Intelligent Techniques to Connect Renewable Energy Sources to the Grid: A review

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***Abstract*—Existing classical power grid systems are very sensitive against the integration of renewable and distributed energy sources due to voltage and frequency fluctuations that cause several problems like power outrage and blackouts. On the other hand, increasing the power capacity of the existing grid system as well connection of the renewable energy sources to the grid are unavoidable. So that, a smooth connection of renewable and distributed power system to the grid is required and many researchers have done several researches on this hot topic. Therefore, intelligent techniques to connect the renewable energy sources to the grid have been addressed in this study and recent researches in this field have been reviewed and some comments have been done for the researchers, young engineers, students, transmission system operators, distribution system operators as well as policy makers and end users.**

***Keywords*—renewable energy sources, smart grid, intelligent techniques, on grid connection.**

I. INTRODUCTION

In recent years, the installed power and investments of renewable energy sources have been increasing day by day. In general, the voltage values produced by renewable energy sources are DC electrical energy, and in many applications such as wind turbines producing AC, there is a conversion to DC and then conversion to AC electrical energy. In this context, power electronic circuits are used for renewable energy sources grid interfaces and smart techniques are applied in control systems in terms of power quality in the grid.

In the literature, there are several researchers who focus on the smooth connection renewable energy sources to the grid. *Alanso et al.* described the ideal location of distributed generators to increase reactive power capability. They used evolutionary optimization algorithms for combination of renewable energy sources in smart grids [1].

Roman et al. Constructed original photovoltaic (PV) module theory, a low-cost high-efficiency DC–DC converter with power line communications (PLC), control, and maximum power point tracking (MPPT) functions. Then, they analyzed construction of grid-connected PV systems: modular topologies, string and centralized [2].

Nakayama et al. conducted a new model integrate automation of future grid for ideal Real-Time distribution of renewables. The simulation results present those local optimizations continually iterated within tie-sets generate to global optimization [3].

Haque et al. predicted PV Power Generation with a Hybrid Intelligent Way. The method uses a combination of a data filtering technique based on a soft computing and wavelet transform model based on fuzzy ARTMAP network, which is optimized using an optimization method based on firefly algorithm [4].

Mahmoud et al. aim to understand adaptive intelligent methods for microgrid control systems. The authors conclude that the need for adaptive control techniques and intelligent optimization algorithms to process important problems in the classical control systems owing to the change of the operating points in microgrids [5].

Kow et al. presented a performance of conventional techniques and artificial intelligence in mitigating Photovoltaic grid-tied related power quality events. According to the review, energy storage system, unified power quality conditioner, static synchronous compensator, dynamic voltage regulator, inverter, power system monitoring is able to remunerate power quality events which lead to by Photovoltaic grid-tied system. Artificial intelligence methods usually outperform conventional techniques aspects of controllability and response time [6].

Khare et al. described an extensive survey of numerous viewpoints of Hybrid renewable energy system. This paper discusses reliability issues, control aspects, optimum sizing, modeling, and prefeasibility analysis. The authors conclude that artificial intelligence method and iterative method do not represent accurate dynamic performance of wind and solar energy system [7].

In today's electricity generation and management, the grid structure is aimed at a more secure, high-capacity and advanced smart grid structure than the existing electricity grid. In order to achieve this goal, smart grid structures are mostly designed at installation scales that include renewable energy sources such as solar and wind energy systems and are demanded as power capacity. In this context, various applications of renewable energy sources in the field were examined. In addition, it is aimed to increase the reliability of the power system by considering the effects of the connection of wind and solar energy sources to the grid with advanced smart strategies, and different models are used to achieve the recommended grid management. These methods are; the alternative modeling technique, two parameter-based alpha model technique and fuzzy logic-based inverter control and the proposed fuzzy fault tree-based technique and the evaluation of the power system considering the effect of model prediction-based boost converter control wind-solar energy systems integration into the grid for reliability. It increases the overall reliability of the entire grid power system when connecting wind and solar power systems to the grid [8].

In reference [9], authors studied the problems that could not be crossed in the operation and control of the electrical grid structure caused by the increasing trend of the connection of electrical energy obtained from renewable energy sources to the interconnected power. Wind energy is vulnerable to meteorological changes due to its structure and needs additional systems such as energy storage. In this case, multiple hybrid grid structures are preferred. These complement the sharing controls of power systems as passive, semi-active and active topologies. Therefore, it was summarized many of the control strategies proposed in the past literature in critically reviewed. In this context, the challenges, and future directions for the implementation of the hybrid topologies for grid-connected microgrid and stand-alone systems are revealed from the analysis carried out.

It is mentioned that renewable energy sources are one of the most suitable options in terms of capacity to meet the exponentially increasing demand for electrical energy, which is more suitable for environmental and social aspects. So that, authors discussed a grid-connected solar photovoltaic/diesel generator-powered hybrid system in order to meet the electrical energy demand. The hybrid system under consideration has been optimized in a recommended software to meet an appropriate value of power reliability at minimum net current cost. In addition, load management technique based on energy efficiency was applied in the system under consideration and compared based on various techno-economic parameters [10].

Moreover, in reference [11], it is stated that a solid-state transformer (SST) is an interesting building block for smart electrical networks in power electronics interfaces. An SST is used as a grid interface unit in an embedded framework for power conversion between data centers and local grids. An SST associate with two or more electrical subsystems and then distributes energy for other subsystems based on an intelligent management algorithm and data-driven energy distribution. The modern SST-based distribution grid is envisioned to integrate several DC or AC loads, energy storage devices and renewable energy sources in a plug and play technique based on a standard protocol, which can form a DC or AC regional microgrid system. Economic dispatch, control management, coordination and energy efficient monitoring are critical issues for the optimum operation of an SST. Authors propose a data-driven coordinated control strategy for a three-stage multi-active bridge converter-based SST topology. Gradually, controller design methodology has been developed that can coordinate various control data according to several SST functions.

Renewable energy sources are considered unpredictable resources. In wind turbines, the rapid change in wind speeds causes power fluctuations and interrupts power system stability during high power operation. To overcome this problem, energy storage systems such as battery storage are added to stabilize the grid and to balance the power produced with the power demand. The battery system is also used to reduce power fluctuations and helps to deliver more power to balance the load requirement. The (EMS) Energy Management System proposed in reference [12] is integrated with a fuzzy logic controller for the operation of both the battery and the wind system depending on the demand requirement. When it comes to the battery management system, smart controllers help to control the State of Charge (SoC) limits of the battery to ensure the required charge and discharge time. The proposed controller has been tested with a wind energy conversion system modeled in MATLAB/Simulink. The simulation results show that the proposed smart controller functions as battery management system, an energy management system and is also used for power balance generation and load, while efficiently reducing the voltage fluctuation during the change in load [12].

For reactive power compensation in smart grids, *Colak et al.* used DELPHI packet program to modelling and simulating of connection. Thus, the researchers focused solving and finding problems, which occur after and before connection [13]. Also, a fuzzy logic controlled synchronous motor was used for reactive power compensation. Their proposing model is more efficient, faster, economical, sensitive and reliable than another one with capacitor groups [14]. A reactive power compensation system has been constructed by using a fuzzy logic controller. Power factor of the system, voltages and Measured currents are used as input variables for the PIC 16F877 controller. Developing system is found more economical, reliable and sensible than others system [15].

In addition, for power quality improvements, *Benyamina et al.* used efficient adaptive neural-fuzzy inference system-based voltage controller for a single-phase boost unity active power factor correction. Thus, the result shows good performances in terms of the accuracy, the response time, power factor, total harmonic distortion [16].

Regarding the control of a e few parallel-connected generators in smart grids with embedded systems, distribution of frequency and phase seen in parallel with the generators is realized with a microcontroller. This developed system has been low cost and reliable. With the necessary detection and protection functions of the microcontroller, inconveniences such as wrong connection and incorrect measurement have been eliminated [17]. In other study, it was carried out to notify the system operator of the phase sequence accuracy and phase disconnection at the time of parallel connection of alternators. The aim of this study is to train engineering students for the situations before and after parallel connection of alternators, and it can be used in industry [18].

Huge trends in electrical energy, such as information technologies and energy policies, affect the electricity generation sector. Thus, increasing the electricity generation potential and new generation information and communication technologies are the main factors in transforming the existing electricity grid into a smart grid. Conventional electricity grids become unable to handle new trends such as power quality and management as renewable energy generation increases. System control is vulnerable to security threats in information and communication problems where advanced control techniques such as SCADA are not available in centralized production in connected systems. In Table 1, an overview of the smart grid system and a comparison with the classical grid system is given [19].

In general, the key elements in the structure of the smart grid system can be summarized with the block diagram shown in Figure 1. Thus, an interactive electricity grid structure is established for smart grid, equipped with smart control techniques at macro and micro level [19].

TABLE I. A COMPARISON OF THE CONVENTIONAL ELECTRIC GRID AND SMART GRID [19].

Conventional Electric Grid	**Smart Grid**
Electric machinery	Digital
One-way communication	Bidirectional communication
Centralized power generation	Distributed power generation
Equipped with only a few sensors	Fully equipped with sensors
Manuel monitoring	Automatic monitoring
Manuel recovery	Automatic recovery
Faults and voltage outages	Adaptive and Islanded
Few user options	More user options

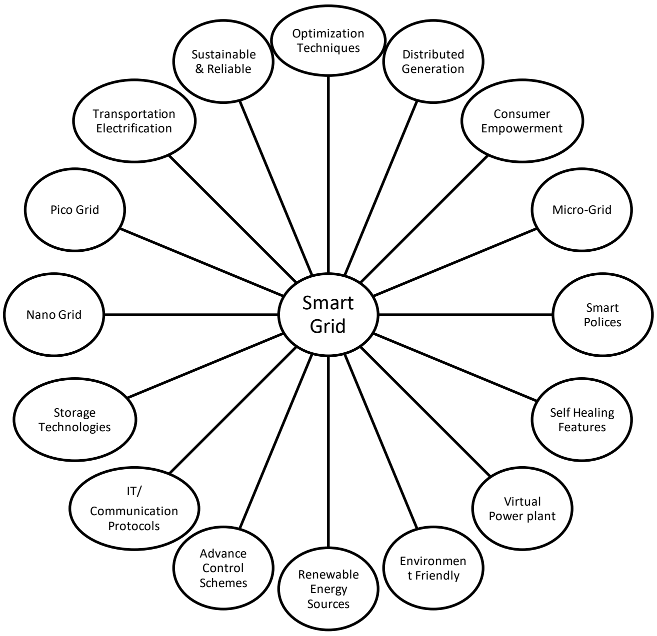

Fig. 1. The key elements in the structure of the smart grid [19].

In this paper, intelligent techniques in the literature to ensure smooth interaction of renewable energy sources and the grid are reviewed. In addition, basic power electronics circuit topologies for renewable energy sources grid interfaces, intelligent techniques and parameter estimation and control systems of these circuits are introduced.

II. GRID INTERFACE TOPOLOGIES

The basic power electronics topologies are used to integrate renewable energy sources into the grid. These basic topologies can be one or more as AC-DC, DC-DC, DC-AC and AC-AC depending on the application. In this section, examples from the literature on power electronics interface topologies used in applications such as wind, solar and fuel cells are given. As seen in Figure 1, SST performance, which is used for voltage matching and insulation purposes within the network interfaces, plays a major role in the connection of renewable energy sources to the grid [20]. SST and power electronics circuit performance can be determined by co-simulation studies using ANSYS-Electronics software [21].

On the other hand, with regard to the use of smart techniques for power electronics interfaces (Interleaved Dual Cascaded Boost Converter-IDCBC circuit), based on artificial intelligence techniques estimation of current and voltage fluctuations in charging Li-Ion battery units in energy storage systems, for charging batteries within safe limits with DC electrical energy obtained from fuel cells (FC), topology is proposed in Figure 3 [22].

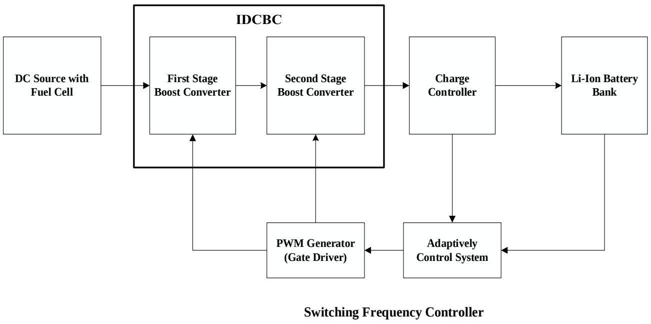

Fig. 3. FC powered battery charging system with boost converter [22].

It is natural that AC electrical energy obtained from wind generators for the application of renewable energy sources with grid interaction occurs at different frequency and voltage values for different wind speed values. In this context, an example of co-simulation study is given in a parametric finite element analysis method proposed in Figure 4 with ANSYS-Electronics R19 software [21]. Thus, in order to capture the maximum power point traction (MPPT) in wind energy systems that can be used in smart grid applications, DC-DC power converter duty ratio control can keep the DC link voltage value constant at a certain value at the inverter input for different wind speed values [23].

Power electronics circuit and SST structures are used together to adapt the voltage values of smart grid applications to the desired level and for galvanic isolation. In such circuits, a high frequency transformer and power electronics basic circuit topologies are used as can be seen in Figure 5. There

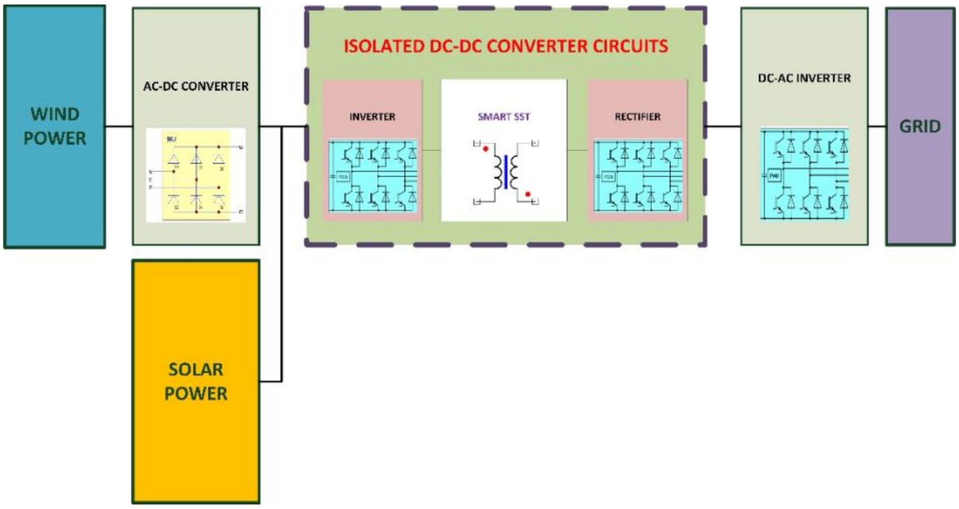

Fig. 2. Basic topologies for renewable energy sources grid interfaces [20].

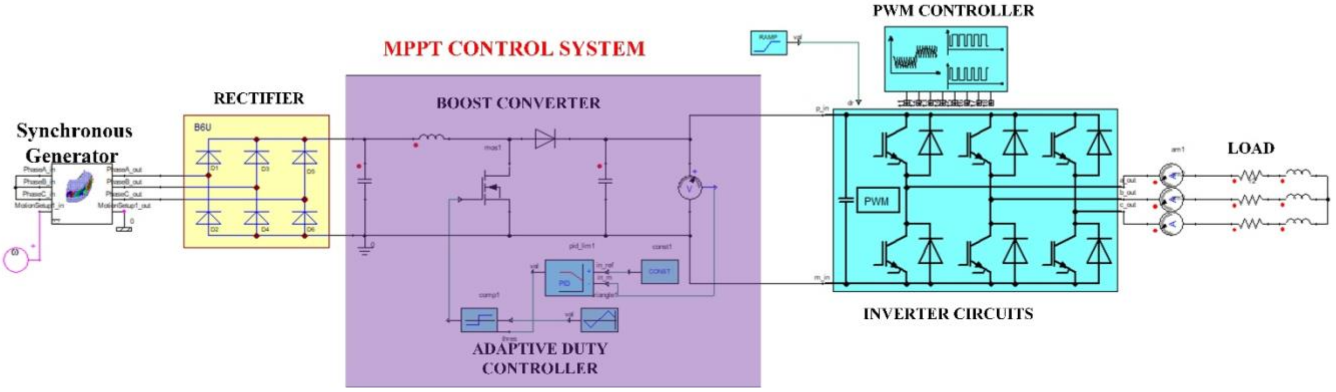

Fig. 4. The co-simulation circuit for wind generators and power electronics interface [23].

can be different approaches as direct power conversion and indirect power conversion [24].

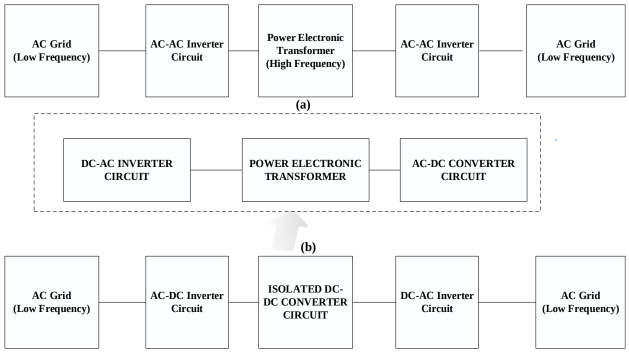

Fig. 5. Isolated power conversion topologies with SST [24].

In order to connect DC or AC electrical energy obtained from renewable energy sources to the grid at constant voltage and constant frequency values, power electronic circuit structures are briefly summarized. Thus, DC-DC, AC-DC and DC-AC power conversion is determined depending on the type of application and the requirement of the renewable energy system.

III. INTELLIGENT TECHNIQUES FOR SMOOTH INTERACTION OF RENEWABLE ENERGY SOURCES AND THE GRID

In this section, the smart techniques in the past literature for the connections between renewable energy sources and the grid are summarized. A topology based on separating a link from the conventional utility grid via a bidirectional AC-DC converter, which provides a flexible way to interact with the low voltage DC link voltage via the solar plant, DC loads and energy storage systems (ESS) in island mode is shown in Figure 6 [25].

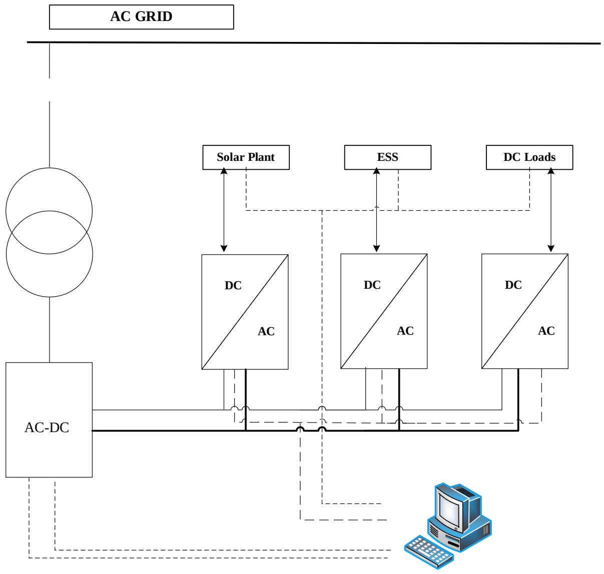

Fig. 6. DC smart grid system with a bidirectional AC-DC converter [25].

Intelligent techniques are used to control the voltage at the common coupling (PCC) point between the power electronics grid interface and the grid with different renewable energy sources for microgrid structures. A microgrid is capable of operating in both grid connected mode and island mode, keeping its frequency offset according to the EN50160 standard. In this context, an energy storage system is used and a wireless system is proposed to keep the voltage/frequency fluctuation within a certain limit range. The algorithm is designed for active and reactive power sharing transfer between parallel power sources such as wind, solar, fuel cell and backup energy storage system. The block diagram of a microgrid containing the consumer load connected to the mains is shown in Figure 7. Different Power Electronics topologies such as converters and inverters have been used to achieve power conversion. For MPPT, not only is it limited to solar energy, but also in wind energy systems, smart techniques have started to be applied in the feedback control system designs of power electronics circuits [26, 27].

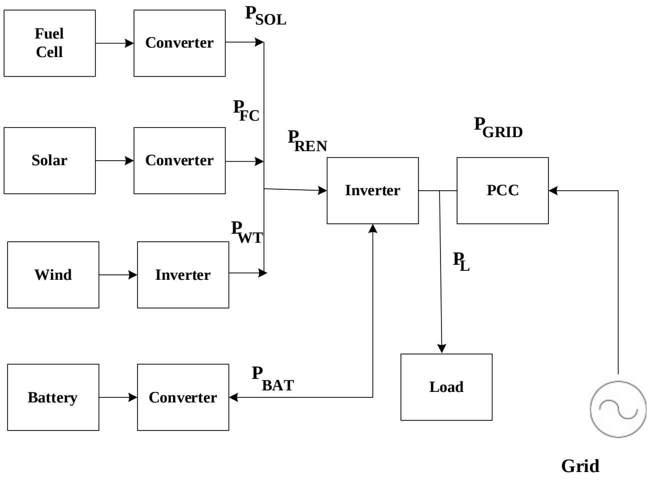

Fig. 7. Block diagram of the grid connected smart grid system [26].

In recent years, the increasing trend in the installation of wind energy sources has also increased the requirements for power electronics interfaces to be designed with grid interaction. In this regard, a very basic demand is to transfer the generated electrical energy to the grid according to the renewable energy resource characteristics. Other special demands needed in wind energy systems are to be a reliable energy source, to have high electricity generation efficiency, to produce cheaper electricity and to have less installation costs, to be designed in more compact structures, to effectively control the reactive and active power transferred to the grid, to ensure uninterrupted. It can be summarized as the need for dynamic grid support and continuous monitoring of the smart grid system with the support of information technologies in order to provide energy [28].

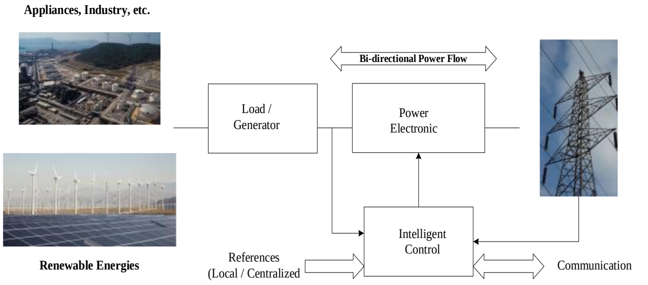

Fig. 8. The renewable energy sources of a smart grid with intelligent control system [28].

The excitation current and speed control are important in wind generator systems in active and reactive power control. This can be explained by the generator side current control not only maximizing the energy production, but also balancing the active and reactive energy transferred to the grid in case of dynamics between mechanical and electrical power. In this context, the requirements for the grid side are met by controlling the power converter with excitation current and speed regulating regulators, which should mimic the behavior of conventional power plants. Thus, a grid interaction equipped with intelligent techniques is required for the power converter to help maintain the grid voltage in terms of frequency and amplitude and withstand grid failures, as depicted in the block diagram given in Figure 9 [28].

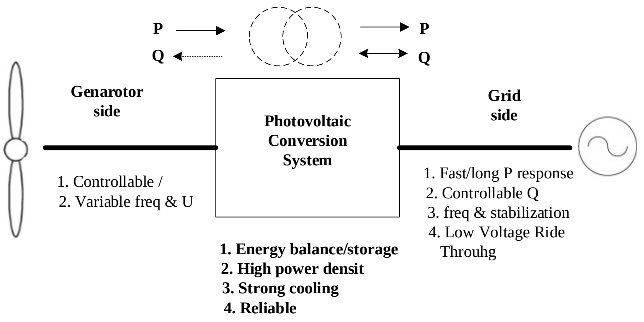

Fig. 9. Active and reactive power directions of a wind energy system [28].

A general classification of active and reactive power requirements for very rapidly developing PV systems is illustrated in Figure 10. However, even when compared to a wind generator, the power capacity of a PV system is not very large. In addition, the power fluctuations of the PV output are also compatible with the behavior of the grid. Thus, due to the nature of PV systems, providing active and reactive power control is less complicated than wind turbine systems [28].

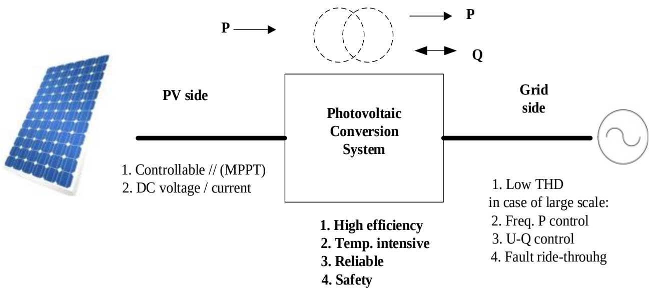

Fig. 10. Active and reactive power directions of a PV systems [28].

In current approaches, networked control systems (NCS) are considered as a kind of intelligent control technique of electric grids as different distributed control schemes. In this control system, voltage and frequency fluctuations and faults that will disrupt the power stability and efficiency of the network in active-reactive power transmission are corrected., The stability and performance of the micro power grid structure are improved by using a feedback control system. In addition, system reliability is increased with information technology infrastructure. In this context, the general structure of microgrid systems consists of tertiary, secondary and primary control within the hierarchy as higlighted in Figure 11. The primary controller does not need much communication with distributed generation power supplies for effective controllability of microgrids. However, the main idea of implementing a Secondary control is to eliminate the voltage and frequency fluctuation errors as a result of the micro power grid of the primary control loop using feedback information systems [29].

Sum up, intelligent techniques for a smooth connection of renewable and distributed anergy system to the existing grid system are hot topics in order to mitigate the voltage, frequency and power fluctuations in the grid, increase the capacity of the system, and to protect the power systems equipment as well as loads.

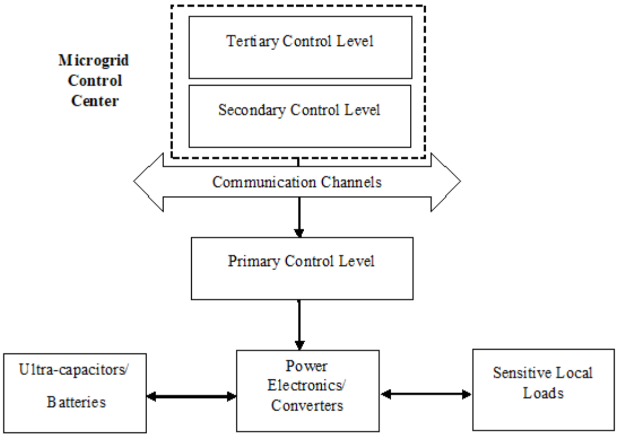

Fig. 11. Networked control systems for microgrids [29].

IV. CONCLUSION

In this paper, intelligent smooth connection of renewable energy sources to the grid has been highlighted, and some of the studies done in this field have been summarized by giving their outcomes. Later on, the importance of the power electronics in grid interactive inverters were introduced by giving the different intelligent inverter topologies. In relation to the intelligent techniques used in smart grids, the types of renewable energy sources and the new approaches taken together with the energy storage system are exemplified. In this context, the importance of active and reactive power control in power management in micro grids fed with more than one renewable energy sources is also explained. Finally, it has been concluded that intelligent techniques to connect the renewable energy sources to the grid are very critical and important for the researchers, young engineers, students, transmission system operators, distribution system operators as well as policy makers and end users.

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