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Modeling of the three-phase converter using a predictive controller based on the dynamic voltage restorer model for improving power quality

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ABSTRACT

Sensitive loads in the distribution system can be easily influenced by issues with power quality. Improving power quality in the distributed system is a major concern. Sag/swell, harmonics, flicker, distortions, etc are delivery consistency concerns on the distribution side. One of the major power quality issues is taken into account by this paper voltage sag/swell. Flexible AC transmission systems (FACTS) with MPCbased voltage source inverter orcurrent source inverter are considered for voltage issues. The model is used in every switching state of the converter to simulate the behavior of device variables. The predictions are measured using a cost function that weighs the degree of precision of control goals. The most successful switching condition is then produced for CSI and VSI. Dynamic Voltage Restore (DVR) and Unified Power Quality Conditioner are the FACTS systems which are used on the distribution side (UPQC). The voltage drop in the system is detected by both devices and restored by injecting the appropriate voltage into the system. Injected Voltage Part Blocks of the Voltage Source Inverter (VSI) or Current Source Inverter (CSI) DVR can be used (CSI). The predictive current control method for DVR with Current Source Inverters(CSI) after duality with Voltage Source Inverters is compared to THDs for voltage deflection/wave amplitude in this paper (VSI). In a MATLAB setting, the simulation is performed.

1. Introduction

1.1. Dynamic voltage Restorer (DVR)

Loads such as nonlinear and domestic loads are very liable to voltage distortions. It can stop at the last equipment for one hundredth of a voltage subsidence, resulting in a complete restart operation. In response, the protection of the quality of electricity in the distribution network is an important situation. Power quality is a broad term that includes various types of disturbances of voltage and current, such as sag/swell voltage, flicker, imbalance of voltage, harmonic current and low power factor, etc. Voltage-based disruptions seriously interrupt various types of loads due to these power quality problems, and voltage sag is the most common problem with the quality of power related to voltage [1,2].

A harmonic is a voltage or current produced by the operation of nonlinear loads, such as rectifiers, discharge lights or saturated magnetic devices, at multiple frequencies of the basic system in a power supply system. A common cause of problems with energy quality is harmonic frequencies within the power grid. Harmonics in electrical systems cause equipment and conductors to increase heating, and speed drives to misfire. One of the abovementioned devices, the Dynamic Voltage Restorer (DVR), is used to protect charges for voltagerelated power quality issues, such as wireless communication networks, advanced medical devices, financial transaction systems, lifts, etc. [3].Before loading, the DVR is connected in series to the grid terminal and injects the amount of compensation voltage necessary to maintain the charge voltage within the specified value [21,26]. For pulse generation by the MPC inverter controller [9], a DVR usually consists of either a Voltage Source

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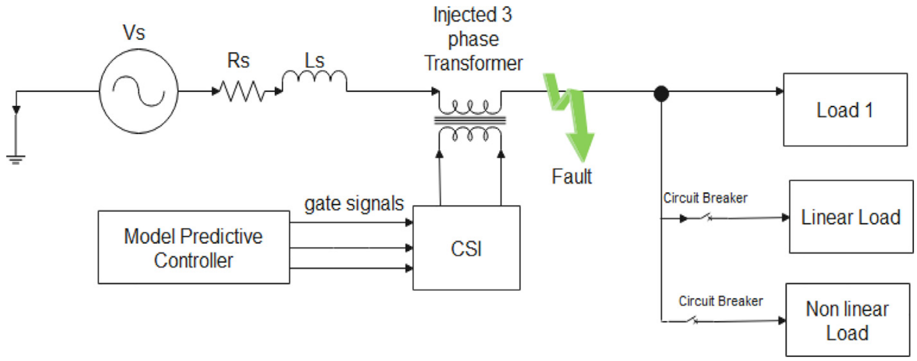

Fig. 1. Schematic layout of Dynamic Voltage Restorer.

Inverter (VSI) or a Current Source Inverter (CSI).The Schematic Configuration of the Dynamic Voltage Restorer is shown in Fig. 1.

2. Configuration

2.1. Current source and voltage source converter model

CSI is the type of inverter that is powered from a high impedance current source. A current or series inductor with a DC source [4] may be the source on the AC side of the inverter. In VSI, because the input voltage is fixed, the input current in CSI [17,20] is constant but adjustable. The outlet current's amplitude is not connected to the load. Depending on the type of load, the waveform and output voltage amplitude. The threephase CSC has S1 to S6 representing the switches(IGBT) and the diode series attached to the switches to block the current reversal is D1 to D6 [10]. Its outstanding current control capability, easy short circuit protection, and ripplefree output current are the advantages of CSI, even though it is more costly than VSI.

To change the supply into a direct and alternating current, the Voltage Source Inverter (VSI) is used.VSIconnectedto MPC that provides signals to the switches. For normal operation, the power is drawn from theDC input power supply (Vdc) and is modulated at AC power on the output phases (Vas,Vbs and Vcs) [21]. The internal VSI consists of several components. (Fig. 2) A DC link capacitor is connected through the DC input to supply a constant voltage source. See Fig 3 schematic representation.

3. Model predictive control

MPC is an important process control model used to control a process in response to a number of constraints. Dynamic process models typically linear analytical models obtained by defining the system, are based on model predictive controllers. Model Predictive Control utilizes a separate time model to predict load cur-

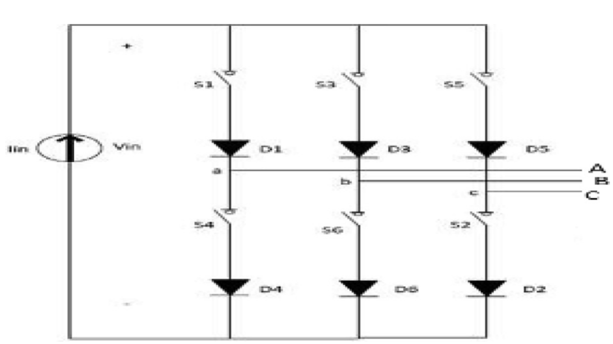

Fig. 2. Schematic diagram of CSI.

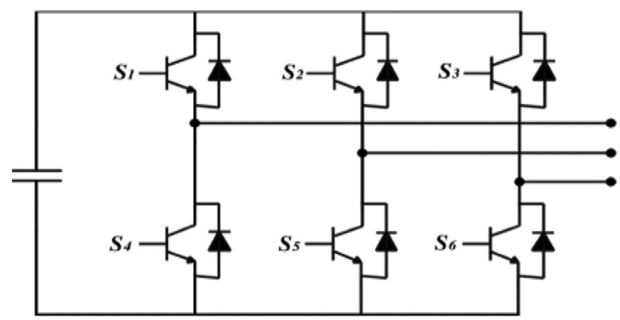

Fig. 3. Schematic diagram of VSI.

rent at a projected sampling time. To estimate predictions and choose the optimal voltage vector to apply, a cost function is used. The synchronous frame of dq with Euler discretization, the following current model is used.

$$i_d[k+1] = i_d[k]\left(1 - \frac{RT_s}{L}\right) + \frac{T_s}{L}\left(v_d[k] + \omega^* L i_q[k]\right)$$

$$i_q[k+1] = i_q[k]\left(1 - \frac{RT_s}{L}\right) + \frac{T_s}{L}\left(v_q[k] + \omega^* L i_d[k]\right)$$

Where the current predictive regulation of d and q frame is id [k + 1] and iq [k + 1] at [k + 1]th, the real currents at kth instant are $i_d[k]$ and $i_q[k]$, R is the resistance and L is the nominal value inductance, $\omega^*$is an angular frequency and Ts is the reference current sampling time.

Fig. 4 shows the MPC block diagram. In general, the load voltages still use the maximum power of the inverter, [13,16]. The cost function selected for regulating the dq components of the charge current in this function is as follows. Where the latest forecasts id[k + 2] and iq[k + 2] are obtained by iterating (1) and (2), the sources provide more information on the implementation of MPCs [6,7].

$$g = \left|i_d^*[k+2] - i_d[k+2]\right| + \left|i_q^*[k+2] - i_q[k+2]\right|$$

3.1. Harmonic distortion

3.1.1. Current ,Voltage harmonics and total harmonic distortion

The current is variable at a fixed frequency, normally 50 or 60 Hz, in a typical AC system.When the unit is coupled to a linear electrical load, At the same frequency as the voltage, a sinusoidal wave is drawn (usually not in phase with the voltage). In power systems, harmonics is defined as a number of positive integers of the fundamental frequency.

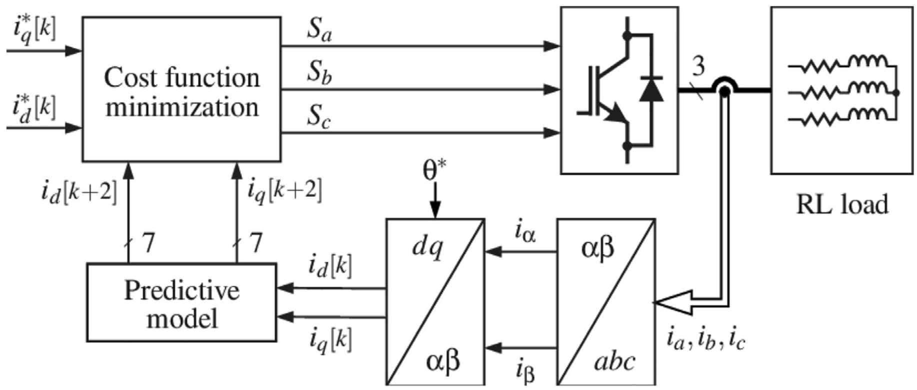

Fig.4. Block diagram of the MPC in the rotating dq frame.

The voltage source impedance is low, only small voltage harmonics can be produced by current harmonics. It is generally true that, compared to the current harmonics, the voltage harmonics are small. An efficient way to look at this is to draw the voltage wave at the basic frequency and try to enforce a phase shift free harmonic current. This means that the actual average power supplied by the present harmonics is zero.

A common measure of the amount of harmonic distortion present in power systems is the THD that can be associated with current or voltage harmonics and is defined as the ratio of total harmonics to specific frequency time values of 100 percent.

4. Simulation

The Distributing system with different loads has power quality issues. Below simulation Fig. 5. shows the distribution system with three different cases.

The DVR output compensates (Figs. 6 and 7) for the voltage deflection in the grid with parameters in Table. 1, Comparing the voltage distortion and current distortion of without DVR in distribution network and with DVR considering VSI and CSI, MPC controller used to generate signals to the converters. improvement, As compensation voltage $V_{dvr,abc}$ is injected in the network. When the source voltage $V_{s,abc}$ can be set at a value of about 600 V during the voltage sag slot for all conditions, indicated in the bottom Fig. 13. Results of the simulation of the proposed method set the voltage of the voltage sag on the sourceside. In order to determine the performance of the DVR in improving voltage quality, the voltage and current distortions are calculated throughout the proposed control scheme. IEEE519 notes that the THD voltage must not exceed 5%.

5. Results

DVR performance in voltage sag compensation from three phase networks. THD of proposed network is reduced to 0.74% comparing with MPC based VSI in DVR injected voltage having THD of 3.89%.

5.1. Voltageand CurrentWaveform

The simulation gives linear, nonlinear load voltage waveforms and Fig. 8 shows symmetrical defects. The source voltage $V_{s,abc}$ has a sudden sag for the linear loads from the nominal value 580 V to 198 V, Source voltage $V_{s,abc}$ has a sudden sag of nominal value 580 V at less than 100 V for nonlinear load and Source voltage $V_{s,\ abc}$has a sudden drop in nominal value 580 V to 0v for symmetrical faults. Therefore the load voltage $V_{L,abc}$ can be held in the voltage sag slot at the nominal value of 600 V in all situations.

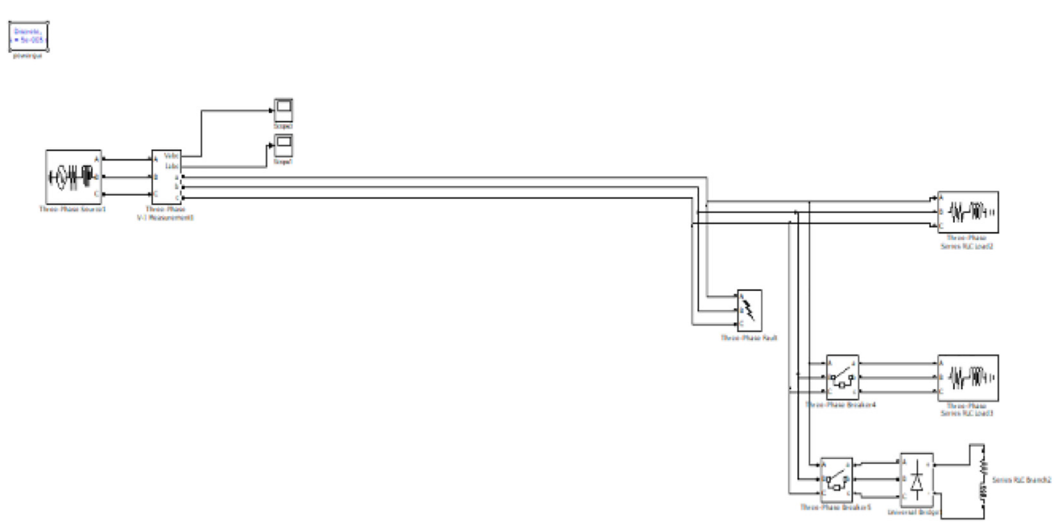

Fig. 5. Simulation without DVR.

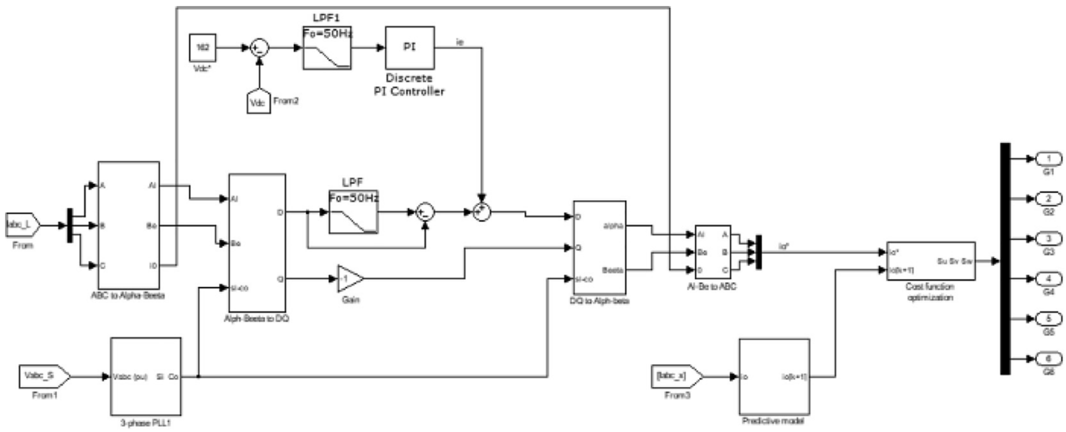

Fig.6. MPC Controlling circuit of DVR.

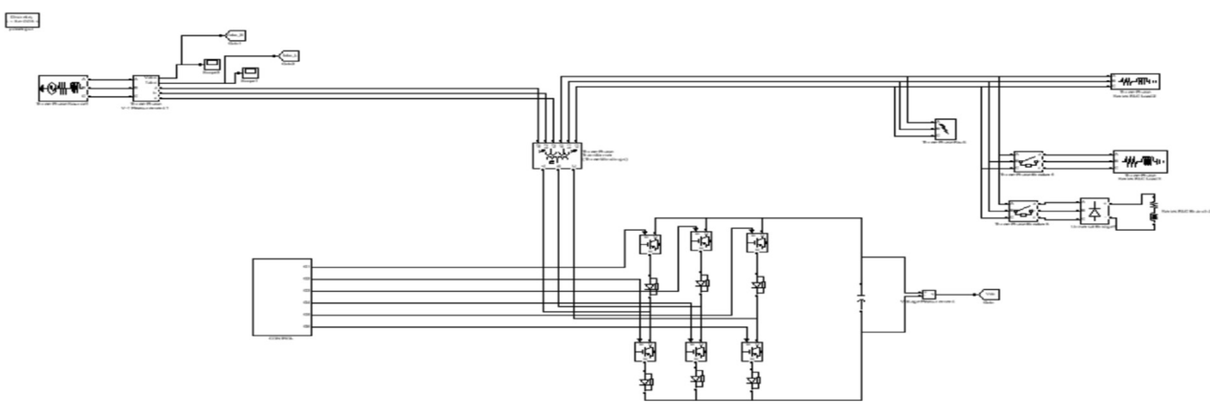

Fig.7. DVR simulation using MPC based CSI in Matlab/Simulink.

Table 1
DVR System Parameters.

Supply voltage (Vs)	440 V
Load Voltage(Vl)	440 V
Load Resistance (Rl)	1 Ω
Load inductance (Ll)	1mH
Transformer resistance (Rt)	500 Ω
Transformer inductance (Lt)	500H

Fig. 9 shows source current $I_{s,abc}$ has an instantaneous wave of the nominal value 18A to 55A for the linear load , the current $I_{s,abc}$ has a sudden swell of the nominal value (Figs. 10-12) 18A above 60A for the nonlinear load, and the source current $I_{s,abc}$ has a sudden swell of the nominal value 18A to 65A for symmetrical defects. Similarly, with the $V_{dvr,abc}$ injection voltage produced by the DVR, the source current $I_{s,abc}$ is regulated from the time stated in Table 2 as shown in Fig. 14 to the value 8A during the described current swell (Figs. 15-17).

5.2 Harmonic distortion voltage and current

5.2.1. FFT analysis (Linear load)

As shown in the figures, the source voltage $V_{s,abc}$ and source current $I_{s,abc}$ comprise the harmonic components for linear loads Fig. 8. and Fig. 9. shows the THD of $V_{s,abc}$is 5.45% and $I_{s,abc}$ is 4.20%.

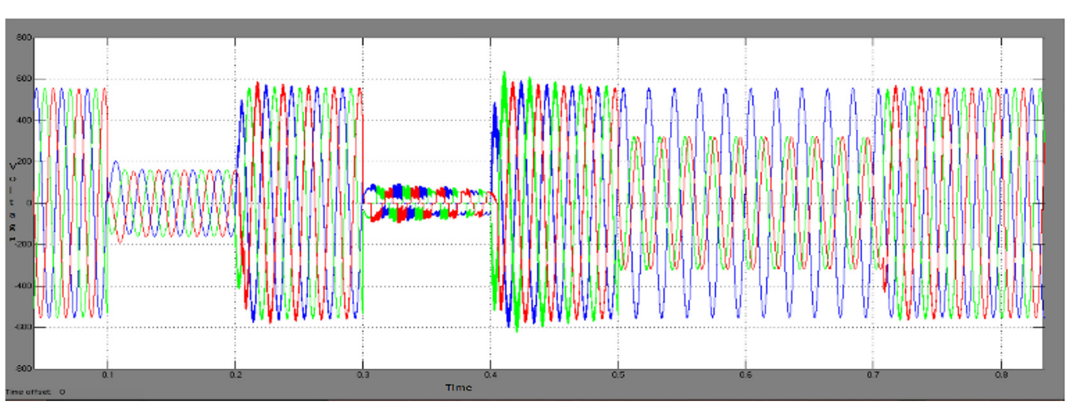

Fig. 8. Source Voltage without DVR.

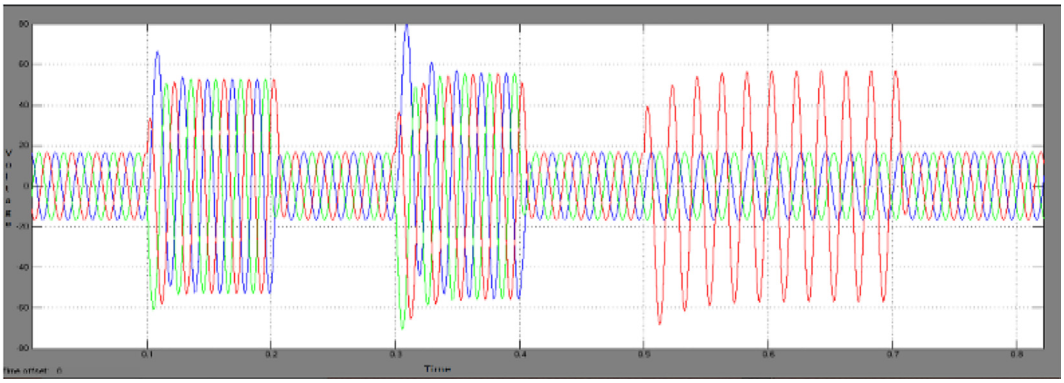

Fig. 9. Source Current without DVR.

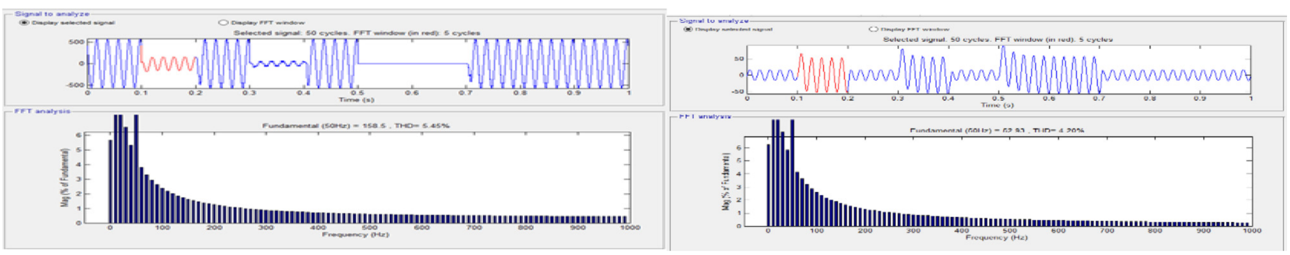

Fig. 10. FFT analysis of Linear load, (a)voltage and (b) current without DVR.

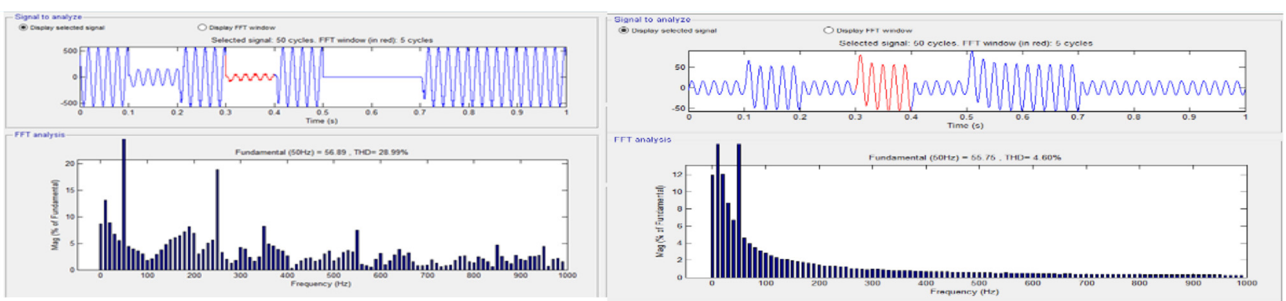

Fig. 11. FFT analysis of Non Linear load, (a)voltage and (b) current without DVR.

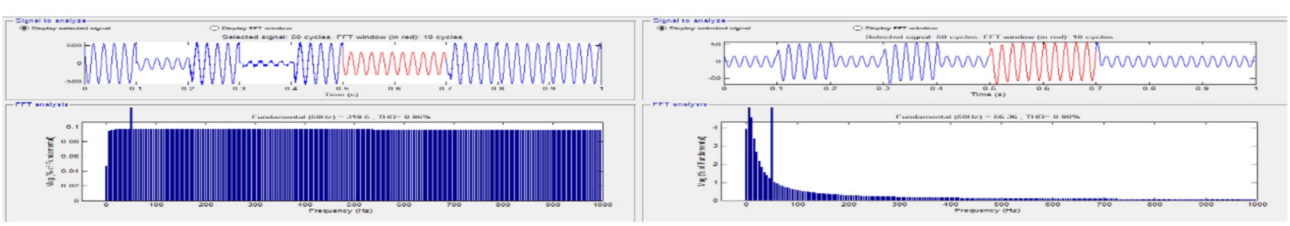

Fig. 12. FFT analysis of symmetrical fault, (a)voltage and (b) current without DVR.

Table 2
Time Period Conditions.

S.No	Type of loads	Time period
1	Linear Loads	0.1 – 0.2
2	Non Linear Loads	0.3 – 0.4
3	Fault created	0.5 – 0.7

5.2.2. FFT analysis (Non linear load)

The source voltage $V_{s,abc}$ and source current $I_{s,abc}$ has the harmonics for nonlinear loads, as shown in the Fig. 8. and Fig. 9. It

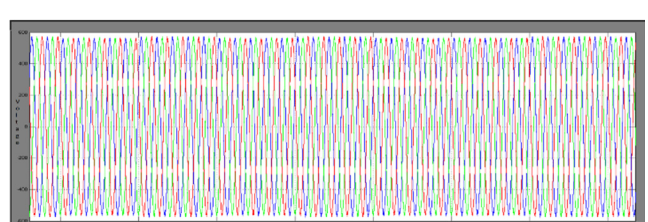

Fig. 13. Voltage with MPC injected DVR.

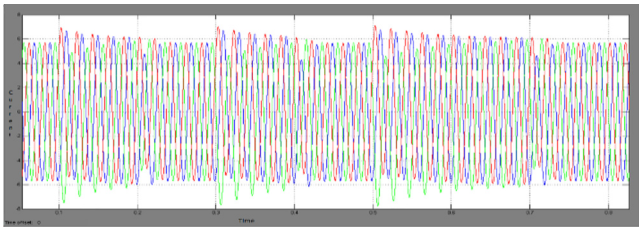

Fig. 14. Current with MPC injected DVR.

shows that the average harmonic distortion of $V_{s,\ abc}$ is 28.99% and 4.60% of $I_{s,\ abc}$.

5.2.3. FFT analysis(Symmetrical Fault)

Source voltage $V_{s,abc}$ and source current $I_{s,abc}$ have harmonic components from t = 0.5 s to t = 0.7 s for symmetric fault, as shown in Fig. 8. and Fig. 9. Total Harmonic Distortion of $V_{s,abc}$ is 0.96 and $I_{s,abc}$ is 0.90 percent.

5.3. Voltage waveform and current waveform

The results of three-phase converter simulation (VSI or CSI) based on MPC with DVR for power quality improvement, As compensation voltage $V_{dvr,abc}$is injected in the network. When the source voltage $V_{s,abc}$can be set at a value of about 600 V during the voltage sag slot for all conditions, indicated in the bottom Fig. 13. The simulation results in wave form of current $I_{s,abc}$is maintained at a value 6A throughout the current wave slot of the periods mentioned in Table 2. Let us consider that the proposed converters controls the DVR to compensate for Complete Harmonic Distortion of the source voltage and current waveforms with the MPC dependent controller.

Let us first consider the MPC-based controller voltage source inverter.

5.3.1. FFT analysis (Linear load)

The results of the linear load simulation show that the MPC based voltage source converter with DVR controls the harmonic distortion of the source voltage up to 3.67% and source current up to 2.24%.

5.3.2. FFT Analysis (non linear load)

The results of the non linear load simulation show that the MPC-based voltage source converter with DVR controls the harmonic distortion of the source voltage up to 3.72% and source current up to 2.25%.

5.3.3. FFT analysis (Symmetrical fault)

The results of the symmetrical fault simulation show that the MPC-based voltage source converter with DVRcontrols the harmonic distortion of the source voltage up to 3.89% and source current up to 1.70%.

Compared the FFT analysis of VSI with MPC based controller injected DVR to the FFT analysis of current source inverter with MPC based controller injected DVR , the total harmonic distortion is mitigated with CSC.

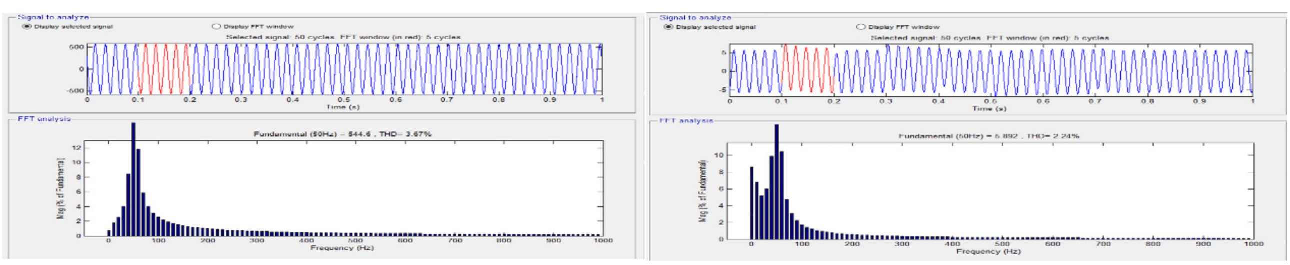

Fig. 15. FFT analysis of Linear load, (a)voltage and (b) current with MPC based VSC injected DVR.

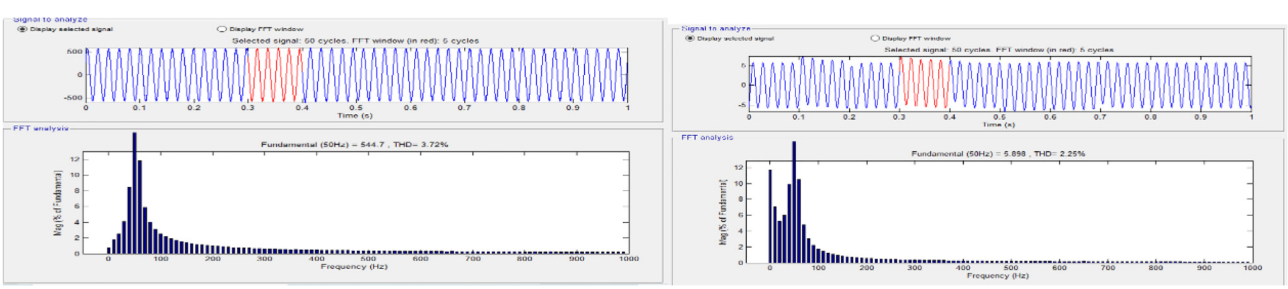

Fig. 16. FFT analysis of Non Linear load, (a)voltage and (b) current with MPC based VSC injected DVR.

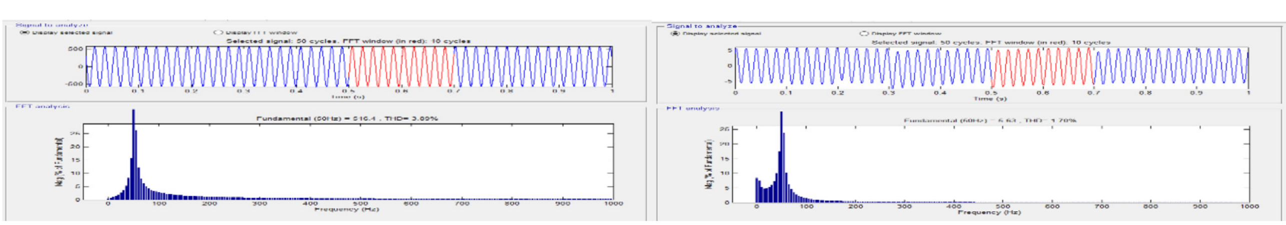

Fig. 17. FFT analysis of Symmetrical fault (a)voltage and (b) current with MPC based VSC injected DVR.

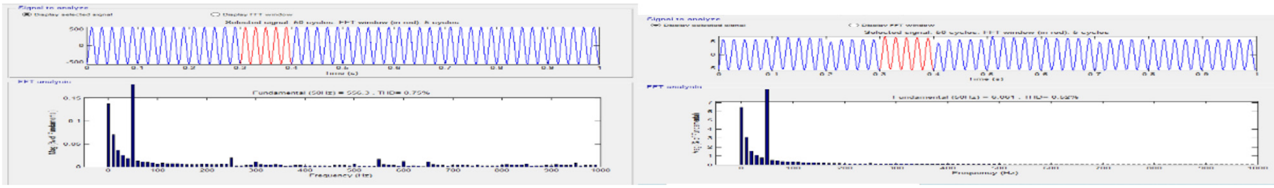

Fig. 19. FFT analysis of Non Linear load, (a)voltage and (b) current with MPC based CSC injected DVR.

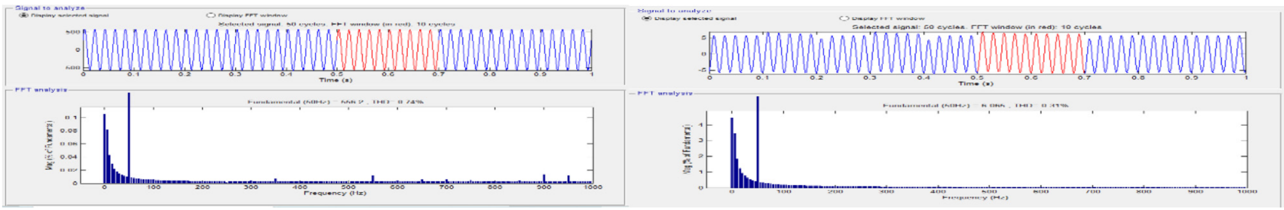

Fig. 20. FFT analysis of symmetrical Fault, (a)voltage and (b) current with MPC based CSC injected DVR.

Table 3
THD's without DVR.

		Linear load	Non linear load	Symmetrical fault
THD %	Voltage	5.45	28.99	0.96
	Current	4.20	4.60	0.9

Table 4
THD's with DVR.

		Linear load	Non linear load	Symmetrical fault
VSC THD%	Voltage	3.67	3.72	3.89
	Current	2.24	2.25	1.70
CSC THD%	Voltage	0.75	0.75	0.74
	Current	0.56	0.52	0.31

5.3.4. FFT analysis (Linear load)

The overall harmonic distortion of $V_{s,\ abc}$ is 3.67 percent and Is, abc is 2.24 percent in the source voltage $V_{s,abc}$ and source current $I_{s,\ abc}$ shown in the Fig. 18.

The results of the linear load simulation show that the proposed DVRCSC system based on MPC has the able to check and regulate the harmonic distortion of up to 0.75 percent of the source voltage and up to 0.56 percent of the source current.

5.3.5. FFT analysis (Non linear load)

The total harmonic distortion of $V_{s,\ abc}$ is 3.72 percent and $I_{S,\ abc}$ is 2.25 percent.The DVR with MPC-based current source converter regulates to compensate for the specified harmonic distortions shown in the Fig. 19.Regulate the harmonic distortion of the source voltage up to 0.75 percent and the source current up to 0.52 percent (Fig. 20).

5.3.6. FFT analysis (Symmetrical fault)

The gross harmonic distortion of $V_{s,\ abc}$ is 3.89 percent and $I_{S,\ abc}$ is 1.70 percent.The results of the simulation of the symmetrical fault show that the proposed DVRCSC system based on MPC has the able to check and control the harmonic distortion of the source voltage up to 0.74 percent and the source current up to 0.31 percent.

The above simulation results of Total Harmonic Distortions has tabulated below for three conditions, the voltage and current values for with out DVR and also the voltage and current values for with DVR in transmission line for two different converter with

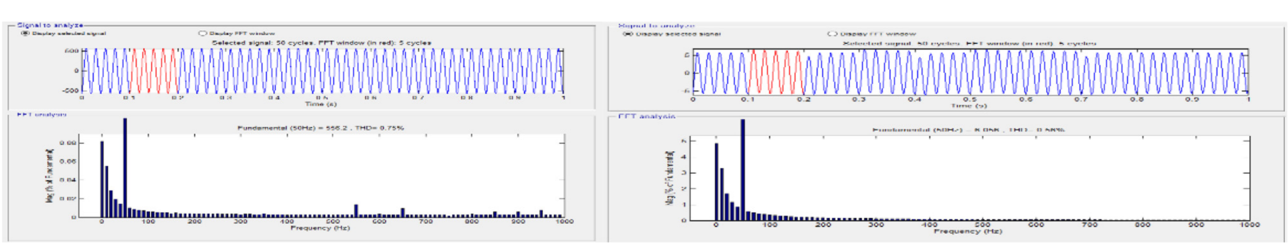

Fig. 18. FFT analysis of Linear load, (a)voltage and (b) current with MPC based CSC injected DVR.

MPC based controller.From the above Tables 3 and 4 it is clear that the THD % is less in the proposed method i.e, the performance of DVR with CSC based Model Predictive Controller.

6. Conclusion

The DVR with MPC-based current source inverter controls to compensate for the specified harmonic distortions.The purpose of a DVR is to minimize voltage and current distortions at the source end that occur in the network. An MPC with DVR CSC is considered to provide energy to the DVR to reduce voltage and current distortions.In this paper, by comparing THD produced from MPCbased DVRinjected VSI for each case, THD voltage swell drops are produced for three distinct cases.The performance of the DVR in mitigatingvoltageandcurrentdistortionsisexamined.In each case the results obtained suggest that the DVR mitigates the THDs independently of the voltage magnitude and current distortions. This reduces the voltage under all three conditions. The total harmonic distortions, which are seen in these cases as well as the voltage sag are summed up.Therefore, it can be concluded that the DVR and CSC based on MPCs are capable of mitigating THD under all proposed conditions. The proposed methodology for three simulation studies was conducted, includingvoltageandcurrentwaveformsanditsharmonicdistortion.To compensate for voltage and harmonic current distortion, the results of the threephase inverter simulation using the MPCbased method can control the DVR.

CRediT authorship contribution statement

D. Sangeeta Sarali: Conceptualization, Methodology, Software, Visualization, Writing - original draft. **V. Agnes Idhaya Selvi:** Data curation, Supervision, Validation. **Karuppasamy Pandiyan:** Writing – reviewing & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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