Chapter

A Review of Hybrid Renewable Energy Systems Based on Wind and Solar Energy: Modeling, Design and Optimization

Salisu Muhammad Lawan and Wan Azlan Wan Zainal Abidin

Abstract

In this chapter, an attempt is made to thoroughly review previous research work conducted on wind energy systems that are hybridized with a PV system. The chapter explores the most technical issues on wind drive hybrid systems and proposes possible solutions that can arise as a result of process integration in off-grid and grid-connected modes. A general introduction to wind energy, including how wind energy can be harvested, as well as recent progress and development of wind energy are discussed. With the special attention given to the issues related to the wind and photovoltaic (Wind-PV) systems. Throughout the chapter emphasis was made on modeling, design, and optimization and sensitivity analysis issues, and control strategies used to minimize risk as well as energy wastage. The reported reviewed results in this chapter will be a valuable researchers and practicing engineers involved in the design and development of wind energy systems.

Keywords: renewable energy, wind, solar, hybrid energy, optimization, modeling, simulation, techno-economic

1. Introduction

According to recent scientific literacy works [1–3], about 78–80% of the world commercial energy comes from fossil fuels, such as, petroleum, coal and natural gas. Those high-carbon sources have negative effects in our environments, such as, effects on heath, land, air and rain. In view of that, the attention of most countries around the globe has been shifted to low-carbon energy. Renewable energy is naturally abundant resources, which can be harnessed without compromising future energy needs. Unlike fossil fuels, which depletes as time goes on. Renewable energy sources like wind, solar, biomass, wave and tidal are abundant sources that can produce clean energy. On recent time, series of renewable energy technology improvement has been witnessed, because the cost of generating electrical power is decreasing [4].

Although, renewable energy is considered as the new technology of generating electricity, the barrier associated with renewable is stochastic and unpredictable weather behavior. Its availability varies depending on the location. That is why, it is necessary to complement renewable with other sources like batteries. Because of this intermittent nature of renewable, single renewable energy source tends to be problematic in terms of energy yield and operational cost. Based on the aforementioned drawbacks, two or more renewable are being combined to form a hybrid renewable energy system (HRES). The main goal of doing this, or to improve electrical power production, to minimize cost, to reduce negative effects associated with burning fossil fuels and to improve the overall system efficiency.

In recent times, the integrated renewable energy system is gaining more attention, because a hybridized system can be efficiently applied to supply high efficiency and reliable electricity to the end-users, unlike a single-renewable source. A HERS can be applied in stand-alone or grid-connected modes. Stand-alone system must have a large storage to handle the load. While in a grid-connected mode, the storage can be small, and the deficient power can be acquired from the grid. It should be noted that, grid-connected mode must have a power electronic controllers for load sharing, voltage, harmonic, and frequency control. Thus HERS operating model is classified into Island mode where the generated electricity is consumed locally and grid connected mode where the renewable energy source is connected to the grid [5].

It is interesting, to note that, among the renewable energy sources, wind power is the fastest growing in terms of global annual and cumulative installed capacity. Wind energy is almost everywhere around the world. But the wind speed strength varies depending on the particular area. Wind energy can be operates during the day and night times, unlike other renewable.

Solar is the cleanest and most abundant renewable energy source available on earth (SEIA 2013). Solar energy can be defined as radiant light and heat from the sun and is harnessed by human using technologies.

The amount of energy harnessed from the sun is depending on radiation and scientists define radiation in two different ways which are energy in wave form (electromagnetic wave) or energy in particle form (photons). The electromagnetic radiation emitted from the sun has the wave length interval from 0.1 nm to 104 m. However, 95% of solar energy reach earth with the intervals of 0.3–2.4 μm only [5, 6]. The photons are traveling through space at the speed of 3.0 × 108 m/s and each photon carry different amount of energy measured in electron volts. Photovoltaic (PV) is derived from two words: photo which means light and voltaic or volt means the unit of electric potential. PV or solar cells, also called the semiconductor that converts sunlight to direct current (DC) electricity. PV cell is typically a thin wafer which consists of an ultra-thin layer of phosphorus-doped (N-type) silicon on top of a thicker layer of boron-doped (P-type silicon). The p-n junction is created through the doping and the electrical field is created near the top surface of the cell. When a sunlight which carries photons strike the PV cell, the current is produced because the photons prompt the electrons flow from n- to p-junction. A typical silicon PV cell will produce about 0.5 ~ 0.6 V under open-circuit condition regardless of size. The current produces is proportional to the intensity of sunlight striking the surface as well as the efficiency and size of the cell. The photovoltaic cell normally connected in series or parallel circuit to produce the desired amount of current. PV modules consist of PV circuits sealed in an environmentally protective laminate. PV module is the fundamental building blocks for a PV system. PV panels involve one or more PV module assembled as pre-wired, field-installable unit. Series of PV panels are called a PV array which is ready-installed unit for power generation. The performance of PV modules and array are basically rated according to their maximum power output (w) tested under Standard Test Conditions (STC). Standard Test Conditions are defined as a cell (module) operating temperature of 25°C (77°F) and incident solar irradiance level of 1000 W/m^2.

Because of the aforementioned reasons, this chapter focuses on design, modeling, optimization, control and sensitivity analysis carried out on a hybrid system based on wind energy with a PV system.

2. Pertinent terms

The terms are technical in nature and there brief explanations will go a long way to concept discussion the hybrid renewable energy power system characteristics, thus, optimization, reliability, grid, micro grid, macro grid, diverse generation, hybrid energy system, and hybrid renewable energy system.

2.1 Optimization

The term optimization is defined as a process, act or methodology of making system design or decision functional or effective as possible according to Hong and Lian [6]. Two practical fundamental methods of optimization exist, thus, the metaheuristics and the simulation-based, will be further discussed in the section of optimization. In another perspective, it is reported that it is finding of an alternative with the highest achievable performance and most cost effective under some constraints through maximizing desired factors and minimizing the undesired ones. However, maximization means an effort to attain desired highest system performance, reliability outcomes regardless of cost and this perception is equally testified by Hong and Lian [6]. However, any practical optimization could be restricted by lack of full data or information, whereas, if some data are available while others are not then linear programming can be employed. Conversely, the optimal sizing of renewable power system components to increase their energy, capacity or performance, thus, providing power, reliability impact is considered optimization according to Kaabeche et al. [7]. Consequently, Power system hybridization is an infrastructural design exploration using optimization tools to configure hybrid renewable energy components to enhance the power reliability enabling zero or minimal loss of power supply probability (LPSP). Probability is the likely hood of getting optimal power supply reliability, and that, notwithstanding all depends on the power supply infrastructure redundancy status. Redundancy of power components can either be fully active or partially actively working with the system structure to allow smooth electric power supply distribution without interruption. Passive means the components are on standby and are only engaged at the point when component failure occurs. Subsequently, system reliability with active redundancy has smoother power supply that does not allow loss of power supply or allows only minimal loss than the passive redundancy reliability component.

2.2 Reliability

Dependable, consistent, trustworthy, and steadfast are always watch words for reliability term, and relating to energy delivery to consumer electric loads it means consistent qualitative power supply. The Power supply system is actually designed with redundancy and diagnostics in order to achieve power supply optimal reliability. Redundancy takes several concepts of the simple arithmetic, such as, N + 1, N + N, or 2N for maximum reliability such as system automation as expressed [8]. The '2N' redundancy element stands out to provide a better redundancy than the others; it means the two coefficient multiplied by existing components as 'N' size. Power supply consistency depends on availability of alternative energy sources and backups such as energy storage subunits as applicable to hybrid renewable energy power supply.

The term hybrid in its self means a mixture of two different components with about similar results for a specific purpose, for example, a hybrid solar-micro hydro renewable energy source (HRES) to supply a rural community with reliable electricity. Conversely, the solar resource is understood to be stochastic by nature and it is the characteristics unlike micro hydro, so they function better when hybridized or designed to work complementing each other. The hybrid resources, improve upon by attaching hybrid energy storages so that the energy converters are supported by energy storage in an effort to attain zero loss of power supply probability (LPSP) [9]. In addition, the preceding hybrid capacity is extended by integrating electronic controller automation in the style of PLC/SCADA. Any consistency in power supply obviously means there should be insignificant loss of power supply probability (LPSP) at any given time in the operation of the system. The probability that a system delivers consistent qualitative output power over long time period is considered to be reliable as interpreted by this author [6]. Hence, a reliable system is characterized by dependable power supply expressed mathematically in terms of mean time before failure (MTBF), and arithmetically expressed as reliability.

$$R = e^{(-tMTBF)} \tag{1}$$

However, the mean time before failure is the predicted elapse time between operating system inherent failures using a Monte Carlo tool of simulation for reliability optimization and Perturb and Observe for maximum power point tracking for (MPPT) optimization.

Dependence on the provision of adequate components spare in case of urgency by employing redundancy is a healthy technical strategy attracting extra intervention costs. Plainly, idleness is what redundancy means and though there are two types, the passive and active types synchronized with the system, whereas, the passive types are most times in the standby mode waiting to be called upon for activity as explained by. Thus, the design of hybrid renewable energy resources structure, hybrid energy conditioner, hybrid energy storages and hybrid control platform for automatic energy management.

2.3 Macro grid

The physical framework of which electric power is produced using diverse generators to supply the load using electric conductors and cables overhead or underground transmission and distribution networks, usually use assorted transmission and distribution equipment. The **Figure 1** represents electric power of three phase grid emanating from the generating station through step up transformer connected to three phase transmission lines and connected to step down transformer that distributes electric power to various consumer loads as explained by Diaf et al. [10]. The grid in **Figure 1** is a three phase alternating current network for alternating current (AC) loads, and conversely, a direct current (DC) model are also use for diverse loads as observed by Rao [11] **Figure 1**. Illustrates multiple grids made available and categorized as micro, and large networks connected to diverse conventional and renewable energy generators.

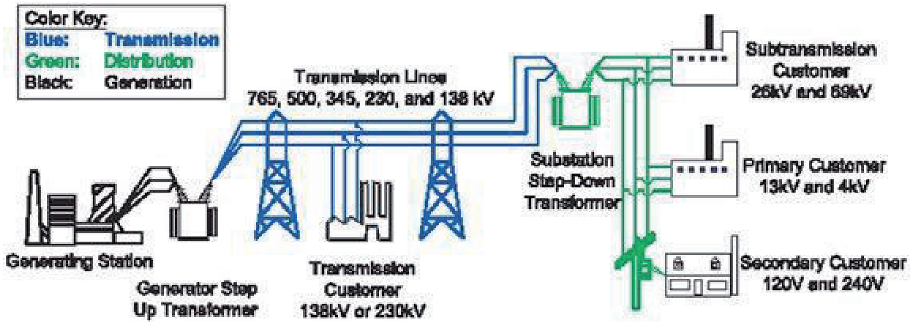

Figure 1.
Electric power multiple grids (transmission and distribution).

2.4 Micro grid

Micro grid is said to be a network designed to integrate distributed energy resources, control operation, power quality issue, and energy management infrastructure for load demand and power supply stability. It is the smallest facility common among the grid with diverse generators using extra low voltage three phase-four wire supply down to single phase three wire or two wires supply configuration to provide electricity supply to consumers load. Furthermore, micro grid is considered to be a group of distributed resources (DER) and loads forming an electrical network. It has a grid of low-voltage distribution energy resource (DER), energy storage system (ESS) and/or micro sources such as photovoltaic, fuel cell, wind turbine, etc. Micro grid may have controllable energy sources such as biomass, hydro, fossil fuel or uncontrollable energy sources like solar and wind or may be flow-of-the-river that is dependent on daily, monthly and annual rain falls. Controlling solar and wind-micro grid is challenging it involves measuring the parameters such as solar irradiance or Insolation, PV array voltage, PV array current, ambient temperature, wind speed, and AC load pattern for a year evaluation. Conversely, the renewable energy storage loss, energy converter average yield, peak period parameters are used for evaluation of micro grid power performance as reported by Mohammadi et al. [12].

2.5 Diverse generations (DGs)

A single source of electric power delivery to the consumer, local load is a diverse generation strategy such as conventional fossil fuel generation like oil, coal, etc. or renewable energy method such as solar, wind, hydro, biomass, geothermal, etc. Diesel or gasoline generators that are usually and commonly use in the rural areas are all categorized as small diverse electric generators' power sources. The diverse generator located by left of the figure and representing either of conventional or renewable energy diverse source according to this author [13]. The integration of diverse energy sources for the operation, control, power management in real time power system make up a micro grid or network as positioned by Ashourian et al. [14]. Obviously, micro grid has distribution structure like the macro grid except that it is a smaller size, in a tiny network, and has a low power capacity. Diverse generation is made into a hybrid design mix whenever the hybrid energy storage is integrated into the micro grid structure to reliably evacuate power to the load.

2.6 Hybrid energy system (HES)

It will be good to start with hybrid energy system (HES). Hybrid energy system is the engineering design of hybridizing power supply components or pairing them, for example, arranging diverse energy resources to work in parallel (equivalent) is very common in power. So, hybridizing is defined as forming crossbreed of pairs of agent for working together to achieve a purpose. Thus, hybridizing is to manually or automatically synchronize two or more electric power generator resources or components to supply electric power to the grid, therefore forming hybrid energy system. Hybrid energy system is an infrastructural design that integrates diverse or multiple energy converters to energy storage, energy conditioners, energy management system. By and large hybrid renewable energy system (HRES) is an extension of HES that uses mix diverse resources as hybrid or all hybrid renewable energy resources to supply the electric power system.

The concept of the hybrid RE power system is the perception to implement reliability portfolio to avert LPSP that will affect the quality of power supply resulting in dynamic change and transient. Hence, reliability is the dependability of systems or components to be able to function appropriately under stated conditions for a specified period without failure. Furthermore, reliability is said to be a probability of success, expressed as reliability (R) equal to "1" minus (Pf) probability of failure i.e., $R = 1 - P_f$. Hence, reliability relates to safety factors and cost factor caused by system downtime, cost of equipment repairs, spare parts, personnel, and cost of warranty claims. High reliability level will of course result from good engineering, reliability concept such as employing the concept of electric power system design optimization. Stochastic parameter dynamics in power supply do affect system reliability as failure is unabated, unless the concept of hybridization is embraced and integrated in the power supply structure as stated [13]. Redundancy is provision of more than one alternative resource power supply or system component to perform certain task (important), duplication of active or passive subsystem, and complete energy storage backup integration in case of failure according to Ashourian et al. [14].

On the other hand, reliability covers several unique modus operandi which provides high quality output, affording utmost availability through redundancy, and advanced problem-solving capabilities of hybrid RE power system as stated by Mat et al. [15]. Thus, HES assume several design types such as multiple fossil fuel energy sources, diesel generator-SPV renewable energy sources or other hybrid renewable energy resources mixture. And the hybrid system reliability can be improved through the integration and optimization of essential components such as energy resources, energy storage and energy management. Hybrid energy renewable systems are economical, less or no fossil fuel consumption for all RER, and have no or less greenhouse gas emission. Solar, hydro and other renewable energy sources are environmentally safe and have adequate power generation potentials. Therefore the integration of these sources with energy storage as hybrid system has economic returns as supported by Mat et al. [15].

2.7 Hybrid renewable energy power system (HREPS)

Hybrid renewable energy power system (HREPS) is a cross breed or mixture of matching (parallel) power system infrastructure designed to offer power supply reliability. Hybrid renewable energy power system (HREPS) has enormous designs or models that consists of five common subunits, namely, (i) renewable energy resource (RER) or energy harvester, (ii) electrical system (energy conditioners), and (iii) energy storages system (ESS), however, (iv) a common Bus and (v) electronic logic controller (ECS) is included for system management. Hence, HREPS has several designs of hybridizing by optimal selection of appropriate components that consists of energy harvester, electrical energy conditioner, ESS, common bus and electronic logic controller, however, all hybrid design emphases on hybridizing RER than any of the five components. Thus, adapting redundancy norm on all subunits in order to avoid loss of power supply probability (LPSP) is necessary in order to realize optimal design. The nomenclature hybrid renewable energy power supply (HREPS) design requires the following project proposal subunits to be, the hybrid renewable energy resource (HRER)-hybrid energy storage system (HESS)-hybrid energy conditioner (HEC)-hybrid energy management (HEMS) of four modules hybridized subunits. Each of the subunit is expected to complement its pair to compromise optimal design to be modulated and simulated using simulation-based optimization in order to achieve power supply reliability devoid of loss of power supply probability (LPSP).

2.8 Hybrid feasibility factors (optimization and levelized costs of electricity)

Hybrid renewable energy power system (HREPS) optimization is hereby defined by Giraud et al. [16] as finding the utmost feasible performance or the most cost effective approach under given constraints by maximizing desired factors and minimizing undesired ones. In the case of this design performance was considered priority so, energy reliability is more pleasant than its scarcity (energy shortages). For illustration, gasoline generators were the only electricity source in the remote and rural areas else the community had to live with lanterns. Consequently, maximization of the means to obtain the highest result for electricity provision is better regardless of the cost. Therefore, an act, process or methodology of making a design to function effectively for specific purpose is termed system optimization as from [17]. Two factors are the probable yardstick in determining the hybrid potential of any given site constraints, namely, the optimization and levelized costs of electricity (LOCE).

2.9 Optimization

Optimum or best methods to explore the hybrid renewable energy system for power supply reliability are enormous. The RE use has been historically, abundantly everywhere, omnipresent, free cost, and non-polluting characteristics leading to the increase of required storage capacity. A small hybrid system is understood to economical and may not meet the user load demand, whereas the large one can provide reasonable power, but it is expensive. Hence, optimal sizing of RE power system demand mathematical model of the system component characteristics using special techniques to extract maximum power from the models. Also, hybrid system has a complex control system due to the stochastic and multiple power harvesters, for example, the maximum power point (MPPT) technique employed in system SPV makes the system more complex [18]. This hybrid and MPPT approach is termed the optimization of the SPV stochastic power component to meet operational power supply demand.

In addition, optimization of hybrid renewable energy power systems has two techniques, the optimum tools or component based on site available energy resources and the sizing of the components, and use the appropriate control strategy that will [19] automate operation of the integrated hybrid system. Optimum HREPS design, configuration can be conducted using several optimization algorithms such as numerical, probabilistic and heuristic methods under some conditions as reported by these authors [11]. Whereas, feasibility factor is an index called localized cost of energy (LCOE) used to find cost of the average price of electricity produced by the HRES over its life. These variables include initial investment, development, capital, operation and maintenance, and fuel costs put together for costs analysis.

However, feasibility factors of using optimization are complex, nonlinear, and nonconvex because of the unique mixed constraints. Optimization approach are said to be fundamentally two, namely, the Simulation-based that is tedious, time consuming, prone to human errors and the metaheuristic method using multiple objectives involving cost, performance, supply-demand management, grid limitations, algorithms such as numerical, probabilistic and heuristic methodology as stressed by these authors [20, 10]. Optimization provides economic, efficient, and reliable power supply alternative energy without LPSP. Several of hybrid renewable energy power system optimization concepts were listed in **Table 1** in six groups. Their names are the graphical construction, probabilistic approach, deterministic approach, iterative approach, artificial intelligence, and software based (simulation-based) as stated by these authors [15]. However, a read-made HOMER software is a tool used to model hybrid configuration for optimization that emphasize on two factors, minimizing cost and maximizing performance constraints as asserted by Hong and Lian [6].

Next, search-based and Monte Carlo simulation (SMCS) is another optimization pattern use for HREPS and energy storage system (ESS) to check power supply reliability. The SMCS allow chronological behavior and reliability of HREPS to be evaluated through of series of simulated experiments for high power loads reported by Ekren and Ekren [21].

Each of the optimization techniques is considered unique because it has design elements that are most appropriate for its application in order to get optimal results. Artificial intelligence optimization consists of five subcategories, generic algorithm, particle swarm, fuzzy logic, artificial neural network, and hybrid model by Arabali et al. [22].

Perturb and Observe method is a conventional maximum power point tracking (MPPT) approach used in the energy conditioner subunit. It is said to be a global maximum point (GMP) because the combination of Perturb and Observe quickly searches for first local maximum point (LMP) and the particle swarm optimization (PSO) search for the global maximum point. Experimental report shows this method to be good for hybrid power system because it can track GMP with faster convergence time and better dynamic response than using just PSO alone according to Hakimi and Moghaddas-Tafreshi [23]. Hence, optimization has several approaches, some of them are hereby listed in **Table 1**, according to techniques and RE system elements under study.

A hybrid renewable energy system optimization and components sizing has found to be economically and reliably better in meeting all load conditions with minimum investment and operation cost. This was a disclosure of many research using genetic algorithm, particle swarm optimization, simulated annealing, ant colony algorithm and artificial immune system algorithm results as reported by these authors [23]. **Figure 2** depicts a graphical representation of optimization showing that it possesses two edges, the energy production and the energy demand control, conversely, the objective function is optimal design reliability inclined toward its constraints. These constraints determine the energy inputs maximize performance and the other hands LOCE minimize costs by Boubekri [4].

Hybridizing diesel with renewable energy to demonstrate the potential of RE to replace diesel generator. HOMER software platform was used to study the load pattern and modeled for HOMER hybrid RE optimization. Hybrid solar-wind-DG

S/N	Optimization technique	Elements	Remarks
1	Graphical construction	Battery and PV array	Use two parameters
2	Probabilistic approach	Performance of hybrid system	Based on statistical data collection approach
3	Deterministic approach	Stand-alone PV with battery bank	Use an equation for determining specific values with constant parameters
4	Iterative approach: hill climbing, dynamic programming, linear, and multiple objective	Hybrid-solar-wind system	Based on LPSP to find possible combination of solar-wind combination
5	Artificial intelligence: generic algorithm, particle swarm, fuzzy logic, artificial neural network, and hybrid model	Hybrid solar-wind system with battery	Based on evolution technique
6	Software based: homer, and developed GUI application software	All of the above	Input file with all necessary information is supplied. The software takes care of other things

Table 1.
Possible optimization techniques.

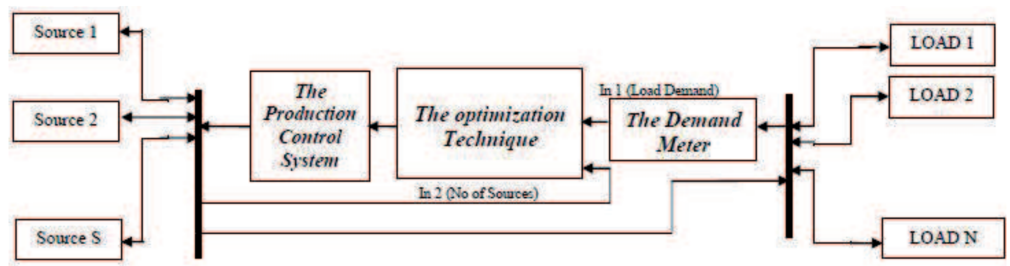

Figure 2.
Hybrid optimization, control and RE power production diagram [4].

were simulated to get four different technology models. The results show PV/hydro/DG has the highest optimization value in comparison to diesel generator only, [6].

Renewable energy (RE) and hybrid energy system (HES) are expanding and the current design method is a simulation based optimization and meta-heuristic optimization methods. HES are medium scale application in remote areas and stand-alone, but they are needed for large scale integration to grid. HES are non-linear, non-convex and composed of mixed variables that cannot be solved using traditional optimization methods. In the alternative, two approaches are used for optional HES design. Simulation based optimization and mete-heuristics optimization methods are limited in view of time consuming, rework, and error proneness analyzed by Arabali et al. [22]. From the onset, design of the hybrid power generation system (HPGS) begins with feasibility studies, analyze the potential and effectiveness using computer simulation as observed by Soysal and Soysal [41].

A systematic optimization methodology is to derive formulae hybrid RE system (HRES) Optimization by integration of demand response, day-ahead and real-time weather forecasting, and uploading model using a receding horizon optimization strategy is another approach. Practically demonstrated to a single family residential house HRES by Nfah et al. [24]. The demand-response and weather forecast methods are used to optimize the HRES in order to have minimize costs and maximize performance.

Furthermore, the state of the arts advanced generators; power electronic logic controller, grid requirements and control are optimized to improve wind power plant characteristics for efficient power delivery and integration according to Khan and Iqbal [25]. Consequently, the power electronic logic controllers, crossbreed SPV, hybrid ESS, and hybrid RER technology are therefore applicable to a solar photovoltaic power system for improved power reliability.

However, the approaches here consider optimization in terms of power supply reliability, but not only of the costs. Therefore, operating HREPS in the long run is economically preferable as costs are reduced no replacement reinvestment costs, fueling costs, maintenance costs, loss of power supply probability costs, and unquantifiable environmental degradation costs as economic parameters that indicate running diesel generator alone for power supply is bears exorbitant cost variables than operating hybrid REPS energy system.

2.10 Levelized cost of energy (LCOE)

Levelized energy cost (LEC) or (LCOE) is the unit-cost of electricity during the life period of power supply system in net present value (NPV) terms, often taken as alternative electricity average price to break even over generating system lifetime. However, LCOE is a general critical decision to proceed with a project development or not. There are two simulation models of the levelized cost of electricity (LCOE) available, namely, the EGC spread sheet and the system advisor model (SAM).

LCOE is mathematically expressed as the life-cycle cost divided by lifetime energy produced interpreted as to break even. The renewable energy systems have higher initial capital costs outlay (ICC), it however amortizes in the long run with free natural fuel, less operation/maintenance costs and environmental friendliness free of GHG impact plus poisonous gases according to Refs. [25, 27]. Finally, localized cost of energy (LCOE) is an index use to cost average price of electricity produced by the HRES over its life initial investment, development, capital, operation and maintenance, and fuel costs as variables.

Hence, effective ways to cut energy cost are:

a. Cut down on development cost, capital cost, operation and maintenance cost

b. Energy production or increase life span of generation infrastructure. A model of wind generator life was improved to last between 20 and 25 years in Denmark, so this applies to other RE infrastructure as observed these authors [19]. However, informed decisions demand trade off in projects selection using pressing priority or objective functions to maximize.

Cut in operation costs includes fossil fuel, and then increase the price and global greenhouse gas emission concern has motivated hybrid renewable energy system standalone applications. Modeling, simulation and multi objective optimization decision tools supporting the leveraged cost of electricity (LCOE), life cycle cost (LCC), greenhouse gas (GHG) emission objective functions use to evaluate power supply reliability, optimization and market price sensitivity. However, it is difficult to justify LCOE and LCC of standalone RE components in rural electrification projects. Conversely, LEC, LCC and GHG fronts are simplified by pairing LCC-LEC and LEC-GHG for decision making according to Khan and Iqbal [25]. HOMER simulation reported that the LCOE of energy of optimized hybrid PV-Wind-diesel-battery is lower than hybrid energy system without renewable energy mix. Consequently, it was concluded that diesel generator supply alone is not feasible as fossil fuel price increases rapidly as reported by Ekren and Ekren [21].

Solar, wind and other renewable integration with energy storage as hybrid system has economic returns of LCOE of providing adequate power, environmental friendliness and reliability for all load conditions as supported by Nema et al. [26] Alternatively, three analyses model were put to test costs-benefits of solar PV, thus, short-run, medium-run and the long-run analyses. The short-run considers costs-effectiveness on incremental increases, the medium-run focus on non-incremental change implications in solar capacity, whereas, the long-run dwell on carbon targets of the twenty-first century. Hence, economics depends on grid integration costs, low-carbon technologies and technological advances potential [27].

The common cost-effective criteria in photovoltaic phenomena rely on policy jurisdiction, frame work such as incentives like fit-in-tariff (FIT), tax credits, carbon reduction certificates variables motivates investors. Economically, return on investment (ROI) is always a prominent business yard stick and motivator for an investor. Conversely, feasibility study on solar PV indicated that it has long term high yield rate of return (ROR), see **Table 2** give details as reported [28].

2.11 Hybrid renewable energy power system (HREPS) bus

Electricity bus is a good conductor in made into a bus-bar for transporting energy from power generator/converter to the grid. Hybrid renewable energy power system (HRES) has two levels of voltage bus the DC and AC produced by the mixture and crossbreed of energy resources.

S/No	PV type	Payback period range (years)	Emission rate (gCO_2-eq/KWh)	Remarks
1	Thin film	0.75–3.5	10.5–50	Environmentally friendly and suitable
2	Mono-silicon	1.7–2.7	29–45	Ditto
3	Advanced PV system technologies			
I	High concentration	0.7–2.0	Lower than above rate	Environmentally friendly and suitable
II	Hetero-junction	Ditto	Higher than above rate	Ditto
III	Dye-sensitized	–	–	Rate research is ongoing

Table 2.
Feasibility on PV types with payback period and environmental impacts.

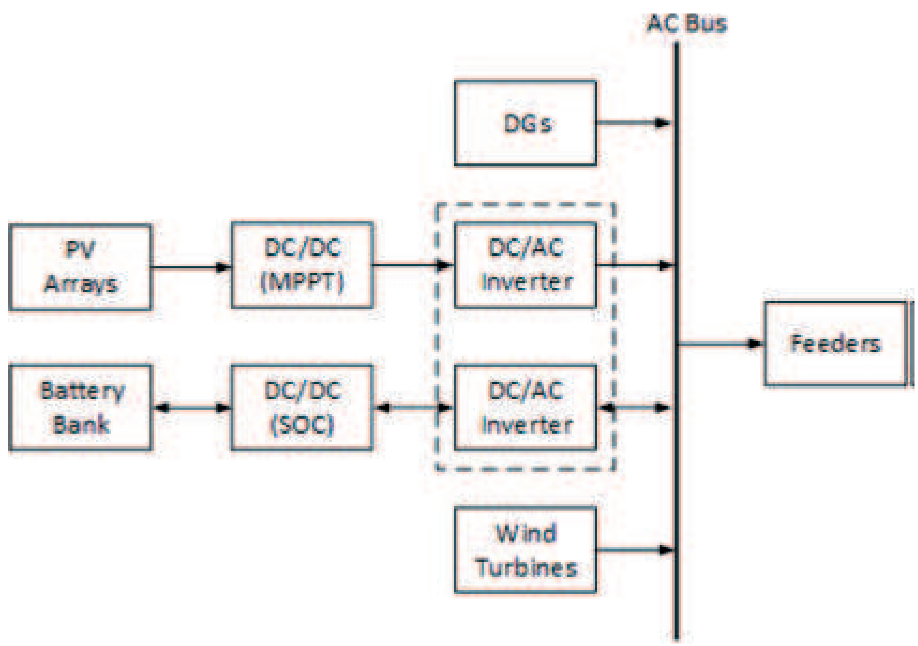

Figure 3.
Series hybrid RE power system with single AC bus for all AC load [15].

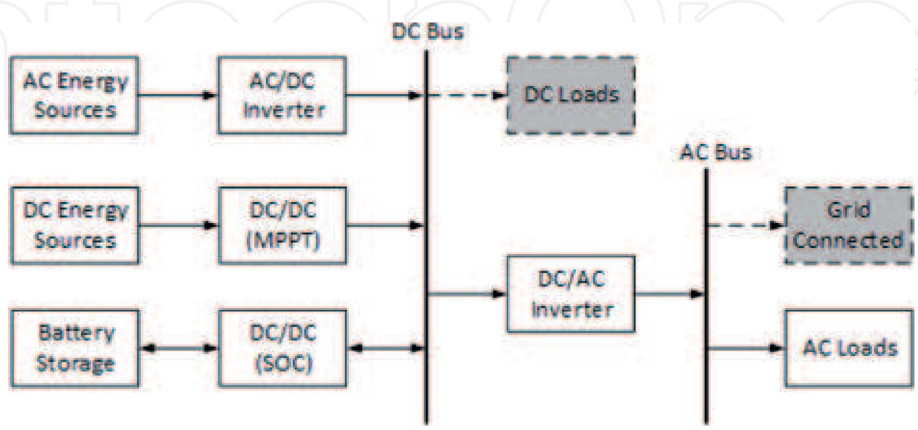

Figure 4.
Parallel (hybrid) RE power system with both AC and DC bus plus AC and DC loads [15].

The two levels AC and DC bus by extension are fundamentally two configurations, namely, the series and the parallel bus arrangements as shown in **Figure 3** for the series connection, **Figure 4** and **Figure 5** for parallel bus as reported by Zhou

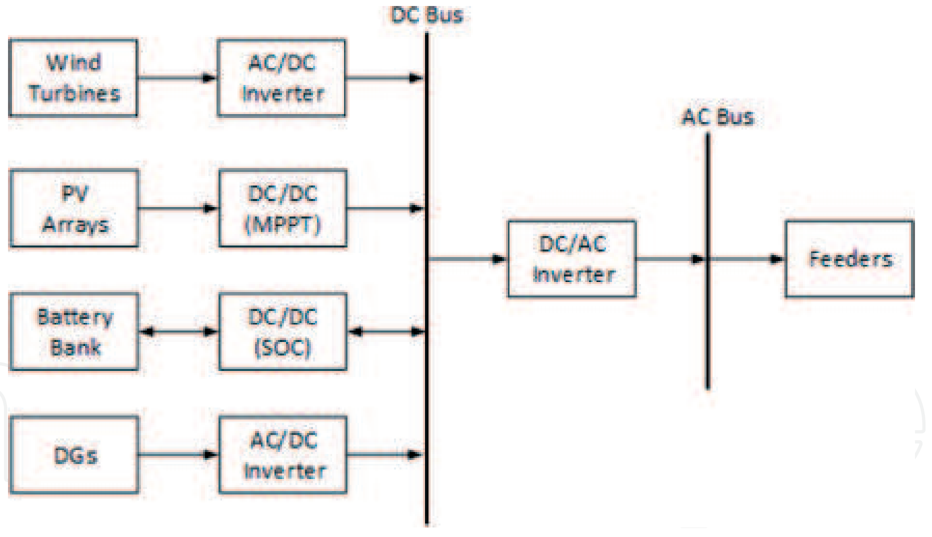

Figure 5.
Parallel hybrid RE system with both AC and DC bus for only all AC loads [15].

Figure 6.
Hybrid RE three phase output voltage waveforms [30].

and Sun [29]. These authors have illustrated the ideology of hybrid methodology can be synchronized to serve the electric load better, meaning mixing energy to improve the power of equivalent RE converter infrastructure to have reliability in power supply delivery.

The **Figures 3–5** are in one line/block schematic representing three phase system for hybrid RE resources to produce output voltage waveform shown in **Figure 6**. However, hybrid RE can be also be designed to supply single phase system for smaller single phase load demand and its output voltage wave is single implied.

2.12 Renewable energy resources (RER) optimal sizing

Hybridizing is a common strategy for improving the sizing of renewable resource (RER) energy resources; it is also known as crossbreeding in the SPV. The optimum scale of renewable energy resource to harvest energy reliably depends on the optimal design of conversion model. Energy converters are RER and come with assorted characteristics, sizes, and brands guide in the design and the implementation of projects. The RER characteristics of solar photovoltaic and micro hydro are the main focal area to be considered for discussion and analysis in this study. Henceforward, RER as the name implies, are replenish able resource that naturally are regenerated in accordance with the climatic condition and topography of the locality of solar, hydro, and so on as established by Mohammadi et al. [12]. The common among the renewable energy resources are solar and hydro considering their technical and economic benefits as considered by Daut et al. [13]. Solar photovoltaic and micro hydro resources have several statistical variations in nature and are therefore are dependent on the peculiarity of specific geographical location's weather.

3. Wind energy and photovoltaic systems

From the deep literature survey conducted, a lot of studies are being done with divergent ideas and necessities on the possibility of integrating wind and PV system. The studies can be classified into, modeling, design, optimization, control and techno-economic strategies. On the other hand, some researchers proposed a stand-alone hybrid system, while others applied wind and PV system in grid connected mode.

3.1 Modeling and design of PV-Wind system

A lot of modeling and design of the PV and Wind have been developed using different approaches. The design can be categorized into two, it can be a grid or stand-alone. A grid PV-Wind system proposed by Harini et al. [31] used Wind generator, wind side converter, DC-DC converter, and grid interface inverter. The MPPT is used to optimize the DC voltage coming from the solar panels. The design was implemented in Matlab environment using Simulink. The schematic diagram of the overall system is shown in **Figure 7**.

PV-Wind hybrid system was used to generate electricity in Iraq; the planned system was simulated using MATLAB solver, where the input variables for the solver were the meteorological data for the selected areas and the sizes of PV and wind turbines. Outcomes revealed that it is achievable in Iraq to implement the solar and wind energy to come up with enough power for some communities in the desert or rural area. Additionally, it is feasible to use such a system as a black start source of power in the course of total shutdown time. Final results also showed that the desired place for this system is in Basrah for both solar and wind energy [32].

A Wind-PV-diesel hybrid power system is developed using HOMER software for a small town in Saudi Arabia which happens to be at the moment powered by a diesel power plant comprising of eight diesel generating sets of 1120 kW each, The

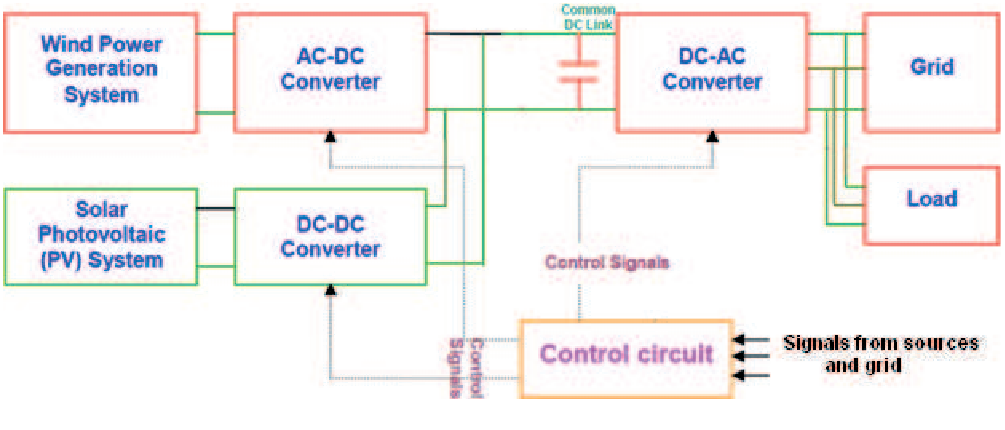

Figure 7.
Schematic diagram of a grid PV-Wind system.

annual contributions of wind, solar PV and the diesel generating sets were 4713.7, 1653.5, and 11,542.6 MWh, respectively [33]. Performance of hybrid PV-Wind for hydrogen generation was studied in Sopian et al. [34]. The system consists of photovoltaic array, wind turbine, PEM electrolyser, battery bank, hydrogen storage tank, and an automatic control system for battery charging and discharging conditions. The system generated 130–140 ml/min of hydrogen, for an average global solar radiation and wind speed varying from 200 to 800 W/m^2 and 2.0 to 5.0 m/s respectively. While authors [35] have design small-scale electric grid based on hybrid PV-Wind, the model is shown in **Figure 8**. Presented results shown that the coupling of subunits reduces annual grid power transfers by more than 10% and increases the renewable power contribution to the demand by almost 7% [35]. To increase efficiency of PV-Wind hybrid system. Multi wind turbines and PV systems was successfully model in Mikati et al. [35]. The simulation outcomes revealed that the power end result of the wind turbines in multi-turbine wind-solar hybrid system improves by 18.69, 31.24 and 53.79%, when used in Shenyang, Shanghai and Guangzhou, respectively, in comparison with the reference system [35]. In the work of [36] as shown in **Figure 9**, a special hybrid PV and Wind was used to power an UV (ultraviolet) water purification system. A 100-W solar-PV system that has a 500-W wind turbine lead in pumping and filtering adequate water in order to meet the safe and clean water demands of 4000 people (16,000 l/day) at an approximated equipment expense of $4630.

One work used [37] a new converter technology to implement a hybrid PV-Wind System using Matlab. The topology utilizes a combination of Cuk and SEPIC converters. This setting enables the two resources to provide the load independently or at the same time dependent on the availableness of the energy sources. Some design

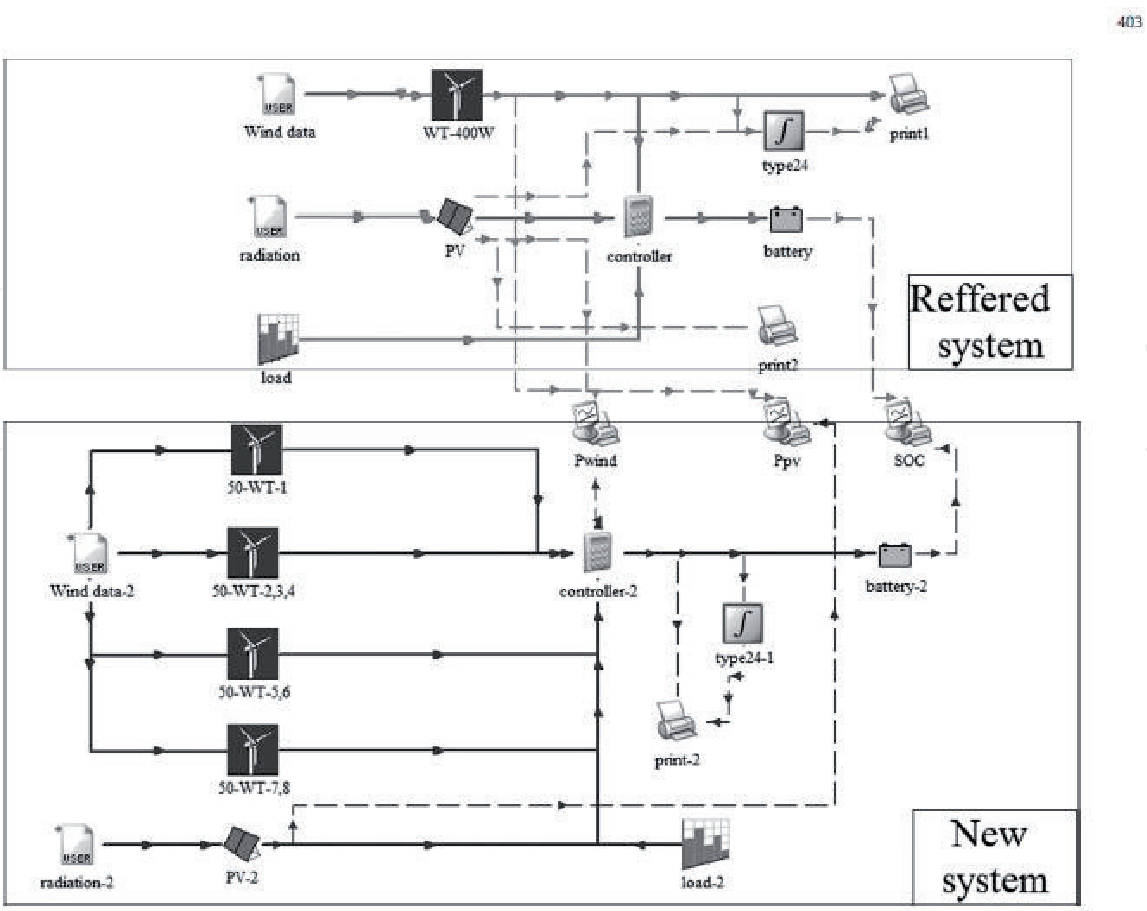

Figure 8.
Simulation models of the two hybrid systems.

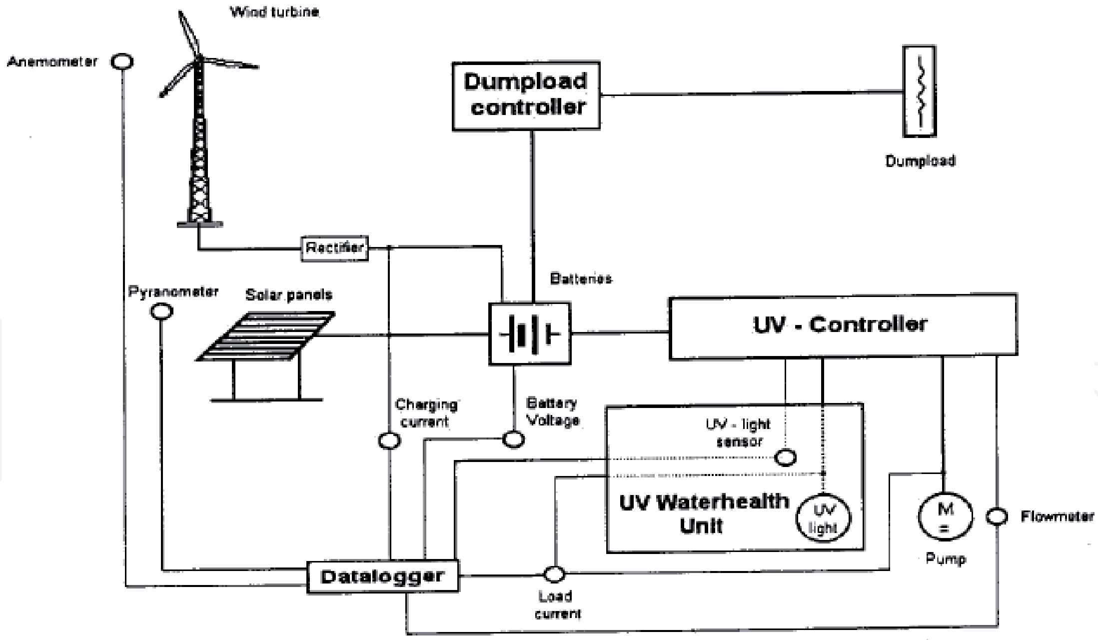

Figure 9.
Schematic of UV water filtration system.

includes control strategy for instance, the work of conducted by Moubayed et al. [38] reported a control of a hybrid solar-wind system with acid battery for storage. Steady-State Functionality of a Grid-Connected Rooftop Hybrid PV-Wind system was designed and tested by Kim et al. [39]. The design considers system consistency, power quality, loss of supply, and the effects of the randomness of the wind and the solar radiation on system. Limited studies are being done on micro generation based on PV-Wind, the best example case is a hybrid system with solar energy and wind energy for micro power production [40]. Residential hybrid PV-Wind was developed in [41]. While a PV-Wind with simple MPPT was implemented, the suggested system is desirable due to its convenience, convenience of control and affordable [42]. Few studies consider power generation to support national grid, example one study conducted in Jordan [43]. The need for additional energy tends to make us search for new energy sources. Authors in [44] designed a domestic solar-wind hybrid energy system as shown in **Figure 10**.

3.2 Optimal sizing of stand-alone

In more remote rural areas, PV and Wind system are widely used to supply electrical energy to consumers. Different methodologies have been applied in that regards. A methodology for optimal sizing of PV and Wind for stand-alone system is presented in [45]. The study aims at minimizing cost using genetic algorithm. The simulation outcomes validate that hybrid PV/WG systems feature reduced system cost when compared to the situations where either solely WG or exclusively PV sources are being used. The work of [46], considered optimization of PV/Wind based on number of solar panels ad wind turbines for minimal cost reduction. The findings of this study showed that optimum battery capacity, with optimum number of PV modules and wind turbines subject to lowest cost can be attained with high accuracy and reliability. One research conducted [12], used particle swarm optimization (PSO) algorithm for optimal sizing of PV and Wind system, though the study is limited to micro-grid system, however, energy storage was included. In Ref. [47], used discrete chaotic harmony search-based simulated annealing (SA) algorithm for optimum design of PV/wind hybrid system. The suggested method is employed to get the best possible design of a PV/

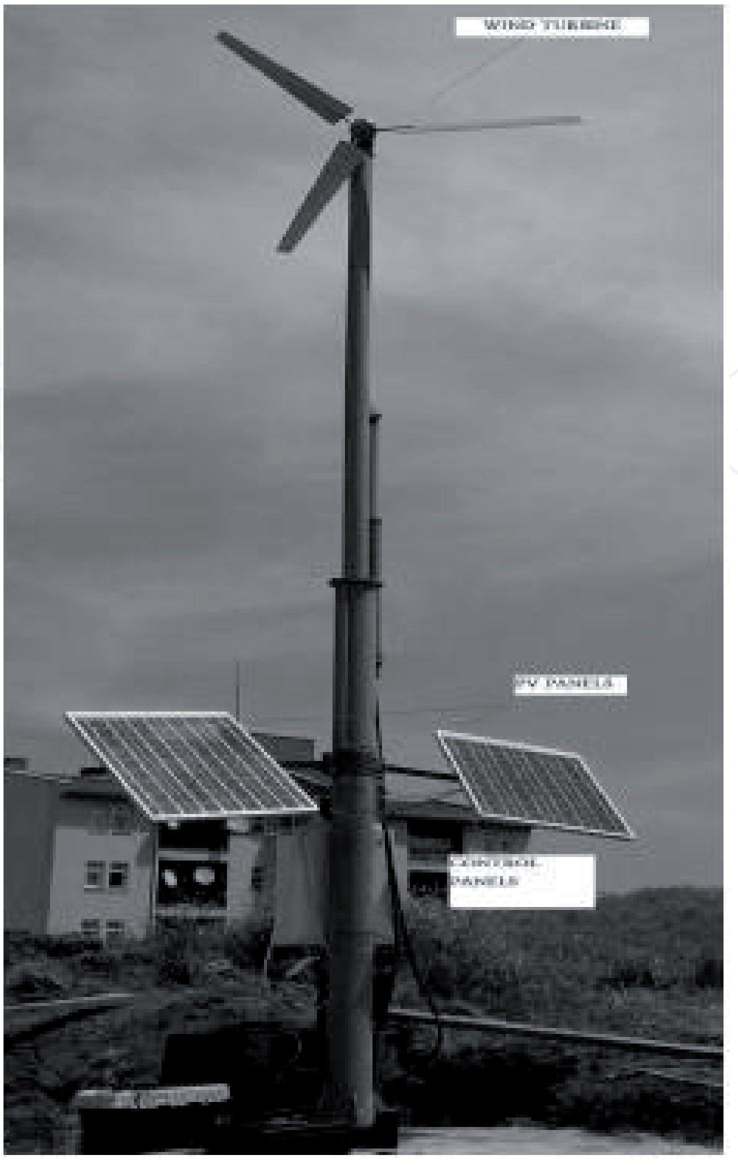

Figure 10.
Image of the designed hybrid system.

wind hybrid system. Simulation results show the outstanding effectiveness of the SA algorithm. The optimization study conducted [48] focuses on off-grid hybrid PV-Wind using different battery technologies based on genetic algorithm (GA) was successfully implemented.

Simulation based optimized design has been proposed for a PV/wind hybrid energy conversion system with battery storage under different load and auxiliary energy conditions was developed [21]. The simulation model of the system is implemented in ARENA 12.0, commercial simulation software, and is optimized using the Opt Quest tool in this software. Consequently, the optimum sizes of PV, wind turbine and battery capacity are attained under various auxiliary energy unit costs and two different loads. The best possible results are verified using loss of load probability (LLP) and autonomy analysis. And the financial commitment costs are examined how they are shared among those four energy sources at the optimum points.

Simulated annealing (SA) algorithm for optimizing size of a PV/wind integrated hybrid energy system with battery storage was reported [49]. The suggested technique is a heuristic strategy which utilizes a stochastic gradient search for the global optimization. The objective function is the minimization of the hybrid energy system total price. And the selection parameters are PV size, wind turbine rotor swept area and the battery capacity. The best possible result acquired by the SA algorithm when compared with other study's result. Therefore, it is actually coming up with that the SA algorithm provides much better result compared to Response Surface Methodology (RSM). The research study is realized for a campus area in Turkey.

Sizing optimization of off-grid PV-Wind using iterative approach was used in [7]. The proposed model takes into consideration the sub-models of the hybrid system, the Deficiency of Power Supply Probability (DPSP) and the Levelized Unit Electricity Cost (LUEC).

3.3 Techno-economic optimization

In this perspective, several techno-economic optimization approaches for hybrid systems sizing have been revealed in the literature. Iterative methodology has been applied to optimize the capacity sizes of various stand-alone PV/wind/diesel/battery hybrid system parts for zero load energy shortfall [50]. The high price of renewable energy systems has brought to slow usage in many countries. Hence, Neuro-Fuzzy method was used for techno-economical of PV-Wind system. The optimization method used is Adaptive Neuro-Fuzzy Inference System (ANFIS), which is successfully applied to model the PV and wind sources. Comparison was made with hybrid optimization model for electric renewables (HOMER) and hybrid optimization by genetic algorithms (HOGA) software and the results prove an accuracy of 96% for PV and wind [51]. The optimized system is simulated in PSCAD/EMTDC and the results show that low excess energy is realized. In this work [10], the technical-economic optimization research of a stand-alone hybrid PV/wind system (HPWS) in Corsica Island is introduced. Consequently, the main purpose of the research is to calculate the acceptable dimensions of a stand-alone HPWS that ensure the energy independence of the typical rural consumer with the lowest levelized cost of energy (LCE).

It is acknowledged that solar energy and wind energy are two of the most feasible renewable energy resources on the globe, The work of [8] highly recommend an ideal design model for designing hybrid solar-wind systems making use of battery banks for determining the system optimum options and guaranteeing that the annualized cost of the systems is reduced while fulfilling the customized needed loss of power supply probability (LPSP). The five selection parameters involved in the optimization method are the PV module number, PV module slope angle, wind turbine number, wind turbine installation height and battery capacity. The offered technique is used to design a hybrid system to supply power for a telecommunication relay station along Southeast Coast of China.

In a related design techno-feasibility of hybrid PV-Wind was employed for a household in China, using HOMER simulation software. The design PV-Wind ration is 72:28, based on the detailed feasibility study conducted in the study areas. Another similar design in Indonesia [52] focuses on onshore remote areas. HOMER software is used to perform the techno-economic feasibility of the PV/wind hybrid system. The final results also display that a wind turbine and battery are the most significant elements of the PV/wind hybrid system to fulfill requirement loads at night hours. Considering that both of these components give the best advantages to system costs, it is very important to select their utmost sizes to reduce the costs, but by considering that no loads are unmet. Object oriented programming was applied to optimize hybrid PV-Wind system in a study conducted by Belmili et al. [53]. Detailed mathematical model was developed together with optimal algorithm for sizing and techno-economic analysis to identify the system that could ensure an effective energy supply with a most affordable financial commitment.

4. Conclusions

This chapter presents detailed work conducted on hybrid system based on PV and Wind. The chapter systematically shows the different methodology used in the design, simulation, optimization and techno-economic aspects of PV-Wind Systems. Some design and application of the hybrid PV-Wind are discussed.

Hybrid renewable energy power system optimal design includes feasibility studies, model-based design, simulation and integration of several hybrid renewable energy resources, energy conditioner, and hybrid energy storage system and hybrid controller for automation to achieve power supply reliability. A hybrid renewable energy system (HRES) technology for reliable power supply has challenges in the design process. Thus, hybrid energy harvester, energy conditioner, energy storage and controller feasibilities, selection and unit sizing, and system configurations are necessary procedures to be carried out. Hybrid energy system components for power, reliability applications related to hybrid energy systems, power system has been reviewed above. In order to highlight the merits of the optimal design of hybrid energy system with a promising sustainable solution for power supply reliability.

The solar photovoltaic flat plate has of enormous adaptable models with the adequate alternative energy potential that could possibly replace conventional fossil fuel system. Application of the best possible of hybrid SPV plate/PEMFC resources, boost maximum power point tracking, integrated multi-level inverter and the hybrid PEMFC-Na_S battery storage, and micro hydropower system yields reliable electricity supply for rural and remote areas.

Hybrid renewable energy power system can offer socio-economic return when enough power is available in rural areas as business activities is going to be established as the communities do some corn/wood mills, small scale industrial ventures to engage more youth in entrepreneurship.

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Conflict of interest

The authors have declared that no conflict of interest with regards to the publication of this chapter.

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Author details

Salisu Muhammad Lawan[1*] and Wan Azlan Wan Zainal Abidin[2]

1 Kano University of Science and Technology, Wudil Kano State, Nigeria

2 Universiti Malaysia Sarawak, Sarawak, Malaysia

*Address all correspondence to: mlsalisu@unimas.my

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