CHAPTER 2
COMPREHENSIVE LITERATURE REVIEW OF DIFFERENT MICROGRID SCHEMES

2.1 INTRODUCTION

Microgrids have a long history. In fact, Thomas Edison’s first power plant constructed in 1882 – the Manhattan Pearl Street Station – was essentially a microgrid since a centralized grid had not yet been established. By 1886, Edison’s firm had installed fifty-eight direct current (DC) microgrids. However, shortly thereafter, the evolution of the electric services industry evolved to a state-regulated monopoly market, thus removing incentives for microgrid developments. It has become increasingly clear that the fundamental architecture of today’s electricity grid, which is based on the idea of a top-down system predicated on unidirectional energy flows, is obsolete [104].

The term Microgrid has been defined by many people in many ways. As recorded at University of Wisconsin, Madison, USA, the term “MICROGRID” has as many as 13 competing definitions [55]. Different definitions of Microgrid:

1. An integrated energy system consisting of distributed energy resources and multiple electrical loads operating as a single, autonomous grid either in parallel to or “islanded” from the existing utility power grid [104].
2. The term microgrid (µG) refers to the concept of single electrical power subsystems associated with a small number of distributed energy resources (DERs), both renewable and/or conventional sources, including photovoltaic, wind power, hydro, internal combustion engine, gas turbine, and microturbine together with a cluster of loads [78].
3. One starting point for the idea of microgrid was a proposed concept with modular technology that can provide grid compatible PV power supply [157]. Hatziargyriou and Strbac [104] defined microgrid as “Interconnection of small, modular generation to low voltage distribution systems forms a new type of power system, the microgrid. Microgrids can be connected to the main
power network or be operated autonomously, similar to power systems of physical islands”.

4. European Commission defines microgrids as small electrical distribution systems that connect multiple customers to multiple distributed sources of generation and storage and commented that microgrids typically can provide power to communities up to 500 households in low voltage level.

5. Early definition by Lasseter [116] implied the concept of microgrid as a cluster of loads and microsources operating as a single controllable system that provides power to its local area. This concept provides a new paradigm for defining the operation of DG. It enables high penetration of DG without requiring re-design or re-engineering of the distribution system itself.

6. Arulampalam et al. [3] have described a microgrid as a combination of generation sources, loads and energy storage, interfaced through fast acting power electronics. This combination of units is connected to the distribution network through a single PCC and appears to the power network as a single unit.

7. As Pepermans et al. [42] describe, some countries define DG on the basis of voltage level while others follow a principle that DG is connected to circuits that feed consumer loads directly. Other countries define DG on the basis of some characteristics like using renewables, cogeneration, primarily, in the form of non-dispatched type etc.

8. The early definition was discussed by Ackermann et al. in 2001 with regard to the purpose, location, power scale, power delivery, technology, environmental impact, mode of operation, ownership, and penetration level. His definition is “Distributed generation is an electric power source connected directly to the distribution network or on the customer site of the meter. The distinction between distribution and transmission networks is based on the legal definition. The definition of DG neither defines the rating of generation source, nor the area of power delivery, penetration level, ownership, treatment within the network operation” [145].

9. The Institute of Electrical and Electronics Engineers, Inc. (IEEE) has defined distributed resources (DR) as sources of electric power that are not directly connected to a bulk power transmission system. DR includes both generators and energy storage technologies. While the definition of DG is given as
electric generation facilities connected to an area electric power system (EPS) through a point of common coupling (PCC) as a subset of DR [56], EPS is defined as facilities that deliver electric power to a load; local EPS as an EPS contained entirely within a single premises or group of premises and an area EPS as one that serves local EPSs. PCC is defined as the point where a local EPS is connected to an area EPS.

10. International Council on Large Electricity Systems (CIGRE) has a Working Group on DG. It defined DG as all generation units with a maximum capacity of 100 MW usually connected to the distribution network, that are neither centrally planned nor dispatched.

11. International Energy Agency (IEA) views DG as units producing power on a customer’s site or within local distribution utilities, and supplying power directly to the local distribution network.

12. Willis et al. state that “DG includes application of small generators, typically ranging in capacity from 15 to 10,000 kW, scattered throughout a power system, to provide the electric power needed by electrical consumers. As ordinarily applied, the term DG includes all uses of small electric power generators, whether located on the utility system, at the site of a utility customer, or at an isolated site not connected to the power grid” [47].

13. However, most accepted definition by Dr. Robert H. Lasseter [119], Professor and Principle Research Scientist, University of Wisconsin, Madison, is “The Consortium for Electric Reliability Technology Solutions (CERTS) MicroGrid concept assumes an aggregation of loads and microsources operating as a single system providing both power and heat. The majority of the microsources must be power electronic based to provide the required flexibility to insure operation as a single aggregated system. This control flexibility allows the CERTS MicroGrid to present itself to the bulk power system as a single controlled unit that meets local needs for reliability and security.”

2.2 MICROGRID AND ITS REQUIREMENTS

The future electricity network must be flexible, accessible, reliable, and economic according to the worldwide smartgrid initiative. This is also echoed by the
Sustainable Energy Authority of Ireland (SEAI) and European Electricity Grid Initiative (EEGI). In order to facilitate these objectives and to reduce greenhouse gas (GHG) emission, research on various configurations of microgrid (μG) system is gaining importance, particularly with high penetration of renewable energy sources. Depending on the resource availability, geographical locations, load demand, and existing electrical transmission and distribution system, μG can be either connected to the grid or can work in an autonomous mode. Storage can also be a part of the μG architecture. The paper presents a critical literature review of various μG architectures. The benefits of grid-connected or isolated μG with storage have also been identified [83].

The application of individual distributed energy resources as microgeneration can cause problems such as local voltage rise, the potential to exceed thermal limits of certain lines and transformers, islanding and have high capital cost [28]. Microgrid can be a better solution for these problems. In a μG system, the DERs must be equipped with proper power electronic interfaces (PEIs) and control to ensure the flexibility to operate as a single aggregated system maintaining the power quality and energy output. Furthermore μGs can reduce environmental pollution and global warming by utilizing low-carbon technology [130].

Sustainability of a μG system depends on the energy scenario, strategy, and policy of that country and it varies from region to region [83]. These topics are beyond the scope of this review.

The white paper proposes that the significant potential of smaller DER to meet customers’ and utilities’ needs can be best captured by organizing these resources into MicroGrids [119].

A microgrid may take the form of shopping centre, industrial park or college campus. To the utility, a microgrid is an electrical load that can be controlled in magnitude. The load could be constant, or the load could increase at night when electricity is cheaper, or the load could be held at zero during times of system stress. The purpose of the Energy Management System (EMS) is to make decisions regarding the best use of the generators for producing electric power and heat. These decisions will be based upon the heat requirements of the local equipment, the weather, the price of electric power, the cost of fuel and many other considerations.
The EMS will dispatch the generators and provide an overview of the Combined Heat and Power (CHP) system [63].

2.3 MODES OF OPERATION OF MICROGRID

2.3.1 Islanded Mode

Piagi and Lasseter [114] argued that the intentional islanding of generation and loads has the potential to provide a higher local reliability than that provided by the power system as a whole. Microgrids can operate either interconnected to the main distribution grid, or even in isolated mode. From the grid’s point of view, a microgrid can be operated within a power system as a single aggregated load and as a small source of power and other services supporting the network. For a customer, it is a low voltage distribution service with additional features like increase in local reliability, improvement of voltage and power quality, reduction of emissions, decrease in cost of energy supply etc.

With the advent of renewable technology, researchers and designers have made remarkable progress in the development of different islanded hybrid system based algorithms. A control scheme is proposed for a three phase isolated photovoltaic (PV)-diesel microgrid without energy storage element. The scheme aims to: track maximum power from the PVA, regulate the load voltage, compensate the load unbalance viewed by the diesel generator, and to control the diesel-engine speed. The first three tasks are achieved by controlling the pulse width modulation inverter interfacing the PV array to the system. The fourth is realized by a modified fuzzy logic controller of the diesel engine. The obstacles encountered on operating the system under certain probable loading conditions are addressed. Two different operation strategies are proposed to provide high-quality power under all loading scenarios, and to achieve the targets of the control scheme. The system operation is investigated under a variety of conditions to prove the aptness of the proposed techniques [4]. The scheme aims to: track maximum power from the PVA; regulate the PCC voltage; compensate the load unbalance viewed by the DDG; and to control the DDG speed. The first three tasks are achieved by controlling the PWM inverter interfacing the PVA to the system. The fourth is accomplished by a modified control
of the DDG. The problem of voltage magnitude and frequency escalation under particular loading conditions is focused.

The disturbance defending ability of the isolated micro-grid is weak, and the randomness and the weak controllability of new energy generation are harmful to system stability. So a completed and accurate model of the isolated micro-grid is needed to do research on key technologies. C. Guanglin et. al. [19] have proposed an operating mode for the isolated micro-grid. A PSCAD simulation model of the isolated micro-grid with wind-solar-diesel-battery hybrid power generation is built based on the operating mode. The model parameters are obtained by parameter identification method. The feasibility and the effectiveness of the proposed approach are proved by simulation and model of an island planning micro-grid. The isolated Wind-Solar- Diesel-Battery micro-grid model, and the control system of the diesel generator control and energy storage master operation mode were designed and simulation respectively. To maintain the long-term safe and stable operation, we put forward the advanced application functions of the energy storing emergency frequency and voltage regulation control.

Depending on the requirements of the consumer group and possibly some legal issues, they may choose either autonomous or non-autonomous operation of the microgrid that supports their energy use. Many DG technologies that exist today will be reviewed, as well as reasons for and pros and cons of their application. Additionally, the micro grid concepts were discussed alongwith pros and cons of the concept [21]. C.L. Smallwood et. al. [21] discussed technical and non-technical challenges of microgrid. A microgrid was established utilizing PV and fuel cells operated in cogeneration modes.

D. Yamegueu et. al [31] presented the results of an experimental study of a PV/diesel hybrid system without storage. Experimental results show that the sizing of a PV/diesel hybrid system by taking into account the solar radiation and the load/demand profile of a typical area may lead the diesel generator to operate near its optimal point (70 to 80% of its nominal power). The proposed method show that for a reliability of a PV/diesel hybrid system, the rated power of the diesel generator should be equal to the peak load. It has been verified through this study that the functioning of a PV/diesel hybrid system is efficient for higher load and higher solar radiation. Experimental results show that the contribution of PV generator for a given load
affects the performance of the diesel generator. As a matter of fact, when the hybrid system operates under small loads (less than 62% of the diesel generator rated power), the PV generator contributes rather to decrease the performance of diesel generator. At this level, the use of dummy loads (for pumping or heating water) to absorb the excess output power and multiple diesel generators running in parallel could be a solution to enhance the system efficiency. It has been also observed a deficit in energy production for load higher than 100% of rated power of diesel generator which could mean that for a reliability of a PV/diesel hybrid system, the rated power of diesel generator should be equal to the peak load. It has been verified through this study that the functioning of a PV/diesel hybrid system is efficient for higher loads and higher solar radiations. This study being conducted with constant loads, it will be of a great interest for future investigation to study experimentally the behavior of the system under variable loads.

The steady state and transient operation of a typical microgrid are studied. The models of two dispersed generation units (photovoltaic system, wind turbine) are presented. Models of the power electronics interface and control strategies for fast control of frequency and voltage magnitude without communication are derived. The approach used by F. D. Kanellos et. al. [35] is the implementation of conventional f/U droops into the batteries inverters, thus downscaling the conventional grid control concept to the low voltage grid. The aforementioned models are combined together and the model of a typical microgrid is simulated.

Loads sensitive to power quality include critical computing, data processing electronic equipment, and semiconductor fabrication machinery. Such sensitive loads demand a highly reliable power supply for a fail-safe operation. It is known that downtime of the sensitive load equipment caused by power quality events results in significant loss of revenue. Conventional approaches to solving these problems use UPS systems or backup generation systems driven by fossil fuel engines. The features are made possible by upgrading operational and control features to enable them to become solutions to the sensitive load problem. A case study is made for designing a microgrid for an office-cum-warehouse facility. The electrical design of this facility is made to determine the location and ratings of two DR [44].

The project is focused on a systems approach to using clusters of microsources with storage to bring high value to electrical energy customers. Advantages of such an
approach include deferred distribution cost, local voltage control and reliability, coordinated demand-side management, and premium power quality. This project addresses the control and placement of distributed resources (DR) as a solution to the sensitive-load problem. In particular, the focus is on systems of DR that can switch from grid connection to island operation without causing any disturbance to critical loads. The presence of power electronic interfaces in fuel cells, photovoltaics, wind turbines, micro turbines, and storage technologies creates a very different situation from more conventional synchronous generator and induction-based sources in power sources and standby emergency power systems.

The paper reviews the concept of distributed generation, discusses its relevance in India, elaborates on the initiatives in the islands of Sundarbans region and reviews another concept called microgrid in light of the emerging technologies suitable for the small islands. An actual field test project in Kythnos Island, Greece has been concisely presented as an example of distributed generation and microgrids for island electrification. In the light of DG and microgrids it can be stated that there exist several technical challenges to achieve ideal island power systems suitable for remote locations. Although large amount of research work is still to be done, even today, microgrids can be realized with commercially available components [55].

The scheme describes and evaluates the feasibility of control strategies to be adopted for the operation of a microgrid when it becomes isolated. In such conditions, the microgrid must have the ability to operate stably and autonomously. An evaluation of the need of storage devices and load shedding strategies is included in this paper. From the analysis performed, the following main conclusions can be derived [61]:

• The forced islanding of the MG can be performed safely under several different power importing and exporting conditions.
• A fast elimination of a fault in the MV network is required; otherwise, motor loads may compromise the transition to islanded operation. Under voltage load-shedding of large motor loads and induction generators could be an interesting possibility.
• Simulation results also indicate that both control strategies tested—SMO and MMO—are effective and ensure efficient and stable MG operation.
• The results obtained suggest that the management of storage devices are absolutely essential to implement successful control strategies for MG operation in islanded
mode with the load shedding procedure assuming also very high importance to avoid fast and long frequency deviations.

J. A. Peças Lopes [62], suggested a low voltage distribution network with large amounts of small sized dispersed generation can be operated as an isolated system in certain conditions. The control strategies to be used in such a system to deal with islanded operation and to exploit the local generation resources as a way to help in power system restoration after a general blackout. From the results obtained, it was observed that storage devices play a key role for the success of system islanding and restoration. The identification of a set of rules and conditions to be checked during the restoration stage by the Microgrid components was derived and evaluated through numerical simulation, proving the feasibility of such procedures. Such a successful verification constitutes a significant contribution and shows that micro generation resources should be exploited further.

Thereafter, a concept of stand-alone hybrid renewable energy systems with hydrogen storage systems have been proposed in 2008-2009 [155],[71] usually incur lower costs and demonstrate higher reliability than photovoltaic (PV) or wind systems. The most usual systems are PV–Wind–Battery and PV–Diesel–Battery. Energy storage is usually in batteries (normally of the lead-acid type). Another possible storage alternative, such as hydrogen, is not currently economically viable, given the high cost of the electrolyzers and fuel cells and the low efficiency in the electricity–hydrogen–electricity conversion. When the design of these systems is carried out, it is usually done resolve an optimization problem in which the Net Present Cost (NPC) is minimized or, in some cases, in relation to the Levelized Cost of Energy (LCE). The correct resolution of this optimization problem is a complex task because of the high number of variables and the non-linearity in the performance of some of the system components. This paper revises the simulation and optimization techniques, as well as the tools existing that are needed to simulate and design stand-alone hybrid systems for the generation of electricity. As a result of this review, we determined that the most frequent systems are those consisting of a PV Generator and/or Wind Turbines and/or Diesel Generator, with energy storage in lead-acid batteries. Energy storage in hydrogen, although technically viable, has a drawback in terms of its low efficiency in the electricity– hydrogen–electricity conversion process, besides the fact that, economically, it cannot compete with battery storage at the present time. However, the importance of considering other objectives besides the
cost is evident, such as, for example, contaminating emissions or reliability. Finally, the design and simulation tools that have been developed over the past few years have been briefly described, highlighting the fact that some of them can be downloaded and used free of cost [71].

The dynamic behavior and stability of an isolated electric power system, fed by a conventional energy plant and a renewable energy system, is proposed. Matlab/Simulink is the used software for simulating the whole system [78]. The simulation results of a hybrid power system with diesel and wind power generation and a grid connected photovoltaic (PV) inverter, demonstrate that the modular simulation system, developed using the matlab programming environment, constitutes a very useful tool for analysis and design of such systems. Simulation studies, using the proposed control approach, indicate that application of these policies may result in reduced load flowing requirements for conventional power generation units, and improve power quality and stability of the interconnected systems.

A hierarchical Automatic Generation Control (AGC) strategy for an islanded microgrid, including wind power, solar photovoltaic, micro turbines, small hydropower and energy storage devices have been proposed by L. Gan et. al. [82]. The upper AGC is for central scheduling. The bottom AGC is to optimize the allocation factors, expecting to meet the requirement of energy-saving generation dispatching (ESGD). Three different bottom controllers are presented. Two of them are designed based on reinforcement learning (RL) optimal decision making algorithm. In order to evaluate their control performance, another proportion-based (PROP) controller which has been put into practical application is also presented. The results indicate that the proposed strategy based on RL algorithm can not only achieve reliability and stability of microgrid in islanded mode, but also reduce fossil energy consumption. This approach [82] is a possible candidate for future microgrid control approaches.

The introduction of a Flywheel Energy Storage System (FESS) [41], [77], [99], [102], and [103] into a isolated hybrid grid increases the renewable energy penetration. The isolated power system studied includes diesel and hydro generators and wind turbines. The simulated and measured results clearly show the positive influence of the energy storage on the system performance. The system has been operating with the FESS for 1 year and has demonstrated improvements in renewable
energy penetration, reduced diesel fuel usage, and improved power system stability and power quality. Renewable energy penetration in isolated grids can be limited by spinning reserve requirements, conventional generator minimum loading, conventional generator step load response, system stability, and reactive power and voltage control requirements. The advantages of connecting a flywheel energy storage system to an isolated power system and the control strategy have been introduced. A sample wind/diesel/hydro power system on the island of Flores, Azores has been presented. Prior to the FESS being installed the renewable energy penetration on this system was severely limited by system stability [102]. This system was simulated, with a good correspondence between simulations and measurements on the real system. The addition of a FESS in the system dramatically improved the system stability and allowed a much higher renewable energy penetration with decreased diesel fuel usage.

S. M. Shahid et. al. [136] have investigated the feasibility of renewables for Saudi Arabia location. Most of the world’s energy consumption is greatly dependent on fossil fuel, which is exhaustible and is being used extensively due to continuous escalation in the world’s population and development. This valuable resource needs to be conserved and its alternatives need to be explored. Saudi Arabia, being blessed with a fairly high level of solar radiation, is a suitable candidate for deployment of solar photo-voltaic (PV) panels for power generation during crisis. Literature indicates that commercial/residential buildings in Saudi Arabia consume an estimated 10–45% of the total electrical energy generated/consumed. In the present study, hourly mean solar radiation data for the period 1986–1993 recorded at the solar radiation and meteorological monitoring station, Dhahran, Saudi Arabia, have been analyzed to investigate the potential of utilizing hybrid (PV-diesel) power systems to meet the load requirements of a typical commercial building (with an annual electrical energy demand of 620,000 kWh). The hybrid systems considered in the present analysis consist of different combinations of PV panels/modules (different array sizes) supplemented with a battery storage unit and diesel back-up.

A fraction of Saudi Arabia’s energy demand may be harnessed from PV systems. The observations of this investigation are informative and can be employed as a tool in the design of hybrid PV/battery/diesel systems for a wide spectrum of applications (for locations having climatic conditions similar to Dhahran). The study encourages the investigation of the PV systems in a broader perspective with due
provision for operation and maintenance cost of diesel generator and initial capital cost of PV [137]. PV/battery/diesel hybrid configuration and has several advantages such as: system load can be met in the optimal way; diesel efficiency can be maximized; diesel maintenance can be minimized; and a reduction in the capacities of diesel and battery (while matching the peak loads) can occur. The present investigation shows that the potential of renewable energy option of solar energy cannot be overlooked.

For the active power control in this paper, a variant of the conventional droop control strategy is used, namely the voltage-droop controller. However, because of the small size of the microgrid and the high share of renewables with an intermittent character, new means of flexibility in power balancing are required to ensure stable operation. Therefore, a novel active load control strategy is presented in [149]. The aim is to render a proof of concept for this control strategy in an islanded microgrid. The active load control is triggered by the microgrid voltage level. The latter is enabled by using the voltage-droop control strategy and its specific properties. It is concluded that the combination of the voltage-droop control strategy with the presented demand dispatch allows reliable power supply without inter unit communication for the primary control, leads to a more efficient usage of the renewable energy and can even lead to an increased share of renewables in the islanded microgrid. The loads can adjust their temporarily power consumption according to the voltage level to enable demand dispatch.

2.3.2 Grid Connected Mode

R.H. Lasseter [116] has discussed some of the key technical issues are power flow balancing, voltage control and behaviour during disconnection from the PCC (islanding), protection and stability aspects. It is expected that microgrids will operate connected to the main grid under most conditions. When failures occur in the medium or high voltage systems, the microgrid is automatically transferred to islanded operation, supplied by it from the micro generators distributed with it, as nin the physical island power systems.

One of the key benefits of grid-connected DG is the increase in service quality, reliability and security [55] and the challenges faced by the autonomous micro grids are discussed in [21].
The methodology presented by [5] represents the modeling and performance analysis of wind/diesel hybrid generating system. Such configurations are typical for remote rural communities which are disconnected from the larger power grid, such as those located on islands or in forests. Controllers are designed to ensure operation of the wind and diesel units in a cooperative manner, in order to reduce the fossil-fuel consumption of the diesel generator. The system has been simulated using PSCAD/EMTDC for different wind speed variations. The objective here was to investigate the behavior of the wind/diesel hybrid power system under wind speed changes, which can be observed in the simulation results. It is shown that in every situation, the wind turbine and the diesel generator supply power in order to meet the power demand. The integration of the models presented here will provide a general tool for the accurate assessment of the power system stability and reliability of wind/diesel hybrid power systems.

Various issues and challenges that need to be addressed in grid integration of renewable energy systems are discussed by A. Rajapakse et. al. [11]. The importance of the simulation tools in grid integration studies is demonstrated through several case studies. Integration of renewable energy into the utility grid can be at either the transmission level or the distribution level, depending on the scale of generation. Large renewable energy generation such as wind farms are directly interconnected to the transmission system. The application of the proposed methods to identify problems and to find the suitable solutions is also highlighted.

Renewable energy resources such as solar and wind energies are highly advantageous compared to the conventional sources of power in many ways that they clean and available infinitely. But the only drawback is that their outputs depend upon the climatic conditions. Wind-Photovoltaic Hybrid System (WPHS) [20] utilization is becoming popular due to increasing energy costs and decreasing prices of turbines and Photo-Voltaic (PV) panels. The aim of this project is to determine the optimal design of a hybrid wind-solar power system for either autonomous or grid-linked applications. The proposed analysis employs quadratic programming techniques to minimize the cost while meeting the load requirements in a reliable manner. Using this procedure, optimum number of PV Modules and wind turbines subject to minimum cost can be obtained with good accuracy. The proposed system reduces both the cost and the amount of CO₂ emitted from the entire setup.
E. Koutroulis et. al. [34] implemented a continuous simulation language of the dynamic model of an Integrated Generation System (IGS) named "Combined Multiple Renewable Energy Sources System Simulator" (CMRESSSS). The software package is a useful tool to evaluate the IGS electric transient behavior during the planning stage. Dynamic transients in normal and faulted conditions are simulated exploiting the main features of the package which are flexibility and Graphic User Interface for easy handling of input data and events scheduling. Different working conditions have been analyzed and the proposed approach has been proved to be efficient and useful for preliminary comparative analysis of dynamic performances.

F.D. Kanellos and his colleagues [35] have raised the technology evolution, environmental concerns associated with central electric power plants and deregulation of the electric utility industry are providing the opportunity for small distributed generators to become very important in order to satisfy the on – site customer expanding power demand. The steady state and transient operation of a typical microgrid are studied. Furthermore, the stability of the microgrid is ensured during connection and disconnection to the grid.

Many older types of electrical generator technologies (Type A and B) could not interface successfully without the additional expense of external reactive power compensation. Newer turbine designs have largely solved this problem [64]. Type C and D generators now provide many of the same services as traditional power plants, and some studies have even indicated that these generators are faster to react and do a better job of maintaining voltage stability than traditional power plants.

Accordingly, an integrated numerical algorithm [68] is built to estimate the energy autonomy configuration of the hybrid system under investigation. Using the proposed numerical algorithm, the optimum configuration selection procedure is verified by carrying out an appropriate sensitivity analysis. The proposed methodology may equally well be applied to any other remote consumer and wind potential type, in order to estimate the optimum wind–diesel hybrid system configuration that guarantees long-term energy autonomy. Finally, a complete energy autonomous three-dimensional surface may be predicted, considering that every point of this surface—i.e. wind turbine rated power, battery bank capacity and annual diesel-oil consumption—guarantees the remote consumer’s energy-autonomy for the entire time period examined. Recapitulating, by incorporating an appropriate cost–benefit model, the proposed methodology may equally well be applied to other remote
consumers and wind potential types, in order to predict the optimum wind-diesel hybrid system configuration that guarantees long-term energy autonomy, minimizing the consumption of imported oil and the corresponding environmental impacts.

The hybrid system consists of a Photovoltaic (PV) array and a Proton exchange membrane fuel cell (PEMFC) connected to the grid [100]. Two operation modes, the unit-power control (UPC) mode and the feeder-flow control (FFC) mode, can be applied to the hybrid system. The objective of the paper is to coordinate the two control modes and determine the reference values of the UPC mode and FFC mode so that all constraints are satisfied. This operating strategy will minimize the number of operating mode changes, improve performance of the system operation, and enhance system stability. With the operating algorithm, PV always operates at maximum output power, PEMFC operates within the high-efficiency range, and feeder power flow is always less than its maximum value. In brief, the proposed operating algorithm is a simplified and flexible method to operate a hybrid source in a grid-connected microgrid. It can improve the performance of the system’s operation; the system works more stably while maximizing the PV output power.

R.H. Lasseter et. al [120] have suggested that the small DER may best meet customers’ needs and add benefit to the utility grid if these resources are organized into MicroGrids operated as single, controllable systems that can connect to the utility grid or operate independently; this is a new approach for integrating DER into the utility distribution system.

The microgrid provides an effective approach to integrating many small-scale distributed energy resources into the bulk electric grid. W.Kleinkauf et. al [157] have proposed an agent-based control framework for distributed energy resources microgrids. The features of agent technology are first discussed. An agent-based control framework for DER microgrids is then presented. To demonstrate the effectiveness of the proposed agent-based control framework, simulation studies have been performed on a dc distributed energy system that can be used in a microgrid as a modular power generation unit.

2.3.3 Hybrid Systems

Stand-alone hybrid renewable energy systems usually incur lower costs and demonstrate higher reliability than photovoltaic (PV) or wind systems. The most usual
systems are PV–Wind–Battery and PV–Diesel–Battery. Energy storage is usually in batteries (normally of the lead-acid type). Another possible storage alternative, such as hydrogen, is not currently economically viable, given the high cost of the electrolyzers and fuel cells and the low efficiency in the electricity–hydrogen–electricity conversion. When the design of these systems is carried out, it is usually done resolve an optimization problem in which the Net Present Cost (NPC) is minimized or, in some cases, in relation to the Levelized Cost of Energy (LCE) \[71\]. The correct resolution of this optimization problem is a complex task because of the high number of variables and the non-linearity in the performance of some of the system components. The simulation and optimization techniques are considered, as well as the tools existing that are needed to simulate and design stand-alone hybrid systems for the generation of electricity. An aspect that became clear, after the review had been carried out, is the paucity of researchers writing papers about multiobjective optimum designs in hybrid systems. However, the importance of considering other objectives besides the cost is evident, such as, for example, contaminating emissions or reliability. Finally, the design and simulation tools that have been developed over the past few years have been briefly described, highlighting the fact that some of them can be downloaded and used free of cost.

The suggested guidelines presented in this work \[81\] are based on the existing guidelines for PV Systems, as a PV–Wind Hybrid system can be roughly thought of as a PV System to which wind generation has been added. So, the guidelines for PV Systems are valid for the PV–Wind System, and only the part referred to wind generation should be included. This has been the process followed in this work. The IEC-61724, as this standard is valid for PV–Wind Hybrid systems and only the part referred to wind generation needs to be added to the standard. So, the proposed method suggests the necessary parameters that should be added to the ones included in the IEC-61724 Standard to characterize the wind generation, which will affect mainly the Electrical Energy Quantities and the Systems Performance Indices.

Control strategies based on active power/frequency and reactive power/voltage droops for the power control of the inverters have been also developed by L. Ye \[86\]. Case studies have been carried out in a distribution network to investigate the dynamic behavior of the microsources in both steady state and fault scenarios.
Simulation results verify the feasibility of the proposed models. Feasibility of the proposed models has been verified by simulation results using EMTP/ATP software.

In the present investigation, hourly wind-speed and solar radiation measurements made at the solar radiation and meteorological monitoring station, Dhahran, Saudi Arabia, have been analyzed to investigate the feasibility of using hybrid (wind+solar+diesel) energy conversion systems at Dhahran to meet the energy needs of twenty 2-bedroom houses. The study recommends a parametric study similar to the one investigated in the present paper and followed up by an economic analysis for designing stand alone renewable energy systems [89].

A software based simulation to understand the hybrid power systems response considering various renewable energy technologies and energy storage options is presented [106], the solution to the problem allows the decision maker to quickly reach an optimal decision when considering the introduction of renewable energy sources to a micro-grid when taking into account the proper mathematical forecasts of both wind and solar resources, as well as considering accurate demand predictions and possible future economic scenarios. A modeling and simulation methodology using a micro power optimization software (HOMER®) to solve the multi-objective renewable energy integration problem considering various renewable energy technologies was presented. Expanding the answers obtained from the single objective tool HOMER® appears to be a fast way of obtaining multiple-objective solutions which avoids the re-formulation of the Renewable Energy Integration Problem and provides real solutions belonging to the Pareto Front. The number of solutions is small and could be given to the decision makers as good estimates of the ranges in which the hybrid system is working.

2.3.4 AC/DC Hybrid Systems

In the last decade, the use of renewable energy in power system is rapidly increasing and the complex grid came into existence. This comprises of AC/DC hybrid microgrids. An investigation of a hybrid DC/AC integration [7] paradigm to establish microgrids (MGs) by using a conventional three-phase local power delivery system. This approach adds an additional DC power line to the local power distribution system in order to collect energy generated by distributed domestic renewable sources. The local renewable distributed generation (DG) works in
conjunction with the conventional grid utility to reduce the power draw from the grid. Researchers designed an energy conversion station to mix energy from the local DGs with energy from the grid utility. This approach, therefore, uses a continuous energy mixing strategy for DC integration of local generation and grid energy to supply energy to MG consumers via the conventional three-phase power distribution system. Thus, local distributed renewable generators do not have to contend with AC integration problems, such as AC stability and line synchronization. This approach can facilitate the transformation of conventional local power distribution systems into reliable MGs in an affordable way for stakeholders and it is a step towards construction of future smart grids. The energy conversion station can easily tolerate any problem in local DGs and it can provide more secure power flow for MGs. In addition to its power supply-distribution potentials, the investigated MG structure has a financial advantage as well: it will not bring an additional cost for conventional grid consumers in MGs. Therefore, it can also encourage smart grid stakeholders to transform conventional power systems into smart grid systems with street-by-street MG installations over conventional power systems.

2.4 METHODOLOGIES AND COMPARATIVE ANALYSIS

During the last decade, remarkable success has been achieved in the field of renewable energy technologies and implementation of the same. Many different applications and feasibility configurations [38] have been developed by researchers using renewable energy systems along with energy storage systems, and employing various methodologies [6], [41]. These are explained in the following sub-sections.

2.4.1 Feasibility and Design of HPS

Different approaches have been proposed for the feasibility and design of hybrid power system. The methodology to perform the optimal sizing of an autonomous hybrid PV/wind system is proposed. The methodology aims at finding the configuration, among a set of systems components, which meets the desired system reliability requirements, with the lowest value of levelized cost of energy. Modeling a hybrid PV/wind system is considered as the first step in the optimal sizing procedure. More accurate mathematical models for characterizing PV module, wind generator and battery are proposed. The second step consists to optimize the sizing of a system according to the loss of power supply probability (LPSP) and the levelized cost of energy (LCE) concepts [131]. The
simulation results, for a LPSP of 0 and a defined profile, show that in order to obtain a total renewable contribution (RC=1), more than 30% of the energy production is unused unless the battery capacity is very large.

G. Bekele et. al [38] have developed a microgrid for Ethiopia. In this work, feasibility of small-scale Hydro/PV/Wind based hybrid electric supply system to the district is studied. The hydro potentials are analyzed with the help of GIS and data obtained from the Ministry of Water Resource (MoWR) of Ethiopia. Meteorological data from National Meteorological Agency (NMA) of Ethiopia and other sources, such as NASA, is used for the estimation of solar and wind energy potentials. Electric load for the basic needs of the community, such as, for lighting, radio, television, electric baker, water pumps and flour mills, is estimated. Primary schools and health posts are also considered for the community. Monthly average wind speed data from NASA is used to synthesize hourly wind speed data using HOMER [51].

The objective of these studies is to diversify the sources of energy available for the country, feeding the energy demand with more reliability and keeping or improving the clean characteristics of the Brazilian electrical matrix [92]. This work is a technical and economical feasibility study of a hybrid generating system, composed by wind, diesel and grid sources, feeding a great costumer with high reliability requirements for its electric supply.

South Africa is currently looking at the potential of generating energy from biomass using Municipal Solid Waste (MSW) collected from landfill sites in different community areas for supplying power to rural and semi-urban localities [93]. This method presented an analysis of energy generation potential of landfill sites in Cape Town area in South Africa and economic analysis of landfill gas to energy (LFGTE) systems which might be developed using these landfills.

The viability of domestic standalone Photovoltaic (PV) hybrid systems in Indian rural areas is presented in [111]. The drawbacks of standalone systems can be addressed by combining minimum of two renewable energy sources to form a hybrid power system offering reliable and uninterrupted supply to remote sites. The different PV hybrid systems available are analyzed and a comparative study is presented in this paper. The economic feasibility and load management in systems comprising of PV wind, PV diesel and PV fuel cell using SIMULINK. In comparison to PV wind energy and PV diesel generator set, PV fuel cell offer sustainable and economical
solution to reliable power supply in remote areas. Recent research concentrates on enhancing the productivity of fuel cell to increase the overall output. A wind-pv-diesel hybrid power system has been designed for a village in Saudi Arabia which is presently powered by a diesel power plant consisting of eight diesel generating sets of 1,120kW each [142]. The sensitivity analysis showed that for every 0.5m/s increase in wind speed, there was an increase of 5% in wind energy contribution to the hybrid power system and the COE decreased linearly and the overall achievable renewable energy fraction (REF) also increased linearly. Furthermore, the wind energy contributed more efficiently to the proposed hybrid power system than the solar pv energy. Lastly, the COE of diesel only power system was found to be more sensitive to diesel price than the COE of hybrid power system.

2.4.2 Techno-Economic Analysis of HPS

The design of hybrid energy system consisting of wind and photovoltaic with battery storage. A diesel generator is added to ensure continuous power supply and to take care of intermittent nature of wind and photovoltaic [29]. The paper proposes the results of technical–economic optimization study of photovoltaic/wind/diesel hybrid with battery storage in Algeria. The primary objective is to estimate the appropriate dimension of stand-alone hybrid photovoltaic/wind/diesel with battery storage that guarantee the energy autonomy of typical remote consumer with lowest cost of energy. A secondary aim is to study the impact of renewable energy potential quality on the system size.

G.N. Prodromedis et. al. [41] have proposed the feasibility of a Renewable Energy Sources (RES)-based stand-alone system for electricity supply based on a Flywheel Energy Storage System (FESS) located on the Greek Island of Naxos. The innovative use of flywheels in parallel connection with electrochemical batteries, as an integrated storage device in the same power plant, was selected to be simulated as it is a necessary buffer covering the load of a typical house.

Rural communities in South Africa endure poor access to electricity mostly due to the lack of grid connected power lines. It is therefore the ideal place to conduct a study on the economic feasibility of introducing HPSs for typical residential loads for the rural community in South Africa. This paper reports on the investigating
economic feasibility of a PV/diesel HPS in various climatic zones within South Africa [65].

The hybrid system have a pay-back period of about thirty-three years and at current costs, central grid power is the least expensive option but may not be available to most rural households far from the grid. Hence it is necessary to supply these areas from isolated power sources [79]. A wind-solar cell hybrid energy system would be cost effective if there is reduction in component cost by installation of many of this hybrid system in a farm thereby lowering the investment cost per kilowatts.

The potential of generating energy from biomass using Municipal Solid Waste (MSW) collected from landfill sites in different community areas for supplying power to rural localities. The method proposed the potential of landfill sites in Cape Town area in South Africa and economic analysis of landfill gas to energy (LFGTE) systems which might be developed using these landfills in South Africa [93].

The hybrid system has been in reliable operation since July 2001. The economic analysis and environmental impacts of integrating a photovoltaic (PV) array into diesel-electric power systems for remote villages is proposed in [129]. The preliminary results reported here demonstrate that the integration of a PV array into a diesel-battery stand-alone hybrid power system reduces the operating costs and the greenhouse gases and particulate matter emitted to the atmosphere. The incorporation of additional renewable sources of energy, such as wind turbines in this system, could further reduce fuel consumption.

2.4.3 Dispatch Strategies

The concept of MicroGrid (MG) has been proposed as a way to solve several problems associated with the integration of small generators in distribution feeders. However, new solutions are required to become MicroGrids technically secure and reliable as well as economically attractive. The method presented the results of economic dispatch applied to MGs operating as an island and connected to the grid. The optimization algorithm was developed and implemented in Matlab [74]. The profits obtained when MicroGrid operates in Optimal Power Flow (OPF) allow assessing the degree of complexity that the Local Supervisory Controller can achieve without compromising the economic viability of MicroGrid.
The restructured electric power industry has brought new challenges and concerns for the secured operation of stressed power systems. As renewable energy resources, distributed generation, and demand response become significant portions of overall generation resource mix, smarter or more intelligent system dispatch technology [80] is needed to cope with new categories of uncertainty associated with those new energy resources. The need for a new dispatch system to better handle the uncertainty introduced by the increasing number of new energy resources becomes more and more inevitable. Traditionally, the real-time dispatch problem is solved as a linear programming or a mixed integer programming problem assuming absolute certainty of system input parameters and there is very little account of system robustness other than classical system reserve modeling. The next generation of dispatch system is being designed to provide dispatchers with the capability to manage uncertainty of power systems more explicitly. A new dispatch system to provide system operators with look-ahead capability and robust dispatch solution to cope with uncertain intermittent resources is presented.

The decentralize or autonomous operation scheme should have the proper power sharing provision among the parallel connected DGs, if possible, without using the control information among them. The real and reactive power controls should be in independent manner, and the DGs should share common real and reactive load in proportion to a pre-determined ratio, regardless of plant parameters. However, MG in distribution network having resistance dominated line interconnection, P-Q control can’t be decoupled as in conventional droop. M. Subkhan et. al. [99], have introduced an improved power sharing scheme applicable for the microgrid, without necessitating the communication line among the DGs.

Two models to determine the size of grid units and dispatch in a wind-diesel power system with hydrogen storage. Both take as data 1-year time series of hourly wind speed and electricity demand, and their objective is to minimize cost. First model, based on linear programming, generates as output a combination of capacities and a year time series for the dispatch variables. Our second model runs a fixed dispatch rule over several capacity combinations and selects the cheapest option. The dispatch rule can then be improved through comparison with the linear programming solution [128]. At present costs, the hydrogen storage-conversion system is excluded from the solutions, so the interesting operation rules associated with the option of
harvesting do not arise. To optimize a wind–diesel system supported by hydrogen storage, we have used a linear programming solution as a benchmark to improve heuristic dispatch rules. The LP solution served as a guideline towards the dispatch rule SEASONS, which is significantly cheaper at intermediate levels of renewable penetration than the stationary u–h–f and u–f–h rules.

2.4.4 Battery Energy Storage Systems

Connecting the storage and DG’s to the grid have both technical and economic impacts. This paper aims at analyzing the technical and economic impacts of distributed generators along with energy storage devices on the distribution system. The technical analysis includes analyzing the transient stability of a system with DG’s and energy storage devices, such as a battery and ultracapacitor [6]. Ultracapacitors and biomass technologies need to be more economical to be cost effective for increased benefits.

Stabilizing future atmospheric carbon dioxide (CO₂) levels at less than a doubling of pre-industrial levels will be a Herculean task, requiring a continuous flow of new carbon-free power 2-3 times greater than today’s energy supply to sustain economic development for a global population approaching 10 billion by the mid 21st Century. The costs of solar and wind power are partially offset by their potential benefits as distributed electricity generation sources. However, even if future development reduces their cost substantially, widespread deployment of solar and wind power in the future will face the fundamental difficulty that they are intermittent, requiring demand flexibility, backup power sources, and very likely enough electricity storage for days to perhaps a week [39].

Energy storage technologies instead convert electricity to other energy forms (gravitational, pneumatic, kinetic, chemical), with a characteristic turn around efficiency usually driven by the simplicity or complexity of conversion and reconversion between electricity and the stored energy form. For example, it can be 90-95% efficient to convert electricity to kinetic energy and back again by speeding up or slowing down a spinning flywheel. Storing electricity by compressing and later re-expanding air is usually less efficient (75%), since rapid compression heats up a gas, increasing its pressure, making further compression difficult. The electric energy lost in energy storage drives up the overall cost of generating reliable electricity from
wind or solar power. Another cost of energy storage is the capital investment required for the energy storage system. These costs are driven by the weight of material or volume of containment vessels needed to store a given amount of energy, termed energy density (kWh/kg or kWh/liter), again characteristic of each energy storage form. Pumped hydroelectric and compressed air energy storage (CAES) are currently economic for energy storage.

The feasibility of a Renewable Energy Sources (RES)-based stand-alone system for electricity supply based on a Flywheel Energy Storage System (FESS) located on the Greek Island of Naxos is proposed. The optimal configuration for the electromechanical connection between the electrochemical batteries and flywheels is also considered in this study [41]. The methodology is already discussed in previous section of this chapter.

L. Yan-Hua et. al. [85] have presented an approach to solve distributed generations interconnecting with power grid. Wind-PV-ES hybrid system could make full use of clean energy and have high reliability. Smooth switching between grid-connected and islanding mode is important to micro-grid stable operation. The approach proposed an improved control strategy combining master-slave control with peer-to-peer control in order to make transition between grid-connected and islanding mode smoother. The model of Wind-PV-ES hybrid system is built with DigSILENT/Power Factory. The simulation result shows that improved synthesis control strategy could ensure power balance and keep voltage, frequency variation within an allowable range.

In cases where fixed power sources, slow reacting sources, and large load transients exist, supplementary fast-reacting power transmission and adsorption can effectively ensure or restore microgrid stability. A battery based energy storage unit is ideally suited to this requirement, because of the reasonable amount of energy storage that can be managed at a significantly slower rate than the natural time constants that exist in a power system as opposed to a solution implementing a flywheel or super-capacitors [122].

Comparison of different types of batteries is shown in the table 2.1 shown below [138]. The Capital cost vs runtime of energy storage systems, Technology size and weight comparison and Comparison of energy storage system are shown in figures 2.1, 2.2 and 2.3 respectively. Different types of energy storage systems like
battery, Flywheel energy storage and ultracapacitors are compared with reference to different parameters.

<table>
<thead>
<tr>
<th>Environmental impact</th>
<th>Flooded/vented lead-acid</th>
<th>Valve regulated lead-acid</th>
<th>Nickel cadmium</th>
<th>Lithium-ion</th>
<th>Ni-MH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead and acid must be safely disposed of.</td>
<td>Lead and acid must be safely disposed of.</td>
<td>Considered even more toxic than lead-acid.</td>
<td>Highly controlled disposal required.</td>
<td>Not toxic.</td>
<td></td>
</tr>
<tr>
<td>Current Cost (relative to other batteries)</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Modest</td>
</tr>
<tr>
<td>Cost trend</td>
<td>Upward (lead prices)</td>
<td>Upward (lead prices)</td>
<td>Downward (projected 20% lower by 2010)</td>
<td>Downward (projected 40% lower by 2010)</td>
<td>Downward</td>
</tr>
<tr>
<td>Gravimetric Energy Density (Wh/kg)</td>
<td>30 - 40</td>
<td>15 - 40</td>
<td>25 - 55</td>
<td>90 - 200</td>
<td>43 - 70</td>
</tr>
<tr>
<td>Volumetric Energy Density (Wh/l)</td>
<td>60 - 80</td>
<td>55 - 80</td>
<td>30 - 150</td>
<td>220 - 500</td>
<td>82 - 170</td>
</tr>
<tr>
<td>Gravimetric Power Density (W/kg)</td>
<td>180 - 200</td>
<td>75 - 415</td>
<td>50 - 150</td>
<td>750 - 1259</td>
<td>250 - 1100</td>
</tr>
<tr>
<td>Broad Field Performance History</td>
<td>More than 100 years</td>
<td>20 years</td>
<td>15 - 20 years</td>
<td>Less than 5 years</td>
<td>Less than 5 years</td>
</tr>
<tr>
<td>Life Expectancy Range</td>
<td>15 - 20 years</td>
<td>3 - 10 years</td>
<td>10 years</td>
<td>6 - 20 years</td>
<td>5 to 15 years</td>
</tr>
<tr>
<td>Operating Temperature Range</td>
<td>60°F to 77°F (15°C to 25°C)</td>
<td>60°F to 77°F (15°C to 25°C)</td>
<td>-4°F to 140°F (-20°C to 60°C)</td>
<td>-4°F to 140°F (-20°C to 60°C)</td>
<td>-4°F to 140°F (-20°C to 60°C)</td>
</tr>
</tbody>
</table>

Table 2.1 Comparison of different types of batteries

![Image of figure 2.1](image.png)

Figure 2.1 Capital cost vs runtime of energy storage systems
2.4.5 Flywheel Energy Storage Systems

The feasibility of a Renewable Energy Sources (RES)-based stand-alone system for electricity supply based on a Flywheel Energy Storage System (FESS) located on the Greek Island of Naxos. The innovative use of flywheels in parallel connection with electrochemical batteries, as an integrated storage device in the same
power plant, was selected to be simulated as it is a necessary buffer covering the load of a typical house. The optimal configuration for the electromechanical connection between the electrochemical batteries and flywheels is also considered in this study. Finally, it can be concluded that systems with low price flywheels are equivalent to those with electrochemical batteries [41].

The methodology describes the sizing and simulation of a flywheel energy storage system (FESS) for an isolated wind hydrogen-diesel hybrid power system in Ramea, Newfoundland. The objective of the proposed flywheel system is to minimize the voltage sag or swelling due to sudden variations of load or wind speed. Currently the hybrid power system in Ramea consists of diesel generators, wind turbines, hydrogen generator and Electrolyzer. Flywheel energy storage system is designed to provide short term energy backup for the hybrid power system in Ramea [77]. HOMER is used for sizing and simulation of the proposed flywheel energy storage system.

Since a few years ago, electrical energy storage has been attractive as an effective use of electricity and coping with the momentary voltage drop. Above all, flywheel energy storage systems using superconductor have advantages of long life, high energy density, and high efficiency. Our experimental machine uses a superconducting magnetic bearing (SMB) together with a permanent magnet bearing (PMB) and plans to reduce the overall cost and cooling cost. The generating motor is used to rotate the flywheel and to generate electricity from flywheel rotation. The generating motor consists of a 2-phase 4-pole brushless DC motor and a Hall sensor [99], [102]. A purpose of this study is the development of a compact flywheel energy storage system using SMB and PMB with new concept. This paper shows the new model of flywheel by using the concept of yajirobei (balancing toy) that the center of gravity of mass is lower than supporting point. By using this concept, the flywheel has higher storage energy compared with conventional ones. Furthermore, we also purpose to improve and evaluate motor drive (DC motor) to increase the rotational speed, and estimate the system at momentary voltage drop.

N. Chaitanya et. al. [102] have proposed sample wind/diesel/hydro power system on the island of Flores, Azores has been presented. Prior to the FESS being installed the renewable energy penetration on this system was severely limited by system stability. This system was simulated, with a good correspondence between simulations and measurements on the real system. The addition of a FESS in the
system dramatically improved the system stability and allowed a much higher renewable energy penetration with decreased diesel fuel usage.

The energy crisis in Uganda has caused a sharp decline in the growth of the industry sector. This crisis has escalated the power disruptions, which have had adverse effects on various sectors. In this paper an electromechanical flywheel battery is proposed as a better alternative in mitigating energy storage problems. It is found that by replacing the battery storage systems with the electromechanical flywheel battery, a saving of up to 35% on cost of energy can be made in the solar home systems and for the industry sector, the power disruptions could be reduced [127]. The use of electromechanical flywheel battery storage would mitigate the environmental problems associated with lead acid battery disposal. These systems can also be used in health centers; schools and telecommunications base stations as they fall within the power/energy range. Integrating the flywheel system into solar home systems would mean making a saving of 35% per kWh with rural systems. More robust and cheap systems are being designed, tested to improve the performance, durability and viability of the flywheel systems. In addition, more be used for more productive activities like education, health, food and other basic household needs hence addressing the Millennium Development Goals, which includes eradication of poverty among others. Research is ongoing at the University of Cape Town to develop a low cost flywheel specifically for rural areas. Comparison of different energy storage technologies are discussed with reference to economic, charging discharging and number of years of operation [138].

S. Samineni and his co-workers [143] presented a new approach using FESS. The U.S. Navy is looking for methods to maximize the survivability of combat ships during battle conditions. A shipboard power distribution system is a stiff isolated power system that is vulnerable to voltage sags, which arise due to faults or pulsed loads, which can cause interruptions of critical loads. A series voltage injection type flywheel energy storage system (FESS) is used to mitigate voltage sags and maximize the survivability of the ship. The basic circuit consists of an energy storage system, power electronic interface, and a series injection transformer. In this case, the energy storage system consists of a flywheel coupled to an induction machine. The stored energy is used for sag correction for the critical load. Indirect field-oriented control (IDFOC) with space-vector pulse width modulation (SVPWM) is used to control the
induction machine. Sinusoidal PWM is used for controlling the power system side converter. The modeling, simulation, and analysis of a FESS with a power converter interface using PSCAD/EMTDC is presented in the method. The instantaneous voltages are compensated within two cycles to keep the voltage tolerance within 5% of rated voltage. The main advantage of this FESS is low cost and high energy density. It can mitigate long duration voltage sags efficiently. The future work will include more detailed analysis of the energy storage system for unbalanced sags and experimental verification and comparison with a laboratory flywheel interfaced to an analog model power system.

2.5 CONCLUSION

In this chapter an attempt is made to review most of the existing schemes of microgrid in power system networks. The chapter also covers the concepts of the different modes of connection of microgrid, with a bibliographical survey of relevant background, practical requirements, the historical events, the present state and techniques. Comparative evaluation of different techniques is also undertaken for identification of optimum techniques for sizing, design and feasibility for different microgrid locations and applications. The citations listed in this bibliography provide representative sample of current engineering thinking pertaining to next generation microgrid and energy storage system problems. This chapter is based on many research articles published in the last 15 years and periodic bibliographic updates on this topic will be useful as the restructuring and enhancing the performance of power system network. Also, different energy storage techniques, used to store the energy generated by intermittent sources of energy, are considered for hybrid system performance enhancement. Although, numbers of microgrid and energy storage systems have been proposed so far there exists a tremendous scope for further improvement especially on the techno-economic analysis and effectiveness for energy storage systems. A clear consensus is presently heading towards dispatch strategies and other energy storage systems and can handle the present day complex power system and hybrid power system problem.