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Current control strategies for single phase grid integrated inverters for photovoltaic applications-a review

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ABSTRACT

In present day scenario, the focus is reallocating towards integration of small and medium scale power plants based on renewable energy sources into the power distribution system. Solar is the fastest growing form of renewable energy and a single phase voltage source inverter is used to interface photovoltaic based plants with the distribution system. The grid integrated inverter has stringent control requirements. A current controller is employed to mitigate the harmonics in the current injected into the grid and regulate the power exchange between the plant and the grid. This paper presents a review of the current control strategies implemented for a single phase grid tied photovoltaic inverter. A comparative performance evaluation of the current control techniques is also presented through simulation and experimental results.

1. Introduction

The power generation sectors are mostly reliant on non-replenishable fossil fuels which contribute to environmental contamination. The coal reserves are diminishing at a distressing rate. Considering the present day scenario, the focus is reallocating towards integration of small and medium scale power plants based on renewable energy sources (RES) into the power distribution system [1]. These plants are called as distributed generation (DG) plants.

As per international energy outlook (IEO), 2016 report [2] renewable energy consumption will increase by an average of 2.9% per year from 2012 to 2040 as shown in Fig. 1. It is expected that the net power generation from the renewable will be equal to the power generation from coal by 2040 and almost half of this renewable power generation will come from wind and solar. Rapid development has led to lower cost of renewable power generation. Solar photovoltaic (PV) is expected to witness an average cost cutting of 40–70% by 2040 and on-shore wind by 10–20%. From Fig. 2, it is observed that solar is the fastest growing form of renewable energy, with net increase in solar power generation by an average of 8.3% per year. It is followed by wind and geothermal power.

Penetration of renewable energy based power plants into the conventional distribution system has increased the use of power electronics converters (PEC). The PECs are used to convert the power generated by the RES based distributed generation (DG) plants into a form of power which is compatible with the distribution grid [3,4]. The PECs integrating the DG plants with the grid have stringent control requirements, which are specified in the standards such as IEEE 1547 and IEC 61727 [19,20].

The typical applications of solar energy systems are solar photovoltaic (SPV) power plants, residential PV, PV lighting systems and building integrated PV. The residential PV systems are either operated as stand-alone system or grid connected system. The stand-alone systems are mainly employed in remote areas where the grid is not present. Here, the output of the power converter which may be either a DC/DC converter or DC/AC converter is directly fed to the load instead of connecting it to the grid. In grid connected mode the power output of the DC/AC converter is injected into the grid. The residential areas are mostly served by single phase distribution system and a single phase voltage source inverter (VSI) is generally employed to interface the SPV based DG plant with the single phase grid. The power exchange between the DG and the grid can be accomplished by decoupling control of the AC current injected into the grid. The current injected into the grid is decoupled into active and reactive components which control the active and reactive power of the system respectively. A dedicated current controller is designed to perform this task. The current controller should achieve unity power factor during steady state and should inject a high quality current into the grid. The controller should also have fast dynamic response. It should regulate the output power factor as per the power demands. The converter interfacing the DG with the grid should compensate for the reactive power demand. Moreover, the design methodology of the controller should be intuitive and its hardware implementation on digital control platform should be simple and effortless [5–10].

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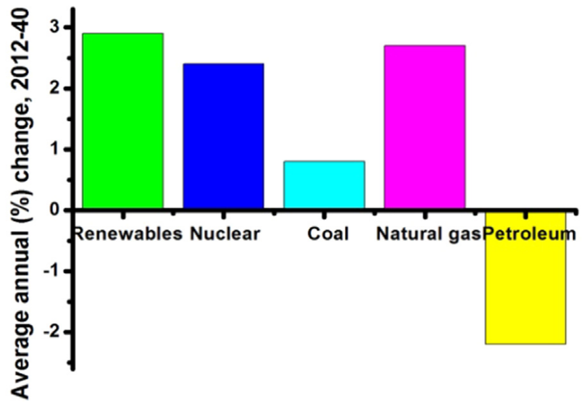

Fig. 1. Average annual change in net electricity generation by different energy source.

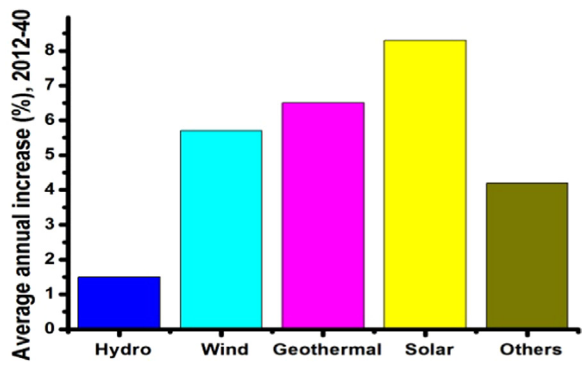

Fig. 2. Average annual change in net renewable electricity generation by energy sources.

Researchers have proposed several current control techniques for single phase grid tied inverters in recent years [21–53]. It is necessary to identify the pros and cons of each control technique which would enable the control engineer to implement the apt control mechanism for its system. In this paper, various current control strategies for single phase grid integrated inverters have been reviewed with their pros and cons. The significant control strategies namely current hysteresis control (CHC), proportional integral current control (PICC), proportional resonant current control (PRCC), dead beat current control (DBCC) and model predictive current control (MPCC) have been designed and analyzed for a grid tied single phase VSI. A comparative performance evaluation of the current controllers during steady state and transient state is also presented.

2. Control issues with grid integration of photovoltaic systems

The grid integration of PV based DG systems is a challenging issue. Several control issues have to be addressed to extract the maximum benefit out of the renewable [9]. Some basic and mandatory concerns are discussed below.

2.1. Maximum power point tracking

The power output from RES is not consistent. It varies with temperature, atmospheric conditions like solar irradiance, wind speed etc. Hence, it is necessary to ensure that the RES based DG delivers maximum power as per its capacity irrespective of the environmental conditions. To accomplish this task a maximum power point tracking (MPPT) algorithm has to be incorporated with the DG plant [11,12]. A power electronic converter (PEC) is dedicated to accomplish this task. The PEC is either a DC/DC or DC/AC converter depending on the system configurations.

2.2. Grid synchronization

Grid synchronization algorithm is the heart of control system for grid integration of renewables. If the grid tied converter is not synchronized with the grid, then large transients may appear at the time of connection, which will damage the system. To realize the synchronization process accurate information of grid voltage amplitude, phase and frequency are required. The synchronization methods are classified under two categories: open loop and closed loop methods [13]. The zero crossing detection method is an example of open loop method. The open loop methods have slow dynamic response and are sensitive to frequency deviations. The closed loop methods include conventional phase locked loop (PLL), synchronously rotating frame PLL (SRF-PLL), sinusoidal tracking algorithm (STA) or the enhanced PLL (EPLL). Some PLL techniques are specially employed for single phase systems such as second-order generalised integrator based PLL (SOGI-PLL) [14]. A new synchronisation technique using multi harmonic decoupling cell (MHDC)-PLL for single phase grid tied inverters is proposed in [15]. The PLL techniques are more popular due to their robustness and accuracy.

2.3. Power flow control

The objective behind grid integration of DG plants and storage systems is to inject power into the grid. The power exchange between the DG and grid has to be performed in a controlled manner [5]. This can be achieved by two methods: one is to control the injected current directly and other is to control the difference in voltage between the inverter output voltage and grid voltage. The voltage control strategies are difficult to realize. Current control technique is easy to implement but the inverters using current controllers do not regulate the power system frequency and voltage, which may cause stability issues, when more power is fed to the grid. The VSI equipped with current control schemes is the best option for integration of DG's and storage systems with the grid [9].

2.4. Power quality control

The main power quality issues associated with grid integration of renewables are the harmonics in voltage across the local load and harmonics in current injected into the grid by the DG inverter [16–18]. Harmonics are signals which are present in the original signal with frequencies which are integral multiple of fundamental frequency of the original signal. The harmonics are produced by the VSI interfacing the DG with the grid or due to the non-linear loads in the system. The total harmonic distortion (THD) is a power quality index denoting the content of harmonics in a distorted waveform [19]. The THD of voltages and currents for grid connected system should be below 5% [20]. Table 1 depicts the maximum THD limits in injected grid current.

2.5. Fault ride-through

As the penetration of renewable energy based DG plants has increased, the DG plants cannot be disconnected from the grid every time

Table 1
THD limits in currents injected into the grid.

Odd harmonics	Maximum THD
< 11th	< 4%
11th − 15th	< 2%
17th–21st	< 1.5%
23rd–33rd	< 0.6%
> 33rd	< 0.3%
Even harmonics	< 25% of equivalent odd harmonics
Total THD	< 5%