

Power Electronics Converters for Variable Speed Pump Storage

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ABSTRACT

This paper proposed the power electronics solution to obtain variable speed of the variable-speed pump storage. The study focused on the types of variable-speed pump storage consists of doubly fed asynchronous machine and power electronics converter. Power Electronics converters used in this model are Cyclo-converter, two levels, three levels voltage source-converter and H-bridge cascaded eleven levels converters. The total harmonic distortions of rotor currents of Doubly fed asynchronous machine and speed change for each type of converters are analyzed. Study explained the H-bridge eleven level converter is the best solution than other types. All simulation models depended on the use of PSIM software program.

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1. INTRODUCTION

At present, the variable-speed pump storage technology is the most effective way to store large amounts of electrical energy. The variable-speed pump storage is also used to improve the controllability, grid balancing, increase energy efficiency and stability of power networks. Variable-speed pump storage is divided into two types: separate pump and turbine connected to generator/motor (now is not used), Single Reversible Pump Turbine machine (Francis machine), it operates as a pump and turbine with the same time [1].

To obtain variable speed doubly fed adjustable speed pumped storage unit (DFASPSU) has been used [2]-[5]. The operation of variable speed doubly fed adjustable speed pumped storage unit is similar to a doubly fed induction machine used now in the wind generator.

The configuration of doubly fed adjustable speed pumped storage unit is shown in Figure 1. The stator of the doubly fed machine is connected through a block transformer to the power network. The rotor is driven by an adjustable blade turbine and fed from a power electronics converter.

Nowadays, the research of power electronics converters used in variable-speed pump storage is a multilevel inverter. Multilevel inverter includes three types: the diode clamped inverter, the H-bridge cascade inverter and the flying capacitor inverter.

The important features of multilevel inverters are: They can generate output voltage with extremely low distortion and lower dv/dt compared to conventional two-level inverters and cycle-converter at the same switching frequency and have smaller common mode CM voltage.

Until now the diode clamped and H-bridge cascaded inverters are used to obtain the variable speed of variable speed pump storage.

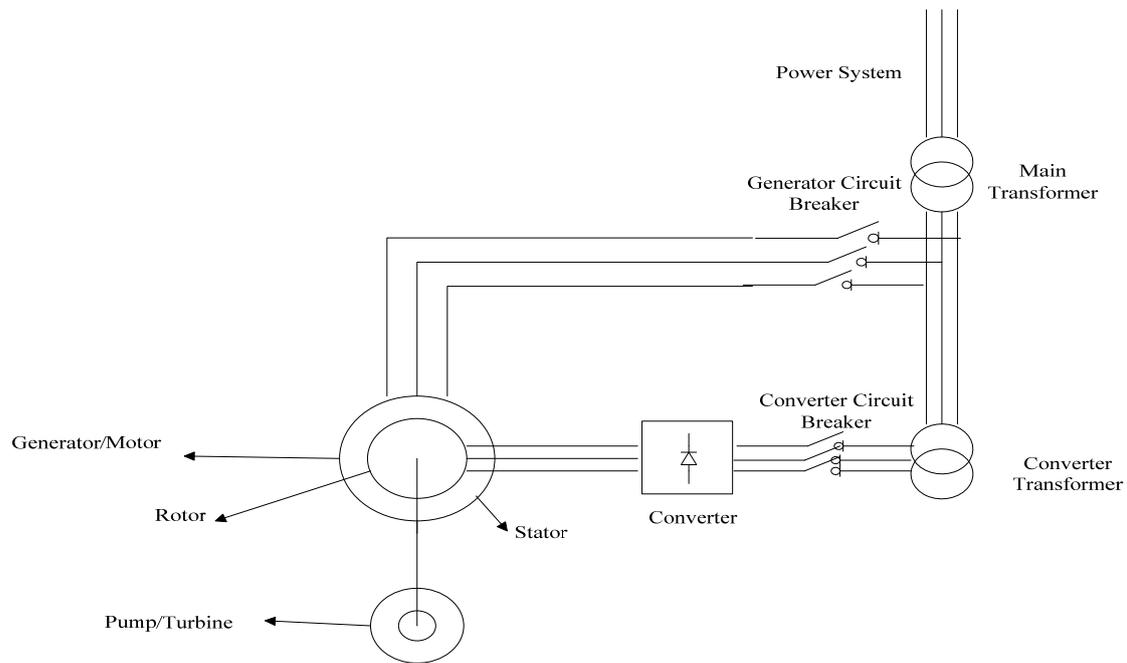


Figure 1. DFASPSU

2. Power electronic solutions to obtain variable speed operation

Now the important point of the power system view, the chance for power control in pumping mode is also one of the most important interests gained by variable speed operation of pumped storage systems. The important point of power electronic drive system is used to obtain a good response time for power control by Take advantage of the inertia of the pump-turbine and the electrical machine, both operating in generating mode and in pumping mode. The power electronics converter fed the rotor of induction machine currently used cycle-converter or back to back converter. Back to back converter is divided into two levels converter or three-level diode clamped converter. The new technology under study used in variable-speed pump storage is multilevel cascaded H-bridge converter [6].

2.1 The cycloconverter

Cycloconverter (AC to AC) is used in high-power applications driving induction and synchronous applications to change the grid frequency from 50 or 60 Hz to a low frequency. It began to develop and apply cycloconverter of speed change in variable-speed drives in hydro electric stations in Japan in the late eighties. They usually use thyristor type GTO in this application in variable-speed pump storage.

The type of cycloconverter used in variable-speed pump storage station is 3ϕ - 3ϕ bridge cycloconverter also called a 6-pulse cycloconverter or a 36-thyristor cycloconverter as shown in Figure 2. The problems of this technology are: the output frequency is less than the input frequency, complicated techniques and structure, required separate SVFC and high THD compare with other techniques shown in Figure 3. The cycloconverter technique is used in Ohkawachi power station in Japan [2] and Goldisthal in Germany [5], [7].

2.2 Back to back two levels voltage source inverter

The topology for a two-level voltage source inverter (AC-DC-AC) for variable-speed pump storage is shown in Figure 4. The inverter and rectifier are composed of six groups of IGBT or GCT switching devices with a free-wheeling diode in parallel with each switch [8]-[10].

The sinusoidal PWM or space vector modulation (SVM) has been designed to generate switching signals for both bridge inverter and rectifier side. SVM improves the THD of rotor current as shown in Figure 5 when sinusoidal PWM used. A two-level inverter AC-DC-AC, have some features, including, simple converter topology and PWM scheme. On the other hand, have disadvantages like High dv/dt , high THD and Machine harmonic losses.

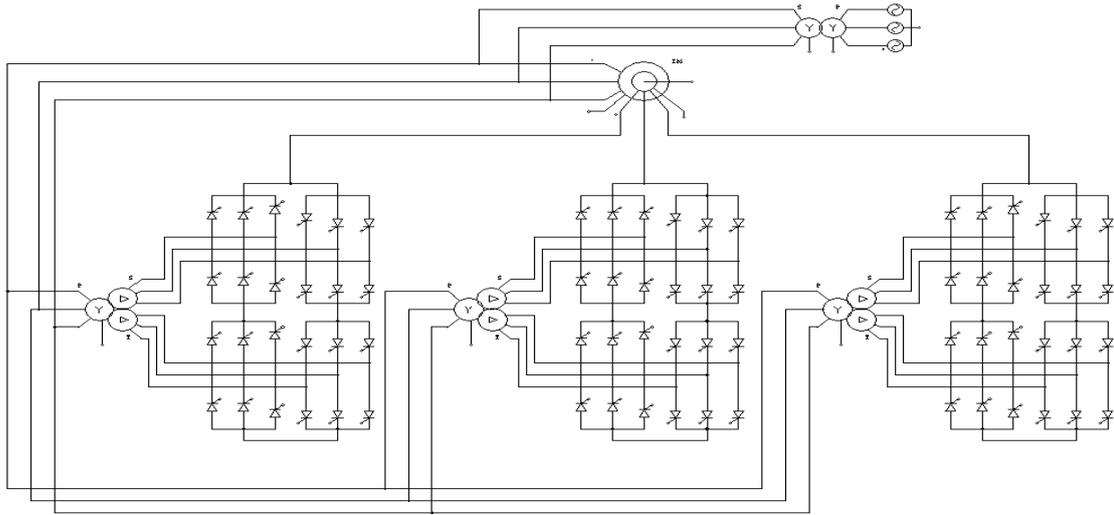


Figure 2. 3 ϕ -3 ϕ bridge cycloconverter

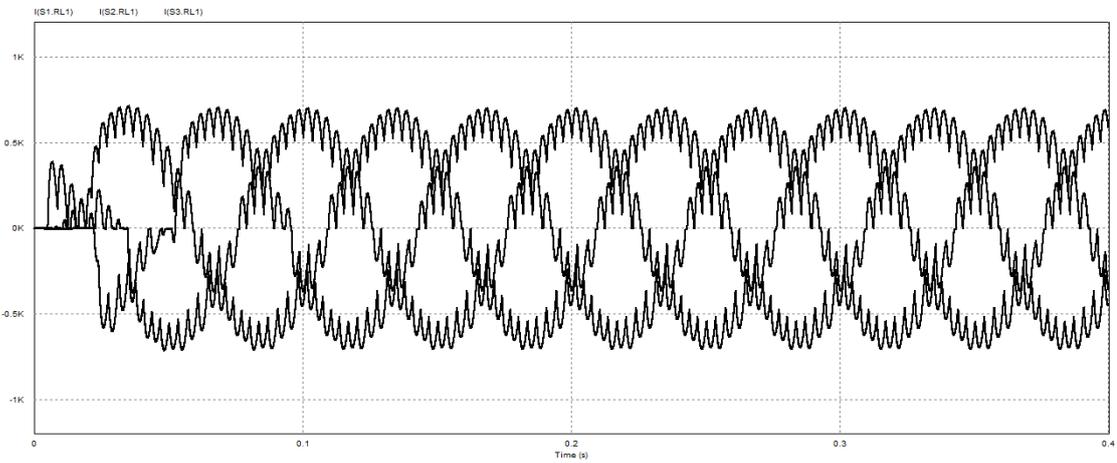


Figure 3. Rotor current from cycloconverter with THD 15.69%

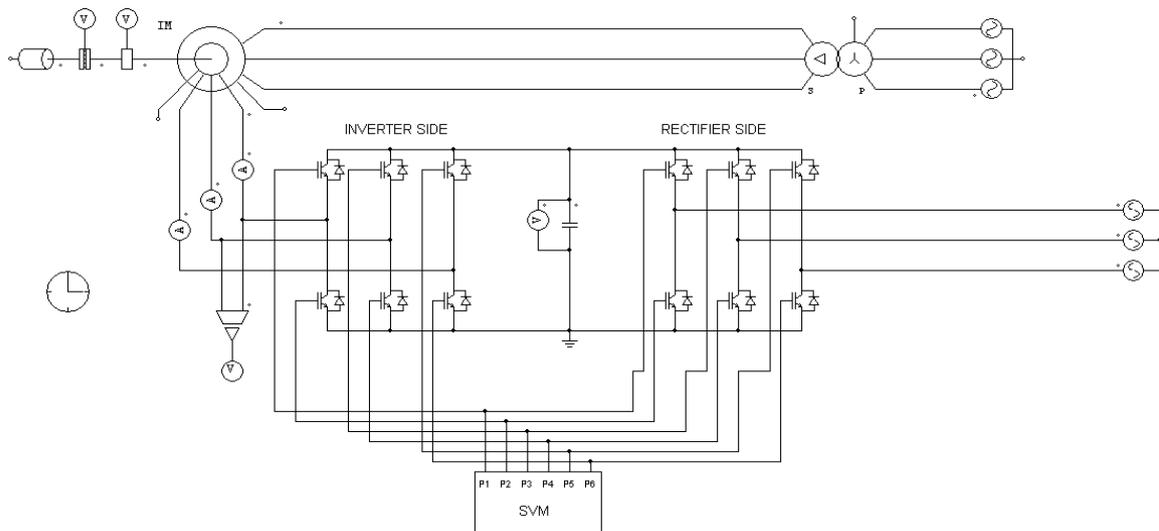


Figure 4. Back to back two levels AC/DC/AC circuit

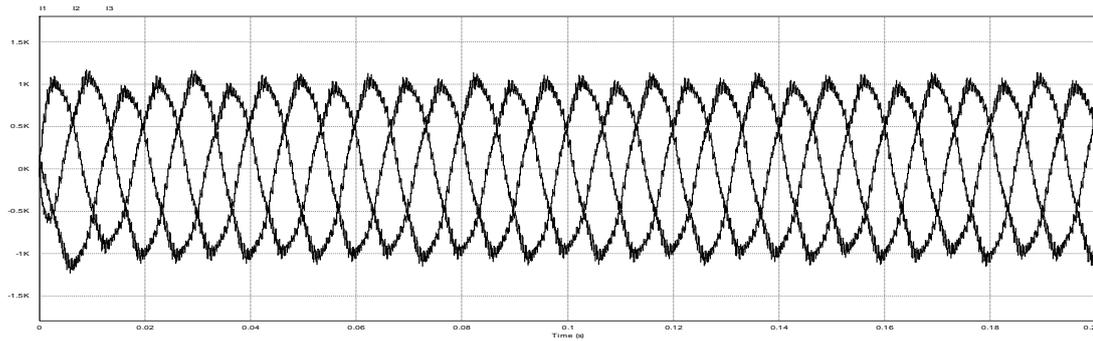


Figure 5. Rotors currents of two level VSI with THD 4.42%

2.3 The three level diode clamped voltage source inverter

The circuit diagram for a three-level voltage source inverter (AC-DC-AC) for variable-speed pump storage is shown in Figure 6. In practice, IGBT, GCT, thyristor technology, GTO, and the GCT can be employed as a switching device [11]. The output of the inverter side is connected to the rotor of the DFAM to produce the variable slip and speed [4], [12]-[14]. The control of the switch of a three-level voltage source inverter is divided into two types; carrier-based PWM and SVM. Carrier-based PWM is used in PSIM simulation model because the other one is more complicated. Figure 7 presents the three-phase rotor currents produce from the AC side.

The three-level voltage source inverter introduces low THD compared with cycloconverter and two-level voltage source inverter. On the other hand, it has some disadvantage which includes: it requires high speed clamping diodes that must be able to carry the full load current and are subjected to severe reverse recovery stresses and complicate a design for levels than three (five and seven) levels.

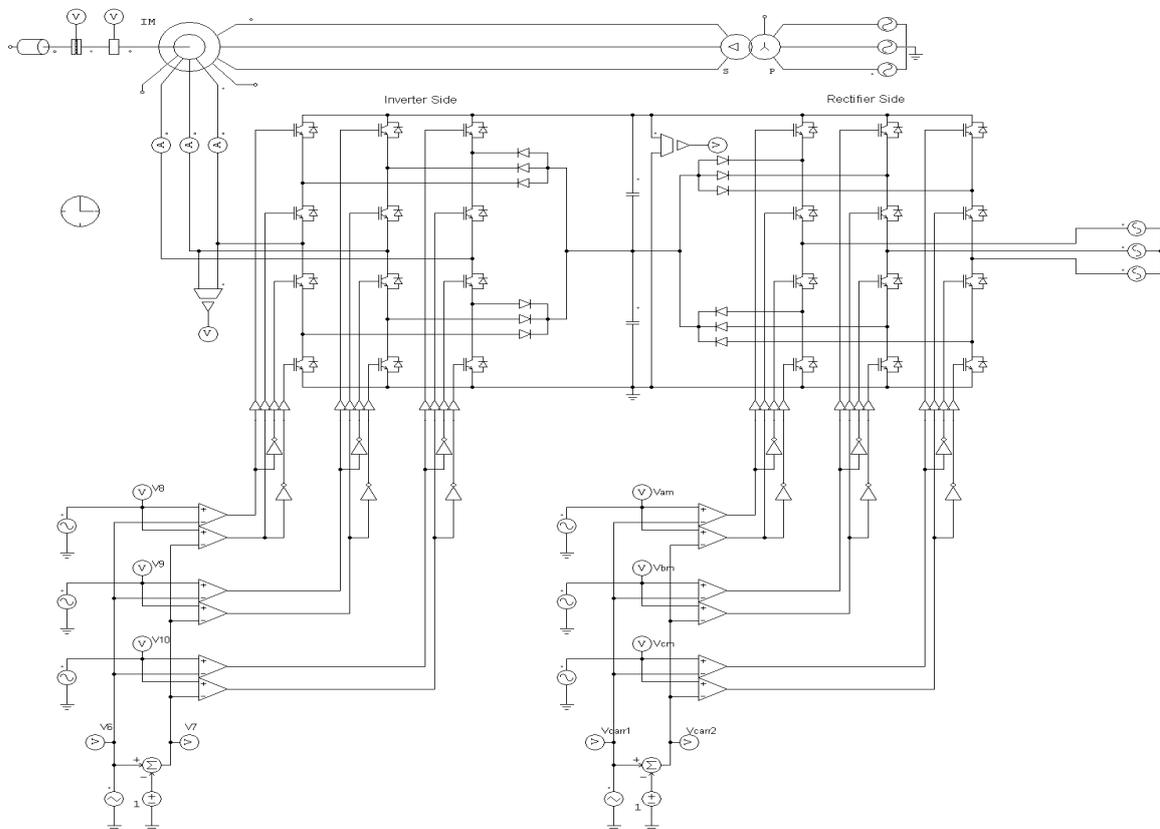


Figure 6. Back to back three levels AC/DC/AC circuit

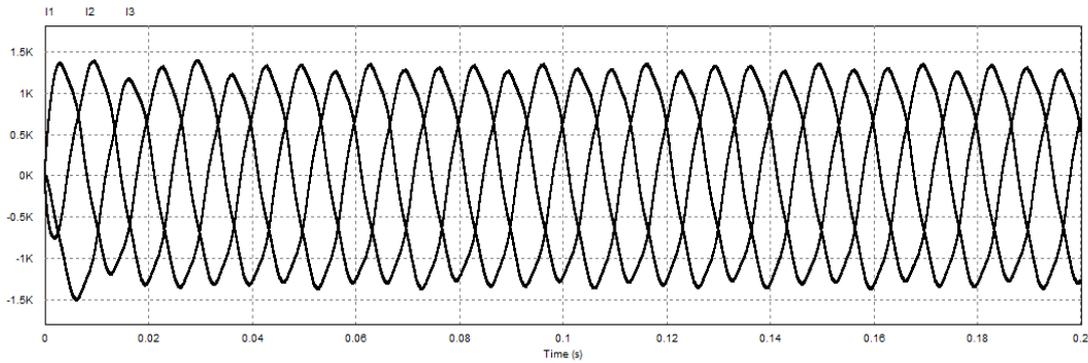
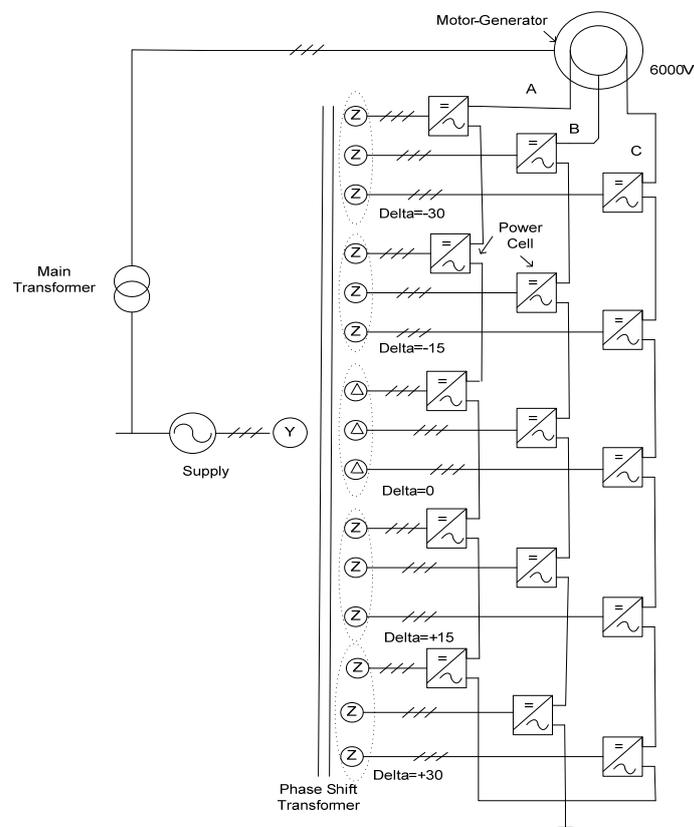


Figure 7. Rotors currents of three level VSI with THD 4.19%

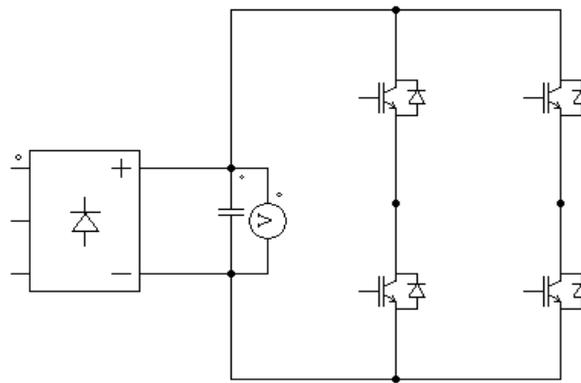
2.4 H-Bridge Cascaded Multilevel Converter

The configuration of variable-speed pump storage based on H-bridge cascaded multilevel converter is shown in Figure 8. It consists of 11 levels h-bridge cascaded multilevel converter, phase shift transformer and wound rotor induction machine. The main purposes of the shift phase transformer are: isolated power supplies for the power cells, improve the THD of the line current and separation between the utility and the converter for common mode voltage mitigation.

The angle between any phases is 15° for the eleven levels of the h-bridge cascaded converter. The secondary winding of the shift phase transformer is connected to rectifier side of power cell. It is connected with construction $(Y/Z - 2, Y/Z - 2, Y/\Delta, Y/Z - 1, Y/Z - 1)$. The pulses of this model are 30 diode rectifiers.



(a) Circuit Diagram



(b) Power Cell

Figure 8. 11 levels H-bridge cascaded multilevel converter

The power cell consists of a three-phase diode rectifier, a dc capacitor and a single-phase H-bridge inverter as shown in Figure 8. B. Each phase composed of five cells with rated voltage 690V; generate 3450 V phase voltage and 6000V line voltage respectively, as shown in Figure 9.

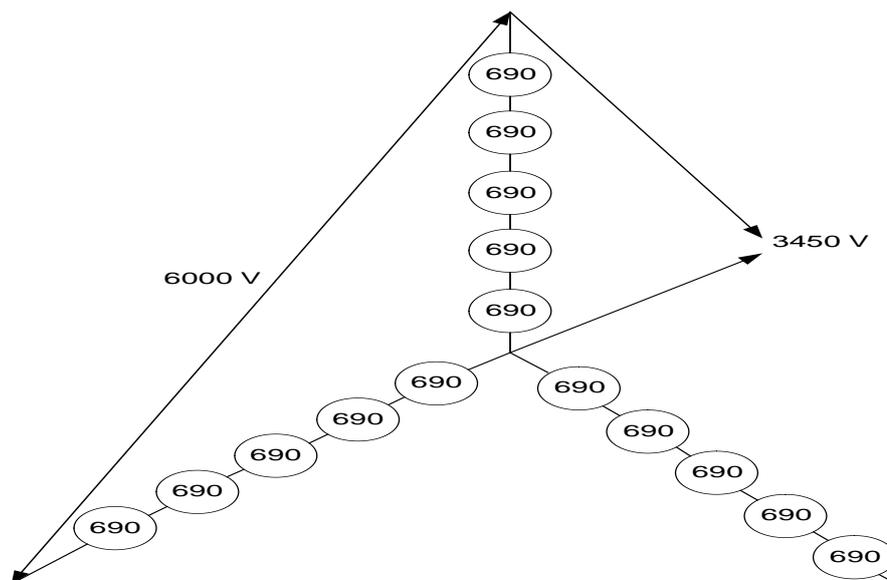


Figure 9. Phase and line voltages of power cell

The in-phase disposition pulse width modulation (IPD PWM) technique has been used to generate switching signals for full bridge inverter side.

The main features of this topology are:

- It requires fewer components than the diode-clamped and circuit for the same number of levels.
- Optimized circuit layout, and packing is possible because each level has the same modular structure.
- Almost sinusoidal output voltage.
- Low dv/dt and currents THD
- They have almost no common mode voltage.

There are a number of disadvantages for the multilevel CHB drive, including: High cost of phase-shifting transformer and large number of cables.

H-bridge cascaded multilevel converter is used to startup the synchronous motor in the pumped storage power stations in China at Xiang Hong station [15].

Figure10. Presents the rotor currents fed variable speed pump storage.

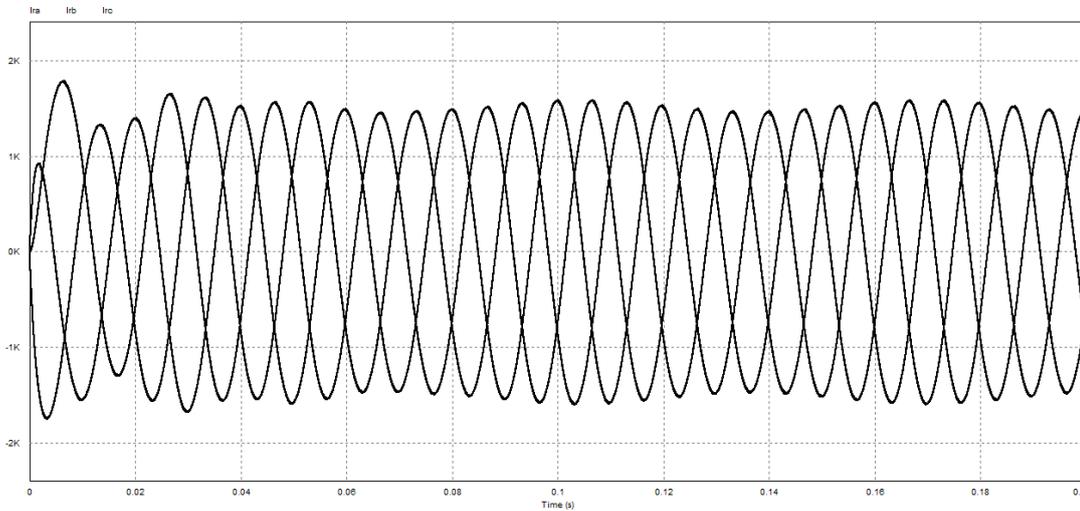


Figure10. Rotors currents of H-bridge cascaded multilevel converter with THD 1.065%

3. Variable Speed Pump Storage Behavior

The parameters of a three-phase induction machine wound rotor type used for all types are shown in Table 1. It is related to mechanical load in term of mechanical speed ω_m given by (1).

$$T_{load} = \text{sign}(\omega_m) \left(T_c + k_1 |\omega_m| + k_2 |\omega_m|^2 + k_3 |\omega_m|^3 \right) \quad (1)$$

Table 1. parameters of the induction machine

Number of poles (P)	4
Rated voltage (V)	6000
Stator resistance (R_s)	1 Ω
Stator leakage inductance (L_s)	1mH
Rotor resistance (R_r)	1 Ω
Rotor leakage inductance (L_r)	1mH
Magnetizing inductance (L_m)	10mH
Moment of Inertia	50m kgm ²
Torque constant (T_c)	10 N.m
Coefficient for the linear term(k_1)	1
Coefficient for the square term(k_2)	1
Coefficient for the cubic term(k_3)	1

Figure 11 Illustrates the variable speed of the wound rotor for 11 levels H bridge cascaded inverter, three levels voltage source inverter and two levels voltage source inverter respectively.

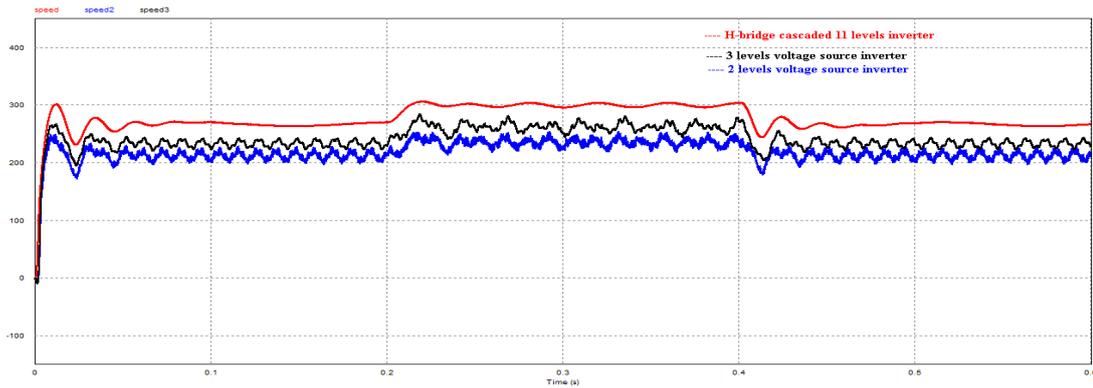


Figure 11. PSIM simulation of variable speed of three types of inverter used in variable speed pump storage

4. CONCLUSION

In this paper, the power electronic converters systems to obtain variable-speed operation of pump-turbines have been discussed. The study includes four types of power electronics converters, cyclo-converter, two levels, three levels of back to back voltage source inverter and H-bridge cascaded multilevel inverter. It has been found that the H-bridge cascaded multilevel converter is the best solution than other types. It has lower dv/dt and currents THD and fast response of speed. All model types have been analyzed by using the PSIM program.

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