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STATIONARY OR ONBOARD ENERGY SYSTEMS FOR ENERGY CONSUMPTION REDUCTION IN A METRO NETWORK

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Abstract - The new approach to energy management issues makes Energy Storage Systems an interesting subject for both researchers and industries. One of the most important consumers of electric energy in urban areas is electric railways (metro trains). Thanks to regenerative braking, there is possibility of reusing braking energy by storing and using it again in acceleration period. Designing, sizing, and controlling such system is still an open discussion. In this paper a new control strategy is proposed based on average modeling of the converter between energy storage and dc grid. The simulation in MATLAB- Simulink is presented, all overhead and metro train data are from Mashhad metro line, and as a result of the proposed control strategy, voltage regulation, energy saving and peak power shaving is obtained.

Key Words: Energy Storage System; Supercapacitor; Urban Electric Railway; Bidirectional converter; Average model

1.INTRODUCTION

Considering transportation as one huge source of carbon emission, using electric transportation could be a good solution. Because of its features like capacity, timing, safety, environmental protection and energy saving ability railway electric transportation has become a good alternative for transportation system based on fossil fuels. While electric railway transportation system deals with frequent braking and acceleration, Using energy storage devices could bring energy management advantages. Surplus energy will be stored in energy storage systems (ESS) in braking period and in acceleration phase, the stored energy will be returned to the grid. Studies have shown that in this way, about 20 to 30 percent of energy could be reused, which makes this subject interesting of both researches and industries.

There are some common energy storages which are being used in railway transportation all over the world, like batteries, flywheels, super capacitors (SC) and hybrid energy storages which are combination of more than one of aforesaid energy storages. Despite of the high energy density of batteries, their charge and discharge time are much higher than super capacitors, besides, their life cycle is about a hundredth of them. In contrast, super capacitors present high power density, long life cycle, and easy state of charge (SOC) determination by measuring terminal voltage and they could be charged and discharged very fast with high currents related in electric railway networks. Beside energy saving purposes, some other advantages could be achieved like, voltage regulation, energy and power compensation, reduction of peak power.

The simulation results in MATLAB- Simulink are presented. Network structure is defined and electrical model in Simulink is presented then the ESS sizing performed by means of train kinetic energy and a control strategy based on line voltage is proposed.

The new control strategy is presented based on average modeling of bi- directional DC-DC converter.

SYSTEM DESCRIPTION

Bidirectional DC – DC Converter-

Bidirectional dc – dc converter is used as a key devices for interfacing the storage devices between source and load in renewable energy system for continuous flow of power because the output of the renewable energy system fluctuate due to change in weather conditions. Bidirectional converter is used between energy source and motor of power supply from battery to motor. Bidirectional dc to dc converter work in both buck and boost mode and can manage the flow of power in both the direction between two dc sources and load by using specific switching scheme and phase shifted control strategy and hence generated excess energy can be stored in batteries / super capacitors. Therefore the basic knowledge and classification of bidirectional dc to dc converters on the basis of galvanic isolation the comparison between the voltage conversion ratio and output current.

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A conventional buck- boost converter can management the power flow in one direction only but power can flow in both directions in bidirectional converter. Bidirectional dc to dc converter are the devices for the purpose of step-up or step-down the voltage level with the capability of flow power in either forward direction or in backward direction. These energy systems are not reliable to feed the power as a standalone system because of the large fluctuations in output and

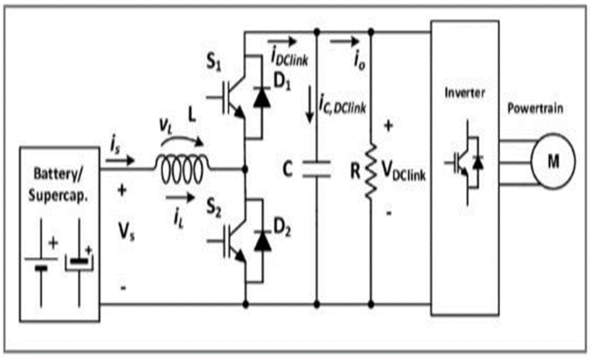

Figure No. 3.1: Bidirectional DC – DC Converter

hence these energy systems are always connected with energy storage devices. These energy storage devices store the surplus energy during low load demand and provide backup in case of system failure and when the output of energy system changes due to weather conditions. Thus, bidirectional dc-dc converters are needed to allow power flow in both forward and backward the direction

Working Principle of Bidirectional DC-DC Converter-

When the buck and the boost converters are connected in anti-parallel across each other with the resulting circuit is primarily having the same structure as the basic boost and buck structure but with the combined features of bidirectional power flow is called Bidirectional Dc-DC converter.

The bidirectional DC/DC converter comes from the common unidirectional DC/DC converter and can achieve energy flow in two directions. Electronic equipment in markets cannot work without a stable power supply system. With the development t of technology, the number of types of electronic products is steadily increasing. The stability of the power supply system is key to guaranteeing good working conditions in electronic production. Moreover, the performance of the power supply directly influences the safety and stability of electronic equipment. At present, numerous uses of renewable energy sources, such as wind and solar energy, have received considerable attention in the context of a micro grid system. A micro grid system develops rapidly and is an independent and controllable power supply system that consists of an energy storage system, micro power supply, energy conversion device, and load.

Specifically, the DC micro grid system operates without problems in frequency stability, reactive power regulation, and AC loss and can connect with new energy, electric and other equipment. A DC micro grid can be used for data centers, residential areas, and other public places [1].In the DC micro grid system, the energy storage system is crucial, and the bidirectional DC/DC converter is its control core. A reasonable design of a DC micro grid system can optimize the operation of micro power supply. In the study of micro grid voltage stability, the key aspects are the hardware circuit and the controlling method in the bidirectional DC/DC converter, which is related to the flow of the energy storage unit. The converters control the energy flow direction of the jbidirectional DC/DC converter as well as the energy storage unit to maintain the stability of the DC micro grid voltage, which can satisfy the grid operation conditions .In a traditional DC converter, the transmission of current is unidirectional, because the reverse breaks down in switching devices, such as the metal-oxide-semiconductor field-effect transistor (MOSFET) and the insulated gate bipolar transistor (IGBT). Moreover, the main circuit has a freewheeling

3.3 Types of Bidirectional DC – DC Converters-

There mainly two types of bidirectional dc – dc converters

- Buck Circuit
- Boost Circuit

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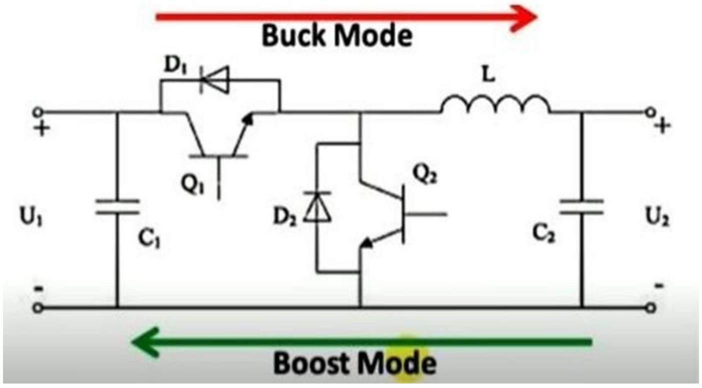

Figure No. 3.2: Buck and Boost Diagram

Working principle of the buck circuit:

According to the continuous current of the inductor, the buck structure consists of three states, namely, continuous, discontinuous, and critical. When the current in the output energy storage inductor is always greater than zero, the current is continuous. If the inductor current is zero at the Switch-off state, then the current is interrupted. The situation between the two cases is the critical current, i.e., the current in the inductor is zero at the end of the switch-off. In the bidirectional DC/DC converter system, the inductor current is in continuous state.

Working Principle of Boost Mode:

The boost structure is also divided into three states, namely, continuous, discontinuous, and critical. In the bidirectional DC/DC system, the inductor current is in continuous state. When the inductor current is continuous, the buck circuit also has two working states in one working period.Fig.3.4 shows the equivalent circuit in the first mode of operation when Q2 is switched on and Q1 is switched off. The voltage of the lithium battery is directly connected with the inductor, the inductor current continues to increase, and the storage energy also increases. The inductor current cannot be produced because Q1 is switched off, and the voltage is generated by the capacitor discharge. When the DC power supply is switched off, the bidirectional DC/DC alters to boost mode, and the voltage output is stable.

Substation-

TO maintain the energy of DC electric railway network the electrical energy from urban grid will pass through transformer and rectifier. Because of the impedance of transformer and voltage drop across the diodes of rectifier there will be some difference between desired voltage and transformed voltage which is modeled by a resistor. There is a diode also to insure irreversible performance of model.

Contact Lines-

These lines are modeled just like the transmission lines. However, as there is no need to concentrate on transient state, inductance and capacitance are neglected.

Train-

In order to obtain electrical power trains movement and its mechanical
characteristics should be modeled. In the resistive forces are identified and the total traction force which a train needs for movement is calculated.

$Fmotor = Meq. a + Fres$

In which Meq is the total mass of train, a is acceleration and Fres is:

$Fres = A + B. v + Cv2$

A, B and C are coefficients which depend on train mass and other characteristics vis the train's speed. The mechanical power then could be calculated:

$Pmech = Fmotor\ v$

The electrical power could be determined as

$Pacceleration$

$= \quad Pmech$

$ngnmnivn$

$Pbreaking = Pmech\ ng\ nm\ nivn$

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Where gear box, motor and motor drive efficiencies respectively. The train is assumed as an active which is modeled by a controlled current source. This is because the output modeling program will be electrical power. To calculate the train's current train's terminal voltage is
Itrain = Ptrain / Vtrain
Where Itrain is train current, Vtrain is the voltage across train and Ptrain is train's electrical power.
In fig the electrical model of the train which is used in simulink is illustrated cf Train current
The parallel capacitor is for power flow in the braking phase, where neither braking resistor, nor ESS is working. Without this capacitor the power could not flow correctly in the system.

Modeling Energy Storage System-
As it was mentioned in introduction there are variety of ESSs and there is a good criterion for differentiating them which is called the Rag one plots [14]. Fig. 4.3 shows a Rag one plot in which you could compare energy density and power density of energy storage devices with each other. It is illustrated that between common energy storages, super capacitors, and specifically Lithium ion super capacitors are more suitable. That is because electric railway DC network deals with very high currents, so charge and discharge time needs to be very fast so that it could store and inject the energy into the grid in a few seconds.
The electrical model of Lithium ion super capacitor is depicted in fig .4.3 SC is the nominal size of super capacitor and Rs, Rp are series and parallel resistance respectively.

ESS Sizing and Designing-
At the beginning of braking phase, the train is moving with maximum velocity and during the braking period its speed starts to decrease until it reaches zero. It means that, at first there is a kinetic energy, while at the end the kinetic energy is zero. This amount of energy is the energy which should be total energy, should be equal to the kinetic energy at maximum speed the capacity of supercapacitor bank could be calculated. The configuration of the bank depends on modulesand their voltage and current limits

Proposed Control Strategy-
There are two main reasons using ESS the first one is to reduce energy consumption and the second one is voltage regulation. As the energy demand changes so fast braking periods or acceleration period a fast response in needed. It is illustrated that there is an ESS placed in second station which consist of bidirectional DC-DC converter and energy storage devices.
The converter is the key to control ESS In the words by controlling the converter the amount and bidirectional of power flow is controlled. System configuration- system consists of 3 stations and two DC substations which are placed in first and third station.
A network consisting of three stations is considered, in which the ESS is placed in the second station. Due to trains movement, the resistance between trains and ESS, and also the resistance between trains and each substation is varied. In Fig.4.4 R1,R3,R5,R7 and R9 represent the overhead line resistance between trains and substation or trains and ESS bus or ESS bus with Substation, while R2,R4,R6,R11 and R12 represents the rail resistance between trains and substation, train and ESS bus or ESS bus and second substation.
In this paper a control method is proposed based on dc bus voltage changes. The main idea is to detect voltage drop or voltage surge and decide whether the supercapacitor should be charged discharged.
In order to implement such control strategy ESS bus measured voltage should be compared with reference voltage. By passing the difference through a PI controller the reference voltage is needed in order to keep supercapacitor voltage changes in the allowed range in other words it acts like soc control loop.

3. CONCLUSIONS
A new control strategy for bidirectional DC- DC converter of stationary ESS was proposed, based on the average modeling of conductors inverters voltage, in order to achieve line voltage regulation. As the main result, the voltage regulation improved and voltage fluctuation decreased by 5% in average and 18% in peak moments.
The average delivered power of substations decreased about 54 KW and the peak power was reduced 268 KW, which shows that peak power shaving goal was achieved. Delivered energy of substations also decreased, so energy saving goal was fulfilled.

Advantages-
1. To provide safety
2. To reduce power loss
3. To reduce size, weight and cost
4. To implement soft switching techniques

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