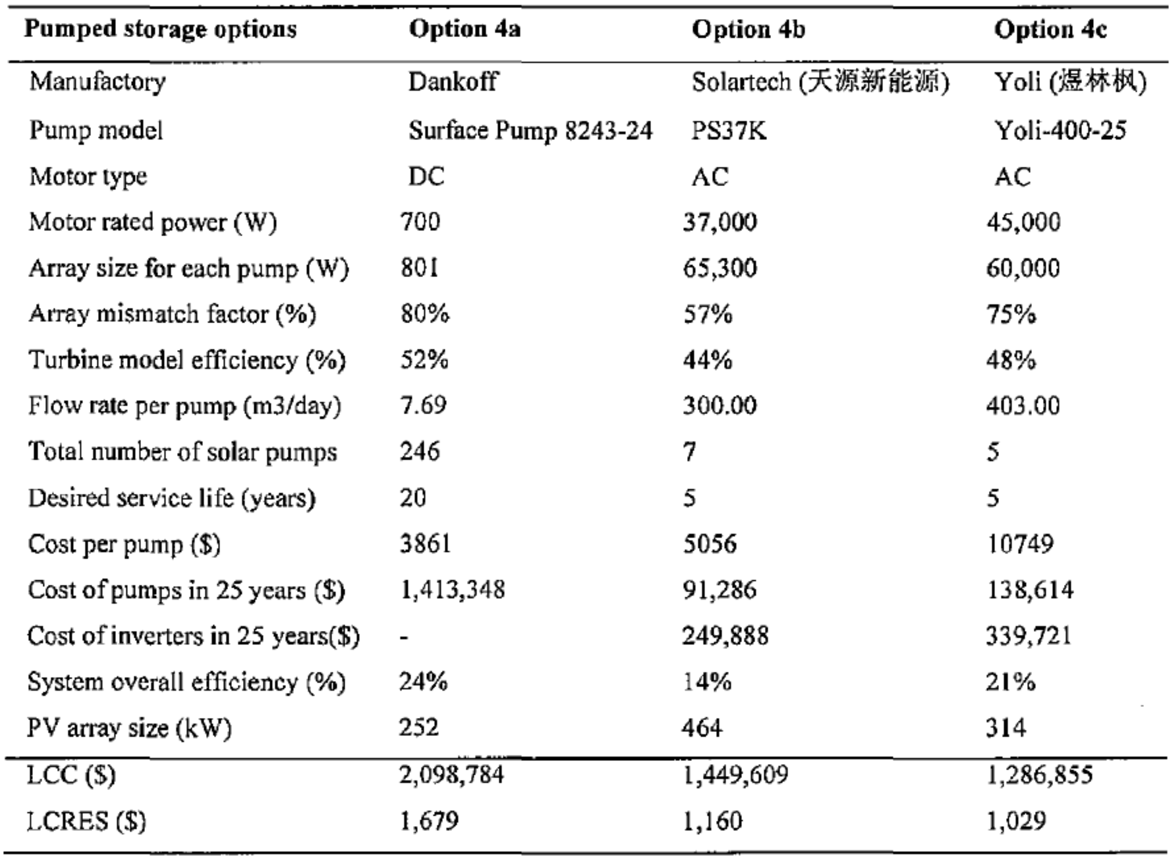
✓ Interprets trend, e.g. "also reveal that"

Option 3, the PHS combined with battery bank scheme, presents satisfying results. The total investment cost of Option 3 is about $2.4millon, only 55% of Option 1. The main reason for the lower total LCC is possibly that many fewer batteries (only $0.27millon) are used in this system. The great majority of LCC is contributed by the pump (accounting for 59%), while battery cost accounts for only 11%.

✓ Uses tentative language when interpreting tables, e.g. "possibly"

As for Option 4, a new approach to balance supply and demand is introduced by the use of a hydraulically controlled turbine. The summary results are presented in Table 6.

Table 6 Pumped storage option without battery comparison (Option 4)



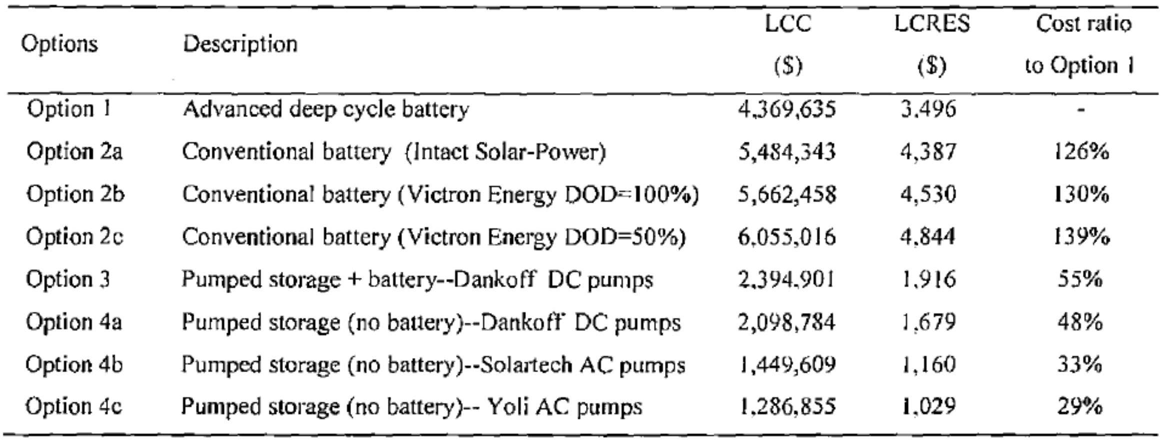
Pumped storage options	Option 4a	Option 4b	Option 4c
Manufactory	Dankoff	Solartech (天源新能源)	Yoli (煜林枫)
Pump model	Surface Pump 8243-24	PS37K	Yoli-400-25
Motor type	DC	AC	AC
Motor rated power (W)	700	37,000	45,000
Array size for each pump (W)	801	65,300	60,000
Array mismatch factor (%)	80%	57%	75%
Turbine model efficiency (%)	52%	44%	48%
Flow rate per pump (m3/day)	7.69	300.00	403.00
Total number of solar pumps	246	7	5
Desired service life (years)	20	5	5
Cost per pump ($)	3861	5056	10749
Cost of pumps in 25 years ($)	1,413,348	91,286	138,614
Cost of inverters in 25 years($)	-	249,888	339,721
System overall efficiency (%)	24%	14%	21%
PV array size (kW)	252	464	314
LCC ($)	2,098,784	1,449,609	1,286,855
LCRES ($)	1,679	1,160	1,029

A summary of all options is presented in Table 7. For the conventional battery utilized in Option 2, the cost ratio is much higher than 100%, indicating there are no cost advantages for stand-alone RESs. However, for Option 3 & Option 4 by PHS, the economic benefits are significant and the cost ratios decrease to less than 1. The minimum ratio is occupied by Option 4c at a cost of only 29%, and the highest cost PHS scheme of Option 3 only costs about 55% of Option 1. Therefore it is obvious that the PHS scheme can be economically competitive with battery solutions for

✓ Contrasts key differences between options renewable microgrid storage applications. This superiority will be further enhanced when the overall efficiency of mini pumped storage schemes are improved because of the growing focus of interest in schemes of this type. The recent decline in PV panel price along with rising costs of batteries will further enhance the cost effectiveness of pumped storage option.

✓ Uses approximate language to interpret figures, e.g. "about"

Table 7 Summary of economic cost for options and the cost ratio to Option 1



Options	Description	LCC ($)	LCRES ($)	Cost ratio to Option 1
Option 1	Advanced deep cycle battery	4,369,635	3,496	-
Option 2a	Conventional battery (Intact Solar-Power)	5,484,343	4,387	126%
Option 2b	Conventional battery (Victron Energy DOD=100%)	5,662,458	4,530	130%
Option 2c	Conventional battery (Victron Energy DOD=50%)	6,055,016	4,844	139%
Option 3	Pumped storage + battery--Dankoff DC pumps	2,394,901	1,916	55%
Option 4a	Pumped storage (no battery)--Dankoff DC pumps	2,098,784	1,679	48%
Option 4b	Pumped storage (no battery)--Solartech AC pumps	1,449,609	1,160	33%
Option 4c	Pumped storage (no battery)-- Yoli AC pumps	1,286,855	1,029	29%

4.3.2. Sensitivity analysis results

Sensitivity analyses were carried out on six key variables: daily energy consumption, desirable autonomy days, peak sun hours, peak load, discount rate, and PV module price.

The sensitivity assessments on daily energy consumption (10 kWh/day - 1000kWh/day) and peak sun hours (2 hours - 7 hours), as an example, are provided in Fig, 27 and Fig. 28.

The results show that it is probably unreasonable to employ PHS for a pico energy storage system with a daily electricity consumption of 10kWh. The costs of Option 4b and 4c are much higher than for Option 1 because the pump capacity used in this study is costly. Therefore, it seems not cost effective to employ pumped storage for this low storage capacity range such as 10kWh and 20kWh. However, when daily consumption is greater than 25kWh, the cost ratio for all PHS schemes can be kept below 0.8. As daily energy consumption increases, the cost ratio can be further lowered and the economic benefits of PHS become steadily more obvious.

✓ Uses tentative language to interpret results, e.g. "probably" and "it seems not to"

Fig. 27 Sensitivity analysis result on daily energy consumption

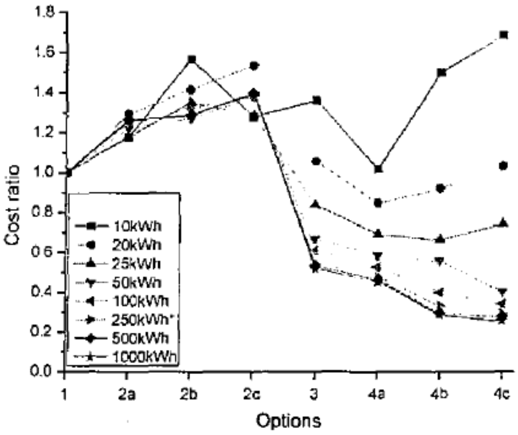
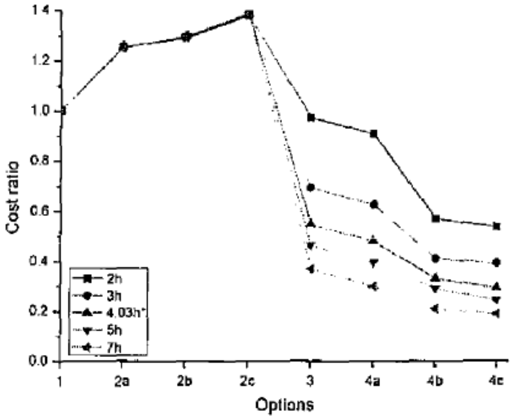


Fig. 28 Sensitivity analysis result on peak sun hours



The sensitivity study of the effects of peak sun hour variations mainly relates to prospects for the implementation of the PHS technology in diverse locations with different mean solar radiation levels. As Fig. 28 indicates, the PHS option would be more cost effective than the battery storage option for place with 2 to 7 peak sun hours of solar radiation. Another significant phenomenon is that any further increase in peak sun hours further improves the competitiveness of the pumped storage scheme. The result suggests that the pumped storage scenario can be applied widely in any location around the world where the number of peak sun hours exceeds 2.

✓ Emphasizes importance of results by using "Another significant phenomenon"

4.4. Hybrid solar and wind system design for a remote island

This part of this project proposed an optimal hybrid renewable energy supply system for the existing 50-100 residents. The work is mainly carried out based on the simulation software (HOMER). Some published studies related to this software were briefly reviewed. Three basic energy supply scenarios were then described, in the form of system configurations and operating strategies. The input parameters and son-le constraints and assumptions were also discussed, followed by the system evaluation criteria in terms of life cycle cost, payback time and environmental effects. Finally, the simulation results of three scenarios were presented in the figures, tables and graphs and discussed.

4.4.1. Optimal system type (OST)

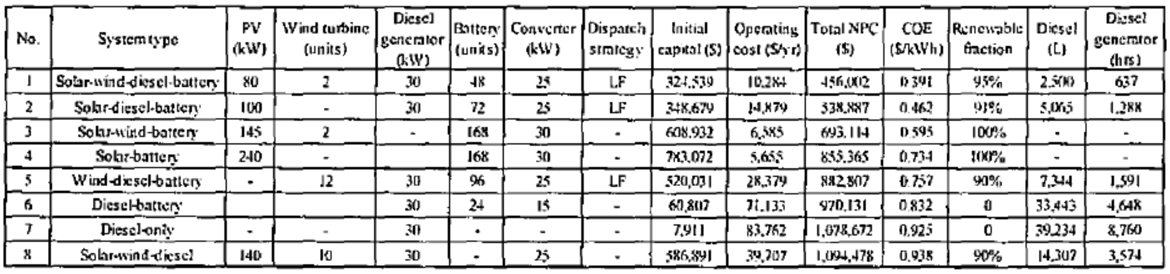
The optimization results in a categorized form with least net present cost (NPC) among many different configurations are summarized in Table 8. The minimum renewable fraction (RF) in the simulation was restricted at 90% (not applied to the diesel-only and diesel-battery system).

✓ Introductory paragraph, explains content and scope

In Table 8, each row represents an optimal system type (OST), which has the lowest NPC in the specific category. The first and second column represents the serial number and system type. The next four columns indicate the presence and size or number of PV array, WT, diesel and battery; the next column presents which dispatch strategy is optimal for every system type; the following five columns highlights a few of the economic results, namely, the initial cost (IC), yearly operating cost, the total NPC, the levelized cost of energy (COE). The RF, annual diesel consumption and the diesel operating hours per year are provided in the last three columns for the hybrid RES with diesel generator.

✓ Explains how to interpret table 8

Table 8 Categorized winners with lowest net present cost



No.	System type	PV (kW)	Wind turbine (units)	Diesel generator (kW)	Battery (units)	Converter (kW)	Dispatch strategy	Initial capital ($)	Operating cost ($/yr)	Total NPC ($)	COE ($/kWh)	Renewable fraction	Diesel (L)	Diesel generator (hrs)
1	Solar-wind-diesel-battery	80	2	30	48	25	LF	324,539	10,284	456,002	0.391	95%	2,500	637
2	Solar-diesel-battery	100	-	30	72	25	LF	348,679	14,879	538,887	0.462	91%	5,065	1,288
3	Solar-wind-battery	145	2	-	168	30	-	608,932	6,585	693,114	0.595	100%	-	-
4	Solar-battery	240	-		168	30	-	783,072	5,655	855,365	0.734	100%	-	-
5	Wind-diesel-battery	-	12	30	96	25	LF	520,031	28,379	882,807	0.757	90%	7,344	1,591
6	Diesel-battery			30	24	15	-	60,807	71,133	970,131	0.832	0	33,443	4,648
7	Diesel-only	-	-	30	-	-	-	7,911	83,762	1,078,672	0.925	0	39,234	8,760
8	Solar-wind-diesel	140	10	30	-	25	-	586,891	39,707	1,094,478	0.938	90%	14,307	3,574

Overall, the hybrid solar-wind-diesel-battery system with 95% RF (scenario l) was found to be the most cost-effective one among all simulated types (No. l). This system consisted of 80 kW PV array, 2 WTs and 48 batteries. The total NPC and COE was $456,002 and $0.391/kWh, much less than a 100% renewable energy system. The total work time of diesel was 637 hours and the diesel consumption was 2,414L/year. The load-following (LF) strategy was considered as the most suitable solution for this hybrid system with two dispatchable sources (diesel and battery), meaning that the diesel never charged the battery bank when it run above the minimum load ratio. The results show that it could be a wise choice to implement this hybrid system with 95% RF on this island, as the energy contribution made by renewable energy is quite significant and GHG emission is not high (6,582kg/year).

The configuration of solar-diesel-battery system with 100 kW PV and 72 batteries was considered as the second energy supply solution (No.2). Due to no WT, the PV and battery bank size increased obviously, indicating that the complementary characteristic of solar and wind resources is important for the RESs applied in the remote areas.

To achieve the target of 100% RF, two approaches might be reasonable: solar-wind-battery system (No.3) and solar-battery system (No.4). The COE of two systems were \$0.595 and \$0.734, respectively. Compared with other system categories, these two system types had relatively higher PV array and battery bank capacities, and hence the total NPC increased. However, it could be a perfect choice to implement a totally renewable power generation system on this island since the renewable energies are sustainable and environmentally-benign.

✓ Uses range of comparative structures, e.g. "relatively higher", "not as high as"

The wind-battery system could not ensure zero CS and 90% RF. However, this target could be achieved through adding a diesel to form a wind-diesel-battery system (the fifth-ranked category in Table 8).

The COE of the diesel-battery system (No.6) was \$0.832, which has zero wasted energy because of the batteries. For the diesel-only (No. 7) system, the IC (used for purchasing only one diesel) was not as high as diesel-battery system, but the O&M was unreasonably high, occupying more than 80% of the total NPC due to high fuel consumption.

The last choice would be solar-wind-diesel system without storage. Although it had a high same RF of 90% with the No.5 system, the diesel consumption doubled. The PV panel and WT were just used to supplement the diesel energy when they were available. Because of no storage device, up to 72.4% of total production was dumped.

Be objective when discussing options use, e.g. "most efficient system", "least efficient system".

In the following sections, two scenarios are analyzed in detail.

4.4.2. Scenario 1 : Solar-wind-battery system

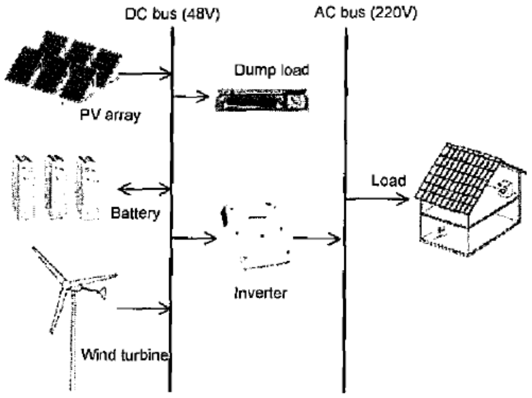
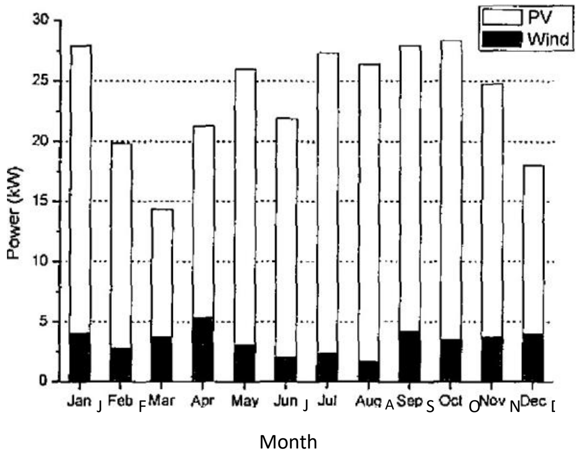


Fig. 29 The physical configuration of the proposed hybrid solar-wind system with battery storage

The system physical configuration for this hybrid solar and wind system with battery storage is shown in Fig. 29. The monthly mean electric production from PV array and WTs is presented in Fig. 30. It can be noted that the solar production took up almost 86% of the total production. In addition, the PV output was extremely high in summer months from Jul to Oct. This is a favorable characteristic since electricity demand is strong in those months. Contrarily, the wind energy contribution mainly depended on the wind resource in different months.

Use full form of word in the text, i.e. "July" rather than "Jul".



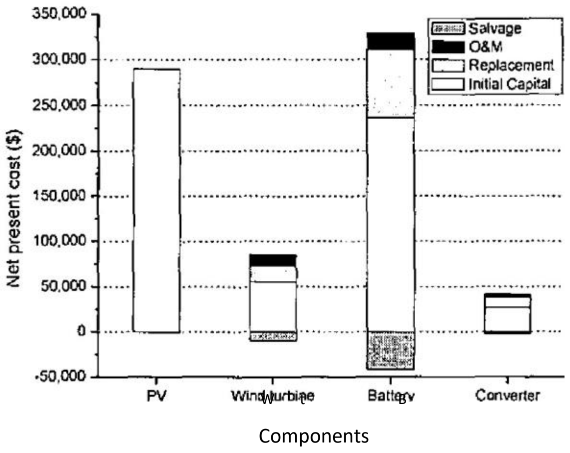


Fig. 30 Monthly mean powered generated by PV and wind

Fig. 31 Cash flow break-down by components and cost type

The cash flow break-down by components and cost type is shown in Fig. 31. The total NPC of the above system was found to be $693,114. The corresponding levelized COE was $0.595/kWh, approximately three times of the current electrical tariff in Hong Kong. However, it is still considered as a cost-effective solution to replace the diesel generator or grid extension by submarine cables and overhead lines. It should be highlighted that the cost of battery bank is nearly 50% of the total NPC, indicating that cost for storage subsystem in stand-alone HRESs is dominant, The PBT of this RES is calculated as 7.3 years, which is a bit longer than other published studies [262, 263].

Use plural form when comparing "time", i.e. "three times".

✓ Compares results to those of other studies

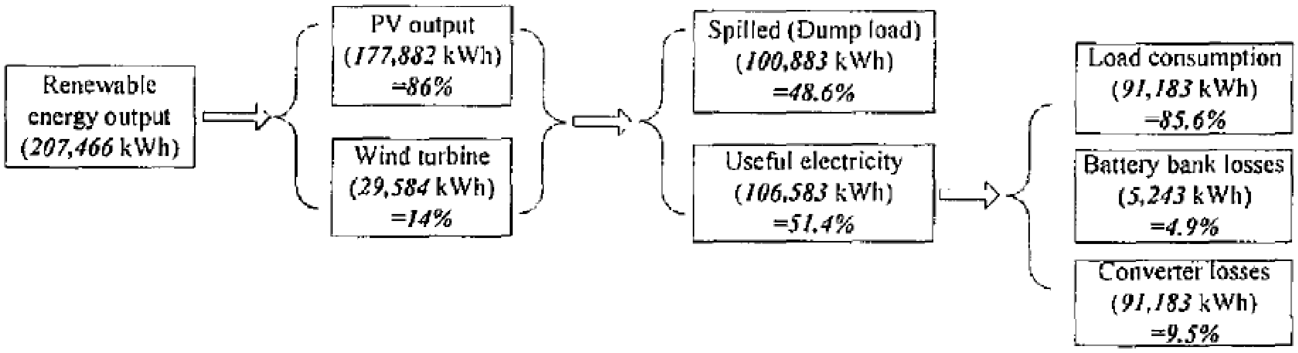


Fig. 32 Summary of the energy flow during the simulated year

Fig. 32 summarizes the energy flow of the whole system. 84% of output was contributed by PV array and 16% by WTs. However, almost 48.6% of the total RE output was in excess and transferred to the dump load. Among the total useful electricity, 85.6% was consumed by the end-users, 4.9% and 9.5% was used to cater for battery bank and converter losses.

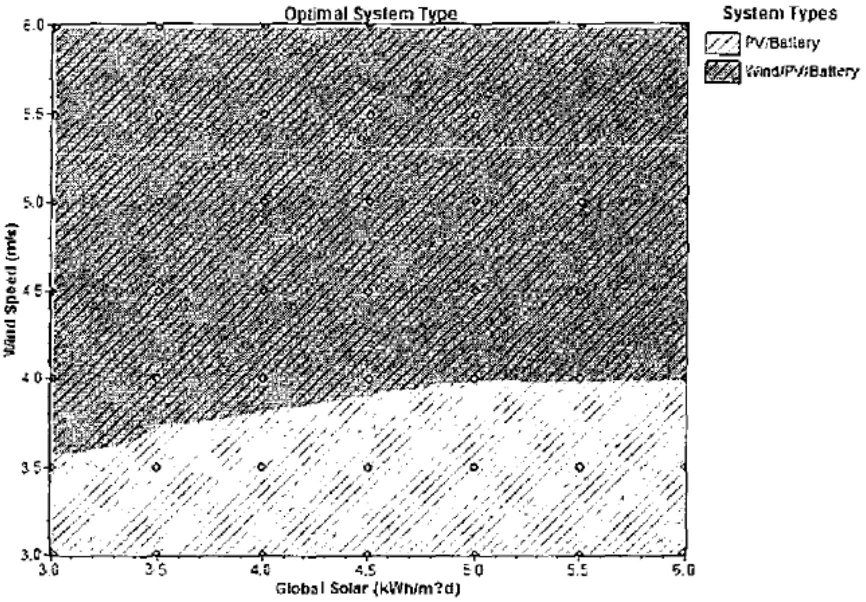


Fig. 33 Optimal system type against with solar radiation and wind speed

The effects of available renewable energy potential (solar radiation: 3 to 6kW/m^2/day and wind speed: 3 to 6 m/s) on the system configuration were examined. The optimal system type graph is presented in Fig. 33. If the average wind speed is lower than 3.5m/s, the solar-battery systems provide the lowest COE, because the WT cannot start or output little energy at such low wind speed. For the wind speed between 3.5 and 4m/s, the solar-wind-battery systems are cost effective for low solar radiation values and solar-battery systems for high solar radiation values. When the average wind speed is 4m/s, it seems that introducing the WT could be economical since it begins to produce electricity.

✓ Clear topic sentence

Use "when" rather than "for" when introducing conditions, e.g. "When the average…" is better than "For the wind speed…"

4.4.3. Scenario 2: Solar-wind-diesel-battery system

The system physical configuration is shown in Fig. 34. From the overall results analysis, it can be seen that the addition of a diesel generator makes the solar-wind-diesel-battery system a more viable option, even with unreasonable high fuel prices in Hong Kong. The results showed that the diesel is only used to cater for peak loads or during the periods of no energy stored and no availability of renewable energy, so that fuel consumption is not very high and thus a high RF can be guaranteed. This study indicates that it is the more economically and technically feasible solution for this island.

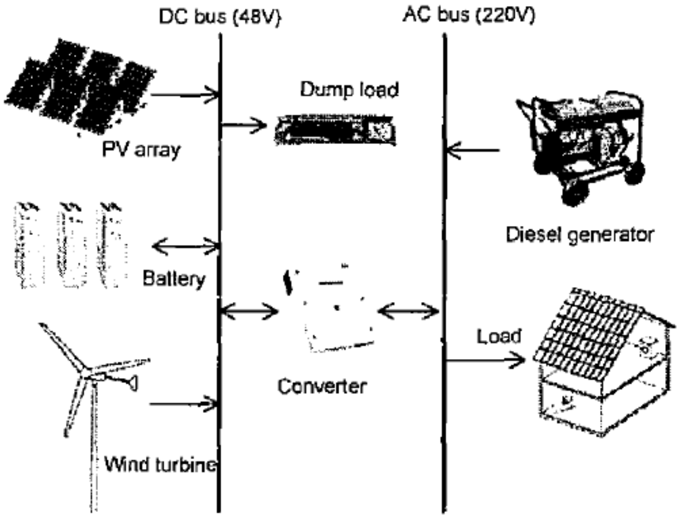


Fig. 34 System configuration of the hybrid solar-wind system with battery and diesel generator

In this study, the results indicate that the optimal dispatch strategy is the combined load following and cycle charging strategy. In addition, the minimum renewable fraction (RF) was applied as a sensitivity variable changing from 50% to 90%, to explore the threshold of RF at which it is the most cost-effective, the simulation results shows that optimal system type in whole range of RF was the one with 95% RF.

Avoid "In this study", write "The results of this study indicate..."

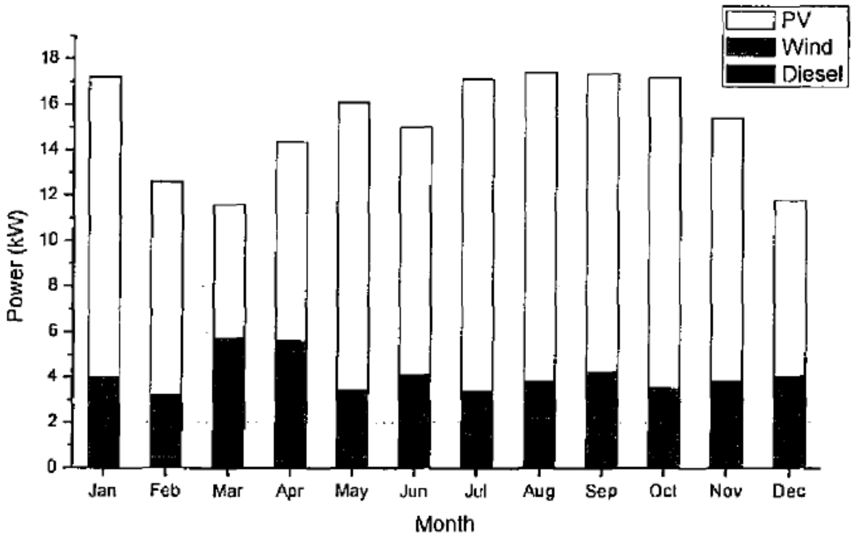


Fig. 35 Monthly mean powered generated by PV, wind and diesel

The monthly mean electric productions from PV array, WTs and diesel are presented in Fig. 35. Compared with the system in scenario l, the PV output was still the dominating part, accounting for about 73%, followed by the wind output (22%). The electricity fraction from nonrenewable diesel was 5%, totally operating for 637 hours. Fig. 36 summarizes the energy flow of the whole solar-wind-diesel-battery system. 21% of the total production was in excess and dumped. Besides, the battery and converter losses also took up 14% of the total usable energy.

Do not use "besides" as a single linking word at the start of a sentence. Use "Furthermore" or "Besides this, ..."

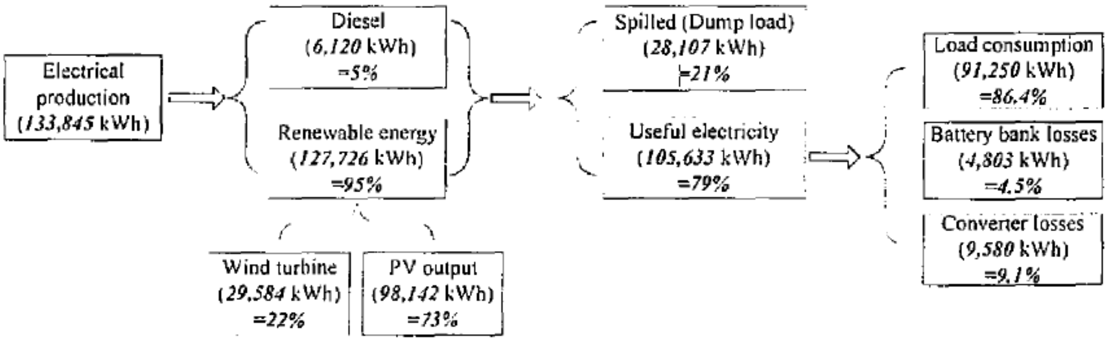


Fig. 36 Summary of the energy flow during the simulated year

The battery bank SOC distributions in scenario 1 and scenario 2 are distinctly different. The SOC results in Scenario 2 close to the two extreme values was very high, the SOC from 95% to 100% accounted for 16%, followed by the SOC values from 30% to 35%. The utilization ratio was notably improved, but the expected lifetime decreased to 14.6 years.

As shown in Fig. 37, the PV array accounts for the major share at 35% of the system total NPC, which is followed by the cost of batteries (25% of total NPC). The WTs needs investment of $75k, sharing approximate 16.6%. Although it just provides 5% of the energy, the total cost of diesel ($74k) takes up 16.2% of system NPC, which is mainly occupied by the fuel cost.

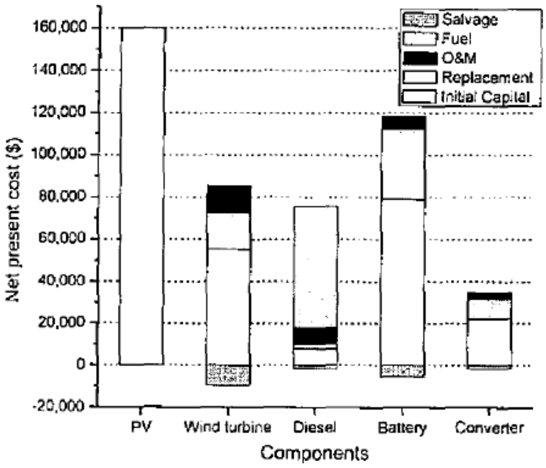


Fig. 37 Cash flow break-down by components and cost type

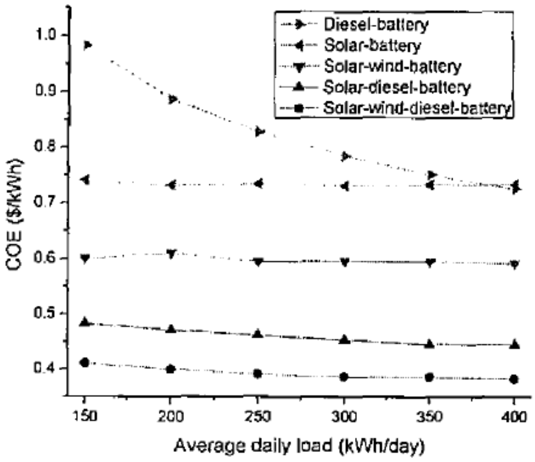


Fig. 38 Cost of energy (COE) for different system types over increasing load

In this study, the capacity shortage fraction (CSF) at 0.5%, 1%, 2%, 3%, 4% and 5% were investigated to understand their effects on system configuration and NPC. The results show that the system configuration and economic performance are same for CSFs in the range of 0% to 3%. When CSF increased from 4% to 5%, the system type changed to solar-wind-battery system without diesel, which is the same as the results in scenario l.

The study shows that the PBT of scenario 2 is 4.2 years, which is similar to the result in [262] and slight shorter than that in study[263]. Additionally, the PBT of scenario 2 is decreased by 44% compared with scenario 1 with 100% RF, indicating the inclusion of diesel is beneficial for the pure RES with respect to the economic index of PBT.

Do not state "study [263], just state the reference, i.e. "than that in [263]."

4.4.4. COE comparison between the five types of systems

As a final remark, attempt was made to contrast the COE values between the five types of systems, and a trade-off established between the available options. The curves in Fig. 38 illustrate that the COE of five different system types with the average daily load from 150kWh/day to 400kWh/day. The solar-wind-diesel-battery systems with RF of over 90% have the lowest COE values over the whole load level, indicating it is the most cost-effective one. The second type is the solar-diesel-battery system. The pure RES type comprised by solar and wind energy ranks in third place, the according COE values are about 1.5 times of the first system type. The solar-battery system type is a technically feasible solution while the high capital cost makes it not so economically viable. The diesel-battery systems have the highest COE vales under the low load level, and the COE values decrease proportionally with load increasing and finally intersect with the solar-battery system type.

Divide section 4.5 into a conclusion and summary of performance, clearly indicate the conclusion by starting a new section, i.e. 5. Conclusion

4.5. Simulation and optimization of a hybrid PV and pumped storage system

This work aimed at investigating a pumped storage system for this microgrid PV generation system and the preliminary results were presented. The term PVPS was then developed to describe the proposed hybrid photovoltaic and pumped-storage system. The mathematical model is reported for describing the performance of the main components in such hybrid systems. The criteria for evaluating the PVPS, in terms of loss of power supply probability (LPSP) and energy utilization rate are discussed. The effectiveness of the proposed method is demonstrated by designing a standalone power system for an isolated island in Hong Kong with solar power as potential power source and pumped storage as potential storage approach. The simulation results indicate that this model can help size the PV and upper reservoir (UR) optimally. The results also demonstrate that a pumped hydro storage subsystem can efficiently compensate for the intermittent nature of solar energy power generation and balance the production and demand in a remote area, thereby making the stand-alone solar energy supply more reliable and economical.

Do not mix tenses in the summary. Past can be used, e.g. "developed" and present can be used, e.g. "is reported", but not both.

The emphasis is on the system design part and the optimum configuration that is found by doing a search in the design space. The proposed sizing method incorporates a simple and novel methodology to find the pumped storage components capacity (turbine, pump, upper reservoir) and the capacity of PV and win turbine. This methodology also helps to plan further load growth, as it gives the durations for which load can be increased without additional capacity growth.

✓ Uses adjectives to evaluate success of the project, e.g. "simple" and "novel"

✓ Explains how study can contribute to knowledge in field, e.g. ""helps plan further load growth"

The establishment of the mathematical models has been presented in the "methodology" section of the report. The models were then implemented on a case study of a remote island, the simulation process being conducted at an hourly time-step. The sizing of PV array and UR were derived from the simulation models. It was calculated that a 220kWp PV array and 10,000m^3 UR could provide a feasible scheme with respect to power supply reliability and costs. This scheme was then studied as a base case and its performance is examined below.

4.5.1. System components performances

The base case simulation results showed that the annual energy output of the PV plant to be 257,171 kWh with an average value of 704.6kWh/day. After deducting the PV inverter conversion loss, the daily average useable PV output of 683.4kWh, can be divided into three parts (as given in Fig. 39): the first part directly supplies the load from 7:00am to 7:00pm, which accounts for 20.2%; The surplus is delivered to the pumps for charging UR between 8:00am and 6:00pm, occupying 72.2%; Once the UR reaches to upper limit, this spilled part of energy (7.6%) is dissipated in the dump load from 12:00am to 6:00pm.

It was found that 72.2% of the PV output was used for pumping, which means that totally 300,252m^3 water was elevated from the lower reservoir to the upper one. The maximum hourly power from PV to pump was 157kW, thus pumping capacity of 160kW, at least, is needed for this system. Sometimes power from the PV might be too small to start a pump of this capacity, but the combination of several pumps, such as 20kW+50kW+90kW, can fulfill the pumping capacity requirement and meanwhile ensure a reasonable efficiency for each pump.

Avoid vague time expressions at the start of a sentence like "Sometimes". Write "PV might occasionally be too small..."

The daily load supplied by direct PV output and turbine over the simulation year is demonstrated in Fig. 40. Turbine and PV power to load for several days are extreme low, indicating the water stored in the UR is insufficient and power supply failure may occur.

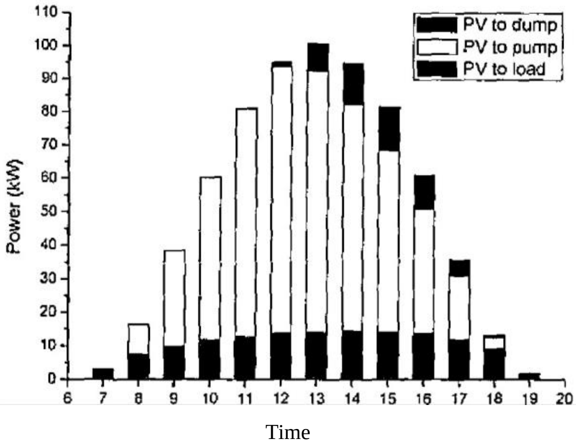


Fig. 39 Breakdown of PV output after the PV inverter

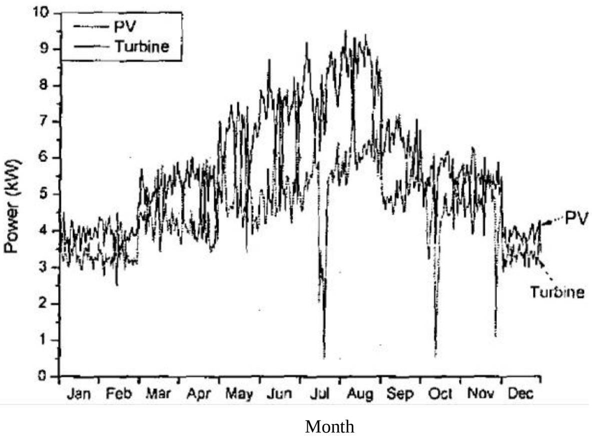


Fig. 40 Daily load demand met by direct PV output and turbine output

The profile of the water stored in the UR is depicted in Fig. 41 which shows that every month experiences great variations. Over the whole 8760 hours, the maximum storage capacity (10k m^3) was available for 276 hours, indicating the UR was fully charged and excess energy was potentially dumped at such situations. In addition, for 150 hours there was no water, meaning no energy was stored in the UR and power supply may fail. The zero water levels in the UR occurred in November may result in the poor solar insolation, the high cooling load demand in July and August could also result in zero quantity of water in the UR even though there was good solar energy in those months. Over the whole simulation, the water stored in the UR was 9614 m^3,meaning the net balance of the storage system is -386 m^3, equivalent to 51 kWh of electricity.

✓ Explains possible causes using tentative language "may result in" and "could also result in"

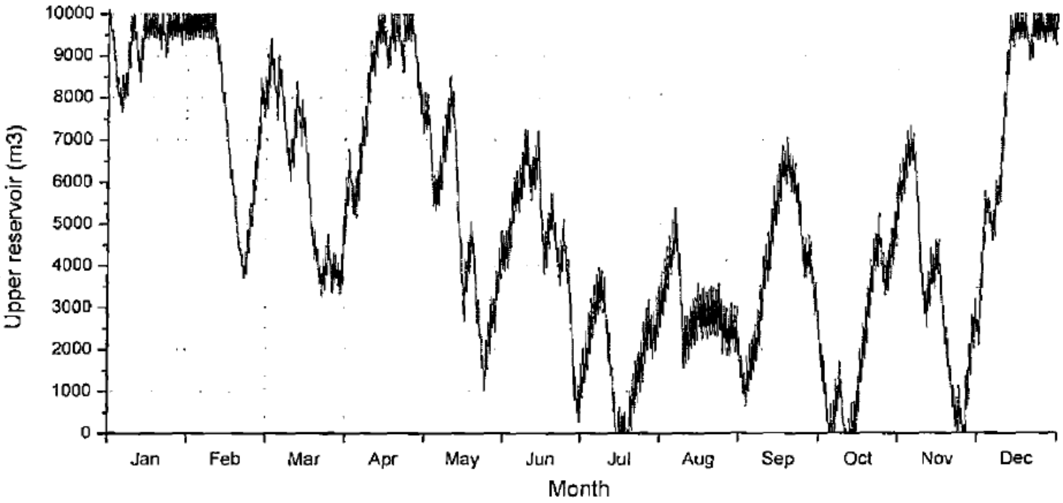


Fig. 41 The quantity of water stored in the upper reservoir

4.5.2. Daily energy and water flow (balance model)

A summary of daily average energy flow and water flow of the PVPS is illustrated in Fig. 42.

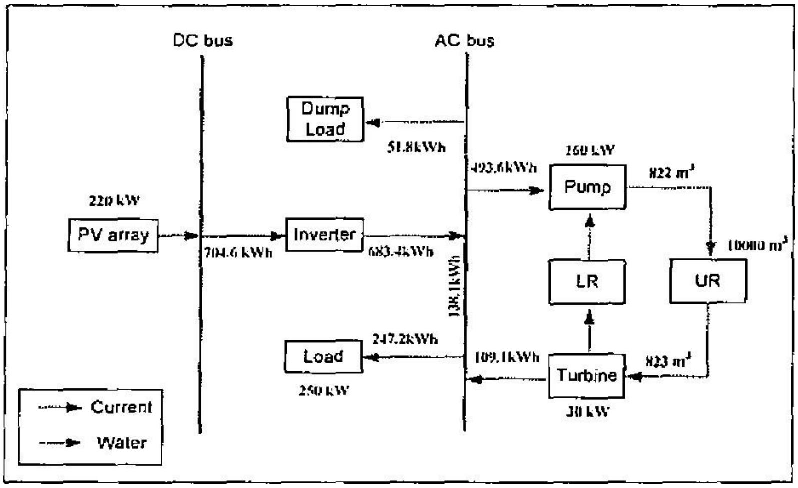


Fig. 42 Daily average energy and water flow of PVPS

4.5.3. System performance indices

Over the simulation period, the PVPS was not able to meet the load either totally or partly for 151 hours. The LPSP is then calculated as 1.7% and corresponding LA as 98.3%. This LPSP value indicates there is only a slight gap in completely reliable power supply, which can be covered by increasing the PV or UR capacity. The base case, only leaves some extreme peak loads unmet, would be economical if an LPSP under 2% can be accepted by the users.

The EENS was 1,050 kWh, about the 1.2% of the total load demand throughout the year, meaning the energy EIR of the system is 98.8%. The overall PV energy utilization rate was 92.4%, on the basis of the dumped energy is 18,911 kWh. The dumped energy quantity is much greater than the EENS value, meaning the potential exists to achieve zero EENS by increasing UR size to cut down the dumped energy and EENS value as well.

4.5.4. Overall efficiency of pumped storage

The overall efficiency of the pumped storage scheme was 21%. Such a relatively low efficiency is due to the losses resulting from double conversions between mechanical energy and electrical energy. The low overall efficiency is also attributed to the utilization of a micro sized pump and turbine since the efficiency of such plant reduces dramatically [121]. Moreover, the cheap but readily available Chinese brand solar pump is also of a low pumping efficiency. This would be improved by employment of superior solar pumps (e.g. Dankoff, SunPumps). Once the reversible pump-turbine set were to be available for the renewables powered pumped storage systems, the roundtrip efficiency of the pumped storage scheme can be greatly enhanced. In addition, the adjustable speed machines being widely in conventional pumped storage stations could also be adopted in the PVPS to improve the efficiency.

✓States result

✓Explains causes for result

✓Highlights possible ways to improve result

✓Highlights how this will affect future results, e.g. "can be greatly enhanced"

Even though the overall efficiency is low, a reliable and sustainable power supply can be achieved throughout the day and night by using PV panels and turbine for power generation. Additionally, the environmental problems connected with batteries can be overcome with the pumped storage alternative. The initial cost of the pumped storage system might not be competitive because of the civil engineering work involved in reservoir construction, but the life cycle cost would be much lower due to less O&M and long lifespan, it is really important for systems installed in isolated areas.

✓States how system could benefit rural communities

💡Avoid spoken expressions, e.g. "really", better "extremely important" or "of great importance".

4.5.5. Sensitivity analysis on the PV and UR capacity

A sensitivity analysis was conducted finally to investigate the uncertainty of varying PV and UR capacity on the results. From above simulation, the base case PVPS with 220 kW PV and

10000m^3 UR might fail in supplying the power over the year. Therefore, the performances of systems ranging in PV size from 200k W to 240kW and UR capacity between 8k m3 and 12k m^3 were studied and the results are presented below.

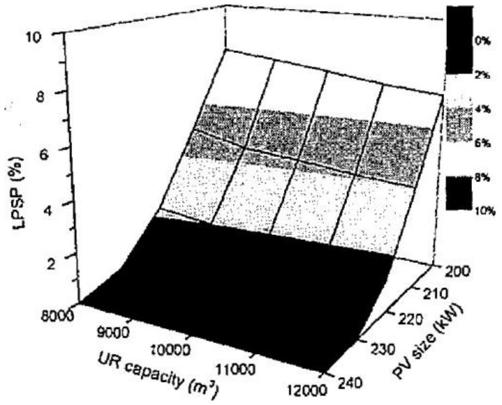


Fig. 43 The LPSP against the variation of PV size and upper reservoir volume

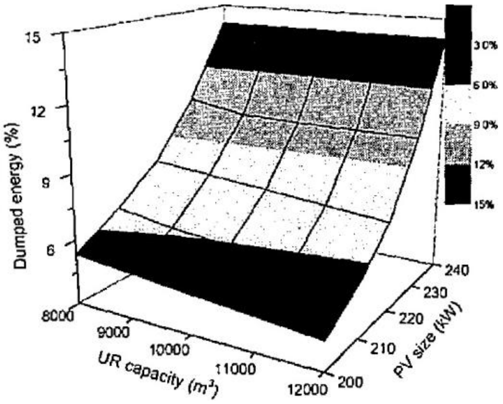


Fig. 44 The excess percentage of PV against the variation of PV size and upper reservoir volume

The LPSP values as affected by PV size and maximum storage capacity of UR are presented in Fig. 43. It can be seen that an increase in PV array capacity can significantly reduce the LPSP. When the PV size reaches 230kW, the LPSP is close to 0%. The effect of increase in the UR capacity on LPSP is only obvious at smaller PV sizes such as 200k W. The maximum LPSP is 8.1% with 200kW PV and 8k m^3 UR. No power supply failure occurs when PV size is 240kW for the whole UR size range, and a PV capacity at 230kW can also result in 0% LPSP if UR is larger than 10k m^3.

However, dumped PV energy quantity will rise if more PV panels are employed in ensuring power supply reliability, as shown in Fig. 44. An increase in the UR capacity can reduce the dumped energy at the smaller PV size but there is no effect at higher PV size. The 200kW system, as an example, has a decrease in abandoned energy from 5.3% to 4.3% when UR increases from 8k to 12k m^3. The two figures illustrate that an increase in the UR capacity can not only reduce the spilled energy but also enhance power supply reliability.

✓ Links paragraphs showing their contrasting contents, i.e. "However"

4.5.6. Sizing curve for PVPS

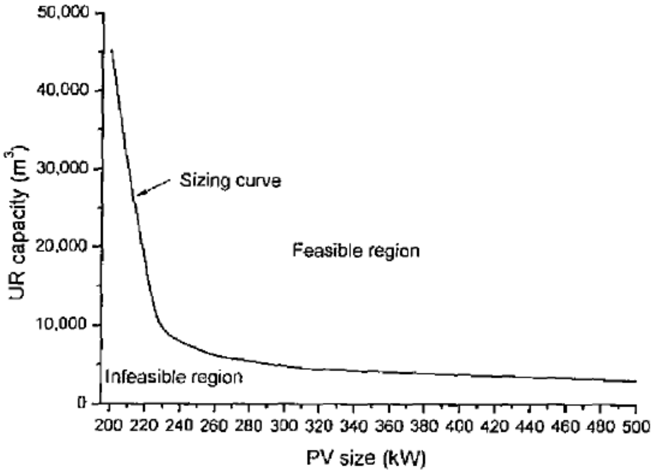


Fig. 45 Design space or sizing curve for PVPS

The minimum UR capacity required to achieve 0% LPSP is used to generate the sizing curve[45] for a PVPS when the PV array ranges from 200 to 500 kWp. As illustrated in Fig. 45, the sizing curve shows the feasible design space for the system which is that portion above the sizing curve. It can also be seen that as the PV size grows, the minimum UR capacity needed decreases rapidly until 230kWp, after which the UR capacity varies only slightly. The lack of solar energy during the night time and on rainy days necessitates a minimum storage capacity to supply the load for those periods, however big the PV array. The next stage will focus on determining the optimum system configuration using both the sizing curve and the economic performance curve (such as minimum cost of energy).

✓Describes graph trends using adverbs, e.g. "decreases rapidly"

5. FUTURE WORK AND TIME ARRANGEMENT

Jul 2012 -Dec 2012	models for all components in the renewable energy based pumped storage system;
Jan 2013-- Jun 2013	Develop optimization algorithm and the multi-objective sizing methodologies (twofold or threefold) to handle the system design problems in respect of the technical, economic and environmental issues.
July 2013 -- Sep 2013	Program and simulate the system performance; employ the developed methodology to examine the effects of a small battery bank and a diesel; simulate the system operating performance of a hybrid solar-wind-PHS-battery-diesel system.
Sep 2013 Apr 2014 Jan 2014 -- Apr 2013	Study the performance of the separated pumped and turbine unit or reversible pumped and turbine; proper allocation (capacity ratio) of wind turbine, water pump, reservoir and hydroelectricity generator, and efficiency of the system.
May 2014 Aug 2014	Experiments design, setup, data collection and performance evaluation
Sep 2014	Examine the economic performance of this system in detail and investigate the pumped storage for grid connected RESs
Establish and refine the mathematical	Prepare the thesis Submit thesis

✓ Gives clear timeline for future work.

💡 Start each section with the same grammar (verbs), i.e. "Design experiments..."

💡 Introduce the subsection with a short paragraph

6. PUBLICATIONS

[1] Ma Tao, Lu Lin and Yang Hongxing. Performance evaluation of a stand-alone photovoltaic system on an isolated island in Hong Kong. 4th International Conference on Applied Energy, July 5-8, 2012, Suzhou, China. (*Accepted*)

[2] Ma Tao, Lu Lin and Yang Hongxing. Simulation Study on Stand-alone Hybrid Solar Pumped Storage Systems. 11th International Conference on Sustainable Energy Technologies (SET201 2), September 2-5, 2012, Vancouver, Canada. (*Accepted*)

[3] Ma Tao, Lu Lin and Yang Hongxing. Feasibility study and economic comparison of pumped hydro storage and battery storage for a remote island powered by renewable energy. (*finished*)

Report: Final report for CLP collaborative project (197 pages)

REFERENCE

This section should be entitled 'References'.

1. Muneer, T., M. Asif, and J. Kubie, *Generation and transmission prospectsfor solar electricity: UK and global markets.* Energy Conversion and Management, 2003. **44**(1): p. 35-52.
2. Chen, N., et al., *Environmental Friendly PV Power Plant*. Energy Procedia, 2012. **16, Part A**(0): p. 32-37.
3. DOE, *International Energy Outlook 2011*. Page 10, U.S. Energy Information Administration. DOE/EIA-0484, September 2011.
4. Zeng, J., et al. *Operational optimization of a stand-alone hybrid renewable energy generation system based on an improved genetic algorithm. in Power and Energy Society General Meeting, 2010 IEEE*. 2010.
5. Ahmad, S., M.Z.A.A. Kadir, and S. Shafie, *Current perspective of the renewable energy development in Malaysia.* Renewable and Sustainable Energy Reviews, 2011. **15**(2): p. 897-904.
6. Chen, H., et al., *Progress in electrical energy storage system: A critical review*. Progress in Natural Science, 2009. **19**(3): p. 291-312,
7. WHO, *The Energy Access Situation in Developing Countries: A Review Focusing on the Least Developed Countries and Sub-Saharan Africa*. World Health Organization (WHO) and United Nations Development Programme (UNDP) (New York and Geneva), 2009.
8. IEA, *World Energy Outlook, second edition*. International Energy Agency Publications, 2006.
9. Raman, P., et al., *Opportunities and challenges in setting up solar photo voltaic based micro grids for electrification in rural areas of India.* Renewable and Sustainable Energy Reviews, 2012. **16**(5): p. 3320-3325.
10. Hansen, U., *Technological options for power generation.* Energy Journal, 1998. **19**(2): p. 63-87.
11. Qoaider, L. and D. Steinbrecht, *Photovoltaic systems: A cost competitive option to supply energy to off-grid agricultural communities in arid regions.* Applied Energy, 2010. **87**(2): p. 427-435.
12. Chakrabarti, S. and S. Chakrabarti, *Rural electrification programme with solar energy in remote region-a case study in an island.* Energy Policy, 2002. **30**(1): p. 33-42.

13. Sopian, K., et al., *Optimal operational strategy for hybrid renewable energy system using genetic algorithms*. WSEAS Trans. Math., 2008. **7**(4): p. 130-140.

14. Bekele, G. and G. Tadesse, *Feasibility study of small Hydro/PV/Wind hybrid system for off-grid rural electrification in Ethiopia*. Applied Energy, 2012(0).

15. Lau, K.Y., et al., *Performance analysis of hybrid photovoltaic/diesel energy system under Malaysian conditions*. Energy, 2010. **35**(8): p. 3245-3255.

16. Elhadidy, M.A. and S.M. Shaahid, *Parametric study of hybrid (wind + solar + diesel) power generating systems*. Renewable Energy, 2000. **21**(2): p. 129-139.

17. IEA, *Renewable Energies for Remote Areas and Islands*. April, 2012.

18. Guerrero, M.A., et al. *Overview of medium scale energy storage systems.* in *Compatibility and Power Electronics*, 2009. CPE '09. 2009.

19. REN21, *Renewables 2011 global status report*. Paris, France: REN21 Secretariat, 2011.

20. Syngellakis, K., *Cost analysis of renewables in Pacific island countries (PICS).* Proceedings of the International Renewable Energy Agency Accelerated Renewable Energy Deployment on Islands with Emphasis on the Pacific Islands, Sydney, Australia, October 26-28, 2011.

21. Wienkes, M., Benson, S., Song, A., & Lefty, D., *2011 global solar outlook.* New York, NY: Goldman Sachs, 2011.

22. Pearson, N.O., *Solar cheaper than diesel making India's Mittal believer: Energy.* Bloomberg Businessweek., February 7, 2012.

23. Krauter, S.C.W., *Development of an integrated solar home system.* Solar Energy Materials and Solar cells, 2004. **82**(1-2): p. 119-130.

24. *Proposal or a feasibility study of renewable energy applications on Dawn Island.* Renewable Energy Research Group of The Hong Kong Polytechnic University, 2009.

25. Givler, T., P. Lilienthal, and L. National Renewable Energy. *Using HOMER software, NREL's micropower optimization model, to explore the role often-sets in small solar power systems case study: SRI Lanka*. 2005; Available from: http://purl.access.gpo.gov/GPO/LPS68114.

26. Kanase-Patil, A.B., R.P. Saini, and M.P. Sharma, *Sizing of integrated renewable energy system based on load profiles and reliability index for the state of Uttarakhand in India.* Renewable Energy, 2011. **36**(11): p. 2809-2821.

27. Bala, B.K. and S.A. Siddique, *Optimal design of a PV-diesel hybrid system for electrification of an isolated island—Sandwip in Bangladesh using genetic algorithm.* Energy for Sustainable Development, 2009. **13**(3): p. 137-142.

28. Shaahid, S.M. and I. El-Amin, *Techno-economic evaluation of off-grid hybrid photovoltaic—diesel—batten.' power systems for rural electrification in Saudi Arabia—A way forward for sustainable development.* Renewable and Sustainable Energy Reviews, 2009. **13**(3): p. 625-633.

29. Himri, Y., et al., *Techno-economical study of hybrid power system for a remote village in Algeria*. Energy, 2008. **33**(7): p. 1128-1136.

30. Strupczewski, A., *Accident risks in nuclear-power plants.* Applied Energy, 2003. **75**(1-2): p.79-86.

31. Skoglund, A., et al., *On the physics of power, energy and economics of renewable electric energy sources - Part II.* Renewable Energy, 2010. **35**(8): p. 1735-1740.

32. Kaldellis, J .K., et al., *Experimental validation ofautonomous PV-based water pumping system optimum sizing. Renewable Energy*, 2009. **34**(4): p. 1106-1113.

33. Sahin, S., *Report on the special issue SET2012, the 10th International Conference on Sustainable Energy Technologies, Istanbul, Türkiye (4-7th September 2011),* Energy Conversion and Management, (0).

34. Vick, B.D. and B.A. Neal, *Analysis of off-grid hybrid wind turbine/solar P V water pumping systems*. Solar Energy, 2012. **86**(5): p. 1197-1207.

35. Prasad, A.R. and E. Natarajan, *Optimization of integrated photovoltaic-wind power generation systems with battery' storage*. Energy, 2006. **31**(12): p. 1943-1954.

36. Zhou, W., et al., *Current status of research on optimum sizing of stand-alone hybrid solar-wind power generation systems*. Applied Energy, 2010. **87**(2): p. 380-389.

37. Bagul, A.D., Z.M. Salameh, and B. Borowy, *Sizing of a stand-alone hybrid wind-photovoltaic system using a three-event probability density approximation.* Solar Energy, 1996. **56**(4): p. 323-335.

38. Bernal-Agustín, J.L. and R. Dufo-López, *Simulation and optimization of stand-alone hybrid renewable energy systems.* Renewable and Sustainable Energy Reviews, 2009. **13**(8): p. 2111-2118.

39. Kaldellis, J.K., E. Kondili, and A. Filios, *Sizing a hybrid wind-diesel stand-alone system on the basis of minimum long-term electricity production cost*. Applied Energy, 2006. **83**(12): p. 1384-1403.

40. Deshmukh, M.K. and S.S. Deshmukh, *Modeling of hybrid renewable energy systems.* Renewable and Sustainable Energy Reviews, 2008. **12**(1): p. 235-249.

41. Rehman, S., et al., *Feasibility study of a wind-pv-diesel hybrid power system for a village.* Renewable Energy, 2012. **38**(1): p. 258-268.

42. Al-Karaghouli, A. and L.L. Kazmerski, *Optimization and life-cycle cost of health clinic PV system for a rural area in southern Iraq using HOMER software*. Solar Energy, 2010. **84**(4): p. 710-714.

43. Nema, P., R.K. Nema, and S. Rangnekar, *A current and future Mate of art development of hybrid energy system using wind and PV-solar: A review*. Renewable and Sustainable Energy Reviews, 2009. **13**(8): p. 2096-2103.

44. Ghoddami, H., M.B. Delghavi, and A. Yazdani, *An integrated wind-photovoltaic-battery system with reduced power-electronic interface and fast control for grid-tied and off-grid applications.* Renewable Energy, 2012. **45**(0): p. 128-137.

45. Sreeraj, E.S., K. Chatterjee, and S. Bandyopadhyay, *Design of isolated renewable hybrid power systems.* Solar Energy, 2010. **84**(7): p. 1124-1136.

46. Notton, G., M. Muselli, and A. Louche, *Autonomous hybrid photovoltaic power plant using a back-up generator: A case study in a Mediterranean island*. Renewable Energy, 1996. **7**(4): p. 371-391.

47. Borowy, B.S. and Z.M. Salameh, *Optimum photovoltaic array size for a hybrid wind/PV system.* Energy Conversion, IEEE Transactions on, 1994. **9**(3): p. 482-488.

48. Ould Bilal, B., et al., *Optimal design of a hybrid solar-wind-battery system using the minimization of the annualized cost system and the minimization of the loss of power supply probability (LPSP).* Renewable Energy, 2010. **35**(10): p. 2388-2390.

49. Diaf, S., et al., *A methodology for optimal sizing of autonomous hybrid PV/wind system.* Energy Policy, 2007. .**35**(11): p. 5708-5718.

50. Dihrab, S.S. and K. Sopian, *Electricity generation of hybrid PV/wind systems in Iraq.* Renewable Energy, 2010. **35**(6): p. 1303-1307.

51. Yang, H., L. Lu, and W. Zhou, *A novel optimization sizing model for hybrid solar-wind power generation system*. Solar Energy, 2007. **81**(1): p. 76-84.

52. Yang, H., et al., *Optimal sizing method for stand-alone hybrid solar-wind system with LPSP technology by using genetic algorithm.* Solar Energy, 2008. **82**(4): p. 354-367.

53. Colle, S., S. Luna Abreu, and R. Rüther, *Economic evaluation and optimization of hybrid diesel/photovoltaic systems integrated to utility grids*. Solar Energy, 2004. 76(1-3): p. 295-299.

54. Ngan, M.S. and C.W. Tan, *Assessment of economic viability for PV/wind/diesel hybrid energy system in southern Peninsular Malaysia.* Renewable and Sustainable Energy Reviews, 2012. **16**(1): p. 634-647.

55. Shaahid, S.M., et al., *Potential of autonomous/off-grid hybrid wind-diesel power system for electrification of a remote settlement in Saudi Arabia*. Wind Engineering, 2004. **28**(5): p. 621-628.

56. Devine, M., et al., *Wind-diesel hybrid options for remote villages in Alaska.* Available from: U.S. Department of Energy's Wind Powering America Program <http://www.ceere.org/rerl/pllblicat'ions/published/2004/AWEA%2004%20Wind%20Diesel%20in%20Remote%20Villages,%20Alaska.pdf>, 2000.

57. Dufo-López, R. and J.L. Bernal-Agustín, *Design and control strategies of PV-Diesel systems using genetic algorithms.* Solar Energy, 2005. **79**(1): p. 33-46.

58. Razak, J.A., et al., *Optimization of PV-Wind-Hydro-Diesel Hybrid System by Minimizing Excess Capacity* European Journal of Scientific Research, 2009. **25**(4).

59. Heide, D, et al., Seasonal optimal mix ofwind and solar power in a future, highly renewable Europe. Renewable Energy, 2010. **35**(11): p. 2483-2489.

60. Lund, H. and B. V. Mathiesen, *Energy system' analysis of 100% renewable energy systems—The case of Denmark in years 2030 and 2050*. Energy, 2009. **34**(5): p. 524-531.

61. Elliston, B., M. Diesendorf, and I. MacGill, *Simulations of scenarios with 100% renewable electricity in the Australian National Electricity Market.* Energy Policy, 2012(0).

62. Esteban, M., Q. Zhang, and A. Utama, *Estimation of the energy storage requirement of a future 100% renewable energy system in Japan*. Energy Policy, (0).

63. Clark Ii, W.W., *Chapter 6 - Analysis: 100 Percent Renewable Energy Systems, in Renewable Energy Systems. 2010,* Academic Press: Boston. p. 127-157.

64. Ma, Y., P. Yang, and H. Guo. *Distributed generation system development based on various renewable energy resources. in Control Conference (CCC), 2011 30th Chinese. 2011.*

65. Whittingham, M.S., *History, Evolution, and Future Status of Energy Storage*. Proceedings of the IEEE, 2012. **100**(Special Centennial Issue): p, 1518-1534.

66. DOE, *Basic Research Needs for Electrical Energy Storage: Report of the Basic Energy Sciences Workshop on Electrical Energy Storage.* U.S. Department of Energy (DOE), April 2007.

67. Daim, T.U., et al., *Evaluation of energy storage technologies for integration with renewable electricity: Quantifying expert opinions.* Environmental Innovation and Societal Transitions, 2012.

68. Baker, J.N. and A. Collinson, *Electrical energy storage at the turn of the Millennium.* Power Engineering Journal, 1999. **13**(3): p. 107-112.

69. Denholm, P. and G.L. Kulcinski, *Life cycle energy requirements and greenhouse gas emissions from large scale energy storage systems.* Energy Conversion and Management, 2004. **45**(13-14): p. 2153-2172.

70. Walawalkar, R., J. Apt, and R. Mancini, *Economics of electric energy storage for energy arbitrage and regulation in New York.* Energy Policy, 2007. **35**(4): p. 2558-2568.

71. Maclay, J.D., J. Brouwer, and G.S. Samuelsen, *Dynamic modeling of hybrid energy storage systems coupled to photovoltaic generation in residential applications.* Journal of Power Sources, 2007. **163**(2): p. 916-925.

72. Connolly, D., *A Review of Energy Storage Technologies: For the integration of fluctuating renewable energy.* Version 4. University of Limerick, Limerick, 2010.

73. Rastler, D., *Electricity Energy Storage Technology Options: A White Paper Primer on Applications, Costs, and Benefits*. Electric Power Research Institute (EPRI), Technical Update, USA, 2010.

74. Gonzalez, A.s B.Ó. Gallachóir, and DE. McKeogh, *Study of Electricity Storage Technologies and Their Potential to Address Wind Energy Intermittency in Ireland*. Project - RE/HC/03/001, Final report, University College Cork, 2004.

75. Luque, A. and S. Hegedus, *Handbook of photovoltaic science and engineering / edited by Antonio Luque and Steven Hegedus.* 2003, Chichester; Hoboken, NJ: Chichester ; Hoboken, NJ : J. Wiley.

76. Company, H.E., Energy storage. http://www.heco.com/,

77. Hamm, A., *Methodology and modelling approach for strategic sustainability analysis of complex Energy-environment systems: submitted in partial fulfilment of the requirements for the degree of Ph. D. in Mechanical Engineering in the University of Canterbury*. 2007.

78. Chen, G.Z., et al. *Determination of installed capacity of pumped storage station in WSP hybrid power supply system. in Sustainable Power Generation and Supply, 2009. SUPERGEN '09. International Conference on*. 2009.

79. Miaomiao, C., K. Longyun, and X. Daming, *Optimal capacity of energy-storing section in PV/Wind hybrid system.* Electric Application, 2006. **25**(6): p. 87-90.

80. Kaldellis, J.K. and D. Zafirakis, *Optimum Energy storage techniques for the improvement of renewable energy sources-based electricity generation economic efficiency*. Energy, 2007. **32**(12): p. 2295-2305.

81. *Stand-Alone Photovoltaic Systems: A Handbook of Recommended Design Practices, SAND87-7023*. Albuquerque, NM: Photovoltaic Design Assistance Center, Sandia National Laboratories, March, 1995.

82. Saini, R.P., *Large-Scale Energy Storage Systems.* Indian Institute of Technology Roorkee, 2011.

83. George C, B., *Feasibility study of a hybrid wind/hydro power-system for low-cost electricity production.* Applied Energy. 72(3-4): p. 599-608.

84. Hadjipaschalis, I., A. Poullikkas, and V. Efthimiou, *Overview of current and future energy storage technologies for electric power applications.* Renewable and Sustainable Energy Reviews, 2009. **13**(6-7): p. 1513-1522.

85. Daim, T.U., et al., *Evaluation of energy storage technologies for integration with renewable electricity: Quantifying expert opinions.* Environmental Innovation and Societal Transitions, (0).

86. Nfah, E.M. and J.M. Ngundam, *Feasibility of pico-hydro and photovoltaic hybrid power systems for remote villages in Cameroon*. Renewable Energy, 2009. **34**(6): p. 1445-1450.

87. Baños, R., et al., *Optimization methods applied to renewable and sustainable energy*: *A review.* Renewable and Sustainable Energy Reviews, 2011. **15**(4): p. 1753-1766.

88. Caralis, G., *Hybrid systems (Wind with pumped storage).* International Conference: RES & Energy Savings in Islands, local planning and European cooperation, 23, 24 & 25 October, Milos.

89. Miller, R.R. and M. Winters, *ENERGY STORAGE: Opportunities for Pumped Storage: Supporting Renewable Energy Goals*. http://www.hydroworld.com/.

90. Padrón, S., J.F. Medina, and A. Rodriguez, *Analysis of a pumped storage system to increase the penetration level of renewable energy in isolated power systems. Gran Canaria: A case study.* Energy, 2011. **36**(12): p. 6753-6762.

91. Katsaprakakis, D.A., et al., *Introduction of a wind powered pumped storage system in the isolated insular power system of Karpathos-Kasos.* Applied Energy, 2011(0).

92. Tuohy, A. and M. O'Malley, *Pumped storage in systems with very high wind penetration*. Energy Policy, 2011. **39**(4): p. 1965-1974.

93. Caralis, G., D. Papantonis, and A. Zervos, *The role of pumped storage systems towards the large scale wind integration in the Greek power supply system.* Renewable and Sustainable Energy Reviews, 2012. **16**(5): p. 2558-2565.

94. Varkani, A.K., A. Daraeepour, and H. Monsef, *A new self-scheduling strategy for integrated operation of wind and pumped-storage power plants in power markets.* Applied Energy, 2011. **88**(12): p. 5002-5012.

95. Katsaprakakis, D.A., D.G. Christakis, and K.G. Kontaxakis, *Introduction of pumped storage system into the existing power production system of Crete.* Technical Chronicles-Scientific Journal of the Technical Chamber of Greece, 2004. **4**(1-2): p. 57-80.

96. Katsaprakakis, D.A., et al., *The introduction of wind powered pumped storage systems in isolated power systems with high wind potential*. International Journal of Distributed Energy Resoures, 2007. **3**(2).

97. Caralis, G., K. Rados, and A. Zervos, *On the market of wind with hydro-pumped storage systems in autonomous Greek islands.* Renewable and Sustainable Energy Reviews, 2010. **14**(8): p. 2221-2226.

98. Bueno, C. and J.A. Carta, *Technical-economic analysis of wind-powered pumped hydrostorage systems. Part I: model development.* Solar Energy, 2005. **78**(3): p, 382-395.

99. Bueno, C. and J .A. Carta, *Technical-economic analysis of wind-powered pumped hydrostorage systems. Part Il: model application to the island of El Hierro.* Solar Energy, 2005. **78**(3): p. 396-405.

100. Kaldellis, J.K., M. Kapsali, and K.A. Kavadias, *Energy balance analysis of wind-based pumped hydro storage systems in remote island electrical networks.* Applied Energy, 2010. **87**(8): p. 2427-2437.

101. Katsaprakakis, D.A., et al., *Pumped storage systems introduction in isolated power production systems.* Renewable Energy, 2008. **33**(3): p. 467-490.

102. Bueno, C. and J.A. Carta, *Wind powered pumped hydro storage systems, a means of increasing the penetration of renewable energy in the Canary Islands.* Renewable and Sustainable Energy Reviews, 2006. **10**(4): p. 312-340.

103. Miranda, M.S., R.O.C. Lyra, and S.R. Silva, *An alternative isolated wind electric pumping system using induction machines.* Energy Conversion, IEEE Transactions on, 1999. **14**(4): p. 1611-1616.

104. Anagnostopoulos, J.S. and DE. Papantonis, *Simulation and size optimization of a pumped—storage power plant for the recovery of wind-farms rejected energy*. Renewable Energy, 2008. **33**(7): p. 1685-1694.

105. Suul, J.A., K. Uhlen, and T. Undeland. *Wind power integration in isolated grids enabled by variable speed pumped storage hydropower plant*. 2008.

106. Kapsali, M. and J.K. Kaldeliis, *Combining hydro and variable wind power generation by means of pumped-storage under economically viable terms*. Applied Energy, 2010. **87**(11): p. 3475-3485.

107. Dursun, B. and B. Alboyaci, *The contribution of wind-hydro pumped storage systems in meeting Turkey's electric energy demand*. Renewable and Sustainable Energy Reviews, 2010. **14**(7): p. 1979-1988.

108. Castronuovo, ED. and J.A.P. Lopes, *Optimal operation and hydro storage sizing of a wind-hydro power plant*. International Journal of Electrical Power & Energy Systems, 2004. **26(**10): p. 771-778.

109. Anagnostopoulos, J.S. and D.E. Papantonis, *Pumping station design for a pumped-slorage wind-hydro power plant.* Energy Conversion and Management, 2007, **48**(11): p. 3009-3017.

110. Papaefthymiou, S.V., et al., *A Wind-Hydro-Pumped Storage Station Leading to High RES Penetration in the Autonomous Island System of Ikaria*. Sustainable Energy, IEEE Transactions on, 2010. **1**(3): p. 163-172.

111. Ruisheng, L. , et al. *Design of wind-solar and pumped-storage hybrid power supply system. in Computer Science and Information Technology (ICCSIT), 2010 3rd IEEE International Conference on*. 2010.

112. Kun, Q, J, Yuxiang, and L. Zheng. *Improve wind energy penetration in an isolated power system by a stand-alone wind pumped storage hydropower plant. in Remote Sensing, Environment and Transportation Engineering (RSETE), 2011 International Conference on.* 2011.

113. Xin, C., et al., *Research on System Configuration of Pumped Storage Power Station Mutually Complemented by Wind and Light Energy.* Journal of Sichuan University (Engineering Science Edition), 2007. **39**(1): p. 53-57.

114. Wenxia, P., F. Yongwei, and Z. Li, *The optimal sizing for pumped storage system in wind farm.* Transactions of China Electrotechnical Society, 2008. **23**(3): p. 120-124.

115. Xu, W., Z. Kuo, and S. Hai-peng, *A new type of windsolar-water complementary power generation system.* China Electric Power Education, 2010. **S2**: p. 341-344.

116. Aihara, R., et al. *Impact of operational scheduling of pumped storage power plant considering excess energy and reduction of fuel cost on power supply reliability in a power system with a large penetration of photovoltaic generations. in Power System. Technology (POWERCON), 2010 International Conference on*. 2010.

117. Aihara, R., et al. *Optimal operation scheduling of pumped storage hydro power plant in power system with a large penetration of photovoltaic generation using genetic algorithm. in PowerTech, 2011 IEEE Trondheim*. 2011.

118. Perez-Blanco, H., S. Richards, and B. Leyde, *When Intermittent Power Production Serves Transient Loads.* Applied Thermal Engineering, 2011(0).

119. Yan, R., et al., *Modelling and optimization of hybrid wind/PVpumped-storage power system.* Applied Mechanics and Materials, 2011. **48 - 49**.

120. Kadar, P. *Storage optimization in a liberalized energy market. in Applied Machine Intelligence and Informatics, 2009. SAMI 2009. 7th International Symposium on.* 2009.

121. Manolakos, D, et al., *A stand-alone photovoltaic power system for remote villages using pumped water Energy storage*. Energy, 2004. **29**(l): p. 57-69.

122. Lorenzo, E., *Solar electricity: engineering of photovoltaic systems* 1994: Sevilla, Spain : PROGENSA.

123. Ahearne, J., *Storage of electric energy, Report on research and development of energy technologies. International Union of Pure and Applied Physics.* Available online http://www.iupap.org/wg/energy/report-a.pdf [2012-06-07], 2004: p. 76—86.

124. Seligman, P., *Australian Sustainable Energy - by the numbers (version 1.3).* University of elbourne, 2010.

125. Pina, A., C.S. Ioakimidis, and P. Ferrao. *Economic modeling of a seawater pumped-storage system in the context of São Miguel in IEEE International Conference on Sustainable Energy Technologies (ICSET 2008).* 2008.

126. Pickard, W.F., *The History, Present State, and Future Prospects of Underground Pumped Hydro for Massive Energy Storage.* Proceedings of the IEEE, 2012. **100**(2): p. 473-483.

127. Denholm, P. and T. Holloway, *Improved accounting of emissions from utility Energy storage system operation.* Environmental Science and Technology, 2005. **39**(23): p. 9016-9022.

128. Celik, A.N., *Techno-economic analysis of autonomous PV-wind hybrid energy systems using different sizing methods.* Energy Conversion and Management, 2003. **44**(12): p. 1951-1968.

(The remaining references have been removed)