Cascaded Multi-Level Inverter with APOD Based PV System for Induction Motor using DTFC Control

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Abstract. In this paper cascaded multi-level inverter based APOD control is designed to achieve harmonic reduction based on induction motor (IM) application which is fed by switched inductor quasi-Z source inverter (SL-qZSI) is proposed. The control method of proposed induction motor is controlled by direct torque and flux control (DTFC). The proposed converter qZSI is achieving the DC link voltage with improvement and to maintain the constant power supply. The proposed control technique for induction motor directs to reliability improvement and the capability of soft starting. The multi-level inverter with cascaded system is using with APOD control to reduce the total harmonic distortion in the supply voltage. The DTFC achieves the reduced settling time and stator inrush current reductions are achieved. The results and proposed system is analyzed and verified using MATLAB/Simulink environment.

Keywords: APOD PWM, Cascaded MLI, DTFC, Harmonics reduction, IM, Switched inductor quasi-ZSI.

1. Introduction
The Induction motor base drive system has more power density and high efficiency. The induction machine based application is able to operate in constant power and constant torque with wide range under high speed operation condition. In many type of system, the induction motors are preferred [1]. The IM machines for drives are normally adopts for the VSI. The super capacitor or battery is used ad DC power source supply for the system. When the input power supply discharges from capacitor or battery at high current, the voltage is decrease greatly. The control characteristics are affected by voltage which leads to output power reduction. The voltage source inverter the converters are used to improve the bus voltage of the IM based system [2]. This conversion system ensures the constant voltage in DC bus voltage and the mismatch between in the DC bus voltage of inverter and the input dc power supply. At mean time, speed and torque of the machine is operating in wide range since the converter is performs boost state operation. The use of predictive algorithms involves a reasonable estimate of the parameters of the system and, more broadly, greater computing power in comparison to conventional control strategies [3]. Today, multi-phase drive systems are seen as a feasible option and for applications needing redundancies to improve tolerance to failures. In addition, the activity is very close to the well-known Direct Torque Control (DTC) carried out at low switching frequencies. The key benefits of multiphase drives involve that the phase current without growing the phase voltage and the existence of
fault tolerance [4]. The Dead-Beat Direct Torque and Flux Control (DBTFC) is another statistical approach, centered on average voltage vectors implemented at constant switching frequency. Industrial drives require soft engine start up. The key downside of CSI fed drive is that because broad inductors are used to realize the current source, they have a slower dynamic reaction compared to that of drives fed by VSI. On IMD applications a cascaded MLI is required [5]. Multilevel inverter has drawn considerable attention many applications due to the without the use of transformer and without the use of complex voltage control circuits [6]. If the number of output stages grows, the output voltage and current harmonics, as well as the EMI decreases. It's because it has basic layout and fast management of this form of MLI. However, in case of cascaded MLI, the need for independent DC-supplies raises the scale, expense and complexity of the multi-winding transformer. In IMD applications even a moving condenser MLI is used. It's because, this MLI requires less independent DC-supplies [7]. However, the MLI flying condenser configuration and control is too complicated. This is because, at the necessary values, the DC-link capacitor voltages and the flying capacitor voltages should be controlled, which needs a very specific and reliable control algorithm. Increasing carrier waveform is out of alignment with its neighbour carrier by 180 degrees in the case of alternate alignment disposition (APOD) modulation [8, 15]. Because in the case of a seven-level inverter, APOD and POD systems are the control methods for MLI and disposition is used to address the APOD System. Using cascaded-inverter with different supplies the multilevel inverter is target the voltage from multiple individual dc voltage sources, which can be solar cells.

In this paper, qZSI converter is utilized to boost power source dc voltage. The high gain is fed to the cascaded multilevel inverter which connected to the induction motor. The proposed system is compared with the [9]. The MLI with cascaded is controlled with the APOD pulse width modulation and harmonics of the MLI is reduced with 11 levels. The voltage can be controlled by the control system of the proposed system using sensors. DTFC is proposed to control the operation of the proposed IM and voltage for the interfaced inverter. The results are analyzed with this article through the MATLAB/Simulink.

2. Literature Survey
The induction motor operation is controlled using the well-known sensor-less based model reference adaptive control method is used to control in the speed and torque. This is based on the lyapunov theory, and stability based control. The improved speed sensor-less vector control algorithm is proposed for the induction motor performance control. The aforementioned control methods are also providing the ripples in speed [10]. Fault diagnosis of single-phase induction motor is analysed and controlled using the acoustic signals. The direct torque flux (DTC) control used in the induction motor as well as the sliding mode controller (SMC) which is giving feedback linearization. It is robustness method and reduces flux ripples. It has low performance during dynamic periods and disturbances [11]. The PV system is fed to the induction motor based water pump. The converter is used to improve the input power supply which is fed to voltage source inverter. The VSI is controlled using f ield oriented control to achieve the speed and torque control. The interleaved boost converter for achieving high voltage gain based on the fuel cell with controller of MPPT system. The interleaving converter system is increasing the passive elements and enhances the cost and size [12]. The water pumping based induction motor is controlled by using the fuzzy logic control with the adaptive speed estimation which is improve the system response quickly, and ripples free operation. The power quality in the drives are controlled using the fractional order PID control is used to improve the settling time reduction, and rise time minimization. In this [13] the multilevel inverter is used to reduce the total harmonic distortion. The Zeta converter based motor control used for industrial applications. The motor speed is tracked using a hysteresis controller on the back EMF. The proposed method is designed to achieve speed and reduce fluctuation in input voltage. It provides an improved capacity with a high voltage gain rate. It's a zeta and quadratic boost conversion combination [14]. The multilevel inverter with trinary modulation control is used to maximize the voltage levels and which is better while compared with PI controller.

3. Proposed system
In this proposed system, as shown in figure 1. The quasi Z source inverter with switched inductor is interfaced with the PV system to improve the bus voltage of the converter and the system voltage is maintained at stable. Switched inductor qZSI voltage is fed to the MLI with cascaded for the PV power supply to IM with levels voltage as well as reduced harmonics. The cascaded MLI is providing 11 levels to run the induction motor which is controlled by using DTFC. This system consists of photovoltaic system, IM, DTFC method, cascaded multilevel inverter, switched inductor qZSI.

**Figure 1. Proposed System Overall Block Diagram**

3.1. PV Energy Generation

Photo voltaic system has PV cells in parallel and series combination which is utilized to improve the power respectively. PV produces energy directly from solar system and according to solar irradiances as well as temperature it will be changed. The PV circuit of single diode model is shown in figure 2. In PV cells the sunlight is directly converted into dc power. According to photoelectric effect phenomenon the PV modules are worked.

The following equation shows that PV model’s current (I) and voltage (V) (I-V) characteristics:

Where,
- \( I \) = PV current (A)
- \( K \) = Boltzmann constant (J/K)
- \( I_L \) = Light generated current (A) in the PV module
- \( V \) = PV voltage (V)
- \( R_sR_{sh} \) = series and shunt resistance of the single diode PV model
- \( Q \) = Electron Charge
- \( I_0 \) = saturation diode current

**Figure 2. Circuit of single diode PV module**

3.2. Proposed qZSI system

The proposed qZSI is used to improve the DC link voltage from the renewable PV system and to maintain the constant voltage for providing input supply of the cascaded multilevel inverter which is developing 11 levels for soft-starting of induction motor (IM). It has low amount of elements to improve the voltage in both modes as illustrated in figure 3. Normally, the qZSI has two states one is non shoot and other is shoot through mode. Through this, the inrush current is limited and motor soft starting performance is accomplished. Circuit comprises of diodes (D_a, D_b, D_c, D_n), inductors (L_a, L_b, L_c), and capacitors (C_a, C_b). Switches in the inverter based conversion legs are turn ON in same time and the relation of the capacitor and inductor voltage is given as,
\[ V_{Lc} = V_{PV} + V_{Ca} \]  \hfill (1)
\[ V_{La} = V_{PV} + V_{Cb} \]  \hfill (2)

Figure 3. Proposed qZSI Converter Diagram

In non-shoot-through state, the two inductors in the proposed circuit diagram are La which is discharged in this mode as well as the another inductor Lb. The diodes of the circuit will not be conducted in this state named as (Da, Dc) are in OFF condition. The charging of the capacitor is done (Ca, Cb).

4. Proposed system control methods
In this paper, is using the IM based quasi ZSI to achieve the high voltage gain and improve the system stability. The overall proposed control method for the induction motor is shown in figure. 4. It is used to control the response of the IM and improving the exact excitation of the proposed cascaded MLI based induction motor. The output torque of the motor is estimated and fed back to the PI controller. The park and Clarke transformations are implemented to achieve the supply voltage accuracy.

Figure 4. Proposed DTFC Control method

The proposed cascaded MLI is controlled using the APOD based PWM control signals are provided for the power switches of the proposed MLI with cascaded system to achieve the 11 levels in the form of harmonics reduction. Each of the m-1 carrier waveforms are required in this method, as represented in figure.5 for an m-level phase waveform, it is 180 degree disposed from other signals. The control method of the cascaded with MLI is shown in figure 6. In this 180 degree phase out in top two signals each other as well as bottom signal.
5. Simulation and results

Overall simulink model is shown in figure. 7 the PV renewable energy is supplied to IM through the multilevel inverter with cascaded along with the proposed quasi ZSI to improve the high DC link voltage of the proposed converter and achieve the proposed system stable response. The cascaded multi level inverter is generating 11 levels with reduced total harmonics. The output regulated voltage is fed to the induction motor (IM) which is controlled by using DTFT method. The PV system is generating 100V for the IM fed quasi ZSI for improving the DC link voltage and achieving the reference speed and torque.
Figure 7. Overall Simulink Model of the DTFC based IM

The DC link voltage is regulated by the proposed quasi Z source inverter which is powered from the solar system generation. The regulated DC voltage is 220V as shown in figure. 8 and it is supplied to the multi-level inverter to improve the output voltage for the proposed DTFC based induction motor.

Figure 8. DC link voltage

The cascaded multilevel inverter is used to produce levels for achieving the harmonics reduction in form carrier arrangement with control technique of APOD control for the generating switching signals for the proposed cascaded MLI. The proposed system inverter is achieving 11 levels with 230V for the induction motor as shown in figure. 9 based systems to reduce the inrush current which is done by the control method of the direct torque and flux control. The speed of the proposed DTFC based IM accomplished the speed of 1600rpm which is settled in the time of 0.4 sec as shown in figure 10.
Figure 9. 11 levels of proposed cascaded multi level inverter

The torque and stator current of the proposed system are represented in figure.10. The multilevel inverter with cascaded system is reduced the harmonics in the output of the inverter is 9.04% as shown in figure. 11.

Figure 10. Proposed System induction motor speed, stator current, torque

Figure 11. Harmonics reduction cascaded MLI voltage

6. Conclusion
The APOD control based cascaded multi-level inverter is proposed to accomplish the harmonics reduction in the inverter AC output voltage which is fed to induction motor based DTFC control method. The PV generation is fed to propose quasi ZSI for improving the input power supply and it is achieved successfully. The DTFC control is achieved the inrush current reduction as well as limits the current for the stator. In this proposed control method, the settling time of the induction motor speed is reduced and DC link voltage is improved. The MATLAB/Simulink platform is used and verified the results of the proposed system successfully.
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