Modeling & Simulation of Passive Shunt Filter for Power Quality Improvement Using TCR and TSC Combination By MATLAB/Simulink

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***ABSTRACT*- Power system harmonics are a menace to electric power system with disastrous consequences. The line current harmonics causes increase in losses, instability, and also voltage distortion. This paper presents the combination of passive shunt filters with Thyristors-Controlled Reactor (TCR) and Thyristor Switch Capacitor (TSC) using MATLAB /Simulink are designed and analyzed to improve the power quality at AC mains. Both passive and active filters have been used near harmonic producing loads or at the point of Common coupling to block current harmonics. Shunt filters still dominate the harmonic compensation at medium/high voltage level, whereas active filters have been proclaimed for low/medium voltage ratings. With diverse applications involving reactive power together with harmonic compensation, active filters are found suitable. One of the way out to resolve the issue of reactive power would be using filters and TCR, TSC with combination in the power system**

Keywords – ***Passive filters, Harmonics, Synchronous Reference frame Controller, TCR, TSC***

I. INTRODUCTION

Harmonics and reactive power regulation are upcoming issues and increasingly being adopted in distributed power system and industries. Vital use of power electronic appliances has made power management smart, flexible and efficient. But side by side they are leading to power pollution due to injection of current and voltage harmonics. Harmonic pollution creates problems in the integrated power systems. It is expected that the continuous efforts by power electronics researchers and engineers will make it possible to absorb the increased cost for solving the harmonic pollution. The thyristor controlled reactors (TCR) of various network configurations are widely used in industries and utility systems for harmonic mitigation and dynamic power factor correction these thyristor controlled reactor operates as a variable reactance in both the inductive and capacitive domains.

The main emphasis of the investigation has been on compactness of configurations, simplicity in control, reduction in rating of components, thus finally leading to saving in overall cost. Based on these considerations, a wide range of configurations of power quality mitigators are developed for providing a detailed exposure to the design engineer in selection of a particular configuration for a specific application under the given constraints of economy and the desired performance.

Fig (1) shows a classical shunt passive filter is connected to the power system through common coupling point (PCC). Because of using non-linear load, the load current is highly non-linear in nature. The compensating current which is the output of the shunt passive filter is injected in PCC, by this process the harmonic cancellation takes place and current between the sources is sinusoidal in nature. The passive filter is popular in cancellation of harmonic voltage in power system.

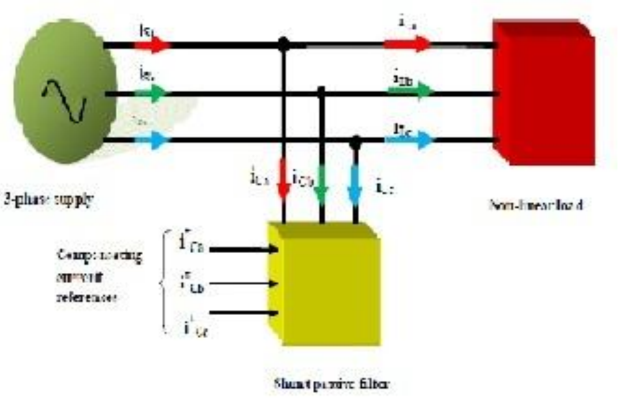

Fig (1) -The Classical Shunt Passive Filter

An overwhelming breadth of the literature, covering different techniques for power quality improvement at ac mains of ac-dc converter is available. The use of passive filters for three phase supply systems, use of thyristor controlled reactor (TCR) and thyristor switched capacitor (TSC) with combination has been the significant developments. Mitigation of power quality problems is synonymous with reduction of harmonic currents or voltage distortion at ac mains. These problems can also be mitigated by improving the immunity of the equipment using better quality material along with proper protection arrangements but it may not result in an effective and economical solution. The design of the passive shunt filter is carried out as per the reactive power requirements. This filter is designed to compensate the requirements of reactive power of the system. Therefore, this passive filter helps in maintaining the dc link voltage regulation within limits along with the power factor improvement. It also sinks the harmonic voltages of frequencies at which the active filters have been tuned.

II. CONTROL TECHNIQUES APPLIED TO PASSIVE SHUNT FILTER

a) SYNCHRONOUS REFERENCE FRAME CONTRO-LLER

The synchronous reference frame theory or d-q theory is based on time-domain reference signal estimation techniques. It performs the operation in steady-state or transient state as well as for generic voltage and current waveforms. It allows controlling the active power filters in real time system. Another important characteristic of this theory is the simplicity of the calculations, which involves only algebraic calculation. The basic structure of SRF controller consists of direct (d-q) and inverse (d-q)-1 park transformations as shown in fig.(2). These can useful for the evaluation of a specific harmonic component of the input signals.

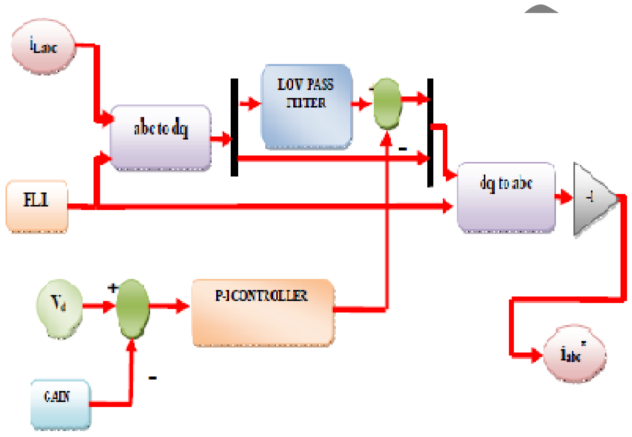

Fig (2) - Synchronous d-q-0 reference frame based compensation algorithm

The reference frame transformation is formulated from a three-phase a-b-c stationary system to the direct axis (d) and quadratic axis (q) rotating co-ordinate system. In a-b-c, stationary axes are Separated from each other by 120˚ as shown in fig(3). The instantaneous space vectors, V_a and i_a are set on the a-axis, V_b and i_b are on the b-axis, similarly V_C and i_C are on the c-axis. The d-q transformation output signals depend on the load current (fundamental and harmonic components) and the performance of the Phase Locked Loop (PLL). The PLL circuit provides the rotational speed (rad/sec) of the rotating reference frame, where ωt is set as fundamental frequency component. The PLL circuit provides the vectorized 50 Hz frequency and 30° phase angle followed by sinθ and cosθ for synchronization. The id-iq current are sent through low pass filter (LPF) for filtering the harmonic components of the load current, which allows only the fundamental frequency components. The P-I controller is used to eliminate the steady-state error of the DC component of the d-axis reference signals. Furthermore, it maintains the capacitor voltage nearly constant. The DC side capacitor voltage of PWM-voltage source inverter is sensed and compared with desired reference voltage for calculating the error voltage. This error voltage is passed through a P-I controller whose propagation gain (K_p) and integral gain (K_i) is 0.1 and 1 respectively.

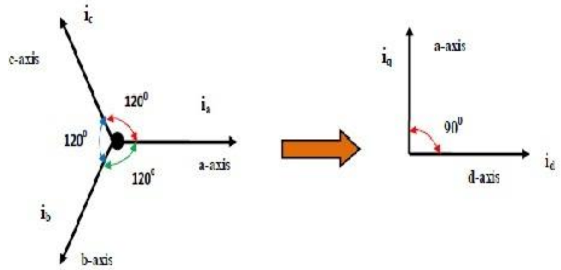

Fig (3) - a-b-c to d-q-0 transformation

b) THYRISTOR-CONTROLLED REACTOR (TCR) AND THYRISTOR SWITCH CAPACITOR (TSC)

(i) TCR
A TCR is one of the most important building blocks of thyristor-based SVCs. Although it can be used alone; it is more often employed in conjuction with fixed or thyristor-switched capacitors to provide rapid, continuous control of reactive power over the entire selected lagging-to-leading range.

(ii) TSC
It consists of capacitor in series with bidirectional thyristor switch. It is supplied from a ac voltage source. The analysis of the current transients after closing the switch brings two cases:

1. The capacitor voltage is not equal to the supply voltage when the thyristors are not fired. Immediately after closing the switch, a current of infinite magnitude flows and charges the capacitor to the supply voltage in an infinitely short time. The switch realized by the thyristor cannot withstand this stress and would fail.

2. The capacitor voltage is equal to the supply voltage when the thyristors are fired. The current will jump immediately to the value of the steady-state current. Although the magnitude of the current does not exceed the steady-state values, the thyristor have an upper limit of di/dt that they can withstand during the firing process. Here di/dt is infinite, and the thyristor switch will again fail.

(ii) TCR-TSC COMBINATION
The TCR-TSC comprises usually n-series of TSC and single TCR that are connected in parallel. The capacitor can be switched in discrete steps, whereas continuous control within the reactive power span of each step is providedby TCR

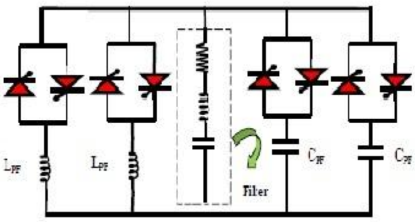

Fig (4) - Circuit diagram of TCR-TSC Combination

As the size of TCR is small the harmonic generation is substantially reduced. The TSC branches are tuned with series reactor to different dominant harmonic frequencies.

The main motivations in developing TCR-TSC were for enhancing the operational flexibility of the compensator during large disturbances and for reducing the steady-state losses. What particularly aggravate the problem in which several voltage swings are experienced and followed by the load rejection. But TCR-TSC can quickly operate to disconnect all the capacitor from the compensator, producing resonant oscillations. The proposed configuration for passive shunt filter with TCR and TSC is shown in fig. (5).

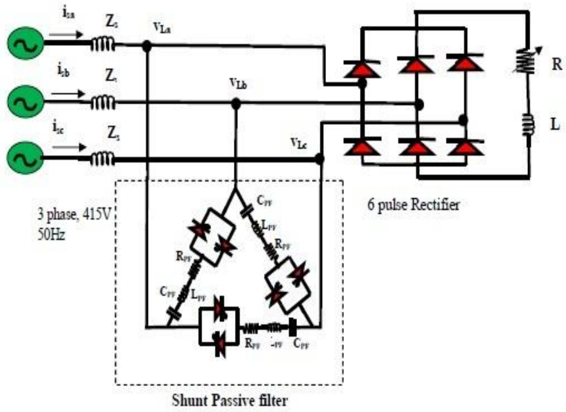

Fig (5) - Proposed Configuration for passive shunt filters with TCR and TSC combination.

c) MODELING AND DESIGN OF PASSIVE FILTER WITH TCR-TSC COMBINATION

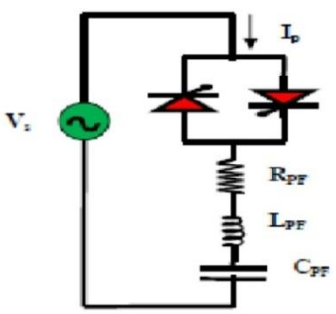

Fig (6) - Circuit diagram of TCR-TSC Combination

Kirchhoff's law equation in Stationary reference frame

$$V_{sk} = L_{PF}\frac{di_p}{dt} + \frac{1}{C_{PF}}\int i_P \, dt \qquad (1)$$

For k=1, 2, 3

Differentiating equation (1) once result in

$$\frac{dV_{sk}}{dt} = L_{PF}\frac{d^2 i_p}{dt^2} + R_{PF}\frac{di_p}{dt} + \frac{i_p}{C_{PF}} \qquad (2)$$

d) MODELING AND DESIGN OF P-I CONTROLLER

The usefulness of PI control lies in their general applicability to most control systems. When the mathematical model of the plant is not known and therefore analytical design methods cannot be used, PI controls prove to be most useful. The standard approach to design is this: a mathematical model is built making necessary assumptions about various uncertain quantities on the dynamics of the system. If the objectives are well defined in precise mathematical terms, then control strategies can be derived mathematically.

The control law is applied to the dynamic model equation-

$$L_{PF}\frac{d^2 i_d}{dt^2} + R_{PF}\frac{di_d}{dt} + \left(-\omega^2 L_{PF} + \frac{1}{C_{PF}}\right) i_d = 2\omega L_{PF}\frac{di_q}{dt} + \omega R_{PF} i_q + \frac{dV_d}{dt} - \omega V_q \qquad (3)$$

$$L_{PF}\frac{d^2 i_q}{dt^2} + R_{PF}\frac{di_q}{dt} + \left(-\omega^2 L_{PF} + \frac{1}{C_{PF}}\right) i_q = -2\omega L_{PF}\frac{di_d}{dt} + \omega R_{PF} i_d + \frac{dV_q}{dt} - \omega V_d \qquad (4)$$

For making system equation (3) & (4) linear, we substitute the two input variables u_d and u_q such

$$u_d = 2\omega L_{PF}\frac{di_q}{dt} + \omega R_{PF} i_q + \frac{dV_d}{dt} - \omega V_q \qquad (5)$$

$$u_q = 2\omega L_{PF}\frac{di_d}{dt} + \omega R_{PF} i_d + \frac{dV_q}{dt} - \omega V_d \qquad (6)$$

The input transformation given in the (5) & (6), the coupled dynamics of the tracking problem have been transformed into decoupled dynamics. Thus the system equation (5) & (6) becomes linear ones.

The corresponding transfer functions are:

$$\frac{i_d}{u_d} = \frac{1}{L_{PF}\, s^2 + R_{PF}\, s + \frac{1}{C_{PF}} - L_{PF}\,\omega^2} \qquad (7)$$

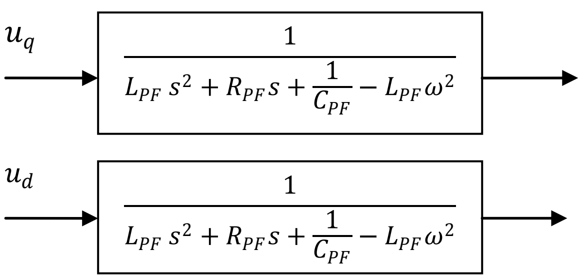

Fig (7) - Block diagram of the closed loop system.

By using error signals $\tilde{i_d} = i_d^{*} - i_d$ and $\tilde{i_q} = i_q^{*} - i_q$ then

Components	Specifications
AC Source	V_s=415 v, freq-50Hz
Non linear load	Three phase thyristor rectifier
Passive filter	L_{PF}=16(mH), RPF=0.83(Ω) C_{PF}=25(μF)

applying P-I compensation u_d and u_q are chosen such that

$$u_d = k_p\tilde{i_d} + k_t \int \tilde{i_d}\,dt$$
$$u_q = k_p\tilde{i_q} + k_t \int \tilde{i_q}\,dt \qquad (8)$$

The transfer function of the P-I controllers is given as

$$G(s) = \frac{U_q(s)}{\tilde{I_q}(s)} = \frac{U_d(s)}{\tilde{I_d}(s)} = k_p + \frac{k_t}{s} \qquad (9)$$

and the closed-loop transfer function of the current loop is

$$\frac{I_q(s)}{\tilde{I_q}(s)} = \frac{I_d(s)}{\tilde{I_d}(s)} = \frac{k_p}{L_{PF}} \cdot \frac{s+\frac{k_p}{k_t}}{s^3+\frac{R_{PF}}{L_{PF}}s^2+\left(\frac{1}{C_{PF}L_{PF}}-\omega^2+\frac{k_p}{L_{PF}}\right)s+\frac{k_p}{L_{PF}}} \qquad (10)$$

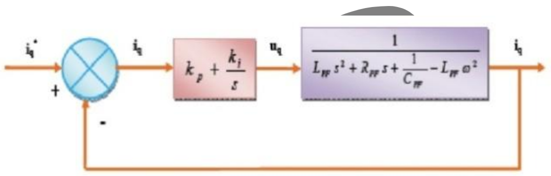

Fig (8) - Block diagram of the closed loop system in q-axis.

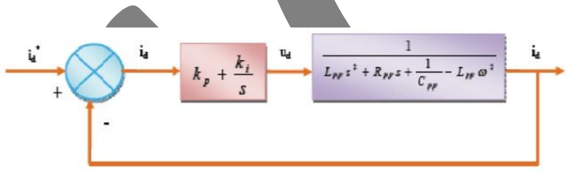

Fig (9) - Block diagram of the closed loop system in d-axis.

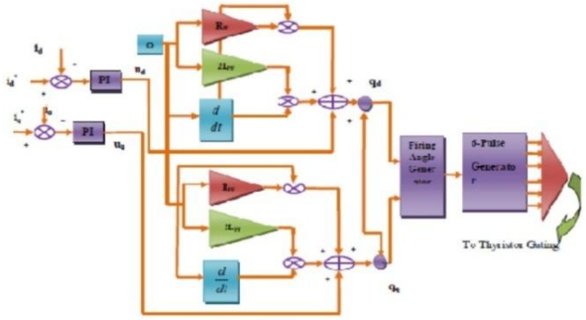

Fig (10) - P-I Controller diagram

III. RESULTS

(a) SIMULATION RESULTS

The simulation results are obtained through Power System toolboxes in SIMULINK by taking system parameter as given below.

i. SYSTEM PARAMETERS

The system parameters considered for the study of Passive shunt filter with TCR and TSC combination is given below in Table (1)

TABLE(1) Specification for Test System

(b) MATLAB BASED MODELING OF PASSIVE FILTER

To demonstrate the performance of these passive filters feeding a three-phase converter with R-L load, these passive filters are modeled in MATLAB environment along with SIMULINK and power system block set toolboxes. Different components of these converters such as low pass filter with R-L load are simulated in MATLAB/SIMULINK.

(c) MATLAB BASED MODELING OF PASSIVE FILTER WITH TCR AND TSC

To demonstrate the performance of these passive filters with TCR and TSC feeding a three-phase converter with R-L load, these are modeled in MATLAB environment along with SIMULINK and power system block set toolboxes. Different components of these converters such as low pass filter with R-L load are simulated in MATLAB/SIMULINK.

(i) Passive Shunt Filter Based Converter with R-L Load

Fig.4 shows the MATLAB model of a passive series filter based six pulse ac-dc converters with R-L load. Depending on the harmonic spectrum of the supply current, the passive filters designed are low pass filter tuned for 5th order harmonic frequency. The subsystem named shunt filter consists of 5th harmonic frequency. Based on the design carried out the filter component values are L=16mH, C=25μF, R=0.83Ω.

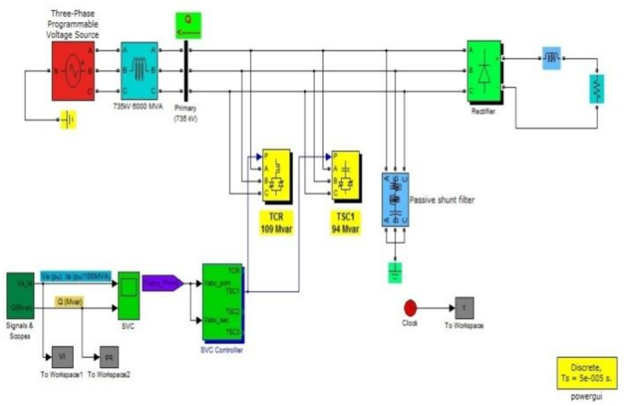

Fig (11) - MATLAB based model of a six pulse ac-dc converter R-L load passive filter with TCR and TSC combination.

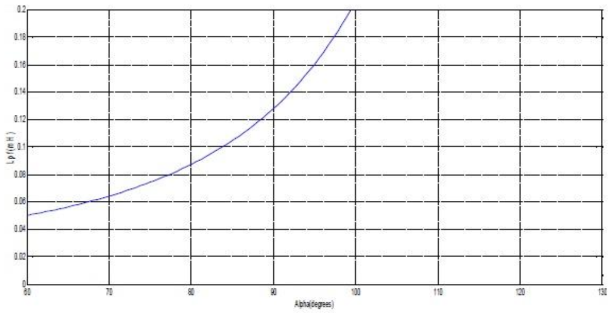

Fig (12) - Inductance and alpha response in star delta connections

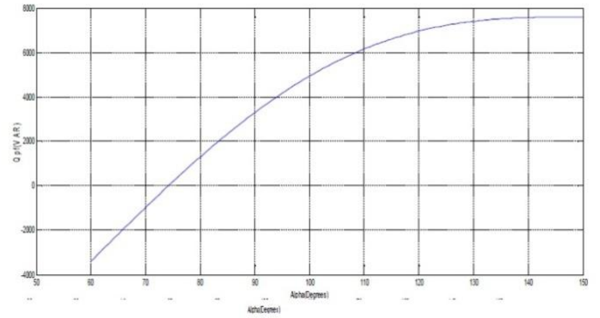

Fig (13) - Reactive Power and alpha response

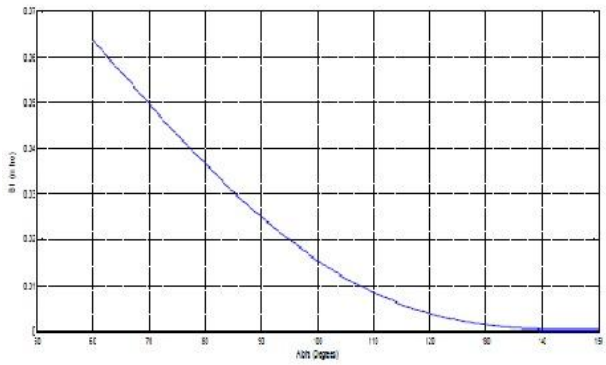

Fig (14) - Susceptance and alpha response

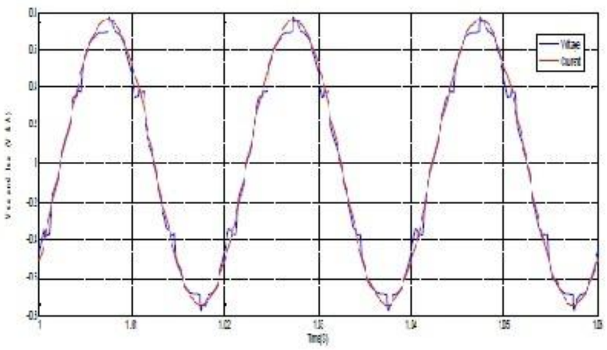

Fig (15) - Voltage and current response of the ac-dc converter with passive filter, TCR and TSC combination.

TABLE (2) Comparisons THD with Different Schemes

Matlab Simulik Model	**Voltage THD%**	**Current THD%**	**Q KVAR**
Without Filter	29.83	7.49	5
With Filter	21.55	1.42	0
Filter and TCR-TSC	7.19	0.7466	0

IV. CONCLUSION

- The effect of multiple harmonic sources can be investigated by applying the superposition principle.
- The SVC harmonic generation modeled by positive-, negative-, and zero-sequence harmonic sources.
- The system represented by linear models at each harmonic frequency.
- The precise evaluation of harmonic distortion must have accurate load modeling.
- Hence the TCR-TSC combination is better in SVC.

V. REFERENCES

[1] "Power Quality":R.C. Duggan, P.C. Sen.

[2] "Power electronics circuits and devices" Muhammad H.Rashid.

[3] "Power system harmonics" :A.J. Arrillga

[4] "Power electronic converter harmonics": Derek A. Paice

[5] Parithimar kalaignan, Sree Renga Raja. "Harmonic Elimination By Shunt Active Filter Using PI Controller" 978-1-4244-5967-4/10/$26.00 ©2010 IEEE.

[6] Position Control of Permanent Magnet Brushless DC motor using PID Controller.

[7] "Simulation of Shunt Active Power Line Conditioner (APLC) for Three Phase AC/DC Converter" by 1 Vaibhav Purwar* and 2 Sanjiv Kr.VSRD-IJEECE, Vol. 1 (9), 2011, 504-513.

[8] J. Chelladurai, G. Saravana Ilango, C. Nagamani, and S. Senthil Kumar, "Investigation of Various PWM Techniques for Shunt Active Filter", International Journal of Electrical Systems Science and Engineering Volume 1 Number 2

[9] George Adam, Alina G. Stan (Baciu) and Gheorghe Livinţ "A Matlab-Simulink Approach to Shunt Active Power Filters".

[10] Shunt filtering techniques for steady-state and dynamic harmonic mitigation and reactive power compensations in power system

[11] N. Senthilnathan Research Scholar School of Electrical Sciences Kongu Engineering College, Perundurai-638 052 "A

Novel Control Strategy for Line Harmonic Reduction using Three Phase Shunt Active Filter with Balanced and Unbalanced Supply".

[12] *PWASET VOLUME 26 DECEMBER 2007 ISSN 2070-3740* "Analysis on Modeling and Simulink of DC Motor and its Driving System Used for Wheeled Mobile Robot".

[13] Sandeep Pande, Hashit Dalvi 1Department of Electrical Engineering, G.H.Raisoni Engineering College, Nagpur, India." Simulation of Cycloconverter Based Three Phase Induction Motor".

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