Energy Based Control Strategy for the Reduction in the Response Time of DSTACOM

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Abstract: - This paper studies the timely issue of response of Distribution Static Compensator when there is reduction in AC and DC loads. DSTACOM is an important device in correcting power quality problems like harmonics reduction, load balancing, reactive power compensation etc. The energy stored in its dc capacitor releases during transients to provide ride through to facilitate load shedding. .The presented algorithm evaluates the reduction in response time of dstatcom based on energy of capacitor rather than voltage. And it is compared with conventional algorithm which regulate the voltage of the capacitor, mainly depends on the values of PI parameters. It is observed that ratio of gains of proportional to integral controller is many times larger in case of new scheme introduced here .Thus the effect of sudden power loss is investigated with and without the DSTATCOM connection and concluded that response time reduces from 0.04 sec to 0.01 sec The present approach is validated through simulations using MATLAB software with its Simulink and Power System Block set (PSB) toolboxes and then graphical programming of LabVIEW software has been utilized to develop analyzer and also to monitor the results . Use of virtual instrumentation for the measurement and monitoring power system improves the performance and reliability of the system.

Key-Words: - DSTATCOM, transient time, voltage source converter, THD reduction, LABVIEW

1 Introduction

Power system requires the supply of electricity with a determine power quality and reliability. With the increase or decrease of loads, the problems created can be very severe and affect the voltage supplied by the distribution network. Also other loads served from the same network will be affected Thus distribution system is facing power quality problems such as excessive neutral current, unbalanced load, harmonics in current etc. due to various reasons such as single phase loads, non-linear loads etc. [7].

DSTATCOM is an important shunt compensator which has the potential to solve many power quality problems faced by the distribution system.[1,2] However there is requirement for AC and DC load DSTATCOM must support instantaneous compensation and supplies DC loads. There are many control schemes reported in the literature for control of shunt compensators[3].Here the control algorithm based on instantaneous symmetrical component theory [4] is implemented. Computation of the average load power is needed for verifying the transient performance, but in this case as DC load power is comparable to average load power hence, plays a major role in the transient response of the compensator. This paper deals with the effects of load variation (AC and DC) on the three phase four wire system and the control of voltage based on the energy of DC capacitor is compared with that of conventional trial method for PI controller are analyzed and simulated. Section 2and 3 explains the principle of operation and modeling of Dstatcom. .Section 4 presents the new control strategy and finally it is implemented through case study in section 5.section 6 give the description of LABVIEW, section 7 describes the mapping of SIMULINK and LABVIEW, system architecture of LABVIEW is mentioned in section 8 which is followed by conclusion.

2 Problem Formulation

A distribution static compensator (DSTATCOM) is a voltage source converter (VSC) based device. When operated in a current control mode, it can improve the quality of power by mitigating poor load power factor, eliminating harmonic content of load and balancing source currents for unbalanced loads[5]-[7]

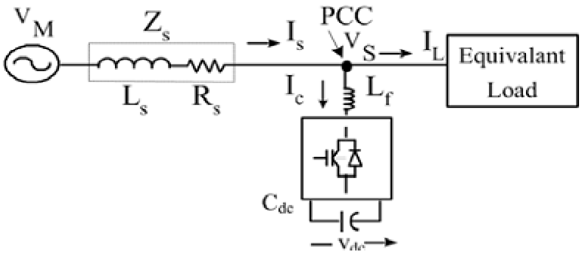

Fig 1: Single line diagram of Dstatcom

Fig 2 shows the three-phase, four-wire-compensated system using an H-bridge VSI topology based DSTATCOM compensating unbalanced and nonlinear ac load. The isolation transformers used prevent a short circuit of the dc capacitor for various combinations of the switching states of the VSI. The DSTATCOM injects currents into the PCC in such a way so as to cancel unbalance and harmonics in the load currents. The VSI operation is supported by the dc storage capacitor with voltage across it.

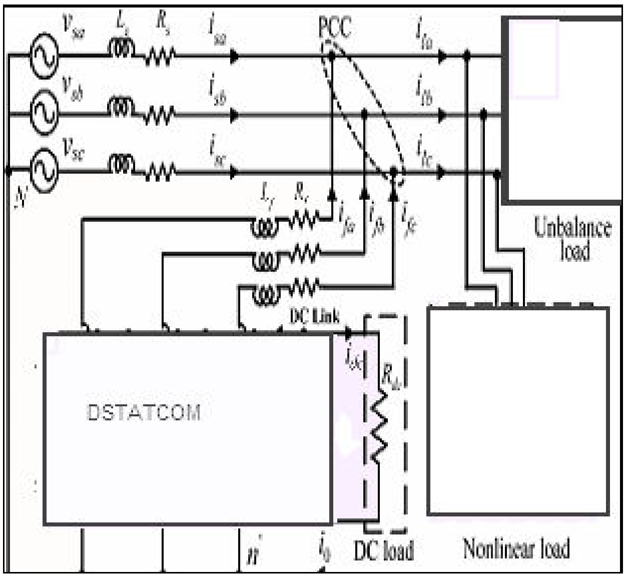

Fig 2: Three-phase, four-wire compensated system using an H-bridge VSI topology based DSTATCOM

3 State-Space Model of the Dstatcom

For the DSTATCOM topology shown in Fig. 2, the pairs of switches S1a-S2a and S4a-S3a are always ON and OFF in complimentary mode. The ON and OFF states of these switches are represented by a binary logic variable Sa and its complement.

The state-space equations are written as follows:

$$\dot{x} = A\,x + B\,u \qquad (1)$$

where state vector x and input vector u are given by

$$x = [i_{fa} \quad i_{fb} \quad i_{fc} \quad v_{dc}]^T$$
$$u = [v_{sa} \quad v_{sb} \quad v_{sc}]^T \qquad (2)$$

System matrix and input matrix are given as follows:

$$\boldsymbol{A} = \begin{bmatrix} -\frac{R_f}{L_f} & 0 & 0 & \frac{(S_a-\bar{S}_a)}{L_f} \\ 0 & -\frac{R_f}{L_f} & 0 & \frac{(S_b-\bar{S}_b)}{L_f} \\ 0 & 0 & -\frac{R_f}{L_f} & \frac{(S_c-\bar{S}_c)}{L_f} \\ -\frac{(S_a-\bar{S}_a)}{C_{dc}} & -\frac{(S_b-\bar{S}_b)}{C_{dc}} & -\frac{(S_c-\bar{S}_c)}{C_{dc}} & -\frac{1}{R_{dc}C_{dc}} \end{bmatrix}$$

$$\boldsymbol{B} = \begin{bmatrix} \frac{1}{L_f} & 0 & 0 \\ 0 & \frac{1}{L_f} & 0 \\ 0 & 0 & \frac{1}{L_f} \\ 0 & 0 & 0 \end{bmatrix}.$$

4 Control of Dstatcom

A block diagram of the control scheme is shown in Fig. 3 The load currents, the PCC voltages and dc bus voltage of DSTATCOM are sensed as feedback signals. The load currents from the a-b-c frame are converted to the d-q-o frame.
The oscillatory components (ac components) are eliminated using low pass filter (LPF) and the dc component is the fundamental frequency part of the load current.

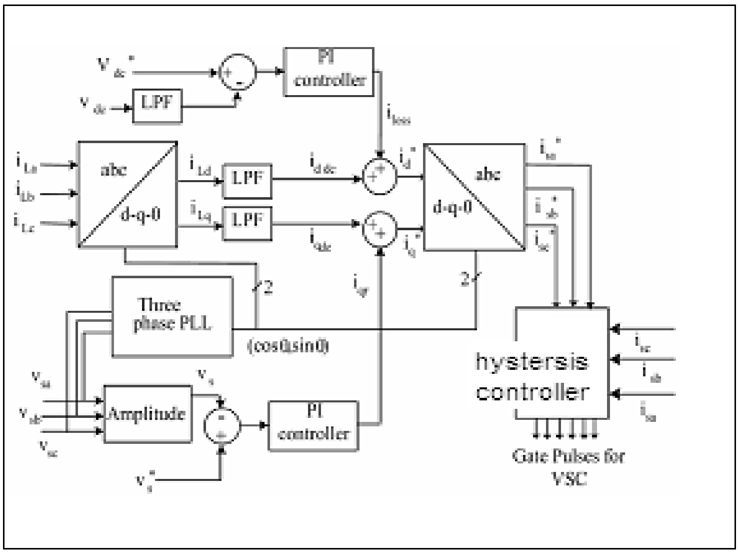

Fig3: Control strategy for dstatcom

The references currents are fed to hystersis controller, which is used for tracking control. Conventionally the dc control loop is given by

$$P_{dc} = K_{p\,dc}\; e + K_{i\,dc} \int e \, dt \qquad (3)$$

Where Kp_{dc} and $K_{i\;dc}$ are the proportional and integral gains respectively for the dc control loop.

Trial and error method is used to determine these constants as it is difficult to find the values in complex system. The error e between the reference dc voltage and the average dc voltage is given as

$$e = V_{dc\ ref} - V_{dc\ av} \qquad (4)$$

Where the dc voltage V_{dc} av is the average of the dc link across H-bridge of all the three phases.

A new control strategy based on energy is introduced in this paper .Based on the ability of capacitor to regulate the voltage under transient condition, value of capacitor can be determined. The energy required by the dc-link capacitor to charge from actual voltage to the reference value can be computed as

$$W_{dC} = \frac{1}{2} C_{dc}(V^2_{dc\ ref} - v^2_{dc}) \qquad (5)$$

Now the total dc power required by the dc-link capacitor is computed as follows:

$$P_{dc} = K_{pe}(V^2_{dc\ ref} - v^2_{dc}) + K_{ie}\int(V^2_{dcref} - v^2_{dc}) \qquad (6)$$

Design of proportional and integral gain in the energy based controller can be determined by solving the equation (3) and (6) by assuming $V_{dc\ ref} + V_{dc}$ is equal to $2V_{dc\ ref}$

Hence it can concluded that ratio of gains of proportional to integral controller is many times larger in case of new scheme introduced here

5 Case Study

A three phase four wire system is modeled in MATLAB/SIMULINK. The ac load consists of a three-phase unbalanced load and a non linear load of bridge rectifier (three phase) feeding a highly inductive R-L load. A resistance connected in the dc link is considered as dc load. The compensator consists of 12 IGBT switches with H-bridge VSI configuration. The system parameters are included in Appendix .The average load power is computed by taking the samples of the load currents and PCC voltages. The dc load power Pdc is generated by using the conventional dc-link voltage controller and fast-acting dc-link voltage controllers. Based on these values, reference compensator currents are obtained by using (1). The performance of the three-phase four-wire system with DSTATCOM is demonstrated for voltage regulation along with harmonic reduction, load balancing. The model is analyzed for switching of load to half of its value from 0.4s to 0.8s. Fig 4 shows simulink model for the proposed system consisting of power supply, loads which are connecting through circuit breaker operated by timer, and Dstatcom also operated through timer. Fig 5 shows the source voltage and current of the system without dstatcom. Load is halved from0.4 to 0.8 sec and it is clearly depicted that it response is non-sinusoidal and contained harmonics.

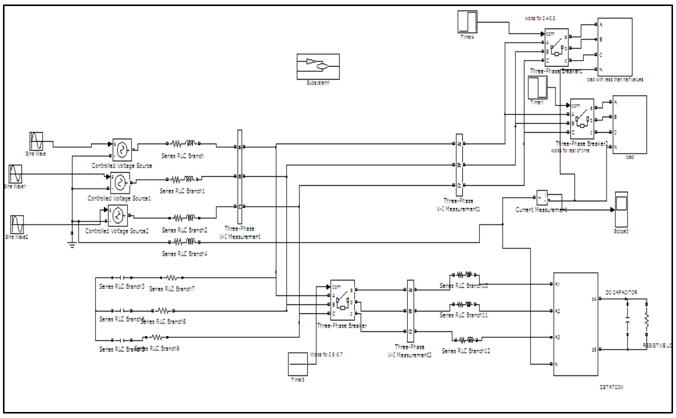

Fig 4: Simulink model

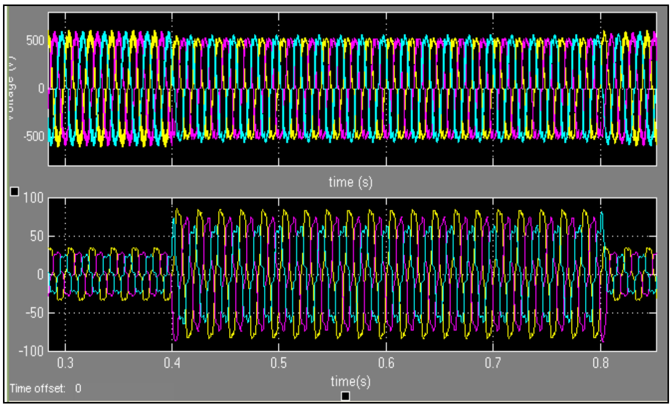

Fig 5: Source voltage and current of the system without dstatcom

5.1 Dynamic Performance of the Conventional and Energy Based Controller

The dynamic performance of the system is observed by introducing a three phase fault at t=0.4 and cleared at t=0.6 as shown in Fig 6. As it can be observed from the figure that source voltage and currents are not sinusoidal and unbalanced. Load is halved from 0.4 to 0.8 sec of time. Fig 6 and Fig 7 shows the dynamic performance of the Dstatcom with source voltages and currents and load voltage and current under fault condition.. Due application of Dstatcom from t=0.6 to t=0.8 source voltages current become sinusoidal and balanced as shown in Fig 8 . The THD of source voltage is reduced to 2.76% from 15.20% of load voltage and for source current to 5.10% from 12.14% of load current. Fig 9 shows the dynamic performance of the load voltages and load current for conventional controller

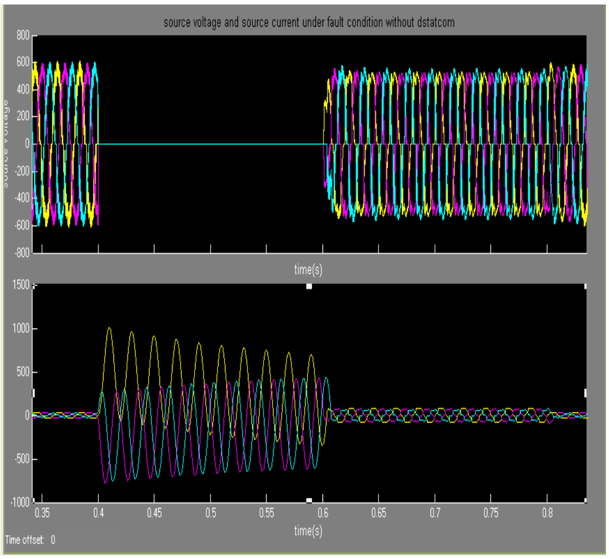

Fig 6: Source voltages and source current under fault condition without Dstatcom

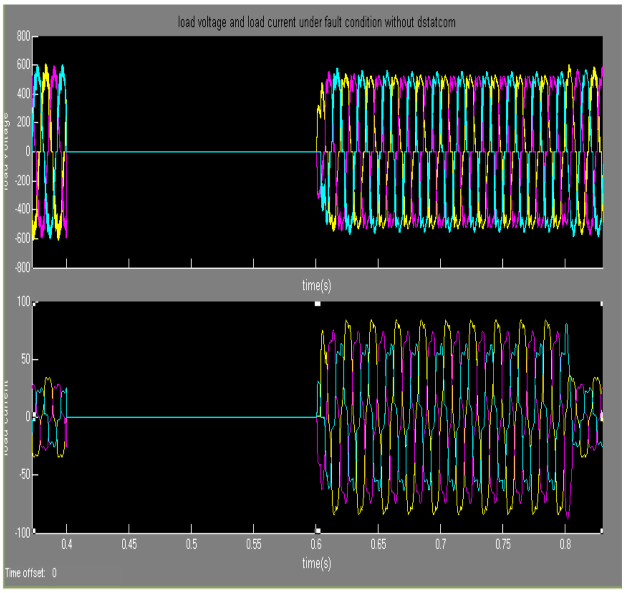

Fig 7: Load voltages and load current under fault condition without Dstatcom

Energy based controller works similarly as conventional controller as it makes the source voltage and source current sinusoidal with less THD. Fig 10 and 11 shows the source voltages and source current and load voltages and load currents for energy based controller

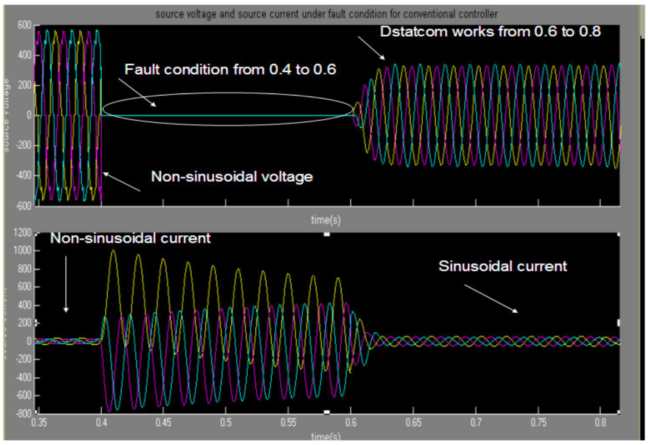

Fig 8: Dynamic performance of the Dstatcom showing source voltage and source current for conventional controller

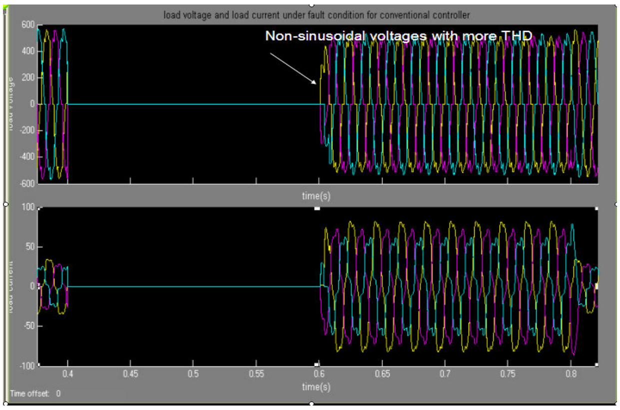

Fig 9: Dynamic performance of the Dstatcom showing of the load voltage and load current for conventional controller

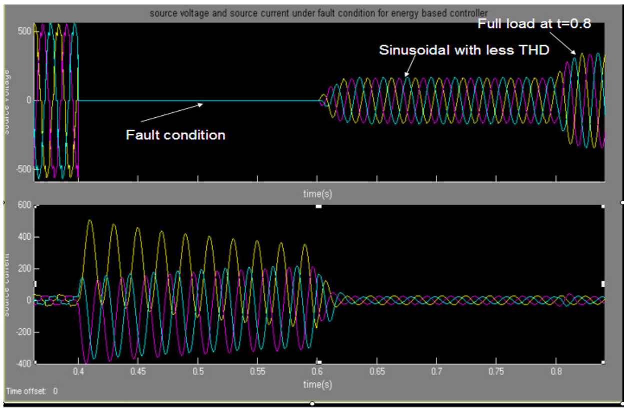

Fig 9: Dynamic performance of the Dstatcom showing source voltage and source current for energy based controller.

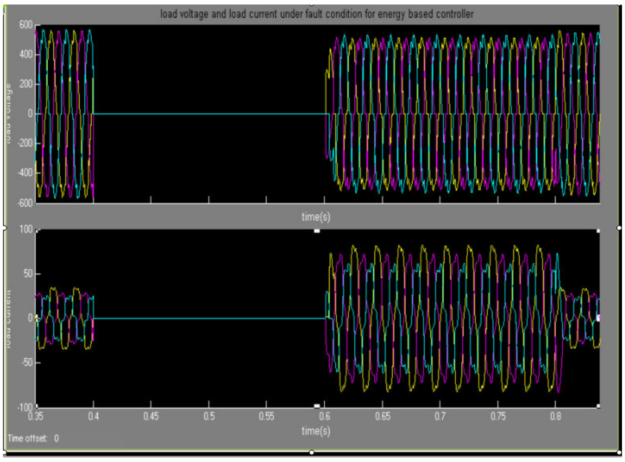

Fig 11: Dynamic performance of the Dstatcom showing load voltage and load current for energy based controller

5.2 Performance of the Conventional and Energy Based Controller

The transient performance of the conventional and energy based voltage controllers are studied by making sudden changes in the ac load supplied by the ac load bus as well as the dc load supplied by the dc capacitor. In the simulation study, the load is halved at the instant t= 0.4 s and brought back to full load at t=0.8s.. A three phase ground fault is introduced at time t=0.4 and cleared at time t=0.6

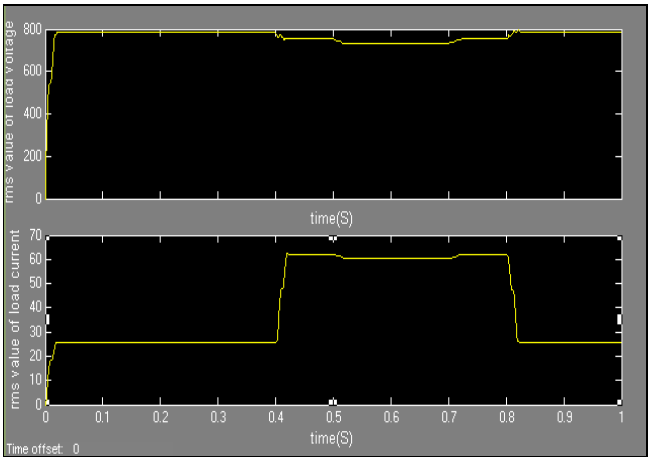

Fig 12: RMS values of the load voltages and load current

The conventional and energy based voltage controller is implemented. The transient performance of the conventional controller is shown in Fig.13 . The total load is a combination of linear unbalanced and nonlinear load is halved at the instant t= 0.4 s followed by fault condition in the load side. But at this instant Dstatcom is not connected .The functioning of Dstatcom is such that whenever there is an increase in capacitor voltage above the reference value due to sudden decrease , the capacitor absorbs surplus power from the source. Based on the values of PI controller gains, the capacitor voltage controller will be brought back to the reference value after a few cycles. Similarly, when the load is switched back to the full load at instant 0.8 s, the dc capacitor supplies power to the load momentarily and, hence, the dc voltage falls below the reference value. The dc capacitor supplies power to the load momentarily. Due to the PI controller action, the capacitor voltage will gradually build up and reach its reference value.

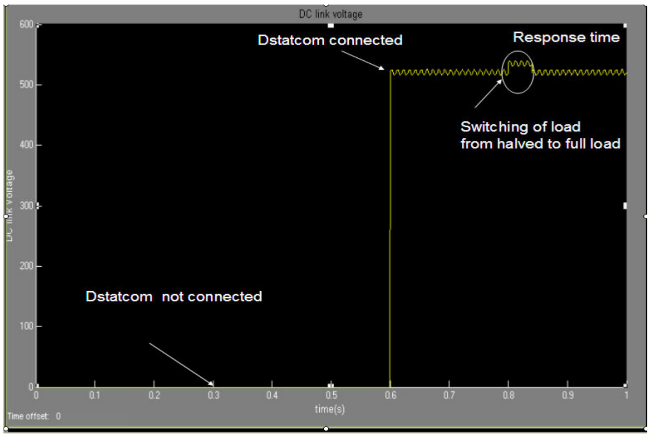

Fig 13: Transient performance of the conventional controller showing the capacitor voltage

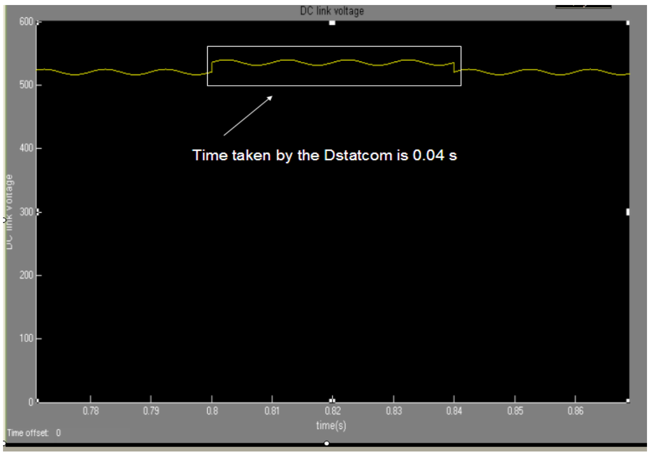

Fig: 14; Response time of Dstatcom using conventional controller

Fig 15 shows the transient performance of energy based controller. A comparative analysis of both the controller is depicted in fig 17

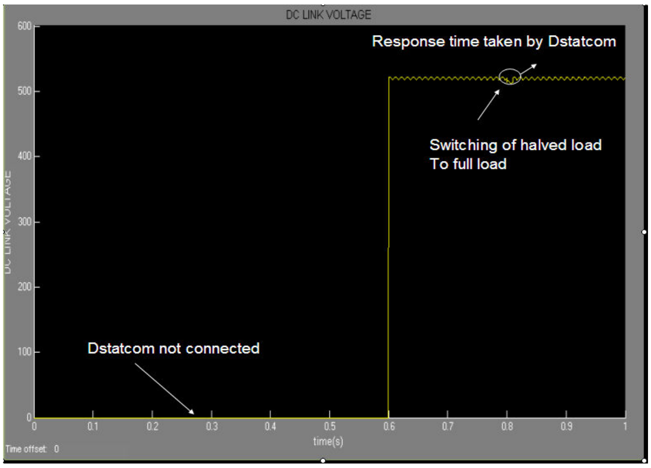

Fig 15: Transient performance of the energy based controller showing the capacitor voltage

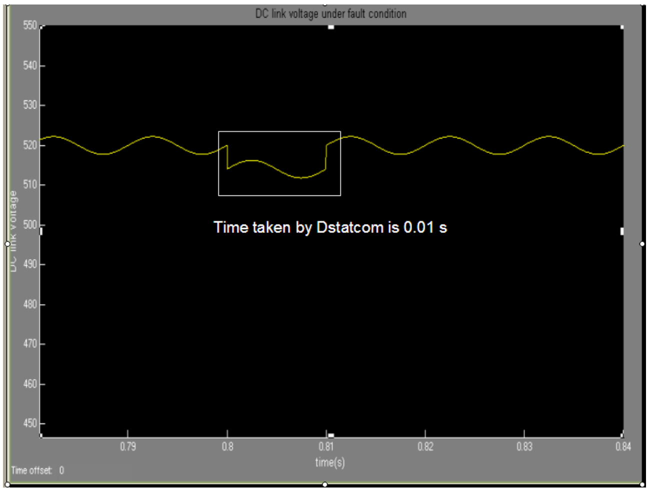

Fig: 16: Response time of Dstatcom using energy based controller

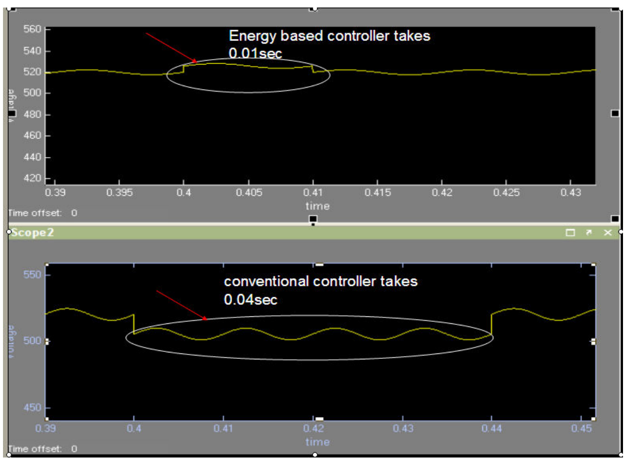

Fig 17: comparative time response of Dstatcom using energy based controller and conventional controller

6 LABVIEW as Analyzer

The SIMULINK toolbox in MATLAB package provides interactive model input and simulation environment for dynamic system simulation. Most kinds of running state and failure state can be denoted by changing model variables so it is convenient to study intricate control algorithm and optimize control parameters. This paper introduces the framework design for the virtual control system of the Dstatcom virtual prototyping. It can simulate processes during Dstatcom running with well-designed GUI. The system is of flexibility and extensibility due to the easy program language.

MATLAB is used to implement analysis and simulation and Lab VIEW (short for Laboratory Virtual Instrumentation Engineering Workbench) is a platform and development environment for a visual programming language from National Instruments (NI).It is a sort of graphical programming software which provides a friendly Graphical User Interface (GUI)/human machine interface (HMI). Because it is very easy to learn and has high stability as well as powerful technical support, it is the most universal software in the visual simulation field. Considering the predominance of LabVIEW, we build this GUI with Lab VIEW. LabVIEW programs are called virtual instruments, or VIs, because their appearance and operation imitate physical instruments, such as oscilloscopes and multimeters. Every VI uses functions that manipulate input from the user interface or other sources and display that information or move it to other files or other computers. The programming language used in Lab VIEW, is a dataflow language. Execution is determined by the structure of a graphical block diagram.[13]

Every VI uses functions that manipulate input from the user interface or other sources and display that information or move it to other files or other computers. A VI contains the following three components:

• Front panel—Serves as the user interface.
• Block diagram—contains the graphical source code that defines the functionality of the VI.
• Icon and connector pane—identifies the interface to the VI so that we can use the VI in another VI. A VI within another VI is called a subVI. A subVI corresponds to a subroutine in text-based programming languages.

Lab VIEW ties the creation of user interfaces (called front panels) into the development cycle. LabVIEW programs /subroutines are called virtual instruments (VIs). Each VI has three components: a block diagram, a front panel and a connector pane. The latter may represent the VI as a subVI in block diagrams of calling VIs. Controls and indicators on the front panel allow an operator to input data into or extract data from a running virtual instrument. However, the front panel can also serve as a programmatic interface. Thus a virtual instrument can either be run as a program, with the front panel serving as a user interface, or, when dropped as a node onto the block diagram, the front panel defines the inputs and outputs for the given node through the connector pane. This implies each VI can be easily tested before being embedded as a subroutine into a larger program.[18]

The graphical approach also allows non-programmers to build programs by simply dragging and dropping virtual representations of the lab equipment with which they are already familiar. The LabVIEW programming environment, with the included examples and the documentation, makes it simpler to create small applications. This is a benefit on one side but there is also a certain danger of underestimating the expertise needed for good quality “G" programming. For complex algorithms or large-scale code it is important that the programmer possess an extensive knowledge of the special LabVIEW syntax and the topology of its memory management. The most advanced LabVIEW development systems offer the possibility of building stand-alone applications. Furthermore, it is possible to create distributed applications which communicate by a client/server scheme, and thus is easier to implement due to the inherently parallel nature of G-code.

7 Components of simulation

Simulation consists of the following components:
Model—that make up the simulation. Models contain inputs and outputs that send and receive The blocks data. Models also contain parameters one can manipulate and signals whose values one can view. For example, a model that generates a sine wave contains parameters that adjust the amplitude and frequency of the sine wave. One can view the value of the sine wave using the model signal. Models can be built using The MathWorks, Inc. Simulink® application software.
Host VI— The VI that one use to manipulate a model. The host VI consists of a front panel and a block diagram. One use front panel controls to manipulate model parameters. For example, one can use a control to change the amplitude of a sine wave. You use front panel indicators to view the values of the model signals. For example, one can use a waveform chart to view a sine wave as one change the amplitude.

The block diagram of the host VI contains the code that defines mappings between front panel controls/indicators and model parameters/signals. You create a host VI using LabVIEW and the SIT Connection Manager Dialog box. Note advanced users can create a host VI using the User Interface VIs.
SIT Server—The server that uses a TCP/IP connection to transmit data between the host VI and the model. You must launch the SIT Server, which starts automatically when you launch The MathWorks, Inc. MATLAB® application software, before running a simulation. By default, the SIT Server runs on port 6011.
Host Computer—The computer on which you run the host VI. The host computer must be a PC running Windows NT, 2000, or XP.
Execution Host—The computer on which you run the MATLAB application software, the SIT Server, and the simulation itself. The execution host can be the host computer or a Windows computer on the same TCP/IP network as the host computer.
The following figure shows how these components work together:

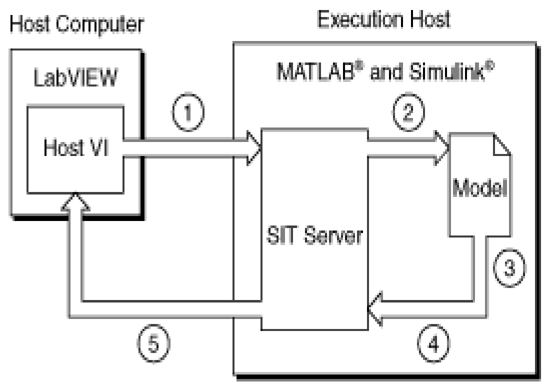

Fig 18: Components of simulation

When one run the host VI, the diagram code initializes the simulation and defines the relationship between host VI controls/indicators and model parameters/signals. As one change the values of front panel controls, the simulation executes the following steps:

1. The host VI block diagram uses TCP/IP to send the new parameter values to the SIT Server.
2. The SIT Server transmits these new parameter values to the model.

3. The model uses these new parameter values to execute the blocks, which update the appropriate signal values.
4. The SIT Server probes the model signals for which you created mappings.
5. The SIT Server transmits the new signal values to the host VI, which updates the front panel indicators.

The Simulation Interface Toolkit (SIT) provides a seamless integration between The MathWorks Inc. Simulink® software and LabVIEW. The Simulation Interface Toolkit automatically generates LabVIEW code to interface with a Simulink® module resulting in a flexible and easy-to-use user interface. First configure the Simulink® model to communicate with LabVIEW. Then can a LabVIEW host VI is created ,that automatically calls, runs and interacts with the Simulink® model.[18]

8 Software Architecture

The VI is designed to monitor the response of Dstatcom for conventional controller and energy based controller. The various parameters that can be analyzed are source voltage and current, load voltage and current, capacitor voltage etc

Front panel Window

The Front panel window is the user interface for the VI. Fig 19 shows a front panel window for the present system. The front panel window is created with controls and indicators, which are the interactive input and output terminals of the VI, respectively.

A front panel control is designed including the following:

- Three phase input supply voltage.
- Knob for controlling the proportional control values.
- Knob for controlling the integral control values.
- Timer for switching the DSTATCOM
- LED gets ON when dstatcom is working
- Option to select conventional controller or energy based controller
- Waveforms like source voltage and current, load voltage and current, capacitor voltage etc

Block Diagram Window

Fig.20 shows block diagram window contains this graphical source code. Front panel objects appear as terminals on the block diagram. The block diagram code of the host VI contains mappings that connect LabVIEW controls to model parameters and LabVIEW indicators to model signals. Mappings can be created using the SIT Connection Manager dialog box.

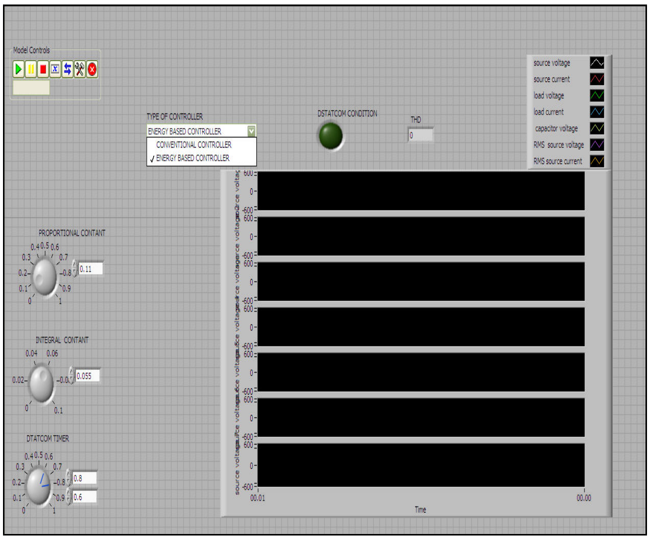

Fig 19: Front panel window designed for the system

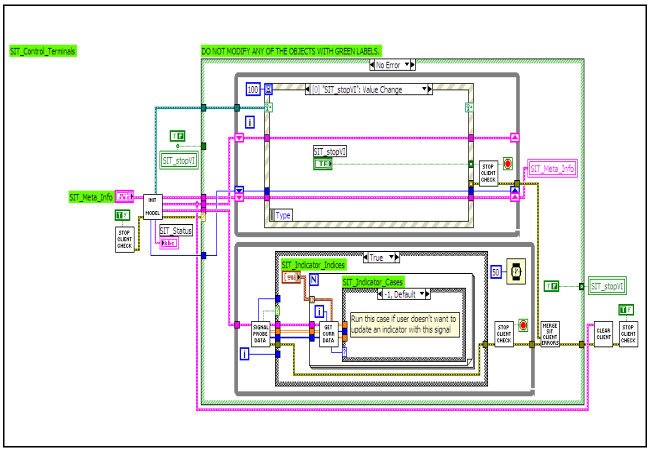

Fig 20: Block diagram window designed for the system

Fig 21 shows the image of the working model of the dstatcom designed using LABVIEW and MATLAB software

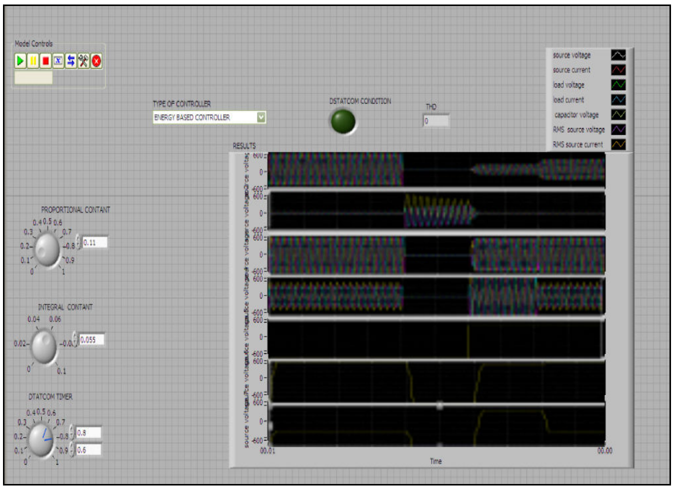

Fig 21: Waveforms in front panel window

The interfacing between both the softwares is done so that PI control values, three phase input values can be changed and results can be verified for different conditions can

Both MATLAB and LabVIEW are powerful programs for technical computing. However, each offers a completely different workflow and user experience. While MATLAB provides an interactive problem-solving environment and excels in symbolic manipulation and sophisticated data analysis, LabVIEW combines robust input-output capabilities with a highly polished collection of GUI components tools for data acquisition and control. Most technical computing challenges can benefit from the combined power of the two approaches

9 Conclusions

A new three-phase four-wire energy based DSTATCOM has been proposed for three-phase four-wire distribution system to improve the power quality. The performance of DSTATCOM system has been demonstrated for load balancing, harmonic compensation, THD has been reduced for both linear and non-linear loads. Thus the transient time has been greatly reduced in energy based controller making a better control strategy for Dstatcom

The future of virtual instrumentation is promising. As such companies as Intel and Microsoft continue to usher in new technologies for advanced productivity and connectivity; virtual instrumentation's benefits will increase. Improvements in PC technology and VI hardware and software will make new applications possible. Companies like National Instruments are promoting VI to make it reach everyone. Quite sooner the traditional instrumentation will be completely moved inside the computer. Thus, An integral assessment of the response of a three-phase network by means of a new indicator has been suggested.

Appendix

Supply voltage =400V (L-L), 50 Hz

Loads: (i) Linear: 25.Ω, 44+j25.5Ω, 50+j86.6Ω

(ii) Non-linear: Three phase full bridge rectifier drawing 5A

DC load =100Ω

DSTATCOM:

Interfacing Inductance, Lf = 25 mH, 0.25 Ω

DC bus capacitance of DSTATCOM: 2000 µF.

DC bus voltage of DSTATCOM: 400 V.

DC voltage PI controller: Kpd=40, Kid=20

Energy based voltage PI controller: Kpq =0.11, Kiq =0.055

Referenced Dc voltage: 520 V

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