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An overview on Stand-Alone Photovoltaic Systems

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Abstract- A standalone PV system is preferred over the grid connected system for the residential and rural area load demands. The lot of lots of research is already carried out for the power electronics converter design of renewable energy systems as well as the controller adopted. The various controllers for inverter operation available are Fuzzy logic, PI, PID and MS-PI. All these controllers are for the PV based system and works on the principles of closed loop system. This work proposes an improved inverter voltage controller using open loop control system.

Keywords - PV System; Open loop Controller; Supervisor Control; Harmonic analysis.

I. INTRODUCTION

The SAPS system uses renewable energy sources, selected in such way to minimize the use of battery and diesel generator. The SAPS system is designed in such a way to select best optimal power flow. The literature survey is carried out and various control techniques is being implemented for supervisory control and energy management.

The concept of energy storage system (ESS) is also survey in the literature due to the fact that heterogeneous energy storage system fails to provide reliable long lasting power to all such loads which goes under dynamic cycles.The dynamic loads at the time of starting, draws large current like induction motor or DC motor which results in accelerating the ageing of battery storage system.

The literature survey of inverter for the hybrid renewable energy system is also carried out. There are so many reports and research paper available in the field of integration of renewable energy sources for hybrid power generation, design of energy storage system and inverter topologies. For this research work, some of research papers are reviewed.

II. MATHEMATICAL MODELING OF STANDALONE & HYBRID RENEWABLE POWER GENERATION

(Ganesh et al., 2014) proposes a renewable hybrid wind solar energy system fed single phase multilevel inverter. The hybrid system is the combination of photo voltaic (PV) array and wind generator. Solar energy is generated by using PV arrays, wind power is generated by using wind generator and both the generated voltages are boosted up by boost converters. These boosted voltages are fed to the single phase multi level inverter.

Due to the intermittent nature of both the wind and solar energy sources, a fuel cell can be used as an uninterruptable power source, which is able to feed a certain amount of power to the load under all conditions. Simulation models are constructed for the both single phase inverter, single phase multilevel inverter and it is validated through experimental results using PIC micro controller.

(Hojabri et al., 2012) discussed power quality consideration for Off-Grid renewable energy systems. This work stated about the best electrical power supply must provide a constant magnitude and frequency voltage. Therefore, good power quality is an important factor for the reliable operation of electrical loads in a power system. However, the current drawn by most of electronic devices and non-linear loads are non-sinusoidal, which results in a poor power quality, especially in off-grid power systems. Off-grid power systems world- wide often struggle with system failures and equipment damage due to poor power quality.

The MATLAB/Simulink is used to model and analyses power quality in an off-grid renewable energy system. The results show high voltage transient when the inductive loads were switched OFF. The voltage and current harmonics are also determined and compared for various types of loads.

(Kim et al., 2008) works on power-control strategies of a grid-connected hybrid generation system with versatile power transfer. The hybrid system is the combination of photovoltaic (PV) array, wind turbine, and battery storage via a common dc bus. Versatile power transfer was defined as multimodes of operation, including normal operation without use of battery, power dispatching, and power averaging, which enables grid- or user-friendly operation.

A supervisory control regulates power generation of the individual components so as to enable the hybrid system to operate in the proposed modes of operation. The concept and principle of the hybrid system and its control were described. A simple technique using a low-pass filter was introduced for power averaging.

A modified hysteresis-control strategy was applied in the battery converter. Modeling and simulations were based on an electromagnetic-transient-analysis program. A 30-kW hybrid inverter and its control system were developed. The simulation and experimental results were presented to evaluate the dynamic performance of the hybrid system under the proposed modes of operation.

A new control method for the parallel operation of inverters operating in an island grid or connected to an infinite bus is described by (Brabandere et al., 2007). Frequency and voltage control, including mitigation of voltage harmonics, are achieved without the need for any common control circuitry or communication between inverters.

Each inverter supplies a current that is the result of the voltage difference between a reference ac voltage source and the grid voltage across virtual complex impedance. The reference ac voltage source is synchronized with the grid, with a phase shift, depending on the difference between rated and actual grid frequency. A detailed analysis showed that this approach was a superior behavior compared to existing methods, regarding the mitigation of voltage harmonics, short-circuit behavior and the effectiveness of the frequency and voltage control, as it takes the to line impedance ratio into account. Experiments show the behavior of the method for an inverter feeding a highly nonlinear load and during the connection of two parallel inverters in operation.

(Jayeshkumar et al., 2015) works on Promotion of distributed renewable energy sources is an economical off grid energy solution for remote locations providing both social and environmental advantages. Integration of different types of renewable energy sources presents challenge in terms of their power management, control & stability.

This paper presented power management of microgrid comprising of wind, microturbine as the sources, Battery energy storage system as stabilizer along with AC/DC load network connected by bidirectional converter. Control strategy and energy management of distributed sources is proposed for achieving smooth transfer of power and stable operation of system.

Hybrid system consists of wind, Micro turbine generator system and storage system is modeled and simulated using MATLAB/SIMULINK for different load and source variation scenarios. The simulation results shows that the system can maintain stable operation under the proposed method of control under varying conditions and also when the system is switched between autonomous and grid-tied modes maintaining voltage and frequency within limits.

(Alnejaili et al., 2015) worked on load side management strategy for (photovoltaic–wind–diesel) hybrid system for medium rural health building located in the Sahara region. The paper presented an overview about geographic and climate data of the location and develops a typical load profile of electrical energy, depending on a real investigation of daily electricity consumption. The result shows that the reduction in the peak consumption is about 20% using the proposed management strategy, which has significant economical, technical, and environmental benefits.

(Morato et al., 2017) presented process supervision and advanced control structure, based on Model Predictive Control (MPC) coupled with disturbance estimation techniques and a finite-state machine decision system, responsible for setting energy productions set-points.

This control scheme is applied to energy generation optimization in a sugar cane power plant, with non-dispatch able renewable sources, such as photovoltaic and wind power generation, as well as dispatch able sources, as biomass.

The control algorithm has the task of performing the management of which energy system to use, maximize the use of the renewable energy sources, manage the use of energy storage units and optimize energy generation due to contract rules, while aiming to maximize economic profits. Through simulation, the proposed system is compared to a MPC structure, with standard techniques, and shows improved behavior.

III. DC-DC CONVERTER FOR SOURCE INTEGRATION

The renewable energy sources, such as Solar Photovoltaic (SPV) systems, when working alone, are regarded greatly insufficient and suffers from poor reliability, sustainability and substantiality in terms of stability in energy density and efficiency of the supply system.

Consequently, the future of energy technology is greatly dependent on the evolution of improved techniques for hybridization of two or more different energy sources. Clean, reliable and durable operation of hybridized energy systems are the responsible factors for its widespread popularity over single-source energy systems. The proper intervention of power electronic interface makes the hybridization of energy sources meaningful.

In the earlier versions of hybridization, different categories of sources were combined through separate dc-dc converters and their outputs connected in series or parallel. Such arrangements had limitation of large number of components, high cost, bulky weight, poor efficiency and complicated design. Various forms of generation sources like fuel cell generators, ultra-capacitors, wind turbine etc. have been considered earlier in order to achieve load levelling and ensure good performance in operations which are transient in nature. In such cases, the converter which is generally a unidirectional converter with step functions is used to connect the generation sources with the dc-link. Several proposals have been made with this respect.

A high frequency transformer is used in conjunction with dc-dc converter in case where a conversion ration with high voltage factor is required and where galvanic isolation is also required. In some other cases, converters which are capable of handling power in dual direction are used to connect the generation sources with the inverter dc-link. A bridge solution, either half-bridge or full-bridge is utilized along with a transformer with high frequency where galvanic isolation is required. In case the galvanic isolation is a mandate, a converter system is used which is connected in parallel to provide the DC generation with voltage regulation.

An innovative solution has been proposed recently which uses a dc-dc converter which is six-way. This is used to connect ultra-capacitor and fuel-cell with a motor drive for achieving power flow in six ways. The uniqueness of this solution is that the voltage of the generation sources viz. the ultra-capacitor and the fuel-cell must be equal to the voltage of the motor drive.

More recently, in one of the works, the interfacing of two different DC generation sources in a bidirectional manner was done using a new structure where there was requirement of only three electronic switches for controlling power and where the precondition was that the motor drive dc-link voltage must be equal or greater than the sum of the two different voltage sources.

It must be noted that in above-mentioned converter systems, the voltage of the dc-link is generally much higher than the voltage level of the generation sources which prevents efficient operation of the hybrid system. Also, in conventional system every source requires a separate input converter which leads to a complicated technical architecture and also higher cost.

Later, with the development of multiple input dc-dc converter (MIC), almost all the limitations posed by the traditional converter were effectively addressed. MIC successfully replaced a single multiple-input system by offering a simple, low cost, more compact, multiple single-input dc-dc converter. Past several research works were also based on the development of isolated and non-isolated types of MIC.

In the isolated MIC a multi-winding transformer is provided to electrically isolate source side from the load side. In such topologies the energy takes the route of magnetic coupling, as offered by transformer core. Whereas, in the non-isolated MIC there is a direct electrical connection between the source and the load. (Caceres et al.,1999; Walker et al.,2004; Gao et al.,2001).

It should be noted that obtaining a regulated dc output is key in use of such dc-dc converter for combining different generation sources in order to cater to the energy requirements of the load. However, in the event of one of the energy sources diminishes, it is not possible to obtain the regulated dc output because of the large variation in input voltage.

Consequently, the solution is to integrate the sources by paralleling them by use of a transformer which is the basis of isolated MIC. The number of input-stage circuit for an isolated MIC is related to the number of independent generation sources we want to operation in parallel.

Each independent DC source, coupled by means of a full-bridge dc / ac converter, can act as a DC current source which enables the isolated MIC to have different generation sources with different voltage levels.

This is especially relevant when one of the energy sources is solar photovoltaic. The output voltage of a solar module depends on solar insolation and ambient temperature. Hence, there is constant variation in input voltage for solar photovoltaic sources. Consequently, it is imperative to use a high-ratio DC-DC converter to achieve stable dc-voltage.

Also, it is important that the input-stage windings of the transformer are wound on the same magnetic core with the output-stage winding so that there is no flux leakage and the input flux can fully pass through to the output flux. Such an isolated MIC has many advantages over non-isolated MIC: a) the voltage levels of the different sources can be different b) the converter can synchronize with different sources individually and simultaneously c) access to soft-switching d) galvanic or electrical isolation is a natural consequence.

It should be noted that it suffers from stress due to high voltage, switching losses, electromagnetic interference issues, and lower conversion efficiency. These are not present in non-isolated MIC.

(Taoet al., 2006; Chen et al., 2002; Matsuo et al., 2004; Zhao et al., 2008; Dobbset al., 2003; Ahmadi et al., 2012).
In most of the MIC/DIC topologies presented in previous research work, the limitations are of selection of voltage levels, limitation in the operating modes, switching scheme complexity, improper selection of switches, inadequacy in analysis and component counts.

(Kumar et al., 2013; Wang et al., 2008; Khaligh et al., 2009). The present work focuses on the designing of power-electronics-based-converter-system to integrate and harvest energy from three different sources working with different voltage–current characteristics. It takes care of all the frailties encountered in the previous research work.

In this work, a bidirectional conducting and bidirectional blocking (BCBB) switch is used in designing the triple input converter (TIC), instead of bidirectional conducting and unidirectional blocking (BCUB) switch. The above-mentioned changes take care of defective operating state related to undesired conduction of the BCUB switches under the event of reverse bias being applied across them.

The developed TIC is utilized to integrate a solar PV source with a storage battery source and an ultra-capacitor bank. The converter possesses the ability to transfer power from the sources discreetly or concurrently by connecting the sources either in series or in parallel. The converter also offers the effective control of flow of power between the sources and the load. Furthermore, the proposed converter is proficient in bidirectional power flow and buck, boost, buck-boost modes of operation. Compact design, flexibility in control of power and selection of source voltage with least part count are the other features of the proposed converter. (Jiang et al., 2011; Nejabatkhah et al., 2012; Athikkal et al., 2017)

IV. VOLTAGE SOURCE INVERTER OPERATION WITH FEEDBACK CONTROL

It is a known fact that the increasing penetration of Distributed Energy Resources (DER) is constantly altering the electrical grids or power systems by shifting the generation from centralized units to decentralized ones. Previously, MW-scale power plants were connected to the grid to supply power to the distribution end of the transmission system. Now, the DER are connected at various voltage levels of the transmission and distribution grid as a function of the size of the DER.

Consequently, grid management has become an issue in relation to control of output active and reactive power. Also, there is electrical power quality issue at the point of interconnection of DER. Therefore, newer regulations have arisen to ensure that the DER's connection to the grid doesn't negative impact the grid or the localized point of interconnection or even the local distribution transformer. One of the key issue is to keep the voltage at the point of interconnection at an acceptable range.

As a step further, the newer regulations mandate ability to remotely control such DERs to further stabilize the grid. (Wai et al., 2013; Zadeh et al., 2012; Akagi, 2005;Hanet al., 2017; Ortegaet.al., 2012; Monfared et al., 2014; Blaabjergetal., 2012; Oruganti et al., 2008).

These developments require high and uncompromising standards by DER, which is achieved partly by use of advanced power electronics in the DER systems. This is more so applicable in case of varying power source such as PV plant where the DC plant output varies as per the varying solar irradiation, ambient temperature and even the local wind speed. Simultaneous consumption and supply of power at various points of the grid tend to disturb the grid stability further.

Hence, it is upon the inverter to properly synchronize with the grid and ensure the grid power quality. An interesting industry-driven phenomenon is also taking place. Owing to increasing need for improved efficiency of the Solar PV systems, the input operating voltage range and maximum-power-point-tracking (MPPT) voltage window of the inverter also needs to be enlarged.

For example, earlier the inverters used to have MPPT window from 450-800V while recent inverters have MPPT window from 100-900V. Also, traditional solar photovoltaic systems used to employ central inverters of capacity of 500KVA or higher.

These central inverters are always three-phase in nature. However, there is a shift towards smaller and smaller units of such solar inverters. This has led to the development of string inverters which basically have 5-6 strings of solar photovoltaic modules. Such strings inverters are available in both formats: single-phase and three-phase.

More recently there are module-level inverters which track the electrical characteristics for each module with the variation of solar insolation and ambient temperature and still keeps the output AC voltage constant. In some cases, particularly where the site has non-uniform shadow, the use of DC-DC optimizers is very popular. Such optimizers are also module specific and they keep the output voltage constant even when on the input side there are modules connected experiencing different shadow profiles.

Such module-level inverters are necessarily single-phase in nature. With all these developments as solar is getting deployed in different site scenarios with variable site parameters like shading, there is a greater need than ever to stabilize the output power parameters of the inverter even with higher allowance of variation at the input side.

There are various techniques in terms of power electronics which are currently being used to achieve voltage-regulation for such different types of inverters used in different types of sites and system designs.

Also, such converters are available for both three-phase and single-phase operation. Given the fact that central inverters with three-phase power output have been in the market for longer period, three-phase power converters are much more developed research area than single-phase converter. (Hredzaket al.,2014; Ashariet al., 1999; Ayvazyanet al.,2008; Esranet al.,2006 Hassaineet al.,2009; Salaset al.,2009)

One of the commonplace topology used for providing controlled voltage source for catering to load is a voltage source inverter which is compatible for operation both in stand-alone and grid-connected mode. There are various techniques for controlling single-phase voltage source inverter. Various techniques include repetitive control by use of digital technique, control by dead-beat, control by sliding-mode in discrete-time and others.

These techniques have their own advantages and disadvantages. The repetitive control technique is used to lessen the harmonic variations of the output which are produced due to non-linearity in the loads.

But they are slow, are inaccurate, need bigger memory and they suffer from reduced performance. The control techniques of sliding mode and dead-beat have very good performance in dynamically varying voltage situation. Also, they are quicker. However, they are complex, are vulnerable to load patterns and errors which are steady-state in nature. The proportional-resonant technique overcomes the issue of errors which are steady-state while being simple in implementation.

Nevertheless, they suffer from they are very sensitive and instable in case of phase-shifting. One of the converters for three-phase systems requiring a null steady-state error utilizes the synchronous reference frame proportional-integral technique. This can also be used for single-phase systems. (Lidozziet al. 2015; Liu et al., 2015; Chen et al., 2013; Karshenasetal., 2011; Limet al.,2014; Leeetal., 2004; Komurcugilet al., 2015)

On an industrial level, generally LC filters are employed to successfully remove the harmonic disturbances in the output voltage. It must be noted that such filers are very susceptible to resonances produced by the inverter. Practically, the real-time feedback control model is popular which can be implemented in multi-loop or single-loop. The controller based on single-loop system has a voltage regulator with resistance.

The resistance is employed in the filter circuit to check the harmonics of the filter circuit which are produced by the switching of the inverter. Such a system is simple yet they have losses due to presence of the resistance. To overcome this challenge, a multi-loop system can be employed which uses active damping with virtual resistance. This also dampens the harmonics which not suffering from additional losses and thereby has better performance than single-loop feedback systems.

While multi-loop system has this advantage over single-loop systems, it requires additional sensor circuits in order to measure the parameters in the control loop.

There are various proposals relating replacing of such sensor circuits with software in order to perform the same function of measuring the parameters. One of the works the load current was monitored physically while the load voltage and current passing through the capacitor was estimated based on the feedback system. This eliminates uses of circuit to measure the load voltage and capacitor current but has the disadvantage of using an LCL filter rather than the LC filter.

Also, because of the use of LCL filter, the output inductor and hence the impedance value rises resulting in increase of distortions. In one of the other works, the load current is monitored physically. And then again, a proposal was made relating use of a double-loop feedback system with use of controllers for both current and voltage. This replaces the sensor which was previously used to directly measure the inverter current and the load current.

Recently, another multi-loop feedback system was proposed which requires lesser number of sensors. This was proposed for single-phase inverter systems which are stand-alone in nature. The scheme makes use of two different variables which are estimated based on the feedback signal. The outer loop controls the voltage of the output signal through a controller. This makes sure that the steady state error is zero. While the inner loop reduces the harmonics produced by the LC filter and it controls the current passing through the capacitor.

The current in the inverter is therefore measured and is utilized for protection as well as control purposes. Also, the voltage and current across the load are estimated. Consequently, this scheme makes use of just one sensor to measure the current. (Razi et al., 2015; Monfared et al., 2012; Li, 2009; Vandoorn et al., 2013; Zou et al., 2014).

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The above system, making use of passive LC filter, although successful in reducing the number of sensors suffers from susceptibility to tolerances of its constituents and variability of the system parameters.

This is overcome by use of active filters. Active filters are electronic converters which can manage nonlinear loads by compensating the voltage and current variations. The have higher reliability in filter performance, are more compact in size and are flexible. But they are expensive as compared to passive filters which is compensated by the fact that passive filters suffer from sever distortions and consequently the cost of operating a passive filter is very high. Therefore, use of active filters have become viable.

This has become the industry standard and there is severe competition to make active filters more affordable while retaining the performance. Again, even the active filters can be used for single-phase or three-phase applications. The active filter used for single-phase inverter systems are naturally relatively lower in power rating.

Such active filters are successful in meeting the required distortion reduction, but they have their own drawbacks. One of the drawbacks is that the system suffers from high computational load. Also, the system is very sensitive to frequency variations in the grid side. And any such fluctuation in the grid frequency results in error in the calculated current. Moreover, the system is not capable to compensate for reactive power.

There are various ongoing works to reduce the high cost of active filters. One such work proposes a new transformation-based control for the single-phase filter. The transformation basically converts the single-phase current and voltage into complex vectors which can be analyzed on a real-time level.

As the single-phase current and voltage are converted into DC equivalents in both transient as well as steady stage, the current and voltage harmonics can be precisely calculated using the installed filter. This reduces the cost of the active filter by use of a capacitor which dampens the fluctuation of the DC voltage of the bus. However, it must be noted that the capacitor used should not be chemical capacitor owing to its large size and shorter life time as compared to other types of capacitors. (Mohanty et al., 2014; Ram et al., 2017; Gupta et al., 2017)

V. PROBLEM IDENTIFICATION

A literature survey was carried out on standalone and hybrid renewable power generation and the main problem with the hybrid power generation system is to satisfy the electrical loads in rural areas at the same time maximizing the usage of renewable energy sources while optimizing the operation of battery and conventional generators.

A supervisory control system should be well developed to determine the operating modes of each generation subsystem for optimized operation. These operating modes must be determined by the energy balance between the total demand (load and battery bank) and the total generation.

Various closed loop controllers are adopted like fuzzy logic, PI & PID controller, PI optimization, etc. The proposed research work focus on the design of simple open loop controller for the control of inverter operation with the variation in load.

VI. CONCLUSION

Thus, in this paper a design of standalone PV system with battery/UC is performed. The system consists of PV, Battery/Uc, DC –DC converter, inverter, filter and varying load units. Generally closed loop controller for inverter or fuzzy logic controller very used for the smooth operation of proposed system but here an open loop controller is designed and used for inverter control with the variation in load.

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