Power Quality Enhancement in Wind Power Generation Integrated Distribution System using Fuzzy Logic Controlled CSC Based DVR

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Abstract: ***In this paper, a model of fuzzy logic controlled CSC based DVR system has been proposed with the objective of performing voltage regulation and harmonics reduction tasks simultaneously in a power distribution system. The distribution system is integrated with a standalone renewable energy source (RES) driven i.e. wind power generation system based on self excited induction generator (SEIG) supplying power to customers having a variety of loads. For power quality (PQ) enhancement in electric power distribution systems, the custom power devices (CPDs) designed with conventional controllers such as proportional- integral (PI), proportional-integral-derivative (PID) etc. are widely used. The objective of using CPD is to mitigate the PQ problems encountered in the power distribution system that includes short and long duration voltage variations, voltage imbalance, waveform distortions etc. Amongst the various types of CPDs, the dynamic voltage restorer (DVR) is considered to be one of the versatile CPD capable of solving multiple PQ problems. In most of the literatures, the DVR is found to be designed and implemented with voltage source converter (VSC) topology and not much research work has been reported on the application of current source converter (CSC) topology in DVR system over the last couple of decades. The proposed CSC based model has been simulated using MATLAB / Simulink for investigating its performance. The simulation results support the validity of the proposed model.***

Keywords: Custom power devices, power quality, wind power, DVR.

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1. Introduction

There has been ever-growing increase in search for sustainable power generation systems utilizing the renewable energy sources such as wind, solar photo-voltaic (PV), solar thermal power, hydropower, bio-energy, and ocean power etc. to supplement the conventional energy demand throughout the world. The fear of depletion of conventional fossil based energy sources viz. coal, oil, and natural gas etc. coupled with the pollution that leads to global warming has compelled many nations to adopt sustainable, clean and environment friendly methods for generating electricity. The RESs are abundantly available in nature and these are integrated in the form of distributed power generation systems (DPGS). In DPGS, the wind and solar power have been widely used due to its easier access and less physical location dependency. When the power generated using RES is integrated with the conventional power distribution system for performing energy exchange, the quality of power deteriorates due to the presence of harmonics emanating from the power electronic converters used. The demand of modern electric power customers for good quality power has been rapidly increasing since recent years and this scenario will continue to remain unchanged as most of the customers' existing as well as impending loads are very sensitive to voltage variations and waveform distortions. Voltage variation is highly unacceptable to those power customers operating their sensitive loads[1]. The integration of RES based power generation system plays a vital role in developing sustainable and resilient power distribution system especially with highly intermittent energy resources such as wind and solar. However, this approach shall face some challenges due to the stringent good quality power demanded by the power consumers. The extensive use nonlinear loads such as power electronics based devices and equipment in industries, offices, and homes are also responsible for polluting the power distribution system. The major PQ problems occur in the power distribution system include voltage magnitude variations such as voltage sag and swell, voltage flicker, waveform distortions (i.e. harmonics, noise, and spikes), transients, etc. In order to resolve these PQ problems, many types of VSC based CPDs have been proposed and developed in the recent years. These CPDs include distribution-static synchronous compensator (D-STATCOM), dynamic voltage restorer (DVR) and unified power quality conditioner (UPQC).The CPDs will provide overall benefits to the customers, manufacturers and power distribution utilities. As a result, there are further research scopes on the energy conversion systems, power electronic converter topologies and advanced control strategies for the successful integration RES based power generation systems to conventional power distribution utilities. The maintenance of the desired voltage profile i.e. voltage regulation in the power distribution feeder bus is quite essential for operating most of the electrical loads such as machines and other equipment properly. Failure to provide regulated voltage magnitude to such loads may cause damage due to overheating, more power losses and voltage collapse. If there is the decrease in voltage magnitude then, the current increases so as to maintain the required power supply. This leads the system to consume more reactive power and causes further decrease in the voltage magnitude. Thus, the profile of voltage magnitude is one of the parameters that decide the power quality. The load voltage waveform distortions caused by harmonics originating from the nonlinear loads connected to the power distribution system are also considered as one of the severe PQ problems. For mitigating this type of PQ problem, various types of filter circuits have been proposed and developed. These circuits include the passive filter, active filter and hybrid filter with shunt and series configurations. The active power filters (shunt, series, and hybrid) are considered to be the most effective and efficient option for solving the waveform distortion problems. The VSC topology has been widely used in the development of Active power filters reported on most of the literature. The concept of custom power (CP) technology at distribution system focuses mainly on the PQ and reliability. However, other PQ improvement tasks such as voltage regulation, voltage balancing, and harmonic mitigation etc. can also be performed by using this technology [1, 2,3,4].

In this work, an attempt has been made to develop a model of Fuzzy logic controlled CSC based DVR system with the objective of performing dual PQ enhancement tasks viz. voltage regulation and harmonics mitigation at a power distribution system integrated with a standalone wind power plant catering power to a variety of loads comprising of 3-phase induction motor, rectifier and resistive loads that resembles the environment of a modern power distribution system. The application of CSC topology will enable to extract its advantageous features and incorporate in the DVR for improving the overall performance. The CPDs are generally designed and implemented by using VSC topology instead of CSC because of the various reasons as discussed at [5, 6, 7].As the output voltage and current waveforms of the CSC topology are good sinusoidal, it will be a better choice for use in the DVR system where the voltage is to be injected in series and synchronism with the distribution feeder bus voltage through the coupling transformers [5].The reliability of the energy storage inductor or reactor used in the CSC is far better than that of the prechargedcapacitor employed in the VSC. The CSC based DVR will operate with greater reliability as the large series inductor can limit the rate of rising of current in the event of a fault. In other words, the CSC topology is more reliable and fault tolerant than a VSC [1, 6, 7]. In VSC topology, the AC side filter circuit is made of inductors which cause a voltage drop and phase shift in the voltages to be injected to the distribution feeder bus thereby complicating the control system of the DVR. However, this issue does not arise in the case of CSC based DVR because the AC side filter is made of capacitors only. Thus, implementation of the CSC based DVR with a robust control mechanism is expected to provide better responses in terms of offering good quality sinusoidal injection voltage, more fault tolerant capability, more reliable, efficient converter operation and simpler AC side filterThe proposed DVR system has been modelled and simulated in the MATLAB / Simulink environment and simulation results are also presented to support the validity and suitability of the model.

2. Basic configuration of the CSC based DVR

Amongst the various types of CPDs, DVR is one of the most widely suggested devices for power quality improvement task at distribution system. It is a series connected CPD which can protect sensitive loads from all supply side disturbances except outages [1]. PQ problems such as voltage sag, swell, voltage unbalances, voltage harmonics and power factor improvement etc. can be resolved with the help of this device [2]. The schematic diagram of a CSC based DVR system is shown in Figure 1.

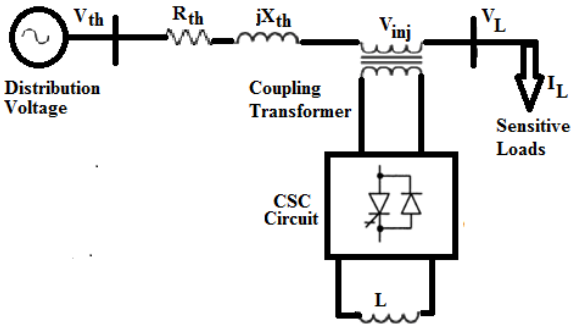

Figure 1: Basic configuration of the CSC based DVR

The ac output voltages of the DVR can be injected into the distribution system at the point of common coupling (PCC) in synchronism with the feeder voltages using the series coupling transformer. The dc link voltage of the DVR system can be supplied either from an external energy source or from an energy storage system. If there is a possibility of the requirement of exchanging active power with the distribution system, then, the dc link power of the DVR should be supplied from a stiff dc source [2]. However, the DVR system does not need passive elements such as capacitors or inductors to absorb or generate reactive power for exchanging with the distribution system [1].

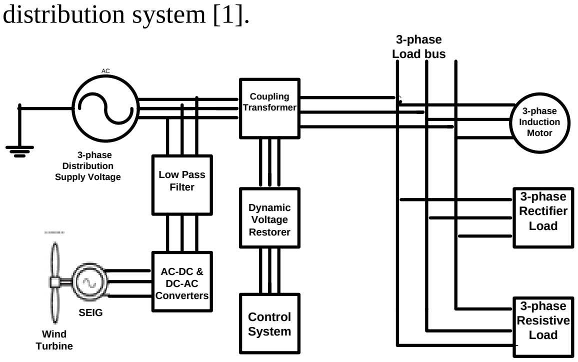

Figure 2: Structure of the proposed model

The main components of a DVR include converter circuit with its control system, coupling transformer, energy storage system and output side passive filter circuit. The structure of the proposed CSC based DVR connected in a wind power integrated distribution system feeding a variety of loads is shown in Figure 2. The dc energy storage element in the CSC based DVR is an inductor 'L' instead of a precharged capacitor. Since the converter topology is CSC, the switches should able to withstand high reverse voltage blocking capability [6, 7, and 9]. Therefore, GTOs are selected as switching device in the converter circuit of the proposed model. The gating signals the GTO switches are generated by using sinusoidal pulse width modulation (SPWM) techniques. A capacitor based passive filter circuit is incorporated on the output side of the CSC for restricting the flow of the higher order harmonic currents towards the coupling transformer and also to provide good sinusoidal voltage and current waveforms. The detailed strategies for designing such filter circuit are available at [6, 9].

2.1 Wind power generation system

As the speed of wind is generally variable in nature, a SEIG driven by wind turbine is chosen for the energy conversion system. The variable speed variable frequency (VSVF) method has the capability of performing efficient energy conversion. In this method, the need for costly blade pitch control mechanism in horizontal axis turbines can also be eliminated. In VSVF method, field excitation of the machine can be achieved by connecting a capacitor bank having fixed value across the stator terminals.
The power developed by the wind turbine can be computed from the relation:

$$P = \frac{1}{8}\rho\,\pi\,d^2\,C_p v^3 \qquad (1)$$

Where P = power, ρ = air density, d = diameter of turbine blade,C_p= power coefficient and v = wind speed [21].The output of the induction generator is variable AC voltage with variable frequency and hence it is converted into DC voltage using a 3-phase uncontrolled rectifier. The output of the rectifier is filtered by using an LC filter and then it is fed as input voltage to a 3-phase pulse width modulated (PWM) based inverter. The AC output voltage with fixed frequency of the inverter is filtered again using a low pass filter circuit and then fed to the distribution system bus.

2.2 Design strategy of the CSC based DVR

The aim of the proposed model to provide the regulated voltage to a variety of loads comprising of the 3-phase induction motor, rectifier and resistive loads with least harmonic content. Since the induction motor load draws heavy current at the time of starting, the voltage magnitude falls and then the motor continues to operate underlagging power factor thereby absorbing reactive power. Thus, the DVR system must generate and provide the required reactive power for maintaining the desired voltage magnitude on the feeder bus. On the other hand, the rectifier load generates current harmonics and feeds it to distribution bus causing unwanted voltage waveform distortion. The resistive load absorbs active power and causes a voltage drop. Therefore, the proposed model needs to be designed in such a way that it also acts as a series active power filter for eliminating problems of waveform distortion. The circuit on the left-hand side of the DVR shown in Figure 1 represents the Thevenin's equivalent circuit of the distribution system. The distribution system impedance, $Z_{th} = R_{th} + jX_{th}$ depends on the voltage characteristics the load bus. When the system voltage, V_{th} falls, the DVR injects a series voltage V_{inj} through the coupling transformer for maintaining the desired load voltage magnitude, V_L, The series injected voltage of the CSC based DVR can be expressed as:

$$V_{inj} = V_L + Z_{th} I_L - V_{th} \quad (2)$$

Where I_L is the load current and this can be obtained from the relation:

$$I_L = P_L + j\, Q_L V_L \quad (3)$$

Where P_L and Q_L represent the active and reactive power components of loads on the feeder bus. The complex power of the DVR can be expressed as:

$$S_{inj} = V_{inj} \times I_L \quad (4)$$

When the injected voltage V_{inj} is kept in quadrature with the load current, I_L no active power injection by the DVR is required to compensate the voltage [10]. The DVR system injects only reactive power as it is capable of generating the reactive power from itself. It must be noted that V_{inj} can be kept in quadrature with I_L only up to a certain value of voltage sag or fall and beyond which the quadrature relationship cannot be maintained to correct the under voltage variation. Under such situations, active power injection into the system is required and the injected active power can be obtained from the energy storage system of the DVR viz. lead acid batteries, flywheel, SMES or from an auxiliary ac-dc converter etc. When the injected voltage magnitude of the DVR is minimized, the desired voltage correction can be achieved with minimum reactive power injection into the system. This aspect of voltage correction is also very important because it minimizes the size of the coupling transformer [10]. Since the DVR is connected in series with the distribution system through a coupling transformer, it can also isolate the harmonics in between the nonlinear load and the source. This isolation can be done by injecting harmonic voltage through the coupling transformer. The injected voltages are added or subtracted to or from the source voltage for maintaining a pure sinusoidal voltage waveform across the nonlinear load. It is controlled in such a way that it offers zero impedance for the fundamental frequency component but appears as a resistor with high impedance for harmonic frequency components. Hence, no current harmonics can flow from nonlinear load to source and vice versa [11]. The time constant of the dc link reactor should be as small as possible for allowing rapid rise or fall of mean dc-link current [6, 9, and 12]. So, the value of dc link inductor must be selected carefully and as low as possible.

3. Control system of the proposed model

In this control system, two control loops namely current control loop and voltage control loop are used. The voltage control loop is responsible for regulating the DC link reactor voltage. The major components of the control system of the proposed model consists a Phase lock loop (PLL), Proportional Integral (PI) controller, the Fuzzy logic controller (FLC) and dq0 transformation block etc. The entire control system can be sub-divided into two sections as Conventional controller section and Fuzzy logic controller section and these are discussed hereunder.

3.1 Conventional PI controller section

In the conventional controller section, the process of sensing the voltage profile at the feeder bus of the power distribution system, calculating the required voltage magnitude for compensation and generation of the reference signals for the SPWM generator to provide switching pulses for the GTO switches used in the CSC are carried out. For generating proper gating signals of the GTO switches used in the CSC, SPWM control scheme is chosen for the proposed model. The SPWM switching strategy has constant switching frequency capability. This constant switching frequency reduces stress levels on the converter switches, offers simplicity and good response. [13]. Also, this approach provides more flexibility than that of the fundamental frequency switching method [6]. The control system only measures the RMS voltage at the point of common coupling (PCC) and no reactive power measurements are carried out. The control system representation for the proposed model is shown in Figure 3. The proposed control system is expected to maintain constant voltage magnitude sinusoidal ac voltage waveform at the PCC where a variety of loads are connected. The reference signal to be processed by the controller is the key component which ensures the correct operation of the DVR. The reference signal estimation is initiated through the detection of essential voltage or current signals for collecting accurate system variable information [11]. The reference source currents are usually generated by using the control schemes such as instantaneous reactive power theory (IRPT), synchronous reference frame theory (SRFT), unity power factor (UPF) based etc. in most of the CPD applications [6, 13]. The SRFT belongs to the time domain reference signal estimation technique and has the advantage of providing fast response to changes in the power system operation. The SRFT is also easy to implement and has minimum processing burden [14].

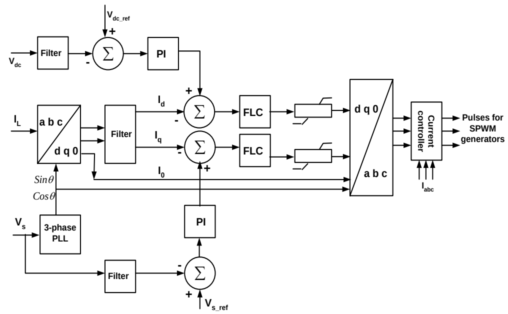

Figure 3: Control system representation of the proposed model

Thus, this control method has been adopted for use in the conventional controller section the proposed model. The SRFT is based on the Park's transformation for converting the 3-phase system voltage and current variables into a synchronous rotating frame. The active and reactive components of the three phase system are represented by the direct and quadrature components respectively and the fundamental components are transformed into dc quantities which can be separated by using LPF [11]. The value of load currents, I_L, source terminal voltage at PCC V_s and the dc link voltage, V_{dc} of the DVR are measured and these are used as input signals for the control system. Firstly, the I_L from the *abc*frame has been transformed into the *αβ0* frame and then it is converted into rotating *dq0* frame by using the Park's transformation relation as:

$$\begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \cos\theta & \cos\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \quad (5)$$

The PLL provides the cos θ and sin θ. To generate of fundamental unit vectors for converting the measured value of $I_L$into *dq0* reference frame, *Vs*is used as the required signal by the PLL. The SRF controller available in the Simulink toolbox of Matlab is used to extract the dc quantities and eliminates the harmonics contained in the reference signal by using a low pass filter LPF [6, 7]. For regulating the load voltage V_L at PCC, the error signal generated after comparing *Vs*throughanother LPFwith a reference terminal voltage V_{s_ref} is fed to a PI controller for reducing the steady state error. This consequently produces a quadrature current signal, I_q and it is added with i_q available in equation (5) that acts as an input signal for the dq0 current controller as shown in Figure 4. The DC error signal obtained after comparing V_{dc} with a reference DC voltage, $V_{dc_ref}$is also first filtered through an LPF and then processed by a PI controller for regulating the dc link reactor voltage and provides direct current signal I_d. This current is now added with the i_d generated in equation (5). Two separate FLC units are introduced to process the direct and quadrature current components so obtained for achieving better performance in terms of regulating the voltage profile as well as mitigating the presence of unwanted harmonics in the next stage of the control system.

3.2 Fuzzy logic controller section

When the process parameters are well known and there is not much variation, the conventional PI controllers are very effective and provide satisfactory performance once tuned properly. Further tuning of the PI controller may be required for good performance if operating conditions of the system to be controlled is a variable one. Since the dynamics of the power distribution system is fast and unpredictable in nature, there is the need for tuning the control parameters of the PI controller at different instants of time and events. So, in order to provide better performance of the proposed CSC based DVR, the fuzzy logic controller (FLC) has been introduced in the control system. The FLC will able to tune the PI control parameters for producing the desired results. The structure of the FLC can be visualized from the block diagram shown in Figure 4.

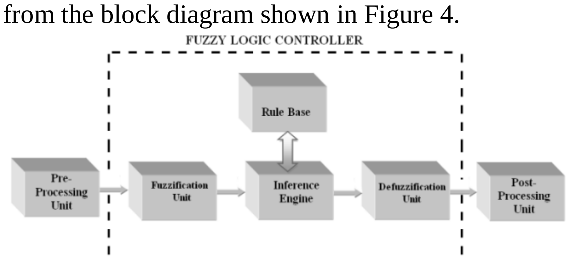

Figure 4: Simplified block diagram of an FLC

The four main components of an FLC are Fuzzification unit (the Fuzzifier), Inference engine, Rule base, and Defuzzifier. The first stage in the fuzzy controller system is to transform the numeric into fuzzy sets. This operation is called fuzzification. From the point of view of fuzzy set theory, the inference engine is the heart of the fuzzy system. It is the inference engine that performs all logical manipulations in a Fuzzy system. A fuzzy system Rule base consists of fuzzy IF–THEN rules and membership functions characterizing the fuzzy sets. The result of the Inference process is an output represented by a fuzzy set, but the output of the fuzzy system should be a numeric value. The transformation of a fuzzy set into a numeric value is called de-fuzzification [7]. In addition, input and output scaling factors are needed to modify the universe of discourse. Their role is to tune the fuzzy controller to obtain the desired dynamic properties of the process controller closed loop [16]. The proposed FLC has two inputs and one output. The inputs to the controller are errors of direct and quadrature components of current obtained in the stage of PI controller section and derivative of these errors. The inputs of the FLC have been chosen as the error in dc link voltage and the change in error in dc link voltage and these can be represented as:

$$e(i) = V_{dc\_ref} - V_{dc}(i) \tag{6}$$

$$de(i) = e(i) - e(i-1) \tag{7}$$

whereas e (i) is the error and de (i) is the change in error in the i[th]iteration. $V_{dc_ref}$is the reference dc link voltage of the reactor and $V_{dc}(i)$ is the dc link voltage in the i[th]iteration. The outputs of the FLC are chosen as the change in $K_p$value and the change in $K_i$value.

$$K_p = K_{p\_ref} + \Delta K_p \tag{8}$$

$$K_i = K_{i\_ref} + \Delta K_i \tag{9}$$

whereK_{p_ref} and K_{i_ref} are the reference values of proportional and integral gains respectively. ΔK_p and ΔK_i are changed in K_p and K_i [18].Five triangular membership functions are chosen the for input variables and the output variable namely NB, NS, Z, PS, and PB representing negative big, negative small, zero, and positive small and positive big respectively in the investigation. Two number of fuzzy inference system files named "dvrcsc3.fis" and "dvrcsc4.fis" have been developed for the upper and lower FLCs respectively.

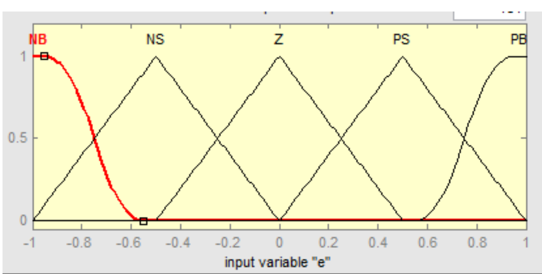

Figure 5(a): Membership function shapes for the error input variable

As shown in Figures 5 (a) and (b), the fuzzy subsets of the membership functions have been chosen as "Z" shaped membership function on the left, "triangular" shaped membership function at the middle and "S" shaped membership function curve on the right side for both the input variables 'e' (error input) and 'de' (change in error) by considering the coverage, sensitivity and robustness of universe [19].

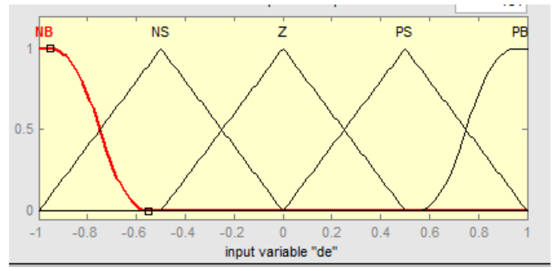

Figure 5(b): Membership function shapes for the change in error input variable

However, for the output variable 'u' only triangular membership functions are used as shown in Figure 5 (c).

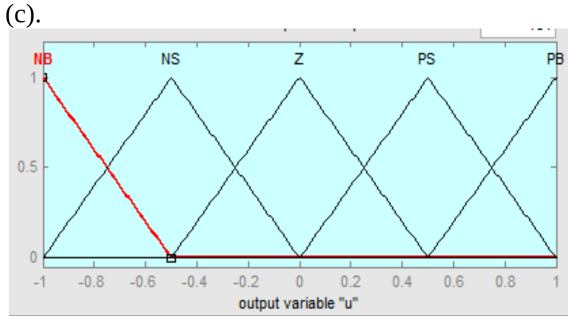

Figure 5 (c): Membership function shapes for the output variable

A set of 25 fuzzy control rules has been formulated and applied while modeling the FLC as depicted in Table 1

I.**TABLE 1:** FUZZY CONTROL RULES

e / de	NB	NS	Z	PS	PB
NB	NB	NB	NS	NS	Z
NS	NB	NB	NS	Z	Z
Z	NS	NS	Z	PS	PS
PS	Z	PS	PS	PB	PB
PB	Z	Z	PS	PB	PB

The FLC with Mamdani type which follows a min–max compositional rule of inference based on an interpretation of a control rule as a conjunction of the antecedent and consequent available in the Matlab/ Simulink platform has been used in the simulation work of the model.The output of the FLCs are fed to two individual integrators and then connected to a *dq0* to *abc* transformation block for producing the stationary frame of reference control signals required in the SPWM generators. An external integrator is used to eliminate the steady state error in the output of FLC [17].The reference source currents, $I^*(abc)$can be obtained from the inverse Park's transformation expression as shown in (5) and further details on this are available at [15].

$$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta & 1 \\ \sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta - \frac{2\pi}{3}\right) & 1 \\ \sin\left(\theta + \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} i_d \\ i_q \\ i_0 \end{bmatrix} \quad (10)$$

The reference source currents obtained from equation (10) is further processed in the SPWM generators for ensuring to provide the desired gate drive signals for the GTO switches used in the CSC circuit of the proposed DVR.

4. Simulation results and discussions

A Simulink model of the proposed CSC based DVR as shown in Figure 6 has been developed for observing the performance of the model. The various parameter settings and constraints of the model are presented in Table 2.

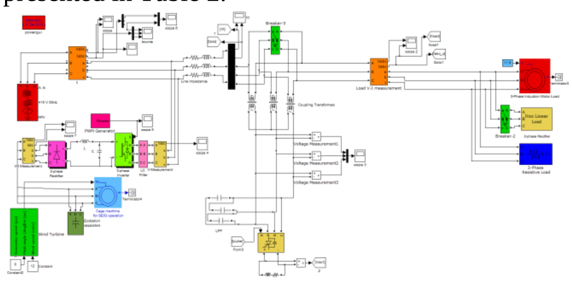

Figure 6: Simulink model of the DVR system

For analysing the impact of the DVR operation on the performance of a modern power distribution system catering power to a variety of loads, four different types of loads comprising of the 3-phase induction motor, 3-phase full wave bridge rectifier, and resistive loads are connected to the distribution system load bus.

II. **Table 2:** Parameter settings of the model

Sl. No.	Name of parameters	Setting values
1	Feeder ratings	415 V (RMS), f = 50 Hz
2	Feeder impedance	R_f= 0.01Ω, L_f= 2mH
3	Feeder system reference	$V_{t\,(Ref.)}$= 400 V(RMS), 50Hz
4	Coupling transformer	5kVA, 50 Hz
5	AC side LPF of CSC	C=2.85mF
6	DC reference voltage	$V_{dc(Ref.)}$ = 800 V
7	DC link reactor of CSC circuit	L_{dc} = 10μH, R_{dc}= 0.01 Ω
8	DC link PI controller gains	$K_{P(dc)}$ = 0.03 $K_{i(dc)}$ = 0.04
9	AC side PI controller gains	$K_{P(q)}$ = 0.8 $K_{i(q)}$ = 0.02
10	Switching frequency	f_s = 20 kHz
11	3-phase induction motor load rating	5.4 HP, 400V, 50Hz, 1430 RPM
12	Nonlinear load	3-phase rectifier with 22.24% THD
13	Resistive load	1 kW
14	Induction generator (SEIG)	P_n= 7.5 VA, $V_{(L-L)}$ = 415 V, f = 50 Hz, Rs = 0.029 Ω, Rr= 0.022 Ω, Lls= 0.67 mH, Llr= 67m H, J = 0.1375 kgm^2, F = 0 Nm, p = 2
15	Wind turbine& speed	P_n= 1.5e 6, β = 0°, λ = 7.4, Cp= 0.73, P_{base} = 2e 6 VA, $(Ws)_{base}$ = 12 m/s

The circuit breaker-1 in the model has been used to connect or disconnect the DVR system with the distribution feeder bus. The results of the simulation run are presented hereunder.

4.1 Simulation results without DVR operation

For observing the impacts of the multiple loads on voltage profile of the distribution feeder bus, the model has been simulated by closing the circuit breaker-1 so as to isolate the DVR from acting on the distribution system. The voltage and current waveforms monitored at the load bus are shown in Figure 7.

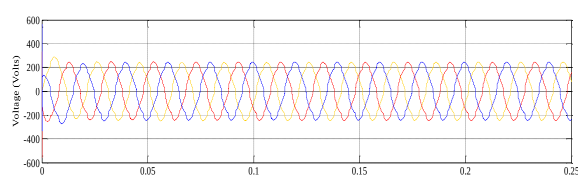

Figure 7(a): Voltage waveform without DVR operation

The voltage waveform in Figure 7 (a) is found to be distorted with lots of harmonics and the voltage magnitude also falls below the desired value of 415 V(RMS) or 586 V (pp).

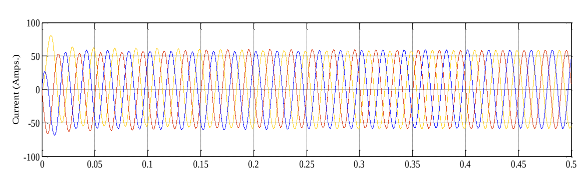

Figure 7(b): Current waveform without DVR Operation

The current waveform at Figure 7 (b) is also observed as unbalanced. The total harmonic distortion (THD) under this condition has been investigated by using the Fast Fourier Transform (FFT) analysis facility available in the Simulink's power graphic user interface (GUI) system. The harmonic spectrum as observed during FFT analysis for the load bus voltage is illustrated in Figure 8. The THD value computed for 3 cycles under this condition is found to be 6.27 %.

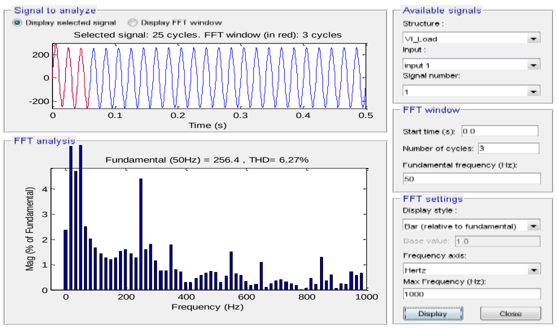

Figure 8: Harmonics spectrum without DVR operation

4.2 Simulation results with DVR operation

The performance of the model has been investigated by opening the circuit breaker-1. Under this arrangement, the DVR is brought into action for regulating the load bus voltage and also to mitigate the harmonics present in the voltage waveform. The Voltage and current waveforms with the operation of the DVR monitored at the load bus are shown in Figure 9 (a) and (b) respectively.

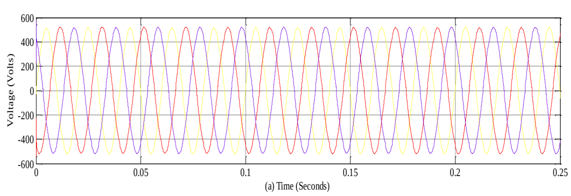

Figure 9(a): Voltage waveform with DVR operation

From the voltage waveform shown in Figure 9 (a), it is observed that the DVR has successfully regulated the load voltage to 415 V (RMS) or 586 V (pp) which is needed for proper operation of the variety of loads connected to the AC power distribution system.

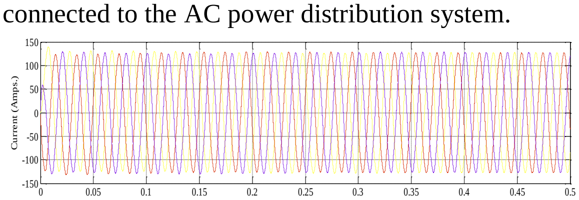

Figure 9(b): Current waveforms with DVR operation

With the operation of the DVR, the load current waveform is also found to be in balanced condition as depicted in Figure 9 (b).Figure 10 shows the THD value of the load voltage obtained from the FFT analysis for three cycles. Under this condition, it is obtained as 1.23 %. This THD value is found to be well within the prescribed limit of 3% for (special applications such as hospitals and airports), 5% (general systems) and 10% (dedicated systems viz. exclusively for converter loads) as per the IEEE Standard 519-1992 [20] available at Table 10.2.

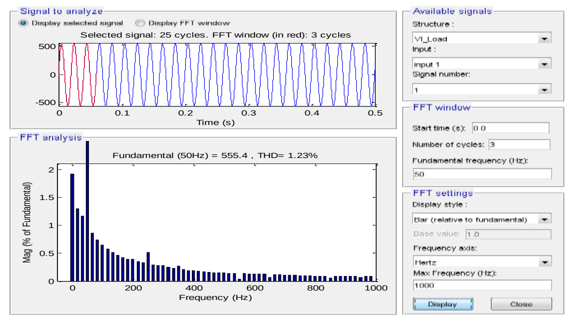

Figure 10: Harmonics spectrum with DVR operation

Thus, from the above simulation studies, it is observed that the proposed model has the capability of performing the dual tasks of PQ enhancement in terms of voltage regulation as well as harmonics mitigation at power distribution utilityintegrated with a standalone RES based wind power generation system simultaneously and effectively.

5. Conclusion

This paper has made an attempt to explore the possibility of using CSC topology in the CPD application by way of developing a model of CSC based Fuzzy logic controlled DVR system interfaced to a power distribution utility which is integrated with a standalone wind power generation system. The advantageous features of CSC topology, design considerations, and steps required to be followed while implementing the model etc. are also discussed. The simulation run results reveal that the CSC based DVR whose PI controller is tuned with FLC can provide effective voltage regulation as well as harmonic mitigation on the load bus under the dynamic behaviour of a variety of loads connected to the distribution system. Therefore, CSC based DVR can be considered as one of the viable solutions for PQ enhancement tasks where there is possibility of exchanging energy between the conventional power distribution system and RES based power generation system. This work will also encourage the researchers to explore the feasibility of using CSC topology in other types of CPD implementation endeavors.

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