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A brief Review on Hybrid Energy Storage Systems for Microgrid application

Abstract. *Microgrids are a local group of loads and energy that may or may not be connected to the traditional grid. Microgrids are particularly useful for improving the process and stability of the local electric grid and providing efficient, low-cost, clean energy.In case the central grid is down, microgrids can keep the power flowing by disconnecting or islanding from it. The microgrid's generators and energy storage systems, then serve the microgrid's customers until power is restored on the central grid. Energy storage systems (ESS) in microgrid are used to convert energy from one form to another that can be stored more easily and economically. A single energy storage system cannot be used for fulfilling the power needs due to limited capability, power density, energy and dynamic response and cost. Thus, hybrid energy store systems come into play. A hybrid energy storage system (HESS) has two or more energy storage systems to achieve appropriate power performance. Various configurations of hybrid energy storage systems have been proposed by researchers. A comparison has been drawn among some of such systems.*

Streszczenie. *Mikrosieci to lokalna grupa obciążeń i energii, które mogą, ale nie muszą być podłączone do tradycyjnej sieci. Mikrosieci są szczególnie przydatne do poprawy procesu i stabilności lokalnej sieci elektrycznej oraz dostarczania wydajnej, taniej i czystej energii. W przypadku awarii centralnej sieci mikrosieci mogą utrzymać przepływ energii, odłączając się od niej lub tworząc wyspę. Generatory mikrosieci i systemy magazynowania energii obsługują następnie klientów mikrosieci do czasu przywrócenia zasilania w sieci centralnej. Systemy magazynowania energii (ESS) w mikrosieciach służą do przekształcania energii z jednej formy w inną, która może być magazynowana łatwiej i taniej. Pojedynczy system magazynowania energii nie może być wykorzystany do zaspokojenia zapotrzebowania na moc ze względu na ograniczone możliwości, gęstość mocy, energię i reakcję dynamiczną oraz koszty. W grę wchodzą zatem hybrydowe systemy magazynowania energii. Hybrydowy system magazynowania energii (HESS) ma dwa lub więcej systemów magazynowania energii, aby osiągnąć odpowiednią wydajność energetyczną. Badacze zaproponowali różne konfiguracje hybrydowych systemów magazynowania energii. Dokonano porównania między niektórymi takimi systemami.**(Krótki przegląd hybrydowych systemów magazynowania energii do zastosowania w mikrosieciach)***

Keywords: Hybrid energy storage systems, microgrid application, deterministic algorithms, evolutionary algorithms:-
Słowa kluczowe: algorytm deterministyczny, hybrydowe systemy magazynowania energii

Introduction

To provide for the ever-increasing energy requirements and to reduce the emission of greenhouse gases, we have been using Renewable Energy Sources (RES). These are namely solar and wind energies. The sporadic nature of these sources impacts the power generation unfavourably and thus provides the customer with the problem of irregular supply of power.

Microgrids are small scale power grid that can work in synchronism with the main power grid (i.e. grid connected mode) or can operate independently (i.e. islanded mode). Sometimes they may be used to provide backup power or augment the main power grid during periods of heavy demand. Microgrids mainly consist of three components: renewable generators, cluster of loads and energy storage systems [1].

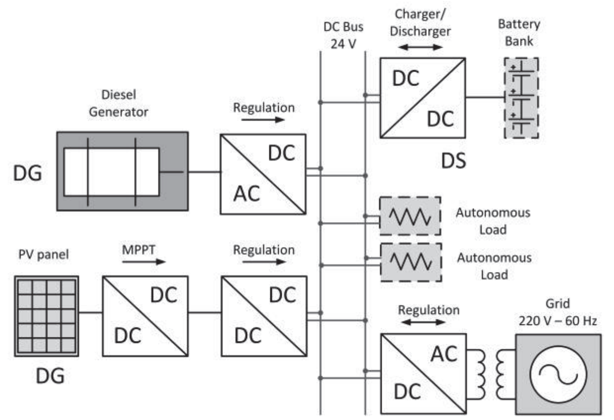

Fig. 1. Block Diagram of Microgrid [2]

The key attributes of an ESS technology are energy density and power density. Energy density is defined as the total energy a system can store for a given mass/volume. Therefore, a device with a higher energy density can supply energy longer to any load. Power density is defined how quickly the device can deliver energy. ESSs like fuel cells and Li –ion batteries, which have high energy density, but low power density has slowed dynamic response. Whereas ESSs like SCs and flywheels, which have high power density, but low energy density can deliver high power but reduces lifespan [3]. At present there are no storage systems that can meet these requirements sufficiently and thus we use HESS. Thus, HESS has a combination of both high energy storage, which meets the long term energy need and high power storage, which delivers the peak powers [4][5].

Various combinations of energy generating systems and energy storage systems are connected together in a hybrid power supply system. Hybrid storage systems like flywheel/capacitor, battery/capacitor are used for the advancement of certain parameters like the frequency control. These are further used with a photovoltaic unit or in a wind energy production system. The size of battery is important to decide to implement it with any plant. The battery capacity, energy storage estimation, cost and benefits may be decided optimally with the help of data gathered for few days or month [6]. A systematic coordination is necessary between the above mentioned energy storage and energy generating units. Hybrid electrical energy storage (HEES) can generate/absorb reactive power without using its real energy (kWh) and has no time limit. Power quality and stability can be improved with HESS using active and reactive power to handle to mitigate voltage instability, harmonics, frequency regulation, load following and ramping, and partial unpredictability in RE output during critical load times, hourly changes in demand throughout the day caused by disorderly inconsistency of RE generation. A HESS is now a viable solution for supporting microgrid and even suggested for electric vehicles which can again be part of microgrds [7], [8].

TYPES OF ENERGY STORAGE SOURCES

As mentioned previously, various types of energy storages can be used in HESS (Table 2). These can be either the basic energy storing devices or a combination of them. As given in the table below, energy storage types can be electrical, mechanical, and chemical and their sub types like electrostatic, magnetic or potential and kinetic and so on. These energy types can be stored in either the basic storage devices or a hybrid version of them. A comparison of energy storage devices has been done in Table 2.

Table 1. Types of energy storage technologies

S.No	Types of Energy Storage	Examples
1.	ELECTRICAL	
1.1	Magnetic	SMES
1.2	Electrostatic	Super Capacitor
2.	MECHANICAL	
2.1	Potential	CASE, PHS
2.2	Kinetic	Flywheel
3.	ELECTROCHEMICAL	Li-ion,Lead acid battery
4.	CHEMICAL	Fuel cell

0.1 Chemical battery

Chemical battery stores chemical potential energy and converts it to electricity. Batteries are very advantageous due to their higher energy density, minimal self-discharging rate, minimal cost, extended life. However, there are some limitations like lower power density and greater temperature dependency. A critical parameter determining battery life is that the way of charging them.

0.2 Flywheel

It is the foremost unique of all the devices used for energy storage thanks to their capability of supplying high power as and when required. The design of the motor generator is extremely critical because it determines the speed of recharging and drawing out energy from the flywheel. This rate is often very high. Flywheels are widely employed and are one among the oldest, simplest, mechanical devices. Their most prominent feature is their ability to store high amount of energy during a short time period; this is often where they surpass batteries. So if flywheel is used with a battery in a HESS there is a very high probability that the performance of the HESS will increase.

0.3 Super Capacitor

Capacitor is one of the easiest and direct ways to store electric charge. The essential construction of a Capacitor comprises two conducting metal plates and a dielectric in between. On charging one among the metal plates, the positive and negative charges are aligned on both its surfaces accordingly. This induces an opposite charge on the corresponding surface of the second metal plate. Their advantage over conventional batteries is their ability to be charged extremely fast and may be recycled multiple times without affecting their efficiency. They were initially developed to handle short summer peak loads with small capacities. However, a serious limitation posed by practical capacitors is their low energy density. For adequate requirement of the capacity of the capacitor, area of the metal plates has to be increased accordingly. Thus, use of huge capacitors is not economically viable neither practically possible.

0.4 Fuel Cell

A battery is used as an energy storing device whereas a fuel cell is used as an energy generating device. It generates energy from fuel. A Fuel cell can consist of a battery. A Fuel cell has a cycle life of 20 years as mentioned in the table below. One of its many advantages include that it does not self-discharge. Other energy storing devices are known to have shown self-discharging properties. It basically converts the fuel's chemical energy to electrical energy.

HYBRIDIZATION BENEFITS AND APPLICATIONS

Power system stability is defined by the three characteristics as phase angle stability, frequency stability and voltage stability. The principle target of the system operator is to guarantee the system security with a significant level of dependability,accessibility and quality from the transmission level, to distribution and lastly down to the end clients arranged on the low voltage levels of the network. An expansion in the integration of renewable energy generation in the power system brings along certain difficulties to energy systems. The renewable energy generation source comprises of wind power, hydro power, solar photovoltaic source and biomass based generation. Excess power generation and unregulated energy generation are the primary limitations to the active side. Similarly, for the load side, excessive or unregulated energy demand or nonlinear load will degenerate the power quality of the energy networks. Energy systems should be managed for the grid steadiness and effectiveness of sustainable energy utilisation. Wind turbines mechanical power in form of wind's kinetic energy into electrical energy [9]. Sun powered advancements utilize the sun based energy of the sun legitimately, and afterward it produces heat, light, and power.Sun based Photovoltaic (PV) Technology includes changing over sun oriented vitality legitimately into electrical vitality by a sun powered cell. A sun powered cell is commonly made of semiconductor materials crystalline silicon that ingests daylight and produces power through a procedure called the photovoltaic impact.

It is seen that there are huge varieties in system inertia that happen during a day. At evening time, the demand diminishes, in this way fewer power plants are worked and in this way the inertia is lower. During high demand, the inverse is valid. On contrasting the situations and sans renewables, it has been seen that the inertia drops essentially while integrating renewable into the generation mix. This is because of the more smaller number of working generators. Along these lines, particularly at nights, the integration of renewable prompts an exceptionally low inertia. Since solar power coincides with time of high demand (high inertia), the impact of solar power on inertia of the system will be smaller than that of wind, which will happen during both high and low demand.The total power system inertia comprises combined inertia of most of spinning generation and load connected to the power system. By integrating more and more renewables in the generation mix, the inertia drops, and the power system can even become completely inertia less.One of the important tasks in current day research is to provide new control strategies for such inertia less systems as a whole, as well as to include so-called 'virtual inertia' in the control of inverter-fed renewable energy sources connected to the power system[10].

It is of paramount importance that in a power system there is a requirement of reactive power (VAR) for maintaining the voltage for deliverance of active power through transmission lines. Various loads such as Motor require reactive power to build up magnetic field[11].If the reactive power is in sufficient, the voltage decreases and subsequently it becomes an impossible task to satisfy the power demand of

Table 2. Comparison of energy storage devices

Device	Power Density (W/Kg)	Energy Density (Wh/Kg)	Cycle Life	Self-Discharging Rate per day
Lead-Acid Battery	75-300	30-50	500-800	0.1-0.3
Ni-Cd Battery	150-300	50-75	2000-2500	0.2–0.6
NiMH Battery	250-1000	60-80	500-1000	0.5–1
Li-ion Battery	250-340	100-250	1000-10000+	0.1–0.3
NaS Battery	150-230	150-240	2500	20
Super Capacitor	100000+	2.5-15	50000+	20–40
Fuel Cell	Different	Different	20 yrs	Not Possible
Fly Wheel	400-1500	10-30	20000+	100

the loads through the transmission lines. So, it is very useful for controlling voltage.Inductive equipment (induction motor / generator,transformer, transmission line) consumes reactive power i.e. I to lag behind V. Capacitive equipment(capacitor) generates reactive power i.e. V to lag behind I. However, the most prominent feature of reactive power is its ability to be generated / absorbed purely by power electronic converter.

HESS CAPACITY SIZING

Sizing the ESS is done by obtaining the correct ESS power and energy capacity to satisfy the unique technical requirements of the MGs. Total expenditure and reliability of system should be two factors that must be considered while considering the capacity sizing procedure [12]. The different approaches of HESS capacity sizing are given in the following flowchart Fig2.

Fig. 2. Capacity Sizing Methods

0.5 Analytical Method

The most commonly used HESS sizing method is the Analytical method. Various power system configurations are studied and system variables are adjusted alongside performance standards. The difference between distribution generations (DG) output power and load consumption determines the operation of HESS[13].

P_{HESS}=P_{DG}-P_{LOAD}

- P_{HESS}<0 corresponds to when load power requirement is more than output power of DGs. In this case the HESS is discharging to provide power to the load.
- P_{HESS}>0 corresponds to when load power requirement is completely fulfilled by the DGs and remaining power charges the HESS.

It does not depend on control strategy, technology or topology. These methods are very straightforward and uncomplicated. This method is a computationally less intensive tool.

0.6 Statistical Method

Statistical methods are more advantageous than analytical methods to determine the energy storage capability in some uses. When available data is inadequate, this method can be used to produce synthetic data. Systems obtained using this method will be mostly indifferent to variation of system parameters.

0.7 Search Bases Method

0.7.1 Heuristic Methods(HM)

To dodge complicated derivatives in non-linear optimization, these methods are used. It is incapable to denote the dynamic functioning of HESS. The best solution may not be accomplished in certain cases.

0.7.2 Mathematical Optimization Methods

The solution can be found in limited number of steps using this method. But when the problem is more compound, mainly for non-linear programming circumstances, this method faces problems in reaching an optimum result[13].

0.8 Pinch Analysis

Pinch analysis is a simple and flexible methodology for minimising energy consumption of chemical processes [14].It is performed by computing thermodynamically possible energy levels. These levels are then reached by regulating temperature, energy supply methods and driving conditions. This computational tool causes less inconvenience.

0.9 Ragone Theory Method

In this plot, the y axis depicts energy available per unit mass or energy density whereas the x axis depicts rate at which the energy is made available or power density. A point in a Ragone plot represents an energy device or technology [15].Ragone plots help in giving information about gravimetric energy density, but not about volumetric energy density. It can be defined for any type of ESS. It can also display the cost impact. The dynamic nature of HESS cannot be properly represented using this method.

HYBRID ENEGRY STORAGES POWER CONVERTOR TOPOLOGIES

There are multiple ways in which HESS can be linked to the MG. Different topologies are applied to combine high power storage (HPS) and high energy storage (HES). There are primarily three types of topologies: active, semi-active and passive Fig3. Based on factors like controllability, cost and efficiency, the most favourable topology is considered[16].

0.10 Passive Topology

The two storages are simply connected with same voltages in passive topology. Internal resistance and current voltage attributes define the power distribution between two sources. The terminal voltage of the storages is not regulated. Therefore, the accessible energy from high power systems is very

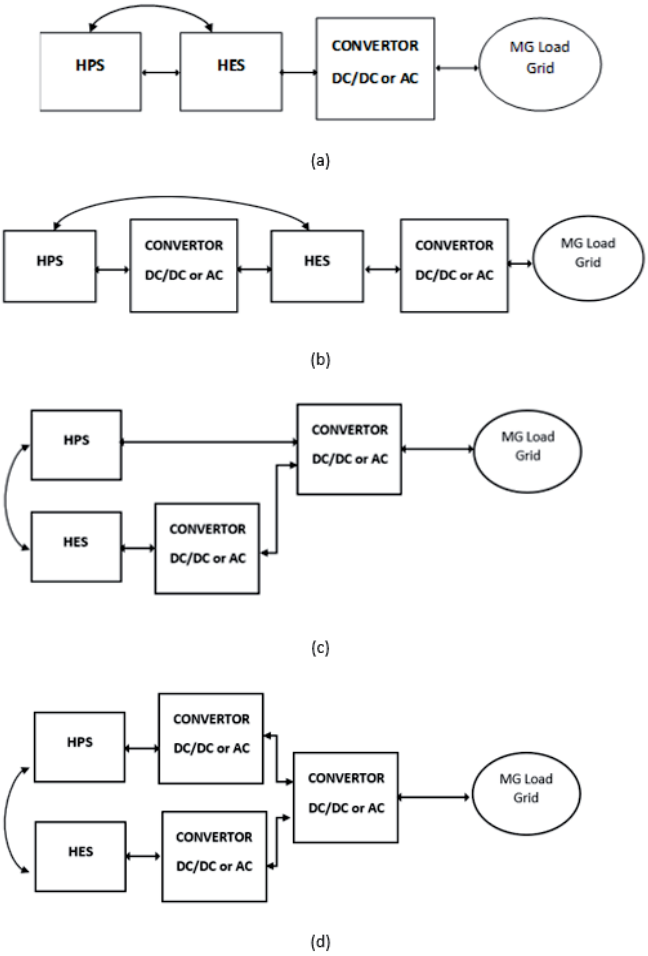

Fig. 3. Types of convertor topologies: (a) Passive topology (b) Semi-active topology (c) Series Active topology (d) Parallel active topology [13]

constrained and it behaves as a low pass filter. It is the most economical topology.

0.11 B. Semi Active Topology

One of the storages is linked to the dc bus and the other storage has a power convertor inserted at its top. This topology presents more controllability and dispatch capacity, but the use of converter needs more installation space and is more costly.

0.12 Active Topology

This topology can have multiple energy sources. Individual power convertors are used to link each source to the system. Even though by using more convertors, the cost and complexity of the system increases yet this topology is more effective than other. Every power source can be operated actively. In an active topology, advanced control programs can be applied. Thus, its controllability is increased.

HESS ENERGY MANAGEMENT AND CONTROL

It is essential to control and optimize power flow distribution for a good operation of any HESS. A number of different control and energy management concepts have been studied so far. As evident from Fig.4 and Fig.5, rule-based and optimization-based are the two main concepts of energy management. Rule-based approaches are implemented for real-time applications as they can accommodate imprecise measurements and slight component variations effectively. Mathematical models are used to frame the rules. Optimization-based concepts are applied for minimization of cost function. Rule based approaches include Deterministic and Fuzzy Logic and they are widely used due to their simplicity and practicality. Optimization based further include off line and real time. Optimization Techniques are used to reduce the global energy consumption and avoid highest power peaks. Optimization based approach improves the battery life time as well.

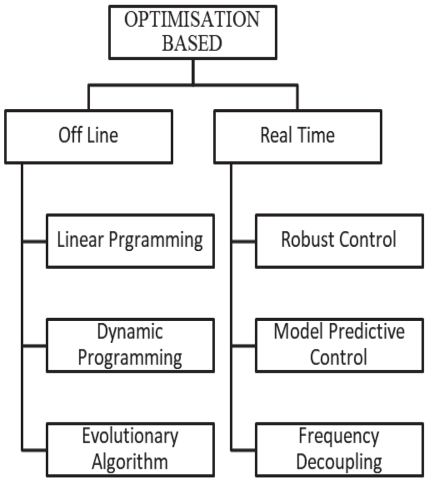

Fig. 4. Optimization based energy management

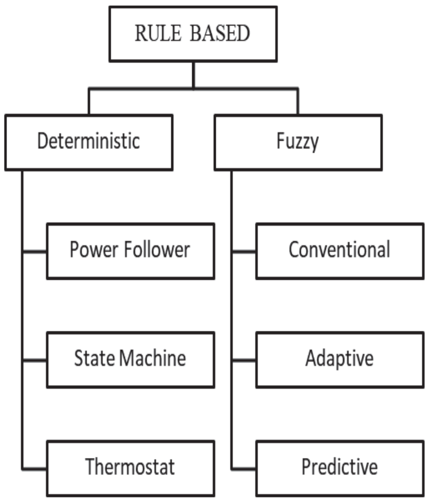

Fig. 5. Rule based energy management

TYPES OF HESS

A comparison table containing proposed HESS systems are given in Table 3 and 4.

CONCLUSION

This paper is for educational purposes and helps for the future work to have a better understanding about Hybrid Energy Storage System (HESS).In this paper various types of hybrid energy storage systems and its integration with renewable energy sources is learned and investigated. HESS helps in active power control and support frequency regulation of the micro grid system during sudden power imbalance in the micro grid.

Table 3. Comparison of different systems proposed

Ref. No.	Grid Connected / Islanded Mode	Energy Source	Storage Technology	Sizing Methods	Objective Function	Summary and Advantage
[17]	Islanded	PV, Wind, Diesel	FC, SC FC, SC	Analytical method	Maximum FC life	A comparison between two storage systems (one is only FC and the other is a combination/hybrid of SC+FC) is done. The hybrid system has advantages over the only FC model: longer lifetime, faster response and power peaks are provided which cannot be reached by SC alone. The efficiency of the hybrid system is 8.5% higher.
[18]	Grid connected and islanded both	PV, Wind	Flywheel, SC, CAES,NAS, Lead Acid	Search based methods	Optimum allocation of HESS	It studies 5 ESS and different combinations of HESS including these. It analyses the HESSs on the basis of lifespan, environmental impact, load shifting and yearly cost. With proper capacity optimization, the cost in grid connected mode and dependability in islanded modes are improved.
[19]	Islanded	PV	FC, Battery	Analytical method	Minimise net present cost (NPC) and declining capacity of carbon dioxide emissions	A case study was conducted in Tehran, which has huge potential for PV waiting to be tapped and three scenarios were considered: only battery, only FC and a hybrid of FC. Energy Hub concept is used for capacity optimization. The hybrid system was more cost efficient and dependable. The studies found out that there was a 15% decrease in NPC with 24% increase in solar potential.
[20]	Grid connected	PV, Wind	Battery, SC	Search based methods	Reduce Greenhouse emissions	In this paper, the capacity sizing of hybrid storage and hybrid power generation system is done concurrently. The results have been verified using real power requirements, solar and wind energy captured. The proposed solution leads to reduced greenhouse gas emissions, increases longevity and increased consistency.
[21]	Grid connected	Wind	Lead-acid Battery, SC	Ragone plot	Minimise life cycle expense	The sporadic nature of wind energy is overcome by using hybrid electrical energy storage. The high power density from SC and high energy density from lead acid battery help in balancing the fluctuations. Ragone plot method is used to optimise the system and to reduce the life cycle expense.

Table 4. Comparison of different systems proposed (continued)

Ref. No.	Grid Connected / Islanded Mode	Energy Source	Storage Technology	Sizing Methods	Objective Function	Summary and Advantage
[22]	Islanded	PV, Wind	SMES, Battery	Analytical Method	Use of dynamic droop control to increase stability of the system.	Since the batteries have low number of cycles and therefore cannot provide high currents, a hybrid system with SMES is able to do so. It takes benefit of dynamic droop control to manage droop gains for both. It provides better frequency and voltage stability. The study was based on Uligam Island of Maldives.
[23]	Islanded	PV, Wind, Diesel	FC, Battery	Search Based Method	To satisfy load demand in cost-effective way.	Harmony Search Algorithm is developed for optimal sizing of components in the system. The economic aspects of the traditional system are compared with and results are given. The main focus is on modelling, cost-analysis and sizing of the hybrid system.
[24]	Grid connected	PV	Battery, SC	Analytical Method	Minimising the life cycle cost	Suggests a methodology to assess to the economic viability and optimal capacity of a HESS. It analyses PV power plant performance under various HESS capacity and suggests an optimal capacity design of HESS and describes a cost benefit function of HESS.
[25]	Islanded Mode	PV	Battery, SC, FC	Pinch Analysis Method	Minimising the annual cost	The study suggests a generic sizing methodology that uses pinch analysis and design space approach for HESS in a PV based remote power system. It studies the variability in load and generation, sizing methodology. A case study is done where a remote village and a telecom tower are selected for off grid variable and constant load respectively.

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