TELKOMNIKA Telecommunication, Computing, Electronics and Control
Vol. 18, No. 6, December 2020, pp. 3202~3209
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i6.13433

Integrated arrangement of advanced power electronics through hybrid smart grid system

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Article Info

Article history:

Received Jun 28, 2019
Revised Jun 25, 2020
Accepted Jul 9, 2020

Keywords:

Battery storage unit
Distributed generators
Fuel cell
Hybrid smartgrid
Photovoltaic
Power electronics
Wave energy
Wind turbine

ABSTRACT

As an enabler component for renewable energy integration, power electronics (PE) technology in smart grid system is one of the most important issues of development the electrification, decentralization and information-technology/operation-technology (IT/OT) digitization within the electrical energy transmission and distribution systems. The arrangement of PE may different along the feeder either for grid-connected photovoltaic (PV), wind turbine, fuel cells, wave energy system and battery storage unit, respectively. This is due to the electric voltage that might need to be converted from alternating current (AC) to direct current (DC) and vice versa. For that reason, this paper proposed a concept of advanced PE as an integrated arrangement of several AC/DC/AC- and DC/AC-converters in such ways that support the previously mentioned grid-connected hybrid renewable energy sources and distributed generators (DGs) along the distribution feeder. Additionally, for the system that supported by battery storage unit, then this hybrid smart grid concept might become the answer for future utility needs.

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1. INTRODUCTION

Power electronics (PE) arrangement is commonly divided as electrical energy transmission and distribution systems [1]. As the transmission in modern energy system is basically composed of high voltage direct current (HVDC) and or directly flexible alternating current transmission system (FACTS). In [1] also states that both HVDC and FACTS are essential to use enormous filters and no opportunity of supply power to end-users on the side from which the source is disconnected. Subsequently, the distribution system composed of PE converters and controllers that matching the distributed generators (DGs), power line, and energy storages.

As the integration of DGs into the distribution system, the distribution controls and protection conventionally put into account and also designed only for uni-directional power flow. However, a wide array of DG unit then is creating unique challenges in the grid as two-way directional power flow of the voltage regulation anxieties [2]. The high penetration level of DG units and large single-phase loads might lead to various problems and operational limit faults in electric power distribution systems. Although voltages are usually well balanced at the supply side, they can become unbalanced at the customer side due to the unequal system impedances, non-uniform distribution of single-phase loads and DG units [3-5].

A modern smart grid energy system, which incorporates renewable energy sources (i.e., photovoltaics (PV), wind power, fuel cells and wave energy), and the inclusion of battery as the energy storage, might integrate through the extensive arrangement of PE. Several investigations have been conducted regarding the integrated arrangement of PE through the system. In [4] has reviewed the smart grid concept for low voltage (LV) feeder which has rooftop PV system as distributed generator (DG) along the three-phase residential feeder and a proposed VRT implemented to overcome the voltage imbalance as one of power quality issues by considering the electrification, decentralization and information-technology/operation-technology (IT/OT) digitization. Another smartgrid concept that has been develop regarding the control and data communication using ZigBee is discussed in [6], while in [7] different wireless communication techniques (WiFi, and WiMax) is also discussed. Other references that discussed the implementation of PE in smartgrid LV network are [8-10]. In [11] discusses PE in smart grid wind turbine system as alternating current (AC) to direct current (DC) rectifier. While the electricity generated from the wind turbine is AC, then its rectified DC electricity is transmitted through the DC transmission line and afterward being fed into battery and as the reserve system for further use of electricity. Later the DC transmission line is directed to the DC to AC inverter for the transformation of AC electricity. In [12-15] review PE as DC converters in smart grid fuel cells system that shows the ability to produce more efficient conversion of power from the fuel cell to the load. Using a DC converter or a combination of DC converters, it might meet up the limitations of fuel cell, which include unregulated voltage, low voltage, low current density, and unstable power. A hybrid DC converter with a storage unit (i.e., battery or a super capacitor or other external supplies) can stabilize the power conditioning to balance the excess and insufficient power condition in the fuel cell. The switching technique as the main element of a DC converter also put into account. In [16, 17] mitigate the integrated of PE in smart grid wave energy system. The use of PE interface allows to increase the absorption of wave power at the same time of providing power and voltage conditioning, and the AC-DC-AC grid interfacing converter system overcome the problem of higher harmonic and voltage dips compensation, respectively.

Since they known as hybrid grid-connected system, in [18] explicitly reviews that PE arrangement through the utility that sourced by PV system, wind power, fuel cells and wave energy is the future trends of renewable energy power system. for that reason, this paper then proposed a concept of the advanced PE arrangement integration through the hybrid smart grid system of PV, wind turbine, fuel cells, and wave energy whereas an appropriate stability between production of clean energy and its consumption is put into account. The rest of the paper is arranged as follow, the briefly common installation method of PVs, wind turbine, fuel cell, wave energy and battery storage unit, respectively and their systems connected to the LV distribution network are described in section 2. Obviously, PEs of those mentioned grid-connected systems are also briefly described. In section 3, the proposed concept of hybrid smart grid system described all those mentioned PEs of the grid-connected systems altogether in such way perform the improvement of the power production through the three-phase LV feederas the advanced PE arrangements that integrated through the hybrid smart grid system. In the conclusion section, the concept of advanced PE arrangement through the hybrid smart grid system can be seen as the main component of smart grid that need to be considered. In addition, the further concept can be development, such as the communication support through the system.

2. PROPOSED SYSTEMS

This section is explaining each DG system namely PV system, wind turbine, fuel cells, wave energy and battery storage unit, which then they altogether integrated into the three-phase distribution network.

2.1. Grid-connected PV system

Since it has been overviewed in [8], three trends have interrupted the ancient utility infrastructure. As the technology and innovation transformit from plants beyond the customer meters known as the electrification, decentralizationand IT/OT digitization, grid-connected PV system is one of the most renewable and clean energy sources that has been utilized over decades. Grid-connected PV is a smart grid system, which includes PE, such as a DC/DC converter that can guarantee maximum harvested sun energy through a maximum power point tracking (MPPT) control, and the converter is used to interconnect PV into the grid [17-19].

Figure 1 illustrates the PE that commonly used for the grid-connected PV system. The inverter extracts as much DC voltage as possible from the PV array and converts it into clean mains AC voltage at the right frequency for feeding into the grid or for supplying domestic loads at the customer sides. Figure 2 illustrates the single-phase system of grid-connected PV with the inclusion of battery. Commonly this system is installed at the rooftop of a household. PV takes energy from the sun and the inverter converts it into electrically energy. The energy is used to run appliances or charge the battery. The battery can be used to run appliances when the solar panel is not producing energy. Table 1 describes the function of every component in the system.

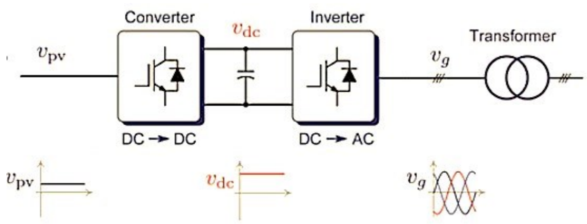

Figure 1. PE through grid-connected PV system

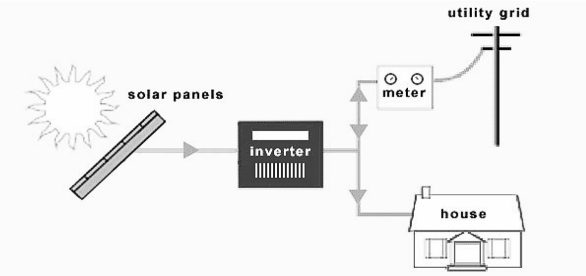

Figure 2. Grid-connected PV system with battery storage unit

Table 1. Grid-connected PV system components [1]

Components	Function through solar home system (SHS)
PV module	• Produces less energy • Assembled into panels that produce massive energy • In paralel, produces a few milliwatts-several megawatts
Inverter	• Transform DC to AC • Different types provide different voltages and efficiencies
Charge controller	• Controls the flow of electricity • Avoids battery damage by cutting the current to loads if the charge level in the battery is below a certain level, or cutting the current from the module in cases of overcharging • Indicator lights on the display show the battery's state of charge
Battery	• Charged at day time • Discharged in the evening to power households
Wiring and mounting	• Included metal frames attached PV Modules to a pole or roof • Connected by wires and contain switches for lightings

2.2. Grid-connected wind turbine

According to [11], the integration of wind turbine in the utility system can increase the efficiency and enhance the power output of the smart grid system. The PE arrangement of grid-connected that has wind turbine as DG rectifiers the AC voltage to DC as the wind turbine generates as shown in Figure 3. This rectified DC voltage is transmitted through the DC transmission line and then feed into battery storage unit as the reserve system for further use of electricity.

The inverter then converts the DC voltage from the battery into AC then transmits it to the three-phase distribution system through the transformer. Figure 4 illustrates the grid-connected wind turbine system. The system relies on the grid whenever the supply from the wind turbine is low. The grid connection passes through the inverter charger which charges the batteries at the same time also supply the load.

Table 2 describes the components of grid-connected wind turbine and their functions through the system [20-22]. Although modern wind turbine systems such as full converter wind turbine generator (FCWTG) is equipped with robust PE system, certain levels of grid faults might lead to the damage of this wind turbine system [22-25]. Therefore, the use of a compensator such as superconducting magnetic energy storage (SMES) becomes a future option for smart grid that involving wind turbine systems [22].

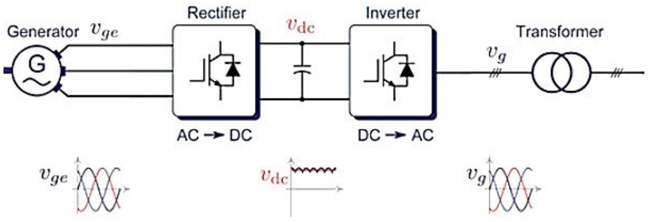

Figure 3. PE trhough grid-connected wind turbine system

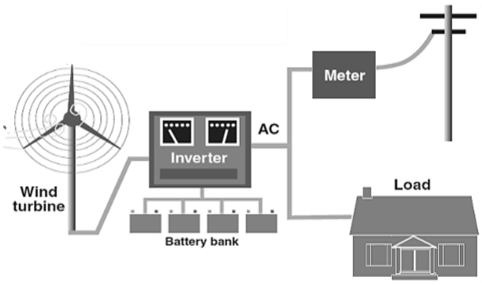

Figure 4. Grid-connected wind turbine with battery storage unit

Table 2. Grid-connected wind turbine components [8]

Components	Function through system
Foundation and Tower	Different configurations proposed for offshore and onshore
Nacelle, rotor and hub	Depends on orientation and blade numbers Depends on wind speed and power output requirement Rotor diameter determined efficiency losses Speed ratio depends on higher more complex aerofoils and noise Blade numbers determined higher efficiency Blade design including angle of attack, lift and drag characteristics
Blade and pitch controls	Blade – fixed stall, angle of attack increases with wind speed until stall occurs behind blade Pitch – blade position changes with wind speed.
Generator	Synchronous/permanent magnet generator: potentially use without gearbox and use of rare-earth metals Asynchronous Generator: slip operation above/below synchronous speed possible
Converter	Transforms AC to DC. Different converters provide different voltages and different efficiencies.
Battery	Storing converted electricity. Typically sized to supply electricity for several days when overcast weather avoids recharging.

2.3. Grid-connected fuel cells

According to [26], Fuel cell can be defined as electrochemical cell that converts fuel into electrical current that can generate electricity inside the cell through chemical reactions between fuel and an oxidant due to trigger electrolyte. The reactants that flow into the cell then flow out, while the electrolyte remains in it. Fuel cell keeps operate continuously as long as the flow of both reactant and oxidant are maintained. In addition, [26] stated that fuel cell also fits for DG applications, and can essentially be described as unchargeable batteries as long as both hydrogen and oxygen are constantly provided.

Figure 5 illustrates the PE arrangement of grid-connected fuel cell system. Fuel cell operates at low voltage DC which need to be boosted through the DC-DC converter and inverted through a DC-AC inverter for connection to the utility grid [27]. In addition, Figure 6 illustrates the grid-connected fuel cell system. Fuel cell systems can be easily placed at any site for the purpose of grid reinforcement. Therefore, fuel cell systems are also able to defer or eliminate the need for system upgrades and improving system integrity, reliability, and efficiency [26].

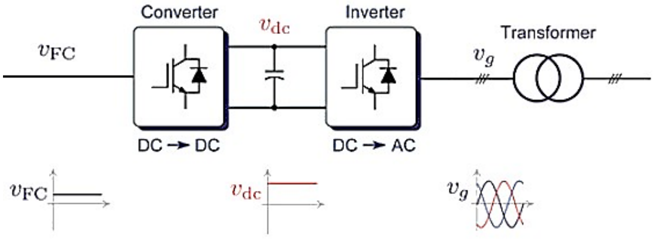

Figure 5. PE through grid-connected fuel cell system

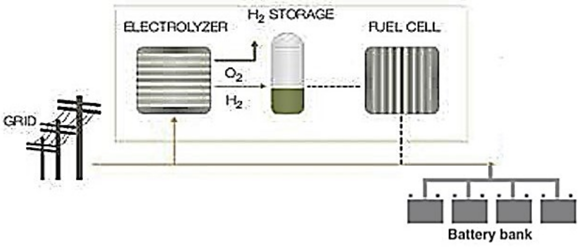

Figure 6. Grid-connected fuel cell system with battery storage unit

According to [28], it is necessary to indentify new materials and novel design and manufacturing methods for electrolytes and electrolyte supports, catalysts and supports, gas diffusion media, cell hardware (including bipolar plates and seals), and components (e.g., compressors, radiators, humidifiers and fuel processors) to meet the fuel cells' efficiency, durability, and cost requirements. In addition, the new materials identification are also needed to improve fuel processing and cleanup, especially for fuel-flexible and biofuels operations to improve durability and reduce system costs. Table 3 describes the tasks of fuel cell and approaches that it gains recently as the trend of grid-connected system.

Table 3. Fuel cell tasks and approaches

Tasks	Approach
Catalysts/Electrodes	• Develop electrocatalysts and electrodes by reducing PGM loading • increase activity, improving durability/stability • increase tolerance to air, fuel, and system-derived impurities • Optimize electrode design and assembly
Fuel Cell Performance and Durability	• Improve component • Improve cell performance with optimized transport • Develop new diagnostics, characterization tools, and models
Fuel Cell Systems	• Develop stationary fuel cell systems for use in distributed generation • Develop auxiliary power units

2.4. Grid-connected wave energy system

According to [29], several persuasive arguments of using the wave energy technology namely high-power density and more certain compare to solar and wind energy. It is proposing enhance possibility by dispatching to grid system. Advantageously, the conversion of ocean wave energy to electricity is considered the most environmentally clean techniques to generate electricity. Figure 7 illustrates PE that is connected between the generator terminals and grid that enables widely ranging speed control for generator. According to [30], the functioned PE can impact the entire device operation in generator speed, which is usually linked to the prime mover speed and in turn has some effect on the damping of the primary power capture stage that consequently affected the power production performance. While, in [31] it stated that PE also meets an important functionality in controlling grid fault current, regulating reactive power flow and and enabling low voltage ride-through of the generator system.

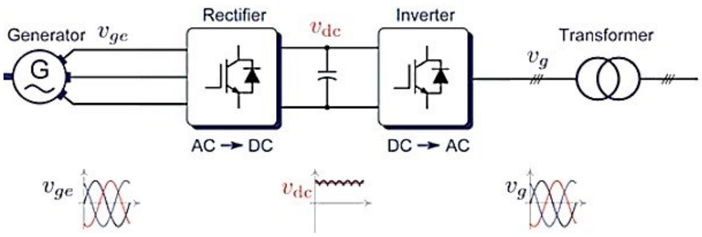

Figure 7. PE through grid-connected wave energy system

2.5. Battery storage unit

A typical configuration of grid-connected battery storage unit consists of rectifier and dc chopper as the PEs that ensures the bidirectional energy flow as shown in Figure 8. Battery is used for storing electric energy from the AC grid. The energy from the DC chopper is used to be transformed electrochemically and stored in the battery. Besides regulating system voltage and frequency, the chopper is also able to react to instantaneous load variability through the switching and synchronizing technology. Thus, then the battery storage unit performs the role of safe guarding the power quality of the network and ensure the voltage and frequency not to fluctuate beyond operation limits [32].

In [33] stated that the appropriate size and placement of decentralized battery as the storage unit is highly dependent on purpose of the battery system. Since battery operational strategies are difficult to simulate simultaneously during a sizing and placement planning calculation. However, according to the authors in [34], when DGs are along the LV distribution feeder, load leveling, peak shaving and power demand management are major applications of a grid-connected battery energy storage system (BESS), especially in an autonomous power network. Specifically, for load frequency control (LFC) issues. In [34] has reviewed in detail different concepts and strategies of the utilization of battery energy storage systems for LFC services.

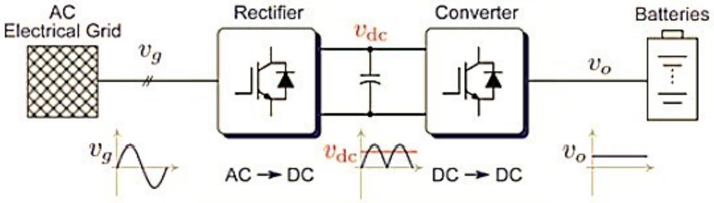

Figure 8. Grid-connected battery storage unit

3. RESULTS AND DISCUSSION

In this section, the authors proposed a concept of advanced PE arrangement (converter, inverter, rectifier and dc chopper) through hybrid smart grid system that has integrated DGs such as PVs, windt urbine, fuel cells and wave energy, respectively, due to fulfill an appropriate stability between production of clean energy and the loads consumption. Figure 9 illustrates a hybrid smart grid system that works at the frequency of 50Hz where DGs and PEs are integrated into the three-phase distribution network. Each renewable energy system works separately along the feeder. The decentralization of DGs need to be coordinating in such way till the three-phase LV distribution system not only well-balanced at the generators' side, but also at the customer load demands.

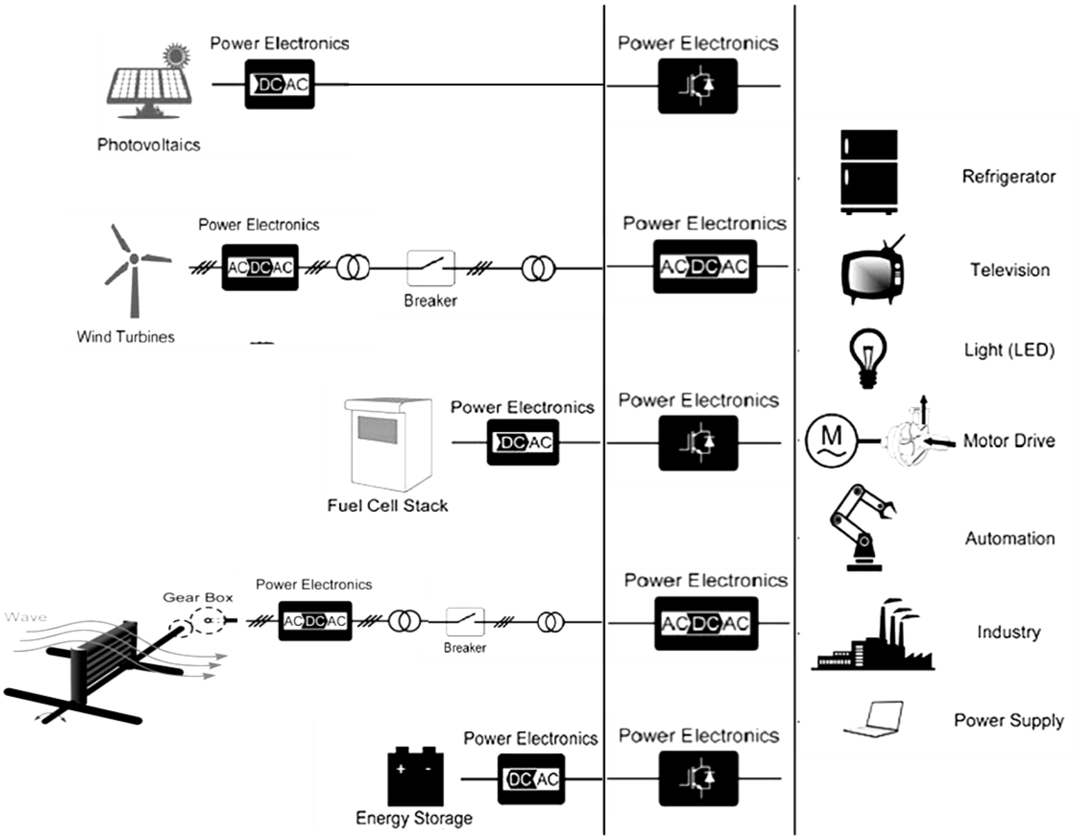

Figure 9. Proposed concept of hybrid smart grid system, from the generation station through grid to load at the customer side

In PV system, the inverter extracts DC voltage from the PV array and converts it into AC voltage for feeding into the grid or for supplying domestic loads at the customer sides. In wind turbine system, as the DG generates the wind into electricity, rectifier converts the AC voltage into DC and feeds the battery. Inverter then converts the DC voltage from the battery into AC then transmits it to the three-phase distribution system through the transformer. In fuel cells system, fuel cells are commonly used for DG applications, and can essentially be described as batteries. Fuel cell operates at low voltage DC, and for that reason, it is need to be boosted through the DC chopper and inverts into AC voltage for its connection to the utility grid. In wave energy system, the rectifier that is connected at the generator terminal converts AC voltage into DC and and feeds the battery. Inverter then converts the DC voltage from the battery into AC then transmits it to the three-phase distribution system through the transformer. As for battery storage unit, the rectifier and DC chopper need to ensure the bidirectional electric energy flow. In addition, DC chopper also plays important roles as it is not only regulating voltage and frequency of the system, but also able to react to instantaneous load variability through the switching and synchronizing technology.

4. CONCLUSION

The proposed concept which describes the arrangement of PE and their integrated to the renewable energy it is explained the results of a designed concept that is given the comprehensive trends. The proposed concept also represents a modern energy system, which combines renewable energy sources, DGs, and smart grid functions. All the grid-connected integration is then become possible through the extensive use of PEs. This hybrid smart grid concept might become the answer for future utility in order to fulfill an appropriate stability between production of clean energy and the loads consumption. As for further trend, the coordination of decentralized of various DGs can be studied to improve the voltage profile and power productions along the feeder. This is also become the authors future work to develop this proposed concept either in simulation or experiments.

ACKNOWLEDGEMENTS

This proposed concept is conducted to fulfill the requirement of output journal papers, which is funded and evaluated as the performance indicator of staff at the Service and Community Centre Politeknik Negeri Lhokseumawe.

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