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# A Comprehensive Perspective of Different Compensators of Railway Traction System

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**Abstract**
Due to their non-linear load characteristics, train locomotives play a significant part in the installation of railway electrification in India and around the world. Numerous techniques have been researched and used with both AC and DC locomotives to enhance power quality. The development of train locomotives is used in this research to provide a viewpoint on various power quality issues as well as to explore the demand for power quality problems and system requirements for acceptable power quality. The many sorts of compensation schemes are contrasted with one another. this would help academics and engineers working on railway electrification.
**Index Terms - Railway Electrification, Power Electronic Converters, Power Quality, and Harmonic and Imbalance Compensation**

## 1. Introduction

The issue of electricity quality has gained more and more attention as rail transportation develops. Due to the non-linear and low power factor (PF) characteristics of the locomotive load, harmonics and reactive power problems will arise [1] [3]. The load on the locomotive is one phase. The electricity grid will experience unbalanced three-phase currents as a result. The symmetrical component analysis predicts that the imbalanced three-phase currents will result in a negative sequence current (NSC). The safe operation of the power grid and the traction power supply system will be severely hampered by harmonics, reactive power, and NSC [4][6].

In [7], NSC is compensated using a static var compensator (SVC). NSC and reactive power compensation are both possible with SVC [8], however harmonic currents couldn't be completely eliminated. Recent years have seen a rise in the use of active power conditioners based on power electronics to address all the power quality concerns in traction power systems.[1][9][10]. In the 1980s, Japanese academics suggested Railway Power Conditioner (RPC) [12]. RPC could simultaneously correct for NSC, harmonic currents, and reactive power. [13] discusses the RPC compensation principle in the V/V traction power system. Quick and smooth tracking of the reference signals must be accomplished. a fuzzy algorithm is modified in accordance with the study of the RPC control approach in [13]. [15] presents a traction system using an RPC that is constructed with a half-bridge converter (HBRPC). HBRPC needs half as many power switches to complete the same task as RPC as compared to standard RPC. [14] recommends using an active power quality compensator to correction of harmonics for the traction system. This device is composed of a Scott transformer and a three-phase, three-wire converter. These investigations show that active power electronics are a useful tool for dealing with traction power system power quality problems. Active devices' capacity, however, is too high for practical application.

In [11], a balancing transformer-based active power conditioner (APC) system for a co-phase traction power supply system is presented. APC has the ability to control PF, suppress harmonics, and compensate for NSC. However, a substantial active capacity is required, increasing the project's initial cost. Hybrid compensation approaches are provided in order to reduce the active component of the compensation device. For harmonic and negative-sequence currents in high-speed electric trains, a

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hybrid power quality adjustment is suggested in [18]. The compensator consists of the RPC, two third filters operated by thyristors, as well as two reactors. The RPC is used to transmit active power, and third filters and thyristor-controlled reactors are used to counteract reactive power. The thyristors simply function as switches in order to prevent extra harmonics. Therefore, in addition to transferring the active power, the RPC will also make up some of the reactive power. Rail traction systems employ a hybrid power quality compensator (HPQC) [16][22]. In a co-phase traction power system with low operating voltage, HPQC can provide system imbalance, reactive power, and harmonic compensation. HPQC reduces the compensatory capacity in a certain way, however it is not possible to keep the capacity at a minimum under various load situations. A passive compensating device has a substantially lower beginning cost than an active power electronics device. The capability of active compensation devices might be decreased by using passive compensation devices.
An asymmetrical connection balance transformer-based hybrid railway power conditioning system with cost-function optimization (ACBT-HRPC) is being researched to address the burgeoning power quality issues in electrified railways [2]. ACBT- HRPC has a significantly higher material consumption compared to other compensators, which is significant in real-world applications. This makes it possible to achieve an acceptable compensation performance at comparatively appealing expenses.
A review of the literature on various compensation techniques is given in Section I. Section II classifies the compensators used in traction systems to enhance power quality. Comparing various compensators is done in section 2 based on the number of active devices, additional devices employed, harmonic compensation, reactive power compensation, and imbalance compensation.

## 2. EQUIPMENT-BASED CLASSIFICATION

Electrical equipment, such as harmonic elimination passive and active filters, is available to address power quality concerns. The SVC manages reactive power and NSC adjustment. RPC, Active Power Quality Conditioner (APQC), and Hybrid Power Quality Conditioner all perform harmonic reduction and current NSC adjustment (HPQC).
Numerous studies propose the heuristic systems ACBT-HRPC, which integrate the aforementioned procedures with operational enhancements, rating decrement strategies, or both.

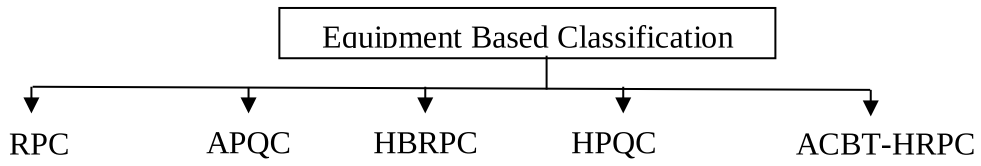


**Fig.1. Power quality improvement strategies classification**

## 3. Railway Static Power Conditioner

The Railway Static Power Conditioner [RPC] is a revolutionary technology that reduces voltage imbalance and variation [12]. The RPC equilibriums the effective power of various phases and corrects reactive power and harmonics to lessen voltage imbalance and volatility. The power system operates high-speed AC electrified railroads while having a relatively limited short circuit capacity.
To increase the control effectiveness of RPC, a dual-loop control approach and fuzzy-algorithm-based recursive PI control were developed [13]. In a steady state, an error was reduced via recursive control, and the controller's settings were controlled in real-time using fuzzy rules. In comparison to other common compensation devices, RPC may be able to successfully enhance the power quality index of the electrified railway by controlling the transfer of active power, compensating for reactive power, and lowering harmonics.

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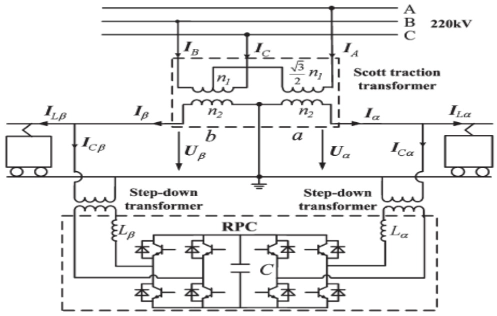

**Fig.2 Scott transformer-based RPC**

## 4. Active Power Quality Compensator

To improve the electricity quality of the traction power system, a brand-new approach for detecting compensating currents and an active power quality compensator (APQC) is suggested [14]. The APQC also includes a Scott transformer and a three-phase voltage converter. The Scott transformer, which functions as both an isolation transformer and a connection between the traction power system and the three-phase converter, creates a nearly balanced three-phase power system while simultaneously changing the traction power system. As a result, APQC employs standard three-phase converters. When taken into account as a compensating component, the power quality index of a traction substation may be significantly enhanced. The suggested APQC may take into consideration currents with negative sequences, harmonics, and reactive power in two feeders of a traction substation, according to modelling and prototype testing results.

The power factors of the two phases both increase to 0.99 when the APQC is turned on, and the present THD in both feeds is decreased to 2.1% for a uniform load condition. It is possible for APQC to simultaneously rectify reactive power, harmonics, and negative-sequence currents in two feeders of a traction substation by applying the recommended control approach and the non-active current detection technology.

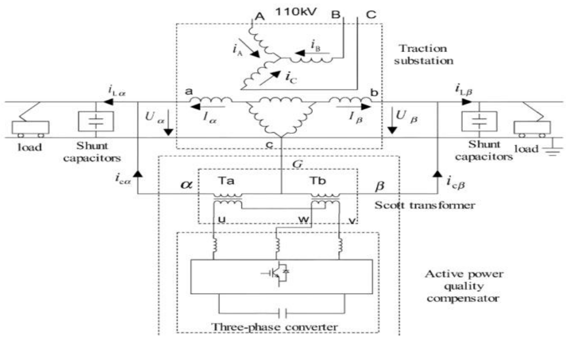

**Fig.3. Circuit configuration of active power quality compensator**

## 5. Half-Bridge Converter-based Railway Static Power Conditioner

Power quality problems like harmonic current and the negative sequence current of electric locomotives are getting worse when high-speed and high-power railway networks are modernized. A half-bridge converter-based railway static power conditioner is made up of two half-bridge converters linked in series by two capacitors (HBRPC). Compared to the traditional RPC, the HBRPC only needs two capacitors and two power switch legs. The proposed conditioner can reduce cost and hardware complexity while still serving the same purpose as RPC because it only has half as many switches as the power switches [15]. To maintain the stability of the dc-link voltage and accomplish dynamic tracking of the current reference signals, a double-loop control is advised for the HBRPC. Balanced voltage regulation is advised in order to prevent the error of two capacitor voltages and maintain the HBRPC's functionality.

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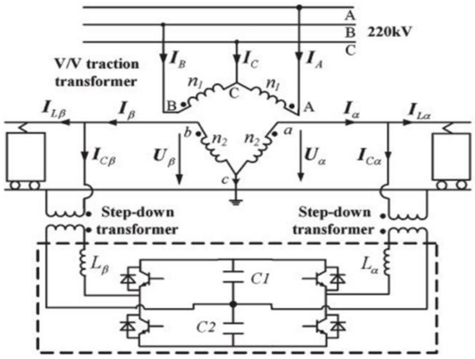


**Fig.4 Circuit configuration of HBRPC**.

Without adjustment, the two traction arms' varied power needs might lead to imbalanced three-phase currents that would comprehend a lot of harmonic currents and NSCs. The HBRPC may correct any specific fundamental and harmonic currents as soon as it is turned on in the system in order to accomplish harmonic current suppression and NSC compensation. The three-phase currents are substantially symmetrical after rectification, and in the steady state, the NSC is virtually zero. THDs for two currents used for traction fell from 16.4% to 6.5 and 5.8 %, respectively. The power quality of the high-speed railway system can be significantly improved by HBRPC's ability to successfully compensate for NSC and harmonic currents.

## 6. Hybrid Power Quality Conditioner

The power quality issues of the electrified railway power supply system were anticipated to be solved by power quality conditioners developed from modern power electronics technology [16][22]. The HPQC makes use of a single-phase back-to-back converter. It links to the feeding phase of the balanced feeding transformer via an L-C branch, and a coupling transformer connects it to the other phase. In order to inject the same compensatory currents into the traction power supply system, the DC bus voltage of the HPQC may be significantly lower than that of an active power conditioner. An HPQC linked to the secondary side of a 110 kV/27.5 kV V/V transformer is used to construct simulated models.

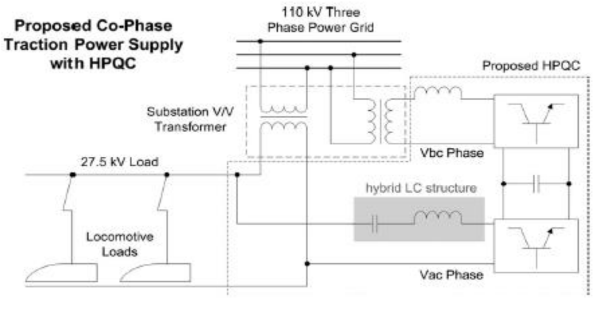


**Fig.5. Circuit configuration of Co-phase traction power supply with proposed HPQC**

As a result, compared to other compensators, the initial cost of the overall system might be lower. Current harmonics, imbalanced currents, and reactive currents might all be corrected at once by the HPQC.

## 7. Asymmetrical Connection Balancing Transformer Hybrid Railway Power Conditioning System

In order to solve the rising power quality difficulties in electrified trains, this research [24] offers a unique compensator. The ACBT has represented much greater material utilization in addition to the filter branches with inductively filtered rectifier transformer (IFRT) utilized for balancing reactive power and filtering harmonics. In order to reduce the investment required for ACBT-HRPC, the

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mathematical link between design capacity and power factor (PF) is examined, and cost-function optimization is suggested. This enables successful compensation performance at a cost-effective rate.

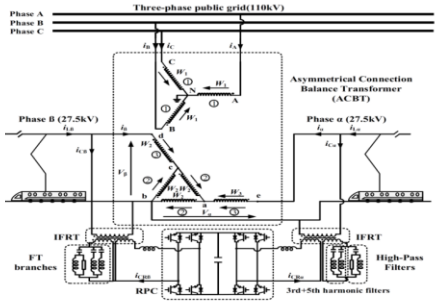


**Fig.7. Topology of ACBT-HRPC**.

A hybrid railway power conditioning system based on asymmetrical connection balancing transformers is suggested to improve power quality in ERPS. The performance of ACBT-HRPC has been demonstrated to be adequate to the careful selection of the ACBT and IFRT and the creative collaboration of RPC and FT branches. The cost-function optimization-based capacity allocation plan is also available and may ensure that the RPC and FT branches run dependably and economically. The ACBT-HRPC is appropriate for industrial applications to enhance the power quality of ERPS, taking into account the features of a relatively low capacity and a high degree of integration.

**Table.1 Performance Features of Different Compensators**

| **S.No.** | **Compensation Strategy** | **No. of Active Devices** | **Additional Devices Used** | **THD** | **The Special Features** | |
|---|---|---|---|---|---|---|
| | | | | | **Merits** | **Demerits** |
| 1. | RPC | 8 | No extra device | 16% | Medium performance, general | more power losses |
| 2. | APQC | 6 | No extra device | 4.77% | Good performance with fewer switches | high voltage dc link capacitors are used |
| 3. | HBRPC | 4 | The Dual loop voltage controller | 6.5% | Least total cost, power losses reduced | dc-link voltage control is complex |
| 4. | HPQC | 6 | 6 extra thyristors,3 capacitors and 3 inductors | 4.63% | Better performance, lower cost | Less reliable due to additional devices used |
| 5. | ACBT-HRPC | 6 | 1 special transformer and some extra filters are | 2.74% | Best performance | High cost due to additional transformer and devices used |
| 6. | RPFC | 8 | Communication lines, central control of substations | 2.09% | Central control of traction substations | High cost |

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## 8. CONCLUSIONS

This paper has reviewed the problems with power quality that electric train traction systems have, as well as potential solutions. To aid researchers in comprehending the essential concepts relating to power quality occurring in electric railway traction systems, the solutions for increasing power quality have been categorized depending on various equipment.

The topic of interest is 25 kV electric trains on the utility public grid and its compensation was taken into account with a focus on static compensator structures and insertion techniques. The effectiveness of compensating for size and complexity in various active switching devices, the requirement for capacitive storage, and additional external devices have all had an impact on the development of compensator features. The SVC enhances harmonic levels and amplitudes in a network since it is the first active approach to account for reactive power and NSCs. The RPC is extensively used in East Asia to concurrently reduce NSCs, reactive power, and system harmonics. With an emphasis on high-speed rail, the co-phase system seems to be the next full generation of supply systems for electrified trains today. The undermentioned conditioners have been taken into account in addition to the adjustment of current (and voltage) imbalance previously mentioned: RPC, APQC, HBRPC, HPQC, and ACBT-HRPC.

To rapidly calculate size and cost, consider all active power, storage, and external devices that are required. Because co-phase systems lack section isolators, high-speed rail systems may be more favorable to them., despite the fact that the HPQC has shown to be a thorough compensator with a number of advantages. It has also been shown that hybrid compensators, such as ACBT-HRPC, are appropriate in a variety of unusual circumstances, such as TSSs with huge capacities.

## 9. FUTURE WORKS

Future research should focus on improving power quality by utilizing a combination of compensation techniques in order to increase system efficiency or reduce costs, similar to the approach examined in [23],[24]. Mass transit increased reliability, and high speed should be the railroad industry's three aces if it wishes to compete with air, sea, and road transportation. The railway industry's future depends on a technology known as magnetic levitation (Maglev), which is still in its infancy and has yet to be commercialized in India. Future competition with other transportation sectors is highly likely for maglev [26]. Maglev should be examined by power quality engineers due to the installation of this technology in the power system, communication systems, and other interconnected systems. Railway electrical smart grids are a new technology with development potential [25].

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