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A Review on Single Phase AC System of Railway Electrification

Rupesh Kumar Sah[1,*], Basanta Kumar Gautam[2]

[1] *Department of Electrical Engineering, IOE Pulchowk Campus, Tribhuwan University, Lalitpur, Nepal, rupesh.sah@pcampus.edu.np*
[2] *Department of Electrical Engineering, IOE Pulchowk Campus, Tribhuwan University, Lalitpur, Nepal. basanta.gautam@pcampus.edu.np*

Abstract

The widespread adoption of 25 kV, 50 Hz single-phase AC supply in long- distance electrified railway systems poses significant challenges to power quality in transmission networks. This paper presents an in-depth investigation into the influence of electric railway systems on a 110 kV transmission system, with a specific focus on locomotives equipped with diode rectifiers. Harmonic currents generated by these locomotives and unbalanced voltages introduced by single-phase traction loads are known to adversely affect power system components, leading to issues such as overheating, additional losses, and interference with communication systems. Focus of this paper is not only to understand the fundamental principles but to conduct a deep exploration of the functioning of various components such as locomotives, contact lines, and substations. High voltage This voltage is supplied from substation or directly from generating station. This High ac voltage(25KV) is first transformed to low AC voltage(415V). Three phase induction motor are used because it provides high torque, reliable and more efficient. The ac voltage in second phase is rectified to DC and then it is converted into three phase ac by the use of VFD. The VFD provides variable frequency and voltage to run the induction motor at different speed.

Keywords—Railway electrification, transformer, PWM inverter, PI control, Induction motor, Gate drive, Cost.

1. Introduction

Railway Electrification is major means of transportation system because it is cheap and convenient (Alan Zupan, July 2013). The traction unit has the capability to continuously alter its track position, this makes it different from typical domestic and commercial electrical supplies. Electric trains have more power-to-weight ratio due to the absence of fuel tanks. This leads to facilitating quicker acceleration, a more substantial practical power limit, an increased speed limit, and diminished noise pollution, resulting in quieter operations. In urban area it is beneficial to clear lines quicker (Anon., 17 February 2023). The first railway electrification was established in Brighton along the South Coast of the UK in 1883. Sweden mirroring Switzerland, commenced the electrification if it's state-owned railway network before World War I. Sweden electrified 120Km on its Malmbanan line for the purpose of transporting ore from mines in Kiruna to the Narvik port in Norway. The abundance of hydropower resources in both Switzerland and Sweden facilitated the provision of power for their railways through hydropower plants (Anon., 17 february 2023). In 20th century railway electrification have extensively increased with more than 375000 km lines is electrified (pamela, 17 February 2023) (Anon., 4 August 2017). Since electrical energy is used to run the system, it is more beneficial for country like Nepal. This system is energy efficient and environmentally friendly. As of 2023, Swiss rail network is world largest electric rail network (Anon., 7 June 2020). Overall, China at first position with 100,000km of railway line is electrified, India in second has more than 60,000km railway is electrified surpassing Russia over 54,000km electrified railway (Anon., 7 June 2020) (Anon., n.d.). Singapore, Switzerland etc have almost 100% is electrified. In Nepal, there is only 57km of railway traction is completed. Government has planned to build east to west railway traction. Janakpur to Jaynagar, diesel locomotive is used although Nepal has a lot of

**Corresponding Author*

hydropower project. Diesel should import from India and also it is more costly than electricity. Here in this paper, I have reviewed how railway electrification works that benefit our country. The main disadvantage of electric traction is very high capital costs which is uneconomical for less traffic area, and also high cost for the establishment of substations and vulnerability of power system (Kalla-Bishop, 1972). There may be the chance for death of birds and animals when comes in contact with electrification system (Anon., 7 June 2020). Dead animals attract other animals brings risk of accidents with trains. Various geographic areas might employ diverse voltage levels and frequencies, introducing challenges to cross-region services. Nepal has total electricity generation reached to 2075MW (Anon., Fiscal year 2021/2022). Reference (R. Akbari, 2009) shows detailed examination and observation of 132kv grid utilizing ETAP software. Moreover, (V. Metha, 2006) and (P. Satnam, n.d.) insights more into electrical distribution system provides comprehensive step by step guide for the real implementation of electric network design. It is selling India to 333MW. More than 3000MW is under construction. We have huge potential of electricity generation and also not depend into any other country. As Nepal boasts a wealth of hydropower, the electrification of railway networks from east to west can substantially contribute to reducing pollution by minimizing reliance on conventional energy sources. Furthermore, the resultant reduction in the cost of transportation aligns with our economic interests, contributing to the overall growth and development of the nation.

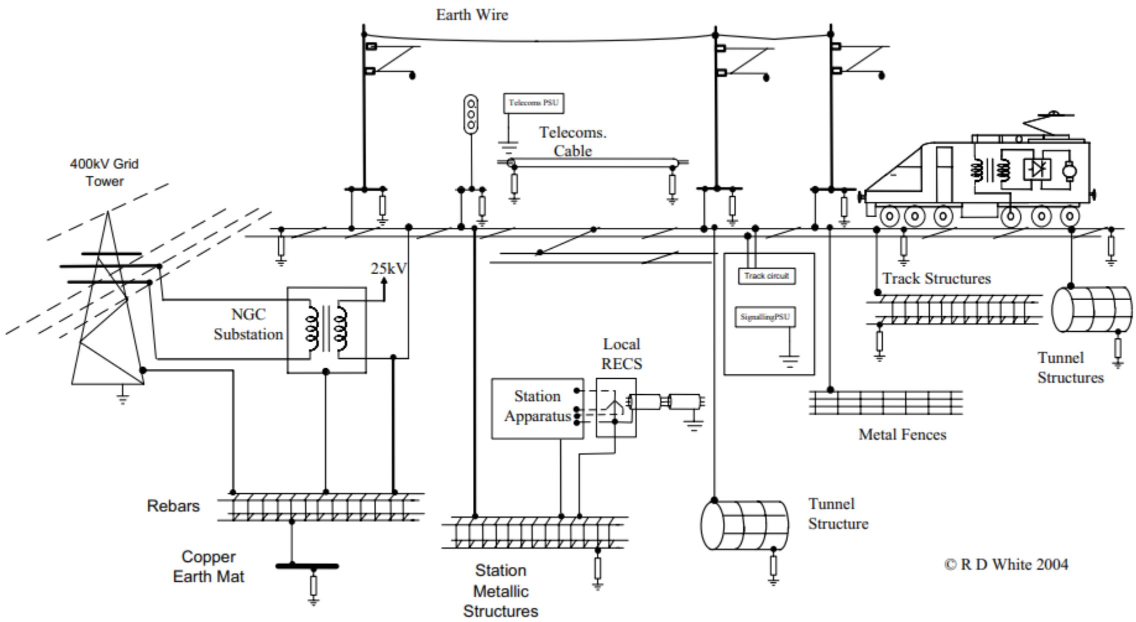

Figure 1. Schematic layout of Ac traction system

1. Power Supply

The power factor will vary from 0.5 to 0.85 which adversely effect on reactive power. In UK, authority is not charged directly for reactive power. Three phase transmission line is not good idea because it is expensive. Rectifier and inverter are used inside locomotive to convert single phase into three phase supply. Transmission of supply

Transmission can be either DC or AC.

Presently, following four types of electrification systems are available:

a. Direct current system—600 V, 750 V, 1500 V, 3000V (White, 2015.) (JR, 1926).

b. Single-phase ac system—15-25 kV, 16 23, 25 and 50Hz

c. Three-phase ac system—3000-3500 V at 16 2 3 Hz

d. Composite system—involve converting of single-phase ac into 3-phase ac or dc.

Earlier, 11 to 15 KV at 23, 16 or 25 HZ are used. It is difficult to get 23, 16 or 25 Hz from generating station. The 25kV rail system has been engineered from the national electricity high voltage (HV) supply system to the requirements of a high-speed, intercity, multi-track railway network that accommodates diverse trains at regular intervals. If electric supply is taken from high voltage transmission line at 50 Hz, then in addition to step down transformer, the substation is provided with frequency converter (JR, 1926). Transmission at low frequency is advantageous because line reactance is less so that line impedance drops and hence line voltage drop is reduced. It increases the frequency and power factor (Yasu oura, June 1998). Typically, incoming power is sourced from 132/220/400kv grid networks. Two separate circuits are usually provided, each of them is capable to bear entire traction load. In the event of one failure, fault does not disrupt the power supply as shown in figure 1. This increases secure power supply. Substations are equipped with switchgear for feeding arrangement and isolation, metering of the electrical demand, communication and SCADA monitoring. There are two ways of supplying power to each of the coaches.

A. Self- Generation:

Two alternators with a capacity of 25 kW each are positioned under the AC coach, while a single 4.5 kW alternator is mounted for the non-AC coach. These are driven through a pulley-belt arrangement, with the driving pulley situated on the coach axle. The generated output is rectified and used to charge a 110VDC battery, ensuring a continuous power supply to both AC and non-AC coaches. The AC load of the roof-mounted packaged units is powered by converting DC into two 25 kVA inverters. This system is implemented in trains that feature a combination of AC and non-AC coaches.

B. Head on Generation

In this method, the power is sourced from the locomotive positioned at the front of the train. The electric locomotive's single-phase 25 kV transformer includes an extra winding, which is transformed into three-phase AC at 750 V through a 2×500 kVA inverter. This AC power is then supplied to the same system. The Electrical Multiple Unit and Main Line Electrical Multiple Units, belonging to another class of trains, employ a similar system for coach lighting. The system resembles the composition of a train set with a power unit at both ends, effectively powering the entire coach load for passenger comfort.

1.1 Cables and conductor

An overhead system is required for this operation that prioritizes the safety of both employees and passengers, ensuring reliability and a high level of supply security for train operators. The assurance of this security is vital for the electrification supply system to consistently deliver the necessary power levels to meet the performance standards outlined in the train timetables. It is important to acknowledge that any increases in service or loads require a reassessment of the electrification system's performance. To run the trains faster, the wire should be straight and good high speed current collection. A second wore over the main cable is used to support. The wires are connected at regular interval. For high conductivity, Copper wire is used and should be multi-strand (19 Strand). These strands made of copper, or aluminium or steel (keenor, 2021). Electricity is gathered from the overhead lines through a single sliding wire, and this energy is supplied to a single-phase induction motor. The wire swings because winds is protect by strong structures. It should protect from lightning by using lightning arrestor. Lightning arrestor of (400A-600A) is used. Polymeric based composite insulators is use to protect from high current.

1.2 Protection

The protection system is comprised of distance protection for both catenary and feeder lines, transformer safety measures for power transformers and autotransformers, along with bus and backup protection. This protective arrangement utilizes a specialized numerical distance protection relay specifically designed for railway traction systems (Menter, 1999). In the event of a fault occurring on the protected section of the line, a trip is activated, prompting the relay to determine the distance to the fault. All autotransformers within that calculated distance are promptly disconnected, and the relay initiates a reclosure process. If the reclosure is successful, the autotransformers are automatically reconnected. In UK, electrification scheme to limit the current to 6KA is upgraded to 10KA. The overhead line is highly affected by strong winds, lightning arrestor, ice coating. Earthing is specific requirement for all contractors in railway system. All non-traction supplies must be earthed for protective provision. Several challenges in 25kv distribution system are charging of OH line at 1st resonant frequency, switching of ac power, Changes in feeding arrangement, Neutral sections, Radio frequency Interference. Types of earthing in railway are functional earth, protective earthing, suppression of electrical noise, equipotential bonding, traction negative return bonding. Under normal condition voltage level limited to 60V rms but it rises to 670V during fault condition for 200ms and 842V for 100ms. Static Var Compensator (SVC) has two main advantages in railway electrification other than reactive power compensation. First one is it permits an elevation in the peak load from the supply system, thereby facilitating an expansion in the spacing of substations. Second one is it diminishes the imbalance in the 3-phase system resulting from the loading of a single phase.

1.3 Pantograph

The pantograph, featuring a low-friction, replaceable graphite contact strip referred to as a "shoe" to reduce lateral stress on the contact wire, made its first appearance in the late 19th century. Among the early designs is the bow collector, credited to Walter Reichel, chief engineer at Siemens & Halske in Germany, and invented in 1889 (Silcove, 2015-04-02) (54703, 1893). When train moves, the contact shoe also moves along with wire potentially creates standing waves that can interrupt the contact and undermine collection of current. Pantographs are activated by compressed air sourced from the vehicle's braking system. This air is employed either to elevate the device and maintain contact with the conductor or, in the case of spring-assisted extension, to lower it (Hammond, 1968) (Ransome-Wallis, 1959). The automatic dropping device (ADD) is a safety mechanism designed to lower the pantograph on electric trains automatically (Xin, 2019). This serves to prevent accidents in situations involving obstructions or emergencies and is alternatively referred to as a pantograph dropping device (Anon., 3 August 2023) (811-32-22, 2023).

2. Transformer

By the use of single-phase system, unbalanced current is generated within 3 phase supply system. To mitigate such effects and reduce the impact on other users, the single-phase traction supply transformers are strategically connected to different phase pairs of the grid supply along the traction (Wenjuan Song, 21 feb 2020). This configuration helps distribute the load along the railway, contributing to a more balanced distribution across the three phases of the grid system The transformer is used to step down 25kv ac to 415V Ac. here only a single wire is coming from supply, the second wire is grounded through rail track. Normally, the rating of transformer in substation is 10 MVA; 132kv/25kv for suburban and 18 MVA; 132kv/25kv for urban area. 132kv supply is taken to minimize the disturbances because of single phase load. But, for high-speed train its rating is 40 to 80 MVA; 400kv/25kv. The track is ground after certain gap throughout the length. This transform er is designed for WAG7, WAP4 locomotive (Railway, Jan 2020).

Normal Voltage =25.0 KV

Rated frequency = 50 Hz

Rated MVA= 5.4 MVA [14]

No load output Voltage = 415V

Insulation = Class A

Motor= 4 MVA

3. Rectifier

In train locomotives, rectifiers play a crucial role in converting alternating current (AC) to direct current (DC) for the efficient operation of electric traction systems. The primary function of a rectifier in a train locomotive is to convert the electrical power supplied by the overhead lines or the third rail, typically in the form of AC, into the direct current required to power the traction motors. There are different types of rectifiers used in train locomotives, and the choice depends on various factors, including the type of electric traction system, efficiency considerations, and operational requirements. The two main types of rectifiers commonly used in train locomotives are thyristor rectifier and IGBT rectifier. The rectifier withstand voltage at rated

engine output and should have sufficient voltage rating. The overall power rating (measured in kilowatts or megawatts) of the rectifier system depends on both the voltage and current ratings. For example, a rectifier system with a voltage rating of 25 kV and a current rating of 500 A would have a power rating of 12.5 MW. These ratings are crucial for ensuring that the rectifier can efficiently convert and deliver the required power to drive the traction motors and other auxiliary systems in the locomotive (Nagar, Lucknow-226 011).
The rectifier's role is not only to convert AC to DC but also to regulate the output voltage and current to meet the specific requirements of the traction motors. Additionally, advanced control systems are often integrated with rectifiers to optimize performance, enhance energy efficiency, and ensure smooth acceleration and deceleration of the train.

4. Induction Motor

If number of boogey will increase, single motor is insufficient to bear the load. A number of motor wheel pairs will then be added to make powerful engine. An engine bogey consists of three three-phase induction motor. The motor should provide high torque and is uniform although speed is varying. Three phase induction motor is best choice for high uniform torque used for traction. The induction motor derives its name because ac voltages are induced in the rotor circuit by the rotating magnetic field of the stator. In various ways, principle of operation of induction motor is similar to the induction process between the primary and secondary windings of a transformer. It has wide range of advantage over Dc motor. Earlier all motors used in locomotives were DC. It has no restriction in speed. motors have a wide speed control range to accommodate various operating conditions, including acceleration, cruising, and deceleration. This capability allows for precise control of the train's speed and contributes to energy efficiency. It can easily operate at 4000 rpm (Engineering, August 2010). The energy is saving due to regeneration and improved power factor are sizable. Its drive is 20% more energy efficient than DC drive. The speed torque characteristics of induction motor is steeper than Dc motor so it has maximum possible tractive effort (Martian Mot, 3 november 2011). Motors used in railway electrification systems typically have higher power ratings compared to ordinary industrial motors (Bhargava, 23 december 2015). Power ratings for traction motors can range from a few hundred kilowatts to several megawatts, depending on the type and size of the train. Voltage rating range from 15kv to 25kv and current ratings are designed from hundreds to over a thousand ampere. Traction motors need to provide high starting torque to accelerate the train from a standstill. This is crucial for ensuring smooth and efficient acceleration.

4.1 VFD

The speed of induction motor is controlled by changing voltage and frequency in constant ratio. This method using PWM to obtain good running and transient performance. The speed of an induction motor depends on a function of three parameters including number of pair poles, supply frequency and slip, so the change of any of these parameters will cause the motor speed to vary. Since the number of poles is fixed by design, the best way to vary the speed of induction motor is by varying the power supply of frequency (Sangita Gohil, October 2017). The synchronous speed is given by

$$Ns = 120f / P \qquad \text{Equation (1)}$$

$$s = Ns - Nr / Ns \qquad \text{Equation (2)}$$

Where, Ns= synchronous speed Nr= Rotor speed

$$Ns \propto f/P \qquad \text{Equation (3)}$$

The torque produced by the motor is directly proportional to the stator magnetic field. The applied voltage to the stator is directly proportional to the product of frequency and stator flux as shown in equation 3. Due to this the flux is directly proportional to the ratio of applied voltage and frequency (P. Agarwal, Bengaluru 2012).

supply frequency throughout the speed range.

$$\varphi \propto v/f \qquad \text{Equation (4)}$$

4.2 Torque speed characteristics

When the motor gets started, it withdraws large current to seven times the rated current. which is a result of the stator and rotor flux. Also, the starting torque is around 1.5 times the rated value for the motor. As the speed increases, the current reduces slightly and then drops significantly when the speed reaches close to 80% of the rated speed. At the normal speed, the rated current flows in the motor which delivers rated torque. At normal speed, if the load is increased exceed the value for the rated torque. The speed gets dropped as the value of slip increases. At a speed of 80% of the Synchronous speed, the load increases up to 2.5 times the rated torque, this is called the breakdown torque. If the load is further increases, it results the fall of torque rapidly and the motor stalls (B. Brindha, n.d.). We can increase the torque further by adding gear ratio between the motor and shaft and the wheel axle (et.al, 2021).

5. PWM inverter

An inverter converts single phase DC power into three phase AC power. An Inverter is a combination of power electronics component to make a circuit which converts a DC input power into an AC output power at a desired output voltage and frequency. This conversion is achieved by controlling turn-on and turn-off devices like IGBT"s, MOSFET. Ideally, the output voltage of an Inverter should be perfectly sinusoidal. However, huge harmonics are present in output and are usually non-sinusoidal. Square-wave and quasi-square-wave voltages are acceptable. The DC power input to the inverter is rectifier.

The Control Circuit consists of a PWM Generator. The sine wave compares with a pulse train and modulating the pulse width accordingly. Thus, obtaining PWM signal which is integrated and then compared to the reference signal. The reference signal is set to sinusoidal. As per required frequency, a triangular wave is set so called carrier wave. The carrier signal should be multiple of 11,22,33. As the frequency of carrier signal increases, the more sinusoidal become the signal. With the help of >= operator, The PWM signal is generated. These PWM signals are applied to the gates of the MOSFET and IGBT"s so as to trigger them. While one of the three pair of IGBT"s is fed signals directly from the relational operator, the other pair is fed the signal after passing through the NOT gate. Thus, the three pairs are switched ON in alternating cycles of operation (Sangita Gohil, October 2017).

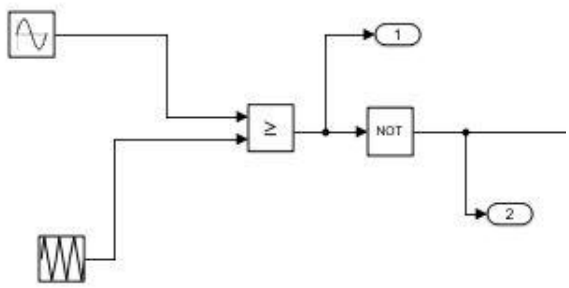

Figure 2. Reference and triangular wave for gate pulse.

The waveforms of Sinusoidal PWM are shown in the figure 2. In this modulation of signals, the triangular waveform (Vc) is Compared with reference sinusoidal waveform (Vm). Vc and Vm are the inputs to the comparator. When the magnitude of sinusoidal voltage is greater than the magnitude of triangular voltage, the output of comparator is high. The output voltage has a train of pulses of unequal width. At the centre, the width is maximum and it decreases on either side. The width of the pulse varies sinusoidal. This is called asymmetric. The width of the pulses is unequal since PWM. The harmonics produced in this voltage waveform will be less than by PWM waveform. By changing the frequency of the modulating signal i.e. sinusoidal signal, we can vary the frequency. Also, we can vary output voltage by the varying value of MODULATING INDEX (m).

$$M = Vm / Vc. \quad \text{Equation (6)}$$

5.1 Closed-loop V/F Control

In closed-loop V/f Control the speed of the rotor is compared to the reference speed. The rotor speed is measured and fed to the comparator. The difference between reference speed and rotor speed is taken as the error and the error is fed to a Proportional controller. The P controller sets the inverter frequency. The Voltage Source Inverter which modifies the terminal voltage and keep the V/f ratio constant according to the inverter frequency (Sangita Gohil, October 2017).

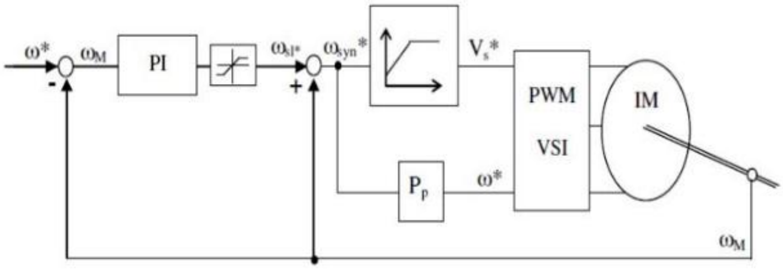

Figure 3. Closed loop v/f control of induction motor

Thus, the maximum torque on the rotor remains constant across the speed range, as the frequency is varied. By maintaining a constant V/f ratio, it results the flux constant. Hence, the speed of the rotor gets measured and compared with the reference speed. This generates an error that is processed by the Proportional Integrator Controller which modifies the supply frequency accordingly. As the PI Controller feeds the Voltage Source Inverter, the voltage is also varied such that the V/f ratio remains constant. This maintains the flux constant which ensures maximum constant torque throughout the speed range. Hence Speed is controlled in the Induction motor.

5.2 PI controller

The PI controller is designed to give desired control signals to PWM generator. The motor speed is taken as feedback and it is compared with the set speed. The error signal is fed as input to the PI controller.
The control later attempts to minimize the error by adjusting the process control inputs. A PI controller is a feedback loop control mechanism widely used in industrial control systems. The PI controller algorithm involves two separate constant parameters: Proportional, and Integral. P depends on the present error, I on the accumulation of past errors, based on rate of current change. The PI controller is usually utilized for speed control applications.

6. Electric braking system

Motor do not stop directly by turning off the supply. However, train moves continuously for several kilometres with lowering speed. In normal induction motor the rotor speed is lower than the speed of rotating magnetic field. We can reverse the condition by lowering the frequency, When the r.m.f speed is lower that the rotor speed the direction of induced current reverse. This makes the induced torque acts opposite direction. This will make the train slower but don't stop perfectly. For this we use pneumatic brakes (Journal, April 2000) (Klink, February 1998).

7. Modelling and Simulation of Railway Electrification

After completing the structure of power system, modelling of train has been chosen very close to the Swedish railway network that uses simulator TPSS (Train Power System Simulator).

7.1 Maximal tractive force diagram

It is the function of voltage of catenary with respect to speed of the train and current drawn by the motor with respect to velocity of the train. After multiplying this current and voltage gives the total power consumed by locomotive and then acceleration of the train can be calculated (Boullanger, 2008-2009).

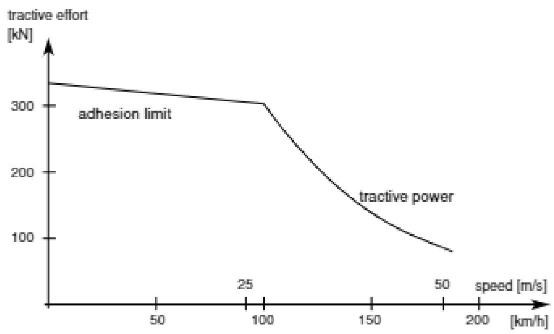

Figure 4 Catenary voltage and speed graph

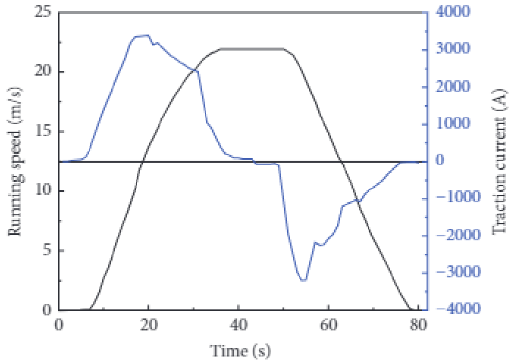

Figure 5 Train peed and current

7.2 Electric model

Practically, there are electrical and mechanical losses between pantograph and wheel of the locomotive. These losses are taken into account for modelling and the efficiency is calculated. Also, Reactive power consumption by locomotive is also considered. For this modelling “TraceFeed Simulation” software is generally used. This software helps to connect train traffic to power system. It is widely used by Norwegian Railway, and Swedish. The reactive power consumption from the simulation is discussed here (Östlund, 2005). Firstly, the power factor is modelled with respect to velocity of train using NN tools and compared with old manual document (Jansson, March 2004)where velocity of the train is input and output is power factor λ.

The reactive power consumption by locomotive is $Q_{motor} = P_{motor} * \frac{\sqrt{1-\lambda^2}}{\lambda}$
This obtained is not fully true but it is good approximation.

8. Economic Analysis

In Bangladesh, a significant contract worth US$3.14 billion was signed between Bangladesh Railway and China Railway Group Ltd on August 8. This contract marks the construction of the Padma Bridge Rail Link, spanning 225 km. The primary aim of this new line is to serve as a vital component of the southwest region's rail network, establishing a direct link with the capital city (Gazette, 2019). Designed as a single-track line, it is engineered for a maximum speed of 120 km/h. The construction phase is projected to last 54 months, with the anticipated completion date set for June 30, 2022. From the numerous data (Gazette, 2019) (Samseer, 2019) (Odditah, 2019) (Technology, 2019) it can be estimated that to construct East-West railway (~ 1000KM) around US$10 billion amount is required.

Cost comparison with road transportation: Railway transportation is often a more economical option for transporting bulk goods compared to road transport. Trains can carry larger volumes per trip, reducing transportation costs and offering competitive freight rates for long distances. Moreover, railways provide efficiency benefits, especially for long-haul journeys, with dedicated freight corridors ensuring quicker transit times. With their larger carrying capacity, railways optimize logistics for industries with high demand for goods.

To analyse the cost disparities between rail and truck shipping, let's look at the scenario of transporting bulk commodities from Houston, TX, to Cleveland, OH (Anon., feb 6 2024). In this instance, truck shipping incurs around $214.95 per ton, whereas rail transportation would cost approximately $70.27 per ton. However, it's important to account for the 1:4 ratios, where each railcar represents four truckloads, to ensure an accurate comparison.

9. Conclusion

In conclusion, the implementation of the discussed scheme for railway electrification, as inspired by reference paper, holds significant promise for the development of the railway electrification system in our country, Nepal. Selection of 25 kV was driven by considerations of power transmission efficiency in relation to voltage and cost, rather than adherence to a precise ratio of the supply voltage. Opting for a higher voltage at a given power level enables a reduction in current, generally enhancing efficiency. However, it was determined that 25 kV represents an optimal balance. Further increase in voltage increases insulation cost significantly that outweigh the benefit from it. The proposed system, which includes specialized numerical distance protection relays and comprehensive protective measures for critical equipment like transformers, conductors, and substations, is poised to enhance the reliability and efficiency of our railway electrification endeavours.

Moreover, the strategic deployment of such a systematic setup of various electrical components aligns with the broader goals of sustainability and environmental conservation. It is crucial to emphasize that while the initial investment in equipment like transformers, conductors, and substations may be substantial, the integration of a reliable protection system ensures the durability and longevity of these assets. Over time, the enhanced operational efficiency and reduced maintenance costs significantly outweigh the initial financial outlay. Therefore, the adoption of this protective scheme not only ensures the resilience of our railway electrification infrastructure but also presents a compelling case for sustainable, cost-effective, and environmentally friendly transportation solutions in Nepal.

References

811-32-22, I. 6. -. I. E. V. -. D. f. I. n., 2023. *pantograph dropping device,* s.l.: www.electropedia.org.

Alan Zupan, A. T. T. a. B. F.-G., July 2013. Modeling of 25 KV Electric Railway system for power quality studies. *IEEE Eurocon 2013 conference,* Issue Zagreb,croatia, pp. 844-849.

Anon., 7 June 2020. *2019 年铁道统计公报"(PDF). Archived from the original (PDF) on 6 June 2020. Retrieved,* s.l.: s.n.

Anon., 17 february 2023. *On track to full electrification: Low carbon railways in India,* s.l.: www.rapidtransition.org.

Anon., 17 February 2023. *Rail – Analysis,* s.l.: IEA.

Anon., 3 August 2023. *IEC 60494-1:2013 - IEC-Normen - VDE VERLAG,* s.l.: www.vde-verlag.de.

Anon., 4 August 2017. *Railway Handbook 2015"(PDF). ,* s.l.: International Energy Agency.

Anon., feb 6 2024. *RSlogistics.* [Online]
Available at: https://www.rsilogistics.com/blog/comparing-the-costs-of-rail-shipping-vs-truck/

Anon., Fiscal year 2021/2022. *NEA booklet,* Kathmandu: NEA.

Anon., n.d. *Status of Railway Electrification (as on 01.04.2023)"(PDF),* s.l.: s.n.

B. Brindha, D. T. R., n.d. *speed control of single and three phase induction motor using full bridge cycloconverter.* s.l., ICPECTS.

Bhargava, B., 23 december 2015. *Railway Electrification systems and configurations.* s.l., IEEE conference.

Boullanger, B., 2008-2009. *modeling and simulation of future railway,* Stockholm: Banverket & KTH Elektro- och.

Engineering, I. R. i. E., August 2010. *A course on three phase technology in TRS applicatio,* s.l.: s.n.

et.al, P. K. a., 2021. *Exploring Engineering 14.4.2.* 5th ed. s.l.:s.n.

Gazette, R., 2019. Padma Bridge Rail Link Contract Awarded. *https://www.railwaygazette.com/news/infrastructure/single-view/view/padma-bridge-rail-link-contractawarded.html*, 10 march.

Gazette, R., 2019. Work to Begin on Chad Rail Network. *https://www.railwaygazette.com/news/infrastructure/single-view/view/work-to-begin-on-chad-railnetwork.html*, 29 april.

Hammond, R., 1968. *Development of electric traction, Modern Methods of Railway Operation pp 71-73,* London: OCLC 467723.

Jansson, N., March 2004. *Electrical Data for the Locomotive Types Rc4 and Rc6 (original title in Swedish),* s.l.: TrainTech. Solna.

Journal, I. R., April 2000. *International Railway Journal P 23,* s.l.: s.n.

JR, C., 1926. Wave Propagation in Overhead wires with ground return. *Bell System Technical Journal ,* Volume 5, pp. 539-554..

Kalla-Bishop, P. M., 1972. *Future Railways and Guided Transport, pp. 8-33.,* s.l.: IPC Transport Press Ltd.

keenor, G., 2021. *Overhead line electrification for railways pp 307-310.* 6 ed. s.l.:s.n.

Klink, D., February 1998. The year of the electronic air brake. *Railway Gazette International.*

Martian Mot, V. H., 3 november 2011. Direct Drive induction motor for railway taraction applications. *The publishing house of the romanian academy,* 12(A), pp. 239-248.

Menter, D. T. s. a. D. F., 1999. Protection scheme for a New AC railway traction power system. *IEEE,* pp. 388-393.

Nagar, R. D. a. S. O. M., Lucknow-226 011. *Specification for Compact Design of Updated Silicon Rectifier for AC Single Phase Locomotive,* s.l.: Government of India, Ministary of Railways spc no. ELRS/Spe/RSI/0030.

Odditah, C. F., 2019. CCECC Sign $11.117 Billion Lagos-Calabar Rail Contract. *https://guardian.ng/news/fg-ccecc-sign-11-117-billion-lagos-calabar-rail-contract*, 29 April.

Östlund, S., 2005. *Electrical traction(original title in Swedish),* Stockholm: KTH.

P. Agarwal, P. S. a. V. A., Bengaluru 2012. Single Phase to three phase cycloinverter with Space Vector PWM controller. *2012 IEEE International Conference on Power , Electronics, Drives and Energy Systems (PEDES),* pp. 1-5.

P. Satnam, P. G., n.d. *Substation Design and Equipment , pp.1-16..* 10th ed. s.l.:Dhanpat Rai Publications.

pamela, 17 February 2023. *Railway electrification is expected to grow worldwide,* s.l.: Railway PRO.

R. Akbari, J. K. M. J. M. A., 2009. Analysis and monitoring of 132kv grid using ETAP software. *IEEE conference, pp. 113-1180, 2009.,* pp. 1113-1180.

Railway, m. o., Jan 2020. *Training packaging on transformer of ac electric locomotives,* s.l.: government of india.

Ransome-Wallis, P., 1959. *Electric motive power, p. 173. ISBN 0-486-41247-4. OCLC 2683266.,* London, Hutchinson: Illustrated Encyclopedia of World Railway Locomotives.

Samseer, M., 2019. Mali Signs $11bn Agreements with China for New Rail Projects. *https://www.railway-technology.com/uncategorised/newsmali-signs-agreements-with-china-for-newrail-projects-4375202/*, 29 APRIL.

Sangita Gohil, p. b. d. g., October 2017. A review on speed control Techniques of single phase induction motor. *IJSR,* Volume 6, pp. 1045-1049.

Silcove, B., 2015-04-02. A Century of Traction. Electrical Inspections. p. 7.

Technology, R., 2019. Abuja-Kaduna Rail Line. *https://www.railwaytechnology.com/projects/abuja-kaduna-rail-line*, 29 April.

V. Metha, R. M., 2006. *³Principles of power system pp. 41-126, 356-585, 2006.* s.l.:S. Chand Publications.

Wenjuan Song, Z. J. M. S. R. A. B., 21 feb 2020. Design of a single-phase 6.5 MVA/25 KV superconducting traction transformer for the chinese fuxing high speed train. *IJEPES.*

White, R. D., 2015.. *DC Electrification Supply System Design.* s.l., 2015 IEE REIS DC.

Xin, T., 2019. *Non-invasive dynamic condition assessment techniques for railway pantographs,* s.l.: University of Birmingham.

Yasu oura, Y. M. a. H. N., June 1998. Railway Electric Power Feeding System. *Japan Railway and transport,* Volume 16, pp. 48-58.