SIMULATION OF DSTATCOM, DEVELOPMENT OF RELIABILITY MODELS AND ESTIMATE THE VARIOUS RELIABILITY INDICES OF THE SYSTEM

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Abstract
Distribution systems are facing severe power-quality (PQ) problems [1], such as poor voltage regulation, high reactive power and harmonics current burden, load unbalancing and excessive neutral current, etc. The load voltages in the distribution Systems are also experiencing PQ [2] problems, such as unbalance in phases, flicker, sag and swell, etc. In order to limit the PQ problems, many standards are also proposed [3-5], such as a detailed investigation is made into the causes, standards, and remedies of the excessive neutral current.

In the paper, a new Multilevel inverter type advanced phase shifted pulse width modulation technique is to be adopted to use as Control algorithm for multilevel inverter topologies like diode-clamped inverter (neutral-point clamped), capacitor-clamped (flying capacitor), and hybrid cascaded H-bridge multilevel inverter First addresses with the three-phase 5-level multi level inverter and second addresses with the three-phase 7-level multi level inverters and comparison with respect of power losses, cost, weight and THD.

The performance of the three-phase four wire Multi level inverter type DSTATCOM is proposed to validate using MATLAB software with its Simulink and power system block set toolboxes. The results will be compared with existing topologies in this area. Also it is proposed to study the development of reliability models and estimate the various reliability indices of the system.

Index Terms: Electrical Distribution Systems, Power Quality, Multilevel Inverter, D-STATCOM, Reliability.

I. INTRODUCTION

A group of controllers together called Custom Power Devices (CPD), which include the DSTATCOM (distribution static compensator), The DSTATCOM, is a shunt-connected device, which takes care of the power quality problems in the currents It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, ac filter, coupling transformer and a control strategy. The basic electronic block of the D-STATCOM is the voltage-sourced inverter that converts an input dc voltage into a three-phase output voltage at fundamental frequency. The D-STACOM employs an inverter to convert the DC link voltage Vdc on the capacitor to a voltage source of adjustable magnitude and phase. Therefore the D-STATCOM can be treated as a voltage controlled source.

The D-STATCOM can also be seen as a current-controlled source. The generalized instantaneous reactive power theory which is valid for sinusoidal or non-sinusoidal and balanced or unbalanced three-phase power systems with or without zero-sequence currents were later proposed [8]. The construction controller of the D-STATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically adjusted so that the D-STATCOM generates or absorbs the desired VAR at the point of connection. The phase of the output voltage of the thyristor-based inverter, V_i, is controlled in the same way as the distribution system voltage, V_s.

The DSTATCOM is based on the instantaneous real-power theory; it provides good compensation characteristics in steady state as well as transient states [11]. The instantaneous real-power theory generates the reference currents required to compensate the distorted line current harmonics and reactive power. It also tries to maintain the DC-bus voltage across the capacitor constant. Another important characteristic of this real-power theory is the simplicity of the calculations, which involves only algebraic calculation [12]. A multilevel inverter can reduce the device voltage and the output harmonics by increasing the number of output voltage levels. There are several types of multilevel inverters: cascaded H-bridge (CHB), neutral point clamped, flying capacitor [2-5]. In particular, among these topologies, CHB inverters are being widely used because of their modularity and simplicity.

Various modulation methods can be applied to CHB inverters. CHB inverters can also increase the number of output voltage levels easily by increasing the number of H-bridges. This Thesis presents a DSTATCOM with a proportional integral controller based CHB multilevel (five level and seven level) inverter for the harmonics and reactive power mitigation of the nonlinear loads. This type of arrangements have been widely used for PQ applications due to increase in the number of voltage levels, low switching losses, low electromagnetic compatibility for hybrid filters and higher order harmonic elimination.

II. OBJECTIVE

In the paper, effort has been made to study the application of the adoption of types of inverters for DSTATCOM applications which causes to decrease the device voltage and the output harmonics by increasing the number of output voltage levels. Inverter circuit is heart of DSTATCOM and various inverter topologies can be utilized in applications of DSTATCOM such as: cascaded H-bridge, neutral point clamped (NPC) and flying capacitor (FC). In particular, among these topologies, CHB inverters are being widely used because of their modularity and simplicity. The simulations are adopted in MATLAB-SIMULINK environment with different combinations of the multi-level inverters and also loads. The following are the estimations obtained:

1. Source voltages and currents
2. Load voltages and currents
3. Neutralizing currents
4. Total Harmonic distortion
5. Power factor
6. DC bus voltage across capacitor
7. Power Quality problems(voltage sag)

III. PROPOSED SYSTEM

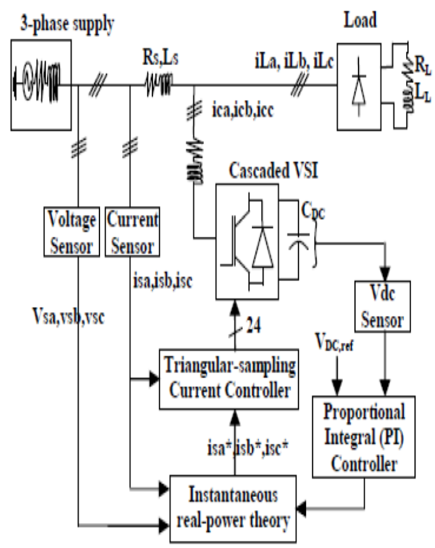

Fig 1: Schematic diagram of DSTATCOM

Instantaneous real-power theory based cascaded multilevel inverter based DSTATCOM is connected in the distribution network at the PCC through filter inductances and operates in a closed loop. The DSTATCOM system contains a cascaded inverter, RL-filters, a compensation controller (instantaneous real-power theory) and switching signal generator (proposed triangular-sampling current modulator) as shown in the Figure 1. The three-phase supply source connected with non-linear load and these nonlinear loads currents contains fundamental and harmonic components. If the active power filter provides the total reactive and harmonic power, is (t) will be in phase with the utility voltage and would be sinusoidal. At this time, the active filter must provide the compensation current therefore; active power filter estimates the fundamental components and compensating the harmonic current and reactive power.

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III. Reference Current control strategy

The control strategy adopted for the shunt active power filter is to calculate the current reference signals from each phase of the inverter using instantaneous real-power compensator. The block diagram as shown in Figure.3, that control scheme generates the reference current required to compensate the load current harmonics and reactive power. The PI controller is tried to maintain the dc-bus voltage across the capacitor constant of the cascaded inverter. This instantaneous real-power compensator with PI-controller is used to extracts reference value of current to be compensated. To enhance the performance of distribution system, D-STATCOM was connected to the distribution system. D-STATCOM to be designed using MATLAB - SIMULINK R2010a 7.10 version [6].

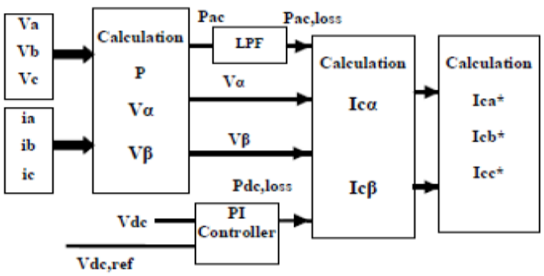


Fig 2: Reference control strategy for instantaneous real-power theory

D-STATCOM Simulations and Results for THD Total harmonic distortion, which is the summation of all harmonic components of the Voltage or current waveform compared against the fundamental component of the voltage or current wave.

VI. SIMULATION MODEL AND RESULTS

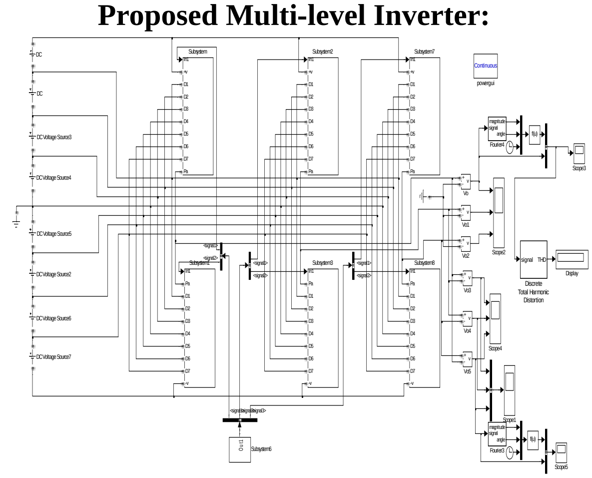
DSTATCOM for mitigating power quality problems like voltage sag obtained by three-phase fault in 3-phase 4-wire distribution network. Inverter is used for the compensation purpose and synchronous reference frame theory with PI controller is adopted with the control of DSTATCOM.

The simulations considered in this thesis are:

1. Simulation of Distribution System without DSTATCOM and APF.
2. Simulation of Distribution system without DSTATCOM and with APF.
3. Simulation of Distribution system with DSTATCOM and with APF by considering Linear load.
4. Simulation of Distribution system with DSTATCOM and with APF by considering Non-Linear load.
5. Simulation of Distribution system with DSTATCOM and with APF by considering Non-Linear load, by varying voltage for observing Power quality problems.
6. By considering different Multi-level inverters like 5-level and 7-level with varying different transformer connections like star-delta, T-connected and zig-zag are observed for Linear and Non-linear loads.
7. Designed nine-level multi-level inverter with sinusoidal Pulse width modulation and applied to Distribution system, with varying different transformer connections like star-delta, T-connected and zig-zag are observed for linear and Non-linear loads.

   From all the observations a differerent combinations are obtained:

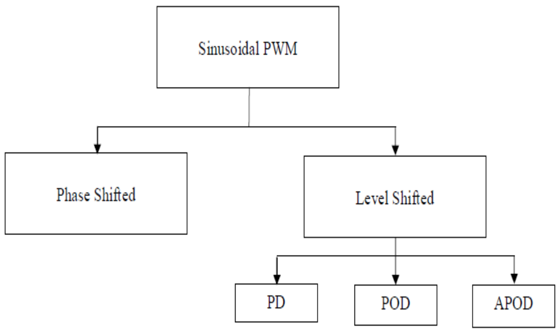
Proposed Multi-level Inverter:



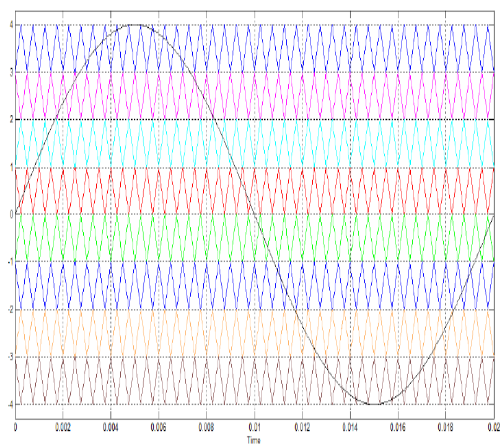
SINUSOIDAL PULSE WIDTH MODULATION:

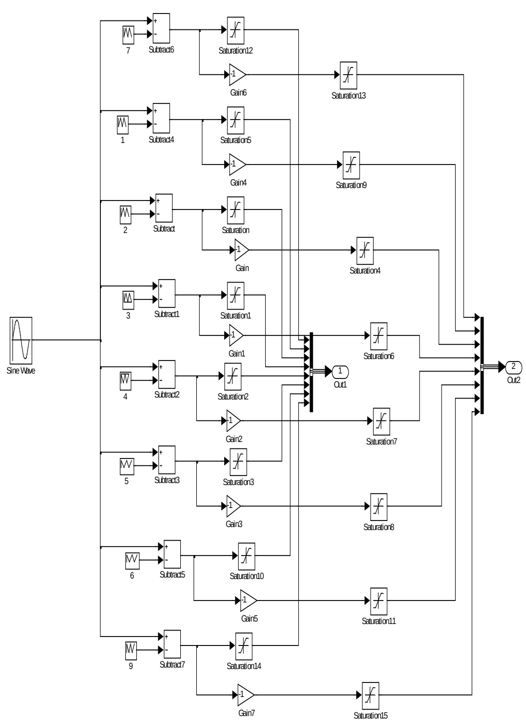
Control techniques for multilevel inverters are based on fundamental and high switching frequency. SPWM, SVPWM and SHE-PWM techniques are mostly used. The SPWM scheme is widely used due to many advantages i.e. simple implementation, low harmonic outputs compares to other schemes, and less switching losses. In SPWM scheme, a high frequency triangular signal is compared with a low frequency modulating signal to generate the control signals. The SPWM is further classified as Phase Diosposition (PD), Phase Opposition Displacement (POD) and Alternative Phase Opposition Displacement (APOD) and is shown in fig.1

Figures 2,3 and 4 shows these disposition techniques. Each of these variations has particular harmonic benefits.



Alternative Phase Opposition Disposition (APOD), where each carrier signal is phase shifted by 180 from its adjacent carriers as shown in figure





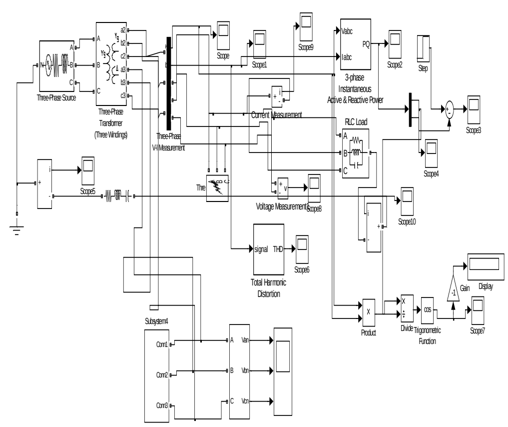
Sinusoidal Pulse width modulation Technique

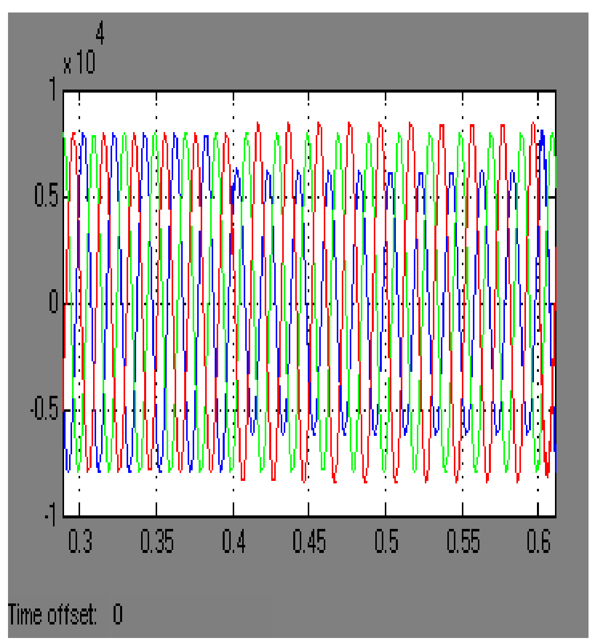
From the case study and analysis, it is clear from the simulation that the alternative Phase Diosposition (PD) scheme is best suited for IGBT/Diode-Clamped Multi-Level Inverter because this scheme produces least harmonics as compared to another two schemes hence the efficiency increases.

A DSTATCOM model with nine-level cascaded bridge type inverters used with the combinations of star-delta, T-connected and Zig-Zag connections for linear and non-linear load. The pulses are generated by sinusoidal PWM modulation.

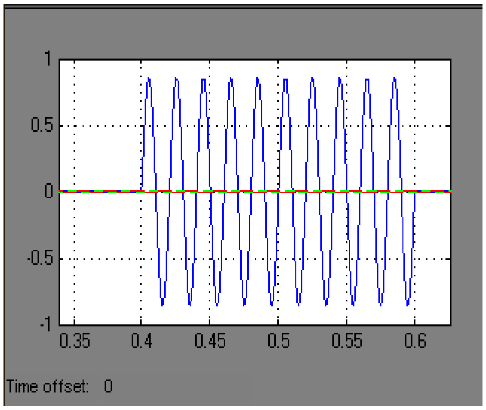
<u>LINEAR LOAD:</u>

1. **STAR-DELTA (Linear Load) With voltage variation applied at 0.4 sec to 0.6 sec**

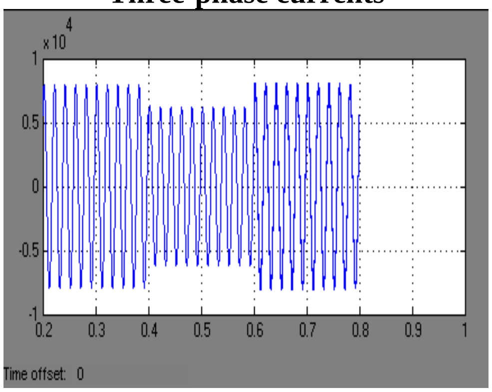




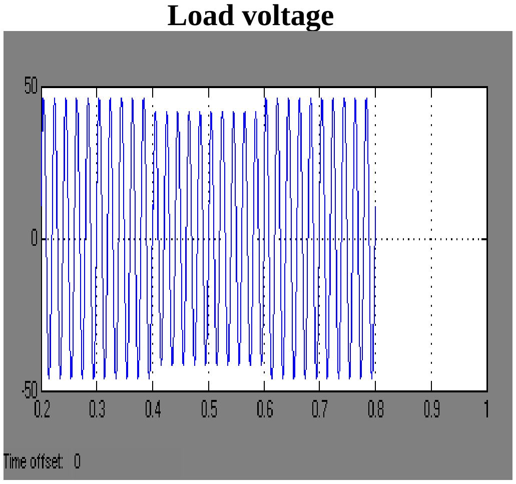
Three-phase voltages



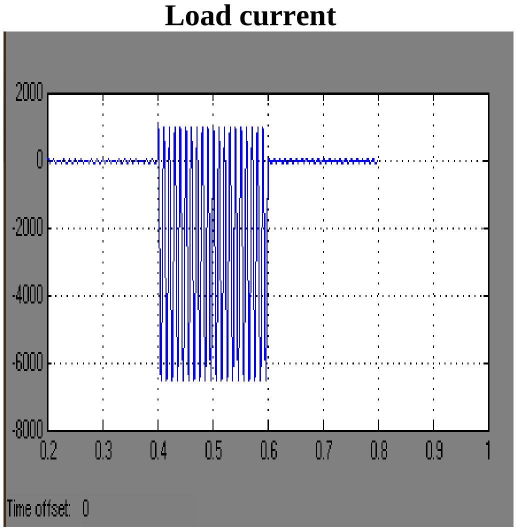
Three-phase currents



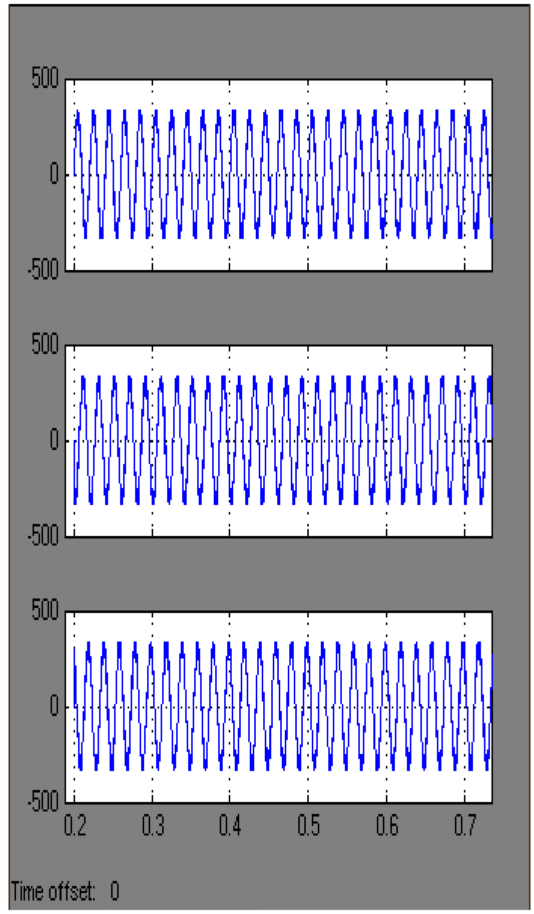
Load voltage



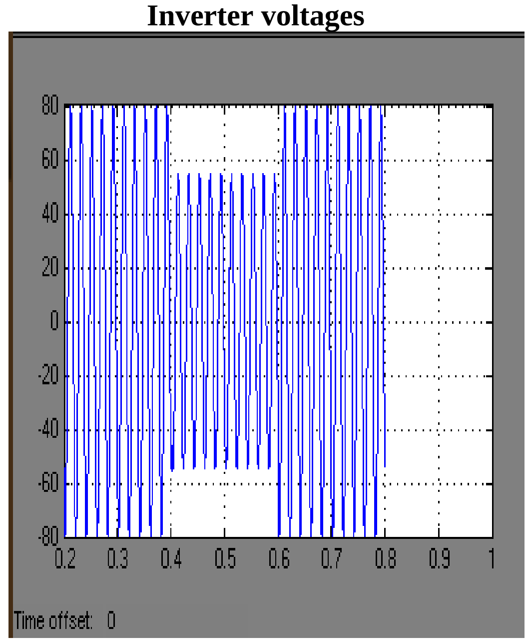
Load current



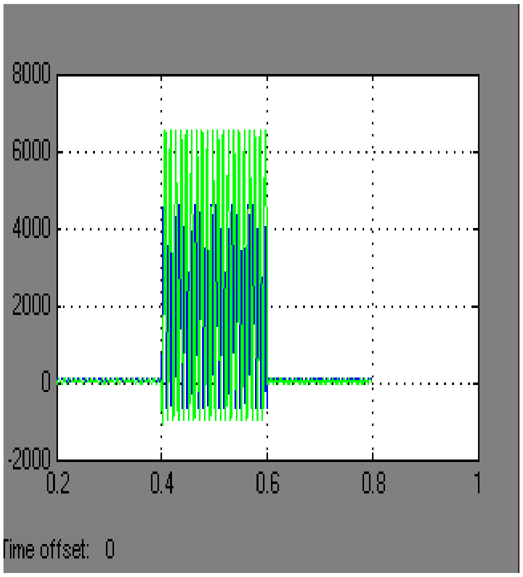
Power loss



Inverter voltages



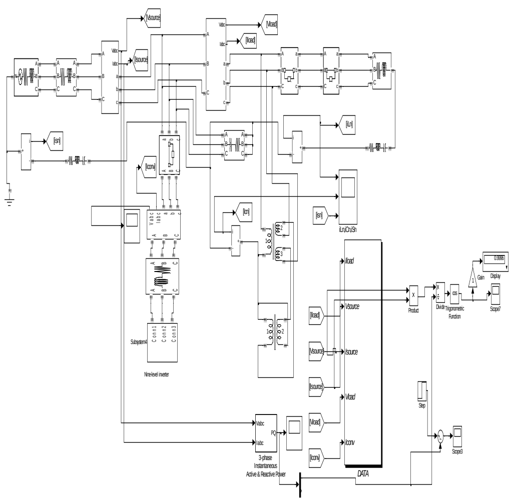
Neutralizing current



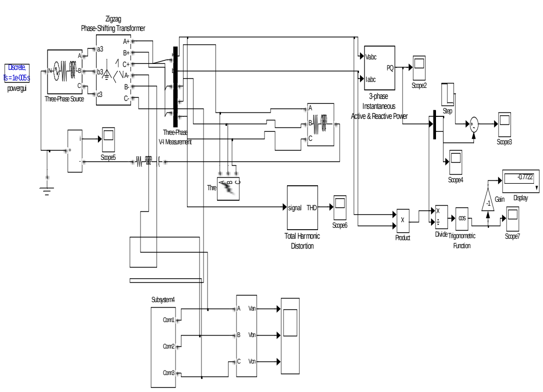
Real and Reactive powers

THD = 0.001252, Power factor = 0.8798

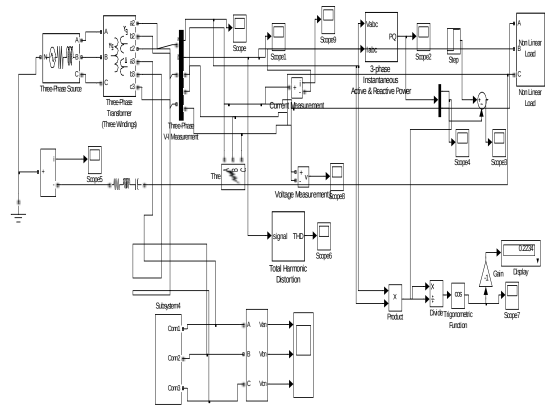
2. T-CONNECTED TRANSFORMER CONNECTION



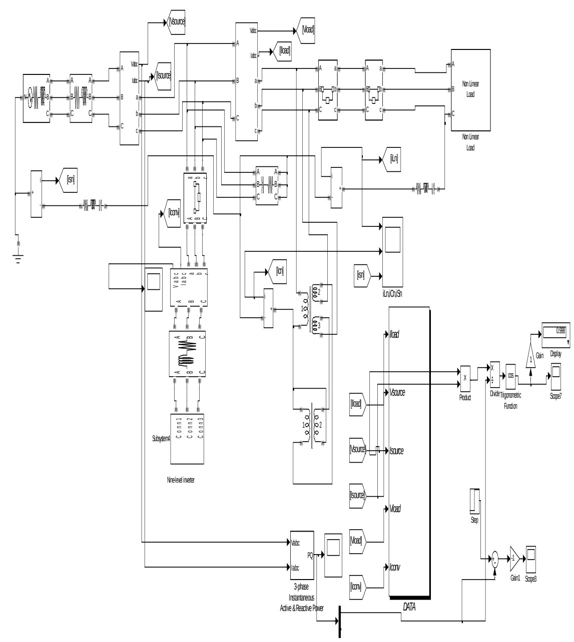
3. ZIG-ZAG TRANSFORMER CONNECTION



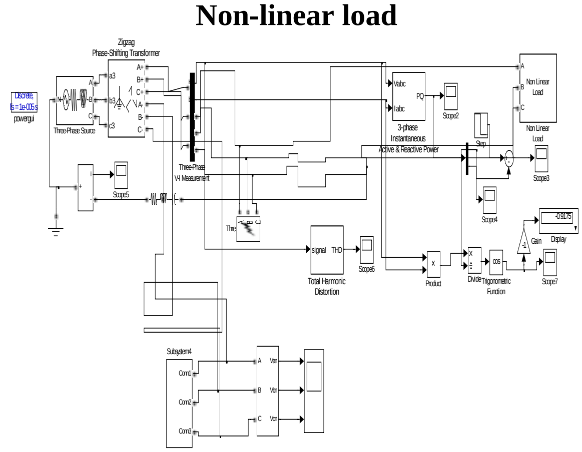
NINE-LEVEL INVERTER WITH NON-LINEAR LOAD AND DIFFERENT TRANSFORMER CONNECTIONS



Star-delta Transformer connection with Non-linear load



T-connected Transformer connection with Non-linear load



Zig-zag Transformer connection with Non-linear load

Parameters compared	With DSTATCOM (Star-Delta transformer connection),		With DSTATCOM (T-connected transformer connection)		With DSTATCOM (Zig-zag transformer connection)	
	Linear Load	Non-Linear Load	Linear Load	Non-Linear Load	Linear Load	Non-Linear Load
THD	0.0012	2.8	0.2611	1.85	0.298	0.42
Power factor	0.8798	0.9567	0.9829	0.9983	0.789	0.6687

Analysis: From the tabular column, it is observed that T-connected transformer is better in power factor and THD estimation, when compared with other transformer connections.

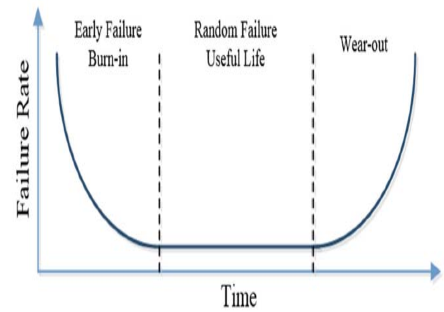
RELIABILITY ANALYSIS:

Extracting the highest possible efficiency from each device has always been the goal of manufacturers. In power converters, this optimal utilization includes high output quality, longer lifespan, less energy consumption, etc. In fact, having a converter with longer lifespan means having a converter with more reliability. Reliability shows the probability of system failure at a given time [17].

The reliability of a system depends on different factors; therefore, to assess that system, it must be divided into smaller parts and reliability of each part then must be investigated. The reliability is usually assessed from various aspects. To determine the reliability of a system, researchers often use indices such as failure rate, mean time to failure (MTTF) and mean time to repair (MTTR) and Availability [18]. Therefore to determine the reliability of a system, first it is necessary to define the basic concepts.

This combined graph can be shown in the form of hazard function, in which case it is called the bathtub curve graph (Figure 2). Similar to combined graph, this graph consists of three parts [21]:

1. The early failure or burn-in period, where the hazard function decreases with time.
2. The random failure or useful life period, where the hazard function is constant.
3. The wear-out period, where the hazard function increases.



1 FIT $=10^{-9}$ failure per hour

Mean time to failure (MTTF) is the average time before the first failure of a component or device after it starts to work. This failure is such that the device is no longer able to continue its normal functions.

$$MTTF = 1/\lambda$$

Approximate Method:

There are two extensively used approaches for reliability assessments to calculate failure rates. The first method is parts count which is a simple way to estimate the reliability of a system. When there is no detailed system information, using this method is preferred. This method uses typical operating conditions called reference conditions to predict the failure rate under these conditions. However, it may be assumed that the device is not working under reference conditions, and the actual operating conditions will affect failure rates calculated from the parts count method. Therefore, this method can be considered as an approximate method. In this method, only the number of components is important, and the construction is not involved. Therefore, this method is typically based on quantitative analyses.

Results and Discussion

With regard to the differences in the structure of power electronic circuits and also differences in the voltage level, base failure rate for each element and for each topology must be calculated separately. Main components of a multilevel inverter generally include the following:

- Diode rectifiers
- DC link capacitors
- IGBT switching devices

Using FIT is one of the standard methods of analysis. As previously mentioned, each FIT is obtained by dividing the number of failures by

one billion hours, and reversing the FIT gives us MTTF.
However, the more correct relationship for failure rate should be as follows:

$$MTBF = \frac{1}{\lambda}$$

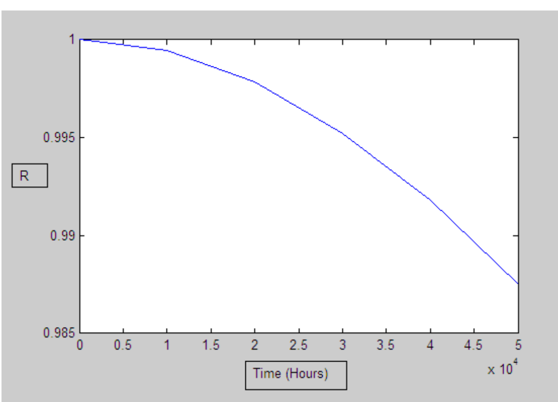
Component/Inverter Type	**Five-level(NPC)**	**Seven-level(NPC)**	**Nine-level(NPC)**
IGBTs	4*6*400	6*6*400	8*6*400
Capacitors	4*300	0	0
Diodes	6*3*100	5*6*100	7*6*100
Total FITs	12,600	17,400	23,700
Failure Rate(failure/10^6 hours)	12.6	17.4	23.7
MTTF	793,650	571,712	**421,940**
1/λ	1.26 e-6	1.74 e-6	2.37 e-6

The graph can be plotted between reliability function and time (hours), where

$$R = 1-(1-e^{-\lambda t})^{n}$$

For Nine-level inverter, n= 2

Time(secs)	Reliability (R)
0	1
10,000	0.99945
20,000	0.99985
30,000	0.9952
40,000	0.99181
50,000	0.9875



Reliability function versus Time (hours)

Quantitative and theoretical with reliability estimation, it can be observed that increased number of levels and thus increased number of power electronics circuit components lead to reduced MTTF.

VII. CONCLUSIONS

A Nine level cascaded multilevel voltage source inverter based DSTATCOM using instantaneous real power controller is found to be an effective solution for power line conditioning. DSTATCOM with the proposed controller reduces harmonics and provides reactive power compensation due to non-linear load currents; as a result source current(s) become sinusoidal and nearby to unity power factor is also achieved under both transient and steady state conditions. The proposed instantaneous real-power controller uses reduced computation for reference current calculations compared to conventional approach.

The cascaded inverter switching signals are generated using triangular-sampling current controller; it provides a dynamic performance under transient and steady state conditions. As evident from the simulation studies, dc bus capacitor voltage settles early and has minimal ripple because of the presence of PI-controller. The THD of the source current is investigated for for SPWM based DSTATCOM. THD simulation results are tested for linear and non-linear loads The reliability analysis is estimated and calculated theoretically by approximate method and obtained plot of reliability using script file in MATLAB environment.

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