Simulation from DC to AC Commutation using a Power Inverter and Filters

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Abstract*- this paper presents an electrical power inversion through the process of converting DC voltages into AC power sources. This is most commonly used when supplying AC power from DC sources such as photovoltaic systems or the grid. This can be achieved using different circuits for switching and control in order to produce a certain signal, amplitude and frequency. Using the CTS California Instruments System, several multi-level converting topologies were simulated. The simulation will show the efficiency of the filter connected to an equipament under test and the THD factor values obtained.*

Keywords: *inverter, multilevel conveter, harmonic distortion factor*

I. INTRODUCTION

Today, the demand for green energy is very strong. One possible option for meeting this demand is to convert solar energy into electrical energy. Electrical grids are complex and dynamic systems affected by multiple eventualities such as continuous connection and disconnection of loads, disturbances and resonances resulting from the harmonic currents flowing through the lines, faults due to lightning strikes and mistakes in the operation of electrical equipment. In addition, power facility upgrades are essential in order to make a profit in the competitive power market. Thus, renewable energy sources such as wind, solar, biomass, and geothermal are attractive alternatives for power utilities. Renewable energy systems offer several advantages over conventional energy sources such as natural gas or coal. First, renewable energy systems are clean sources of energy found in most regions, and they emit no greenhouse gases. Renewable energy sources are also abundant, free, and generally not affected by political instability.[1]

In order to maximize the amount of energy injected into the electric grid and the total economic benefit achieved by a gridconnected PV installation during its operational lifetime period it is indispensable to maximize the reliability of the individual components and devices comprising the PV system[2]. Consequently, grid variables cannot be considered as constant magnitudes when a power converter is connected to the grid, but they should be continuously monitored in order to ensure that the grid state is suitable for the correct operation of the power converter. Moreover, when the power managed by this power converter cannot be neglected with respect to the rated power of the grid at the point of connection, the grid variables can be significantly affected by the action of such a power converter. Therefore, power converters cannot be considered as simple grid-connected equipment since they keep an interactive relationship with the grid and can actively participate in supporting the grid frequency and voltage, mainly when high levels of power are considered for the power converter. This implies, however, that the grid stability and safety conditions can be seriously affected in networks with extended usage of power converters, as is the case of distributed energy systems based on renewable energies. For this reason, many international grid codes have been in force during the last few years in order to regulate the behaviour of photovoltaic and wind energy systems in both regular steady-state and abnormal transient conditions, e.g. in the presence of grid faults.[3]

The energy injected into the electric grid can be maximized by applying an effective maximum power point tracker (MPPT) control strategy [5] and designing the PV inverter such that the PV array output power is efficiently processed by the PV inverter [6]. The reliability characteristics of the PV system components are usually expressed using indices such as the failure rate or the mean time between failures (MTBF) [4]. The quality of the power provided by the photovoltaic system for the local AC loads and for the power delivered to the utility is governed by practices and standards on voltage, flicker, frequency, harmonics and power factor [7]. Deviation from these standards represents out-of-bounds conditions and may require disconnection of the photovoltaic system from the utility. This process is supported by the photovoltaic (PV) solar panel, which produces various DC output voltages and output power. In the conversion from DC to AC power, dedicated inverters maintain the right working point for the solar panel to maximize its use of solar energy[6]. The power loss in the inverter reduces the total energy extraction of the solar installation as a whole. Minimizing this loss as well as minimizing the inverter size and cost are important directions in the process of making solar energy a viable source for the future.

II. THEORETICAL CONSIDERATION

A. The inverter

Therefore, the elevated technical requirements of the offshore wind farms channel the researches towards ensuring frequency and voltage stability injected into the power system [8, 9] and active and reactive power control. There have also been researches aimed at ensuring a fast response for the transitory regime that involves changing the power injected into the system [10, 11, 12].

The power converters interfacing the AC-DC conversion system, respectively DC-AC, usually depend on the topology of the application, but they must meet three conditions [13]:

- Reliability;
- Efficiency in terms of power quality;
- Lowest possible cost.

Unlike other equipments, this type of converters, presents a capital advantage, namely that they must inject the voltage into the grid at a fixed frequency. The disadvantages are related to the high voltage and power levels and power quality problems. We should bear in mind that the grid into which the voltage is injected is of infinite power. The grid has a very different behaviour from the consumers that fall into the category of non-linear loads. Hence, any converter solution [20] must consider two issues: the choice of switching device, the type of converter chosen and the command principle used for obtaining a sinusoidal voltage with the same frequency as the grid. The most common multilevel inverters topologies are as follows: diode clamped multilevel inverters DC-MLI (Fig. 1.), flying capacitor multilevel inverters FC-MLI (Fig. 2.) and cascaded H-bridge multilevel inverters CHB-MLI (Fig. 3.).

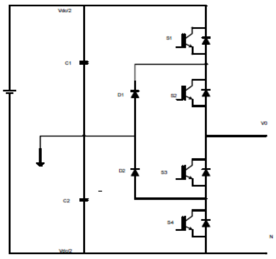


Fig. 1. Diode clamped multilevel inverters

The purpose behind the design of the multilevel converter is to obtain a a better sinusoidal voltage and current output by using switches in series.

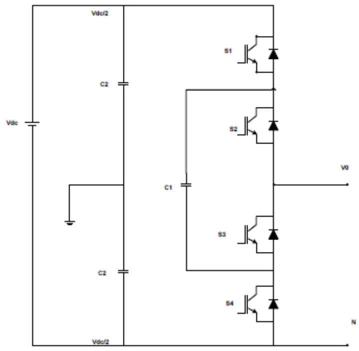


Fig. 2. Flying capacitor multilevel inverters

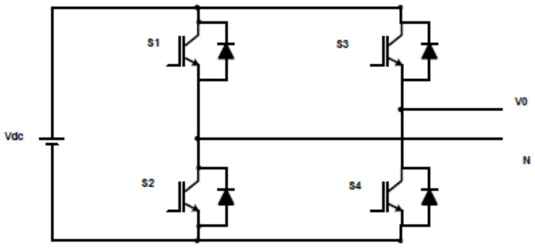


Fig. 3. cascaded H-bridge multilevel inverters

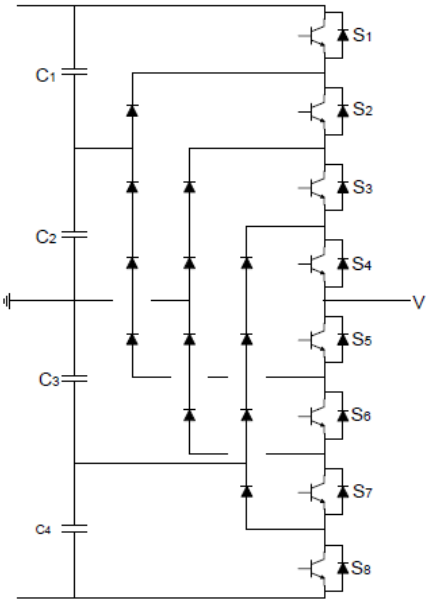


Fig. 4. One phase of the 5-level multilevel converter

Therefore, by using switches in a series configuration, the importance of the switching angles becomes apparent, because the voltage and current output must have a low harmonic distortion[4]. The concept behind this type of multilevel converter is the use of diodes to limit the power devices voltage stress. The voltage over each capacitor and each switch is Vdc. An n level converter needs (n-1) voltage sources, 2(n-1) switching devices and (n-1) (n-2) diodes. In a 5-level diode clamped multilevel converter: n=5. Therefore:Number of switches=2(n-1)=8;Number of diodes= (n-1) (n-2) =12;Number of capacitors= (n-1) =4. A 5-level diode clamped multilevel converter is shown in Fig. 1. To achieve a specific output voltage, e.g. Vdc/2, switches S1 to S4 should conduct at the same time. For each voltage level, four switches must conduct. The output voltage has a maximum value equal to half the value of the DC source. This is one the main disadvantages of the diode clamped multilevel converter. To solve this, we can use a voltage source twice as bigger or we can cascade two diode clamped multilevel converters. The most attractive features of multilevel inverters are as follows.

- They can generate output voltages with extremely low distortion and lower *dv/dt*
- They draw input current with very low distortion.
- They generate smaller common-mode (CM) voltage, thus reducing the stress in the motor bearings. In addition, using sophisticated modulation methods, CM voltages can be eliminated [8].
- They can operate with a lower switching frequency

B. The filter

Most power filters are passive low-pass filters with some distinctive feature. The topology of the filter should be selected by considering the required suppression and expected filter terminations. Depending on the source and load impedances there are four possible filter configurations [3]: T, π, LC, or CL configuration. These basic configurations, or stages, are repeated several times to achieve the necessary suppression. The performance of filters with a higher number of stages is less dependent on the source and load impedances. However, every stage also adds to the cost and size of the filter, which is why in most cases EMI filters have one or two stages.

Accurate modeling of EMI noise generation and propagation in power converters are the first step in predicting and managing the EMI noise in a system. The effective EMI prediction often relies on the engineer’s experience or extensive numerical simulation models. Owing to the effectiveness of filtering the conducted EMI noise separately by common-mode and differential-mode, each mode of the noise is dealt with the respective section of an EMI filter [4].

III. SIMULATIONS

CTS Series products company California Instruments offers efficient testing solution in terms of price-quality ratio aimed at verifying product compliance with a number of testing standards in AC and DC.An important part of the California Instruments CTS System is the power analyzer in compliance with the IEC standards, which provides detailed information regarding the voltage and the current. Measurements of both harmonics and interharmonics are made in real-time with no measurement gaps. For a better comparison between converters, we used the CTS system to simulate the output values of multilevel converters. Highlighting the influence of the deforming regime in order to eliminate it can be done in the laboratory with the aid of the programmable source. Due to the characteristics of nonlinear multilevel converters in the distributed generation systems appear harmonic current and voltage, with negative effects on other handsets and lead to reduced energy parameters. Medium power linear loads which are found within the platform have a share in total harmonic pollution and acute problem arises therefore limit this pollution. Examples of such equipment are adjustable drives with AC and DC motors, uninterruptible power supplies digital automation, etc. The interface with the supply is often a converter. For a waveform measured with a digital instrument (Figure 5), harmonic analysis is shown in Figure 6, where harmonic levels are represented as percentages in relation to fundamental.

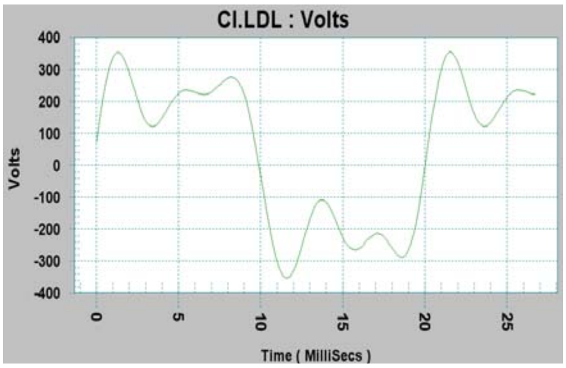
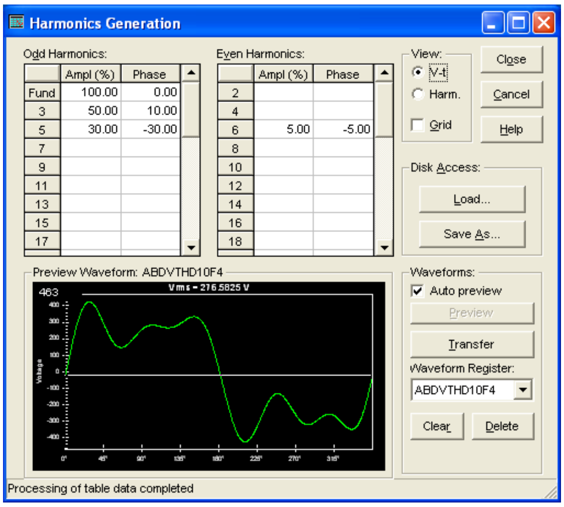


Fig. 5. Waveform of measured voltage

Fig. 6. Harmonic analyse of measured voltage



Odd Harmonics:

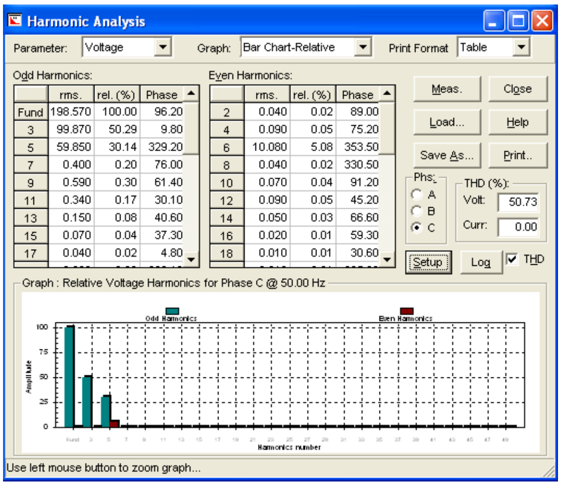
	Ampl (%)	Phase
Fund	100.00	0.00
3	50.00	10.00
5	30.00	-30.00
7		
9		
11		
13		
15		
17		

Even Harmonics:

	Ampl (%)	Phase
2		
4		
6	5.00	-5.00
8		
10		
12		
14		
16		
18		

Processing of table data completed

Fig. 7. Rebuilt waveform voltage



Parameter: Voltage Graph: Bar Chart-Relative Print Format Table

Odd Harmonics:

	rms.	rel. (%)	Phase
Fund	198.570	100.00	96.20
3	99.870	50.29	9.80
5	59.850	30.14	329.20
7	0.400	0.20	76.00
9	0.590	0.30	61.40
11	0.340	0.17	30.10
13	0.150	0.08	40.60
15	0.070	0.04	37.30
17	0.040	0.02	4.80

Even Harmonics:

	rms.	rel. (%)	Phase
2	0.040	0.02	89.00
4	0.090	0.05	75.20
6	10.080	5.08	353.50
8	0.040	0.02	330.50
10	0.070	0.04	91.20
12	0.090	0.05	45.20
14	0.050	0.03	66.60
16	0.020	0.01	59.30
18	0.010	0.01	30.60

Phs: ○ A ○ B ● C

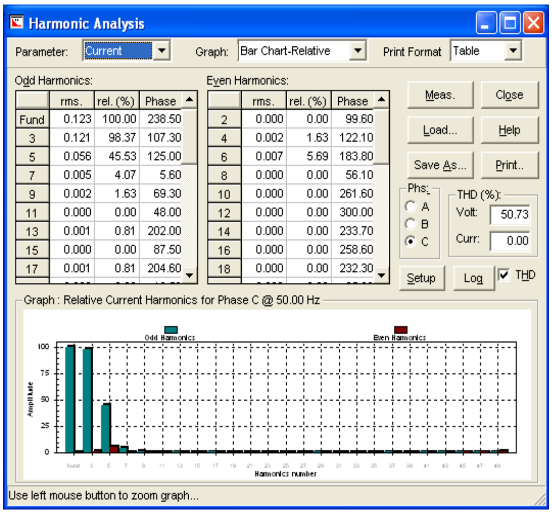
THD (%): Volt: 50.73 Curr: 0.00

☑ THD

Graph : Relative Voltage Harmonics for Phase C @ 50.00 Hz

Use left mouse button to zoom graph...

Fig. 8.Harmonic analysis of the rebuild waveform



Parameter: Current Graph: Bar Chart-Relative Print Format Table

Odd Harmonics:

	rms.	rel. (%)	Phase
Fund	0.123	100.00	238.50
3	0.121	98.37	107.30
5	0.056	45.53	125.00
7	0.005	4.07	5.60
9	0.002	1.63	69.30
11	0.000	0.00	48.00
13	0.001	0.81	202.00
15	0.000	0.00	87.50
17	0.001	0.81	204.60

Even Harmonics:

	rms.	rel. (%)	Phase
2	0.000	0.00	99.60
4	0.002	1.63	122.10
6	0.007	5.69	183.80
8	0.000	0.00	56.10
10	0.000	0.00	261.60
12	0.000	0.00	300.00
14	0.000	0.00	233.70
16	0.000	0.00	258.60
18	0.000	0.00	232.30

Phs: ○ A ○ B ● C

THD (%): Volt: 50.73 Curr: 0.00

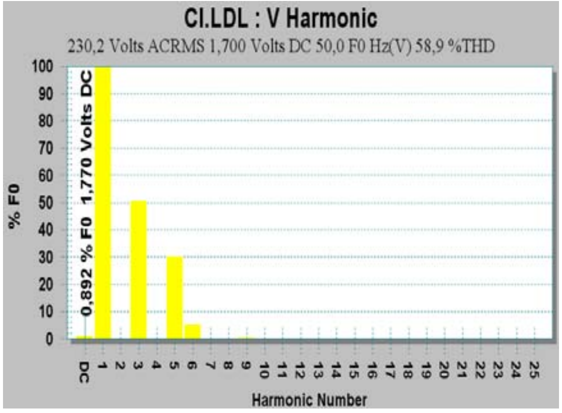
☑ THD

Graph : Relative Current Harmonics for Phase C @ 50.00 Hz

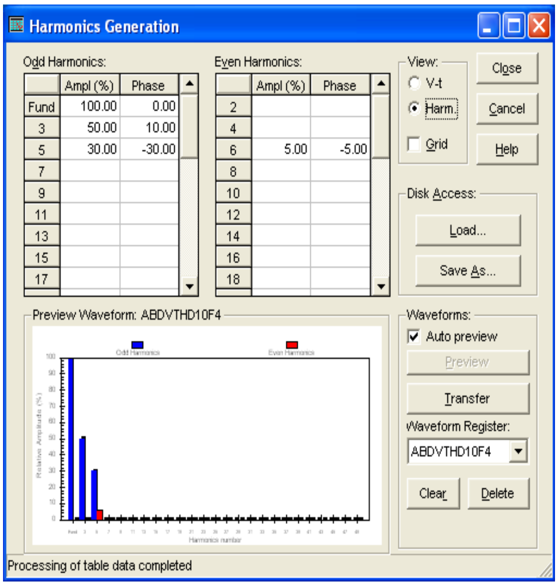
Use left mouse button to zoom graph...

Fig. 9. Harmonic analysis of the generated voltage

Even if non-linear loads are the main cause of the appearance of harmonic currents, their movements lead to voltage harmonics, that we find



at the point of common coupling (PCC), where in



Odd Harmonics:

	Ampl (%)	Phase
Fund	100.00	0.00
3	50.00	10.00
5	30.00	-30.00
7		
9		
11		
13		
15		
17		

Even Harmonics:

	Ampl (%)	Phase
2		
4		
6	5.00	-5.00
8		
10		
12		
14		
16		
18		

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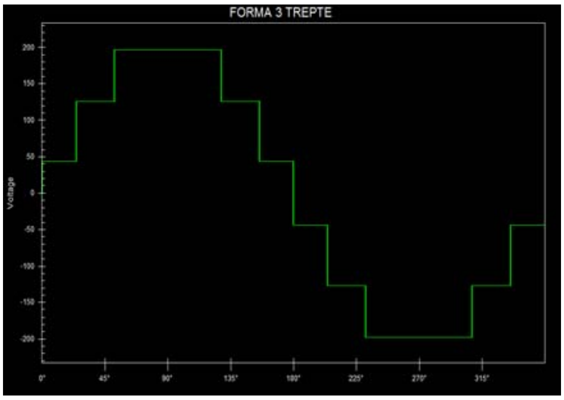
Fig.10. Harmonic analysis of the absorbed current

addition to the nonlinear load loads are connected and that are influenced by the supply voltage non-



sinusoidal.

In order to see the THD factor values it has been used an induction motor (asynchronous) phase squirrel cage having the following characteristics:

A = 230 Vac; P = 460 W; cos ϕ = 0.8; η = 0.8. Load was powered by the source program shown above, having waveforms generated by a genetic algorithm for inverters with different levels of pulses and waveforms generally used for multilevel inverters command generated by the programmable source library.

Fig. 11. Inverter ideal waveform

Load operation, waveform deviates from the ideal form shown above, is shown in Figure 12. It may be observed the same aspect waveform, less the existence of a ripple caused by nonlinearity engine.

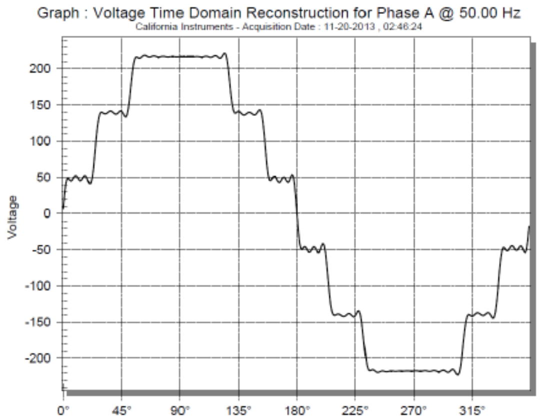


Fig. 12. Three level inverter waveform obtained

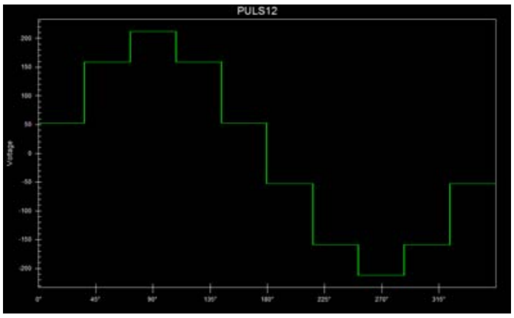


Fig. 13. Inverter waveform generated by programmable library

It can be seen that the third harmonic is reduced from 4.95% to 0.68%, which contributes significantly to increased efficiency in operation of the engine (its operating temperature drop).

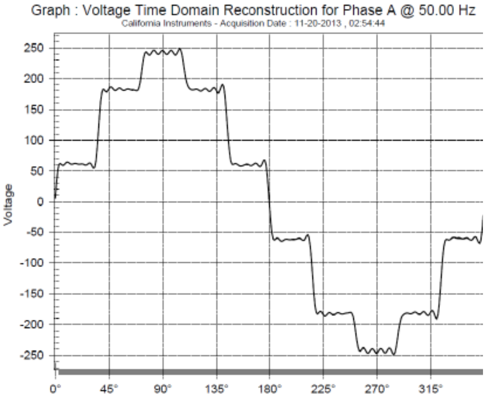
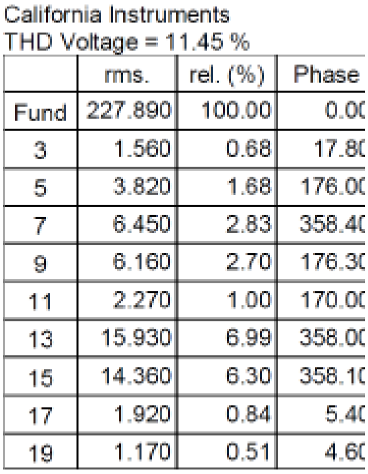


Fig. 14. Three level inverter waveform obtained from the programmable source

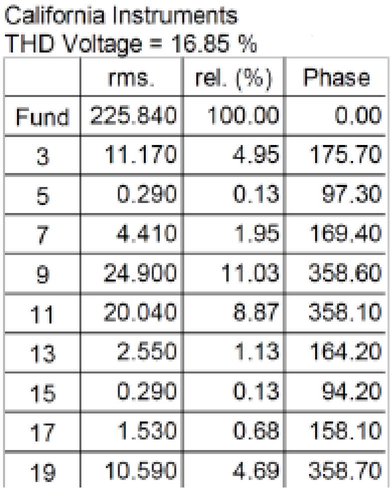
On the other hand, there is an increase in the level of the fifth-order harmonics and the seventh voltage. Fifth harmonic order increases to 1.68% and the seventh order increase at 2.83%. Given that these two negative sequence harmonic components determines and may cause fluctuations in operation, it is important that these harmonic components to be filtered with the aid of harmonic filters.

Table 1. Harmonics level with THD=11.45%


California Instruments
THD Voltage = 11.45 %

	rms.	rel. (%)	Phase
Fund	227.890	100.00	0.0
3	1.560	0.68	17.8
5	3.820	1.68	176.0
7	6.450	2.83	358.4
9	6.160	2.70	176.3
11	2.270	1.00	170.0
13	15.930	6.99	358.0
15	14.360	6.30	358.1
17	1.920	0.84	5.4
19	1.170	0.51	4.6

Table 2. Harmonics level with THD=16.85%


California Instruments
THD Voltage = 16.85 %

	rms.	rel. (%)	Phase
Fund	225.840	100.00	0.00
3	11.170	4.95	175.70
5	0.290	0.13	97.30
7	4.410	1.95	169.40
9	24.900	11.03	358.60
11	20.040	8.87	358.10
13	2.550	1.13	164.20
15	0.290	0.13	94.20
17	1.530	0.68	158.10
19	10.590	4.69	358.70

IV. CONCLUSION

The choice of the inverter topology should be based on the invertor use. Each has advantages and disadvantages. By increasing the number of voltage steps the THD value will drop on the other hand the cost and weight of the equipment will increase. Also, since the switching angles are not identical, each swich will have a separate control circuit. The cascaded H-bridge multinilevel inveter has the smallest weight and cost among the multi-level invertors but also the highest losses. This invertor can be used in applications where cost and weight are more important then the power loss.

This analysis of the multi-level inverters highlights the set of problems that arise in connecting the renewable energy sources to the power grid. The main factor that has to be considered is the harmonic distortion, which should be minimal, at the power grids designated frequency and the fact that the grid's frequency is fixed, which in itself constitutes an advantage when choosing the type of converter needed. In each cases we the filter is necessary for the waveform to be more accurate.

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