Abstract - The generated solar photovoltaic power can be stand-alone or grid-connected. In both systems, power quality issues arise and can affect the network. The harmonic distortions can affect the system significantly if they are not mitigated. This paper presents the design of the component values of a single tuned filter that is required to mitigate harmonics. The design aspects of the filter are presented and discussed. The simulation results are analysed and validated using ETAP software.

Keywords: - Grid-connected PV systems, Power quality, harmonics mitigation, Single tuned filter, ETAP Software.

INTRODUCTION

Throughout the last decades, world energy generation using high greenhouse emission gas sources has been increased with the catastrophic warming of the earth. The majority of those energy comes from burning coal, gas, and fossil fuels around the world. Right now, a lot of studies around the world are going on to find better ways of generation of energy to reduce the undesirable impacts of conventional fossil fuel-based technologies. As a result of progressive advance in technology, policy, and finance, the solar power generation is currently becoming more reliable, efficient, and commercially competitive source of energy (Sioshansi), (Ahmed G. E. Mousa, 2016). Nowadays, the renewable energy plays a significant role in electrical power generation and among them, the solar photovoltaic (PV) energy plays a major role in the electrical power generation as it is clean and green energy product as well as its technical benefits (Peter Meier, 2014), (S. Sarkar, 2016).

Each source of energy has unique requirements and benefits. However, the sun, mother of all energy resources is a uniquely clean and infinite source of free energy that has brought a global potential for rapid growth of annual growing rate in most of the developed countries around the world. Nevertheless, these renewable energy generation units are connected to the power system by different ways depending on the real source availability on the ground. Further with the aspect of achieving high security and reliability of the power system, the renewable sources interconnects to the power networks.

This scenario of power systems becomes a challenging task to maintain a good power quality (PQ) of the network. The growing use of more electronic equipment has added more and more PQ problems to the power system (Yew Weng Kean, 2015), (Zobaa, 2016). Harmonic distortion is one of the significant PQ problems. Below is the table for power quality issues, its causes, effects and severity (Eklas Hossain, 2018).

<table>
<thead>
<tr>
<th>Power Quality Issues</th>
<th>Causes</th>
<th>Effects</th>
<th>Severity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage sag</td>
<td>Excessive loads, source voltage variation</td>
<td>Overloading problems **</td>
<td>**</td>
</tr>
<tr>
<td>Voltage swell</td>
<td>Start/stop of heavy loads, inrush current</td>
<td>Damage of equipments *</td>
<td></td>
</tr>
<tr>
<td>Harmonics</td>
<td>If a sinusoidal voltage is applied across the nonlinear loads</td>
<td>Losses in electrical equipments, overheated transformers or motors **</td>
<td>**</td>
</tr>
</tbody>
</table>

**** = Catastrophic, *** = Severe, ** = Moderate, * = Mild

Table 1. Impacts of power quality issues.
When the electrical energy is being generated using solar PV panels, harmonics will be created as power electronics-based equipment is used to convert the DC power into AC power. The increased harmonic distortion will reduce the efficiency of the system. Thus, it is important to measure these harmonics, and then take corrective actions to reduce their negative impacts on the system (S. V. Swarna Kumary, 2014).

Power quality problems also include harmonic disturbances that severely affect the reliability of power system (Mansoor Ahmed Soomro I. A., 2014). It increases frequency level which exceeds the base frequency (50 Hz / 220 V) values.

\[ f_h = h \times f_f \]  

(1)

Where:
- \( f_h \) = Harmonic frequency (for \( 3^{rd}, 5^{th}, 7^{th} \) harmonic and so on).
- \( h \) = Integer value.
- \( f_f \) = Fundamental frequency (i.e. 50 Hz)

This paper presents a grid connected solar photovoltaic system that is installed on the roof of Dr. C.V. Raman University’s building. The PV System utilizes 32 solar panels and 1 inverter of 10 kW. Here, multi-crystalline silicon solar panel is used, and it has wattage of 300W. Each module has 72 solar cells. In this paper, single tuned filter have been used to mitigate the harmonics and enhancing the performance of a harmonic distorted grid-connected PV system using ETAP Software. This paper also presents the design for the component value of a single tuned filter. In addition, the grid-connected PV system, and filter is modelled and simulated using ETAP Software.

### POWER QUALITY STANDARDS

Development of power quality standards is one of the key factors in power quality analysis. Mainly there are two types of standards: IEEE and IEC. Power quality standards with their basic guidelines are illustrated in table 2.

<table>
<thead>
<tr>
<th>Power Quality Standards</th>
<th>Corresponding Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE-519</td>
<td>Limit harmonic current and voltages at the point of common control (Eklas Hossain, 2018), (Dr. John Cheng).</td>
</tr>
</tbody>
</table>

Table 2. Power Quality Standards.

**IEEE Standards 519-2014** (Dr. John Cheng)

- The limits in this recommended practice are intended for application at a point of common coupling (PCC) between the system owner or operator and a user, where the PCC is usually taken as the point in the power system closest to the user where the system owner or operator could offer service to another user.
- These standards represent a shared responsibility for harmonic control between system owners or operators and users.
- All users limit their harmonic current emissions to reasonable values and,
- Each system owner or operator takes action to decrease voltage distortion levels by modifying the supply system impedance characteristics as necessary.

### GRID CONNECTED PV SOLAR POWER SYSTEM

As we know that now-a-days solar is in great demand. It is widely used in generation of electricity by capturing the sunlight via the solar panels. These panels convert light energy into electrical energy (DC).

Now in grid connected PV solar power system, the power is being transferred to the grid. This power should be synchronised as that of the Power available in the grid. The grid connected system has two important tasks to perform:
- **(1)** Tracking of maximum power from the solar panels with the help of suitable MPPT method (Ajay Kumar, 2017).
- **(2)** The voltage at the PCC must be sinusoidal and at the same level of grid voltage (Ajay Kumar, 2017).

### SINGLE TUNED FILTER DESIGN

The single tuned filter is the most common type of filter which is used in industry for mitigating the harmonic. This filter is inexpensive and simplest as compared with other filters for mitigating the harmonic problems (Young Sik Cho, 2011), (Dawid Bula, 2010). This filter is connected in shunt with the distribution system and it will offer low impedance to current. A very simple arrangement of the single tuned passive filter is shown in the figure 1 (Bhim Singh, 1999). For designing the single tuned passive filter,
it is important to calculate an appropriate resistor, capacitor and inductor values that enable to mitigate harmonics in power frequency. The equation of resonant frequency for single tuned frequency is given by following equation.

\[ f_r = \frac{1}{2\pi\sqrt{LC}} \]  

(2)

\( f_r \) = Frequency resonant in Hertz.

\( L \) = Inductance of Filter in Hertz.

\( C \) = Capacitance of Filter in Farad.

Following are the steps, to design a single tuned filter: - (D. M. Soomro, 2015)

**Step 1:**
Determine the three-phase capacitive reactive power \( Q_{c}\) in VAR.

The harmonic filters can also provide a large percentage of reactive power for the power factor correction. When the capacitor is installed in a system with a real power \( P \), the power factor can be improved from \( PF_0 \) (Existing Power Factor) to \( PF_1 \) (Desired Power Factor) where:

\[ Q_{COM} = P \times [\tan (\cos^{-1} PF_0) - \tan (\cos^{-1} PF_1)] \]  

(3)

**Step 2:**
Determine the capacity of the capacitor \( Q_c \).

\[ Q_c = \frac{h_n^2}{h_n^2 - 1} Q_{COM} \]  

(4)

**Step 3:**
Calculate the capacitive reactance \( X_C \), at the fundamental frequency (f).

\[ X_C = \frac{\nu^2}{Q_c} \]  

(5)

\[ C = \frac{1}{2\pi f X_C} \]  

(6)

**Step 4:**
Calculate the inductive reactance \( X_L \) and inductance \( L \) at the fundamental frequency.

\[ X_L = \frac{X_C}{h_n} \]  

(7)

\[ L = \frac{x_L}{2\pi f} \]  

(8)

\( h_n \) = The harmonic order.

**Step 5:**
Calculate the resistance \( R \) for a specified quality factor \( Q \). The range value of \( Q \) lies between 30 and 50.

\[ R = \frac{X_n}{Q} \]  

(9)

\[ X_n = \sqrt{X_L X_C} \]  

(10)

**Step 6:**
At tuned frequency,

\[ X_L = X_C \]  

(11)

The impedance value is given by formula,

\[ Z = R + (X_L - X_C)^2 \]  

(12)

Therefore,

\[ Z = R \]  

(13)

Low impedance value is suitable to eliminate the dominant harmonic currents flowing into system and pass the sinusoidal current, thus improving power quality with increased power factor.

Note:
The above calculations are calculated ideally and can be varied when applied in real time basis with loads as in the case of the project presented in this paper.
DESIGN IMPLEMENTATION

ETAP harmonic packages offer an automatic harmonic filter sizing requiring only the harmonic order and its harmonic current magnitude. However, automatic sizing do not compensate reactive power by filters and so capacitors are used to do the same. So in order to get the optimum configuration of filters, the automatic filter sizing feature is used by using harmonic order and its current magnitude.

After setting the harmonic order and the harmonic current, the obtained parameters from the design are set in the menu as shown in Figure 4. Filter type is set to single-tuned as default and the parameters are set in the specified space.

The single line diagram without PF correction and filtering is shown in figure 5. To calculate the required capacity for PF correction, load flow analysis was carried out which is shown in figure 5.

RESULT AND DISCUSSION

This section deals with the results of the project with or without single tuned filter that was used to mitigate harmonics present in grid connected PV solar power system.

THD of grid connected PV Solar Power System via simulation in ETAP Software.

On software simulation of PV connected distribution system by ETAP software the THD analysis without filter at bus 3, bus 4, and bus 5 is 4.91%, 4.38% and 4.23% respectively, as shown in figure 6.

To reduce THD, filter is connected to bus 3, which significantly reduces THD to lower values thus providing more stability to the system. Single tuned filter is tuned to eliminate 11th order harmonics.
On software simulation of PV connected distribution system by ETAP software the THD analysis with filter at bus 3, bus 4, and bus 5 is 2.59%, 2.30% and 2.22% respectively, as shown in figure 7.

![Figure 7. THD of grid connected PV system with single tuned filter.](image)

Below is the table depicting THD at bus 3, bus 4 and bus 5 with and without single tuned filter.

<table>
<thead>
<tr>
<th>Single Tuned Filter</th>
<th>THD at Bus 3</th>
<th>THD at Bus 4</th>
<th>THD at Bus 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Without Filter</td>
<td>4.91%</td>
<td>4.38%</td>
<td>4.23%</td>
</tr>
<tr>
<td>With Filter</td>
<td>2.59%</td>
<td>2.30%</td>
<td>2.22%</td>
</tr>
</tbody>
</table>

Table 3. THD values with and without single tuned filter.

**CONCLUSION**

Now-a-days the use of power electronic devices like diodes, transistors, etc. have made the system somewhat unstable. As in the case of grid connected PV solar power system, the power is also unstable due to the harmonics generated by the power electronic devices (here, the inverters). To mitigate these harmonics and improve the power quality, the use of filters are the perfect solution. To use these filters, it has to be designed. This paper presents all the formulas related to the design of the component value of single tuned filter. Before actually using it on real time basis, it is first simulated using the ETAP software, as in the case of the project presented in this paper.

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**References**


**AUTHORS’ PROFILE**

**Abhijit Kumar.**
M. Tech. Scholar (Power System Engineering), Department of Electrical and Electronics, Dr. C.V. Raman University (C.G.)

**Email ID:** Kumar.abhijitog@gmail.com

**Amit Agrawal.**
Assistant Professor, Department of Electrical and Electronics, Dr. C.V. Raman University (C.G.)

**Publications:** More than 17 research papers are published in different international and national journals.

**Achievement:** Awarded for the excellence in research under the Category HEI Professor by “Auropath Global Awards 2019”.

**Email ID:** Amitagrawal_bit@rediffmail.com

**Raghvendra Singh,**
Assistant Professor, Department of Electrical and Electronics, Dr. C.V. Raman University (C.G.)

**Email ID:** Raghvendr2010@rediffmail.com