Research of Intelligent Lead-acid Batteries Charger in Coal Mine

Yonghong Deng\textsuperscript{ab}, Zhishan Liang\textsuperscript{a}, Haiyu Chen\textsuperscript{a}, Yuanhong Li\textsuperscript{ab} and Quanzhu Zhang\textsuperscript{b}

\textsuperscript{a}College of Geophysics and information Engineering,China University of Petroleum(Beijing),Beijing 102249,China
\textsuperscript{b} School of electronic and information engineering, North China Institute of Science and Technology, East Yanjiao, Beijing, 101601, China

dyhsyjdyx@163.com; 1195078260@qq.com; qzhzhang@ncist.edu.cn

Abstract. The scheme of intelligent lead-acid battery charger is studied, and the advantages and disadvantages of the 5 kinds of intelligent charger are compared and analyzed. A most intelligent and fast charger scheme is put forward. The intelligent charger has the advantages of bidirectional energy flow, small volume, light weight, convenient voltage regulation, small starting current, fast dynamic response, high intelligence, wide input voltage and fast charging. The intelligent charger is made up of various power conversion units. PWM technology is adopted to transform the input three-phase AC380V/AC660V to the DC0V to DC550V through voltage transformation. The intelligent charger scheme is novel, advanced in technology and superior in performance. It can be popularized and applied in the coal mine industry.

Keywords: Mining electric locomotive, lead-acid batteries, intelligent charger, high-frequency Transformer, phase-shift PWM technique, charging modes

1. Introduction

From coal mine safety production point of view, mining electric locomotive is an important mine mechanical and electrical transport equipment. Lead-acid battery electric vehicles have mobility, flexibility, low power supply costs, no sparks and other advantages of explosion-proof. Therefore, the majority of rail electric locomotives used lead-acid batteries\textsuperscript{[1-5]}. Lead-acid battery is relying on the charging device to charge it repeatedly, to achieve the re-use of electrical energy. Therefore, the charger device is an important coal mine used with the lead-acid battery pack. The performance of the charger device directly affects the operational efficiency, service life and reliability of the lead-acid battery. The design of the charger for mining electric locomotives is of utmost importance. This equipment has drawn more and more attention from coal mining enterprises in recent years\textsuperscript{[6-10]}. According to the fast charge theory, the charging process releases the polarization voltage of the battery pack to the power grid instantaneously through the charger, or the battery pack is normally discharged back to the power grid through the charger instantaneously. This charging method increases the charging current or can maintain long-term charge current. Overall, this charging method shortens the charging time \textsuperscript{[11-12]}. Both of the above chargers do not discharge the battery rapidly and are also difficult to charge all the battery packs. According to the actual requirements of mine chargers and the need for fast charging, it is of great significance and broad market prospects to study the mining of lead-acid battery packs for high-frequency smart chargers with bidirectional flow of energy for fast charge and discharge.
In summary, mine lead-acid battery smart charger should have the following characteristics: (1) Taking the actual situation of coal-mine lead-acid batteries in series parallel into account, the charger requirements of lead-acid battery pack, it is necessary to charge all battery packs. The charging voltage output by smart charger should be continuously adjustable between DC0V ~ DC550V. (3) Taking the coal mine power supply and underground harsh environment into account, the charger should automatically adapt to AC380V / AC660 two kinds of input voltage. (4) Taking the requirements of lead-acid battery charging mode into account, the charger can realize stable voltage and can realize multi constant current charging function.(5) The charger should meet the requirements of the charging of the lead-acid battery group in coal mine. The equipment is small in volume, light in quality, easy to move, transport and repair.(6) Considering the explosion protection requirements of the underground, the charger is natural heat dissipation. (7) Charger has the ability to automatically adapt to underground power supply voltage fluctuations. Therefore taking into account the advanced technology and engineering practicality, the study of rapid charge and discharge of lead-acid batteries for mining high-speed smart charger, has important significance and broad market prospects.

2. Comparison of several schemes for intelligent charger control circuit

2.1. An intelligent charger scheme for input power frequency transformer and thyristor phase control

This intelligent charger scheme adds a thyristor phase controlled voltage regulator charger to the input power frequency transformer, as shown in Fig.1, which is widely used in the industry at present. It is a typical AC - direct (AC/DC) voltage conversion mode. The voltage regulating part is realized by phase controlled rectifier with thyristor. The electrical isolation is realized by the power frequency transformer. The primary winding of the transformer by different Y- delta connection, to meet the requirements of AC380V/AC660 two power supply.

The advantages of the power supply of the circuit is relatively simple, transform more directly, not only to achieve the electrical isolation of input and output, but also achieved by the AC voltage to DC voltage output transformation, while increasing the control of output voltage and current regulation, have a certain effect.

The shortcoming is also obvious, because the output voltage of thyristor phase controlled rectifier is 300 Hz, and the pulsating DC voltage is larger, so the charging of battery pack still has some unfavorable factors. If a smooth filter reactor is added to the DC side, the volume and weight of the charger will be increased. In this scheme, the volume and weight of the equipment are greatly increased because of the existence of the input transformer, and the quality of the added flameproof shell is heavy (more than 750 kg). Therefore, the rough charging mode, large volume and heavy weight are the disadvantages of the traditional battery charger, which need to be improved.

![Fig.1. Electrical principle block diagram of intelligent charger for thyristor phase controlled rectifier](image)

Secondly, the multi section constant current charging process of the battery group can not be realized. When the battery group is badly in loss of electricity(Excessive electrical time leads to low output voltage) the charging current must be strictly controlled, and the charging current is limited by reducing the output voltage of the charger, and the pulse of the charging voltage should be as small as
possible. Otherwise, the charging current is too large, the battery is overheated and the plate is aging. The life of the battery is greatly shortened. The traditional charger basically uses analog electronic control circuit, it is difficult to achieve multi-stage constant current charging function, and it is impossible to achieve charging current and battery voltage adaptive charging condition. This is also a significant drawback of traditional charger.

Finally, the two input voltages of the AC380V/AC660V cannot be automatically adapted to the two types of input voltages. It is adapted to the connection mode of changing the power supply to the original side winding of the transformer.

2.2. Input power frequency transformer with uncontrolled rectifier and IGBT chopper voltage regulation intelligent charger scheme

The intelligent charger scheme is called input power frequency transformer plus uncontrolled rectifier and IGBT chopper voltage regulator intelligent charger scheme as shown in Fig.2. The scheme is a "AC direct to direct (AC/DC/DC)" charging scheme. The chopped wave step-down (Buck) converter will cut the DC voltage of the power frequency rectifier to less than DC550V (it can be continuously regulated according to the charging voltage, such as DC0V ~ DC550V), which is used to charge the lead-acid battery group. The voltage regulation part is realized by the IGBT chopping mode, and the electrical isolation is realized by the power frequency transformer. The primary winding of power transformer uses Y- delta different connection, to adapt to the requirements of AC380V/AC660V two power supply.

The advantage of this intelligent charger is that it relies on the power electronic power converter to complete the voltage transformation. This scheme achieves a constant voltage and constant current charging multi segment. The voltage is continuously adjustable, the technology is advanced, and the degree of automation is high. But the disadvantage is that the electrical isolation is realized by the power frequency transformer, and the inductance is added to the DC side, so the charger is large in volume and heavy in weight. The scheme, like the first one, can not automatically adapt to the two input voltages of the AC380V/AC660V, which is accomplished by changing the connection mode.

2.3. Uncontrolled rectifier and chopper plus H bridge IGBT inverter and high frequency transformer isolation and rectification intelligent charger scheme

The scheme of intelligent charger called uncontrolled rectifier plus IGBT chopper plus H bridge inverter and finally added high frequency transformer and rectifying intelligent charger scheme is shown in Fig.3. The scheme is a "cross - Direct - to - Direct - to - direct (AC/DC/DC-DC/AC/DC)" charging scheme, consisting of two sets of converters of AC/DC/DC and DC/AC/DC. Automatically adapt two power supply AC380V/AC660V level AC/DC/DC converter, the DC voltage of the charger controlled rectifier will not reduce, it realizes the input AC380V/50Hz (power frequency) or AC660V/50Hz (frequency) AC voltage into a DC voltage to the DC voltage of the converter. The secondary converter will rectify the intermediate DC voltage inverter and output the charge voltage required by the storage unit. The voltage regulating part is mainly realized by chopper and high frequency transformer, and the isolation of electrical apparatus is realized by high frequency transformer.
This scheme can realize constant voltage and constant current charging multi segment. The voltage is continuously adjustable, the technology is advanced and the automation level is high. It can automatically adapt to two input voltages of AC380V/AC660V. The adoption of high frequency transformer reduces the volume of the device and lightens the quality. It integrates voltage regulation and electrical isolation into one, and the integration degree is high. However, the intelligent charger scheme can not achieve both the two-way flow of energy and the discharge of the lead-acid battery. The charging speed can be further improved.

Fig. 3. IGBT chopper and H bridge inverter with high frequency transformer intelligent charger electrical principle diagram

2.4. Uncontrolled rectifier and H bridge IGBT inverter and high frequency transformer isolation and rectification intelligent charger scheme

This scheme is shown in Fig.4 for the uncontrolled rectifier plus the H bridge IGBT inverter and the high frequency transformer isolation and rectification intelligent charger scheme. The scheme is a "AC direct to AC (AC/DC/AC/DC)" charging scheme. The H bridge converter transfers the DC voltage to DC300V after power frequency rectification, which can be regulated continuously according to the output voltage, such as DC0V to DC300V, to charge the lead-acid battery group. The voltage regulation part is realized by H bridge inverter, and the electrical isolation is realized by high frequency transformer.

The advantage of this charger is that it reduces the volume of the device and reduces the quality. It integrates voltage regulation, electrical isolation and integration, and relies on power electronics technology and microcomputer control technology. Constant current and constant pressure charging is convenient. It is advanced in technology and high in automation. It automatically adapts to two kinds of input voltage of AC380V/AC660V.

The same kind of smart charger will be more expensive than the traditional charger. In particular, to adapt to two kinds of power supply (AC380V/AC660V), the charger has to output the DC voltage of DC0V to DC300V. The variable ratio of the high frequency transformer is designed according to the minimum value of the power supply (The value of the AC380V’s lower limit fluctuates to 75% of the voltage value of AC285V). At the same time, according to the maximum output DC voltage DC300V, the calculation change ratio is 1.3:1; at this time, the original side winding current of the high frequency transformer is 92A according to the rated output current 120A. The original winding and the secondary winding current are basically the same, increasing the difficulty of the design of the high frequency transformer, including the increase of weight and volume.

At the same time, it is assumed that the input power is AC660V used to charge the battery group of the coal mine DC48V. If the control system uses full bridge phase shifted PWM control technology, the phase shift angle of the control system is less than 10 degrees. To meet the charging voltage requirements of all the battery pack, the phase shift range of the charger control system is at least from 10 to 180 degrees. Its stability efficiency remains to be verified.
2.5. Intelligent fast charger scheme for multi power unit

This intelligent charger scheme is actually an improvement in the above charger scheme. The entire main back route is composed of multi power units, as shown in Fig.5. It is mainly composed of 6 parts: PWM rectifier, bidirectional DC/DC converter, bidirectional H bridge inverter 1 (fast rectifier module 1), high frequency transformer, fast rectifier module 2 (bidirectional H bridge inverter 2), and control systems. The variable ratio of the high frequency transformer is set to 1:1.

When the system is in the charging operation condition, energy flows from the power grid to the battery pack: Power grid → PWM rectifier → Bi-directional DC/DC converter → H bridge inverter 1 → High frequency transformer → Fast rectifying module 2 → Battery pack. When the system is in the discharge operating condition, the energy flows from the battery pack to the grid: Battery pack → Bidirectional H bridge inverter 2 → High frequency transformer → Fast rectifying module 1 → Bi-directional DC/DC converter → PWM rectifier → Power grid.

The PWM rectifier [13], when charged, works in the condition of rectifying, and can output a stable DC voltage, which can be adapted to the input power with a large fluctuation range. When working in the inverter, the energy of battery pack can be quickly fed back to the power grid without external discharge resistance unit, which improves the control performance, flameproof performance and reliability of the charger. The input current is sinusoidal and the unit power factor of the system is improved.

To sum up, the charger used in this scheme is automatically compatible with two kinds of input voltage, and the output charging voltage DC0-DC550V and charging current DC0A-DC120A are continuously adjustable, which can charge all specifications of battery pack. By calculation, the duty cycle of Buck chopper can be fixed, the phase shifting angle of 1 H bridge inverter can be adjusted automatically, the duty ratio of coordinated control buck chopper and the phase shift angle of H bridge inverter 1 will be charged to the battery pack. This strategy is easy to implement, control simple and dynamic response fast. All power devices work at the best state and consume less, making the charger efficient and reliable, enabling fast charging and discharging, energy saving and environmental protection.

Through the comparison of the above 5 kinds of intelligent charger schemes, combined with the current technology level and practical application, we think that fifth kinds of intelligent charger schemes are the preferred charger schemes in the current lead-acid battery charger.

3. Conclusion

The intelligent charger scheme for lead-acid battery group is proposed in this paper. It integrates power electronic converter technology, microcomputer control technology, field bus network technology and mechatronics technology. The problem of over voltage and over current charging, resulting in battery heating and scrapping and slow charging speed in the charging process of coal mine lead-acid battery group is well solved. Through the analysis and experiment, the following conclusions are drawn.

1) The smart charger of the lead-acid battery group is small in volume and light in weight, which realizes the miniaturization and lightening of the intelligent charger of the coal mine lead-acid battery group. The same output power (capacity), compared with the traditional charger, can be reduced to the original 1/3, and the weight can be reduced to the original 1/4.

2) In the control system, the full digital microcomputer control and phase shift PWM control technology are used.
(3) In the improvement of the main circuit, the bidirectional flow of energy is realized, and the speed of charge and discharge is fast.

(4) In the aspect of function expansion, intelligent charging is realized by microcomputer control. The charging characteristics are multi segment and adaptive, and the charging curve can be adjusted by multivariable control, and the service life of the battery is prolonged.

(5) It can automatically adapt to the input of two kinds of power supply. The charging voltage can be adjusted continuously, and the charging current can be set according to the need.

Fig. 5. Electrical schematic of a multi power unit intelligent charger

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4. References

[1] Deng Yonghong, Pan Yumin, Zhang Quanzhu, Huang Chengyu. Mine lead-acid battery pack smart charger J. Power Technology, 2013,37(10):1801-1803.

[2] Deng Yonghong, Xu Mingyan, Li Xuezhe. Research on high frequency intelligent charger of lead-acid battery in mine J. Coal Science and Technology, 2015,47(3): 132-135.

[3] Zhang Quanzhu, etc. Mine electric locomotive lead-acid battery smart charger J. Case Automation, 2009;10(28): 121-123.

[4] Zhang Quanzhu, Zhang Feiping, Pei Cui-ling, Deng Yonghong. A new type of mine lead-acid battery smart charger J. Mining Industry, 2013;39(3): 35-39.

[5] Zhang Xiaoqun, Gao Yanxia, etc. Mine motor vehicle battery smart charger development [J]. Coal Mine Machinery, 2007;1(28): 121-123.

[6] Han Xiangfeng, Li Zhen wall, etc. Mine lead-acid battery high-power smart charger development J. Coal Mine Machinery, 2009;1(30): 132-134.

[7] Li Ning, Zhang Hongtao. Mine special type lead-acid battery charging technology J. Coal Mine Machinery, 2013;34(5): 250-252.

[8] Liu Yingcan. Mine electric locomotive battery system using the status quo analysis and upgrading of the direction of research J. Coal Engineering, 2012;10: 121-122.

[9] Guo Fengyi, Miao Chuanhai, Zhang Jihua. Design and implementation of intelligent lead-acid battery charger J. Journal of Computer Applications, 2012;21(3): 76-79.

[10] Feng Chuan-hua. Study on mine embedded intelligent charger based on fuzzy control J. Journal of Changchun Institute of Technology, Natural Science Edition, 2011;12 (1): 58-62.

[11] Zhou Zhimin, Zhou Jihai, Ji Aihua. Charger circuit design and application M. Beijing: People's Posts and Telecommunications Press, 2005.

[12] Wang Gonggong. Lead battery operation and maintenance M. Beijing: Water Conservancy and Electric Power Press, 2006.

[13] Chen Yao, Tong Yibin, Jin Xinmin. New algorithm for harmonic analysis of SVPWM based on PWM rectifier J. Proceeding of the CSEE, 2007,27(13): 76-80.