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Review article

Reconfigurable solar photovoltaic systems: A review

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ABSTRACT

Even though solar power generation has become an emerging trend in the world, its penetration into the utility grid as a distributed generation source is not a satisfactory measure due to the inherent issues related to solar photovoltaic systems (SPVSs). In addressing these issues, microgrids have been identified as suitable integrating platforms for distributed, clean energy resources such as SPV. Different SPV and microgrid architectures are available for different applications depending on the resource availability and controllability. Reconfigurability is a concept that makes a system adaptable to two or more different environments by effectively utilizing the available resources. The review explains the applications of reconfigurable approaches on solar PV systems such as reconfigurable PV arrays, power conditioning unit (DC/DC converter, DC/AC inverter), microgrid controller and topology of distribution network with relevant studies. An analysis is also presented considering the unique features of reconfigurable systems in comparison to the static systems.

1. Introduction

Nowadays, there is more consideration towards renewable energy generation in addressing the growing demand for electricity and life-threatening environmental impacts resulted by greenhouse gas (GHG) emission. Today, there is an emerging interest in solar and wind power generations. Therefore, the government and many other organizations are willing to provide financial support to increase the penetration of renewable energy generation into the utility grid. As a result of the high penetration of distributed generation into the distribution network, it will transform the existing utility grid into a more complex, unstable, unreliable structure [1, 2, 3]. A reliable and uninterrupted power supply can be achieved by developing microgrids that integrate distributed generation and loads which are located within a small geographical area [1, 4, 5, 6]. SPV has become the most attractive renewable source due to its high life span together with low maintenance requirements and costs. Due to its modular nature and lightweight, transportation and installation are much easier when compared to other technologies [7, 8, 9]. Considering these desirable features, a growth in SPV integration to the utility grid can be expected. Even though solar photovoltaic microgrids (PV MGs) can reduce the impact on the distribution network, SPVSs may suffer from issues related to power reliability, quality and conversion efficiency. Therefore, it is a necessity to modify existing solar PV MG architectures [10, 11, 12]. SPVSs and microgrids consist of power electronic interfaces (PEI) which make these systems highly controllable and flexible for modifications [13, 14, 15]. The reconfigurable power system is one of the proposed concepts to increase the controllability of the existing power system [16, 17]. It is expected that the SPVS based reconfigurable systems will play a major role in future distribution networks.

This review paper starts with presenting the reconfigurable approach with the advantages and different modes of operation. Then the applications of reconfigurable approaches on solar PV systems such as reconfigurable PV arrays, power conditioning unit (DC/DC converter, DC/AC inverter), microgrid controller and topology of distribution network are presented with related studies. An analysis is also presented considering the unique features of reconfigurable systems in comparison to the static systems.

The paper is organized as follows: Section 2 presents solar PV systems, associated components, and different solar microgrid architecture highlighting their functions for which reconfigurable concept can be applied. Based on that, section 3 presents a critical discussion on reconfigurable solar PV systems. This discussion is supported by a summary on the reconfigurable systems, their advantages and a cost analysis. Then section 4 presents a conclusion of this study.

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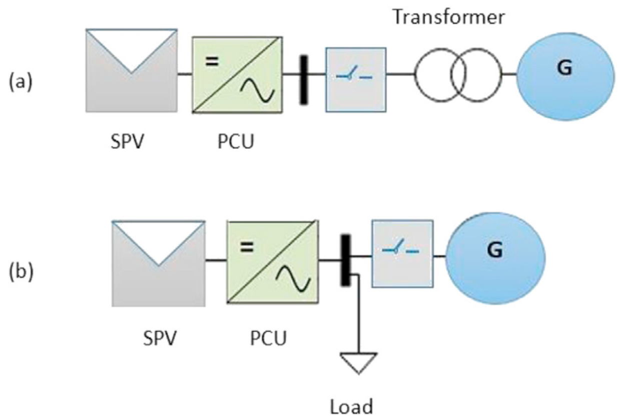

Figure 1. Solar PV system architectures (a) Solar farm (b) Rooftop solar PV.

2. Solar photovoltaic systems

Solar PV generation has become more prominent in addressing rural electrification requirements through standalone solar PV systems (SPVSs). Later, considering the environmental benefits and the increasing trend of economic value with the technological development, SPVSs were connected to the utility grid. Therefore, two main types of SPVSs can be identified as standalone SPVSs and grid connected SPVSs. In this study, grid connected SPVSs are under concern. Depending on the functions and system architecture, grid connected SPVSs can be categorized as rooftop SPVSs and solar farms. The system architectures of those systems are shown in Figure 1.

Generally, a rooftop SPVS can be a home system or an industrial system or a commercial building-mounted system, which intends to supply the local demand and to transmit available excess power to the main grid. Nevertheless, solar PV farms do not feed the local loads and directly supply power to the utility grid. SPVSs are connected to the utility grid through low or medium voltage distribution network or the high voltage transmission network. According to the scale of the SPVS, we can identify three scales as utility-scale (above 1MW), medium-scale (1MW-10kW) and small scale (below 10kW) SPVSs. Generally, solar farms are connected to the medium voltage distribution system or high voltage transmission network. SPVs for industrial or commercial buildings are medium-scale SPVs that are connected to the medium or low voltage distribution network. SPV home systems are considered as small-scale SPVs and they are connected to the low voltage distribution network. Figure 2 illustrates the connections of each specified SPV to the utility grid.

2.1. Solar photovoltaic module

A solar PV cell shows a non-linear characteristic. Therefore, an appropriate model is required to represent the electrical characteristics of solar PV cells, rather than representing through a single current or a

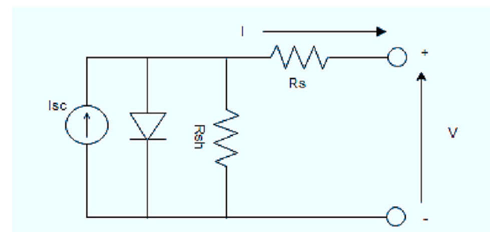

Figure 3. Electrical equivalent 5 parameter model based on one diode theory.

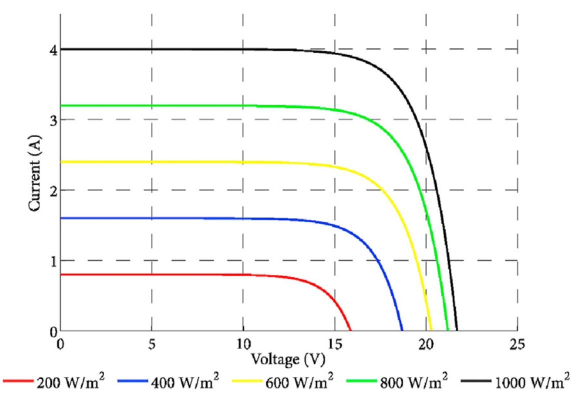

Figure 4. I–V characteristics.

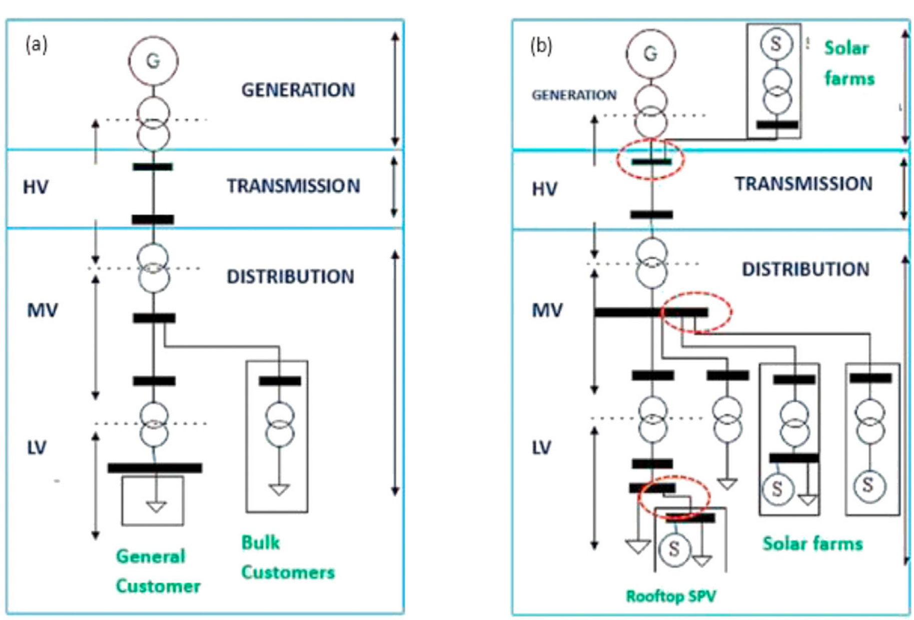

Figure 2. Structure of (a) conventional utility grid (b) with the connection of different types of solar.

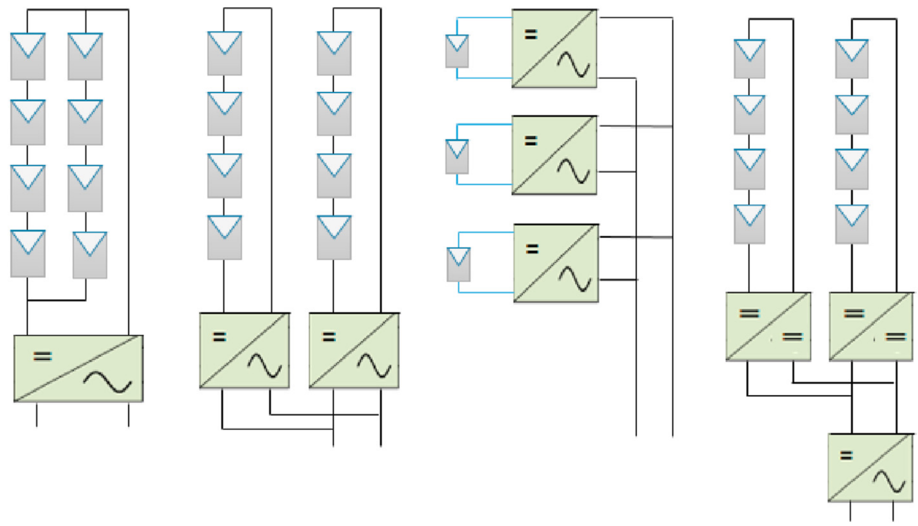

Figure 5. SPV architectures (a) Central inverter (b) String inverter (c) Module inverter (d) Multi-string inverter.

Table 1. IEEE standard 1547: Operational limits.

Feature	Limitation
Maximum output voltage	±6% of the nominal grid voltage
Frequency range	±1% of the nominal frequency
Total harmonic distortion	THD <5
Power factor	0.9 lagging

voltage source. The 5- parameter model is the most used model due to its simplicity and accuracy. This model is shown in Figure 3 [18].

$$I = I_{PV,Cell} - I_{s,Cell}(exp^{\frac{V}{aV_t}} - 1) \quad (1)$$

The first term in Eq. (1), is proportional to the irradiance intensity whereas the second term, the diode current, expresses the non-linear relationship between the PV cell current and voltage. According to the equations, solar PV characteristics depend on different factors such as solar irradiation and cell temperature as shown in Figure 4.

2.2. Power conditioning unit

The main function of the power conditioning unit (PCU) is converting generated Solar DC power into usable AC power. The PCU typically consists of a DC-DC converter and a DC-AC inverter. The DC and the AC sides are connected to solar PV generator and the utility grid or AC load respectively. Special circuit breakers, input filters, etc. are also interfaced in a PCU depending on the applying conditions and the ripple current.

PCU is an important subsystem in designing SPVSs, since the number of inverters and power conversion stages and their configurations significantly affect the performance, reliability, mismatch rejection and costs of the system. In practical scenario, different architectures are available for the SPVSs depending on the type of the power conditioning unit. The mostly used architectures are central inverter, string inverter, multi-string inverter and modular inverter [19] as shown in Figure 5.

According to the IEEE standard 1547, the specified operational limits of grid connected solar PV system are as in Table 1.

In literature, different types of solar inverters can be found. According to them, mainly three kinds of solar inverters are available. Two of them are traditional inverters namely Voltage Source Inverter (VSI) and Current Source Inverter (CSI). The other one is a trending inverter that is called as impedance Source Inverter (ZSI). ZSI was introduced to overcome issues with aforementioned traditional inverters such as inverter failures during shoot through stage, having single stage power conversion with single controllable parameter (Modulation index only) [20]. ZSI is capable of both DC-DC and DC-AC conversions within the same inverter having two controllable parameters; Modulation index and shoot through duty. However, the harmonic injection to the network is one of the issues related to solar inverters. Nowadays many researches are interested in increasing the performance of PCU.

- Maximum Power Point Tracking (MPPT)

To achieve MPP, different controlling methods are proposed in the literature. There are well recognized MPPT methods in the literature that are proposed to achieve MPP in solar PV systems under uniform irradiance condition and Partial Shading Conditions (PSC) [64].

There is an important consideration of the maximization of energy capture by solar panels. Therefore, solar tracker designing has come into the picture. There are several studies on the performance evaluation of solar trackers. Technical and economic performances of solar trackers for different solar irradiation levels are analyzed under [65]. This study is mainly focused on medium and high latitude countries in the northern hemisphere. Another important study on solar trackers is ranking available trackers considering the energy output and the levelized cost of electricity [66]. This provides a suitable platform for the designers on low latitude countries in African, Asian and American continents. A similar approach is presented in [67], in evaluating the solar tracker performance with the latitude. Likewise, many useful studies have been done for the benefit of the designers in including solar trackers in their system designing.

2.3. Problems associated with grid connected SPVS

Nowadays there is an emerging trend to integrate solar PV arrays to the low voltage system with the governmental intervention. But there are critical issues that are inherent to SPVS to be solved. These critical issues can be discussed in the grid point of view and SPVS point of view by considering each subsystem of SPVSs as presented by Figure 6. The main aim of this section is to introduce possible impacts that SPVSs may impose on the network.

2.3.1. Reverse power flow

With the introduction of distributed generation sources such as SPV to the utility network, traditional centralized power generation architecture

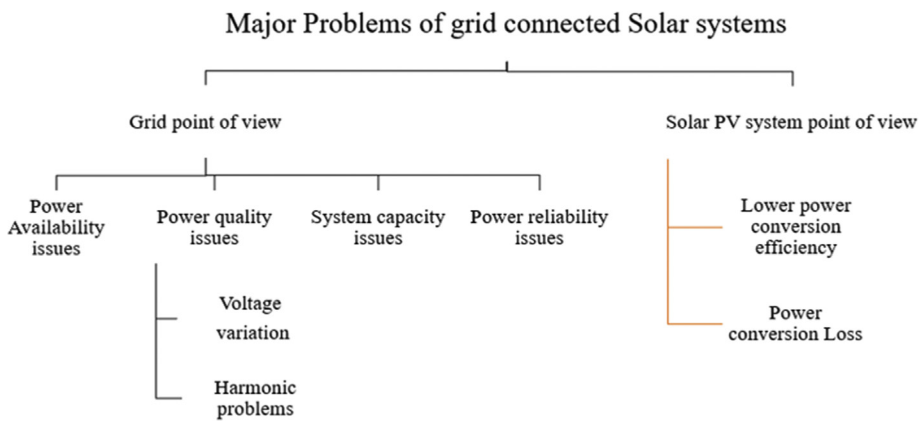

Figure 6. Problems with grid-connected solar PV systems.

transforms into a hybrid power generation architecture. Under a high penetration scenario, daytime solar generation results in surplus power, which is exported to a neighbouring feeder or the transmission lines. This causes a reverse power flow in distribution substation levels, feeders, and sections. Generally, the distribution feeders of the distribution network are designed only for unidirectional power flow. As a result, the over-current protection coordination and the operation of voltage regulators may get affected. Suitable protection methods should be implemented for feeders to overcome these issues by considering feeder basis studies and allowing bidirectional power flow as proposed in the literature [21, 22, 23, 24].

2.3.2. Power quality problems

The critical problems related to grid-connected systems are voltage variations and harmonic problems.

- Voltage problems

Voltage fluctuations are resulted by rapid variations of solar irradiation and cloud passing. As the SPV penetration increases, the subjected distribution network may get vulnerable to significant voltage fluctuations. The reverse power flow due to excess solar power generation or operating at a unity power factor without considering the reactive power requirements may lead to a voltage rise in the distribution network [25, 26, 27, 28]. The magnitude of the voltage rise is affected by the feeder configuration, the distance between the distribution feeder and the SPV source along the feeder path, the connections of fixed capacitors and the level of solar irradiation. In industrial practice, the absence of voltage regulation functions results in solar generation spillage or unintentional islanding situations which may cause interruptions to the penetration of sustainable power generation into the main power system. According to IEEE Std. 519-1992, limitations on the voltage at PCC and islanding conditions are given in Table 2 [29].

This problem has been minimized by implementing controllable, switched capacitors instead of fixed capacitors and lowering the voltage reference of existing load tap changers (LTCs) and line voltage regulators (LVR) [21]. However, rapid voltage fluctuations may result in the frequent operation of LTCs, LVRs and voltage-controlled capacitor banks. This will reduce the life expectancy of each voltage regulator and require frequent maintenance [21].

In addition to these solutions, allowing SPVS to control the reactive power, distributed network reconfiguration, clustering distribution network into several microgrids including SPV and creating SPV based microgrids are proposed in [2] and these solutions can be identified as the most effective solutions in reducing the limitations on the integration of distributed generation sources to the grid. In addition to that, photovoltaic-electrical vehicle (PV-EV) novel technique is proposed in [2].

Table 2. IEEE STD.519-1992: Voltage limitations and requested time for Islanding.

Voltage (at point of utility connection)	Maximum trip time
V < 50%	0.1s
50% < V < 85%	2.0s
85% < V < 110%	Continuous operation
110% < V < 135%	2.0 s
135% > V	0.05 s

- Harmonics

This problem is a critical power quality issue that appears due to the involvement of a power electronic inverter based SPVS. A solar power conversion unit is the heart of the SPVS that has been implemented with power electronic-based components. Harmonics are generated as a result of the switching operation of DC/AC power conversion. Significant harmonic injection to the utility grid may result in parallel and series resonances, overheating of capacitor banks and transformers and false operation of protection devices. In IEEE Std. 519-1992, the possible maximum harmonic levels are specified. According to that, the total harmonic distortion of the voltage (THDv) should be below 5% and individual THD should be below 3% [25].

According to many researches, well-designed harmonic filters, multilevel inverters, z-source inverters, and DC microgrids are the most promising solutions. At present, the harmonic levels of most of the modern PWM inverters are considerably low (below 3% THD). This figure is better than that of the distribution networks, as most of the loads connected to distribution networks consist of rectifier front ends [30]. According to [31], the maximum possible penetration of SPV (with THDi <2%) into the distribution network was determined as 60% of rated power from the power transformer by considering the limits of harmonic distortion voltage of the distribution network.

2.3.3. Power availability

The contribution of SPV in addressing demand is limited to the daytime. But the peak demand of most power systems occurs in the night time. Therefore, this expensive asset cannot be utilized as a peak shaver. However, different solutions have been introduced in increasing the effective utilization of SPV. The following techniques are some of the solutions which are introduced to the existing power system structure to absorb the excess PV production.

- Energy storage-different types of energy storage devices have been proposed in literature such as battery energy storage, pump storage power plants, etc.

- Load shifting - shifting suitable loads to meet the excess generation with the modernization of the power system into the smart grid concept by increasing the controllability of the power system.

2.3.4. System capacity

Solar power generation is limited in the daytime. But, in most of the developing countries, due to the increase of domestic activities, the peak demand occurs at night time. Even though there are grid-connected SPVS which can be utilized as peak shavers, the capacity of the transmission and distribution system of the country should be expanded to supply the peak load. The maximum benefits of an SPVS cannot be achieved without energy storage devices or peak shifting methods at the load side.

2.3.4.1. Power losses. The main problem regarding SPVS is that the actual energy extracted from SPV is lesser than its potential energy generation. This occurs as a result of the electrical mismatch of the SPV array, the impedance mismatch between the solar PV system and the load and power conversion losses in the complete system.

2.3.5. Impedance mismatch losses

The characteristics of an SPV module vary with the heat and insolation. To extract the maximum power from an SPV module, impedance mismatch losses should be minimized. Impedance mismatches reduce the overall conversion efficiency of an SPV array. Therefore, maximum power point trackers (MPPTs) are used with solar arrays. These MPPTs are dc/dc converters that utilize MPPT algorithms to track the MPP, under dynamic environmental conditions.

SPV is considered as an intermittent power source as its power output varies with the time of generation. Availability of solar power generation only during the day time, inability to cater to the night peak, less controllability, etc. are some of the common issues associated with SPVS.

Consisting of several power conversion stages, poor fault tolerance capacity [32, 33], limitations of energy storage capacity and optimum operation are some of the critical issues that are associated with SPV architecture. A higher voltage stress on the inverter and harmonics injection to the power network are the other drawbacks in existing SPV inverters [34, 35, 36]. Initially, SPV inverters are modules that inject power into the utility grid. Later on, newer designs have been introduced to emphasize safety, to support intelligent grid integration and to reduce the cost. Designers are looking forward to exploring new technology, which has not been used in existing solar inverter modules, to further improve the performance and reduce the cost.

2.3.6. Power conversion losses

A conventional SPVS consists of a single power conversion stage which is dedicated for DC/AC conversion. Although a voltage level is specified for the operation, higher or lower voltages may present in the system. Therefore, a line transformer or a high-frequency transformer or a buck or a boost converter can be used to overcome this issue. These are the additional power losses associated with the power conversion architecture. As in literature, the Z source inverter based SPVS has achieved satisfactory results to overcome this problem [37, 38].

2.4. PV microgrid

In electrical power systems, different types of SPVSs are found such as grid connected and off-grid SPVSs, solar farms, rooftop SPVS and PV microgrids. The relationship of solar PV MG with other SPVSs is given in Figure 7.

A microgrid is a group of interconnected loads and distributed energy resources within clearly defined electrical boundaries that act as a single controllable entity for the grid. It operates in both grid-connected and island modes. A solar photovoltaic microgrid (PV MG) is defined as a group of interconnected loads and SPVSs which acts as a single controllable entity and operates in both grid-connected and islanded conditions. Generally, a conventional SPVS is unable to operate in the islanded mode on its own. However, this problem can be addressed with a battery energy storage such that, a solar PV MG consists of SPVSs, battery storage units, controllable loads and controllers. A comparison between solar home systems and solar PV microgrids is given in Table 3.

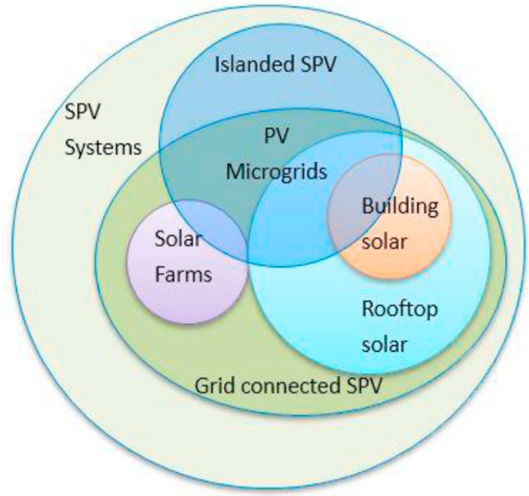

Figure 7. Relationship of PV microgrid with other Solar PV.

2.5. PV microgrid architecture

PV microgrid architectures can be classified in different ways based on various facts as follows.

Considering boundary of microgrid,

- According to the customer base,
  - ❖ Single customer microgrid architecture
    - o Type of customer
      - ■ Residential (home) PV microgrid
      - ■ Commercial building microgrid
      - ■ Industrial microgrid
  - ❖ Multiple customer microgrid architecture
    - o According to the geographical area,
      - ■ Feeder microgrid architecture
      - ■ Partial feeder microgrid architecture

Considering the microgrid itself,

- Power Architecture (the power flow);
  - ❖ According to the type of the power lines,
    - o AC power architecture
    - o DC power architecture
    - o DC-AC power architecture
  - ❖ According to the nature of sources,
    - o Solar-Battery based power architecture
    - o Solar -Wind-based power architecture
    - o Solar - diesel-based power generator architecture
    - o Solar – mini - hydro based power architecture
- Control Architecture (According to communication and control data flow),
  - o Centralized control architecture
  - o Decentralized control architecture
  - o Hierarchical Architecture
  - o Multi-agent-based MG control architecture
  - o Reconfigurable Control Architecture

Table 3. Features of solar PV microgrid over a solar home system.

Solar home systems	Solar PV microgrid
Loads highly depend on the grid supply and intermittent, uncontrollable SPV generation.	Power supply to the loads can be maintained even when the SPV power is not available.
Utility grid has to undergo more stresses in supplying the night peak	Reduce the stress on the grid during the night peak (peak shaving).
System capacity should bare the peak demand.	Have the ability to control loads such that the consumption from the utility grid can be reduced.

Solar microgrids are categorized as single and multiple customer microgrids depending on the customer base of the microgrid. Single customer microgrids are powered through rooftop solar PV systems while multiple customer microgrid are powered through rooftop solar PV systems or solar farms or both of them. Generally, single customer based microgrids may be home microgrids or commercial building microgrids or industrial microgrids while multiple customer microgrids may be partial feeder microgrids. Full feeder microgrids are based on the number of customers and the geographical area. Figure 8 shows possible electrical boundaries and PV microgrids according to the customer base [39].

Based on the involvement of AC and DC systems, there are different PV- microgrid architectures as AC PV-microgrid, DC PV-microgrid and hybrid PV-microgrid and can be illustrated as in Figure 9. In AC PV-microgrids, the main bus is an AC bus where AC loads are directly connected while DC power sources (solar and battery) and DC loads are connected through DC/AC inverters and AC/DC converters respectively. In DC PV-microgrids, the main bus is a DC bus where DC loads are directly connected while DC sources (solar and battery) and AC loads are connected through DC/DC converters and DC/AC inverters respectively. However, a hybrid PV-microgrid is a combination of both AC and DC PV-microgrids with bidirectional converters [33].

Based on the control architecture, PV MG architecture can be recategorized as follows [40].

- Centralized control architecture
- Decentralized control architecture
- Hierarchical control architecture
- Multi-agent control architecture
- Reconfigurable Control Architecture

In the centralized concept, the sources are controlled by a central controller which may place at a remote location. In the decentralized concept, each source is individually controlled to share the demand change, without any interaction between controllers. The multilayer (hierarchical) control architecture is a better approach to overcome most of the issues associated with centralized and decentralized control. A multi-agent-based system is an advanced version of a decentralized system in which controllers interact with each other in achieving microgrid functions. The reconfigurable control architecture is the latest concept which increases the reliability, flexibility and controllability of power systems to use available resources in an optimized way to get reliable power supply while having cost benefits.

3. Reconfigurable solar PV microgrids (RSPVMGS)

Reconfigurable systems have the ability to change their configurations depending on the operational conditions. This concept is beneficial for the systems in which the configurations are easily convertible. The introduction of reconfigurability enhances system reliability, capacity together with further system developments [41].

Today, most of the power system components do not solely come up with hardware such that these components are interconnected with different controlling and monitoring systems. Existing traditional approaches are no longer sufficient to meet the evolving controlling and monitoring requirements of the modern systems. A modern power system requires a dynamic wide-area view, fast and predictive analytics and system-wide coordination. Therefore, moving towards reconfigurable power system components is the solution to fulfil future requirements. Reconfigurability can be introduced to a power system at the hardware level as well as in the control level to adapt to the on-demand functional requirements through changing its hardware topology or control methodology.

Different reconfigurable solutions are available for different sections of SPVSs such as PV array, power conversion unit and PV connected microgrids, and the summary of the discussion is in Figure 10 and Figure 11.

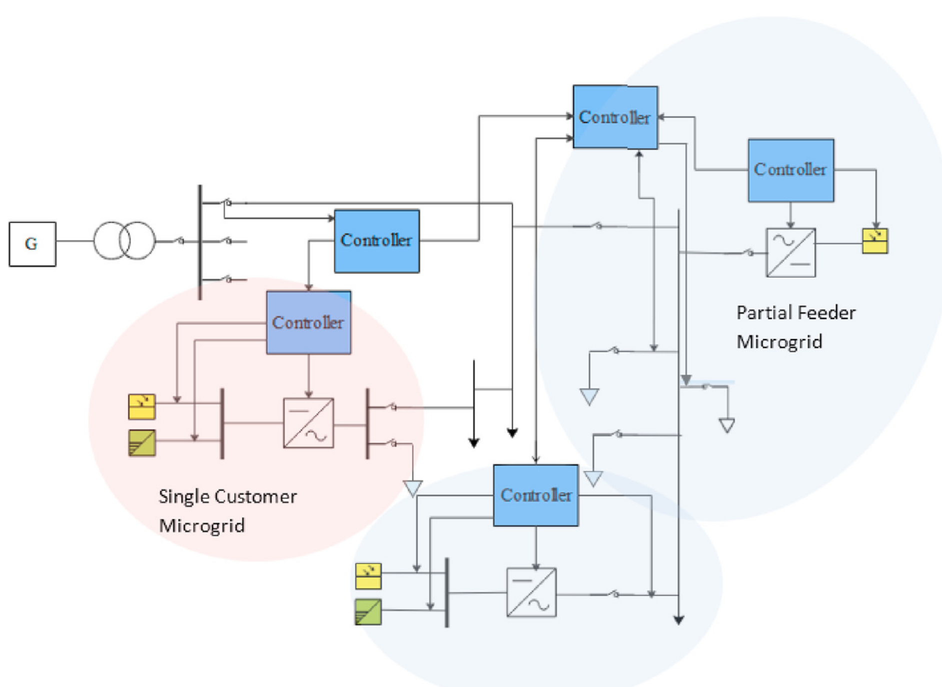

Figure 8. Different PV microgrid structures.

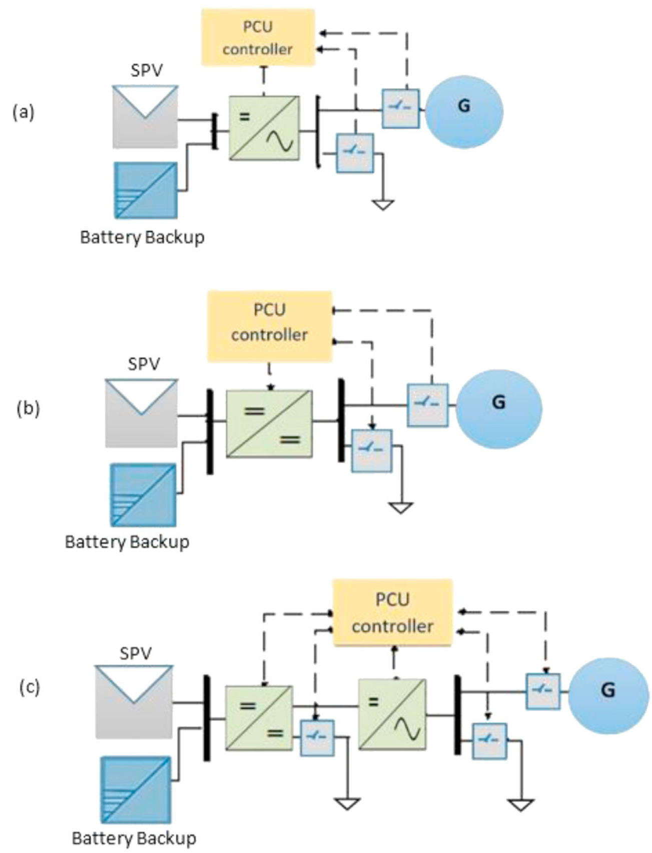

Figure 9. PV microgrid structures according to AC/DC systems (a) AC microgrid (b) DC microgrid (c) Hybrid microgrid.

3.1. The reconfigurable operation for solar PV array

The solar PV array reconfiguration is one of the solutions for electrical mismatch losses in an SPVS such that reconfigurable systems change the inter-connections between the solar modules in a solar PV array. Reconfiguration approach is applicable only for central inverters, string inverters and multi-string inverters. Generally, module inverters do not follow this approach since the electrical mismatch problem does not create a significant effect on these inverters. According to the configuration of connections of solar PV modules in a solar PV array, they can be categorized as,

- Series
- Parallel
- Series-Parallel
- Honeycomb
- Total cross-tied
- Bridge-linked

Figure 12 illustrates these configurations. Series and parallel connections are the basic configurations that are used to provide the required power output. Other configurations are modified versions of basic configurations which are designed to minimize the partial shading effect while providing the same power output as the basic configurations [19, 42, 43, 44].

In literature, ample research papers were published related to this research area. Most of these researches are focused on series-parallel (SP) and total-crossed-tied (TCT) configurations. As a reconfiguration approach, most of the researchers have used the irradiance equalization technique as a control objective [45, 46, 47]. The reconfigurable array basic structure is as in Figure 13 [48].

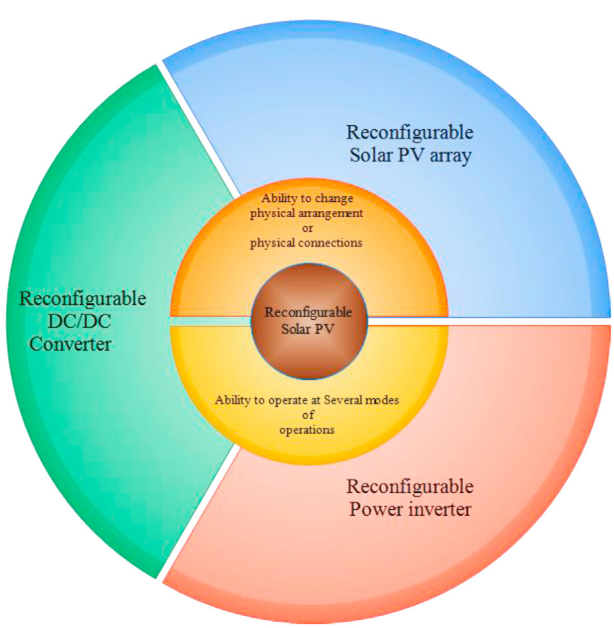

Figure 10. Summary of the function of reconfigurable solar PV systems.

3.2. The reconfigurable operation for power conditioning unit

In an SPVS, the solar inverter is the main controllable device that is engaged in maximum power point tracking (MPPT) and grid synchronization in addition to the DC/AC conversion. Different types of solar inverters have been proposed considering different perspectives. Out of these proposed inverter types, the reconfigurable solar inverter has drawn significant attention and this concept can be applied not only for DC/AC inverters but also for DC/DC converters.

3.2.1. Reconfigurable solar converter

In [48], a new concept called Reconfigurable Solar Converter (RSC) is under discussion. It is a conventional 3-ph SPV converter, with a minimum modification to the utility-scale. Its system configuration is an SPV plant type with a battery backup. The system structure of the proposed converter is given in Figure 14. This system consists of an SPV array, a battery backup, a conventional 3-ph inverter, a harmonic filter, a transformer and additional switches. Here, the reconfigurable unit is a single-stage power conversion unit and its controllability has been improved to change its configurations according to the requirements of the grid and the battery, and the availability of SPV generation. The proposed power conversion unit has the ability to operate in five major modes of operations through additional switching. These modes are,

- PV to the grid - SPV provides power supply to the grid.
- PV to the battery - SPV provides power supply for the charging of the battery.
- PV-Battery to the grid - Both SPV and battery supply power to the grid.
- Battery to the grid - Battery is sending power to the grid.
- Grid to the battery - Battery is charging from the grid supply.

Here, reconfiguration is proposed to improve the power conversion efficiency compared to the dual-stage power converter and to maximize the utilization, whenever the peak shifting is required. Therefore, it is expected that the proposed converter could reduce its cost, weight, and volume, and also support the economic dispatch requirements. As discussed, the new converter adds technical, financial and economic values to the conventional SPVS and can be applied to both SPV home systems and MGs.

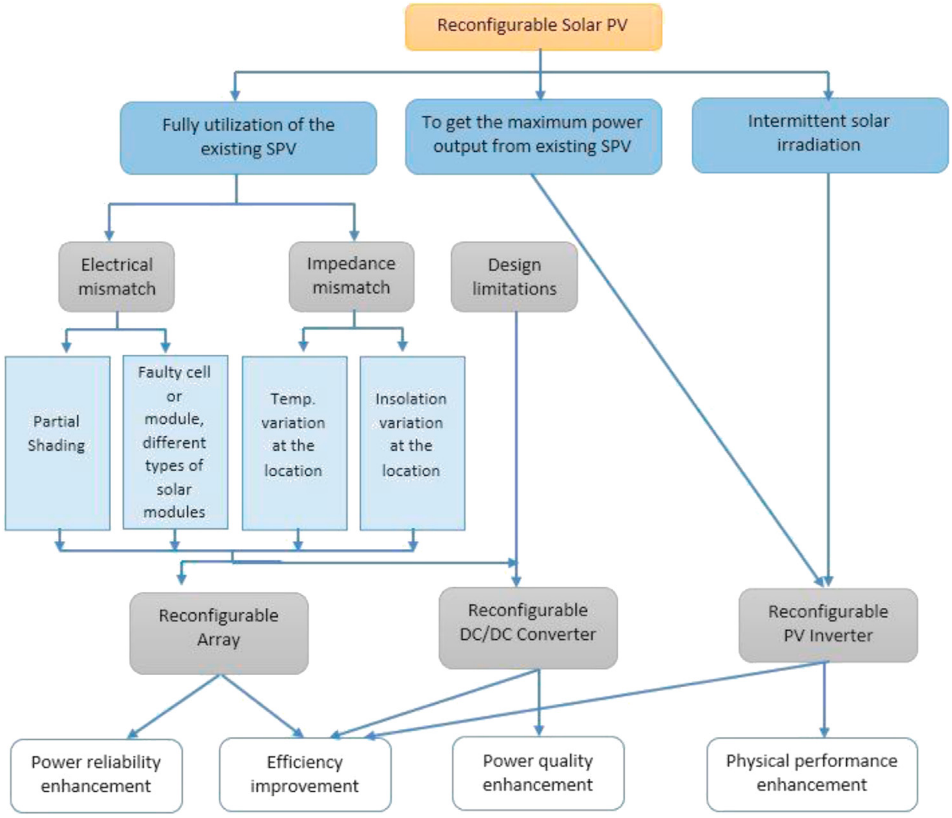

Figure 11. Summary of the application of reconfigurable solar PV systems.

A comparison between the performances of a microgrid connected RSC and conventional two-stage inverter (TSI) with a bidirectional converter for battery power controlling, is presented in [49]. According to this comparison, the RSCs have more economic benefits together with an improved controllability over TSIs under the same power output conditions.

Another application of RSC has been proposed in [50] for a distributed PV-battery architecture by considering a solar farm, to reduce the effect of the intermittent nature of SPV generation. Here, RSC in [26] is

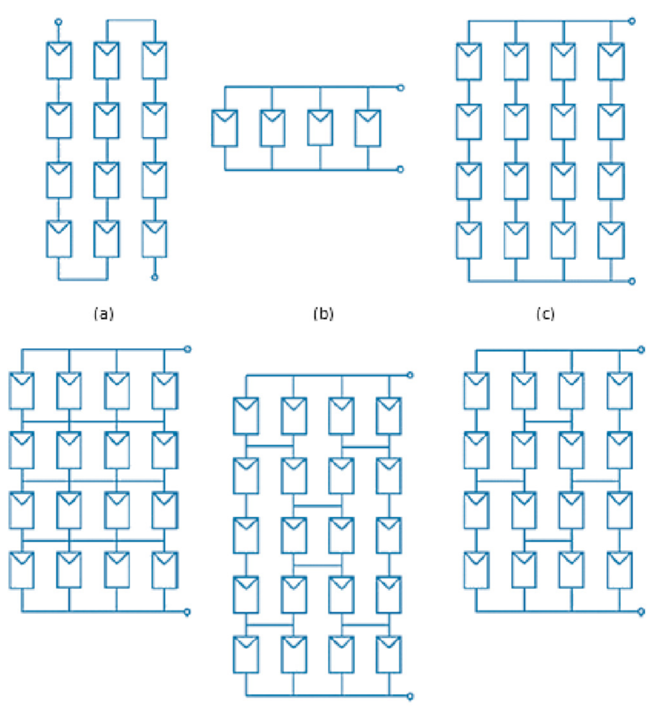

Figure 12. Reconfigurable array basic structures (a) Series (b) Parallel (c)Series-Parallel (d)Total-cross-tied (e) Bridge-linked (f) Honeycomb.

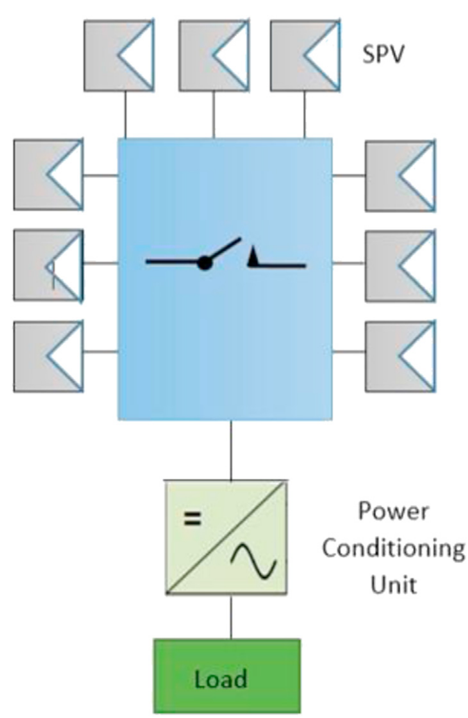

Figure 13. Reconfigurable array basic structure.

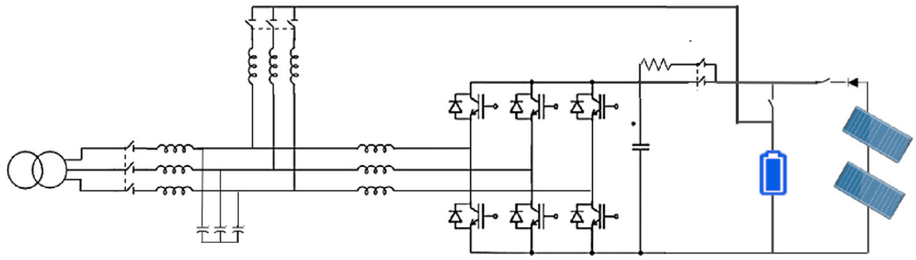

Figure 14. Structure of reconfigurable solar converter.

modified to a single-phase RSC such that it can be used for peak shifting. The same modes of operation in [48] apply to this model. These modified modular RSCs are connected in series with an additional battery backup to eliminate the grid side transformer. Therefore, the proposed architecture does not contain a transformer and this may result in reduced power losses and costs. Due to its modular nature, RSCs have the ability to independently control each array and allow the connection of small and multiple energy storage systems. There is a separate energy storage system that is used in smoothing the power flow variations through a ramp rate control.

Recently, a new inverter topology for solar-powered AC/DC hybrid homes has been developed by improving the concept of RSC in [51]. The main consideration of this new inverter is to reduce the harmonic distortion which is created due to the extra power conversion in supplying DC load from DC power supply while achieving the maximum utilization of utility-scale solar inverter. The performance of each mode of operation and transitions between these modes are under consideration. Total Harmonic Distortion (THD) can be compared between these two scenarios; connecting a dc load to additional DC-AC and AC-DC converters with the same rating and the newly proposed topology. Developed topology has been practically implemented and validated. A significant harmonic reduction (by 16% from THD) and an efficiency improvement have been achieved by introducing a DC supply for DC loads (by creating a DC microgrid).

3.2.2. Reconfigurable single-input dual-output converter

A new concept for reconfigurable single-phase converter is proposed in [52]. It is introduced as a single-input dual-output (SIDO) converter to supply DC loads that require high and low voltage levels in domestic microgrid operation (electronic equipment, electric vehicle charging, scooter charging). Here, a high DC voltage is required for higher DC loads such as electric vehicle charging, scooter charging, and a low DC voltage is required for smaller DC loads such as electronic equipment. This newly proposed converter has the ability to operate in three different modes by changing its configuration through static switches, depending on the availability of SPV generation and DC load demand.

- RES DC/DC SIDO mode - two different voltage supplies are provided through solar power generation depending on the DC load demand and solar power availability. As the name of this mode implies two separate outputs are available as buck and boost converter outputs with one input.
- Grid/RES double DC output mode - Here, the SIDO converter has been reconfigured into a separate H bridge converter and a buck converter. Here, SPV is connected to smaller DC loads through a buck converter and the grid supplies the large DC loads through an H-bridge converter.
- Grid double DC output mode - SIDO converter reconfigures into a single input double cascade converter by a series connection of an H-bridge converter and a buck converter. Static switches are available in this model to feed two-levels of DC loads. Generally, the cost of an

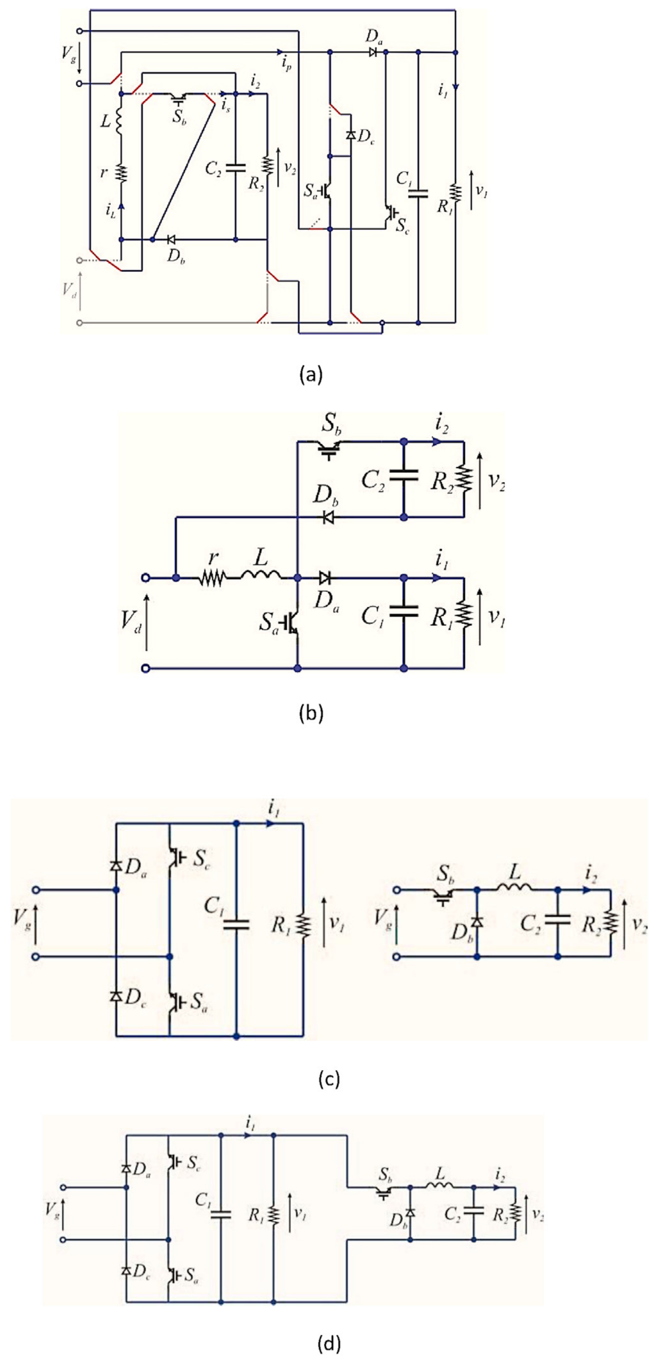

Figure 15. Modes of operation of RSC (a) Structure of SIDO (b) Structure of SIDO at RES DC/DC SIDO mode (c) Structure of SIDO at Grid/RES double DC output mode (d) Structure of SIDO at Grid double DC output mode.

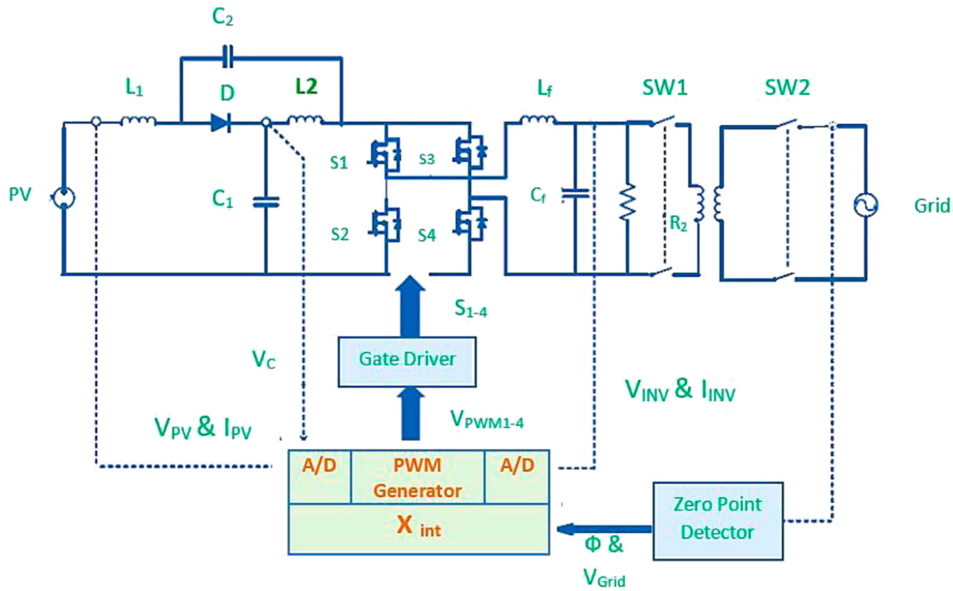

Figure 16. Structure of single-phase RSVPS.

equipment is directly related to the number of components of the equipment. Therefore, this converter is implemented such that a low number of associated components are required to achieve the grid connected operation in the form of a microgrid. In addition to that, maintaining the same system with the reduction of components increases the utilization coefficient of the system.

Structures for different modes of operation of RSC are given in Figure 15.

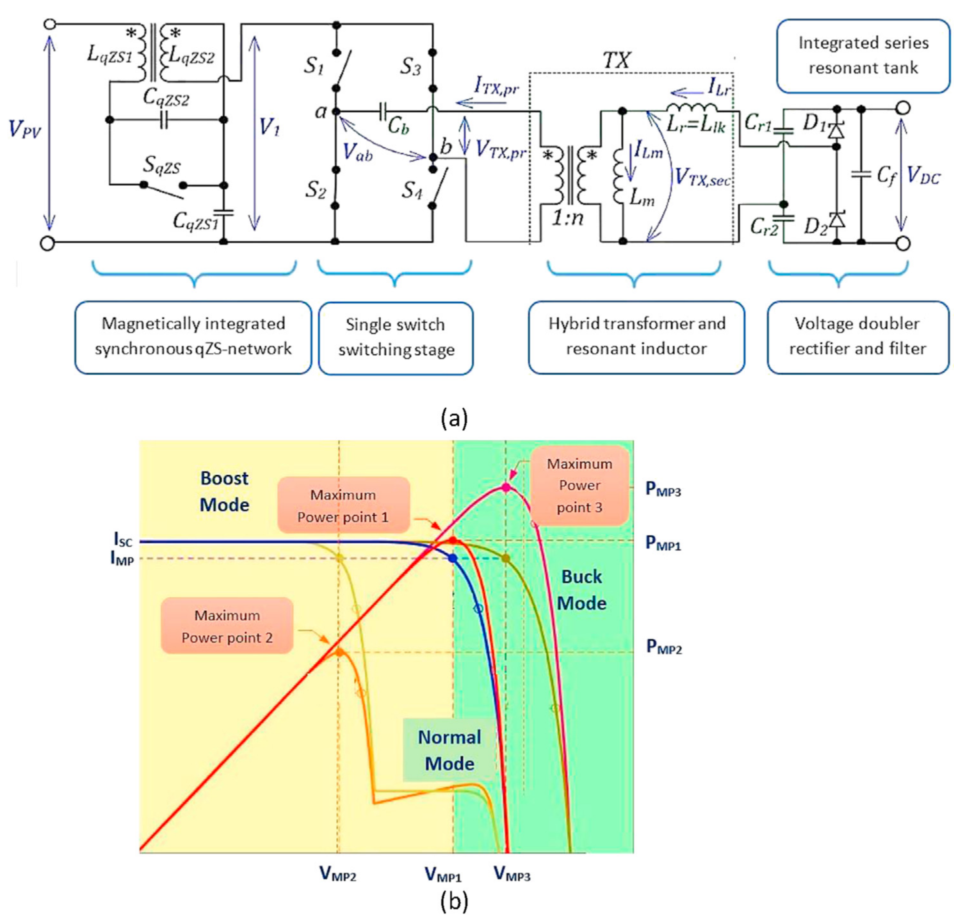

Figure 17. qZSSRC (a) Structure of qZSSRC (b) Characteristics of qZSSRC.

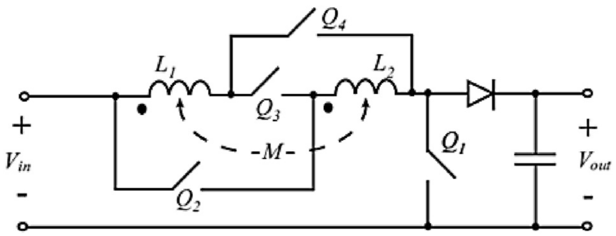

Figure 18. Structure of boost converter with reconfigurable inductor.

3.2.3. Reconfigurable PV system

In [53], another new concept for a single-phase RSPVS which is equipped with a quasi Z-source inverter is proposed to maintain an uninterrupted power supply to the loads in a case of grid failure. The proposed system structure is given in Figure 16.

This reconfigurable system can be operated in two modes [54],

- Grid-connected mode - normal operation of the grid-connected inverter.
- Standalone mode – when the grid is failed, the system gets disconnected from the grid and operates as a standalone system

Transients may appear in the system as the mode of operation changes. Therefore, an indirect current controlling method has been proposed to compensate these transients. The proposed indirect current controlling method is implemented in the MATLAB/Simulink environment and tested under different loading conditions. The above proposed reconfigurable model ensures system reliability in the case of grid failure.

3.2.4. Quasi-Z-source series resonant DC/DC converter

A reconfigurable operation method for a quasi-Z-source series resonant DC/DC converter (qZSSRC) is proposed in [55]. The main consideration is on MPP tracking of solar panels, under partial shading conditions and different temperatures. Here, the incremental conduction method can be used to calculate the reference input voltage. This converter provides a wide range of input voltage and load regulation capability to the SPVS. The proposed system has the capability to change its configuration into two different configurations as a full-bridge converter or a traditional series resonance converter (SRC) and a single switch qZSSRC as given in Figure 17a and it is operated in following three different modes depending on its point of operation.

- Buck mode – The system shifts to this mode of operation, at the startup of the qZSSRC and at low-temperature operating conditions.

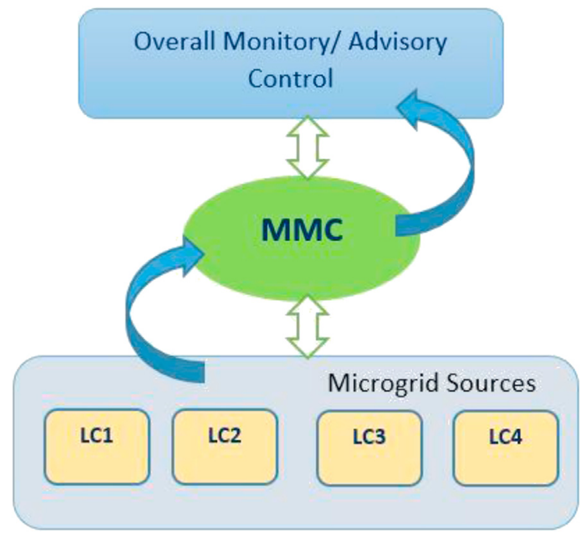

Figure 20. Proposed reconfigurable control architecture.

Here, the system functions as a single switch quasi Z-source dc/dc converter.

- Normal mode - This is a boundary between buck and boost modes. The system is operated as a full-bridge qZSSRC at the resonant frequency in half cycle discontinuous conduction mode.
- Boost mode - The system shifts to this mode of operation when the system is operated at high-temperature and partially shaded conditions. Here, the system functions as a full-bridge qZSSRC at the resonance frequency in half cycle discontinuous conduction mode.

The characteristic curves of qZSSRC are shown in Figure 17b.

As the main modifications, implementation of the magnetically integrated synchronous qZS-network and a resonant voltage-doubler rectifier (VDR), a reconfigurable buck-boost switching stage and a special control algorithm with smooth transitions between the operation modes can be stated. The proposed control algorithm is intended to achieve a desired dynamic behaviour in MPP tracking with smooth transitions between three modes of operation. The peak efficiency has been improved by almost up to 97% at the nominal voltage (including all losses in the converter). Here, the number of passive components and switching devices which are in operation at a time are higher, when compared to the other DC/DC converters. This can be highlighted as the main disadvantage of this converter [56].

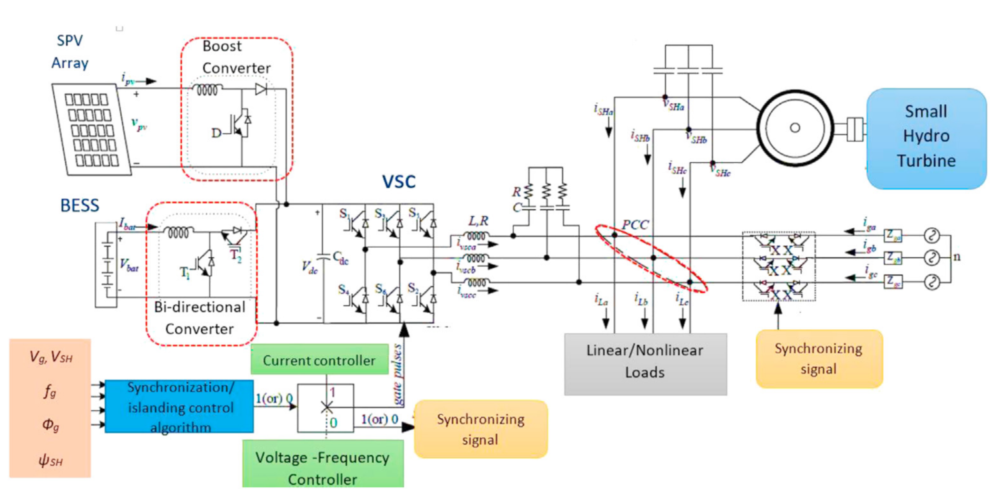

Figure 19. Structure of reconfigurable microgrid.

Table 4. Comparison of reconfigurable Solar PV systems/microgrid.

	Micro grid	Advantages	Reconfigurable section	Modes of operation	Added features	Validated through
RSC [48]	No, (Utility scale solar PV power plants)	• Single power conversion system to perform different operation modes • The solar plants can be controlled more effectively and its power can be dispatched more economically due to flexibility of operation • Maximize its utilization and reduced cost, volume and weight	VSC (3ph)	1)PV to grid 2)PV to battery 3)PV-Battery to grid 4)Battery to grid 5)Grid to battery	• Added additional cables and mechanical switches to conventional the three-phase PV inverter system to operate as a dc/dc converter in addition to its dc/ac conversion. • Optional inductors are included if the ac filter inductance is not enough for the charging purpose • The synchronous reference frame proportional-integral current control is employed for power control	Hardware implementation
RSC for distributed PV-Battery systems [50]	No, (Utility scale solar PV power plants)	• Possible for peak shifting • Possible for Smooth power variation • Enable to connect different types of PV modules and small energy storage systems • Reduced power conversion losses by removing step up transformer	VSC (1ph)	1)PV to grid 2)PV to battery 3)PV-Battery to grid 4)Battery to grid 5)Grid to battery	• Grid side transformer is removed from distributed multilevel modular RSC • Power controlled through ramp rate controlling method • Additional, separate battery is used to help ramp rate controlling	MATLAB -Simulink simulation
RSC with DC bus [51]	Yes (AC/DC, domestic microgrid)	• Improves the efficiency, reduces volume, and enhances the reliability. • Increased dc side of the inverter efficiency (90%) than that of dc appliances connected in ac side (72–80%) • Reduce 16% of current harmonics (THD)	VSC (1ph)	1)PV to grid 2)PV to battery 3)PV-Battery to grid 4)Battery to grid 5)Grid to battery	• Same as RSC (Jha & Triar, 2019), utilize single conversion of ac power to dc and vice versa • DC loads are directly connected to the DC link without connecting to AC side through AC/DC converter	Hardware implementation
Reconfigurable SIDO inverter [52]	Yes (Domestic Microgrid)	• Flexible to operate different power conversion modes • Solution to meet the demand of mixed power supply (AC and DC) with single converter • desirable performance under both steady-state and transient conditions. • Reduced no of components, maximize its utilization, reduced cost, volume and weight	Single-input dual-output (SIDO) converter (DC/DC and AC/DC converter (1ph))	1)RES DC/DC SIDO mode 2)Grid/RES double DC output mode 3)Grid double DC output mode	• Single input dual buck-boost converter has been modified adding 11 static switches • Measures have taken to meet mixed power supply demand (AC and DC) • Supply two level of dc loads demands	MATLAB -Simulink simulation
Ref [53]	Yes	• Enable to supply uninterrupted power supply for critical loads at grid failure •Improved reliability of the solar PV system	Quasi Z-source inverter (DC/AC converter (1ph))	1)Grid connected mode 2)Islanded mod	• Single-phase quasi-Z-source inverter is used as Solar PV converter • Indirect current control-based controller is developed	MATLAB -Simulink simulation and hardware implementation
Reconfigurable quasi-Z source Inverter [55]	No	• Capability of wide range voltage regulation for MPP tracking • Reduced power losses due to partial shading and impedance mismatch • Improved peak efficiency of converter closed to 97% • Smooth transition between three modes of operations	DC/DC converter (quasi-Z source Inverter)	1)Boost mode (full bridge qZSSRC) 2)Normal mode (full bridge qZSSRC) 3)Buck (single switch qZSC)	• Implementation of magnetically integrated synchronous qZS network and resonant voltage-doubler rectifier (VDR) and its specific controller	Hardware implementation

(continued on next page)

Table 4 (*continued*)

	Micro grid	Advantages	Reconfigurable section	Modes of operation	Added features	Validated through
Ref [60]	No (residential solar PV System)	• Increasing solar energy capture during low light periods. • Smaller current ripple without increasing the volume to meet peak current saturation requirements. • Reduce the necessary PV panel size, inductor volume, or both.	Inductor in DC/DC converter	1)High L (High Inductance) 2)Low L (low inductance)	• A standard boost converter has been modified by replacing source side inductor from coupled two inductors and adding 3 additional semiconductor switches.	Numerical simulation and hardware implementation
Ref [61]	Yes (small hydro, PV, battery microgrid)	• Extracting maximum power from SPV system • Providing uninterrupted power supply for critical loads • Maintaining power quality in the micro grid • The THD of load voltage and grid current is below 5% even under nonlinear loads	VSI (3ph)	1) Grid connected mode 2) Islanded mode	• Small hydro generator was connected at PCC • Consideration the effect of non-linear loads • Compensation of load reactive power. • The performance of the reconfigurable system has been verified under all types of disturbances	MATLAB -Simulink simulation

3.2.5. Z-source inverter

ZSI has become an interesting research area related to solar PV inverter performance enhancement in terms of power quality, efficiency and reliability by minimizing the harmonics in the output, introducing fewer power conversion stages and managing converter failures resulted by inevitable shoot-through conditions and capacitor failures respectively [20, 57]. In addition to that, ZSI is used in grid connected and islanded operation of SPVS together with reactive power controlling [59]. As a novel approach, ZSI based MPPT is available for solar power applications [58]. However, the combined operation of grid connected mode and islanded mode while night time reactive power compensation is not proposed for a residential system. Furthermore, solar PV systems based reconfigurable systems will play a major role in future distribution networks.

3.2.6. Reconfigurable inductor

Most of the researches are focused on the reconfigurability of the entire converter. There is a low consideration of the reconfigurable operation of a single element of a system. In [60], a reconfigurable inductor is proposed as a solution for low-efficiency solar PV boost converters, under low insolation conditions with high current and voltage ripples. This approach can also be used to overcome design limitations on inductor sizing to prevent saturation at high insolation levels. Here, the standard boost converter is modified with three switches and replaced the inductor with a coupling inductor such that it can be reconfigured into two different modes.

- High-L - where, inductors are connected in series to reduce output current and voltage ripple of the solar PV system at low insolation.
- Low-L - where, inductors are connected in parallel. This mode of operation prevents reaching saturation at high insolation levels.

Practically implemented models are available for SPVSs with considerable power efficiency improvements. It is useful to recharge batteries of the standalone solar system to supply the loads under low insolation levels. The structure of the converter is given in Figure 18. Here, a two-stage power conversion architecture is under consideration.

3.3. Reconfigurable microgrids

The reconfigurability has been introduced for microgrid control architecture as well as for microgrid topology architecture. Most of the researches are based on battery-based inverters for microgrids such that there is a low consideration towards AC generation including wind, hydro and diesel generators. But recently, grid-connected SPV-battery and hydro generation based reconfigurable systems have been proposed [61]. The point of common coupling (PCC) is the common connection point for the grid, the microgrid and the non – linear loads in the system.

Table 5. Advantages of reconfigurable operation in power system.

For solar PV arrays Technology [19, 44]	**For Solar PV systems**		**For microgrid**	
	• DC/DC converter [55, 60]	DC/AC inverter [48, 51, 52, 53, 54, 61]	Control architecture [40]	Microgrid operation (Distribution network) [4, 62, 63]
• Solution for Electrical mismatch	• Solution for Electrical mismatch [55]. • Solution for Impedance mismatch [55] • Solution for design Limitation [60] • Maximize its utilization and reduced cost, volume and weight [60]	• To improve power quality at PCC [61] • Maximize its utilization and reduced cost, volume and weight [48, 51, 52] • To increase the reliability [53]	• To increase the reliability	• Optimum MG operation • Distribution network power loss reduction • Load balancing • Service restoration for critical loads
System efficiency increased, power availability, power quality and power reliability at PCC is improved. Maximize its utilization and reduced cost, volume and weight.			Reliability increased	

Table 6. Cost saving methods of reconfigurable systems.

Reference	Application	Modes of Operation	No. of additional switches	Circuit parameters				Cost saving from
[1, 48]	Reconfigurable solar converter (RSC) for utility-scale PV-battery application	Mode 1—PV to grid. Mode 2—PV to battery Mode 3—PV/ battery to grid Mode 4—battery to grid	6	Lithium –ion Battery Parameters				Avoid separate DC/ DC converter for battery charging
				Battery Capacity	5.9 kWh/51.2Ahr			
				Battery nominal voltage	115.2 V			
				Min. Battery voltage	90 V			
				Max. Discharge current	52 A			
				Max. Pulse discharge current	150 A (<2s)			
				Max. charging Voltage	132 V			
				Max. Charging current	10A			
				Inductance value of a coupled three-phase inductor in the dc/dc operation				
				DC Application	Inductance value			
				Only A	1.42 mH			
				Only B	1.58 mH			
				A & C	0.50 mH			
				A & B & C	0.13 mH			
[50]	Reconfigurable Solar Converter (RSC) for Integration of energy storage with a PV system where ramp-rate control and peak-shifting is desired.	Mode 1—PV to grid. Mode 2—PV to battery Mode 3—PV/ battery to grid Mode 4—battery to grid	6	• PV panel: (Sharp NU-U235F3) 235 Watt • DC-link capacitor for each cell: 3300μf • Inductance L = 0.05 mH				Avoid separate DC/ DC converter for battery charging and it support for ramp rate controlling
[51]	A reconfigurable single-phase inverter topology for a hybrid AC/DC solar powered home.	Mode 1—PV to grid. Mode 2—PV/ battery to grid Mode 3—PV to battery Mode 4—battery to grid	5	Component				Avoid separate DC/ DC converter for battery charging and it allows DC loads
				Battery	12V, 9Ah			
				Filter Capacity (C1)	47uF			
				Filter Inductor (L1)	2.3mH			
				Switching frequency	4000 Hz			
				DC link Capacitor (C2) 2 nos	2200uF, 16 V			
				Resistance (R1)	1kΩ			
				Solar Panel				
				O/C Voltage (V)	22.09			
				S/C current (A)	8.36			
				Voltage at MPP (V)	17.7			
				Current at MPP (A)	7.62			
				Diode quality factor	1.25			
				No of series connected module per module	1			
				Number of modules per string	3			
				Series resistance (ohm)	0.165			
				Parallel resistance (ohm)	80			
[52]	A flexible power converter with static switches that can change the configuration to provide different conversions with same hardware structure.	RES DC/DC SIDO mode Grid/RES double DC output mode Grid double DC output mode	3	Symbol	Description		Value	Enabling dual renewable source input
				Vd	RSE Input		96V	
				V1	Higher level output DC voltage		230V	
				V2	Lower level output DC voltage		48V	
				Fs	Switching frequency		20kHz	
				L	inductance		5mH	
				C1	Higher voltage level capacitance		1uF	
				C2	Lower voltage level capacitance		1uF	
[53]	A reconfigurable photovoltaic system based on the structure is developed by combining a single-phase quasi-Z-source inverter and the grid-connected system.	Grid Connected Mode Standalone operation	2	Name	Specification	Name	Parameter	Converter could operate either as a full-bridge or a single-switch quasi-Z-source dc-dc converter for 0.4% California Energy Commission (CEC) weighted energy efficiency improvement.
				Rated output power	200W	Inductors L1, L2	3mH	
				Rated power of stand-alone Load	100W	Capacitors C1, C2	470uF	
				Input Voltage	100V	Output Inductance L0	1.5mH	
				System Output Voltage	110Vrms/60hZ	Output Capacitance C0	4.75uF	
				Switching Frequency	12kHz	Power Switch	IRF840	

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Table 6 (*continued*)

Reference	Application	Modes of Operation	No. of additional switches	Circuit parameters		Cost saving from
[55]	Novel soft-switching galvanically isolated buck-boost dc-dc converter as a module integrated converter for photovoltaic applications.	Normal mode Boost mode Buck mode	4	Input voltage range, V_{pv}	10…60V	
				Nominal input Voltage, V_{pv}	34A	
				Maximal input current, I_{pv}	12A	
				Input voltage range of boost mode	10…33V	
				Input voltage range of buck mode	33…60V	
				Output voltage, V_{dc}	400V	
				Switching frequency, f_{sw}	105kHz	
				Resonant frequency, f_r	105kHz	
				Operating power range	25..250W	
				Component	Type	
				$S_1…S_4$, S_{qzs}	Infineon BSC035N10NS5	
				D_1, D_2	CREE C3D02060E	
				L_{Mi}	11uH	
				C_{qZS1}, C_{qZS2}	25uF	
				C_f	100uF	
				L_{lk}	24uH	
				L_m	1mH	
				N	6	
				C_{rl}, C_{r2}	66nF	
				C_b	12uF	
				Dead-time of inverter switches	200nS	
				Dead-time of S_{qzs}	70nS	
[60]	A modified boost converter with a reconfigurable inductor is presented for increasing solar energy capture during low light periods.		4	The self-inductance $L_{11} = 215.9$ μH, $L_{22} = 215.8$ μH series resistances around 100 mΩ The mutual inductance $L_{12} = L_{21} = 215.5$ μH		Reduced separated inductor for lower energy production to reduce harmonics and increase energy efficiency of the inverter

Depending on the grid availability, the proposed reconfigurable microgrid is designed to be operated at two modes;

- Grid-Connected mode
- Islanded mode

Here, the reconfigurable operation is intended to be applied for the control strategy of a microgrid. This reconfigurable system consists of three different controllers as MPPT controller, bidirectional inverter controller of battery energy storage system (BESS) and voltage source converter (VSC) controller of the SPV system. But the solar inverter is the main component that performs the reconfigurable operation by changing the inverter control mode to the current controlling in the grid-connected mode and to the voltage-frequency controlling in the islanded mode. As a key feature of the above-proposed system, the automatic synchronization of the microgrid to the utility grid while providing an uninterrupted power supply for the critical loads, maintaining the power quality in the microgrid and considering the effect of non-linear loads can be highlighted. The reconfigurable microgrid structure is given in Figure 19.

3.3.1. Reconfigurable control architecture

The next-generation PV inverters are intended to provide a variety of new control features (e.g.; voltage regulation, power curtailment, ramp-rate control, and communication-assisted protection) to enhance the interaction between utility-scale PV-DG plants and the grid. This coordinated controlling and operation can be achieved through localized or utility-wide supervisory control systems.

In [40], a reconfigurable architecture is proposed for a microgrid consists of distributed generation resources including SPV and power backups. In this study, as control architectures, the conventional centralized, decentralized and hierarchical architectures are under consideration. The main aim of applying reconfigurable concept to the control architecture is to ensure the microgrid operation even there are failures in controllers, data transmission networks, etc. This control architecture consists of four main control layers (local controller (LC), emergency controller, secondary controller and global controller) and an additional control layer called adversary control (ADVC) layer. Here, the global and secondary layers reside in the master microgrid controller (MMC) while the emergency control layer resides in ADVC, MMC and LC. All controllers are interconnected via the communication layer to operate as a centralized controller. According to the proposed reconfigurable architecture, the microgrid is operated through a decentralized controller. When a failure of LC occurs, the MMC functions as a centralized controller. In an emergency, where both LC and MMC are failed, ADVC functions as a centralized controller. The proposed reconfigurable microgrid can be physically implemented and tested for reconfigurable operation under various operating modes and events. The corresponding reconfigurable control architecture is given in Figure 20.

3.3.2. Reconfigurable distribution networks

With the introduction of distributed generation sources, the distribution network has gained an active nature. High penetration of distributed generation may lead to critical issues related to power reliability, power quality, harmonic levels and protection. Voltage fluctuations, voltage flickers, voltage sags, and dips and harmonics are the main power quality issues related to SPVS.

In addressing these problems, reconfiguration of the distribution network into a cluster of microgrids or connecting distributed generations like solar and wind through microgrids can be identified as a promising solution [62]. Moreover, it will lead to the reduction of the power consumption from the utility grid.

The radial distribution network of the proposed system is subjected to reconfigurability, focusing on energy costs and the frequency of supply interruptions. This study highlights that to exploit the benefits from the reconfigurable approach, the most appropriate nodes for the microgrid operations under certain conditions should be distinguished. This proposed system is beneficial to distribution system operators (DSOs) to upgrade their services, exploit new businesses, and hold off investments on modern networks. Microgrid regulators may also find this planning strategy advantageous in terms of profits that can be gained through customer operations and subsides for distribution system advancement [63].

3.3.3. Reconfigurable distribution networks into microgrids

The main aim of distribution network reconfiguration is to advance the microgrid operation with an economic load dispatch concept considering the uncertainties of the system such as load variations and the cost of SPV, wind generation and battery storage. And also vector regression-based machine learning approaches can forecast such uncertainties in the system. Vaccine-enhanced artificial immune system (Vaccine-AIS) is a suitable multi-modal optimization technique to solve the optimization problem related to this proposed model. The reconfigured network has the capability to adjust its configuration by itself. This approach allows the maximum utilization of renewable energy while reducing the power loss in the distribution network.

Recently, a new robust optimization technique has been introduced to reconfigure distribution feeders into multiple microgrids for optimum microgrid planning under system uncertainties [4]. It is proposed to partition the distribution feeder into several microgrids through SSW. TSW allows the distribution feeder to change its configuration. The system optimization problem should be solved by analysing economic, technical and reliability factors to decide the optimum configuration of microgrids. Here, the robust optimization provides a suitable platform to solve the optimization problem under system uncertainties such as renewable generation, demand, and the market price.

A microgrid planning model based on economic, technical and reliability aspects can be modelled through the multi-integer nonlinear programming model together with the Grey Wolf Optimization (GWO) algorithm. The proposed microgrid planning model can be implemented and validated on the IEEE 30-bus distribution network in MATLAB/Simulink environment. As important outcomes of this reconfigurable approach, the reduction of the cost of the unserved energy, voltage fluctuations and the power loss in distribution feeders can be stated. And also, Monte-Carlo simulation results verify the robustness of the model. Furthermore, this approach has proved that the microgrids with a reconfigurable topology have better performing abilities when compared to a conventional fixed system.

The summary of the critical review is on reconfigurable Solar PV systems/microgrid is shown in Table 4 while the advantages are shown in Table 5.

In addition to that, the costs of the reconfigurable approaches which are under discussion are analysed in terms of associated components, number of switches and the compactness of the systems. Reconfigurable systems are compared with other systems considering their modifications to achieve a low cost as in Table 6.

Most of the researches are focused on the dual mode operation (grid connected and islanded) of ZSI based residential solar systems. And also, there is an emerging approach for reactive power control at night through solar inverters in residential systems which have already been technically and economically proven by researchers. However, the combination of dual mode operation and reactive power controlling through ZSI based residential solar PV systems remains as a research gap. Considering this research gap in solar reconfigurable systems, a study on Z-Source Inverter based reconfigurable architecture for solar photovoltaic microgrid is in [68]. The control architecture of this study is developed in MATLAB/Simulink environment.

4. Conclusion

As the definitions of roles and responsibilities of the distribution level change, the associated regulatory and industrial requirements may also get transformed. SPV sources and BESSs are expected to function beyond their conventional scopes in maintaining the power quality of the system. Therefore, a control architecture is required to optimally integrate the battery storage as a resource to the network. Structure of control systems, coordination frameworks, communication techniques and the overall industrial structure should have undergone major changes. And it is also critical to review, understand, re-architect and manage these new changes simultaneously, as these sectors are interconnected with each other. The suitability of the existing reconfigurable systems highly depends on the application, objectives, reconfiguration methods and structures. The main objective of the above discussed reconfigurable solar array systems is to reduce partial shading losses. PCUs have been used to reduce partial shading losses, electrical mismatch losses and the cost, weight and volume to enhance performances by overcoming its design limitations. Reconfigurable microgrids have been introduced to improve the reliability and power quality. A predefined controlling function is dedicated to each configuration. Since a predefined function is unique to a particular configuration, configuration changes may occur when the existing system parameters go beyond its set limits.

DNR is widely under discussion to achieve common objectives of every configuration such as enhancing the power supply availability for critical loads, reducing the power losses and increasing the quality and the stability of the DN by considering the effects of DG integration. Different optimization strategies can be used to determine the best configuration in achieving the above-mentioned objectives. A reconfigurable architecture has been proposed for power and control architecture of SPV based systems and microgrids. There is a positive trend for reconfiguration of power system components, especially for solar PCUs, microgrids and microgrid control architecture. The reconfiguration of both power and control architecture will provide more benefits to the next generation microgrids. The reconfigurable concept is applicable for conventional microgrids, DC microgrids and grid-connected SPV generation, but not for SPV microgrids. Few researches are based on the reconfigurable architecture with the quasi-Z-source network for DC/DC converter operation. According to the study, a conceptual reconfigurable architecture for a residential MG is proposed where there is an adversary controller provides control signals in addition to main microgrid controller to operate the PV microgrid according to preset main grid power requests during grid disturbances such as reactive power control during voltage sags and rise.

Declarations

Author contribution statement

All authors listed have significantly contributed to the development and the writing of this article.

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Data availability statement

No data was used for the research described in the article.

Declaration of interests statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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