Enhancement of Power Quality and Power Flow with Fuzzy-based RIPFC for AC Railway Traction System

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Abstract Typically, electrical railway systemhas attracting technology in this world for transportation.However, many advantages and disadvantages are involved in thisrailway electrical technology. The main concern of the electrical railway system is to maintained the quality of power at various loading circumstances. In this work, railway power quality compensator (RPQC) is utilized for compensating the power quality issues in AC-based railway networks. In order to enrich the active power, railway interline power flow controller (RIPFC) is integrated to the system with fuzzy logic controller. Moreover, the proposed RIPFC and RPQC are different single phase converters, however, both are link through back-to-back (B2B) link for sharing the power through same dc link. The system has been implemented in the MATLAB/Simulink Environment. As per the simulation outcomes, the fuzzy based coordinative controllers yield better enhancement in mitigating the deviations of harmonics, voltage drop, and power quality issues.

Keywordselectrical railway system, RPQC, RIPFC, B2B, fuzzy controller.

1.0 Introduction

A railway electrification system supplies electric power to railwaytrains and trams without an on-board prime mover or local fuel supply. Electric railways use either electric locomotives (hauling passengers or freight in separate cars), electric multiple units (passenger cars with their own motors) or both. Electricity is typically generated in large and relatively efficient generating stations, transmitted to the railway network and distributed to the trains. Some electric railways have their own dedicated generating stations and transmission lines, but most purchase power from an electric utility. The railway usually provides its own distribution lines, switches, and transformers [1]-[3]. Power is supplied to moving trains with a (nearly) continuous conductor running along the track that usually takes one of two forms: an overhead line, suspended from poles or towers along the track or from structure or tunnel ceilings, or a third rail mounted at track level and contacted by a sliding "pickup shoe". Both overhead wire and third-rail systems usually use the running rails as the return conductor, but some systems use a separate fourth rail for this purpose[4].

In AC systems, the voltage level of the three phaseupstream power system is converted by the traction transformerto required voltage level of the locomotives in the single phaseoverhead network [5]. The traction transformer can havevarious connections such as scott, V-x, Woodbridge, Roofdelta, etc [6]. Electric locomotives that use electric energy tocreate the driving force, Based on the voltage level and powersupply system, have different types. Electric locomotives aremade in single-voltage, multi-voltage and hybrid (electric anddiesel) forms [7]. Based on the type of overhead networkvoltage and the type of electric locomotive, four differentarrangements for power transmission in the electric locomotiveare possible as follows: DC/DC, DC/AC, AC,DC andAC/DC/AC [8]. All conversions are performed by powerelectronic converters such as inverters, rectifiers andcycloconverters that these devices produce nonlinear andharmonic currents in the system [8, 9].In the electric railway power system, trains are single-phaseloads that generate negative sequence currents in the upstreampower system [10]. Locomotives are the main source ofharmonics [9]. Harmonic Characteristics of Different types ofelectric locomotives have similar high order harmonicbehaviors and generally produce a large amount of 3th, 5th and7th harmonics [11]. The reactive power is the exchange ofenergy between the source and the load reactive section, and thepower factor can be used to evaluate the presence of reactivepower. Due to motorized loads and power electronic convertersin electric locomotives, the power factor of the traction feedingsystem is low. Therefore, the potential capacity of theequipment, such as traction transformer, is less used and causesvoltage drop and increase in losses in the system [12]. Inaddition to the imbalance, reactive power and harmonics in thetraction power system, there are other power quality problemssuch as harmonic resonance, low voltage frequencyoscillations(flicker) [8, 10, 13].

In this work, railway power quality compensator (RPQC) is utilized for compensating the power quality issues in AC-based railway networks. In order to enrich the active power, railway interline power flow controller (RIPFC) is integrated to the system with fuzzy logic controller. Moreover, the proposed RIPFC and RPQC are different single phase converters, however, both are link through back-to-back (B2B) link for sharing the power through same dc link.

2.0 SYSTEM DEISGN

A. RPQC Topology

RPQC contains two Separate single phase voltage sourceinverter (VSI) that are connected B2B by sharing the same dc link capacitor which is developed for harmonic, reactive power and negative sequence current compensation. RPQC placed in parallel with the load by an interface reactor. The interface reactor converts the inverter's voltage into a current signal. Therefore, this compensator can be modeled as a current source. This inductance allows the DC link capacitor to be charged to a voltage exceeding the maximum voltage of the system. The interface reactor limits the amplitude of the fluctuations ofcurrent during commutation. In addition, without an interface reactor, it is not possible to connect the traction sinusoidal voltage to the non sinusoidal voltage of the inverter output. The DC link capacitor is used to feed the voltage source inverters. Due to the lack of a source of power in the DC link, the voltage of this link is kept constant by the capacitor. The DC capacitor is charged before starting the compensating system operation. During the operation period, compensator receives only a small amount of the fundamental component current to overcome the compensator's loss. The RPQC connected to the traction substation is shown in Fig. 1.

B. Control System

1) theory of compensation: According to Fig. 1, RPQC with active power transfer between secondary phases, causes the active currents to equalize in both phases and the imbalance disappears on the three-phase side. The harmonic and reactive currents are also generated by the switching of the converters of each side and injected into the network. Therefore, the primary side at the traction transformer is devoid of anyharmonic, reactive, and negative sequence currents.

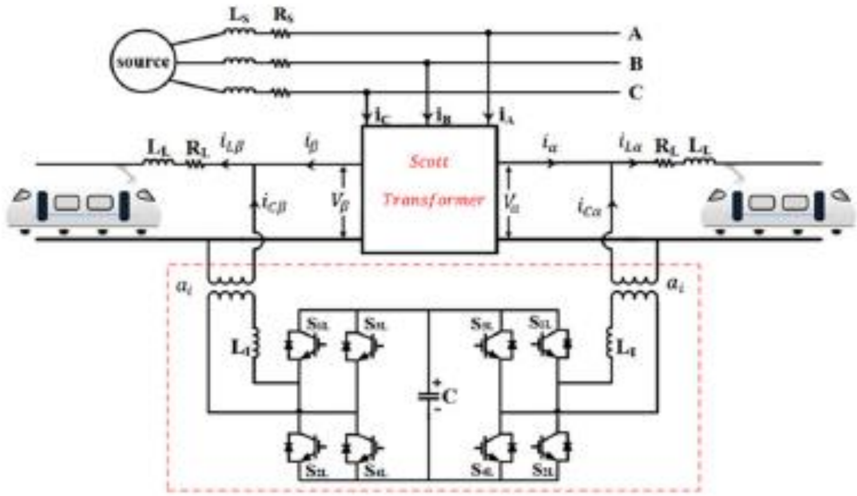


Figure 1 RPQC connected to the traction substation

Secondary voltages can have different angles. However, The secondary phases voltage are:

The secondary phases voltage are:

$$\begin{cases} V_\alpha = V_{rms}\measuredangle 0^\circ \\ V_\beta = V_{rms}\measuredangle -90^\circ \end{cases} \quad (1)$$

Where $v_{rms}$is effective voltage. If the power factor oflocomotives is assumed to be unit, then the load current's in the two phases α and β are calculated as follows:

$$\begin{cases} I_\alpha = I_{L\alpha} = I_{rms}\measuredangle 0^\circ \\ I_\beta = I_{L\beta} = I_{rms}\measuredangle -90^\circ \end{cases} \quad (2)$$

$$\begin{cases} I_A = \frac{2}{\sqrt{3}}\frac{N_2}{N_1} I_{rms} = I_L\measuredangle 0^\circ \\ I_B = \frac{N_2}{N_1}\left(-\frac{1}{\sqrt{3}} - j\right) I_{rms} = I_L\measuredangle 240^\circ \\ I_C = \frac{N_2}{N_1}\left(-\frac{1}{\sqrt{3}} + j\right) I_{rms} = I_L\measuredangle 120^\circ \end{cases} \quad (3)$$

Therefore, if the secondary side currents of the traction transformer are balanced and free of reactive and harmoniccurrents, the primary side currents are also balanced, and free of reactive and harmonic currents. The corresponding phasor diagram for balanced secondary side load of unity power factor is drawn in Fig. 2.

***2) control method*:**

In order to extract the compensatorreference currents, it should be noted that the studied system is a single-phase system, and most theories for determining the reference current for active power filters based on three-phase systems have been developed. Several methods have beenproposed for measuring non-sinusoidal currents and extracting reference currents, most of which are based on the theory of instantaneous power [5]. These instantaneous power theories, first introduced by Akagi et al and subsequently developed by various researchers, are only used for analyzing three phase systems [11].

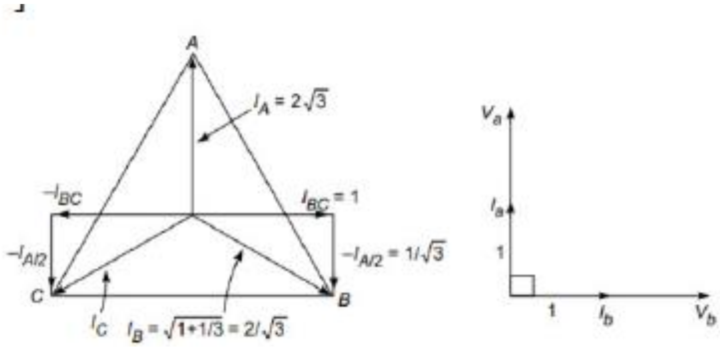


Figure 2 scott connection

One of the methods for extracting reference currents insingle-phase systems is based on the separation of the measured current into active, reactive and harmonic components, which is called a three-component or FBD method [10]. According to this method, current of one of phases, such as α phase, is considered as follows:

$$i_\alpha(t) = i_{\alpha p}(t) + i_{\alpha q}(t) + i_{\alpha h}(t) \quad (4)$$

$$V_\alpha(t) = V \sin \omega t$$

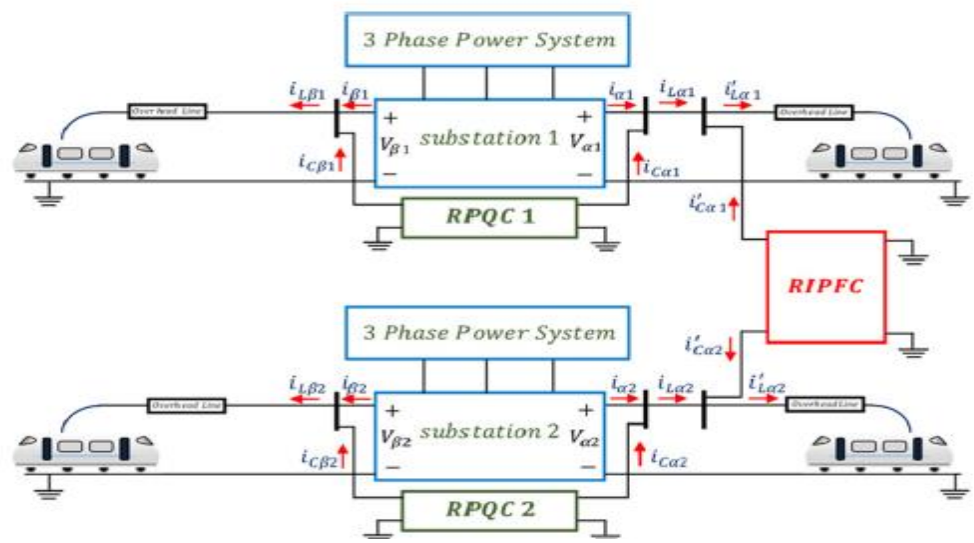
$$i_\alpha(t) = I_{\alpha p} \sin(\omega t) + I_{\alpha q} \sin(\omega t - 90°) + \sum_{n=2}^{\infty} I_{\alpha n} \sin(n\omega t - \varphi_n) \quad (5)$$

$$i_\alpha(t) \times \sin(\omega t) = \frac{I_{\alpha p}}{2}(1 - \cos(2\omega t)) - \frac{I_{\alpha q}}{2}\sin(2\omega t) + \sum_{n=2}^{\infty} \frac{I_{\alpha n}}{2}\left[\cos((n-1)\omega t - \varphi_n) - \cos((n+1)\omega t - \varphi_n)\right] \quad (6)$$

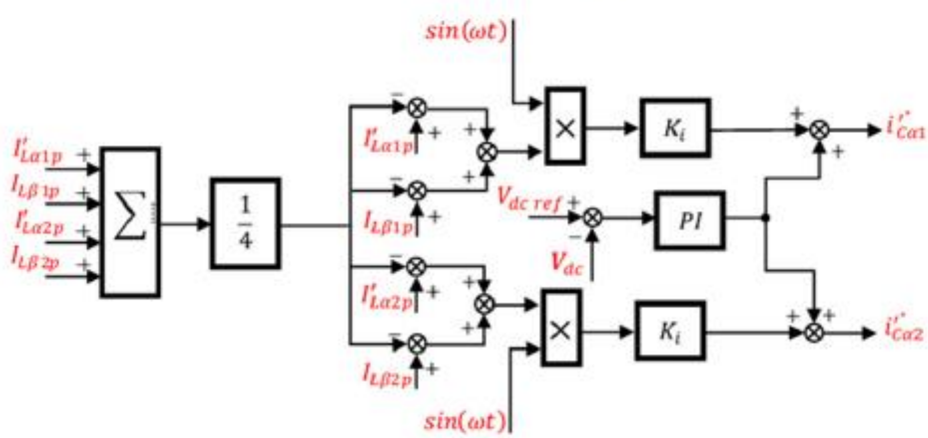
$$i_\alpha(t) \times \sin(\omega t - 90°) = \frac{I_{\alpha q}}{2}(1 + \cos(2\omega t)) - \frac{I_{\alpha p}}{2}\sin(2\omega t) + \sum_{n=2}^{\infty} \frac{I_{\alpha n}}{2}\left[\cos((n-1)\omega t - \varphi_n + 90°) - \cos((n+1)\omega t - \varphi_n - 90°)\right) \quad (7)$$

The proposed structure RIPFC is in parallel, unlike theconventional one which is installed in series with the lines. Based on the control objectives and management of power distribution in each substation, a certain amount of active current as a current demand in the phase with lighter load and the same amount of active current as a supply current in a phase with heavier load Appears. Which causes the transfer of active power from the line with lighter load to a heavier load line at

two traction substations. Active power transfer between lines with different control goals can take place. However, in this paper, the control system with the goal of equalizing the active current in all phases at two traction substations has been developed.Fig. 3, shows the RIPFC control system forextraction reference currents.



(a)



(b)

Figure 3 The structure of RIPFC

These currents are generated by the hysteresis current controllerand injected into the network. Therefore, the load of each phase seen by RPCs varies with the loading values of each phase, and the amount of power transfer from the lighter load to the heavyloaded section is also considered. after the RPCs operation, the active currents will be equal in all four phases of the system.

3.0 Railway Interline Power Flow Control

In some cases, such as railroads with two parallel lines orstations that are interspersed with different rail lines, it is possible to transfer a certain amount of active power between different lines. For this purpose, the same RPQC topology is used by changing the structure of the control system. Each of traction substations has its own RPQC that compensates reactive power, harmonic and negative sequence current between the two secondary phases of each traction transformer.

The RIPFC connected to the two different traction substation is shown in Fig 3. The proposed structure RIPFC is in parallel, unlike the conventional one which is installed in series with the lines. Based on the control objectives and management of power distribution in each substation, a certain amount of active current as a current demand in the phase with lighter load and the same amount of active current as a supply current in a phase with heavier load Appears. Which causes the transfer of active power from the line with lighter load to a heavier load line at two traction substations. Active power transfer between lines with different control goals can take place. However, in this paper, the control system with the goal of equalizing the active current in all phases at two traction substations has been developed.

4.0 Fuzzy logic controller

In recent years, the number and variety of applications of fuzzy logic have increased significantly. The applications range from consumer products such as cameras, camcorders, washing machines, and microwave ovens to industrial process control, medical instrumentation, decision-support systems, and portfolio selection. To understand why use of fuzzy logic has grown, you must first understand what is meant by fuzzy logic. Fuzzy logic has two different meanings. In a narrow sense, fuzzy logic is a logical system, which is an extension of multivalve logic. However, in a wider sense fuzzy logic (FL) is almost synonymous with the theory of fuzzy sets, a theory which relates to classes of objects with unsharp boundaries in which membership is a matter of degree. In this perspective, fuzzy logic in its narrow sense is a branch of fl. Even in its more narrow definition, fuzzy logic differs both in concept and substance from traditional multivalve logical systems.

In fuzzy Logic Toolbox software, fuzzy logic should be interpreted as FL, that is, fuzzy logic in its wide sense. The basic ideas underlying FL are explained very clearly and insightfully in Foundations of Fuzzy Logic. What might be added is that the basic concept underlying FL is that of a linguistic variable, that is, a variable whose values are words rather than numbers. In effect, much of FL may be viewed as a methodology for computing with words rather than numbers. Although words are inherently less precise than numbers, their use is closer to human intuition. Furthermore, computing with words exploits the tolerance for imprecision and thereby lowers the cost of solution. Another basic concept in FL, which plays a central role in most of its applications, is that of a fuzzy if-then rule or, simply, fuzzy rule. Although rule-based systems have a long history of use in Artificial Intelligence (AI), what is missing in such systems is a mechanism for dealing with fuzzy consequents and fuzzy antecedents. In fuzzy logic, this mechanism is provided by the calculus of fuzzy rules. The calculus of fuzzy rules serves as a basis for what might be called the Fuzzy Dependency and Command Language (FDCL).

5.0 Simulation Results

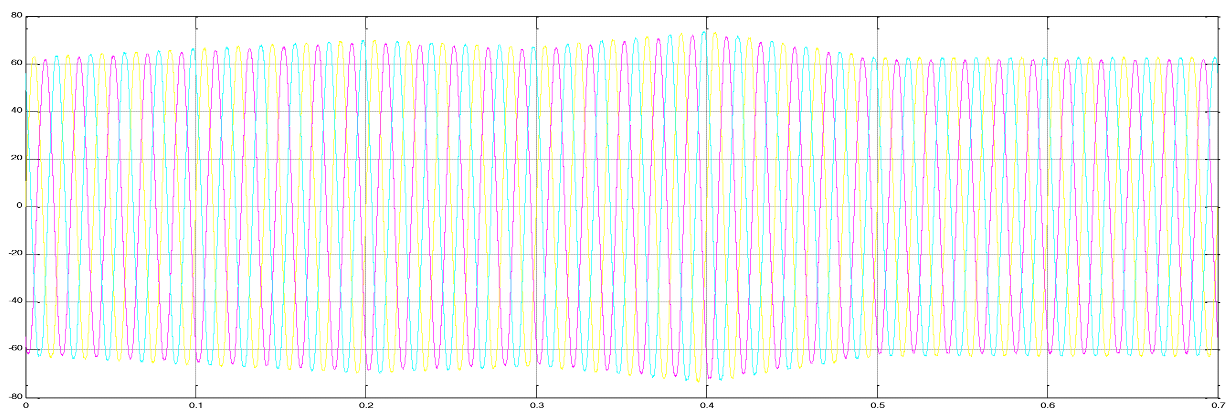


Fig.4 Source current of traction unit 1

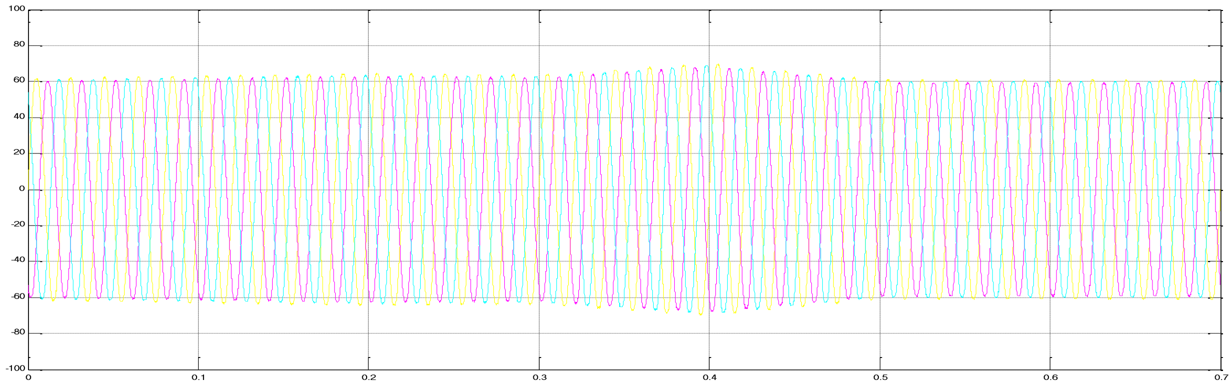


Fig.5 Source current of traction unit 2

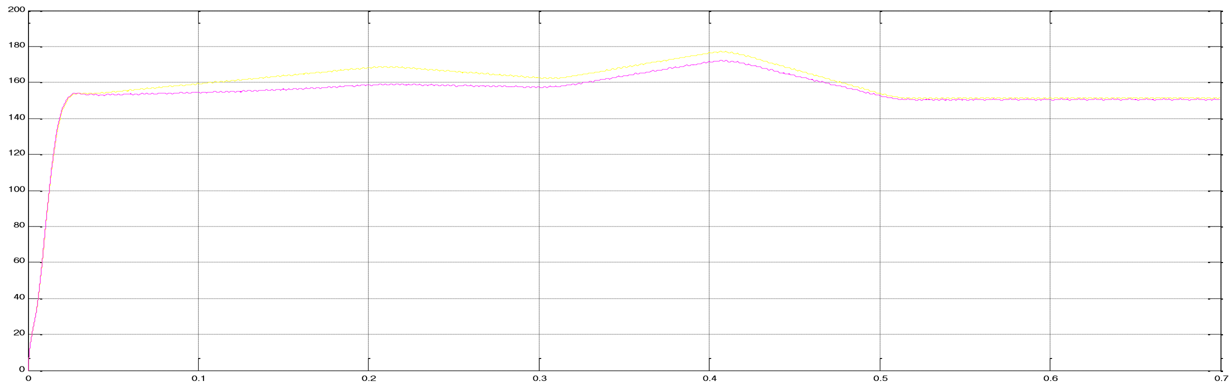


Fig.6 Reactive Powers

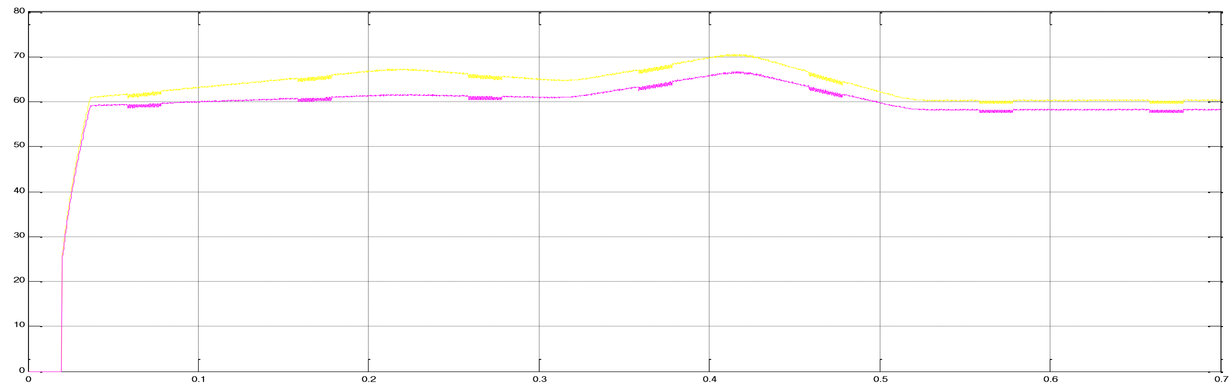


Fig.7 Current magnitudes of traction units

6.0 Conclusion

In this work, railway power quality compensator (RPQC) is utilized for compensating the power quality issues in AC-based railway networks. In order to enrich the active power, railway interline power flow controller (RIPFC) is integrated to the system with fuzzy logic controller. As per the simulation outcomes, the proposed RPQC and RIPFC with fuzzy controller reduces the harmonic distortions, minimize the negative sequence current, and drops in voltage. Therefore, the designed suggested system is an effective control approach for improving the power quality.

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