ISSN No: 2348-4845
International Journal & Magazine of Engineering, Technology, Management and Research
A Peer Reviewed Open Access International Journal

Power Quality Improvement of Electrical Railway System by Fuzzy Logic Based Direct Power Control with Space Vector Modulation

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Abstract:

This paper is to develop Power Quality in Electric Railway systems with the help of Fuzzy Logic based Direct Power Control with Space Vector Modulation (DPC-SVM). This can be achieved by general filtering and harmonic compensation using the proposed method. By this method we can also control the power flow exchange between the grid and the load, so that instantaneous active and reactive power is maintain constant. This power can be produced only by a balanced system without current and voltage harmonics. Fuzzy Logic compensation is proposed to diminish the Total Harmonic Distortion (THD) to International standards. The results from simulator assessments show the controller benefits and the applicability of the suggested strategy in railway systems.

Keywords:

Active filters, harmonics distortion, power control, rail transportation power system.

I.INTRODUCTION:

Electrical Railway Systems now-a-days becomes more advantages in the fields like transportation, energy-saving and environment friendly. These electrical locomotives are fundamentally single phase loads where the load conditions and speeds changes during every short span of time, because of these load changes, harmonics occurs in the system causing unbalance at the point of common coupling. Special traction transformers like V/V, Le-Blanc and Scott were used to convert the three-phase supply to one or two single-phase supplies with 90^(o)shift [1].

Harmonics and unbalance will create a lot of problems to the power system, extra losses in overhead lines and underground cables, transformers and electrical machines, issue in the operation of protection system, over voltage, slip in measuring instrument, and glitch of low efficiency of client delicate loads [2]. Therefore it will be a great problem to maintain stability in power systems due to these harmonics and unbalance, filters and unbalance compensators are used to maintain the power system stable and to improve the power quality [3].

Passive LC filters were used to eradicate current harmonics by connecting it parallel with the load; these have some disadvantages like, passive filters were not suitable for variable loads, they are premeditated for specific reactive power, and the variation of load impedance can detune the filter [4].Over loads can happen in the passive filter because of the course of harmonics originating from non-linear loads associated close to the association purpose of the passive filters.

To overcome the problems of the passive filters, active filters were Introduced [5]-[10], they insert harmonic voltage or current with proper magnitudes and phase angles into the system and reduce harmonics of non-linear loads, however they neglect the sequence components introduced by the harmonics, there initial cost will be more and has high power losses and also they cannot provide simultaneous compensation of Harmonics & Unbalance in the system. Direct Power Control (DPC) was Implemented to provide simultaneous correction of harmonic content and load unbalance commonly found in railroad systems [11]-[14], with dissimilar transformer connections in the power substation.

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This control doesn't need coordinate transformations because it operates directly on Instantaneous active and reactive powers. High dynamics guaranteed by hysteresis controllers and look up-table. But this control scheme also has some drawbacks like high sampling frequency and variable switching frequency. To conquer these disadvantages a Space vector modulation was proposed to this DPC control scheme and this is so called as Direct Power Control with Space Vector Modulator (DPC-SVM) [15] [16]. Presently the control scheme has double features, features of SVM (i.e. constant switching frequency, unipolar voltage switching's, low current distortions) and also the features of DPC (i.e. simple and robust structure, lack of internal current control loops, good dynamics etc.) PI controllers were utilized as a part of its outline to analyze the generated active and reactive powers with the referenced active and reactive powers. PI controller has maximum overshoot and high settling time, finding of proportionality and Integral gains will be difficult and the steady state errors will be high.PI controller is replaced with fuzzy logic controller in the design of DPC-SVM controller to get the better harmonic reduction and unbalance compensation.

II. HARMONIC & UNBALANCE COMPENSATION BY DIRECT POWER CONTROL WITH SPACE VECTOR MODULATOR:

On healthy three-phase strategy providing balanced linear loads, the instantaneous active and reactive terms of the complex power are constant and equal to p(t) = 3VI cos(φ) and q(t) = 3VI sin(φ), whereas for similar balanced three-phase systems, the instantaneous active and reactive power with unbalanced nonlinear loads includes average and oscillating terms. To compensate for load imbalance and reduce harmonic injection from the load to the supply system.

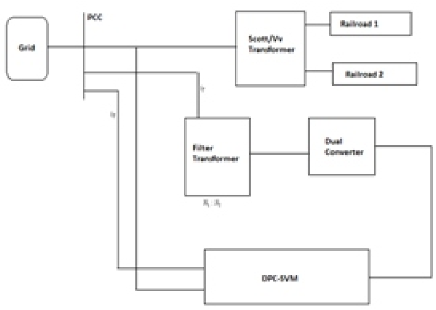

Fig. 1 Block diagram of the system

The proposed controller, shown in Fig. 1, is targeted at keeping constant the instantaneous active and reactive power exchange with the supply. In this project, this is achieved with a shunt active filter openly coupled to the power system by a voltage step-up filter transformer. For the railway application, the power stage in the filter is a three-phase volts source converter (VSC) with a rating between 10% and 15% of the distribution transformer rated power.The controller combines the complete instantaneous active and reactive power taken by the combination of traction system and filter. In the suggested compensation scheme, the controller selects the converter voltage V_r necessary to keep constant the total instantaneous active and reactive power drawn from the grid, performing in this way as a three-phase current balancer and harmonic filter [17].

Consign is used to decrease the modifications in the dc link of the filter's power level. This will modify instantly the power taken by the traction system plus the filter losses. The reactive power reference Q_ref offers an additional degree of freedom that can be used to adjust the system's power factor. The block diagram of DPC-SVM control scheme is shown Fig. 2.In this Direct Power Control with Space Vector Modulator active and reactive powers both were used as control variables SVM and Fuzzy Logic controller were used in its design for constant switching frequency. The reference values will be generated by outer DC voltage link and then the control will

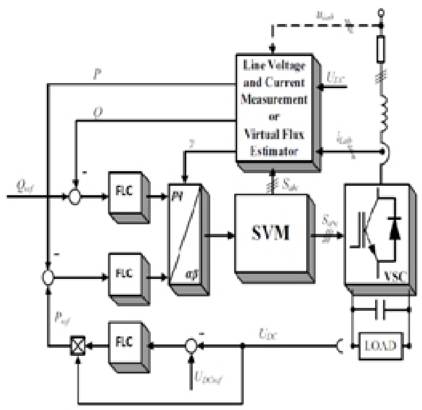

Fig. 2 Proposed DPC-SVM with Fuzzy Logic Controller.

also generate the values of P and Q, both should be compared by the Fuzzy Logic Controller the error will be suppressed and again the values of P and Q will be sent to the SVM, then SVM will set the voltage level of the system for every particular time by sending switching signals to activate VSC.

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III. INSTANTANEOUS ACTIVE & REACTIVE POWERS GENERATION:

A. Basis of p-q Theory: Clarke Transformation:

This DPC-SVM method operation is in based on the control of instantaneous active and reactive powers, which are characterized by the supposed Instantaneous Reactive power or p-q theory [18]. This Theory utilizes Clarke Transformation [19] as a part of order to express phase magnitudes of a three-wire active three-phase rectifier in orthogonal axes α-β, being those previously placed in a-b-c axes, as seen in Fig. 3 and (1) (analogous equations would be obtained in the case of currents).

$$\begin{pmatrix} V_\alpha \\ V_\beta \end{pmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{pmatrix} \begin{pmatrix} V_a \\ V_b \\ V_c \end{pmatrix} \qquad (1)$$

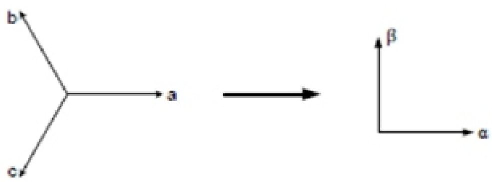

Fig. 3 Transformations from 3ϕ a-b-c to 1ϕ α-β axes

The $\sqrt{\frac{2}{3}}$ factor in (1) is essential for power magnitudes to keep their value after the transformation.

B. Vectorial equations in stationary α-β axes:

It is conceivable to characterize a supposed instantaneous voltage (current) space vector from its α-β segments, as indicated in (2).

$$V = V_\alpha + V_\beta \qquad (2)$$

In connection with this, it can be demonstrated that, in the case of balanced sinusoidal three-phase systems, the voltage (current) space vector has constant amplitude and rotates at an angular velocity of , being the pulsation of the sinusoidal signals.

C. Vectorial equations in rotary d-q axes:

It is also possible to define a rotary reference system d-q, which rotates, at an angular velocity of , in the same direction as the voltage space vector does. Relation between α-β and d-q systems and decomposition of vector into both pairs of axes are shown in Fig 4.

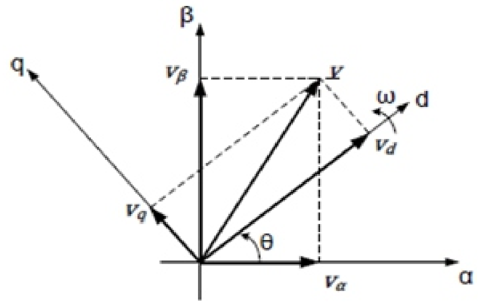

Fig. 4 Relation between α-β and d-q axes

Relations between the expressions of vector v in α-β and d-q systems can be easily obtained from Fig. 3, and are shown in (3).

$$\begin{aligned} V_d &= V_\alpha \cos(\theta) + V_\beta \sin(\theta) \\ V_q &= -V_\alpha \sin(\theta) + V_\beta \cos(\theta) \end{aligned} \qquad (3)$$

D. Instantaneous powers in p-q Theory :

As Clarke Transformation keeps power values constant after its application, three-phase instantaneous power in a three-wire three-phase active rectifier can be obtained through both of the expressions in (4)

$$\begin{aligned} P_{est} &= U_a I_a + U_b I_b + U_c I_c \\ &= L\left(\frac{dI_a}{dt} I_a + \frac{dI_b}{dt} I_b + \frac{dI_c}{dt} I_c\right) \\ &\quad + U_{dc}(S_a I_a + S_b I_b + S_c I_c) \end{aligned} \qquad (4)$$

$$\begin{aligned} q_{est} &= \frac{1}{\sqrt{3}}\big((U_b - U_c) I_a + (U_c - U_a) I_b \\ &\quad + (U_a - U_b) I_c\big) \\ &= \frac{1}{\sqrt{3}}\{3K\left(\frac{dI_a}{dt} I_c - \frac{dI_c}{dt} I_a\right) \\ &\quad - U_{dc}[S_a(I_b - I_c) + S_b(I_c - I_a) + S_c(I_a - I_b)]\} \end{aligned} \quad (5)$$

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In connection with this, two different instantaneous powers are defined for these electrical systems in p-q Theory: instantaneous active (p) and reactive (q) powers [17]. The possibility of calculating them from α-β magnitudes, as seen in (5), is the main p-q Theory feature that DPC-SVM takes advantage off.

IV. Space Vector Modulation (SVM):

The space vector modulation method contrast from the carrier situated in that route, there are no different modulators utilized for each of the three phases. Rather than them, the reference voltages are given by space voltage vector and the output voltages of the inverter are considered as space vectors. There are eight feasible output voltage vectors, six active vectors U1 – U6, and two zero vectors U0, U7 (Fig.). The suggestion voltage vector is realized by the sequential switching of active and zero vectors.In the Fig. 5 Uc reference voltage vector and eight voltage vectors were drawn, which relate to the possible conditions of inverter. The six active vectors separate a plane for the six sectors I - VI. In the each sector the reference voltage vector Uc is obtained by switching on, for a proper time, two adjacent vectors.

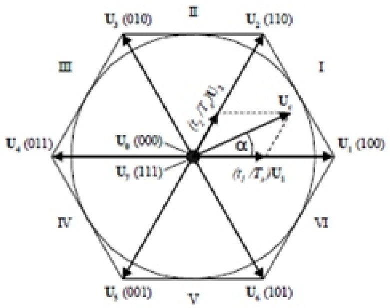

Fig. 5 Principle of space vector modulation

V. Fuzzy Logic Controller:

Mamdani Fuzzy rule base system is implemented in this paper to reduce the harmonics more effectively; Mamdani fuzzy inference method is the most commonly seen fuzzy methodology. This was the first control system built using fuzzy set theory. It consists of two inputs and one output to form If and then rule to get the desired output. The fuzzy Inference system is used to edit the rules and to define the number of membership functions [20].

The rules will be formed in the fuzzy Inference System which will opened by typing Fuzzy in the command window [21], the rules will be formed according to the application. Rules which had developed in FIS should be saved in a file by exporting it to file, for each and every operation with Fuzzy model the FIS file with rules should be imported from file and should be exported to the workspaces then only the model will run and the output will be shown.

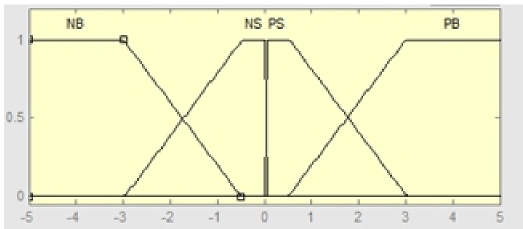

Fig. 4 Membership function for input1

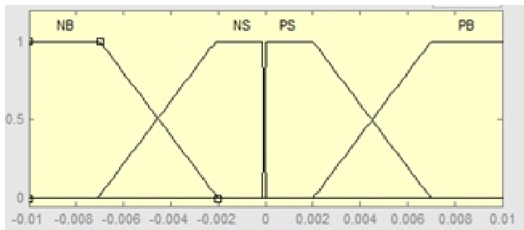

Fig. 5 Membership function for input2

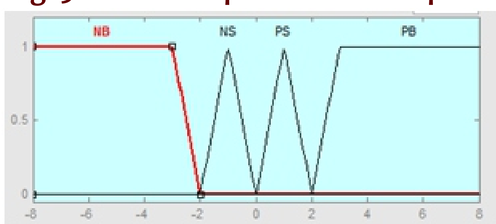

Fig. 6 Membership function for output

	NB	NS	PS	PB
NB	PB	PB	NB	NB
NS	PS	PS	NS	NS
PS	NS	NS	PS	PS
PB	NB	NB	PB	PB

Table I. Rule box

From the above rule box we can form the rule base with 2 inputs and one ouput, the rules are as follows

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Rule1: If input1 is NB and input2 is NB then output is PB.

Rule2: If input1 is NB and input2 is NS then output is PB.

Rule 16: If input1 is PB and input2 is PB then output is PB.

VI. SIMULATION RESULTS

The system is modelled and simulated in MATLAB/SIMULINK. Scott transformer and V-V transformers both involved in the modelling and their results and the reduction of THD table is shown below.The following table shows the current Total Harmonic Distortion (THD) of the system for both uncompensated and compensated cases using V-V and Scott transformersTable 2 Simulated THD by DPC-SVMwith PI and fuzzy.

Fig 6 shows the Scott railroad simulated waveforms for four various load profiles, at t=0.1 first maximum load is applied and then minimum operating load is applied from t=0.1 to t=0.132. after this an emergency load is applied as an emergency condition to phase i at t=0.132 to t=0.164.

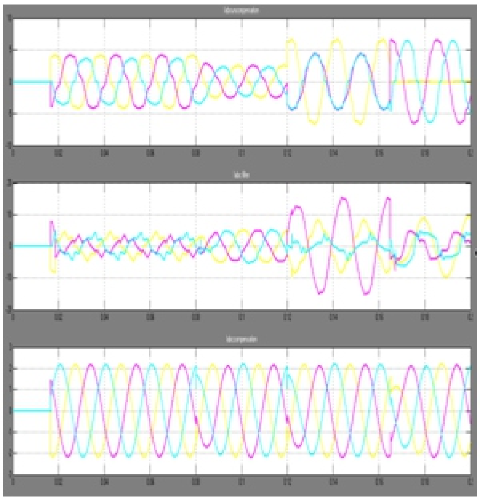
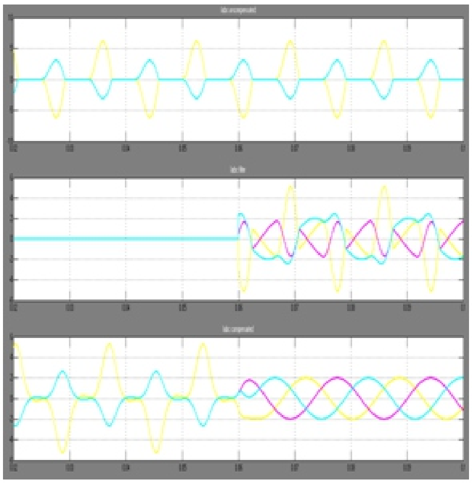
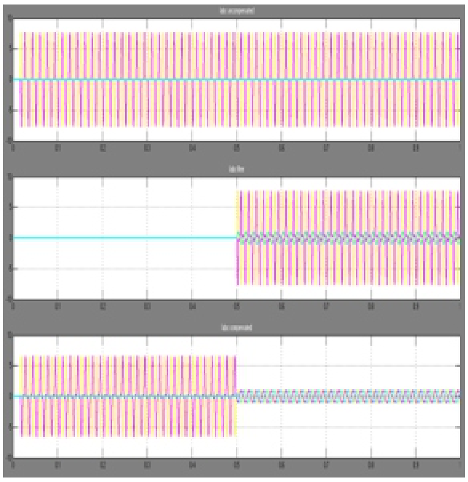


Fig 6 Scott railroad



(a)



(b)

Fig 7(a) Scott rectifier load ,7(b) V/V rectifier load

The above figure shows the simulated waveforms of Scott and V/V rectifier loads, in the case of rectifier load a single-phase rectifier bridge-based load is formed and is given to the secondary of the transformer.

VII. CONCLUSION:

The Fuzzy Logic Based Direct Power Control with Space Vector Modulator is designed in this paper to develop the power quality in electrical railway system and also in power system. The fuzzy logic controller has several advantages, which are applicable in various fields. In order to improve the better results, Fuzzy logic controller is proposed in the design of DPC-SVM for the harmonic and unbalance correction in electrical railway system.

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The proposed DPC-SVM compensation scheme with the fuzzy logic controller is implemented in SIMULINK/ MATLAB and that results are observed from TABLE II. This technique diminishes the current THD to values consenting to international regulations, and also directs the power factor observed in the point of common coupling between the traction substation and the grid.

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