Analysis of generated harmonics in DFIG driven by wind turbine during linear & nonlinear load

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Abstract. Due to the growing interest in electricity, both conventional and non-conventional energy sources are growing. As the number of powertrains increases, just as the interconnectivity of these components grows terrifyingly, so does the power response along with the variable overcurrent. Which acquires the majority of power shares in an environmentally responsible manner. One thing that sets wind power apart is how little it costs. With a proven capacity of around 21262 MW, India's wind farm ranks fifth in the world with an exceptionally high annual expansion rate [1]. Management New Harmless to Ecosystem Strength (MNRE) and association of Tamil Nadu, Maharashtra and Gujarat movements. Considering the 7.6 Gw of wind cap that has been produced in the last 15 months, the target is to produce an additional 10 Gw in FY 2019[2]. The Twofold Dealt with Acknowledgement Generator (DFIG) structure was found to be affected by the wind in uneven stacking. The electricity produced makes endless sounds available [3]. The proposed study depicts the evaluation of noise produced by wind-related electricity. The combined dynamic channel uses the DFIG system for both direct and indirect loads. This work recreates the sounds produced by direct and indirect loads using mutt dynamic channel reduction for Grid Side Control (GSC) and Rotor Side Control (RSC). The end product of this effort shows that using the unequal weight system, the value of sounds dropped to 4.96% from 29.66%. Additionally, it shows that in cases where the nonlinear weight has no effect on the structure, the consonant value is exactly 0.14%. Various research projects are now being carried out in an effort to develop channels that can suppress consonant levels higher than the dedicated hybrid feed channel.

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MATLAB R2018a variant is used to generate the model for the proposed work. The model is shown in the Simulink section of MATLAB under Programming.

1 Introduction

Electric power is transmitted through electric power sources, which serve as the foundation for the public economy. These sources are responsible for providing a reliable and efficient supply of electricity to meet the needs of consumers. They are strategically located, managed, and constructed to ensure the safety and stability of the power grid. When comparing DFIG (Double Fed Induction Generator) to fixed speed generators, there are several advantages, including speed control. This is achieved through the management of the rotor side converter. The Double Fed Induction Generator is a commonly used model in various versions. The rotor is magnetized by feeding it directly from the grid. There has been a significant amount of examination and growth in the field of wind energy, with many new wind farms utilizing variable speed wind turbines to optimize energy capture and overcome the limitations of fixed speed systems. The DFIG is an integral component of these variable speed wind turbine systems [4].

Additionally, environmental barriers hinder the expansion of transmission network capacity to meet future demands. This is a significant issue in the field of electrical architecture, as massive hardware failures can lead to power outages. In such cases, additional control strategies are necessary to manage the system. One potential solution to this problem is a managed volume structure. Sustainable energy sources are those that produce energy while maintaining their original design. Wind power is considered superior to most unlimited resources in this regard. The Earth's surface has experienced disproportionate warming due to solar radiation, with wind being the primary cause of these air masses. This difference in warming forces between surrounding air masses can lead to a shift in overall temperature. The development of directly grid-connected asynchronous squirrel cage induction generators followed the overview of directly grid-coupled synchronous generators. Regulate the amount of power collected from the wind at high wind speeds, pitch control or stall control can be utilized [2].

All efficient energy sources can be utilized to generate wind energy. A comprehensive analysis of the futility of this endeavour is necessary. This is achieved through the use of a dual write generator (DFIG), which has undergone numerous reliable iterations and utilizes variable speed generators. [3]. the organizational structure of the DFIG is nearly identical. As shown in Figure 1, wind power is rapidly growing in India. A more modern approach to wind energy is the use of a variable speed wind turbine with a doubly fed induction generator, replacing the traditional continuous-speed wind turbine with a directly grid-coupled squirrel cage induction generator. Numerous experiments have been conducted on modelling wind turbines with a directly grid-coupled squirrel cage induction generator, both with pitch management and stall control for electrical power.

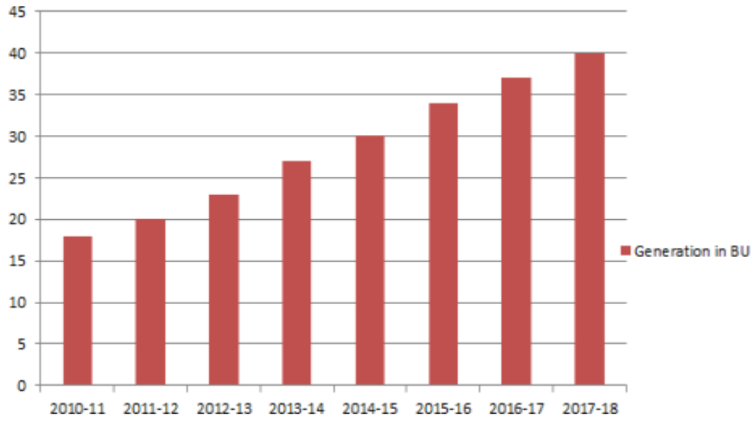

Fig. 1. India's wind system power production [6]

2 Double turbine driven with induction generator wind turbine

A wind turbine, often known as a wind generator, is a multi-purpose device that converts active rotational energy into electrical energy. Below is a list of specific terms related to wind turbines: Betz limit: x Power factor: Power factor is the ratio of the generated power output to the available wind power. - Only 59.3% of the wind's kinetic energy can be converted into mechanical energy in the wind turbine, which drives the rotor. Probably the highest possible power factor for a wind turbine is this. x Tip speed ratio (λ): - The ratio is determined by skill and ideal modification The relationship between the outer tip speed of the blade and the wind speed is known as the peak speed ratio or TSR for wind turbines. Top speed is due to the design of the cutting edge [5]. TSR for wind that is quite productive is 6-7.

2.1 Doubly Fed Induction Generator (DFIG)

In current wind turbine systems, the doubly fed induction generator (DFIG) has become a fundamental element. It is the recommended option for maximizing wind energy capture, especially in variable wind conditions, due to its exceptional ability to reach different speeds [6].

2.1.1 Principles of DFIG operation

A DFIG works on the same idea as an induction machine where electrical sources are connected to a wound rotor. This arrangement allows for variable speed operation, which is necessary to optimize energy recovery from changing wind speeds. Three-phase rotor windings are necessary to create a magnetic field that dynamically interacts with the stator field to generate electrical power.

Multi-phase slip ring system with multi-phase wound rotor

The multi-phase DFIG rotor winding architecture increases overall system efficiency by enabling precise control of the rotor currents. The DFIG guarantees excellent performance in a wide range of operating situations and facilitates seamless electrical connectivity and management when combined with a multi-phase slip ring system. The DFIG power generation process is based on the dynamic interplay between the stator and rotor fields. The DFIG power generation process is based on the dynamic interplay between the stator and rotor fields. Power is produced in the stator winding as a result of electromotive forces induced by changes in the rotor magnetic field caused by changes in rotor currents. Effective energy conversion and system stability depend on this dynamic interaction.

Access to DFIG control

DFIG uses sophisticated control algorithms to efficiently interface with the grid and control the rotor currents. There are two common ways to check:

1. Vector current control on two axes:

The rotor currents are manipulated in two orthogonal directions by this method to achieve the respective performance characteristics [7]. The DFIG can optimize power generation and grid interaction and dynamically adapt to changing load requirements and wind conditions by precisely controlling the amplitude and phase of the rotor currents.

2. Direct Torque Control, or DTC:

DTC is an advanced control system that directly regulates the torque generated by the generator without the need for a separate flux control. This method, which is well-known for its stability and quick response time, is especially helpful in circumstances requiring exact power settings and great network sensitivity [8, 9].

2.1.2 Advantages of DFIG in wind farms

The use of DFIGs in wind turbines has a number of significant advantages.

1. Variable Speed Operation: The DRUG's ability to operate at different speeds optimizes overall performance and increases energy capture efficiency, especially in windy conditions.
2. Flexibility of grid integration: Robust control over rotor currents and sophisticated control techniques enable smooth grid integration, which promotes efficient power transfer and grid stability.
3. Advanced Control Capabilities To maximize system performance, precise output power regulation, reactive power support and network synchronization are enabled using sophisticated DFIG control methods.
4. Stability and Reliability: Sophisticated control algorithms combined with the robust design of DFIG systems provide stability, reliability and resistance to network fluctuations and failures.

The continued research and development of DFIG technology aims to reduce system costs, solve grid integration issues, increase energy conversion efficiency, and further improve control strategies. New trends include:

Advanced Control Algorithms: Research on new control algorithms to improve the dynamic response and interaction capabilities of the DFIG network, such as model predictive control (MPC) and artificial intelligence-based methods.

Integrated Energy Storage: Integrating energy storage devices with Distributed Field Generator (DFIG) configurations increases grid stability, facilitates energy storage and activates grid support services, increasing the resilience and flexibility of the system as a whole.

Fault Tolerance and Reliability: Research aims to increase system reliability, develop predictive maintenance strategies, and strengthen DFIG fault tolerance capabilities to ensure long-term operational sustainability [10, 11, and 12].

Figure 2 shows the speed sensors approaches and power converter architectures that can be employed in the design process of a pitch and torque controller. Pitch angle such as grid integration, control flexibility, variable speed operation, and system reliability, the dual-fed induction generator (DFIG) is a remarkable technological innovation in wind turbine systems. The development of DFIG technology is expected to lead to future improvements in renewable energy production, making it a desired rotor speed and resilient energy.

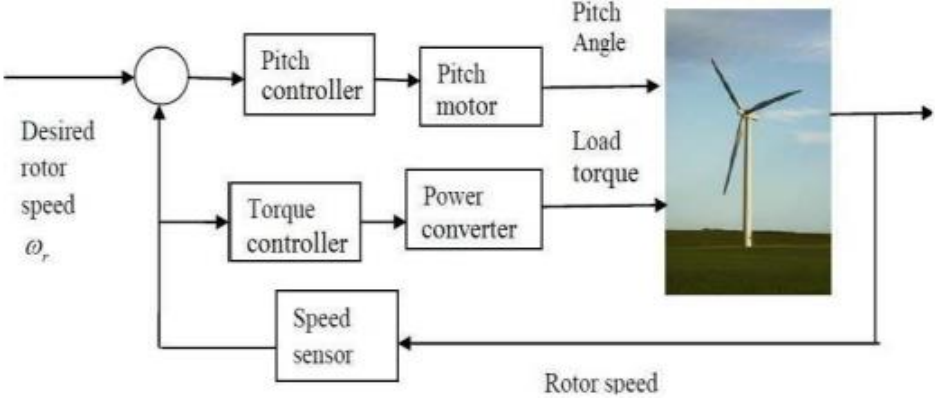

Fig. 2. Diagram of the closed-loop control system for a wind turbine

3 Hybrid active filters: increasing the quality of electrical energy

3.1 Overview of Hybrid Active Filters (HAF)

In many different applications, hybrid active filters offer an advanced method of reducing harmonics and improving power quality. They integrate passive power filter (PPF) and active power filter (APF) capabilities to successfully address harmonic and power quality issues.
Principle of operation of the hybrid active filter [13].
Hybrid active filters work by combining passive and active filtering methods in a complementary way. Important operating instructions include:

1. Low Impedance Harmonic Channel: HAFs offer harmonic signals a low impedance channel, essentially grounding them to stop them propagating through the power system and directing them away from sensitive equipment.
2. Injection of out-of-phase signal: HAFs can actively cancel unwanted harmonics by injecting out-of-phase signals containing harmonic components, greatly reducing harmonic distortion levels in the power system.
3. Flexible Filter Structures: HAFs provide a variety of filter configuration options, including the use of series and passive filters in conjunction with non-linear loads and parallel-parallel lateral active and passive filters.

3.2 Hybrid active filters have advantages

Compared to conventional active and passive filters, the use of hybrid active filters has the following advantages:

Cost Effectiveness: HAFs can offer strong harmonic reduction capabilities at a much lower overall cost compared to standalone Active Power Filters (APFs).

Resonance Mitigation: HAFs contribute to stable and reliable operation by reducing the danger of resonance in the power system, a common problem with simple passive filters.

Dynamic Response: HAF has the ability to rapidly change and adapt to changing harmonic circumstances and load changes, unlike passive power filters (PPFs).

Improved Power Quality: Harmonic Reduction Filters (HAFs) reduce voltage distortion, improve waveform integrity, reduce device stress and prevent failure by effectively suppressing harmonics.

3.3 Application of hybrid active filter

Hybrid active filters are widely used in many power systems and sectors such as [14]:

Industrial Settings: To reduce harmonics and guarantee stable operation of sensitive equipment, HAFs are used in industrial environments with non-linear loads, including rectifiers, power electronic converters and variable frequency drives (VFDs).

Renewable Energy Integration: HAFs help regulate harmonics produced by different energy sources in renewable energy systems such as wind turbines and solar inverters, ensuring grid compatibility and compliance with power quality regulations [15].

Data Centers: By reducing harmonics caused by IT equipment, increasing system reliability, and reducing the risk of downtime, HAFs are essential for data center energy infrastructure.

Utility Grids: To reduce harmonic distortions from various loads, maintain grid stability and improve overall power system performance, HAFs are integrated into utility grids.

Perspective patterns and advances

The following developments are likely to lead to further developments in hybrid active filters:

- Advanced Control Algorithms: Sophisticated control algorithms including model predictive control (MPC) and adaptive filtering are included to maximize HAF performance and adaptability.

Energy Storage Integration: Integrating energy storage devices with HAF [16]

- IoT and Monitoring Systems: Adoption of IoT-enabled diagnostic and monitoring systems for fault finding, predictive maintenance and real-time performance monitoring of HAF installations.

In many applications, hybrid active filters offer an excellent way to reduce harmonics and improve power quality. The combination of active and passive filtering capabilities, economy and increased system reliability, they are positioned as a key piece of technology in today's energy infrastructure [17, 18]. The development and use of hybrid active filters is expected to be critical to achieving efficient and sustainable energy management as business and energy systems change.

Alternating current (AC) is an example of current generation in which the flow of current varies between positive and negative directions around a baseline. When the line is not connected to non-linear load, the voltage and current's wind speed calculated cycle is expressed by the waveform shown in Figure 3.

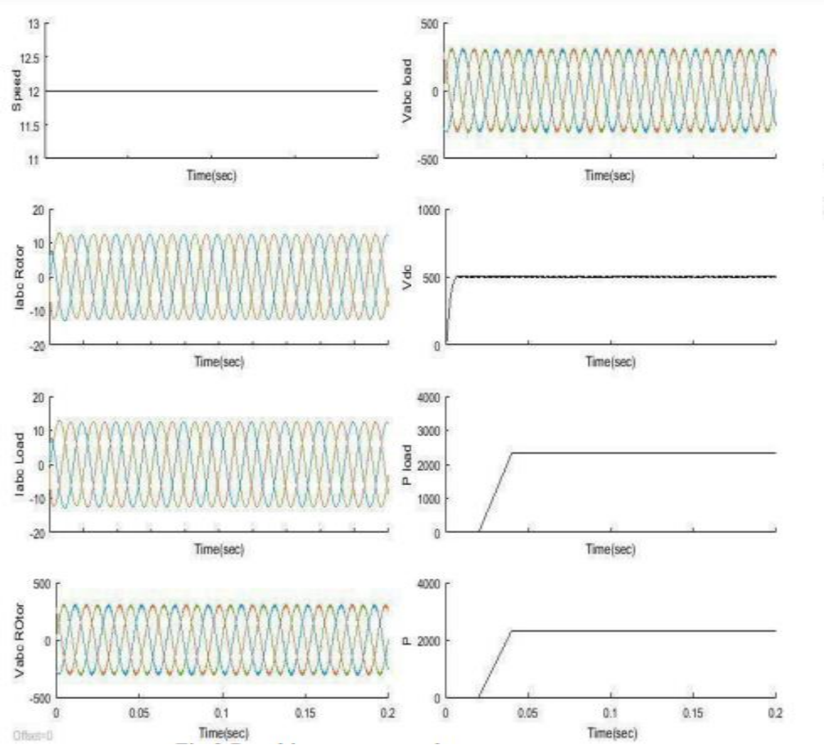

Fig. 3. Power and currents as a result

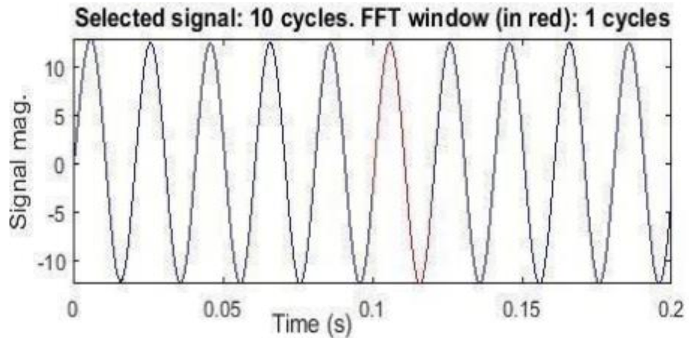

Fig. 4. A waveform simulation

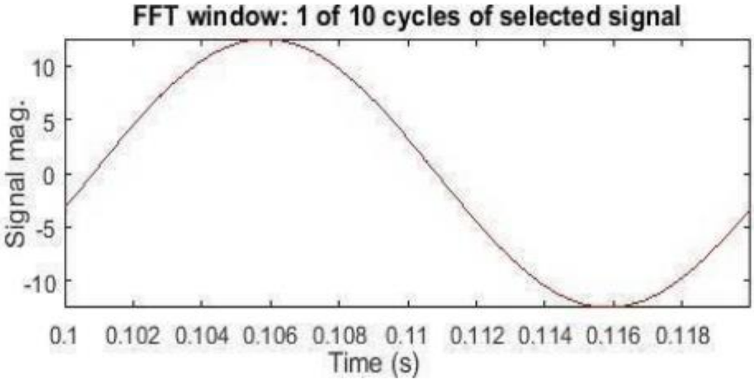

Fig. 5. Analysis of distortion using a single cycle

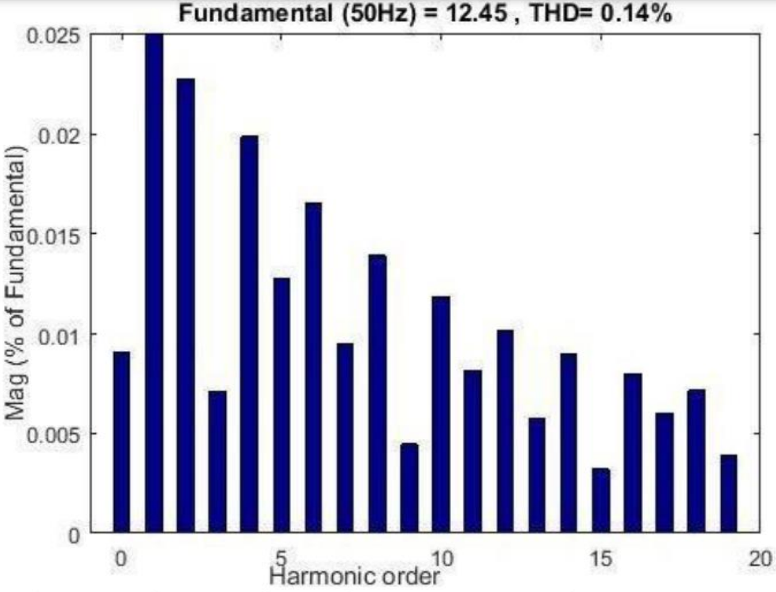

Figure 6. Harmonic spectra in the absence of non-linearity

When a line is connected to a non-linear load, the voltage and current's wind speed calculated one cycle is expressed by the waveform shown in Figure 4. From this figure 5, the distortion was calculated for a single cycle using harmonic order THD = 0.14%, based on the specific distortion spectra characteristics of the load shown in Figures 6.

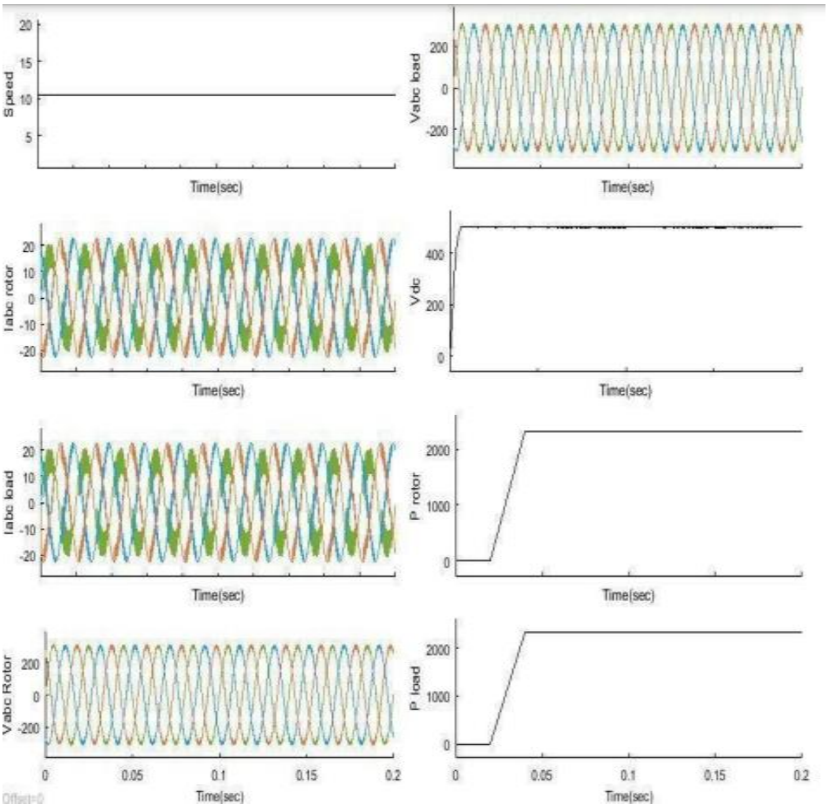

Fig. 7. Current and power as a result

If a load's conductance varies in response to applied voltage pulses that match the voltages and current waveform output are shown in Figure 7.

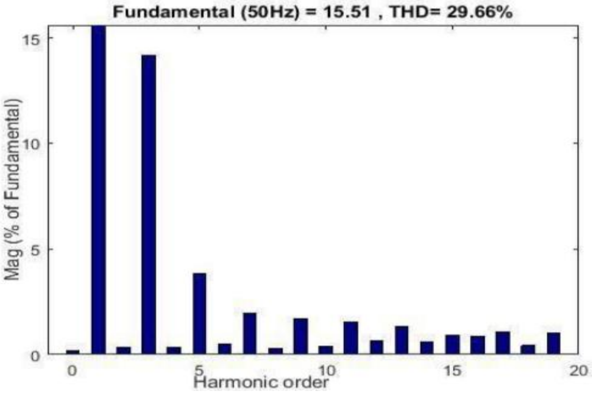

Figure 8. Modelled waveform

Figure 8 shows the magnitudes of the fundamental frequency 50 Hz currents as a percentage of the fundamental component of current distortion (with a THD of 29.66%).

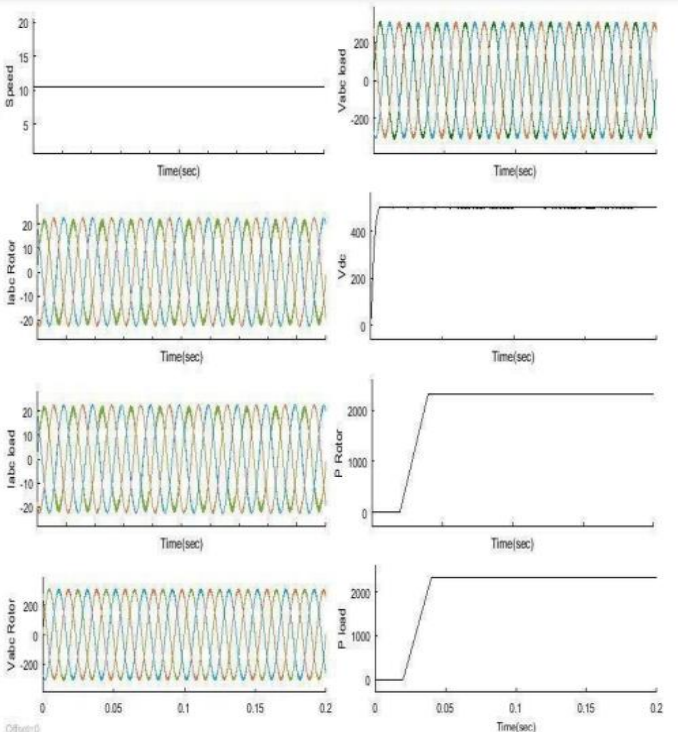

Fig. 9. Analysis of distortion using a single cycle

Figure 9 shows that the fundamental deviation refers to the ratio of the single cycle value of all components except the fundamental wave to the mean square value of the entire signal. A unit wave whose frequency is the same as the frequency of a non-sinusoidal wave.

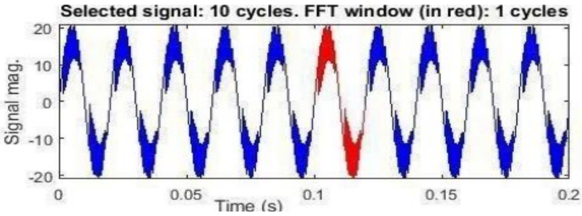

Fig. 10. Harmonic spectra in the presence of non-linear connections

Figure 10 displays the output of harmonic spectra, which are generated by non-linear loads as positive integer multiples of the fundamental frequency.

4 Analysis and simulation results

Non-linear loads degrade the overall power quality of the system and cause harmonic distortion when connected. These distortions can result in equipment stress, voltage fluctuations and inefficiencies. It is necessary to use filters, especially hybrid active filters in your situation to reduce these harmonics and improve system performance [19]. By combining active and passive filtering methods, hybrid active filters provide a comprehensive strategy that successfully reduces the harmonic content to an appreciable limit. The system in simulation both with and without nonlinear loading, as well as with hybrid active filters included. This enables a full understanding of how filters affect system performance, power quality and waveform characteristics [20].

4.1 Flows and output analysis

1. There is no nonlinear loading

The basic reference for waveform analysis, which shows how the system behaves under typical operating conditions, is without nonlinear loads. This situation helps to guarantee system performance without harmonic distortion.

2. No filter and non-linear load

The influence of harmonics on voltage, current and power waveforms is demonstrated by introducing non-linear loads without filters. This case illustrates the distortions and inefficiencies caused by non-linear loading as well as the necessity of harmonic mitigation techniques [21].

3. Using an active hybrid filter

The use of hybrid active filters in the simulation significantly reduces the harmonic content, as shown by the improved voltage and current waveforms. The filtered output shows more sinusoidal and cleaner waveforms, indicating better power quality and less distortion [22].

Future paths and improvements

Other optimizations could be explored in the future, such as the following:

- Fine adjustment of the filter parameters for the best possible suppression of harmonics.
- Incorporation of control and monitoring systems for adaptive adjustment of filters in real time.
- Investigation of sophisticated filter control techniques to mitigate dynamic harmonics.

5 Conclusion

Using Matlab/Simulink simulation and our proposed methodology, we found that nonlinear loads had a large effect on total harmonic distortion (THD). The THD increased by 29.66% after the addition of non-linear loads, underscoring the necessity of harmonic reduction techniques for power systems. A hybrid active filter to solve this problem and it worked incredibly well to manage THD, reducing it to 4.16%. This significant drop shows how well hybrid active filters work in reducing harmonic distortions caused by non-linear loads and improving power quality.

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