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SIMULATION BASED STUDY OF POWER QUALITY IMPROVEMENT AND SPEED CONTROL IN INDUCTION MOTOR WITH HYBRID RENEWABLE SOURCE

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Abstract

This paper presents modeling and simulation-based study of system consisting of a hybrid energy source based on solar photovoltaic and wind turbine energy sources, a traction load, specifically an induction motor and a shunt active power filter connected between sources and load to improve the power quality in MATLAB Simulink. To compensate the drawback of overheat of solar cell and dependency on single source, hence these two sources should be used together forming a hybrid renewable source with MPPT(P&O). This paper also comprises speed control of the induction motor using V/f method with comparative analysis of characteristics of the induction motor under controlled and uncontrolled speed. Speed control method involves switching devices such as IGBT which is a non-linear load. Due to introduction of non-linear load, there is an unfavorable effect on system efficiency and power quality, especially THD. In order to improve power quality, a FACTS based device SAPF is connected between source and load based on hysteresis controlling scheme, using STATCOM scheme. We commence the paper with details of solar and wind energy sources followed by the power quality improvement followed by characteristics of speed control of the induction motor.

Keyword:- IGBT, FACTS, THD, SAPF, STATCOM, MPPT, P&O.

Introduction

The world energy consumption is increasing day by day, with pre-existing energy sources becoming increasingly reliant on non-renewable sources such as coal and oil. Renewable energy sources are becoming the best choice for power generation and limiting global warming, with solar PV being the fastest of all renewable sources. Solar PV is an energy source that uses the photovoltaic effect to convert light energy to electricity energy. It consists of solar cells which are a solid-state device that employ diffusion and recombination of electrons in the cell to generate current. The cells connected together are called solar modules and modules, forming a solar array. Depending on the technology, solar can be used as a secondary energy source, but wind sources coupled with solar can result in a great energy supplying source with less frequent shortage. The uneven heating of the atmosphere by sunlight, surface changes, and rotation of our planet all contribute to the formation of wind. Permanent Magnet Synchronous Generators (PMSG) are a type of electricity generator that converts wind energy into electricity [10]. Energy is created by spinning cutting blades around a rotor, which is then turned by a driving shaft and generated by the rotor. Similar to solar energy it provides benefits over non-renewable resources against environmental issues.The fundamental concept is to run a generator with a fixed frequency but variable speed, allowing for operation across a wider range of wind speeds and reducing noise. Wind turbines with varying speeds are controlled to deliver the greatest power regardless of the wind speed, using MPPT [4]. Induction motors are electric devices with broad industrial applications and residential uses. They are widely used in both industrial and home settings due to their durability, low maintenance requirements, and affordability. Electrical drives are mainly used for control, but have drawbacks such as low efficiency, erratic speed control, and high space requirements. Power electronics have revolutionized the way power is used, allowing converters to handle more power. Variable speed drives are now more effective and powerful than those built smaller and more effective.

Electrical equipment is exposed to transient overvoltages (surges/spikes) (8%), swells (13%), flickers, unregulated voltages (18%), voltage dips/sags (31%), interruptions or waveform disturbances (power factor, harmonics (18%), others) [2]. The flicker effect is a flickering of lights induced by rapid variations in voltage. The harmonics are created by non-linear loads such as Power electronics like rectifiers, inverters, electronic starters, motor drives with variable frequency, switching power supplies, and discharge lamps etc. FACTS devices are used to mitigate the THD. Static Synchronous Compensators (STATCOM) are active devices that use advanced power electronics to regulate voltage and current, and mitigate harmonics [1].

Harmonic Background

As solar gives less efficiency in the winter season, the wind energy is used as an alternative to feed the requirement because wind speed is high in the winter season thus, they produce more energy [5]. Since PV modules are very expensive it is needed to be utilized at maximum and exploit all of the available output power [7]. Hence It is recommended to run the PV module and wind turbine system at peak power point to generate maximum power in order to boost efficiency [9]. To operate the PV module and wind turbine system at the peak, a special method is used known as “maximum power point tracking” abbreviated as MPPT [4].

Scalar control method offers a broad speed range and starting performance; an inverter with PWM control is utilized to generate changeable frequencies in this sort of control [10]. Shaltout, A.; Youssef, O. E. M. (2017) stated in their paper that by combining the slip speed with the real rotor speed, the corresponding synchronous speed is calculated in order to derive the frequency command, and voltage command is obtained through V/Hz control [11].

Harmonics are spectral elements with frequencies that are multiples of the fundamental frequency by an integer. The main cause of harmonic voltage distortion is the nonlinear loads [2]. It was stated in Lv, Qin; Zhao; Guo; and Zong's (2020) publication that the methods for power system harmonic detection and its suppression are diverse, intricate, and varied, and the results vary. The prevalent research approach in harmonic control today and in the future is the active power filter harmonic suppression method [6]. Hoon, Yap (2017) et. al. in their paper states that the greatest way to reduce harmonic contamination is to use a shunt active power filter (SAPF), however its efficiency is entirely reliant on how quickly and precisely its control algorithms can work. Harmonics extraction based on a Instantaneous power (PQ) theory algorithm uses a sequence of mathematical calculations of the instantaneous power in a balanced three-phase system used to realize the evaluation, using the Clarke transformation for in α-β-frames computation [3].

Problem identified

The 21st century presents developing and rising economies with a dual energy challenge: increasing demand and low carbon emission. The solar cells often face problems with irregular output due to its overheating and intermittency. Compared to other renewable energy sources, solar panels have a low efficiency. Wind power, total electric demand, and supply resources all exhibit uncertainty and variability. The location and intermittent nature of wind turbine machines can cause power quality problems such as voltage dips, frequency variations, and low power factor. Large voltage reductions may occur quickly even though the capacity of the running generators may be sufficient. The network's imbalance and redistribution of actual and reactive power may cause the voltage to fluctuate beyond the point at which it is stable.

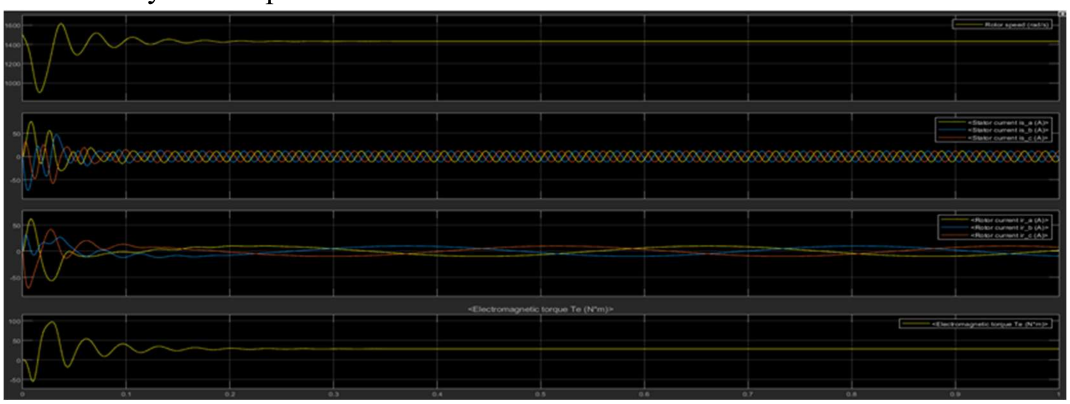

Figure 1: Uncontrolled field parameters of induction motor

A speed control is applied to control the rotational speed of machines and motors. This is essential for the work's quality and outcome because it directly affects how the machine operates. With the current system in place, a less complicated and more effective design is needed.

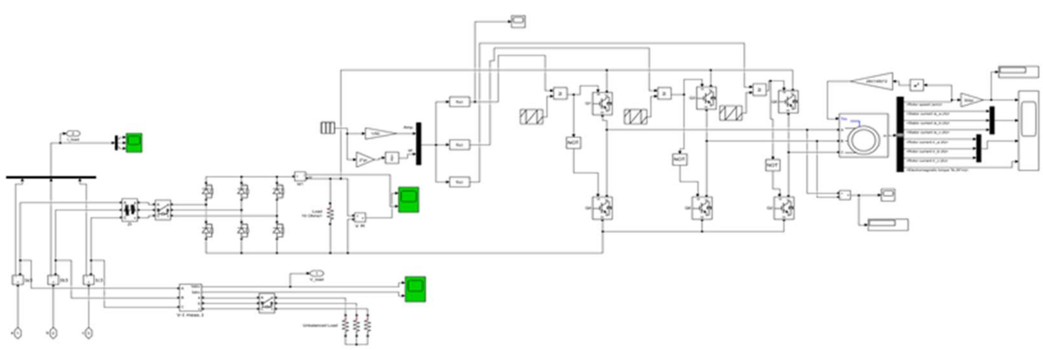

Figure 2: Balanced and Unbalanced load with V/f controlled motor as a non linear load

Harmonics in the system can be observed in the current waveform in its initial phase without any active power filters (APF) or passive power filters (PPF). The third harmonic, with a peak of 0.5 pu, and the fifth harmonic, with a peak of 0.2 pu and continuing, are the harmonic magnitudes depicted in the image. This results in a Total Harmonic Distortion (THD) of 30.26% of the fundamental.

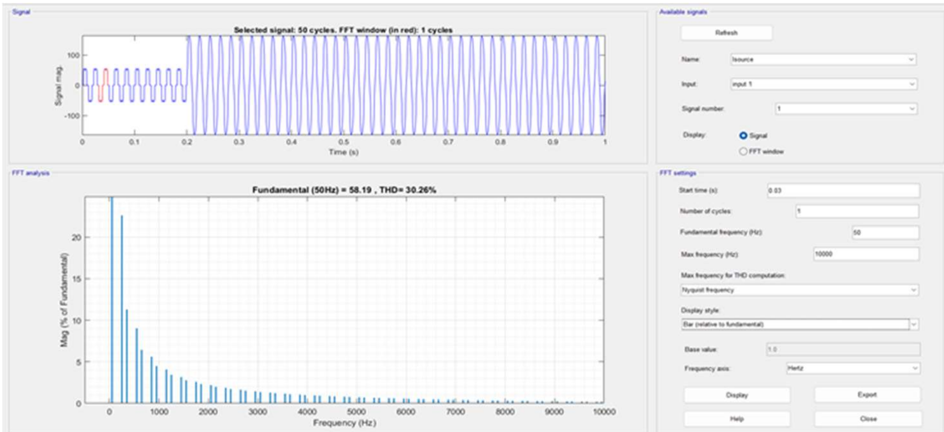

Figure 3: FFT analysis representing the magnitude of harmonics relative to fundamentals

Proposed Methodology

The ratings were defined and the desired output to be 100 kW and VmA = 290 V, we selected the module type among all available, 1Soltech 1STH-215-P. The PV array is subjected to constant irradiance and constant temperature of 1000W/m2 and 25 C respectively.

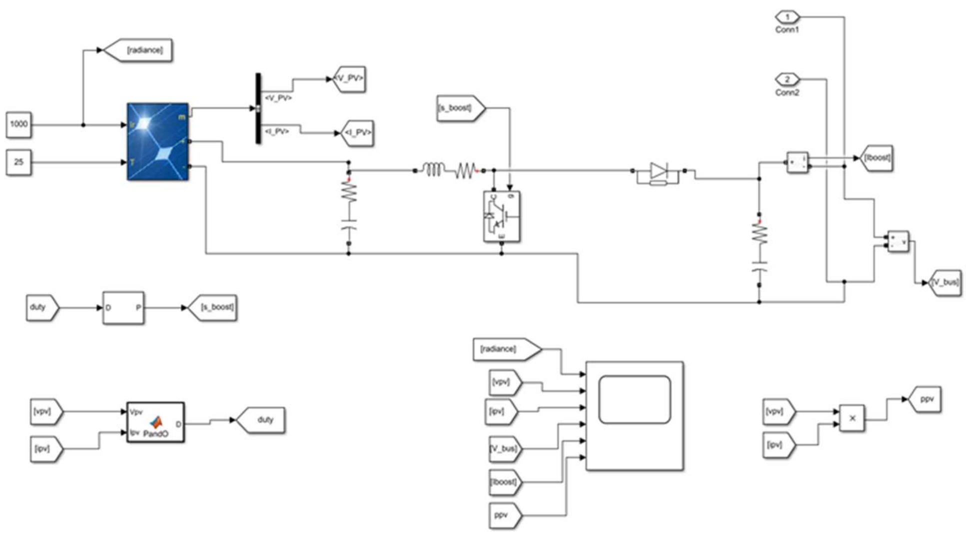

Figure 4: Solar module system with MPPT(P&O) model as a renewable source

For compensating the small output of the solar module, a boost converter is employed to amplify the dc output. The voltage and current from the PV array are taken as input to the MPPT P&O block comprising P&O algorithm and gives duty as the output, which is given as the gate pulse to the IGBT for the working of the boost converter. The process by which the wind is used to generate electricity is called wind energy or wind power. In WECS, we use a 12.3Kw wind turbine and PMSG machine, it is a PMSG based wind energy system with MPPT. To develop a base torque, we took Pm value 12.3e3 and the rated generator speed (λ*speed/radius) where λ=8.1, speed=12 and radius=1.3 and speed in ω_r. For ripple free output a series RLC (with R=0.005, C=500e6) is used. A boost converter is used to step up value. The pulse generated from the P&O MPPT method is provided to the IGBT.

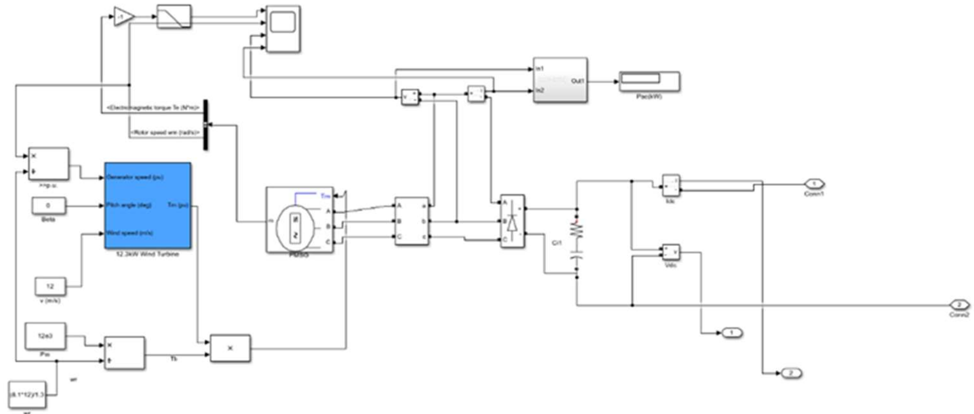

Figure 5: Wind turbine system with MPPT(P&O) model as a renewable source

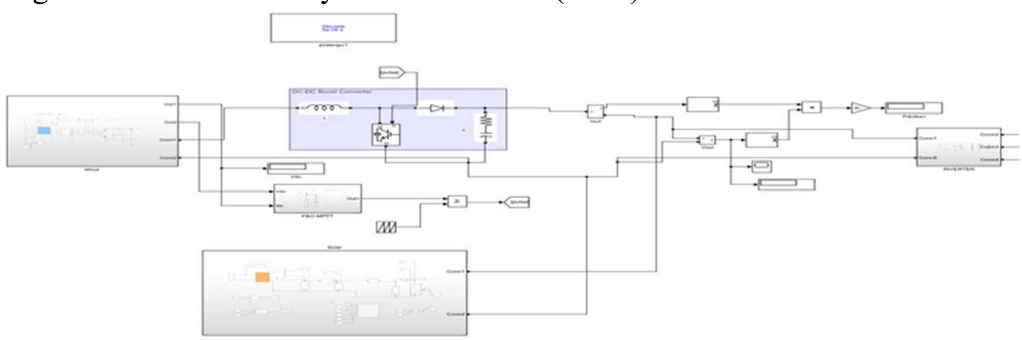

Figure 6: Proposed hybrid source model

Now using the calculated (i.e., C=6.6094e^{-4}, L=4.5573e^{-5}) in the DC-DC boost converter and the load (RL) of 13.5, along with MPPT(P&O). A voltage measurement V_{out} is connected at the output and a current measurement I_0, and product of the mean of two is converted into kW. And is coupled with solar source to form a hybrid source. Later this hybrid source is inverted to AC using an inverter.

This generated power will be stepped up and sent to the distribution end, further towards the railway 15 transmission line. For the Railway transmission line it will be stepped down to a standard requirement (Indian railway engine uses 25kV). The motor selected is a squirrel cage asynchronous motor (induction motor) with a rating of 4kW, 400V with a speed of 1430 rpm. There the transmitted power will be stepped down to a voltage suitable to feed 400V to the motor.

So, using the formula for rated torque calculation, we get

$$T_{rated} = \frac{P_{rated}}{\frac{2\pi}{60} N_{rated}}$$

$$T_{rated} \simeq 27$$

Considering the loss of energy during operation and the dip in the torque during transient operations, we estimated it to be 4-5% increase in feeded torque in uncontrolled operation of an asynchronous (induction) motor. We take $T_{rated} \simeq 28$.

Keeping in mind the less complexity and new adaptive model of work, the model is designed using torque, speed power and slip relation. The design this paper presents is aimed for high initial torque and approaching maximum speed with less delay possible. Unlike conventional methods, where the PI controller is used to generate a slip command using reference and actual speed, it uses the relation between speed, torque and power. We deduced a suitable relation

$$T_s = \frac{P_{rated}}{(1-s)\omega_r}$$

$$(1-s)T_s = \frac{P_{rated}}{\omega_r}$$

$$(1-s)T_s = T_r$$

Using the above relations mentioned a design was proposed which utilized the relation between slip, speed, power and torque. This logic of above relation was simplified while using $T_{rated} \simeq 28$ and compiling the equation in a single gain block and correlating it with speed-torque characteristics. For the supply of an induction motor the model uses a voltage source inverter coupled with Scalar Vector Pulse Width Modulation (SVPWM). A repeating sequence block is used to govern the time delay and the frequency magnitude output complementary to each other. For an AC supply to deal with, a rectifier is connected in between.
THD refers to the total harmonic distortion (THD) of a voltage or current waveform caused by the combined effects of all the harmonics in the network.

$$THD(\%) = \sqrt{ID_2^2 + ID_3^2 + ID_5^2 + \ldots . ID_n^2}$$

The harmonic mitigation of the Shunt Active Power Filter (SAPF) is notable since it is mostly based on the method used to measure the reactive power and harmonics of the current, as well as the compensation control. The P&Q theory and the harmonic current compensation methods utilized in PWM-based voltage source inverters significantly impacts the efficiency of the harmonic current compensation.

Now the current flowing can be expressed as:

$$i_S = i_L = [i_{fL} + i_H] - i_C + i_{dc}$$

In virtue of DC-link capacitor (DC cap and DC cap1 in series) operation, the current in the system changes to sinusoidal with the fundamental frequency, such that the current flowing is:

$$i_S = i_L = i_{fL} + i_{dc}$$

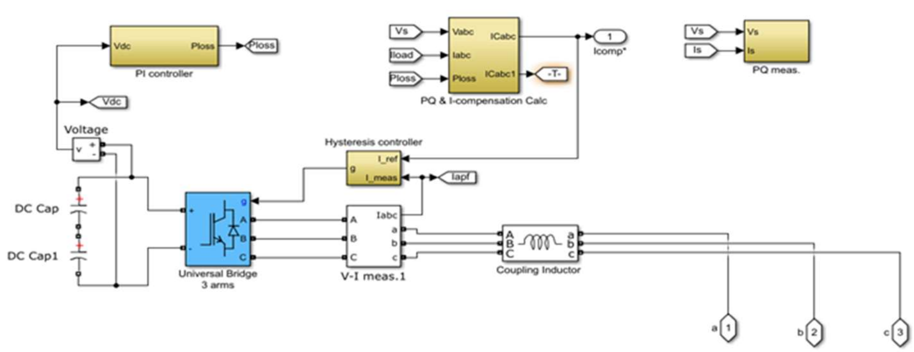

Figure 7: The proposed model of Shunt Active Power Filter

The instantaneous reactive power theory (P-Q theory) is essentially based on the Clarke transformation, which converts the a-b-c stationary reference coordinate to the 0-α-β rotational coordinate. In our paper because of the load the zero sequence values are neglected.

$$\begin{bmatrix} v_0 \\ v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\tfrac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \begin{bmatrix} i_0 \\ i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix}$$

The fundamental instantaneous power components P and Q will show as a DC signal in αβ-frames, while P and Q imbued with harmonics will appear as ripples. Inverse Clarke transformation is used to create the reference current i_ref using the extracted harmonic components i_αβH. Due to its reliance on LPF, it also has delays in extracting the essential component [2017][11]. In the α-β coordinate, the complex sum of the active and reactive powers (P and Q) can be represented by

$$S = P + jQ = v_{\alpha\beta} i^*_{\alpha\beta} = (v_\alpha - jv_\beta)(i_\alpha + ji_\beta) = (v_\alpha i_\alpha - i_\beta v_\beta \ ) + j(v_\alpha i_\beta - i_\alpha v_\beta \ )$$

The compensation current is calculated using the expression given below while neglecting the zero sequence values. Further, these value of α-β are used for calculation of a-b-c type values using an inverse matrix transform [2017][31].

$$\hat{p} = P - \underline{p} + \underline{p_{loss}}$$

$$\begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix} = \frac{1}{v_\alpha^2 + v_\beta^2} \begin{bmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} \acute{p} \\ Q \end{bmatrix} \begin{bmatrix} i^*_a \\ i^*_b \\ i^*_c \end{bmatrix} = \sqrt{\tfrac{2}{3}} \begin{bmatrix} 1 & 0 \\ -1/2 & \sqrt{3}/2 \\ -1/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} i^*_\alpha \\ i^*_\beta \end{bmatrix}$$

The hysteresis band current approach is used to create the switching signals for the voltage source inverter. In order to keep the actual current within the hysteresis band, the reference current is compared to the actual current, and the VSI switches are turned on and off in accordance with the error. A proportional-integral controller is utilized in the DC-link voltage control loop to maintain a constant DC-link voltage and efficiently correct the harmonic current and evaluating compensation current, it uses a reference voltage value as described here as 850V and compares it with the voltage across DC-link providing the energy consumed and maintaining the value via DC-link loop.

Results

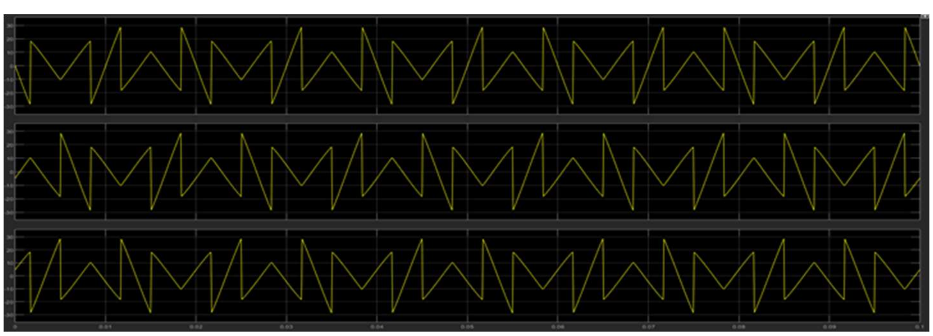

Figure 8: Waveform of compensation current

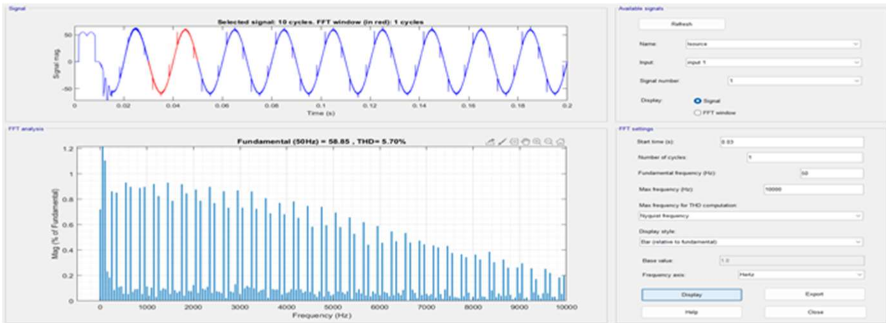

Figure 9: FFT analysis representing the magnitude of harmonics relative to fundamentals

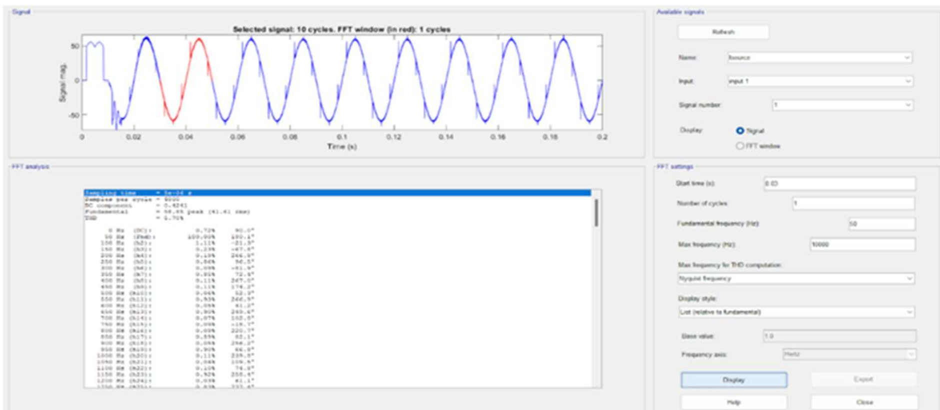

Figure 10: FFT analysis representing the %magnitude of individual harmonics distortion relative to fundamentals

The waveform above shows the pattern of compensation current derived for the compensation of harmonics current.

After the shunt active power filter is connected to the point of common coupling and in parallel with the nonlinear load, the waveforms of the source current and load current are filtered. The FFT analysis as in Figure 9 demonstrates that the Total Harmonic Distortion (THD) has decreased. It is observed that the total harmonics distortion has decreased by 82.6% of the initial value, and brought it down from 30.26% of the fundamental value to 5.70% of the fundamental value. While the THD dropped by 82% of its initial magnitude, the individual harmonic distortions were also mitigated to a minimum level by 82% to 83% of their initial individual value and share in harmonic distortion.

Conclusion

The designed system was simulated in the MATLAB/Simulink. In order to get the most power out of the PV system, the P&O was used to provide the best duty cycle when compared to Constant duty cycle control and other methods. It was designed to be a hybrid source in order to have load sharing and compensation. The model proposed in the study, its implementation, and its outcomes are discussed. The goal of achieving max speed and max torque under controlled conditions, with speed-controlling VSI that uses PWM, while employing hybrid energy as a source was successfully accomplished. The system has been found to be effective in traction applications and drives. Under balanced and unbalanced nonlinear load conditions posed by the VSI-based induction motor, the THDs were decreased from 30.26% to 5.70% by using the proposed SAPF, according to the FFT spectrum analysis. i.e., by 82.6%. The system was able to mitigate the harmonics and reduced it by approximately 82.6%.

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