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Power Fluctuation Control in Hybrid Renewable Energy Systems Using Particle Swarm Optimization: A Comparative Study

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ABSTRACT
Renewable energy sources such as wind power and solar energy have strong volatility and intermittence, while hybrid energy storage plays an important role in power balance of microgrid and smooth power fluctuation of renewable energy. In recent years, with the rapid development of microgrid, it has become a highly efficient and flexible new distribution power grid that can be tightly integrated with existing power systems. The proportion of renewable energy power generation is increasing. The variability and intermittency of light intensity, caused by cloud movement and weather conditions, can create fluctuation in the photovoltaic (PV) power generation. The word "optimize" means to evaluate the best solution. Thus, optimization is finding the optimal solution of a given problem by considering the objective function using randomly selected inputs from a bounded set of keys. Power Engineering involves decision-making and problem solving on every project design, development, construction, operation, and maintenance. These processes aim to either minimize cost or maximize productivity, depending on any number of process variables. This article is related to a comparative study of use of various optimization techniques for controlling of power fluctuation in a hybrid system.
Keywords — Hybrid power system; Optimization techniques; Particle swarm optimization; battery energy storage system (BESS).

I. INTRODUCTION

The word "optimize" means to evaluate the best solution. Thus, optimization is finding the optimal solution of a given problem by considering the objective function using randomly selected inputs from a bounded set of keys. Power Engineering involves decision-making and problem solving on every project design, development, construction, operation, and maintenance. These processes aim to either minimize cost or maximize productivity, depending on any number of process variables. Thus, optimization is a complex problem-solving technique that computes the optimum solution set of decision variables while ensuring that all concerned constraints and limitations are met. Every optimization problem is unique because there is no single method/strategy to solve an optimization problem. Hence, many optimization techniques and tools have been developed over time, each implementing some unique feature for solution-finding. Also, different optimization problems may yield different results for the same problem.

The branch of mathematics that encapsulates complex decision-making and solution finding problems is termed Operation Research. Its history can be traced back to a period even before World War II. Operations Research involves various mathematical programming techniques, stochastic process techniques, and statistical methods. Mathematical techniques involve problem-solving based on a set of decision variables bounded by a group of constraints. Stochastic techniques include analysis of randomly selected input variables having known probabilistic distribution functions. Statistical methods include modeling physical problems based on experimental data. Most optimization techniques and algorithms developed are based on mathematical programming, which is highly applicable for engineering applications.

The design and operation of HRES present many computationally complex decision-making scenarios. Real-time problems in HRES are dynamic and complex, and computation of all possible solutions becomes simply impossible. This necessitates the application of optimization tools and techniques for solving them, most of which are based on heuristic and meta-heuristic algorithms. Heuristics use trial-and-error strategies with learning methods and are known to find optimal solutions in a short time. However, they cannot be accurate and do not yield the best results.

Further development led to metaheuristic algorithms in the 1980s and '90s, which are more complex but are guaranteed to provide the best results. At times the best result may be difficult to implement. Hence the aim should be to find the most optimal and feasible solution which satisfies all constraint criteria. Most metaheuristic algorithms are nature-inspired which emulate a particular natural process to find the optimal solution. Some of these algorithms are trajectory-based (hill-climbing) or population-based (GA, PSO). Here tabulates the timeline of various metaheuristic optimization algorithms developed.

One of the significant issues in HRES is the optimal planning and sizing of the system components to minimize/maximize an objective function satisfying the given constraints. To solve the optimization problem applied to Hybrid Renewable Energy Systems many traditional and artificial intelligence based optimization techniques. All these techniques should efficiently search, to find an optimal combination of the system components, such as number and type of PV panel, slope of the PV panels, number and type of wind turbine, hub height of the wind turbines and number of batteries, to maximize the reliability and minimize the cost, without over/under sizing the system components.

II. LITERATURE REVIEW

Rohani et al. (2010) analyzed the feasibility of a hybrid system using HOMER. The proposed system consisted of a PV system with a storage battery system and wind turbine. To further increase the reliability of the power supply, fuel cells were used. The plan was so designed that PV and wind fed the load for the regular operation, whereas battery and fuel cells would be used for backup supply. The simulation results showed that the distributed generation using PV with battery storage, wind, and fuel cells would offer an economical and environmentally friendly solution for the remote location in the islanded mode operation.

Kanchev et al.(2011) proposed an energy management system for a microgrid. The analyzed microgrid consisted of PV with a battery storage system and micro gas turbine. The implementation of the energy management system was carried out in two parts, one system to manage at the main microgrid level, i.e., the generation site, and the other system to manage local power variations. A communication network was designed for the transfer of data between two systems. The system evaluated the PV generation by predicting the weather forecast. Thus, the proposed energy management system, by taking the reference of power generation and forecasting local variables, managed the power flow by different sources.

Raju et al. (2012) analyzed the control of inverter for the interconnection of distributed generation system to the grid. The proposed method was designed and analyzed using MATLAB/Simulink. The scheme used a three-phase four-leg inverter controller, which could be used to deliver AC power to the grid and also compensate for different network parameters like current unbalance and load current harmonics. It could also provide reactive power requirement of load, thus eliminating the requirement of extra power conditioning equipment. The controller was designed so that the inverter could transfer bidirectional power with the feeder.

Kusakana et al. (2013) investigated the possibility of using and developing hydro kinetic power to supply reliable, affordable and sustainable electricity to rural, remote and isolated loads in rural South Africa where good water resource was available. HOMER software was used to simulate the model, and the results were compared with other supply options. It was concluded that the proposed system was the best possible solution among the available options. The system offered economic and green supply to the region.

Malla et al. (2014) analyzed standalone Photovoltaic–Diesel Generator–Battery system during weather variations. The power output of the PV system varied with sudden clouding. MATLAB was used for designing and simulation the standalone model. Takagi–Surgeon (TS) fuzzy based dc voltage control was proposed to get maximum power during clouding. Under light load conditions, reloaded operation of PV from its entire power point (MPP) was incorporated to maintain absolute power balance of system, and frequent ON/OFF operation of DG was avoided. The proposed inverter control helped keep balanced PCC voltages and balanced DG currents under unbalanced load conditions. The balancing of DG currents reduced the oscillations in generator torque which increased the fatigue life of the shaft. Moreover, the inverter control also led the inverter to supply the reactive power required by the load. Hence, DG need not supply reactive power, thus reducing the atmosphere's diesel consumption and Greenhouse gases.

Tobnaghi et al. (2015)discussed the effect of solar radiation and temperature on the performance of Solar cells. A reflective lamp was used to illuminate the solar cells, and measurements were performed at 15º, 25ºand 500ºC for temperature changes taking illumination constant. For radiation effect, measures were taken at light intensities of 1000, 800, and 500 W/m2, keeping the temperature consistent. Effects of location, orientation, and tilt angles were also studied. The output of solar cells was high at higher intensities and higher temperatures.

Mohammed et al. (2016) presented an assessment of PV Modules Degradation based on the performances and visual inspection in Algerian Sahara. With time, the output power of the modules decreased due to an increase in series resistance and decrease in shunt resistance, the degradation rate ranging between 33% and 7% in 11 years of operating, the yearly average speed is around 1.5%. The different types of degradations that can be visually noticed were de-lamination, burn marks due to hot spots, cracks, defects in anti-reflective coatings, discoloration of encapsulating, etc.

Yi et al. (2017) proposed the energy management system monitoring technology of hybrid photovoltaic cell systems under cameras and islands. The PV array is connected to the bus array via a DC / DC boost converter in this topology. The battery pack uses two DC / DC boost converters to control the charging and output processes. . There is also a lo20ad AC that consumes power on the bus. In addition, when the photovoltaic power fluctuates due to unstable inequality or the photovoltaic line dies due to a fault, CAPMS can ensure a reliable power supply to the system.

Acharya et al. (2018) proposed a power imbalance mitigation strategy to use power-required inverters and to manage the demand side in a separate MG. Photovoltaic media-connected inverters and thermostatically controlled loads are used as agents to alleviate power imbalances driven by the power generation side and the demand side. TCL's control not only reduces VU but also keeps customers safe. To verify TCL's ability to participate in VU mitigation, a less balanced load bending was adjusted.

Hou Houcheng et al. (2019) Renewable energy such as wind and solar power are highly volatile and fragmented. Hybrid energy storage plays an essential role in the current balance and the variability of the microbalance of renewable energy. The hybrid energy generation method is proposed to aim at Microgrid Island operating modes, including wind energy, photovoltaic systems, and conventional loans. A mathematical objective improvement model is proposed based on the power and output power and state (SOC) of the energy storage media. This model has the lowest average and minimum variability in renewable energy production. Given the situation where the capacity of the energy storage media is too low or too high, a power adjustment strategy based on ambiguous control was developed. Finally, the validity and efficiency of the proposed method were verified using the MATLAB program.

Jingnan Zhang et al. (2020)There is a lot of heavy load at the end of the hull, and many activities such as starting and stopping the ship, restoring, and controlling will have a significant impact on the cost of the DC bus. On the hull, threatening the safety of navigation. And based on the system design of the hybrid energy storage system in the ship's network, it can reduce the problem of bus cost fluctuations. Therefore, studying the efficiency and cost improvement of hybrid energy storage systems has practical value and importance. This paper presents a life-based hybrid energy storage model and a cost-equivalent model. It offers a hybrid energy storage system modeling conditions to enhance the capacity of a hybrid energy storage system.

Yang Rui et al. (2021) aim is to monitor and improve the work strategy for a multi-power vessel energy management system. First, a combined energy conversion model between diesel engines, energy storage, new energy, and loads was developed to improve the power distribution of ships with multiple energy sources. An improved particle swarm algorithm is proposed to enhance the plans of multiple gas generators in multiple power plants, and a strategy to mitigate the fluctuations in the fuel capacity of many power vessels based on a virtual battery model is proposed.

III. HYBRID RENEWABLE ENERGY STORAGE STSTEM

Speculations on future energy scenarios are ripe across the globe. But, oil and natural gas alone will not remain dominant sources of power for the future. Countries worldwide are seeking greener ways to meet their energy demands, which are economically and environmentally sustainable. In the past, renewable power was only advocated by scientists and environmentalists, but declining costs and expanding markets have emerged as an implementable solution to improve energy security. The total energy supplied by the renewable sources is 76 EJ with an investment of 214.4 billion USD in 2013, a 30% increase from 2004 as per REN21 (2014). In 2013, about 560 GW of power was generated from renewable systems.

By the end of the 21st century, it became clear that conventional centralized generations could no longer electrify remote customers at a competitive price due to many challenges in the grid. This past decade has been a “Decade of Change” for renewable power sectors and renewables, which are now viewed as economic drivers for creating jobs, diversifying revenue and energy portfolios, and stimulating technical innovations. Their abundant availability and diversity have enabled Distributed Generation (DG) to develop as an alternative solution for grid expansion. Micro and smart grids emerged as modern, small-scale grids connecting distributed generators to localized loads that may act independently or connected to the power grid.

A. Issues in Integrating Renewables in HRES

Many challenges are to be met for the successful implementation and operation of the HRES based DG system. Renewable power systems suffer from power quality and intermittency issues and also require significant investments. Different energy sources have different energy costs associated with them like Combustion Heat to Power (CHP) engines cost only about 1100 $/kWh whereas, fuel cells are expensive amounting to 22000 $/kWh. Thus, setting up an HRES needs a deep understanding and economic analysis of various available DER options. With support from government policies and cutting-edge innovations, many a cost of renewable power generation systems is coming down, thus promoting investments in green energy. Unpredictability and non-controllability of renewable power sources prove to be a massive issue while interconnecting renewable with the power grid. The grid connectors ensure that any faulty disturbance or imbalance originating in the DER’s of the HRES is not transmitted to the grid. Many nations having > 60% of renewable penetration are currently facing this considerable challenge. Forecasting, better and improved grid management, and stricter grid code enforcements are considered options for managing this issue. Quality issues from voltage sag/swell to harmonics to LVRT/HVRT can be caused in the DER’s and their connected power converters, which may affect the quality of power delivered to the consumer and endanger the grid. All these factors are foreseen, and appropriate control strategies are implemented before connecting the HRES with the grid. DG’s of MG’s must be provided with required connectivity controls to ensure a smooth transition from isolated or grid-connected mode.

Many economic implications need to be addressed for HRES DG’s. Operating a DG in a liberalized market will enable DG operators to break the monopoly of power markets. Thus market liberalization and deregulation and its further impact on generators and consumers of energy need to be explored. Even this is lacking without proper regulatory frameworks to ensure monetary and energy transfers between the grid operators and HRES DG systems. Thus a fitting legal design needs to be in place for modernizing and liberalization of power systems.

B. Need for Energy Storage in HRES

Spinning Reserve and Short-term backup: Coal and oil-based power generators provide turnover storage for conventional energy systems. ESS can be used as a power supply for HRES DG to help increase power when needed. They can respond in a matter of minutes to a few seconds, while oil-based systems require a lot of start-up time and acceleration.

Load leveling and final shaving: If a renewable system is used, it generates electricity when there is a natural resource, not necessarily during peak demand. Therefore, this energy inequality can result in power outages and power losses. Through the ESS, this non -uniform energy can be transferred to meet the peak of demand and correct the load deflection. You can also use ESS to educate customers on energy efficiency, demand response planning, energy use, and consumer protection to achieve a balanced cost reduction.

Integration of renewable energy into the DG: the ESS can eliminate non-compliance with renewable energy. European countries with solid solar access have noticed a phenomenon called duck shape curvature more than their energy. This happens at night when the entire solar power is depleted and the night's peak appears immediately, which poses a challenge for network regulators to increase power generation to increase demand. This can be prevented by applying the ESS to compensate for the duck curvature. As mentioned earlier, ESS can effectively eliminate renewable energy changes.

Power quality support: ESS can improve power quality, such as low power output and power control. The ESS used needs high density and short response times, such as flywheels and supercapacitors.

Long-term stroke: Dams and reservoirs have been used to store water for electricity generation since ancient times. More heat and air storage systems have recently been described to store electrical energy in large quantities. They have been proven to reduce the cost of energy savings and ensure long-term energy storage (e.g., a few days to a few months).

C. Types of Energy Storages Systems

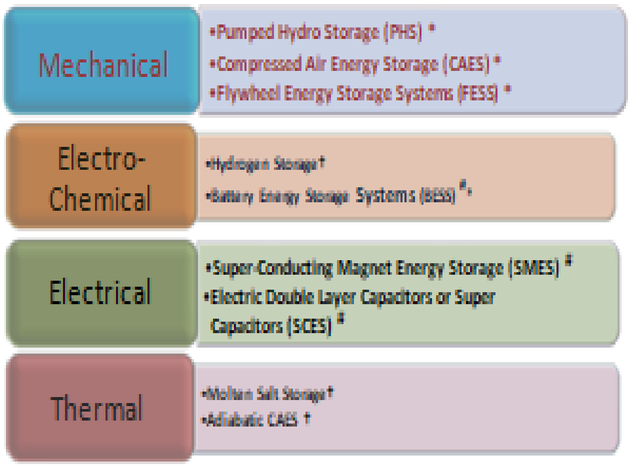

Fig. 1 Energy Storages Systems

Storing energy for later use has been practiced since olden times. But recent technological developments and innovations have enabled various forms of energy storage technologies, as listed in Fig 1.

Pumped Hydro Storage (PHS): Hydro storage systems store water in natural or artificially constructed confinement areas like dams and reservoirs. This water is then made to run through turbines to capture their kinetic energy and convert it into electricity. They include about 95% of the world's energy storage capacity. Pumped hydro storage comprises two reservoirs of water located at different elevations. When water flows from the upper reservoir to the lower reservoir `electricity is generated. Low-demand energy can be saved by using electric power to pump the water from the lower reservoir to the upper reservoir. The efficiency of such systems depends on the efficiencies of pumps, turbines, and storage capacity, and it is estimated to be around 70-80%. They can hold substantial energy capacities for many months and have long lifetimes of about 50-60 years. Disadvantages of PHS include geographical limitations, availability of water, significant investment costs, and more extended gestation periods. Further advancements in the PHS have speed pumping and response improvement control to enable usage of PHS in ramping applications.

IV. PARTICLE SWARM OPTIMIZATION TECHNIQUE

Particle Swarm Optimization (PSO) is a stochastic optimization technique. Created by Dr. Kennedy and Dr. It was Eberhart in 1995. Similar to the behavior of a flock of birds, the algorithm mimics the pattern of a chicken in flight to find the best feeding path. Compared to a genetic algorithm (GA), a combined micro -algorithm has many advantages such as fewer parameters that need to be adjusted, higher computational efficiency, and higher conversion efficiency. PSOs have been widely used in various industries, such as enhancing automatic monitoring to detect ovarian cancer patient areas, improving global solar radiation estimates, and improving load balancing. Mechanics [24]. One of the most common uses of a PSO is to determine the monitor's battery usage in car-powered applications. Another popular application is optimal energy management in hybrid noise systems. Ismail proposed a PSO-based method for evaluating the SOC of a lithium-ion battery. This method uses a region model with the same circuit type to estimate the SOC of a LiFePO4 battery. This article focuses on using an electrochemical battery model based on the chemical structure of a lithium cobalt oxide (LCO) cathode. Evaluate SOC based on PSO.

In many studies, balanced power generation and load requirements strategies have been developed and implemented to control and balance the system according to load/power generation changes or network/supply interruptions. Take control of the Microgrid frequency; based on the BESS analysis method, the balanced generation, and load application are proposed and performed at the best level. The best results and models are based on the analysis method. BESS is not offered. Results and answers of the determination of the optimal size of the BESS-based PSO are presented in the discussion section. The best gold standard based on the BESS analysis method is determining the minimum BESS scale from the minimum BESS price to balance power generation and load after the loss of a public network. And to prevent microgrid instability and system collapse. Displays the overall flow chart at the optimum level of the BESS -based analysis method.

V. CONCLUSIONS

A hybrid electricity generation system is a better and more efficient electricity generation solution than traditional energy. It has higher efficiency. It can be delivered to remote areas that the government cannot reach. So that electricity can be used where it is generated, thereby reducing transmission losses and costs. The cost can be reduced by increasing the output of the equipment. People must actively use unconventional energy. It is very safe for the environment because it does not generate emissions and hazardous waste like traditional energy sources. This is a cost-effective solution for electricity production. It only requires an initial investment. Its lifespan is also very long. All in all, it is a good, reliable and economical solution for electricity production. After this detailed study of particle swarm optimization technique we have concluded that it is one of the best technique for controlling of power fluctuation in case of hybrid renewable energy system.

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