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IMPLEMENTATION OF A NEW CONTROL ALGORITHM IN DISTRIBUTION STATIC COMPENSATOR (DSTATCOM)

Bolisetty Parthika[1], A. Sateesh Kumar[2]

[1]*Student of EEE Branch, Vaagdevi College of Engineering, Bollikunta, (INDIA)*
[2]*EEE Department, Vaagdevi College of Engineering, Bollikunta, (INDIA)*

ABSTRACT

This paper presents the implementation of distribution static compensator (DSTATCOM) using a control algorithm based on Kernel Incremental Metalearning Algorithm (KIMEL). It demonstrates the functions of DSTATCOM such as reactive power compensation, harmonics elimination, and load balancing under linear and nonlinear loads with its self-supporting dc-bus voltage. KIMEL control algorithm is more effective because it is less sensitive to variation of internal parameters of the control algorithm and has less number of internal constants. The present control algorithm based on KIMEL will be used for the extraction of fundamental active and reactive power components of load currents that are required for the estimation of reference supply currents. These reference supply currents are used for gating pulses generation by using indirect current control principle. The response of DSTATCOM using present control algorithm will be studied through simulation.

Index Terms—Constant forgetting factor, distribution static compensator (DSTATCOM), learning rate, load balancing, power factor correction (PFC), zero voltage regulation (ZVR).

I INTRODUCTION

The electric power system consists of three major functional blocks: generation, transmission and distribution. As per reliability consideration in power system, generation unit must generate adequate amount of power, transmission unit should supply maximum power over long distances without overloading and distribution system must deliver electric power to each consumer's premises form bulk power systems. Nonlinear loads based on electronics and magnetic cores are continually on the increase, which introduce nonlinearity within the supply system [1]. Nonlinear behavior of connected loads is the main reason of harmonics distortion within the supply voltage and currents. Generally, power quality is known in the "powering" part according to its definition. It's the variations within the voltage and current waveforms from ideal sine wave [2]. in the area of power quality mitigation, active filers have taken sufficient result in mitigate electric power quality disturbances, like harmonics suppression and reactive power compensation in the supply system [3]–[5]. an improved version of an active filter in terms of features is known as distribution FACTs or custom power device and has several functions compared to conventional active filter [6]–[8]. Chen bird genus and Chen [9] have described a classification of various control algorithms for estimation of harmonics and their elements. Algorithms embody phase-locked loop (PLL) primarily based, artificial neutral network (ANN)-based algorithm, Kalman filtering, etc. selection of a filter is determined by nonlinear behavior of loads in terms of crest issue, voltage rating, and current rating. Acceptable limits of various of varied of assorted power quality indices to take care of the extent of power quality are defined by various international standards [10]. Style of power circuit components and control algorithm is the key issue of distribution static compensator (DSTATCOM) within the real-time application.

Some of the control algorithms are model-based controller, improved PLL-based control algorithm used for delay signal cancellation, adaptive theory-based improved linear sinusoidal tracer within the application of DSTATCOM, etc. de Araujo Ribeiro et al. have reported an implementation of an adaptive pole-placement control algorithm with variable structure control scheme for power factor correction (PFC), harmonics elimination under nonlinear loads. Main feature of this algorithm is zero steady state tracking error using internal model technique. concept of hybrid system like thyristor-controlled reactor and resonant impedance-type active filter for load balancing and harmonics suppression, extraction of harmonics and reactive power in grid connected system, and multi resonance frequency-locked loop for synchronization are mentioned in the literature. Akagi has discussed control strategy and also the suitable installation point of active compensator on a feeder and recommended voltage detection in time domain for stability and its installation at the consumer end. Ramos and Costa-Costello have reported an implementation of active filter using repetitive controller with second-order internal model. Adaptive feature with frequency variation is considered because the main feature of this algorithm. some of the applications of voltage source converter (VSC) primarily based DSTATCOM are compensation of harmonics in distributed power generation system, lagging reactive power compensation for system voltage control to increase the photovoltaic (PV) installation of a distribution feeder, power quality improvement at bus bar wherever various kinds of nonlinear loads are connected and power quality improvement in small hydro power generation , and removal of dc current from single-phase system etc.

Metalearning algorithm learns the base learning algorithm, to improve performance of the learning system. Generally, metalearning algorithms show fast convergence rate and lower mean-square error (MSE) than the compared to basic learning algorithms. A kernel incremental metalearning (KIMEL) algorithm is based on concept of gradient descent and function base variable step learning rate is used for extraction of fundamental components. It varies between 0 and 1 and is free from setting of additional lower and upper boundaries. Generally, the metalearning rate is considered as a small value so that the step-size parameter varies slowly around its mean value. It is widely adopted in analyzing variable step-size adaptive algorithms. Application of metalearning-based control algorithm with variable learning rate is limited in the area of power quality technology. Since disturbances in supply lines do not remain constant, an algorithm based on variable learning rates is more useful compared to fixed learning rate algorithm. Tuned value of learning rate (τ) directly depends upon the level of load current disturbances.

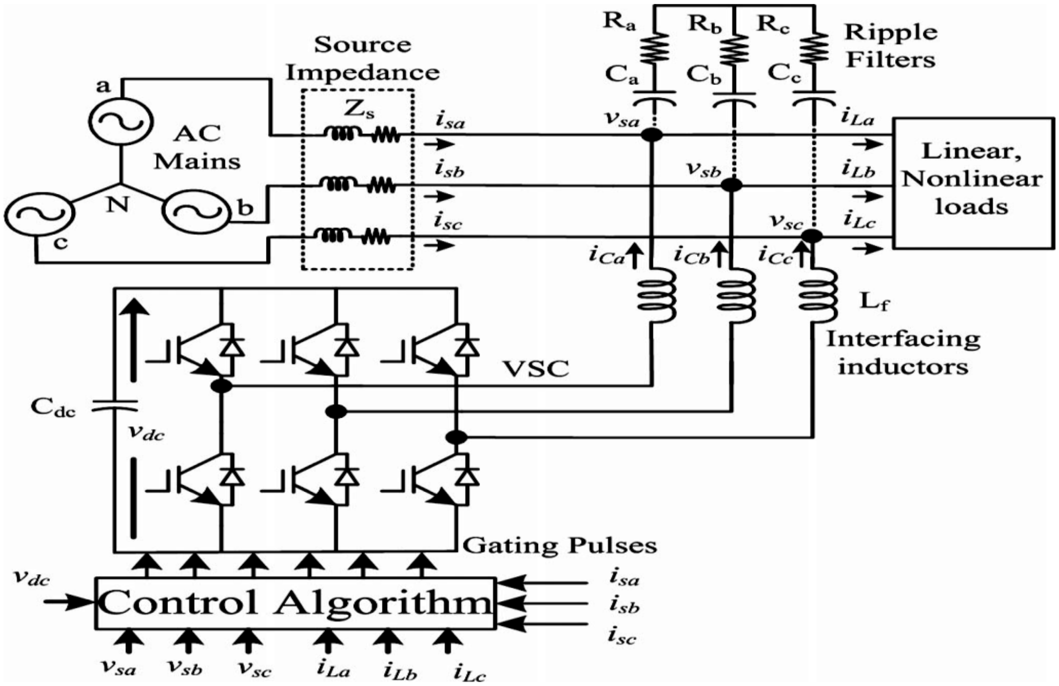


Fig. 1. Three-phase VSC-based DSTATCOM with linear and nonlinear loads.

In this project, a KIMEL algorithm is implemented in shunt connected compensating custom power device as DSTATCOM for extraction of active power and reactive power current components of three-phase linear and nonlinear loads. Proposed control algorithm is used for reactive power compensation, harmonics suppression, and load balancing with self-supporting features of dc-bus voltage. Advantages of this algorithm is that it has only two internal parameters as metalearning rate (θ) and the forgetting factor (λ), which have wide ranges for choice to produce the desired response. It is less sensitive, due to variations in metalearning rate and the forgetting factor, and adaptive in nature. Thus, it is not necessary to select an exact internal parameter, which is the main drawback of some other conventional algorithms. DSTATCOM based on tuning of learning rate is much effective where the controller input signals change rapidly and consumer wants a very quick response at any time instant. In the estimation of fundamental components of active and reactive powers of load currents, variable learning rate is estimated based on sensed input signals and selected value of internal parameters. In this case, kernel incremental metalearning algorithm (KIMEL) control algorithm is more effective because it is less sensitive to variation of internal parameters of control algorithm and has less number of internal constants.

II SYSTEM CONFIGURATION AND CONTROL ALGORITHM

Three-leg VSC-based DSTATCOM consists of interfacing inductor/ transformer, control algorithm, and other auxiliary components. Its basic circuit diagram in three-phase grid supply is shown in Fig. 1. R_s and L_s are considered as supply resistance and inductance, respectively. A small shunt passive ripple filter is also necessary for reduction of high-frequency switching noise produced by switching of VSC. It is a series combination of small value resistance (R_f) and capacitor (C_f) connected as point of common coupling (PCC). Three-phase diode rectifier is modeled as a nonlinear load.

A block diagram of a KIMEL control algorithm for extraction reference source currents is shown in Fig. 2. It is applied for the estimation of fundamental active and reactive power components of reference supply currents with unit vector of PCC voltages[11][12].

The phase voltages in-phase unit vectors at PCC (V_{sa}, V_{sb} , and V_{sc}) are computed as

$$u_{spa} = \frac{v_{sa}}{V_t}, \quad u_{spb} = \frac{v_{sb}}{V_t}, \quad u_{spc} = \frac{v_{sc}}{V_t} \tag{1}$$

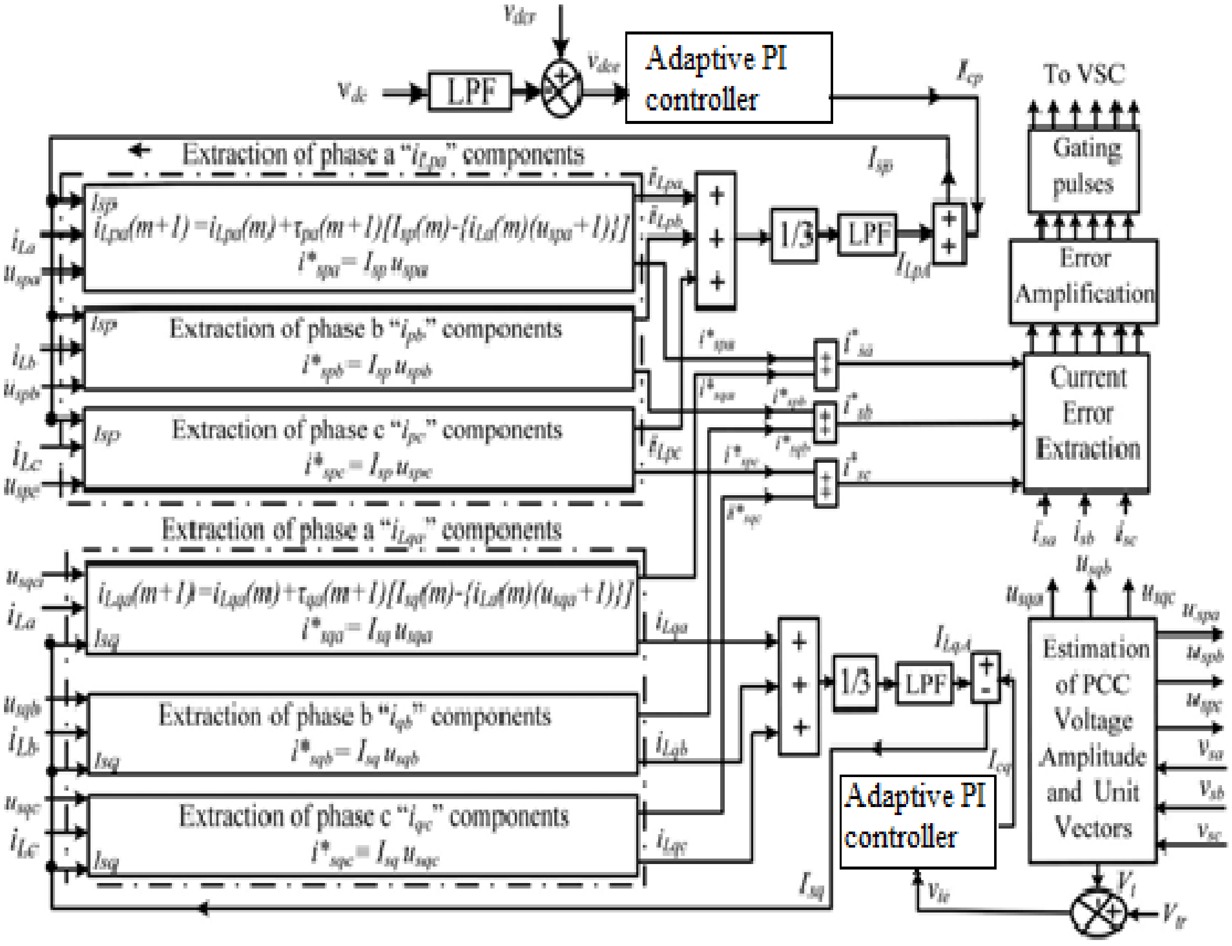


Fig. 2. KIMEL control algorithm for estimation of reference supply currents.

Where magnitude of PCC voltages is estimated as

$$V_t = \sqrt{\frac{2}{3}\left(v_{sa}^2 + v_{sb}^2 + v_{sc}^2\right)}. \qquad (2)$$

Reference voltage of self-supporting dc bus V_{dcr} and sensed dc-bus voltage V_{dc} of DSTATCOM are subtracted and error (V_{dce}) in dc-bus voltage is supplied to the dc-bus voltage Adaptive proportional–integral (PI) controller. The output signal of the dc-bus voltage adaptive PI controller is used as loss components of VSC. At (m + 1)th sampling instant, it is formulated as

$$\begin{aligned} I_{cp}(m+1) = I_{cp}(m) + k_{pd}\{v_{dce}(m+1) - v_{dce}(m)\} \\ + k_{id} v_{dce}(m+1) \end{aligned} \qquad (3)$$

where I_{cp} (m+1) is considered as a part of total active power component of supply current and k_{pd} and k_{id} are the adaptive PI controller gain constants of self-supporting dc bus.

The estimation of weights of fundamental active power components of load currents are achieved using a KIMEL control algorithm. The estimated value of active power component of phase "*a*" of load current is expressed as

$$\begin{aligned} i_{Lpa}(m+1) = i_{Lpa}(m) + \tau_{pa}(m+1)[I_{sp}(m) \\ - \{i_{La}(m)\varphi_{pa}(m)\}] \end{aligned} \qquad (4)$$

where ϕ_{pa} (m) and τ_{pa} (m+1) are the projections of the input as voltage template and learning rate of proposed control algorithm for phase "a." Variable ϕ_{pa} (m) is considered as (u_{spa} + 1) from polynomial kernel. Its update relation is given as

$$\tau_{pa}(m+1) = \frac{1}{1 + e^{-\beta_{pa}(m+1)}} \qquad (5)$$

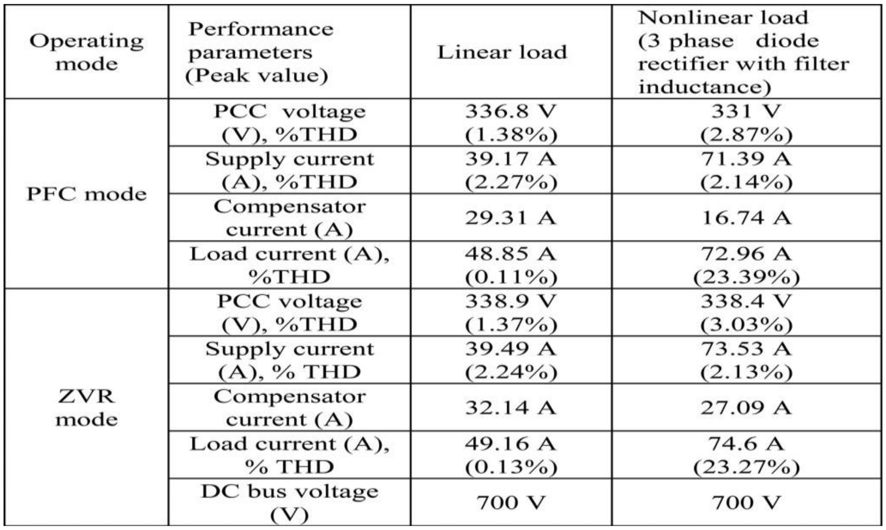
And

$$\begin{aligned} \beta_{pa}(m+1) = \beta_{pa}(m) + \theta e(m)[\lambda \tau_{pa}(m+1) \\ \times \{1 - \tau_{pa}(m+1)\} e(r) k(m,r)] \end{aligned} \qquad (6)$$

where i_{Lpa} (r), I_{LpA}(r), and I_{sp} (m) are the magnitude of phase "*a*" load current, average amplitude of load active power components of current at the rth sampling instant, and the total active component of reference supply current at mth sampling instant, respectively. Other components as θ and λ are metalearning rate and forgetting factor, respectively. Gaussian kernel is used for expansion of k(m, r). In this application, selected values of θ and λ are 0.6 and 0.7, respectively.

TABLE I

PERFORMANCE OF DSTATCOM



Operating mode	Performance parameters (Peak value)	Linear load	Nonlinear load (3 phase diode rectifier with filter inductance)
PFC mode	PCC voltage (V), %THD	336.8 V (1.38%)	331 V (2.87%)
	Supply current (A), %THD	39.17 A (2.27%)	71.39 A (2.14%)
	Compensator current (A)	29.31 A	16.74 A
	Load current (A), %THD	48.85 A (0.11%)	72.96 A (23.39%)
ZVR mode	PCC voltage (V), %THD	338.9 V (1.37%)	338.4 V (3.03%)
	Supply current (A), % THD	39.49 A (2.24%)	73.53 A (2.13%)
	Compensator current (A)	32.14 A	27.09 A
	Load current (A), % THD	49.16 A (0.13%)	74.6 A (23.27%)
	DC bus voltage (V)	700 V	700 V

These factors are responsible for online tuning of learning rate. But accuracy and stability of this control algorithm very much depend upon the estimation of τ_{pa} $(m+1)$. Similarly, for extraction of reactive power components, it is represented as τ_{qa} $(m + 1)$.Similarly other phases (b and c) active power components of load currents are formulated as

$$i_{Lpb}(m+1) = i_{Lpb}(m) + \tau_{pb}(m+1)[I_{sp}(m) - \{i_{Lb}(m)\varphi_{pb}(m)\}] \tag{7}$$

$$i_{Lpc}(m+1) = i_{Lpc}(m) + \tau_{pc}(m+1)[I_{sp}(m) - \{i_{Lc}(m)\varphi_{pc}(m)\}] \tag{8}$$

where , τ_{pb} and τ_{pc} are the learning rates of phase “*b*” and phase “*c*,” respectively.

III SIMULATION RESULTS AND DISCUSSION

MATLAB with Simulink and Sim Power System (SPS) toolboxes is used for the development of simulation model of a DSTATCOM and its control algorithm. The performance of KIMEL in time domain is simulated for PFC and ZVR modes under nonlinear loads respectively. The performance of control algorithm DSTATCOM is observed as follows.

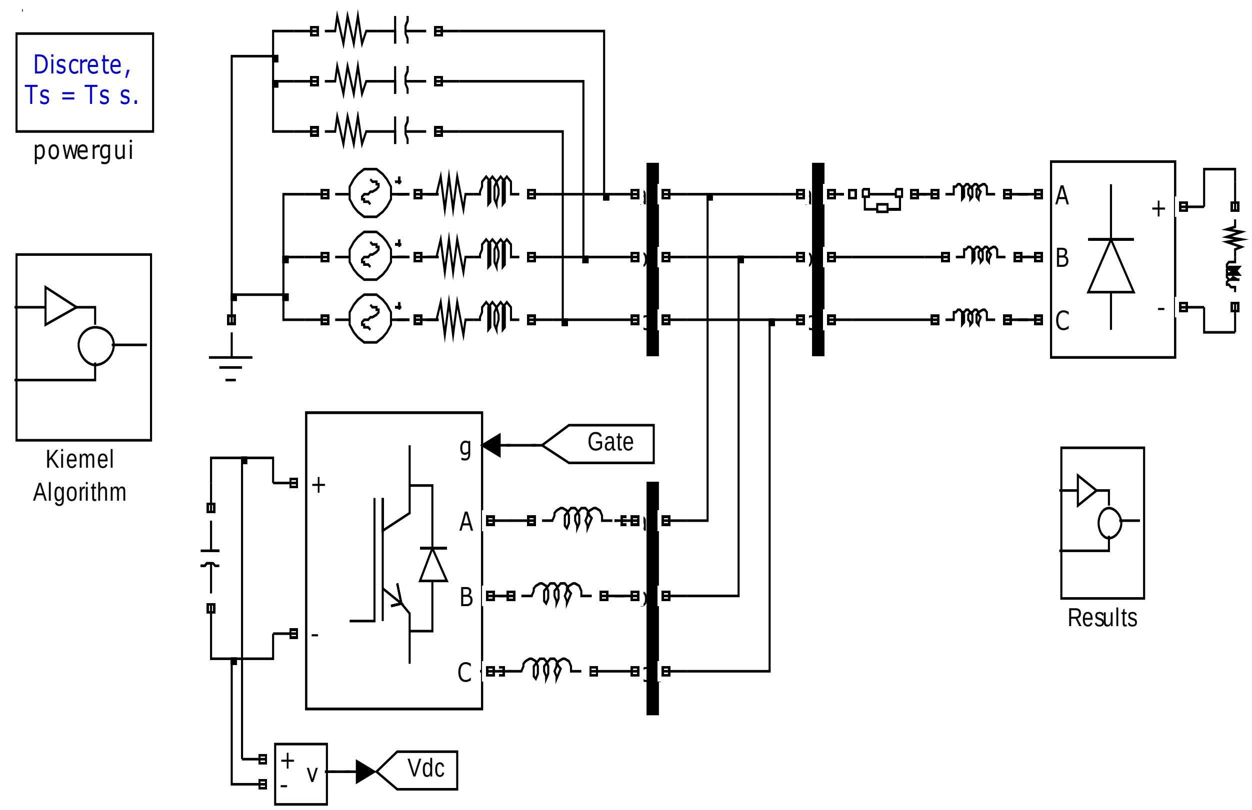


Fig.3 Simulation model

3.1. Performance of Control Algorithm

Fig. 3 shows the extracted control signals of a KIMEL algorithm that are used for extraction of reference supply currents. It includes extracted learning rate for active component (μpa), load active power current without filter ($iLpa$), average magnitude of load active power components ($ILpA$) after filter, total active power components (Isp), including dc-bus PI controller outputs (Icp), variation of learning rate for reactive component (μqa), extracted amplitude phase “*a*” load reactive power current without filter ($iLqa$), average magnitude of load reactive power components ($ILqA$) after filter, total reactive power components (Isq), including ac voltage PI controller outputs (Icq), three-phase reference supply currents sensed supply currents (is), respectively. These variables are shown with PCC voltage (vs) and load currents (iL) in the application of ZVR mode. After comparing reference supply currents ($i* s$) and supply currents (is), it is concluded that both are tracking each other with variable learning rates (τpa and τqa) under varying loads. It has proved a fast and an accurate extraction of control variables used in learning based control algorithm.

3.2. Performance of DSTATCOM in PFC Mode

The dynamic performance of a VSC-based DSTATCOM with KIMEL control algorithm for PFC mode under linear load is shown in Fig. 4.

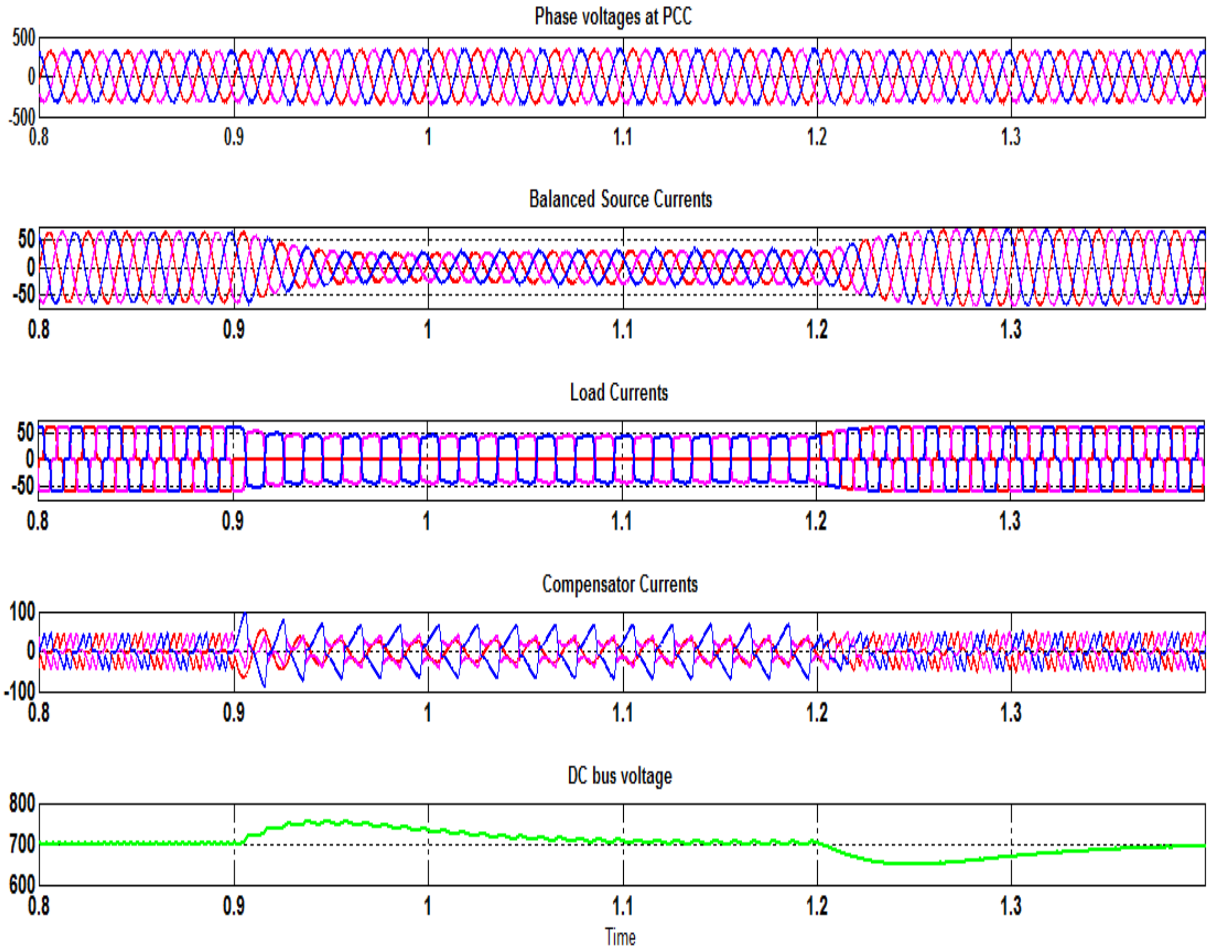


Fig.4.Simulation results for performance of DSTATCOM under varying nonlinear loads in PFC mode.

The performance indices are phase voltages at PCC (*Vs*), balanced source currents (i_s), load currents (i_{La}, i_{Lb}, i_{Lc}), compensator currents (i_{Ca}, i_{Cb}, i_{Cc}), and dc bus voltage (V_{dc}), which are shown under varying loads (at t = 0.9–1.4 s). It shows the functions of DSTATCOM and its control algorithm for reactive power compensation and load balancing. Fig. 5 shows the dynamic performance of a VSC-based DSTATCOM for PFC mode at nonlinear load. The performance indices are phase voltages at PCC (*Vs*), balanced supply currents (*is*), load currents (i_{La}, i_{Lb}, i_{Lc}), compensator currents (i_{Ca}, i_{Cb}, i_{Cc}), and dc-bus voltage (V_{dc}), which are shown during load dynamic in phase "*a*" during time (*t*) equal to 0.9–1.4 s. The waveforms and harmonics spectra of phase "*a*" voltage at PCC (V_{sa}), supply current (i_{sa}), and load current (i_{La}) are shown in Fig.4, respectively. It is observed that the DSTATCOM is able to perform the functions of load balancing and harmonics elimination.

3.3. Performance of DSTATCOM in ZVR Mode

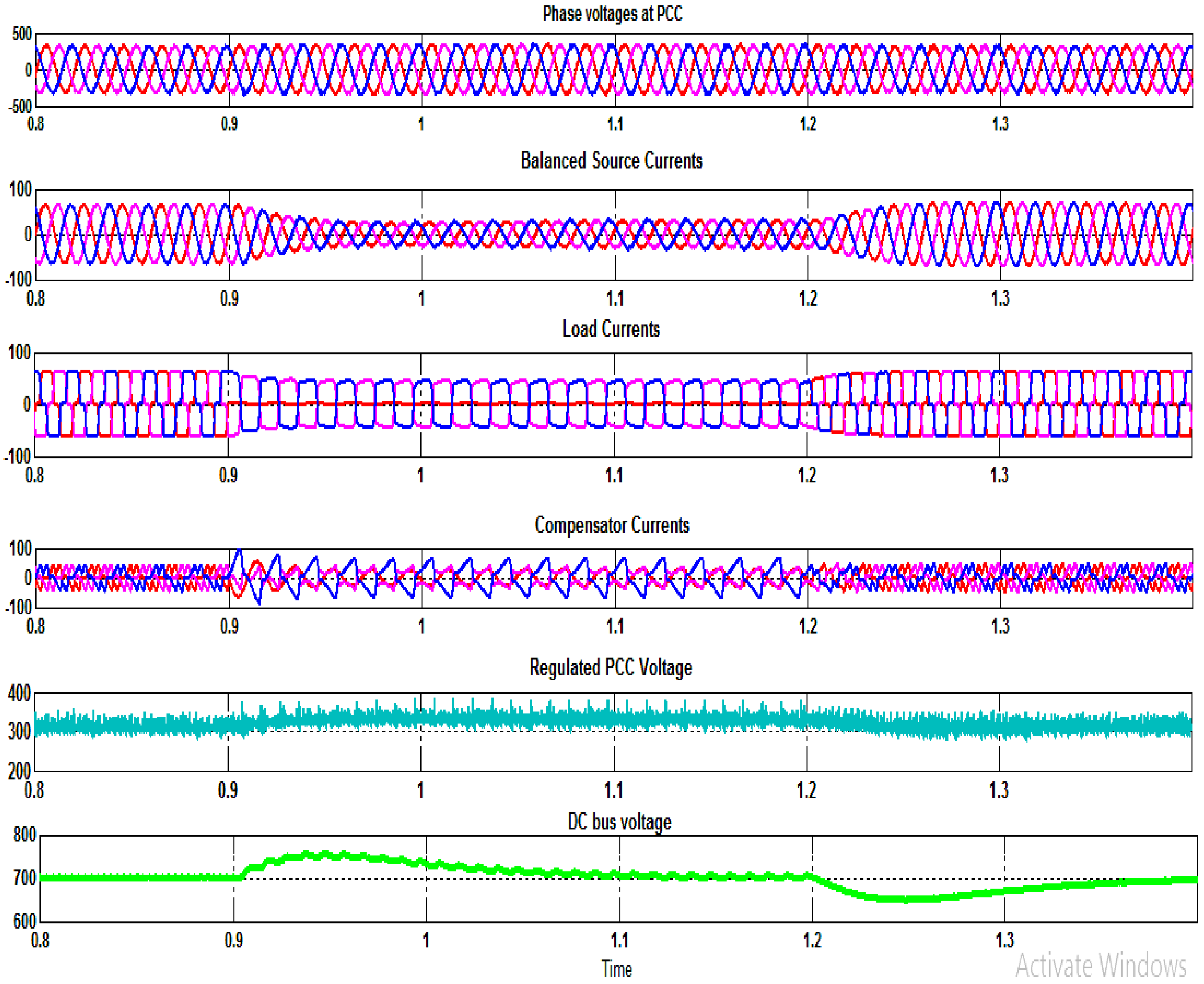


Fig.5. Simulation results for performance of DSTATCOM under varying nonlinear loads in ZVR mode.

Fig. 5 shows the dynamic performance of the DSTATCOM used for reactive power compensation to achieve ZVR and load balancing under linear loads (at t = 0.9–1.4 s). The performance indices are PCC phase voltages (V_s), balanced supply currents (i_s), load currents (i_{La}, i_{Lb}, i_{Lc}), compensator currents (i_{Ca}, i_{Cb}, i_{Cc}), amplitude of regulated PCC voltage (V_t), and dc-bus voltage (V_{dc}) under time-varying linear loads. In this ZVR mode, the amplitude of PCC voltage is regulated to the reference amplitude by injecting the leading reactive power components. It is observed that the DSTATCOM with KIMEL control algorithm is able to perform the functions of voltage regulation along with load balancing and reactive power compensation

The dynamic performance of DSTATCOM in terms of PCC phase voltages (V_s), balanced supply currents (i_s), load currents (i_{La}, i_{Lb}, i_{Lc}), compensator currents (i_{Ca}, i_{Cb}, i_{Cc}), amplitude of voltages at PCC (V_t), and dc-bus voltage (V_{dc})

waveforms are shown in Fig.5 during load variation at time (*t*) equal to 0.9– 1.4 s. It shows the smooth supply currents without any overshoot under such load change. The PCC voltage is also regulated at different operating condition of loads. Table I shows the simulation results demonstrating the performance of DSTATCOM. These results show satisfactory performance of DSTATCOM for reactive power compensation, harmonics elimination and load balancing of nonlinear loads.

IV CONCLUSION

The steady-state and dynamic responses of VSC-based DSTATCOM and implementation of DSTATCOM under nonlinear loads using KIMEL control algorithm with self-supporting dc bus have been studied through simulation. Some functions of DSTATCOM such as reactive power compensation, harmonics elimination, and load balancing have been proven for power quality improvement. Based on the steady state and dynamic response, it is concluded that proposed control algorithm with DSTATCOM is capable to shape the supply currents towards a sinusoidal, balanced with unit power factor.

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