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Research Article

Distribution System Power Quality Improvement Using D-STATCOM

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Abstract

Power quality can be explained as the set of limits defined for a system's electrical parameters so that the whole electrical system can function in its intended manner & performs without significant losses. Power quality constraints like power factor correction, voltage regulation, load balancing, and harmonic elimination can be maintained and fixed using Distribution Static Compensator (DSTATCOM). In the presented work, author has presented a detailed comparative study of three different effective control strategies for DSTATCOM to target reactive rower compensation and Total Harmonic Distortion (THD). The results are demonstrated in details using simulation performed in MATLAB-SIMULINK software which shows the good capability of these different control algorithms to provide good power quality for electrical system.

Keywords: Power quality improvement, DSTATCOM, power factor correction, reactive power compensation, Total Harmonic Distortion(THD), IRPT, SRFT, Unit templates, MATLAB-SIMULINK

Introduction

In power system, distribution system distributes electrical power for local use i.e., for end consumers. The detailed study will give us bus voltage, branch current and real power flow, reactive power flow for a specific generation & load condition in order to solve lots of issues such as planning and forecasting, design, operation and control of electrical power. Power quality can be explained as the set of limits defined for a system's electrical parameters so that the whole electrical system can function in its intended manner & performs without significant losses. There are numerous power quality problems we face on daily basis like voltage sag, voltage swell, transients, unbalanced load, harmonics, poor power factor etc that are required to be dealt with to improve power quality of the system. The voltage level is challenged whenever there is an increase in the load demand, as it increases the burden on line. In distribution system as we move away from the source the voltage level decreases because of occurrence of high losses.[1] Losses occur in lines due to factors like harmonics, long lines, etc. There exist classical methods to deal with such losses like placing shunt capacitor in the line but when they get tuned with the system resonance, they resonate. To manage the current harmonics because of the presence of non linear load in the system, we utilize passive filters consisting of capacitors, inductorsand damping resistors thus provides simple solution but are large in size and weight.[2]

Thus FACTS (Flexible Alternating Current Transmission System) devices such as DSTATCOM are used as they are having the technical advantages like responding quickly to the changes in the network. Voltage of a distribution bus is maintained using distribution static compensator (DSTATCOM) through reactive power compensation. It is connected in shunt to the distribution system through a coupling inductor & contains VSC (Voltage Source Converter) & a DC energy storage device. A VSC based in IGBT switches obtains three phase AC voltage from the DC voltage across storage element.[2] Thus the main goal of the work is to study and implement the DSTATCOM model in distribution system to improve the power quality of distribution system using different control algorithms for DSTATCOM. We will be targeting the reactive power compensation i.e.; power factor correction and THD reduction as the main goal to enhance the power quality of electrical grid since DSTATCOM has turned out to be promising tool for such quality improvement. The control strategy used for

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DSTATCOM will affect its quality of performance. However to achieve this goal, size and placement of the DSTATCOM is an important consideration. Based on the literature review, determination of the optimal location, sizing of DSTATCOM and its control algorithm has a considerable impact on improving power quality of distributionsystem.

The principal goal of any compensation process is to have a fast response, flexibility and should be easy to implement. The result's approval will be based on the Grid standards of Central Electricity Authority of IndiaRegulations.

The basic idea is to study the power quality issues and its best possible solutions. To achieve this goal we have used three different control strategies for the comparative study i.e.; Instantaneous Reactive Power Theory (IRPT), Synchronous Reference Frame Theory (SRFT) and Unit Template (UT) method to achieve power factor correction and THD reduction in the system according to the Indian Grid Standards. So that same DSTATCOM can be used to deal with the power quality issues in different situations with non linear loads in fragile environment of electricity grids. All results has been interpret through the simulations that has been performed in MATLAB- SIMULINK (SimPowerSystem) & comparison has been done to show the effectiveness of the implemented control algorithms.

Methodology

To incorporate DSTATCOM in distribution system, literature research and analysis is done. Both reactive and active power can be injected using DSTATCOM. The active power flow between DSTATCOM and grid depends upon the phase angle difference and the reactive power flow depends upon the voltage magnitudes difference between the two voltages of grid and DSTATCOM. The reactive power output of a DSTATCOM will vary proportional to the system voltage. However when capacitor is used to compensate reactive power then power varies according to the square of the system voltages. Figure.1 shows the basic control idea of implementing DSTATCOM in thesystem.

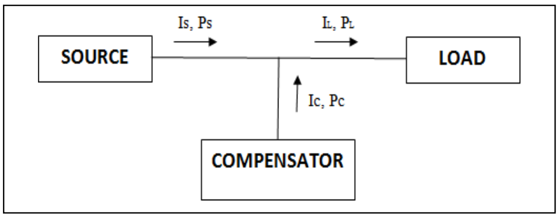

Figure 1.Basic control idea of implementing DSTATCOM

The performance of the DSTATCOM relies on its control. Shunt connected DSTATCOM & storage unit are connected to the grid using coupling inductor. The main objective of the control strategy is that it should be easy to implement as well as should offer flexible and fast response. The main steps to implement the control algorithms of a DSTATCOM are:

- System voltage and currentmeasurements
- Compensating signal(s) calculations
- Generation of controllingpulses

Source reference current is made to be balanced to make the load balance because source is supplying only real power. Reference source current used to decide the switching of the Control algorithms extract the actual fundamental frequency component of load current. DSTATCOM can be controlled using various algorithms out of which we have implemented algorithms:

- Instantaneous Reactive Power Theory(IRPT)
- Synchronous Reference Frame Theory(SRFT)
- Unit Templatemethod

Instantaneous Reactive Power Theory (IRPT):

This theory is based on the conversion of three-phase quantities to two-phase quantities in α–β frame. The calculation of instantaneous active and reactive power is done in this frame. It uses the Clark's Transform to generate two orthogonal rotating vectors (α and β) from the three phase vectors a, b and c (r, y and b according to Indian nomenclature). This transform is applied to the voltage and current and generates reference current for the controllingof gate signals of VSC. This theory is mainly used for reactive power compensation. Sensed source side voltage inputs Va, Vb, and Vc and load side current values ILa, ILb, and ILc are used by the controller to generate appropriate reference current Iref. That reference current is then been sent to the pulse generator unit to generate switching signals for the VSC of DSTATCOM. Figure.2 shows the reference current extraction using thisstrategy.

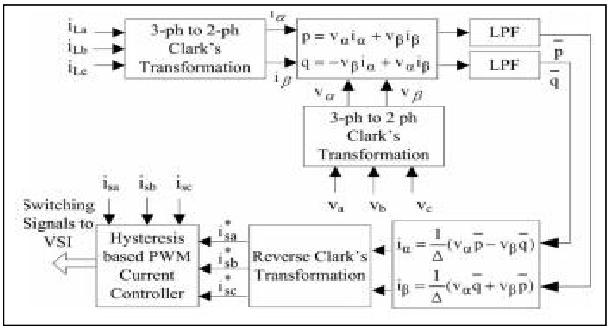

Figure 2.Block diagram of the reference current extraction using IRP theory

Synchronous Reference Frame Theory (SRFT)

SRF theory is based on the transformation of currents in synchronously rotating d–q frame Sensed source side voltage inputs Va, Vb, and Vc and load side current values ILa, ILb, and ILc are used by the controller to generate appropriate reference current Iref. Sine and cosine signals are then generated using phase-locked loop (PLL) from voltage signals. Current signals are converted to d–q frame and these signals are filtered and converted back to abc frame (Isa, Isa, and Isc), which are then passed to a hysteresis-based signal generator to generate final switching signals for VSC of DSTATCOM (Figure.3). It focuses mainly on THD & loadimbalance.

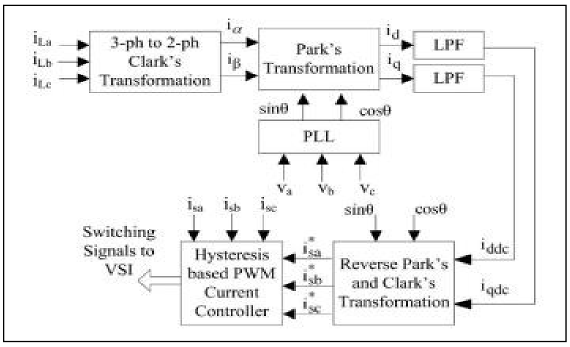

Figure 3.Block diagram of the reference current extraction using SRF theory

Unit Template Method

In this control strategy, reference current is generated using unit templates which are derived from PCC voltages and is further divided into two components.Those two components are such a way that one is in quadrature and other is in phase with PCC voltages. The unit templates in phase are obtainedas:

uap=va/Vt; ubp=vb/Vt; ucp=vc/Vt

The unit templates in quadrature with PCC voltage is obtained as:

uaq=(-ubp+ucp)/√3;
ubq=(uap√3+ ubp -ucp)/2√3;
ucq=(-uap√3+ ubp -ucp)/2√3;
ubq=(uap√3+ ubp -ucp)/2√3

The output of the PI controller provides a base to calculate in- phase component of the reference source current. Unit templates are used to calculate three-phase in-phase components of reference source currents. Pulse are generated of the basis of comparison done between the reference source current and actual source current and thus control the operation of DSTATCOM. Figure.4 gives a brief idea about DSTATCOM controlled by its algorithms and then attached to thesystem.

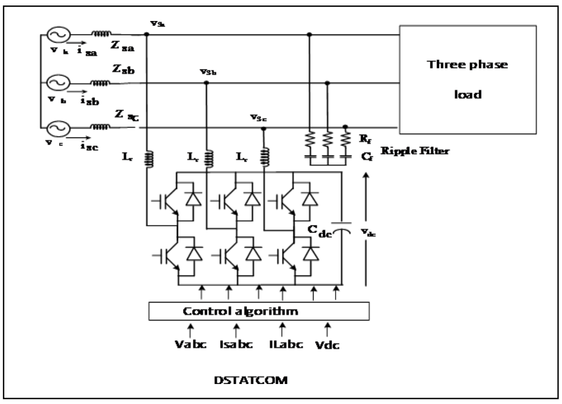

Figure 4.Schematic diagram of DSTATCOM connected to grid

Modelling Ofdstatcom

The effectiveness of DSTATCOM relies on the control algorithm utilized for generating the switching signals for the VSC. DSTATCOM has been attached to the grid of the system at PCC using coupling inductor. It has control unit & pulse generation unit for the implementation of control strategy and to provide gate pulse for VSC respectively. A controller unit for the DSTATCOM is simulated based on mentioned three control strategies to target power factor correction and reduced THD as the main goal. Generation of gate pulse plays a major role for the reduction of THD. Using this technique we can control system variables between boundaries & can give correct switching signals for DSTATCOM operation. Measurements required for algorithm implementationare:

- Three phase linevoltages
- Three phase linecurrents
- DC Voltage across Capacitor

Steps to activate operation of DSTATCOM:

- Source RMS voltage amplitude isobtained.
- Reference currents are obtained using various algorithms.
- Generated reference current & actual current sensed by sensors are subtracted to obtain errorsignal.
- Derived error signal & its defined boundariesare used for controlling the switching of IGBT of DSTATCOM
- Thusbidirectionalflowofreactivepoweriscontrolled by DSTATCOM.

The modeling of DSTATCOM has been done in MATLAB-SIMULINK using SIMSCAPE (SimpowerSystem) toolbox. The DC link voltage is regulated nearly to reference estimation of 700V and DC Link capacitor has been kept at 1000uF.

Test System Andresults

The grid system having source, distribution lines and combination of linear and non linear loads along with DSTATCOM have been simulated using MATLAB- SIMULINK. The control strategies IRPT, SRFT and UT are used to generate reference current for the required gate pulse by DSTATCOM.

Grid System without DSTATCOM

The power system contains combination of two numbers ofRL linear loads and one purely non linear load which is been supplied real and reactive power by a three phase source of 415V, 50Hz. Second linear RL load is switched at different time interval; accordingly it acts as a dynamic load for the system. The total demand of real power and reactive power required by load is been fulfilled by source. The Simulink model of the three phase grid system without compensator is shown in Figure.5. The source voltage and current when DSTATCOM is not the system are shown in Figure.10. From Figure.6 it is easily noticeable that the second load is switched on at the time t= 0.35sec and switched off at time t=0.65sec, current magnitude increased due to dynamic load condition. Because of the reactive power requirement of linear dynamic load, the current is lagging in behavior from the source voltage.

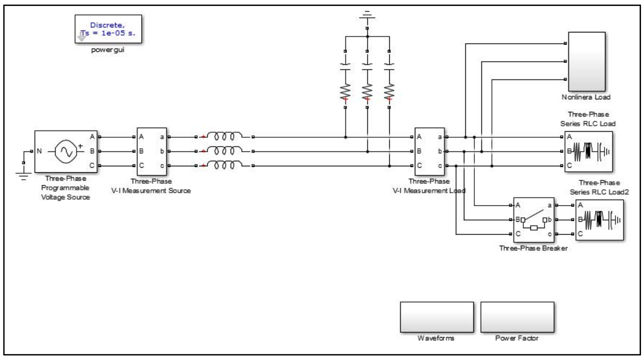

Figure 5.Grid system without DSTATCOM connected

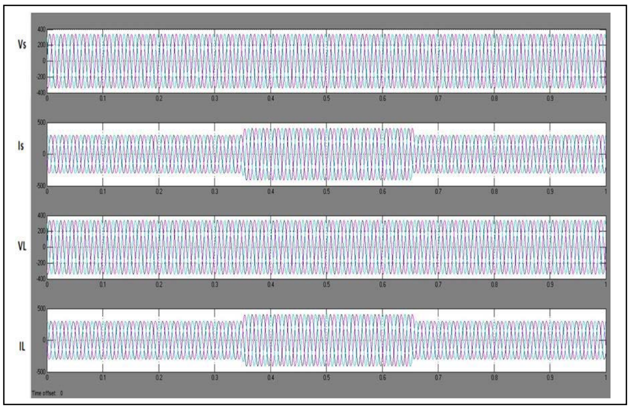

Figure 6.Variations in Is & IL Waveforms without DSTATCOM due to dynamic load

Grid System with DSTATCOM Compensator

The Simulink model of the DSTATCOM controlled by three different control strategies was implemented and connected to the system is shown in Figure.7. Simulink model of the DSTATCOM is shown in Figure.8. The DSTATCOM unit has been connected to the grid in parallel through coupling inductors for the reactive power control of the system. Control unit has been design using IRPT, SRFT and Unit templates algorithm to control the gate pulse of Voltage Source Converter present in DSTATCOM. System will take values of parameter required and I_ref will be obtained which will then be compared with the source current value to generate error signal through which gate pulse will be generated. Here we have used Hysteresis control method for the pulse generation. Those gate pulses will control VSC of DSTATCOM.

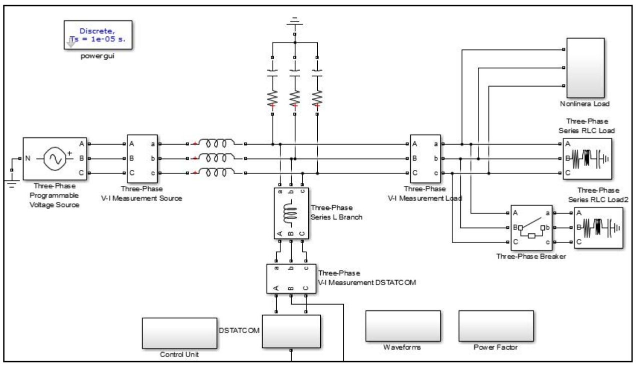

Figure 7.Three phase system with DSTATCOM connected

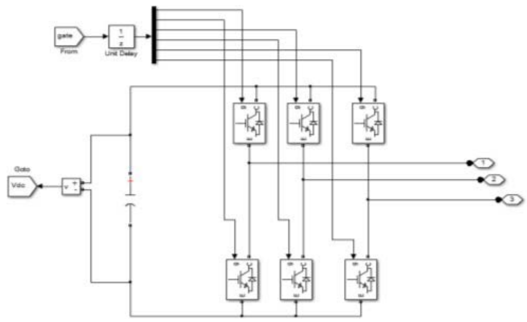

Figure 8.Simulink Model of DSTATCOM

Table 1.System Parameters for simulation

Parameters	Values
Source voltage	415 V
System frequency	50Hz
DC Link Capacitor	1000uF
Continuous Load	P = 50KW
	QL=50KVAR
Temporary Load	P = 20KW
	QL= 15KVAR
RC Filter	R=15Ω, C=1uF
Coupling Inductance	3.0mH

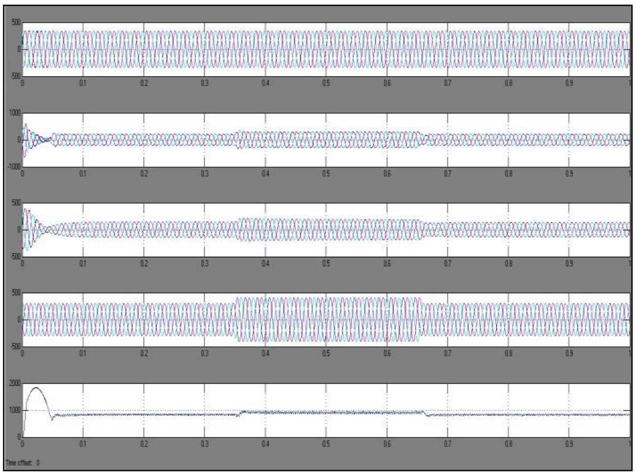

Figure 9.Waveforms Vs, Is, Iref, IL, Vdc when DSTATCOM is connected to the system

Table.1 shows the system parameters kept for simulation. Waveforms of system without compensator & with compensator are being shown in Figure.6 & Figure.9 respectively.

Results

As shown in Figure.10, there is a phase difference in the source voltage and current (phase a) waveform which shows the dropped power factor of the system source side. Also, the current waveform is distorted. As shown in Figure.11, Figure.12 and Figure.13, the phase difference in current and voltage waveform has been fixed which shows the fixation of power factor reduction of the system using UT, SRFT and IRPT controls respectively. Also it provides a smooth waveform which shows THD reduction using these three algorithms. The magnitude of source current has also beendecreased.System with no DSTATCOM had THD of 7% and PFmax (maximum power factor) of 0.7(lagging) as shown in Figure.14. Connection of DSTATCOM to the system provides input power factor of 0.99 (lagging).

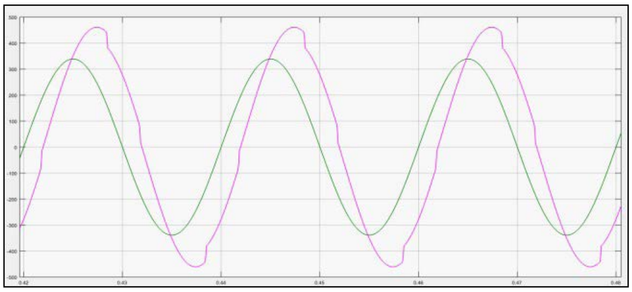

Figure 10.Waveforms of Vsa & Isa without DSTATCOM

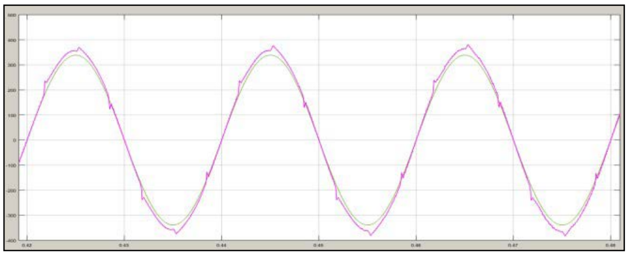

Figure 11.Waveforms of Vsa & Isa using IRPT

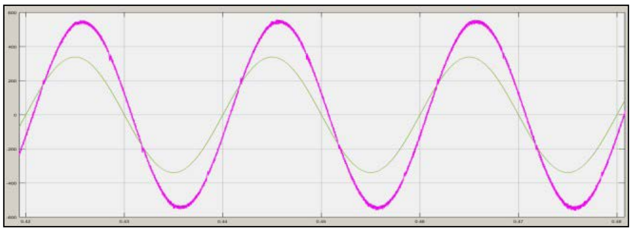

Figure 12.Waveforms of Vsa & Isa using SRFT

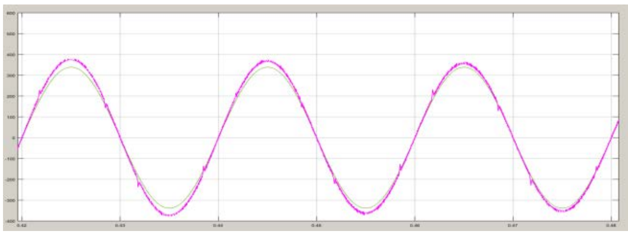

Figure 13.Waveforms of Vsa & Isa using UT

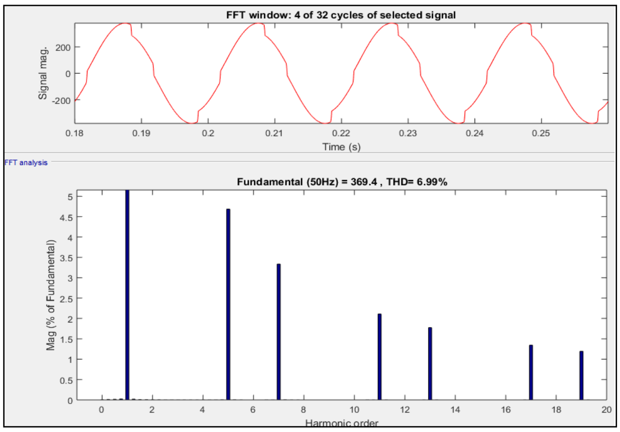

Figure 14.FFT analysis for source current without DSTATCOM

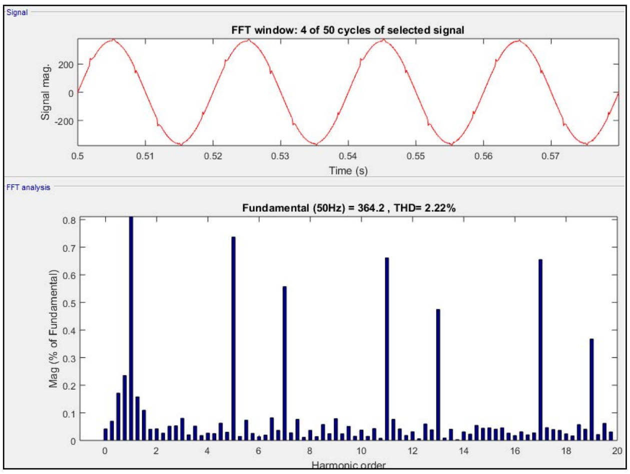

Figure 15.FFT analysis for source current with DSTATCOM using IRPT

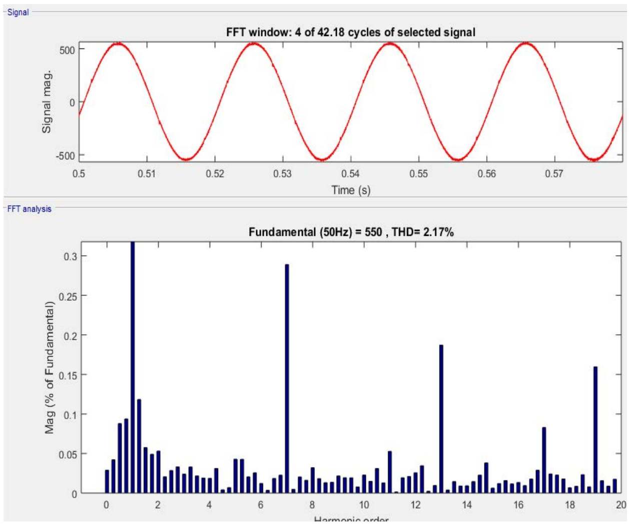

Figure 16.FFT analysis for source current with DSTATCOM using SRFT

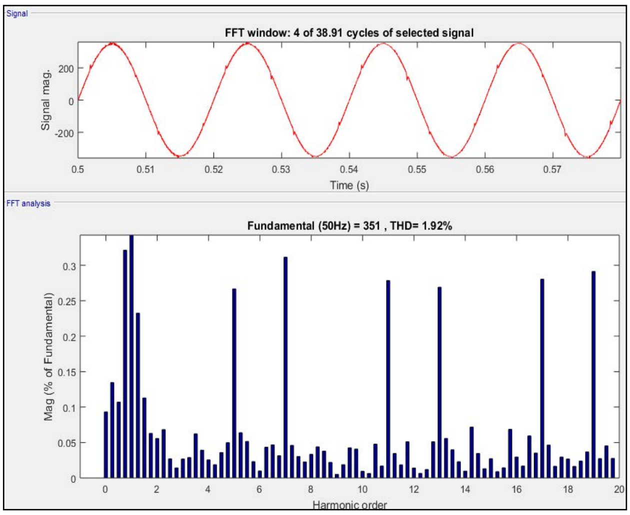

Figure 17.FFT analysis for source current with DSTATCOM using UT

Table 1.Comparison between three control strategies

Control Strategy	PFmax	Time (ms)	THD (%)
IRPT	0.9997	180	2.22
SRFT	0.96	157	2.17
UT	0.9997	172	1.92

Table.2 shows the comparison between three control strategies. First column shows the control strategies, second column shows maximum power factor achieved; third column shows the time taken to reach maximum power factor and the last column shows THD reduction. It can be seen that IRPT & UT both can give nearly almost unity power factor to the system whereas SRFT in providing little less as compared to these both strategies still is providing good power factor 0.96(lagging). On the other hand SRFT is faster as compared to both these algorithm in order to reach the maximum power factor. In case of THD reduction, UT has done the best to the system by providing the leastTHD%.

To carry out an accurate comparative result between these three strategies, we had done some observations on the basis of few contraints over which we will be concluding the behavior of DSTATCOM with three different control strategies. The constraints as taken for the increasing value of capacitance in the system and are mentionedas:

- The nature of max power factorachieved
- The nature of time taken to achieve maximum power factor by thealgorithm
- The nature of time taken to achieve a particular decided value of powerfactor
- The nature of power factor at a particular given time

Based on these constraints we observed that:

- IRPT: Using IRPT strategy in DSTATCOM we reached to the observations that as the value of capacitor increases in thesystem:
- The max power factor achieved isincreasing.
- Time taken to achieve maximum power factor is increasing.
- The power factor achieved at particular given time is increasing and becoming stablethereafter
- The time taken to reach a given power factor value is reducing and becoming stablethereafter.

SRFT: Using SRFT strategy in DSTATCOM wereached to the observations that as the value of capacitor increases in thesystem:

- The max power factor achieved isincreasing.
- Time taken to achieve maximum power factor is increasing.
- The power factor achieved at particular given time is increasing and becoming stablethereafter.

UT: Using UT strategy in DSTATCOM we reached to the observations that as the value of capacitor increases in the system:

- The max power factor achieved isincreasing.
- Time taken to achieve maximum power factor is increasing.
- The power factor achieved at particular given time is increasing initially but then decreasing after a certain value ofC
- The time taken to reach a given power factor value is increasing.

Conclusions

DSTATCOM unit is connected with the framework to enhance power quality. Instantaneous Reactive Power Theory, Synchronous Reference Frame Theory and Unit Templates Method were implemented for DSTATCOM unit's control pulse generation. The DSTATCOM unit is successfully able to improve power factor by reactive power compensation and successfully reduced THD. Detailed study has been carried out to accomplish the above targets. All three strategies were able to achieve power factor of minimum 0.9 (lagging) to almost unity power factor which was initially of 0.7(lagging). System could also achieve THD reduction (nearly 2%) which satisfies the limits of Grid standards of Central Electricity Authority of India Regulations. However it can be concluded that SRFT is the fastest of the sethree to provide power factor correction where as UT is the best strategy if we have THD reduction as the main goal to achieve.

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