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Swarm intelligence for the optimization of microgrid fed from hybrid energy sources

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Abstract

An effective optimization method for handling the intricacies of microgrids powered by hybrid energy sources has arisen: swarm intelligence. This approach takes its cues from the cooperative behavior of natural systems like ant colonies, bird flocks, and fish schools. Powering these systems are a variety of renewable and non-renewable resources, including solar photovoltaics, wind turbines, biomass, and diesel generators. Efficient power generation, load management, and cost optimization are greatly hindered by the inherent unpredictability, intermittency, and uncertainty of renewable sources. Some swarm intelligence algorithms that can tackle these problems effectively include Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), and Artificial Bee Colony (ABC). Reduce operating costs and improve system stability by optimizing power flow, economic dispatch, and energy storage management using algorithms that mimic cooperative decision-making and distributed problem-solving. In addition, swarm-based approaches can optimize performance in real-time by dynamically adapting to changing environmental conditions, load demands, and fault scenarios. Sustainable and cost-effective energy management is supported by this paper's focus on the application of swarm intelligence in optimizing hybrid energy-fed microgrids. It highlights the advantages of swarm intelligence over conventional optimization approaches in terms of convergence speed, scalability, and robustness.

Keywords: Swarm intelligence, optimization, microgrid fed, hybrid energy

Introduction

There has been an electric power system in operation for about a hundred years. A large portion of the world's electrical power comes from thermal power units that burn coal. Building thermal power facilities close to coal mines is a practical way to minimize the high transportation costs of coal. Due to resource constraints, power generation in Hyde is similarly confined to a certain region. Customers or end users are spread out across the nation, even while power generation is concentrated in one area (Kumar, N. 2016). To set up a traditional power grid, you need high-voltage transmission lines to link various producing plants. The system consists of low-voltage distribution lines, long-distance, high-voltage overhead transmission lines, and large-scale, strategically placed generating plants. The bulk of the nation's electricity is transported on HVAC lines and, on occasion, HVDC as well. It is subsequently delivered to customers at a lower voltage level. All of the grid's generation and consumption changes are reflected in a synchronous network with centralized generation (Weihl, B. 2010).

The stability of the grid may be measured just by the frequency of the voltage in the network, which is an advantage of synchronous systems. Striking a balance between fluctuating generation and shifting demand is the basic strategy used for power system control. Serious economic damage and resource loss may occur from not doing so. At its standard level, the power system frequency is achieved when energy generation and demand are in balance. Frequency will decrease if generation stays constant and demand keeps going up, while frequency will go up if demand goes down (Singh, Y. 2015). It is well-known that AGC and LFC may be used in conventional power systems to keep the supply and demand of electricity in equilibrium. When the frequency of the power system deviates from its expected value, the frequency control systems initiate a control action. Increasing the coal burning rate or, in the case of a concealed plant, the water input pressure, are two common methods for controlling the steam pressure. It is important that the chosen approach can efficiently deal with sudden changes in frequency deviation. Thermal power plants, on the other hand, react more slowly in these kinds of situations. The power provider is forced to implement load shedding in times of extreme weather and widening supply-and-demand gaps (Jia, H. 2013).

Power generation and demand are subject to temporal unpredictability; in the case that AGC and LFC are unable to keep up, the operator will have no choice but to implement load shedding in order to avoid under-frequency tripping. Automatic generating control (AGC) is not suitable for renewable energy sources that are unregulated and have intermittent outputs, like wind and solar (Raju, P. S. 2009). The grid's balancing requirements also necessitate precise timing of load shedding. The demand for electric power has steadily outpaced the increase in generation capacity as the power system has evolved. It seems promising to use renewable energy (RE) technologies like solar and wind power. Although these resources have low power densities in their natural distribution, they nevertheless need to be linked to the power grid in order to have a major impact (Verma, Y. P. 2020).

Electrical Power Grid

There has been an electric power system in operation for about a hundred years. When it comes to total power generation, coal-fired thermal power plants are a major player. Setting up thermal power plants close to coal mines is a great way to minimize the high transportation costs of coal. Due to resource constraints, hydel electricity generation can only take place in specific areas. Customers or end users are spread out across the nation, even while power generation is concentrated in one area. To set up a traditional power grid, you need high-voltage transmission lines to link various producing plants. The system consists of low-voltage distribution lines, long-distance, high-voltage overhead transmission lines, and large-scale, strategically placed generating plants. Much of the country's electrical power travels on HVAC (High Voltage Alternating Current) lines—and sometimes HVDC (High Voltage Direct Current) lines—before being lowered in voltage and sent to homes and businesses. The technology is called a synchronous network with centralized generation, and the changes in consumption and generation are visible throughout the whole grid. The frequency of the voltage is the only parameter in a synchronous system, and it indicates how reliable the grid is. This is one advantage of the system. Striking a balance between fluctuating generation and shifting demand is the basic strategy used for power system control. Huge economic and resource losses would follow from not doing so. The power system frequency remains constant when demand and generation are in balance. While the first generation stays the same, the frequency will decrease if demand keeps rising and the reverse is true if demand keeps falling. In traditional power grids, AGC and LFC are acknowledged ways to keep generation and demand in balance. When the frequency of the power system deviates from its expected value, the frequency control systems initiate a control action. A common method of control is to adjust the steam pressure, which may be achieved by increasing the coal combustion or, in the case of a hydroelectric plant, by boosting the water intake pressure. It is important that the chosen approach can efficiently deal with sudden changes in frequency deviation. Bear in mind, too, that thermal power plants react very slowly under these conditions. The energy provider is forced to implement load shedding in cases of severe weather when the gap between supply and demand is widening. Because demand varies over time, operators must implement load shedding measures to avoid under-frequency tripping in the event that power generation is unable to keep up with demand using means such as Automatic Generation Control (AGC) and Load Frequency Control (LFC). Wind and solar power, which produce electricity intermittently and without human intervention, do not use Automatic Generating Control (AGC). In order to address the power system's balancing requirements, it will be necessary to schedule and modify load shedding. The demand for electric power has steadily outpaced the increase in generation capacity as the power system has evolved.

Hybrid Renewable Energy Sources

Renewable energy sources must be developed and improved upon immediately due to the complexity of industrial fuels. Solar, wind, hydro, and tidal power are all examples of renewable energy sources that come highly recommended. Wind and solar power plants are examples of hybrid energy sources whose production is intrinsically dependent on environmental factors. That makes meeting the load requirement difficult. Hybrid power generation needs energy optimization tools with sophisticated control methods to handle this critical situation. It is possible to increase the energy production of hybrid power plants and fulfill the need for peak loads by combining converter and inverter technologies with improved control approaches. An energy model that combines wind and solar power has been conceptualized and tested in this research. Converters and inverters are crucial to the reliability and performance of wind and solar power systems. The energy management system that runs on batteries can reduce power outages thanks to their capacity. Figure 1 shows the hybrid system's block diagram.

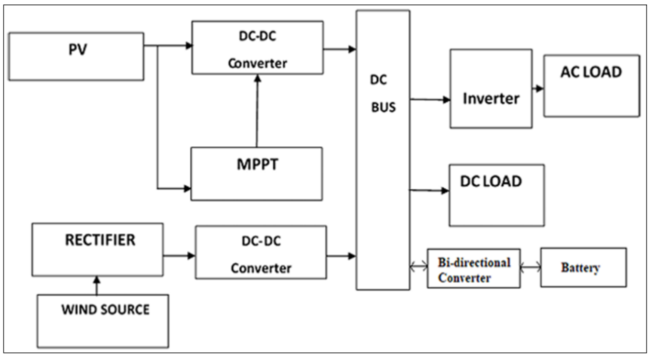

Fig 1: Block diagram of Hybrid system

The system as a whole make use of hybrid power generating technologies that harness the energy of the sun and the wind. The photovoltaic (PV) system collects the abundant solar energy and converts it into usable power. Maximum power point tracking systems rely on photovoltaic modules as its component. By utilizing a solar energy collecting method, the photovoltaic cell is able to convert sunlight into electrical energy. Increasing the power-generating capacity of PV modules is possible through the use of a maximum power point tracking algorithm. Wind turbines, gearboxes, generators, rectifiers, direct current (DC) converters, and alternating current (AC) converters are the components of wind power systems. The first stage in generating stable wind energy is to use a rectifier to transform the produced energy into direct current (DC). Next, a DC-DC converter is used to boost the voltage. When the hybrid power generation reaches its full capacity, a bidirectional converter is used to charge the battery. The hybrid power system will draw from the batteries to make up for power fluctuations. Using several power sources, which necessitates hybrid production systems, can significantly improve load stability in real time. Achieving great productivity is also possible with the hybrid system. Using a storage battery to store and convert the energy output as needed is essential for harnessing the renewable energy that is produced by wind turbines and PV systems.

- Solar Power System
- Maximum power point tracking
- Necessity of Maximum Power Point Tracking
- MPPT Algorithm
- Modeling of Wind Power Generation

DC-DC Converter

In a conversion circuit, DC-DC converters are most commonly used to change the level of DC voltage. By manipulating the current flow across the inductor and switching on and off the MOSFET, a DC-DC converter may alter the DC power levels. By adjusting the converter's duty cycle—the amount of time the switch is on or off—the variable DC voltage level may be controlled. Depending on the power source's availability and the load's demands, several DC-DC converters can be used to adjust the voltage level.

Below, a few of them are mentioned.

1. Buck converter
2. Boost converter
3. Buck-Boost converter

1. Buck converter

A buck converter is a device that lowers voltage. Figure 2 shows the buck converter's schematic.

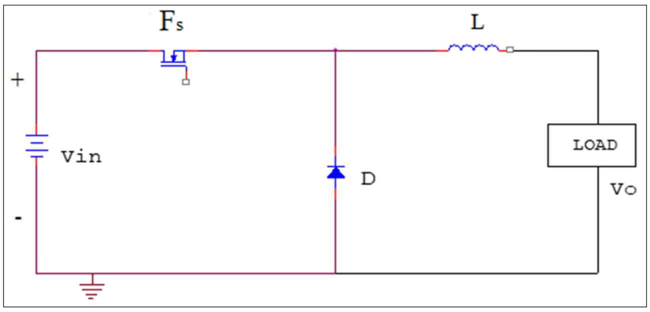

Fig 2: Circuit diagram of buck converter

In Figure 2, you can see the buck converter's schematic. When the switching element is turned on, a voltage is applied across the load, and current is sent from the source to the load. The load voltage is zero and current is flowing in one direction when the switch is open. The voltage on the load side drops as a result of the switching action when power moves from the source side to the load side. The duty cycle applied to the pulse from the switch gate and the voltage from the source are used to determine the voltage at the output. Both the switching action and the current flowing through the inductor control the buck converter's output voltage.

2. Boost Converter

Boost converters are designed to raise the voltage level. Figure 3 depicts the boost converter's circuit layout.

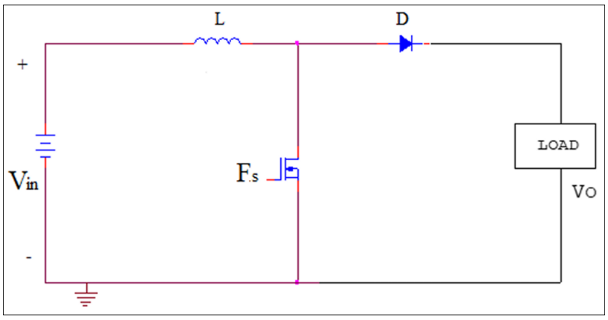

Fig 3: Circuit diagram of boost converter

Figure 3 shows the circuit with the switch closed, which separates it into two loops. Two loops, one at the input and one at the output, make up the system. The inductor L is energized at the input side by means of the closed loop. As the current increases, the switch will eventually turn on. Opening the switch allows the diode to transmit the energy stored in the inductor to the load system. Thus, the inductor's linear discharge causes the capacitor to charge.

3. Buck-Boost converter

The load-side output voltage may be controlled and stabilized with the help of the buck-boost converter. Figure 4 shows the buck-boost converter's circuit configuration.

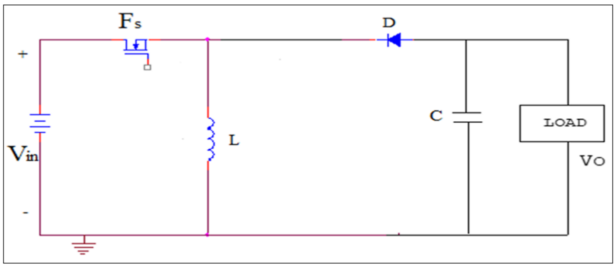

Fig 4: Circuit diagram of buck-boost converter

An increase in the current passing through the induction coil initiates energy conservation as soon as the switch is switched on. It is claimed that the circuit is activated. With the switch turned off, the diode will release the energy contained in the inductor and send it to the load. The time of the switch determines the output voltage, which might vary. The switching action determines the buck-boost converter's functionality; it may also operate as a boost converter. In buck converter mode, it runs when duty rates are less than 50%, and in boost converter mode, it operates when duty rates are greater than 50%.

DC-Coupled Hybrid Systems

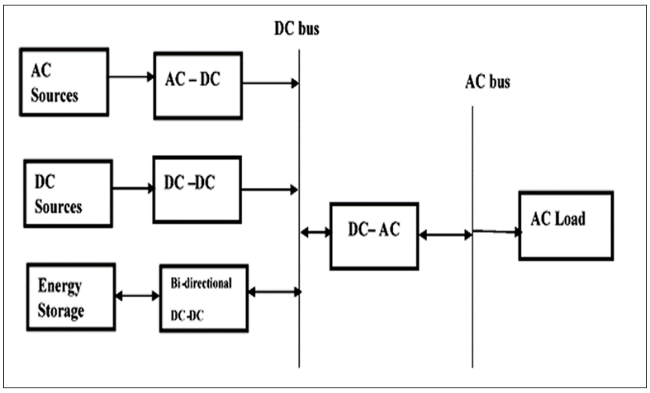

Fig 5: Schematic diagram DC - coupled hybrid energy system

All of the renewable power sources in a DC-coupled system are either directly connected to the DC bus or linked through appropriate power electronic converters. Figure 6 shows the system's block diagram. All of the converters in the system are linked to the grid bus, and they include AC-DC, DC-DC, bidirectional DC-DC, and DC-AC converters. Before feeding the output voltage into the inverter for DC-DC conversion, the hybrid system uses a DC-DC converter to stabilize it. It is possible to run the load system thanks to the stable AC voltage. Optimal operation of a DC-linked hybrid system is to increase plant-specific power output while simultaneously reducing load-side power flow anomalies.

Hybrid System with Multi-Connected Boost Converter

It is recommended to use a DC-DC converter system to improve the power quality in hybrid wind/solar power systems, as shown in Figure 7. Buck and boost converters, which are DC-DC converters, are part of the proposed design. Another component of the proposed system was an energy management mechanism that relied on batteries.

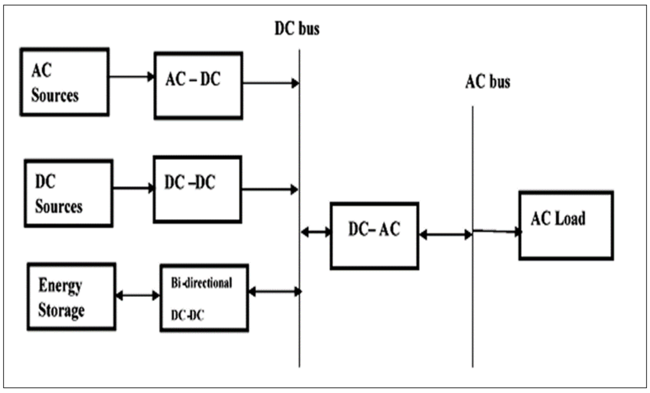

Fig 6: Hybrid system with multi-connected boost converter

To get the most out of the DC bus power, this energy management design is what you need. The battery backup system will make up for the DC grid system's needs in the case of variations in solar and wind power output. In order to power the AC load, the DC electricity is transformed into AC power by use of an inverter.

Conclusion

Optimization methods based on swarm intelligence have recently arisen as powerful resources for controlling microgrids powered by hybrid energy sources; these methods provide efficient, flexible, and resilient answers to difficult problems in energy management. Algorithms like Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), and Artificial Bee Colony (ABC) enable dynamic coordination among diverse renewable and non-renewable sources while considering load demands, grid stability, and cost-effectiveness. These algorithms mimic the collective behavior of natural systems like ant colonies, bird flocks, or fish schools. By combining these methods, we can optimize power flow in real-time, seamlessly transition between sources, and intelligently schedule storage systems, all of which increase dependability and decrease reliance on traditional fuels. Swarm intelligence is also well-suited to dispersed and variable generating settings because it naturally deals with the nonlinearities, uncertainties, and intermittent nature of renewable sources. This makes microgrid systems more sustainable, reduces losses, and improves operational efficiency. Swarm intelligence offers a resilient, decentralized, and scalable framework for optimizing hybrid microgrids, which helps with cleaner energy production, less environmental impact, and economic viability. This aligns with the long-term goals of smart grid development and sustainable energy infrastructure.

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