Abstract

In this paper we have focused on islanding detection in an inverter based system which is connected by a multilevel inverter to the grid. The total harmonic distortion of output voltage waveform of this inverter is optimized by means of optimization algorithms. Since passive methods have a wide non detection zone and from other hand active methods inject disturbance to grid we decide to focus on a hybrid method. In this approach the total harmonic distortion of PCC voltage waveform as a passive parameter is observed and if it shows an abnormal value which is out of threshold range switches to active method. In this method by injecting harmonic to the grid and calculating the impedance, islanding can be detected which causes by using this proposed approach we have a small non detection zone, lower power consumption and harmonic distortion.

Keywords: Distributed Generation (DG); Islanding Detection; Multilevel Inverter; Total Harmonic Distortion (THD); Optimization; PSO Algorithm; Harmonic Injection; Impedance Measurement; Hybrid Method.

1. Introduction

DG systems play an important role in the stability, reliability and power quality of electrical grid [1]; development of mechanical and electrical equipments made a large attention to this systems in recent years. DGs generally are divided to following parts by regard to their generation source [2]. Concern of cost, pollution and lacking of fossil fuels has spread the use of renewable resources such as photovoltaic systems, fuel cells which are based on DC sources and can be connected to utility thorough inverters and form an inverter based DG System.

![Figure1. Classification of distributed generators](image)

An essential part in power system is protection and DGs aren’t separate from this rule. Islanding detection is the most important external protection for DG systems which are connected to utility. When DG is connected to utility and serves the load, it is possible that because of an electrical fault or etc the connection of load and grid has been cut and DG serves the load lonely; this situation must be detected in standard time and the connection between DG and load broken. This action prevents from damaging equipment, supply the safety of person(s) who repairs distribution grid or etc because of unbalancing in generated and consumption electrical power which is injected to system by means of DG [3, 4].

As said active and passive methods have their special advantages and disadvantages. In this paper we try to combining these methods and present a more performance and effective method.

43
In section 2 review multilevel inverters and show how optimize THD of output voltage waveform. The proposed islanding detection method is presented in section 3 and section 4 shows the proposed scheme of system. Simulation and results is presented in section 5 and final section is conclusion.

2. Multilevel inverter

Renewable resources which are based on DC sources can be connected to utility through inverters, easily. Development of power electronic and advantages of multilevel inverters absorbed a significant attention to themselves. Low switching frequency and stress, high reliability and their topology which let us control output voltage value and THD without any changing in frequency or topology are the most important advantages of multilevel inverters [5].

In multilevel inverter by means of changing in switching angles can determine fundamental value of output voltage and THD. Since this system is connected to utility in addition to voltage and frequency must consider power quality factors which one of the most important factors is THD. In PWM inverters because of high value of harmonics using filter is necessary but in this proposed multilevel inverter THD is optimized by PSO algorithm and there isn’t any need to filter. As in multilevel inverters by increasing the number of levels or DC sources, THD decreases and we must serve a high power and voltage load we focus on 13 level (6 equal DC source) inverter which is more common. It is necessary to say that in operational condition usually DC sources are non-equal which in this paper not been study. By defining an objective function will determine optimized angles that minimized THD and set the output voltage on desire value in same time. We try to close our outage to IEEE 519 standards (below 5%).

![Figure 2. Single-phase structure of a multilevel cascaded H-bridges inverter](image1)

![Figure 3. Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources](image2)

The main part of optimizing is formulation of problem. In multilevel inverter, the output voltage waveform $V(t)$ as shown in above figures can be represented as follow (1) by using Fourier series:

$$V(t) = \sum_{n=1}^{\infty} (a_n \sin na_n + b_n \cos na_n)$$ (1)

Since the output voltage of multilevel inverters has a quarter wave symmetry, even harmonics are eliminated ($b_n = 0$). The amplitude of each harmonic ($a_n$) is expressed by angles $\theta_1, \theta_2, \ldots, \theta_s$ as [6]:

$$V_1(V_f) = \left(\frac{4}{\pi}\right) \sum_{k=1}^{s} (V_{dc1} \cos(\theta_1) + \cdots + V_{dck} \cos(\theta_k))$$
\[ V_3 = \left( \frac{4}{3\pi} \right) \sum_{k=1}^{s} (V_{dc1}\cos(3\theta_1) + \cdots + V_{dk}\cos(3\theta_k)) \]

\[ V_5 = \left( \frac{4}{5\pi} \right) \sum_{k=1}^{s} (V_{dc1}\cos(5\theta_1) + \cdots + V_{dk}\cos(5\theta_k)) \]

\[ \vdots \]

\[ V_n = \left( \frac{4}{n\pi} \right) \sum_{k=1}^{s} (V_{dc1}\cos(n\theta_1) + \cdots + V_{dk}\cos(n\theta_k)) \]

And

\[ 0 < \theta_1 < \theta_2 < \cdots < \theta_s < \left( \frac{\pi}{2} \right) \]  

Now for founding a relationship between the above relation and our objective function (THD), we define Ma or amplitude of the fundamental voltage component:

\[ Ma = \frac{\pi V}{4sV_{dc}} \]  

Following formulation which is formulated for single phase, satisfy desire fundamental value of output voltage and THD optimization in same time.

\[ f(\theta_1, \theta_2, ..., \theta_s) = \left[ Ma - \frac{V_1}{sV_{dc}} \right] + \left( \frac{V_3 + V_5 + V_7 + \cdots}{sV_{dc}} \right) \]  

3. Proposed islanding detection method

In first step present a short definition of islanding. As shown in following figure the connection of load and grid for each reason cut and DGs lonely serve the load can say islanding is happened.

![Figure 4. System architecture](image)

Now rewire different islanding detection methods. The active and passive methods are the most common methods which are used. Passive method uses monitoring of local voltage, current, frequency and harmonic sensing at PCC; low cost and no influence on power quality of distribution system are the most important advantages of this method but in contrast we face to a large non detection zone and the efficiency of method depends on consume and supply condition. Active method uses disturbance signal injection from DG to drive the operating point of the system towards to the frequency/voltage trip limits. This method has a small NDZ but injecting disturbance has a high and direct influence on utility [7].

Since hybrid method based on combination of passive and active methods and this approach set a balance between these two methods, we focused on hybrid method to present a more efficient method.
In this proposed method THD of voltage at Point of Common Coupling (PCC) is measured and compared with a threshold value as a passive method to islanding detection. In normal condition voltage at PCC is summation of inverter and grid voltage waveform which shows smooth waveform in comparison with islanding condition and from other hand in normal condition since grid supply a high share of power so the PCC voltage is grid voltage and THD is very low [8, 9]. As THD is more sensitive to load varying and give a more clear view in different or special conditions of utility and this method isn’t influenced by several inverters is a good choice for this purpose but wide range of loads make difficult to set an appropriate threshold value.

As said since passive methods have a large NDZ in order to support this NDZ employ an active method as backup. If passive method detects islanding by regard to received signals, switch to active method. In this approach by injecting harmonic with a sub harmonic frequency such as 75 HZ which not exist in utility thorough inverter will measure seen impedance by inverter thorough relation (6) as shown in figure 6[10]. It is clear that in normal condition the impedance of grid and load are parallel and since the grid impedance is small so total impedance is close to grid impedance but in islanding condition the grid is disconnected and since grid impedance is small in comparison with load so we have a significant increase in seen impedance by inverter. By means of (6) can calculate the impedance, easily. The figure 6 shows the progress of harmonic injection and impedance measurement.

\[ |Z| = \frac{V_{\text{inv,75}}}{I_{\text{inv,75}}} \] (6)

In following figure the flowchart of proposed method is shown. The most advantages of this hybrid method are: large NDZ of passive method is supported by an active method; since the active method which inject disturbance to utility is selected as secondary method causes while we have no un-normal changing in THD, the active method not employed so power consumption decreases, power quality and reliability increases, we have and effective detector in every condition of utility and no need to use synchronizer to current injection.
4. Simulated system and proposed scheme

This section presents the parameters and proposed scheme of simulated system. For this purpose, different parts of simulated system are studied in detail. Following table shows parameters of system. System is simulated in MATLAB/Simulink environment.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inductance of inverter load [mH]</td>
<td>33.7</td>
<td>Nominal frequency [Hz]</td>
<td>50</td>
</tr>
<tr>
<td>Capacitance of inverter load [μF]</td>
<td>300.86</td>
<td>RMS voltage [V]</td>
<td>230</td>
</tr>
<tr>
<td>Resistance of the grid [Ω]</td>
<td>0.2</td>
<td>Resistance of smoothing inductor [Ω]</td>
<td>0.1</td>
</tr>
<tr>
<td>Inductance of the grid [H]</td>
<td>0.2e-3</td>
<td>Inductance of smoothing inductor [H]</td>
<td>5e-3</td>
</tr>
</tbody>
</table>

PV arrays are modeled by 6 equal DC source which in order to achieve desire RMS of output voltage set alls to 55 volt. Matlab function is consist of PSO algorithm and objective function which by receiving PCC voltage and reference voltage and DC sources voltages determines optimized switching angles to minimization of output voltage THD.

Parallel RLC load with quality factor equal to 2.5 is supposed and the other parameters of system are presented in above table. The FFT analysis is used to harmonic spectrum. Following figure shows general view of simulated system.
Figure 8. Simulated system

5. Simulation and results

At first pay to conclude results of optimizing THD in multilevel inverter and output phase voltage waveform of this inverter is shown in following figure in standalone mode.
Now by means of FFT analysis tool in Matlab simulation environment present the harmonic distortion of output inverter single phase voltage waveform in following figure.

As it clear in single phase will achieve to 6.08% of THD which it in three phase system has no triple harmonics and decrease to lower than 5% and we will have and standard system with no filter.
Now we have a comparison between THD of voltage waveform in different situations. As it is predictable THD of grid voltage because of its sine waveform is close to zero. In islanding condition since inverter serves the load lonely with a restrict power and from other hand RLC load deforms voltage waveform, we have a significant increase in THD. In normal condition THD value depended on power of utility and DG; if the share of DG in load serving be more so the THD increases too.

Table 2. THD of voltage at PCC for different conditions

<table>
<thead>
<tr>
<th>Condition</th>
<th>No DG</th>
<th>No grid</th>
<th>DG + grid</th>
</tr>
</thead>
<tbody>
<tr>
<td>THD of voltage at PCC (%)</td>
<td>Approximately 0</td>
<td>20 (more than 6)</td>
<td>1 (0 to 6)</td>
</tr>
</tbody>
</table>

By regard to previous table and threshold value simulate an islanding condition and assume that passive method (THD measurement) detected islanding and switch to active method. In harmonic injection method by measuring voltage and current of injected signal to system through inverter, calculate seen impedance by inverter and as it clear in following results we have an increase in impedance value which the conclusion of grid impedance lacking. Our results in normal condition are:

Figure 11. FFT analysis of output phase voltage of inverter in normal condition
By means of relation (6) the impedance is calculated in normal condition:

$$|z_{\text{normal}}| = \frac{269.2}{25.45} = 10.557$$

Now in islanding condition:

Figure 12. FFT analysis of output phase current of inverter in normal condition

Figure 13. FFT analysis of output phase voltage of inverter in islanding condition

Figure 14. FFT analysis of output phase current of inverter in islanding condition
\[ |Z_{\text{islanding}}| = \frac{269.2}{12.87} = 20.916 \]

A simple calculation (voltage/current) showed that seen impedance has a noticeable increase in islanding in comparison with normal condition which this increase depend on load and grid parameters

6. Conclusion

As said, active and passive methods have their special advantages and disadvantages but by a suitable employment of them, can achieve to desire result. This paper presents a hybrid method to islanding detection in inverter based DGs. Employing optimization algorithm causes THD reduction and eliminate filter and increase power quality. The proposed method decreases power consumption, harmonic, losses, NDZs and increases reliability, power quality by a good combination of active and passive method which these are main advantages of this method.

References