Enhancement of Performance Parameters of Three Phase Induction Motor by Current Source Inverter: An Overview and Key Issues

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***Abstract*-This paper presents a literature survey on enhancement of performance parameters of three phases Induction Motor by Current Source Inverter. Also presents the current status of the improvement of current control, frequency control, speed control, and reduction of harmonics in three phases IM by CSI. Authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references in the field of improvement of current control, voltage control, frequency control, speed control, and reduction of harmonics in three phases IM CSI.**

Keywords-Harmonic Analysis; Harmonic Distortion Factor; Induction Motor Drive; CSI

I. INTRODUCTION

Previously the inverters were fed from a voltage source and the load current is forced to fluctuate from positive to negative, and vice- versa.[85] To cope with inductive load, the power switches with freewheeling diodes were required, where as in a CSI the input behaves as a current source . The output current is maintained constant irrespective of load on the inverter and the output voltage is forced to change.

The circuit diagram of a single phase transistorized inverter is shown in figure (a). Because there must be a continuous flow from the source, two switches must always conduct- one from the upper and one from the lower switches. The conductions sequences 1-2, 2-3, 3-4, and 4-1 as shown in figure (b) the switch states are shown in table I. transistors Q1,Q4 in figure (a) act as the switching devices S1,S4, respectively.

If two switches, one upper and one lower, conduct at the same time such that the output current is ± IL, the switch state is one; whereas if these switches are off at the same time, the switch state is zero. The output current waveform is shown in figure. (b). The diodes in series with the transistor are required to block the reverse voltages on the transistors.

When two devices in different arms conduct, the source current IL flows through the load. When two devices in same arm conduct, the current source bypassed from the load. The load current can be expressed.

$$I_0=\sum_{n=1,3,5,...}^{\infty} \frac{4I_L}{n\pi} \sin\frac{n\delta}{2} \sin n(\omega t)$$

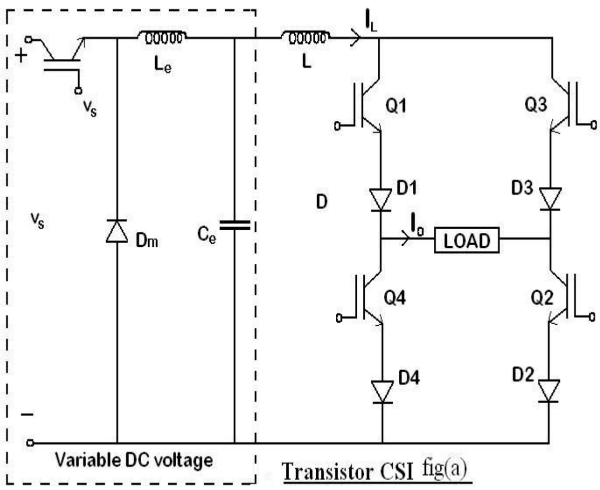

Fig.1 Transistor CSI model

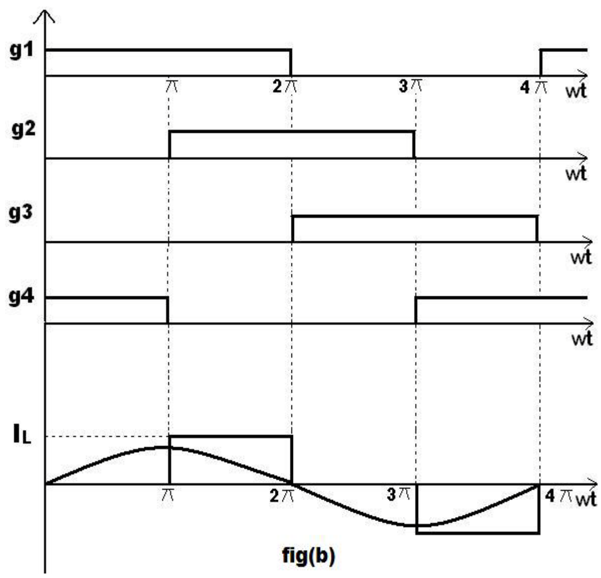

Fig.2 Switch mode representation in waveform

TABLE 1 SWITCH MODE OF TRANSISTOR

State	Switch state S1	S2	S3	S4	I_0	Component conducting
S1 & S2 are on ; S4 & S3 are off	1	1	0	0	I_L	S1 & S2; D1& D2
S3 &S4 are on ; S1 &S2 are off	0	0	1	1	- I_L	S3 & S4; D3& D4
S1 & S4 are on ; S3 & S2 are off	1	0	0	1	0	S1 & S4; D1& D4
S3 & S2 are on ; S1 & S4 are off	0	1	1	0	0	S3 & S2; D3& D2

II. A LITERATURES SURVEY REGARDING WITH CURRENT SOURCE INVERTER APPLIED TO INDUCTION MOTOR FOR IMPROVEMENT OF CURRENT CONTROL, FREQUENCY CONTROL, SPEED CONTROL, REDUCTION OF HARMONICS AND OTHERS PERFORMANCE PARAMETERS.

A. Methods of Control

The following methods of control such as current, voltage and speed control as follows:

1) Current Control

Prasad. N. Enjet, et al. [1], presented a new approach for the control of a current source PWM inverter is proposed to achieve instantaneous current control capability. The proposed scheme provides instantaneous current response in the ac motor by altering the modulation index of the current source PWM patterns. In order to achieve this task optimum programmed PWM patterns with selective elimination of lower order harmonics in the motor line currents are employed.

Mika Salo, et al. [2], suggested the control of the current-source PWM inverter fed induction motor drive. In this the vector control system of the induction motor is realized in a rotor flux oriented reference frame, where only the measured angular rotor speed and the dc link current are needed for motor control.

Yu Xiong, et al. [3], introduced a very simple structure of a new topology which consists of a switching strategy that can ensure equal current division among the branches and current harmonics reduction. Yu Xiong, et al. [4], addressed a new kind of three-phase multilevel CSI topology. This new multilevel CSI’s synthesize the staircase current wave from several levels of balance inductor currents. The switching strategy can ensure equal current division among the branches and current harmonics reduction.

Robert Dawley, et al. [5], applied a control strategy for multi-level (three-level) three-phase dual CSI for high power drives applications. DC current sharing between the dual inverters is implemented by a simple Space Vector based PWM scheme for both CSI. A second alternative scheme to achieve dc link current sharing using a simple flux-based control is also proposed.

Suroso, et al. [6], stated a new topology, that consist a basic H-Bridge CSI working as a main inverter is connected in parallel with inductor-cells operated as auxiliary circuits. The inductor-cells work generating the intermediate level currents to obtain a multilevel current waveform without additional external DC power sources. The proposed circuit generates the multilevel output current waveform with low harmonics distortion by using small inductors.

Mika Salo, et al. [7], introduced a high performance vector controlled PWM current source inverter (PWM-CSI) fed IM drive where only the measured rotor angular speed and the dc-link current are needed for motor control. Novel methods for compensating the capacitive currents of the motor filter and damping the motor current oscillations in the transient conditions are presented.

Marcn Glab, et al. [8] proposed a control system for the IM fed by a PWM CSI based on a multiscalar model. The vector model of the IM fed by CSI with output capacitors of inverter is given.

2) Voltage Control

Peter Eichenberger, et al. [9], presented in this literature paper an induction machine, fed by a compensated CSI with semiconductors having turn-off capability. The principles of a three phase hysteresis controller for the stator voltages are transformed into the complex-plane. A predictive vector controller for the stator voltages was derived.

Jod Espinoza Geza, et al. [10], paper proposes a symmetrical PWM CSI topology with a two loop control Structural voltage regulated current source inverter which ensures instantaneous output voltage control through on-line PWM current pattern generation. Lixin, et al. [11], describes the boost mode test of a CSI fed permanent magnet synchronous motor (PMSM) drives. By using a dc-dc converter together with the CSI, the output voltage of the CSI can be boosted. The modified field oriented control scheme for this CSI PMSM drive is explained and tested in real-time control.

Hongyuan Liu, et al. [12], describes the control of CSI used in direct-drive wind power generation system, where CSI serves as the actuator of the control and optimization. This function of CSI is realized through the control of CSI dc terminal voltage.

P. Cancelliere, et al. [13], suggested an approach to the modulation of a CSI, conceived in order to achieve fast and precise voltage control. Two control methods are analyzed and compared; these are current space vector modulation and a novel voltage-controlled modulation of the current. It shows that the new method is computationally lighter than the synchronous frame PI voltage control. Gaku ando, et al. [14], introduced a new SRM drive method by using the CSI. The problem of huge induced voltage generated by using the current source inverter is solved by the proposed inverter circuit which has a voltage clamp circuit.

Dorin O. Neacsu et al. [15], explained direct topology for AC/AC conversion with reduced passive components and extended output voltage range. Jose R., et al. [16], proposed voltage regulated CSI which has the ability to control multiple loads with fast response and offers similar performance to VSI's and it can maintain balanced sinusoidal voltages for the two extreme cases of non-linear and unbalanced loads. R.W. Menzies, et al. [17], provides a concept which applies pulse width control to a current source GTO inverter supplying a remote load without ac generation to reduce voltage imbalance caused by unbalanced loads. Jose Espinoza, et al. [18], proposed a Voltage controlled CSI which are the duals of CC-VSI's and with the advantages of CSI they can also provide fast and accurate line voltage control.

3) Speed Control

Gui-Jia Su, et. al. [19] focused on extending the constant-torque and constant-power operation ranges of an IPM machine by utilizing the voltage boosting capability of the CSI. Paul M. Espelage, et. al. [20] proposed a drive which features a wide speed range of operation, high inverter efficiency, and good motor current and voltage wave shape over the speed range.

V. N. Nandakumar, et. al. [21] suggested a simple and unique technique of controlling the speed and torque of a 2 kVA salient pole synchronous machine as a brushless dc drive.

Isao Takahashi, et. al. [22] proposed a paper which describes a surface mounted PM motor with the ratings of 5 kW and 180,000 rpm for super high speed drive applications such as machine tool.

Behrooz Mirafzal, et. al. [23] presented a new approach for the speed control of PWM CSI-IM drive systems. This approach is conceptually based on the well-known feedback linearization technique in nonlinear control theory; the commanded DC link current is generated as a specific nonlinear function of speed in the control algorithm so that the torque-speed characteristic of the CSI-IM system is forced to emulate the torque-speed characteristic of a separately excited DC motor.

B. Reduction of Harmonics and Switching Losses

Yuexin Yin, et. al. [24] presents a new electric drive system topology, which is based on PWM CSI. It is aimed at reducing the current harmonics drawing from paper mill distribution systems. Albert Ming Qiu, et. al. [25] suggested the minimization of the line and motor-side harmonics in a high power current source drive system. Vincenzo Delli Colli, et.al. [26] introduces a novel approach to the voltage controlled CSI. The switching strategy is based on the current space vector modulation.

Yu Xiong, et. al. [27], proposed a new type of split-control three-phase 5-level CSI. Each phase of the inverter operates separately, so that multilevel PWM technique can be applied to reduce output current harmonics. Miguel Aguirre, et. al. [28] introduced the design of a shunt active filter implemented with a multilevel CSI connected to the medium voltage level of a power distribution system to deal with reactive power and harmonics in a standard medium voltage distribution network. N. Binesh, et. al. [29] explained a novel Space Vector Modulation for a 5-level parallel CSI with DC current balance control. In this, lower switching frequency is achievable due to switching design which minimizes the switching loss. Fabiana Pottker de Soma, et. al. [30] introduced a new technique to control a single Phase active power filter based on a full-bridge CSI through the Sensor of the input current, allowing the compensation for current harmonics and phase displacement of any linear, non-linear and multiple loads.

N. Vázquez, et. al. [31] proposed to use the CSI instead of VSI, this type of inverters can accept a low input voltage to inject current to the ac mains, because co-generation systems requires converters which able to inject current with low harmonic content. Katsuya Hirachi, et. al. [32] presented a new control strategy to reduce the harmonic component of the single-phase PWM CSI sufficiently even when the ripple current in the smoothing reactor is large. Yu Xiong, et. al. [33] explained a new kind of three-phase multilevel CSI topology is presented in this paper. The new multilevel CSI's synthesize the staircase current wave from several levels of balance inductor currents. The switching strategy that can ensure equal current division among the branches and current harmonics reduction is presented. Hak-Jun Lee, et. al. [34] introduced a current controller design of CSI-fed PMSM (Permanent Magnet Synchronous Machine) drive system in order to attenuate resonance due to the LC filter.

Adrian Schiop, et. al. [35] presented a paper, for the trapezoidal modulation, the formula of the n order harmonic current and can be determined the optimal value for modulation index for cancellation or certain harmonics reduction. P.Saranya, et. al. [36] introduced a generalized technique for realizing PWM patterns which provides selective harmonic elimination (SHE) for CSI to selectively eliminate lower order harmonics with minimum switching frequency.

C. Performance Parameters of Three Phase IM

Ashish Bendre, et. al. [37] proposed a new PWM CSI topology using one controlled switch and six SCRs, the converter uses active commutation to realize pulse width modulation in a conventional SCR based CSI. P. C. Loh, et. al. [38] this paper proposes the design of a tri-state CSI using only an additional semiconductor switch for introducing unique free-wheeling states to the traditional six active and three null states of a CSI.

Zhiqiao Wu, et. al. [39] presents a high performance interior permanent magnet (IPM) machine drive using a current source inverter for EV/HEV applications which improve the performance of the machines. Miguel Aguirre, et. al. [40] suggested a novel modular single rating inductor MCSI topology made by identical modules where all inductors carry the same amount of current. The current balance is achieved by a Phase- shifted Carrier SPWM proper implementation, easy to implement on a FPGA, which allows minimizing switching frequency by taking advantage of the three different zero-states of the topology. Craig R. Bush, et. al. [41] introduced a new CSI that is primarily intended for single-phase photovoltaic applications. The salient features of the proposed topology are low frequency, reduced-size passive components and improved maximum-power-point tracking performance.

Stephen M. Williams, et. al. [42] explained a six-switch CSI for power-line conditioning using a 5-kVA test model of the CSI with insulated gate bipolar transistors controlled by a digital signal processor. Geza JOOS, et. al. [43] explained a modified CSI circuit which removes most of the restrictions at the 'cost' of an extra switch. Additional advantages include faster response times through modulation index control and higher efficiency. M. X. Wang, et. al. [44] presented an active filter comprising a three-phase CSI operating in PWM. Optimal management of switching pattern makes it possible to isolate the three phases and then to achieve accurate model of the PWM inverter, it allows fast and accurate control of the active filter to compensate the nonlinear load harmonic currents.

J. Santana, et. al. [45] provides a view of an incremental global model that describes the cross saturation effect in the induction generator excited by a CSI and supplying a diode bridge with d.c. load. Using the small-perturbation technique the correspondent small-signal linear models are obtained. Zhiqin Shu, et. al. [46] this inverter achieves output power regulation primarily through pulse width modulation within the inverter bridge. The results in a faster system dynamic react with improved efficiency. Suroso, et. al. [47] presented an H-bridge CSI connected with current-cell circuits working to generate the intermediate level currents of multilevel current waveform. This reduces inductor conduction losses. B. M. Han, et. al. [48] proposed a system composed of 3-phase CSI with an H-type soft-switching module, which consists of two semiconductor switches, two diodes, and an L-C resonant circuit which would be suitable for high power application with less switching loss.

Nobuyuki Kasa, et. al. [49] introduced a filed oriented controlled (vector controlled) CSI-fed IM drive system. In which, the motor speed is expected from the d component of the stator voltage. The test results with the sensor-less vector control algorithm are satisfactory at the transient and the normal operating conditions.

G. Tulasi Ram Das, et. al. [50] explained a simple state space mathematical model which describes the motor-inverter combination in the interlude and commutation periods is used for digital simulation. The performances of SPM and IPM motors are compared. The digital computer results in increase in inductances limit the highest frequency of operation while improving the torque characteristics of the motor.

A. Poli E, et. al. [51] presents design, simulation and implementation of FPGA based current controller for single phase bridge. The paper emphasizes new matrix based approach to the modeling of the discrete event systems. Yidan Li, et. al. [52] proposed a simplified trapezoidal integration algorithm as a state-space equation solver to reduce the computational time. An interpolation method is introduced to correct errors caused by the lack of synchronization between the real-time simulator and the digital controller.

D. Applications

Fernando M. htunes et. al. [53] suggested a new cell which lends itself as a generic current multilevel one is applied to a five level CSI with output current harmonics minimization and without the use of high frequency modulation. In this cell, inductors acting as current sources ensure equal current division among switches. DC current balance in the inductors is achieved also without closed-loop control. Two switching strategies are used to demonstrate the performance of the cell.

Sangshin Kwak, et. al. [54] proposed an approach of a multilevel power converter topology based on dual current source inverter or large IM drives, which employs the LCI and utilize its soft switching operation, yielding cost effective solution compared with the conventional multilevel CSI using two GTO CSIs. Gerry Moschopoulos, et. al. [55] proposed a CSI with an auxiliary circuit connected across the dc link inductor, whose purpose is to place zero current notcher in the dc bus current at appropriate instants. This allows switches in the main power circuit to commutate under zero current switching conditions.

C. Photong, et. al. [56] proposed that a single-stage power conversion approach based on a CSI inverter with series capacitors is proposed, proven to provide improved efficiency and smaller DC inductor size and the capability to ride through AC grid faults with full reactive power injection support when compared to a standard CSI.

Jianyu Bao et. al. [57] introduced a new kind of three-phase MCSI topology is derived from the application of the duality on such MVSI topology. This allows the wealth of existing knowledge relating to modulation of multilevel VSI to be immediately mapped to the multilevel CSI.

F. Gaol et. al. [58] suggested the unique diode-inductor network added between current source inverter circuitry and current boost elements, the proposed buck-boost current source inverters demonstrate a double current. Suroso et. al. [59], proposed a common-source CSI the number of gate drive power supply can dramatically be reduced into only a single power source without using a bootstrap technique. The simulation and experimental results proved that the inverter works properly to inject an AC current into power grid with a unity power factor operation. Gregory

Morozov et. al. [60] explained a novel CSI feedback mechanism which combines two existing CSI feedback schemes to achieve The employed CSI reporting schemes are the quantized, codebook-based feedback scheme and the sounding based feedback scheme. The performance of the two feedback schemes is evaluated separately through system level simulations. Suroso et. al. [61] suggested that the multilevel CSI circuit is capable to operate at high switching frequency if required, because all of the power switches are connected on the common potential level.

Craig R. Bush et. al. [62] introduced a low frequency ripple that is common to single-phase inverter has been eliminated; improved maximum-power-point tracking performance is readily achieved due to the tightened current ripple even with reduced-size passive components. Fujio Tatsuta et. al. [63] explained that the tip speed ratios of the individual turbines with different wind velocities can be controlled almost constant with the proposed control method for a large and capricious change in the wind velocity, making an effective operation of the system possible.

S. Woolaghan et. al. [64] proposed a Brushless permanent magnet (PM) drive systems offer a high efficiency over a wide power/torque-speed operating envelope, the loss of control of the power silicon gate drive circuitry during flux weakening operation, control of high-speed low-inductance machines. G. Ertasgin, et. al. [65] explained that the output current is easily controlled using the boost switch and simple open-loop control. The advantage of this arrangement is the ability to conveniently simulate the PV cell over a wide range of irradiance, total harmonic distortion and power factor requirements.

Hasan Kömürcügil , et. al. [66] proposed that for three-phase CSI based on a model of the converter in the rotating dq frame. The control equations are derived by making use of Lyapunov's direct method. The amplitude of the dc current is adjusted by employing a proportional-integral regulator in the output voltage control loop.

H. Feshki Farahani et. al. [67] proposed that an inverter designed and constructed which can be operated in single and three phase mode with any number of harmonics elimination capability. In CSI with resistive- inductive loads, over voltages in output voltage waveform appears. To remove this over voltage, a capacitor is used.

Yan Xiangwu et. al.[68] proposed that direct current control method based on the synchronous rotational axes (d, q, 0) is proposed. This strategy transforms AC variables in the three-phase static symmetric axes into direct values in the synchronous rotational axes (d, q, 0), so the problem of controlling the AC variables is transformed into adjusting the direct values.

Patrick R. Palmer et. al. [69] Abstract-This paper will concentrate on the use of series connected IGBTs in a PWM CSI. We show that the voltages imposed on the IGBTs are controlled by the switching in other branches. This and the voltage sharing circuits for 'off' IGBTs may be optimized for low losses. Muhammad S. Abu Khaizaran et. al. [70] presents an investigation of the use of high voltage IGBTs in the CSI for high power motor drives. Study of the switching transients within the CSI, particularly with regard to advanced gate drives techniques and snubberless operation. IGBTs and diodes maybe controlled and that snubbers are not necessary for voltage control.

Hayato Oishi et. al. [71] A novel single-phase soft-switched CSI which connects the photovoltaic arrays with the utility grid, is studied. To provide the soft-switching capability under the pulse width modulation for a line-commutated thyristor inverter, an auxiliary resonant switch to bypass the current on dc side is connected across dc input of a thyristor inverter.

G.S. Perantzakis et. al. [72] proposed controller predicts the load current for all voltage vectors generated by the inverter. The current error for each voltage vector is calculated and the vector that ensures the smallest value of current error is selected as the inverter voltage vector for the next sampling period. M. M. Amin et. al. [73] proposed for grid-connected permanent magnet wind generators the main advantages of the topology are: high efficiency due to less power losses and reduced number of switching elements, high output power density realization, reduced passive component ratings proportionally to the frequency. Wang Ping Qi et. al. [74] presents a Charge Controlled Modulation strategy for a CSI is studied, which controls the CSI output current integral (charge) to follow a ideal charge track. Charge Controlled modulation is a carrierless scheme switching at a variable frequency. P. Cancelliere et. al. [75] presents a power supply for an axial flux in-wheel motor with a fractional number of slots per pole and per phase. A soft switching ZCS CSI is adopted in order to improve machine and converter efficiency. The chosen topology allows direct motoring and regenerating operation directly from the battery.

Boniface H. K. Chia et. al. [76] presents the artificial neural network (ANN) will be trained based on Feedback Linearization control scheme. Radial Basis Function Neural Networks (RBFNN) is used as online approximators to learn the unknown dynamics of the system. Boniface H. K. Chia et. al. [77] presents a nonlinear control approach to the MIMO svstem of a CSI based Static Synchronous Compensator (STATCOM). A nonlinear mathematical model of STATCOM installed in transmission system is derived.

Faa-Jeng Lin et. al. [78] presents the operating principles of the newly designed driving circuit for the USM, in which the inherent parasitic capacitances formed by the polarized piezoelectric ceramic of the USM are parts of the two parallel resonant tanks, is introduced.

Katsuya Hirachi et. al. [79] presents a new control strategy to reduce the harmonic component of the single-phase PWM CSI sufficiently even when the ripple current in the smoothing reactor is large. Principles of the proposed control strategy and simulation results are described.

K.Hirachi et. al. [80] presents an effective Pulse Area Modulation control strategy to eliminate the harmonic current components in AC side of the single phase current source PWM inverter. The principle of the proposed control strategy for this inverter system is described, and its simulation results are introduced and evaluated. SCrgio Daher et. al. [81] presented the generalized structure and control problem of a multilevel CSI using a generalized current multilevel cell introduced. The necessary control laws are established and the control problem of the seven-level and nine-level structures is studied. Optimizing the step width of the inverter output current ensures current harmonic reduction.

Santana et. al. [82] presents the modeling and behavior study of the Induction generator excited by CSI and supplying a diode bridge at constant output voltage. This system can be used in autonomous applications with variable speed drive, such as wind, ocean wave or hydro power plants.

Sotudeh, R et. al. [83] proposed the characterization of the GTO and the snubber components by formulation of the CSI equivalent circuit during the device commutation period. From the equivalent circuit the state equations are derived thereby obtaining accurate voltage and current waveforms of the GTO and associated snubbers.

Armen J. Baronian, et. al. [84] presented steady state analysis, modeling and digital control design of a single phase CSI power supply system in standalone mode. The multi-functional features associated with modern parallel processing inverter systems can be realized with the proposed bidirectional power conversion scheme.

III. SUMMARY OF THE PAPER

The following chart (Shown in Fig.3.) and table (Shown in Table 2) gives summary of the paper as follows:

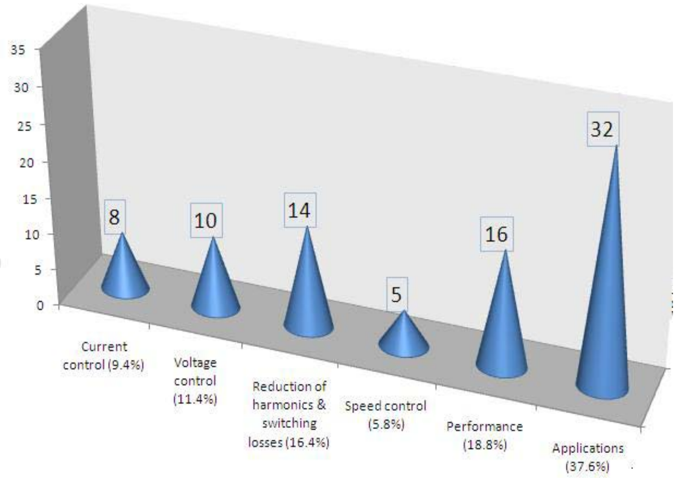

Fig.3 Summary of the paper as chart form

TABLE 2 SUMMARY OF THE PAPER AS TABLE FORM

Methods/Techniques	Total No. of Literatures Reviews out of 85 Literatures	% of Literatures Reviews out of 85 Literatures
Current Control	8	9.4%
Voltage Control	10	11.4%
Speed Control	5	5.8%
Reductions of the harmonics	14	16.4%
Performance	16	18.8%
Applications	32	37.6%

From above Table 2 and chart (shown in Fig.3.) It concludes that the 9.40% of total literatures are reviews based on current control methods, 11.40% of total literatures are reviews based on voltage control, 5.80% of total literatures are reviewed on speed control methods, 16.40% of total literatures are reviewed on reduction of harmonics, 18.80% of total literatures are reviewed on performance point of view, and 37.60% of total literatures are reviewed on applications point of view of three phase Induction Motor by CSI.

Finally it is concluded that the maximum research work carryout from the application's point of view of three phase Induction Motor by CSI.

IV. CONCLUSION

This paper has been addressed a survey of several technical literature concerned with CSI inverter with for harmonics reduction and power factor of three phase Induction Motor. A literature survey also shows the significant improvements in operational performance parameters of the CSI technique such as reduction harmonics, voltage, current harmonics, power factor, switching frequency, and other parameters. The authors strongly believe that this survey article will be very much useful to the researchers for finding out the relevant references as well as the previous work done in the field of reduction of harmonic and improvement of power factor of Three Phase Induction Motor by using CSI. So that further research work can be carried out.

Even though, excellent advancements have been made in classical method i.e. harmonics distortion factor they suffer with the following disadvantages: It needs large inductance to generate constant current source and since current is limited, the dynamic response of CSI is slow.

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