Application of Frequency Estimation Techniques to Minimize Power Quality Problem

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Abstract

Through the use of a technique known as frequency estimation, the objective of this study is to explore a topic that pertains to power quality and the elimination of harmonics in the power system. Under a wide range of less-than-ideal conditions, such as voltage imbalance, harmonics, dc-offset, and so on, the objective of this research is to investigate the performance of a number of different methodologies for estimating phase and frequency. The bulk of the techniques have been shown to be incapable of estimating the frequency of the grid signals when the grid signals are characterized by dc-offset. This has been demonstrated via the use of a number of different methods. An approach to frequency estimation that is referred to as modified dual second order generalized (MDSOGI) is presented in this article. Under all of the circumstances that are not perfect, this technique makes an accurate prediction as to the frequency with which it occurs. It has been shown by experiments that the results are correct. It is necessary to further integrate the control scheme with the notion of instantaneous reactive power in order to construct a control scheme for a shunt active power filter that is capable of functioning under such conditions. A prototype for the experimental system is now being developed in order to show improved performance capacity.

Keywords: Power Quality, DC-Offset, MDSOGI, and Frequency Estimation Method are some of the associated

I. Introduction

Large-scale, centralized power facilities were responsible for the generation of the vast majority of the world's energy years ago. Despite the fact that these facilities were often located in close proximity to the major source of energy (for instance, coil mines), they were placed at a considerable distance from load or consumer centres. Conventional fossil fuels such as coal, gas or oil were used in thermal power plants, which had massive rotating turbines. These plants were used to generate electricity. This was the process by which the energy was produced. Immediately after the generation of the electricity, it is sent to the rest of the globe by means of the extensive transmission lines, which, by a fortunate coincidence, are a component of a passive network. The last phase involves the use of the (radial) distribution network in order to successfully deliver the electricity to the end customer. A system like this would only let power to move along a single path, and that path would be from the station that produced the power to the people that used it.

The production, transmission, and distribution of electricity (single player) were all under the state's entire control at all times. The fact that there were so few non-linear loads in the utility system also contributed to the fact that the issue with the power quality, in particular the distortion of the voltages and currents, was not nearly as significant as it was made out to be.

There is a distinct departure from this pattern that has occurred throughout the course of the last several decades. Primary contributions to the drift include the depletion of fossil resources, the decreasing efficiency that arises from the transmission of information across enormous distances, and the high expenditure that is involved in growing the capacity of transmission. All of these factors contribute to the drift. An additional factor that has played a significant role in this change is the rising environmental concerns over the harmful and greenhouse gases that are generated by centralized power plants.

When it comes to the generation of electricity, the utilisation of renewable energy sources like wind, solar, fuel cells, and other technologies that are analogous to these might potentially help to the resolution of these issues. The production of energy may be decentralized and carried out in close proximity to a number of different demand centres, in contrast to the centralized power plants that are often used. In addition to this, the capacity of the generating unit may now vary anywhere from a few kilowatts to several megawatts, and the state no longer has a monopoly on the production of energy (or there are only a few power producers).

In addition to the influence of environmental rules and the evolution of technology, deregulatory policies have had a considerable impact on the general structure of the electrical generating, transmission, and distribution systems. As a consequence of this, new circumstances have come into existence in the sector of power generating. As was just said, the generation of energy at the present time makes use of a wide range of diverse technologies and is carried out on a far greater scale.

There is a possibility that generating units may even be placed on distribution lines. It is no longer the case that the flow of electricity is straight. Given all of these factors, the contemporary electricity system faces a number of issues.

II. Literature Review

In order to satisfy the requirements of the study, we have chosen a few significant research publications, which are as follows:

A novel hybrid method for the identification of PQ disturbances in electrical power networks was given by Abdoos, A. A., et al. (2016) [1]. This method is comprised of four stages: the simulation of PQ events, the extraction of features, the selection of dominating features, and the classification of features. For the purpose of extracting probable features from PQ events, the techniques of variational mode decomposition (VMD) and S-transform (ST) are used. Furthermore, it analyses the signals in both the temporal and frequency domains after decomposing them into modes. The elimination of duplicate features is accomplished via the use of wrapper-based methods such as sequential forward selection (SFS) and sequential backward selection (SBS), as well as a feature selection method based on Gram–Schmidt orthogonalization (GSO) that falls under the category of filter-based approaches. When it comes to distinguishing PQ events, SVMs serve as the backbone of the classifier. Experiments that were carried out in great detail demonstrate that the approach that was presented is effective in terms of speed and accuracy even when used in noisy conditions. It is also possible to accurately recognize the beginning and ending points of PQ events.

An investigation into the topic of constructing mathematically valid techniques for determining the composition of higher harmonics was carried out by Abdullazyanov, E. Y., and colleagues (2015) [2]. It is essential for contemporary power systems to include higher harmonics into their electrical grids because these harmonics raise the level of responsibility that exists between power providers and their consumers. It offers a solution to the problem of energy conservation, which is the primary and most significant reason for its existence. In addition, the division of duty for guaranteeing the right power quality between the company that supplies electricity and the people who use it is an essential factor to take into account.

Alfieri, L., et al. (2017) [3] created new power quality (PQ) indices for the assessment of waveform distortions in the frequency range of 0 kHz to 150 kHz. These indices were designed for the study of waveform distortions. In particular, a number of indices that were previously available have been modified by making the necessary adjustments so that they may be used on waveforms that exhibit a wide variety of frequency responses. For instance, numerical applications show that the proposed indices are useful tools for identifying problems (such as overheating, equipment malfunctioning, losses due to skin effects or eddy currents) in the presence of both low-frequency and high-frequency distortions in the case of renewable energy generation sources. This is demonstrated by the fact that the proposed indices are effective tools.

Together, Almutairi, M. S., and Hadjiloucas, S. A unique method for regulating distortions in non-sinusoidal power systems was developed by [4] in 2019. This method makes use of the non-linearity current index (NLCI) to estimate the value of the shunt single-tuned passive filter (STPF) compensator. The goal of this method is to maintain the power factor within reasonable bounds. At the point of common coupling, the strategy that has been recommended aims to minimize the nonlinear current that is created by the loads of customers in the power system to the maximum degree that is feasible (PCC). Other practical constraints for the total voltage and individual harmonic distortion limits are also taken into consideration in the design that has been proposed. This design also ensures compliance with the guidelines established by IEEE 519-2014 and maintains distortions at an acceptable level while adhering to the capacitor loading constraints that have been established by IEEE 18-2012. A well-documented IEEE standard is used in order to assess the performance of the compensator that the optimal construction would be. The foundation of this standard is comprised of numerical examples of nonlinear loads that were gathered from previous publications.

In their study, Al-Ogaili, A. S., et al. (2020) [5] conducted extensive investigation and analysis of the performance of two well-known time-domain harmonic extraction techniques. These strategies are the synchronous reference frame (SRF) theory and the instantaneous power (PQ) theory, respectively. In order to carry out comprehensive simulation work under two conditions, namely steady-state conditions and dynamical-state conditions, while taking into consideration a wide range of highly nonlinear loads and factors, the MATLAB-Simulink platform is used. To be more specific, each control approach is included into a three-phase SAPF controller that was built with the assistance of a three-level neutral point clamped (NPC) inverter in order to function as a platform for evaluation. A comprehensive set of data is provided in order to illustrate the efficacy of the SAPF's mitigation performance when each harmonic extraction approach is used.

Askarian, I., et al. (2017) [6] focused on the creation of a system for detecting and monitoring disruptions and oscillations in the electric power grid. This system was designed to identify and monitor such disturbances. Despite the fact that the nature of the unknown harmonic contents is unknown, they proposed a one-of-a-kind real-time harmonic estimate technique that is capable of quickly and reliably predicting the dc component of the grid voltage, in addition to the synchronous and asynchronous harmonic contents of the grid voltage. It is possible to implement the technique that has been recommended in the control system of power converters, which has the potential to enhance the reliability and resilience of future microgrid systems. The effectiveness of the proposed harmonic estimator is evaluated within the framework of power converter grid synchronization, which serves as a case study for the purpose of this investigation. Even in the presence of disturbances and changes in the grid's voltage, the converter is able to inject a sinusoidal current that is smooth, as shown by the outcomes of the simulations and tests that were conducted for the case study. The results that were obtained provide evidence that the harmonic estimating method that was provided is not only dynamic but also accurate in a short amount of time that was considered.

An analytical hierarchy process (AHP) inspired technique was presented by Bajaj, M., et al. (2020) [7] for the purpose of determining the power quality (PQ) of distorted distribution power networks where renewable-based distributed generators are present. Voltage harmonics, voltage sags, voltage imbalance, and steady-state voltage profiles at each bus are the four PQ phenomena that are taken into consideration by the proposed approach for evaluating power quality (PQ). I.e. Based on photovoltaic (PV), wind, and fuel cell renewable energy sources, the approach is shown in MATLAB/Simulink on an IEEE 13 bus test distribution system that has been enhanced with nonlinear loads and distributed generation (DG) systems. Due to the results, the success of the technique was confirmed when it came to assessing the entire PQ performance of each bus and comparing it to the threshold level of unity. The results of the investigation are used to make a comparison of the performance of DN PQ with that of three RES-based DGs. A further use of the created index is to investigate the impact that the utilisation of custom power devices (CPDs) and an excessive penetration of renewable energy sources have on the performance of distribution network power quality (PQ).

Additionally, Baraniak and Starzyński, J. et al. (2020) [8] produced simulation models based on measurements taken from the actual charger and data provided by the equipment's producers, as well as simulation models that have been extensively described in the literature; and It was determined, based on the study's findings, if electric car chargers had a negative influence on the quality of electric power, and consideration was given to the prospects presented by the development of charging systems that include vehicle-to-grid (V2G) capabilities. When selecting power supply cables, it is important to take into account the influence of higher current harmonics created by converter systems, which may cause the cables to heat up. This is one of the proposed revisions to the technical standard.

Blazek, V., et al. (2020) [9] offered an investigation of the effect that home appliances have on the quality of the energy that is used by the end user. The conclusions of the research have an impact on the final consumer, which is the level of the electricity grid that is the lowest. The research used a total of 120 different combinations of grid-connected electrical appliances. Within a microgrid, each combination has three different devices. The information that was acquired and statistically analysed revealed that certain types of home appliances had a significant influence on the differences in power quality attributes they exhibited. The devices that had an effect on the THDV, FREQ, and voltage fluctuation (V) are shown by the analysis of the results of the experiments. Investigations were conducted to determine the significance of several device parameters with regard to the power quality variation. When developing a prediction model, this brought to light the most important factors to take into consideration. In the future, smart grids will look like this. A significant drop in the amount of energy that is derived from renewable sources is one of the major aspects. In their paper, they go into depth about this occurrence. They investigated the effect that smart home technology had on individual quantities using a model that was really used. Additionally, they investigated devices that had a significant impact on the quality of the electricity. For the purpose of enhancing the effectiveness of the prediction model, they provide an explanation of their unique behavior and how it is relevant to the event.

An optimised allocation approach of power quality (PQ) metres in a medium voltage (MV) distribution system (DS) was developed by Bottura, F. B., et al. (2019) [10]. This methodology took into consideration the probable harmonic resonance situations. When it comes to determining harmonic resonance frequencies and computing critical modal impedances, the HRMA methodology is the method of choice. Through the use of the HRMA, it is possible to generate a binary observability matrix that incorporates the observability of nodes for hypothetical harmonic resonance frequencies. The allocation problem is modelled as a constraint integer linear programming problem in order to guarantee that the stated harmonic resonance frequencies are observed in their entirety. Taking into account harmonic resonance circumstances, DS operation scenarios, and client capacitor banks for PFC, the final solution that is realistic identifies the optimal locations to place PQ metres. A total of two CIGRÉ MV test DSs and an IEEE 34-node test feeder were used in order to test the allocation method. Four PQ metres are required in order to perform a comprehensive monitoring of the potential harmonic resonance frequencies in both test DSs. Even when the capacitor banks are changeable, the final allocation method has been shown to be suitable.

A unique concept for load modelling was presented by Brunoro, M., et al. (2017) [11], which includes the ZIP model and the admittance matrix in a comprehensive manner. This combination brings together the benefits of load characterization with the traditional ZIP model, which provides some physical information about the load in addition to the frequency crossing that is supplied by an admittance matrix. As a consequence of this combination, the advantages described above are integrated. Using this information, it is able to accurately compute the harmonic power injection in the load bus, which is subsequently used in the process of calculating the harmonic voltage of the load bus. In spite of this, the present design continues to take into consideration the possibility of imposing a limit on the ZIP coefficients in order to define the power ratio in terms of constant impedance, constant current, and constant power simultaneously with constant resistance. An electronic load case study is offered, which includes a description of the procedure for determining the load model parameters. This approach comprises exhaustive search and multiple linear regression, among other things. The applications of the model in an electronic load are shown with the help of data obtained from a power quality metre. The results demonstrate that the harmonic model that was proposed was able to properly represent the load, and that the parameters that were identified were able to provide information on the kind of modelled load that was being represented.

The research conducted by Bubshait, A. S., et al. (2017) [12] focused on a four-leg inverter that was connected to the grid side. This inverter was designed to inject the available energy and also function as an active power filter, therefore reducing load current disturbances and enhancing power quality. Both linear and nonlinear loads, as well as three-phase and single-phase loads, are investigated. In addition to supplying active and reactive power as required, the utility-side controller is responsible for compensating for disturbances that are caused by reactive, nonlinear, and/or unbalanced single- and intra-phase loads. In the event that wind power is not available, the controller is intended to improve power quality by making use of a dc-link capacitor that is linked to the grid. The control structure that has been presented is based on conservative power theory decompositions, which does not exist anywhere else in the existing body of research. This option provides decoupled power and current references for the control of the inverter, which enables more flexibility and power. Evaluation of the performance of the proposed control algorithm in full real-time was carried out with the assistance of real-time software benchmarking. To test the control techniques in hardware-in-the-loop, a real-time simulator and a TMSF28335 DSP microcontroller are used. This enables for the testing of the control methods. Because of this, we were able to remove passive filters from our control system that is based on the smart grid, which resulted in the system being more compact, adaptive, and reliable.

As a consequence of power system harmonics, Buzdugan, M. I., et al. (2017) [13] provided an overview of a few difficulties that have arisen in low voltage distribution grids at the end-user level. In this section, we will briefly cover harmonics sources, their analysis, effects, and measurement methodologies. We will place a significant focus on the limits that are mentioned in the various standards, which will serve as the main reference. The authors presented two case studies of power electronics equipment that had significantly distorted currents and, as a consequence, high harmonic content. These case studies were discussed in detail. Examples include a piece of domestic equipment that has been tested in a laboratory environment and is powered by a switch-mode power source. This particular piece of equipment has been tested. The second kind of drive, known as a variable speed drive, has been put through its paces in an industrial environment, which is to say, under conditions that come from the real world. In conclusion, the use of harmonic measurements and analysis makes it possible to pick or develop retrofitting mitigation countermeasures that are capable of mitigating the effects of harmonics.

Cai, W., et al. (2020) [14] conducted an investigation on the influence that the uncertainty principle has on the power quality monitoring issue. According to their findings, the problem has been resolved by using perfect atomic decomposition (IAD). The novel method relies on a combination of time and frequency bases in order to identify the power quality waveform. This is accomplished by employing a pair of time bases. Because of this, it is feasible to reduce the uncertainty associated with both the frequency and the temporal aspects of the situation simultaneously. Through the use of the orthogonal matching pursuit approach, the sensing process (OMP) is brought into existence. The novel approach is able to offer faithful sensing and accurate analysis for a broad variety of power qualities, as shown by the results of simulated and field power quality testing, as well as comparisons of methods that have been created. In smart substations, the approach has also been shown to be an efficient way for monitoring the power quality during operations.

Multi-carrier sine pulse width modulation (MCSPWM) and space vector pulse width modulation (SVPWM) were the two multilevel pulse width modulation (PWM) approaches that Chokkalingham, B., (2018) [15] taken into consideration for NPC-MLI. There are a variety of limits that are imposed to both techniques, including voltage profile, total harmonic distortion (THD), common-mode voltage (CMV), and neutral point fluctuation. These restrictions are then compared and evaluated (NPF). The results of the comparison between the SVPWM technique and the MCSPWM techniques indicate that the SVPWM approach is superior to the MCSPWM approaches. For the purpose of experimentally verifying the analytical and simulation results gained via the use of MATLAB/Simulink for control systems, the FPGA-SPARTAN – III generation – 3AN –XC3S400 is utilised. This device is equipped with a 2KW NPC-MLI fed variable speed–drive system.

An investigation on the Open Power Quality (OPQ) initiative was conducted by Christe, A. J., (2020) [16]. To be more specific, it intends to construct and implement a power quality sensor network that is distributed and low-cost. This network will provide producers, consumers, researchers, and regulators with valuable new types of information on existing electrical grids in real time. During the year 2019, they carried out a pilot study at the microgrid run by the University of Hawaii, which lasted for three months and involved the installation of an OPQ sensor network. Based on the results of the pilot study, it has been shown that the Open Power Quality (OPQ) system is able to gather trustworthy data on power quality in a way that provides significant new insights into electrical grids.

In the next piece of work that the author will provide, the author will examine the performance of DSOGI-FLL and the recommended MDSOGI-FLL based frequency estimate technique for usage in the DSTATCOM application when an idealized offset error is present. According to the simulation findings that were produced from this technique, the grid current will be free of dc offset when the MDSOGI-FLL method is used in the DSTATCOM programme. Additionally, the total harmonic distortion (THD) will be much lower than its present value of 5%.

III. Methodology

Following is an explanation of the approach that was used during the study work:

The DSTATCOM implementation is based on the SRF theory, which states that the creation of reference current is mostly dependent on the phase information that is contained in the grid signal. This reference current is responsible for the generation of switching pulses, which are then used by DSTATCOM in order to fulfil the reactive power need of the load that is connected at PCC, as seen in figure 1.

In order to calculate the performance of the DSTATCOM under normal circumstances and in the presence of an offset component in the utility signals, both the suggested (MDSOGI-FLL) and traditional (DSOGI-FLL) techniques are used. Two different techniques, namely the suggested MDSOGI-FLL algorithm and the standard DSOGI-FLL algorithm, are used to determine the phase (frequency) information.

In order to evaluate the robust performance of the recommended MDSOGI-FLL for frequency estimation with that of the conventional DSOGI-FLL for reference current generation, it is feasible to do so with the assistance of the results of the simulation.

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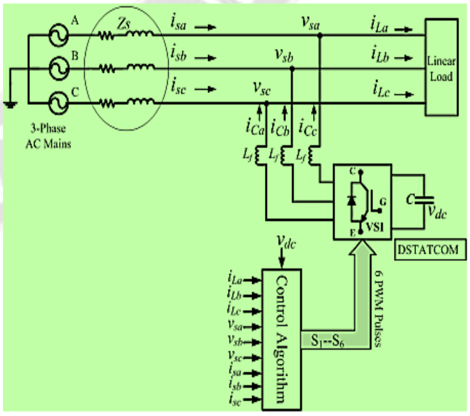

Figure 1. The DSTATCOM setup in its schematic form

The connection diagram of a three-phase VSI-based DSTATCOM is shown in Figure 1. This diagram is located at the point of common coupling (PCC), which is the point at which three-phase AC mains supply the linear load (R-L) with source impedance (Zs). The many different utility

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indications, and so forth. PCC voltage (vsa, vsb, VSI), load currents (iLa, iLb, iLc), source currents (isa, isb, isc), and DC bus voltage (vdc) of VSI that are employed in DSTATCOM are detected and sent to the control algorithm in order to create pulse width modulation (PWM) switching pulses (S1—S6) via the use of voltage switching modulation (PWM). In order to inject the compensating current (iCabc) at PCC, these switching pulses will activate the voltage source inverter (VSI). It is possible to achieve unity power factor operation by providing the reactive power demand of the load (at the PCC) by the injection of compensating currents iCabc at the PCC through the coupling inductance Lf. This brings the supply current (isabc) into phase with the supply voltage (vsabc), which shows that the power factor operation is in harmony. Table 1 contains a tabular representation of the parameters that were used in the development of VSI-based DSTATCOM.

Supply voltage (RMS)	415 (line-line voltage), 50 Hz
Linear load 1	3.2 kW,0.5kVAR
Linear load 1	0.7 kW,0.5kVAR
DC-link capacitor	C = 4000µF
DC-link voltage v_{dc}	700 V
Coupling inductor	Filter inductance L_f = 15 mH
Source impedance	Rs = 0.01 Ω, Ls = 1mH

Table 1. DSTATCOM configuration.

IV. Results and Discussion

Presented in this section are the results of the simulation that was performed on the performance of DSTATCOM. It was determined that the simulation was carried out with the supply voltage in perfect condition and with an offset error present. In the event that the phase-angle (frequency) information is obtained by both the DSSOGI-FLL and the MDSOGI-FLL that was indicated, the performance analysis is carried out and compared. The schematic representation shown in Figure serves as the foundation for this idea. 2, an investigation of the performance of the DSOGI-FLL based DSTATCOM as well as the planned MDSOGI-FLL based DSTATCOM for reference current extraction for load reactive power compensation is carried out. Each and every one of the simulation findings that are presented in this section were produced by using the parameters that are shown in Table 1.

A typical implementation of the DSOGI-FLL algorithm for the DSTATCOM application is shown in Figure 2, which exhibits the performance of the method. In this particular example, the grid signal is examined without any measurement offset error being present. The DSTATCOM is able to effectively respond to the linear load 1's need for reactive power in a consistent manner. In the results for the time period spanning from t=0.16s to t0.25s, it is possible to see this phenomenon. There is also the possibility of seeing the step change in linear load at the moment t=0.34s after the event has occurred. When the D-STATCOM is connected at time t=0.34s, it not only satisfies the needs of linear load 1, but it also satisfies the reactive power demand of linear load 2, as was previously mentioned. At t=0.16 seconds, the DSTATCOM is activated, and at t=0.25 seconds, it is deactivated. Both of these times are in seconds. There is a clear correlation between this and the fact that it begins to function at t=0.46s and ceases functioning at 0.55s. Since the beginning of this time period, it is possible to acknowledge that DSTATCOM has been meeting the load reactive power requirement (as seen in Figure 2(d)) during this whole duration. During the DSTATCOM actions, the variables 2(a) and (b) demonstrate that the supply voltage and current are both in phase with one another. It responds pretty well even when there is a rapid change in the weight that is being carried. In Figure, the frequency information that has been calculated for the grid signals is shown. (3(a)). The conventional DSOGI-FLL keeps a precise monitoring of the frequency in the ideal supply voltage to ensure that it is always accurate.

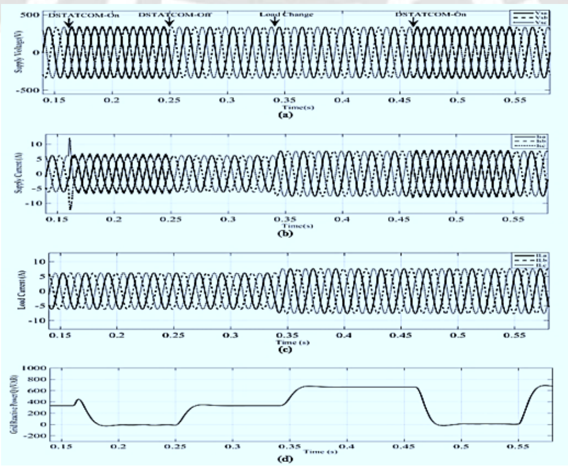

Figure 2. (a) supply voltage (b) supply current (c) load current (d) grid side reactive power

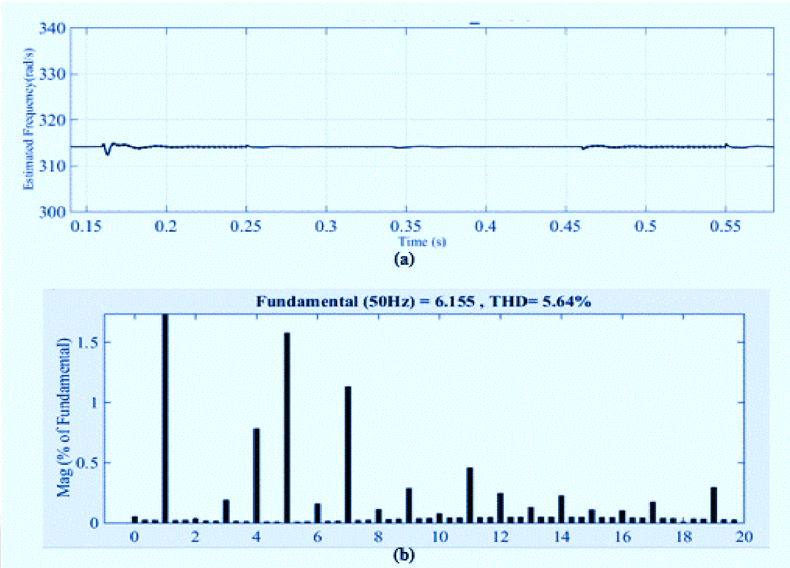

Figure 3. Shows the results of using the DSOGI-FLL method for D-STATCOM (without taking into account any offset error in supply measurement): (a) estimated frequency (b) frequency spectrum supply current when D-STATCOM operates.

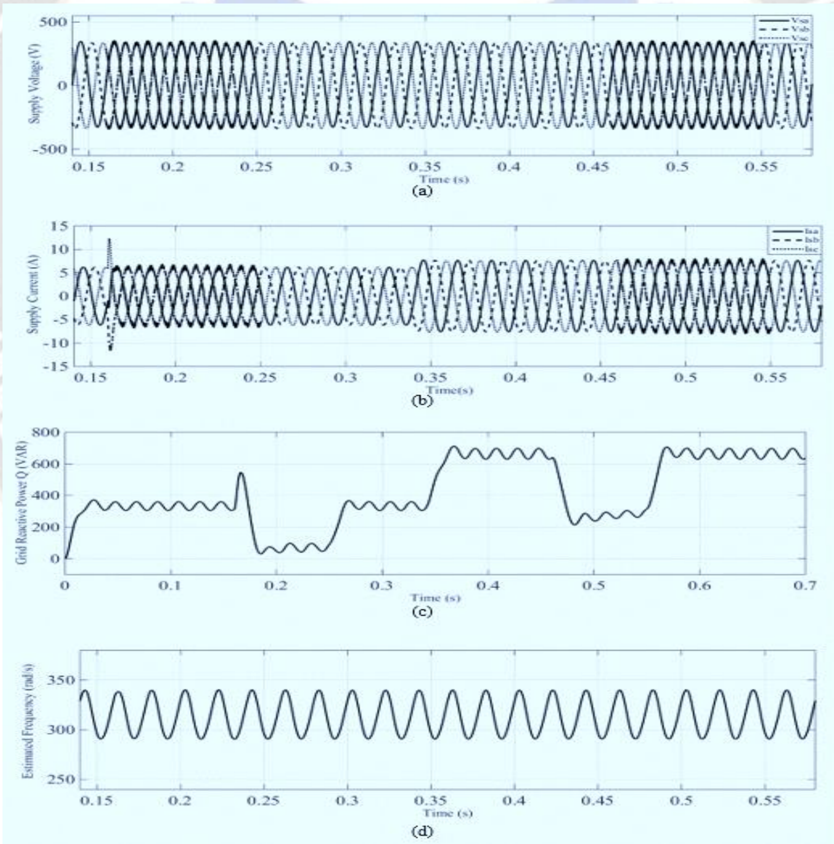

Figure 4. D-STATCOM results with DSOGI-FLL algorithm (with offset error in phase-a of supplymeasurement): (a) supply voltage (b) supply current (c) grid reactive power (d) estimated frequency

When the supply voltage is impacted by the measurement and data processing constraint, the results of the simulation of DSTATCOM reactive power compensation are represented by the number 4. The offset, which is equal to four percent of the RMS phase voltage, is placed into phase-a of the three-phase supply voltage so that this analysis may be carried out. There is a representation of the findings in Fig. (a) through (e)) using the traditional DSOGI-FLL technique for frequency estimation. The inappropriate reactive power correction in relation to the load demand is seen in Figure 4 (c). As a result of the oscillatory response of frequency calculated by the DSOGI-FLL method, which is unable to effectively estimate frequency in the event that there is an offset mistake in the grid signal, this phenomenon has occurred. At the end of the day, if the reference current extraction is not exact, then the offset error in the source current is passed on to the reactive power compensation.

V. Conclusion

Based on the analysis that was presented earlier, we are able to draw the conclusion that the performance of DSOGI-FLL and the suggested MDSOGI-FLL-based frequency estimation method in the DSTATCOM application is evaluated in ideal conditions as well as within the presence of offset error. In the absence of an offset error in supply voltage for DSTATCOM reactive power compensation, both of the frequency estimation algorithms are able to accurately estimate the frequency. On the other hand, when the grid voltage that is being sensed is characterized by the existence of a dc-offset, DSOGI-FLL is unable to accurately estimate the frequency, which results in the grid current having a dc offset and a larger total harmonic distortion (THD). Due to the fact that the MDSOGI-FLL provides an accurate estimation of the frequency, it is possible to create an approximate compensatory current.

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