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IMPLEMENTATION OF HVDC TRANSMISSION FOR VERSATILE ELECTRIC TRACTION SYSTEM USING VOLTAGE SOURCE CONVERTER

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Abstract- This paper aims at implementing of HVDC transmission which is emerging technology that should be adopted more in India . At present most of our states in India consist of railway network operating on High voltage Ac system(25kV AC). To provide versatile electric traction system High voltage AC system is converted to HVDC system which can be utilised for long distance traction system .Constant High voltage DC is maintained in grid by constructing of converter stations every 20km -40km apart. For metros ,passenger and goods train high voltage is reduced to medium voltage .Operating of railway system in DC gives reliability and less transmission losses. This paper presents a new idea of implementation of renewable resources like solar and wind system. In HVDC grid, green energy like solar and wind system can be integrated. Integration can be done by using of boost converter which can able to boost to high voltage. Bi-directional converter with battery storage is connected in order to supply power to grid when solar and wind energy is unavailable thus providing multi-terminal power system. Integrating of renewable sources is simple and easy since renewable energy is more available nowadays even in rural areas. Proposed system is drawn in MATLAB simulink and integration of solar and wind system is modelled. Results are obtained and waveforms are verified to deliver the proposed system in traction application.

Keywords-Voltage source converter, High voltage DC(HVDC), Traction, Bi-directional converter.

I INTRODUCTION

Electric traction offers many advantages over diesel-based systems generating power on board (fast acceleration, better performance on steep gradients, possibility of regenerative braking, environmentally more friendly, etc.), which surely explain its sustained growth, both in developed and emerging countries . Currently, two main categories of railway electrification systems [6] exists depending on the power needs.AC systems, with voltages ranging from 132kV to 25 kV (16.7Hz or 50–60 Hz), usually found in long distances or routes with heavy traffic. Thus make difficult operation than DC system .DC systems, with voltages ranging from 25 kV to 30kV DC which are adopted mainly for trams, suburban trains and medium distances. Light rail, metro and inter-urban services may use both aerial catenaries or third rail, with voltages ranging from 25 V. These dc systems are adequate for rolling stocks with low power demand (less than 5 MW).

Owing mainly to historical reasons, the number of ac electrification systems is really high. Such a diversity of electrification options has a number of drawbacks. Multi-terminal dc networks or hybrid system [7] are also promising candidates for on-board electrical systems of ships and aircrafts, oil-drilling platforms and EV charging stations. To overcome the limitations of AC system, an alternative solution has been proposed.

The method of railway network is operating under single phase 25kV AC which is collected by using pantograph and equipment are present inside the rail. Equipment are step down transformer, voltage source converter and DC series motor which requires more space to be allocated inside train. Integration of renewable resources are not possible. Frequency variation and power oscillations will occur in AC transmission system. Transmission losses is high when compared to DC system. Fig.1 shows Transformer connection of a traction substation and associated autotransformers for the 25 kV AC electrification system.

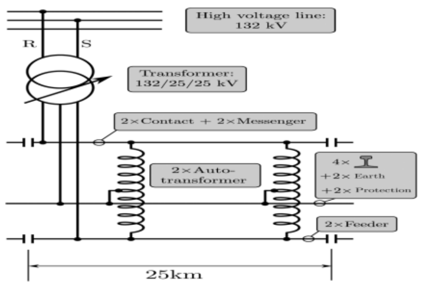

Fig. 1. Transformer connection of a traction substation

II PROPOSED SYSTEM CONFIGURATION

High voltage technology and DC feeder solution for electric railways [2],[1].The proposed method in fig.2 mainly deals with HVDC transmission by converting of high voltage 132kV AC Transmission lines into 25kV-30kV DC line.VSC(Voltage Source Converter) plays important role in converting AC to DC which is present outside the train. This type of converters use IGBT (Insulated Gate Bipolar Transistor) switches for high power applications like traction applications. For every 20km, converters are installed to provide constant 28kV DC.

High voltage 28kV DC is collected by using of pantograph in train and converted to medium voltage 5kV DC using DC-DC converters (Buck converter-stepping down of voltage) .The Medium voltage is fed to run DC series motor which can be used for electric traction system .Nowadays , both AC and DC systems are used but for high starting torque like traction load, DC series motors are used.

In 28kV high voltage DC transmission lines ,integration of renewable energy sources is possible. For solar and wind energy systems ,the converters used are Bi-Directional DC-DC converters and Boost converters .

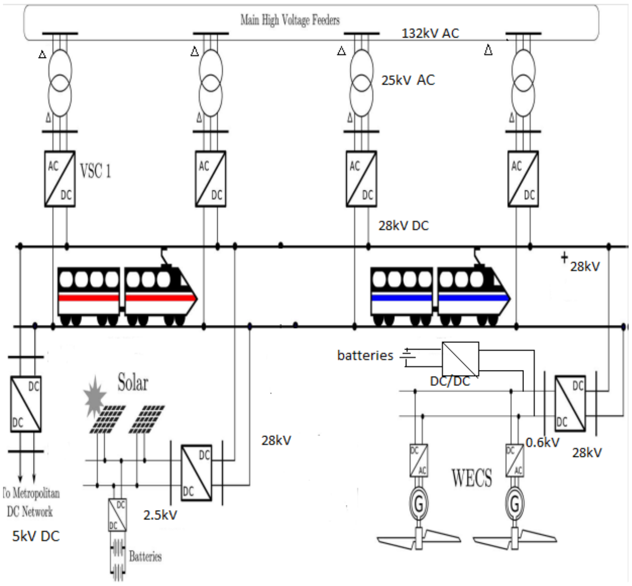

Fig .2 Block diagram of proposed method

Bi-directional converters are used in order to supply power to the grid of 28kV DC .When solar and wind energy is available it can be boosted to produce 28kV DC and supplied to the grid .In absence of solar and wind energy system voltage ,28kV DC is supplied to the grid using battery storage system and can also be utilized for household purposes. Battery storage provides supply to customers at the event of block outs.

The transformer used here is delta-delta configuration. This connection is generally used for large, low-voltage transformers. Number of required phase/turns is relatively greater than that for star-star connection. Another advantage of this type of connection is that even if one transformer is disabled, system can continue to operate in open delta connection but with reduced available capacity.

A. VOLTAGE SOURCE CONVERTER

Voltage source converter consist of the IGBT devices which have resulted in higher switching speed and lower energy losses [3].Advance technology of VSC HVDC[10].Use of VSC in industrial and traction application[5].High-Power IGBTs [4]are expected to take the place of high-voltage GTO thyristor converters in the near future. New control converter topology and active power control principles[11].Intelligent IGBT or intelligent power module (IPM) is an attractive power device integrated with circuits to protect against over current, overvoltage, and overheating.

B. MEDIUM VOLTAGE DC SYSTEM

MVDC system [12],[8] is derived from HVDC system by converting high voltage DC to medium voltage. Here in this proposed system, from 28kv HVDC line MVDC is obtained using buck converter and fed to DC series motor for traction application. DC voltage is stepped down to approximately 5kV DC used for running metros and trams.

C. BUCK CONVERTER FOR MVDC SYSTEM

The dc-dc buck converter as shown in fig.3 can operate in two distinct modes with respect to the inductor current depicts the continuous conduction mode(CCM) in which the inductor current is always greater than zero. When the average value of the output current is low (high R) and/or the switching frequency f is low, the converter may enter the discontinuous conduction mode (DCM). In the DCM, the inductor current is zero during a portion of the switching period. The CCM is preferred for high efficiency and good utilization of semiconductor switches and passive components. The DCM may be used in applications with special control requirements because the dynamic order of the converter is reduced (the energy stored in the inductor is zero at the beginning and at the end of each switching period). It is uncommon to mix these two operating modes because of different control algorithms.

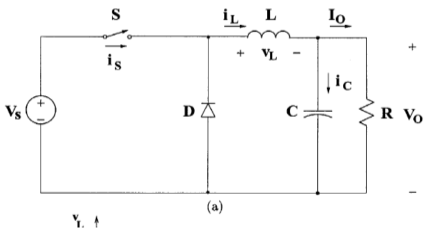

Fig.3. Circuit diagram of buck converter

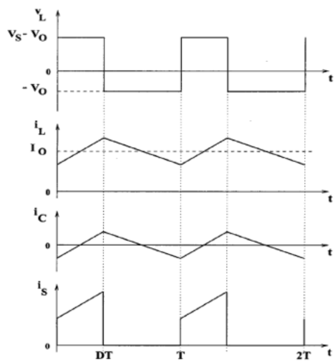

Fig .4. Waveforms of buck converter

For the buck converter, the value of the filter inductance and capacitance that determines the boundary between CCM and DCM is given by equations,

$$L_b = \frac{(1-D)R}{2f} \quad (1)$$

$$C_{min} = \frac{(1-D)V_O}{8V_r L f^2} \quad (2)$$

Equations (1) and (2) are the key design equations for the buck converter. The input and output dc voltages (hence, the duty ratio D), and the range of load resistances R are usually determined by preliminary specifications. The designer needs to determine values of passive components L and C, and of the switching frequency f. The value of the filter inductor L is calculated from the CCM/DCM condition using Equation (1).The value of the filter capacitor C is obtained from the voltage ripple condition Equation (2).waveforms of buck converter is as shown in fig.4.

III INTEGRATION OF RENEWABLE SOURCES WITH THE GRID

A. SOLAR ENERGY CONFIGURATION

Economic dispatch for power system with wind and solar energy integration [9].In proposed system single solar panel 117.7W will able to deliver 25V DC which is combined with 100 panels in series configurations to produce 2.5kV DC. Maximum power point tracking is measured to obtain power of 117W.

Open circuit voltage equation ,ground leakage current and diode current equation of solar cell is calculated using the equations (3),(4) and (5).

$$Voc = V + IRsh \quad (3)$$

$$I_d = I_D\left[\left(\frac{QVoc}{AKT}\right) - 1\right] \quad (4)$$

Where

I_d= the saturation current of the diode in Ampere.
Q = electron charge = 1.6 10^{-19}Coulombs
A = curve fitting constant
K = Boltzmann constant = 1.38 · 10^{-23} Joule/°K
T = temperature on absolute scale °K
The load current is therefore given by the expression:

$$I = I_L - I_D\left[e^{QVoc}_{AKT} - 1\right] - V_{oc}/R_{sh} \quad (5)$$

Bi-directional converter consist of both DC-AC and AC-DC converters shown in fig.5 .It is used to store the energy and then give back energy using battery storage. The working of DC-AC converter is similar to that of AC-DC converter. Thus by maximum tracking of solar energy output 2.5kV DC is fed to DC-AC converter and followed by AC-DC converter. The output voltage is stored in battery when the solar energy output is more than 2.5kV DC. Stored voltage is discharged to grid through boost converter when solar energy generation is less than 2.5kV DC.

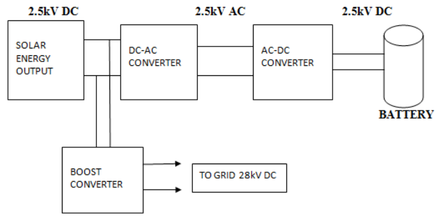

Fig.5. Block diagram of Bi-directional converter with battery storage for solar energy

Boost converters are used to boost the solar voltage since solar voltage obtained is less than that of grid voltage .So in order to provide constant voltage, grid voltage is boosted .Fig.6 depicts a step-up or a PWM boost converter. It consists of dc input voltage source V_S, boost inductor L, controlled switch S, diode D, filter capacitor C, and load resistance R. The converter waveforms in the CCM are presented in Fig.7. When the switch S is in the on state, the current in the boost inductor increases linearly and the diode D is off at that time.

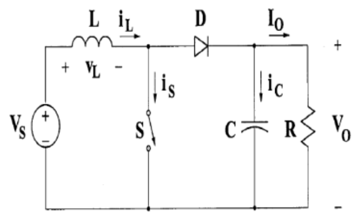

Fig.6. Circuit diagram of boost converter

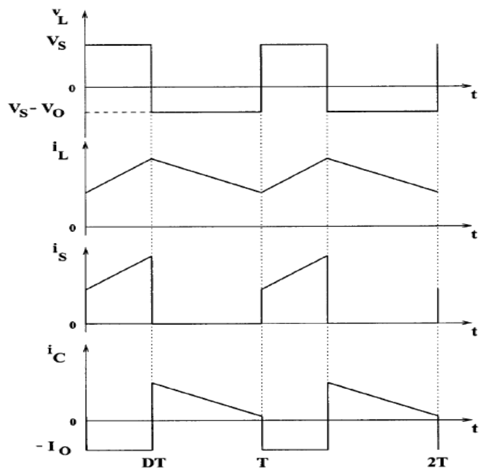

Fig.7 Waveforms of boost converter

When the switch S is turned off, the energy stored in the inductor is released through the diode to the output RC circuit.

Using Faraday's law for the boost inductor, the voltage equation is given by equation (6).

$$V_S DT = (V_O - V_S)(1-D)T \qquad (6)$$

The boost converter operates in the CCM for L > Lb as shown in equation (7) where

$$L_b = \frac{(1-D)^2 DR}{2f} \qquad (7)$$

As shown in Fig.7, the current supplied to the output RC circuit is discontinuous. Thus, a larger filter capacitor is required in comparison to that in the buck-derived converters to limit the output voltage ripple. The filter capacitor must provide the output dc current to the load when the diode D is off. The minimum value of the filter capacitance as in equation (8) that results in the voltage ripple Vr is given by

$$C_{min} = \frac{DV_O}{V_r Rf} \qquad (8)$$

At D = 0.5, and f =100 kHz, the minimum capacitance for the boost converter is C_{min} =50 mF. The boost converter does not have a popular transformer (isolated) version. In this proposed method 2.5kV DC obtained from solar panels is boosted using boost converter and constant grid voltage of 28kV is maintained.

The battery used for storage is nickel-metal hydride .The active material of the positive electrodes of a nickel–metal hydride (NiMeH or NiMH) battery in its charged state is NiOOH, the same material as in a NiCd battery. The negative active material in the charged state is hydrogen, a component of a metal hydride. The metal alloy is subjected to a reversible absorption/desorption process during charge and discharge of the cell. The reaction for the reversible charge/discharge process is indicated below in equation (9).

$$NiOOH + MH \rightleftharpoons Ni(OH)_2 + M \qquad (9)$$

An aqueous solution of potassium hydroxide is the main component of the electrolyte .Only a small amount of electrolyte is used in sealed nickel–metal hydride cells, most of which is absorbed in the separator and the electrodes. In the cell, oxygen can be transported from the positive to the negative electrode and can recombine there with hydrogen to form water. Thus, the cells can be used like dry cells and can also be installed in any desired position.

The discharge characteristics of sealed nickel-metal hydride cells are very similar to those of sealed NiCd cells. The open-circuit voltage is between 1.25 and 1.35 V/cell, and the nominal voltage is also 1.2 V. The electrical characteristics are quite similar to NiCd batteries, even though their energy efficiency is about 80–90% and the maximum power available is less than that in NiCd batteries. The latter is of little relevance in autonomous power supply systems. Memory effects are less pronounced than in NiCd batteries.If the positive electrode gains a negative potential, hydrogen is generated at the positive electrode. Some of the gas can be absorbed by the metal of the negative electrode, but the rest remains as gas in the cell.NiMeH batteries are seen as an interim technology between NiCd and Lithium batteries.

B.WIND ENERGY CONFIGURATION

In proposed system wind mills will able to deliver 0.6kV DC which is combined in parallel configurations .Maximum power point tracking is measured to obtain maximum power and two boost converters are used to supply constant voltage of 28kV DC . A necessary condition for the speed to be at the maximum power point is given by equation (10).

$$\frac{dP}{d\omega} = 0 \qquad (10)$$

Bi-directional converter in fig.8 consist of both DC-AC and AC-DC converters .It is used to store the energy and then give back energy using battery storage. The working of DC-AC converter is similar to that of AC-DC converter explained in chapter 2.Thus by maximum tracking of wind energy output 0.6kV DC is fed to DC-AC converter and followed by AC-DC converter. The output voltage is stored in battery when the wind energy output is more than 0.6kV DC. Stored voltage is discharged to grid through boost converter when solar energy generation is less than 0.6kV DC. Operation of boost converter for wind system is same as that used for solar energy described above.Only difference is 0.6kV DC is boosted to 28kV DC. Here two boost converters are connected to obtain the constant 28kV DC. Series configuration of two boost converter is used. Here the battery operation is similar to that explained for solar system.

IV RESULTS AND DISCUSSIONS

Proposed method consists of HVDC transmission grid , integration of solar and wind energy with the grid is done by using boost converter. The simulation diagram of proposed method is drawn. Main block of this method consist of voltage source converter block which includes the triggering of IGBT to produce constant DC output voltage of 28kV.High voltage 28kV DC is converted into 5kV DC using buck converter block .Simulation voltage values are obtained in display scope . Simulation diagram of single panel solar output is obtained and is multiplied with 100 Panels to produce 2.5kV DC. Boost converter is used in solar part to produce voltage of 28kV DC .

Bi-directional converter used in solar system for battery storage consists of IGBT circuits triggering due to PWM signals. This promotes DC-AC-DC link for storage. Simulation block diagram of wind system consist of wind turbine-generator block and rectifier block .Wind system use two boost choppers in order to produce 28kV DC voltage. Wind system also consist of DC-AC-DC link for battery storage and SOC level of battery is monitored. Simulation blocks are drawn and simulated to verify the output waveforms. Waveforms are obtained after simulation of proposed method in MATLAB. Waveforms are measured with respect to time interval in seconds. the input three phase voltage is 132kV AC. The output voltage(28kV DC) of voltage source converter is measured and waveforms are obtained as shown in Fig.9.Converting 28kV DC to 5kV DC is done by using buck converter . Waveforms of output voltage and current of buck converter obtained is shown in Fig.10. Actual solar output are obtained from 100 panels in series combination and is boosted to produce 28kV DC output. The waveforms showing Actual and boosted solar output is shown in Fig.11.

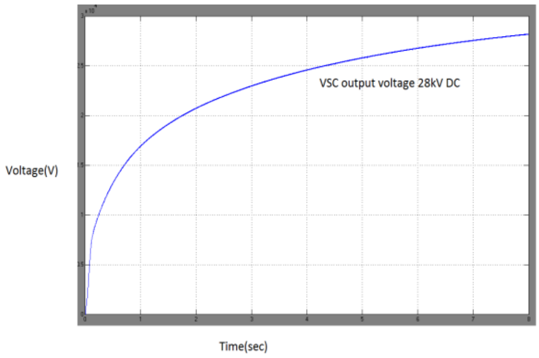

Fig.9. Output voltage waveform of voltage source converter

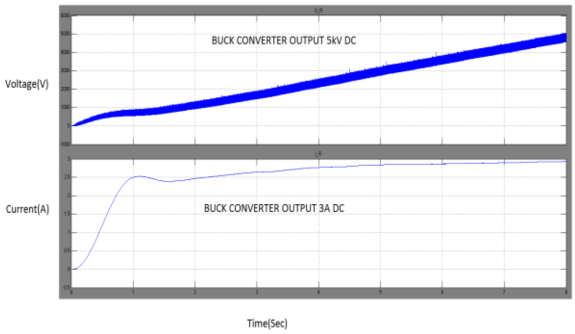

Fig.10. Output voltage waveforms of buck converter

Bi-directional converter provides the necessary DC-AC-DC link and output DC voltage is stored in battery. Actual wind output are obtained and is boosted to produce 28kV DC output.

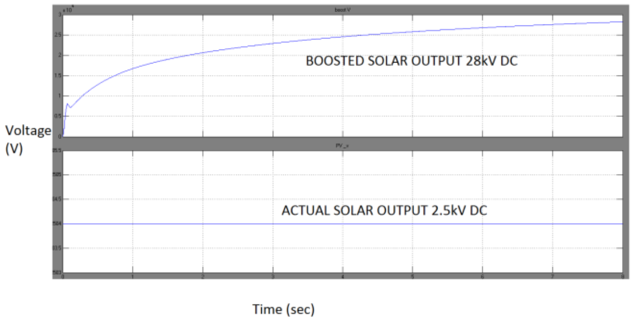

Fig.11. Solar output voltage waveforms

The waveforms showing actual and boosted wind output is shown in Fig.12. Bi-directional converter provides the necessary DC-AC-DC link and output DC voltage is stored in battery.

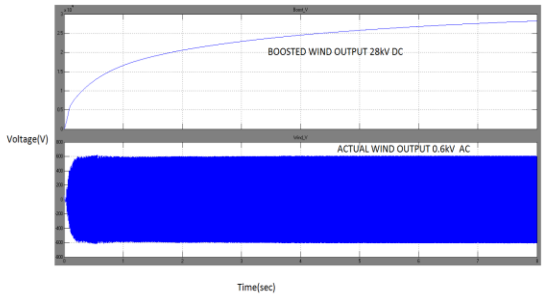

Fig.12. Wind energy output voltage waveforms

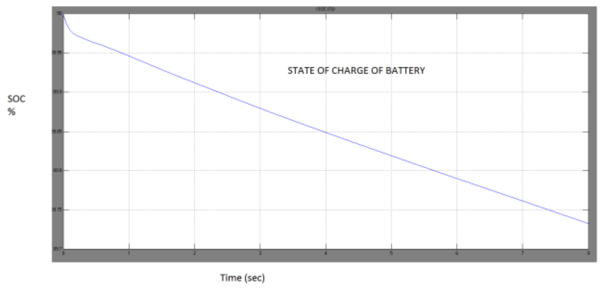

Fig.13. State of charge of battery

SOC level of the battery is calculated to know the state of charging or discharging of battery for solar and wind systems.SOC level is measured in percentage and steep slope downward denote the state of discharging of battery as shown in fig.13.At last the HVDC grid voltage (constant voltage) 28kV DC are verified and waveforms are obtained as shown in fig.14.Output waveforms of HVDC transmission line, solar energy system and wind system are obtained and the results obtained from the simulation have been analyzed.

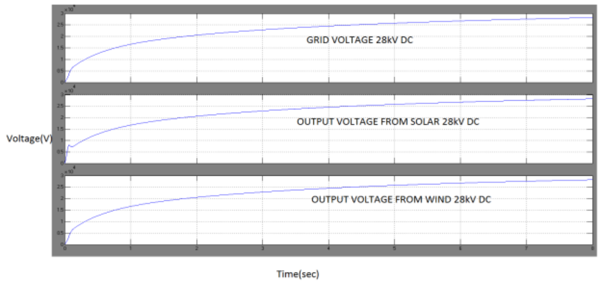

Fig.14. Grid voltage waveforms (HVDC)

V CONCLUSION

In this paper, a new method, implementation of HVDC has been introduced. Using voltage source converter versatile electric traction system is developed which avoids use of auto-transformers and also provides reactive power compensation by not installing load sharing equipments like STATCOM's. Less maintenance is required since it gives flexible operation of electric traction system. No risk of commutation failure in converters since using IGBT devices. Faster response due to increased switching frequency in converters. Eco-friendly system using of renewable resources. Stable and secure system which aimed at providing advanced technology when HVDC combines with smart grid technology. It provides better power quality to customers. This paper also indicates the proposed system to be adopted as real time application which provides multi-terminal power system. Compared with the advantages of proposed system, conventional system transmission losses are reduced. Proposed method is simulated in MATLAB and results are obtained to verify the concept in order to implement as real time application.

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