PSO Based Neutral Current Compensation in a Three Phase Distribution System Using Electric Springs

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***Abstract*— Secondary distribution system is generally Three Phase Four Wire system which is directly connected to consumers. Due to the unbalanced configuration of these networks, a net current flowing through the neutral conductor. The presence of increasing number of non linear loads also causes significant neutral current in the system. The nonlinear loads draw harmonic and reactive components of current from ac mains. The excess neutral current and harmonics are the serious issues as they deteriorate the overall performance of distribution systems. The proposed strategy employs a new three phase Electric Spring circuit for reducing neutral current and a Hysteresis Current Controller for eliminating harmonics from the system. MATLAB/SIMULINK software platform is used for simulation. The application of the proposed method has been investigated for different load conditions and the results are presented.**

***Index Terms*— Electric Spring (ES), Hysteresis Current Controller, Neutral Current, Particle Swarm Optimization (PSO), Smart load, Total Harmonic Distortion(THD)**

I. INTRODUCTION

The three-phase, four-wire (3P4W) electrical distribution systems have been widely used to deliver electric power to single-phase and/or three-phase loads in manufacturing plants, commercial and residential buildings. In these systems, single phase electrical loads are connected from line to the neutral of the three phases. These single phase loads are not completely balanced, thus resulting in current through the neutral conductor. These are not the only sources for neutral current but there are other sources such as non-linear loads, where even perfectly balanced single-phase non-linear loads on 3P4W system may result in significant neutral current. Nonlinear loads, such as power electronic based equipment, have phase currents which are non-sinusoidal and the vector sum of balanced, nonsinusoidal, three-phase currents does not cancel each other and result current in the neutral conductor [2].

The excessive neutral current causes increased line losses, deterioration of system voltage profiles, overload system phases overloading, mal-functioning of protective relays, saturation problem in the distribution power transformers, increased communication interference, deterioration of power quality, system security and reliability of the electric supply, etc.

Harmonics contamination is a harmful problem in Electric Power System. The typical loads in a three-phase four-wire distribution system are computer loads, lighting ballasts, small rating adjustable speeds drives (ASD) in air conditioners, fans, refrigerators and other domestic and commercial appliances etc. These loads has a significant portion of the third harmonic current component. The harmonics will degrade the quality and reliability of the power supply [3].

II. RELATED WORK

The aim of smart distribution system is on the efficiency enhancement by reducing distribution power losses, improving reliability, maximizing asset utilization and better power quality and integration of distributed energy resources. Therefore, modern distribution systems are gaining attention over several power quality issues such as poor voltage regulation, high reactive power, harmonics current burden, phase unbalancing, excessive neutral line current, etc. There are various methods that deals with mitigation of neutral current.

Conventional passive and active power filters have been employed to solve the problems of harmonic currents and neutral-line current in three-phase four-wire distribution power systems [4]-[6]. The performance of passive filter is often significantly affected by the system impedance. The capacity and manufacturing cost of the power converter used in active filter is very high, thus limiting wide application of active power filters.

In comparison to the conventional passive and active filter methods, the electromagnetic filter is simpler, less expensive device, particularly for low voltage applications [7]. However, nonzero filter resistance, nonzero leakage flux, and nonideal magnetic coupling does not allow perfect filter performance. The zig-zag transformer is connected to the load in parallel, has been employed to attenuate the neutral-line current due to the advantages of low cost, high reliability and simplified circuit connection [8]. However, application of this method may result in the neutral voltage variation or raising the neutral voltage of the load side.

The electric spring is a new demand side management technology [9] . It can provide electric active suspension functions for stability of voltage and frequency in a distributed manner for future smart grid [10]. The change from output voltage control to input voltage control of a reactive power controller makes the electric spring suitable for future smart grid applications. For the compensation of neutral current, a new three-phase Electric Spring topology is proposed and its operating principle is explained.

The widespread use of non-linear loads causes, significant amounts of harmonic currents are being injected into power systems. Passive power filters (PPF) are generally used as traditional way for harmonic suppression which has made up of basic components like power capacitor, power inductance and resistance. It cannot filter the non-characteristic harmonics. The active power filter works on the operating principle by detecting harmonic current to calculate the amount of the compensating current needed for feeding back to the power system inorder to cancel the harmonic current [11]. There are various current control methods for such active power filter configurations, but for quick current control and easy implementation hysteresis band current control method has the highest rate among other current control methods such as sinusoidal PWM.

III. METHODOLOGY

A three-phase Electric Spring is a three-phase inverter with a small battery storage on its DC link . The inverter output of each phase is connected to the primary side of an isolation transformer. The secondary sides of these isolation transformers are connected in series with three noncritical loads in star connection with the neutral line connected to the neutral point of three phase power source. The series connection of the electric spring and the non critical loads is collectively known as smart load. Critical loads in star connection are connected in parallel with this smart load. The neutral point of the critical load is also connected to the neutral point of power source.

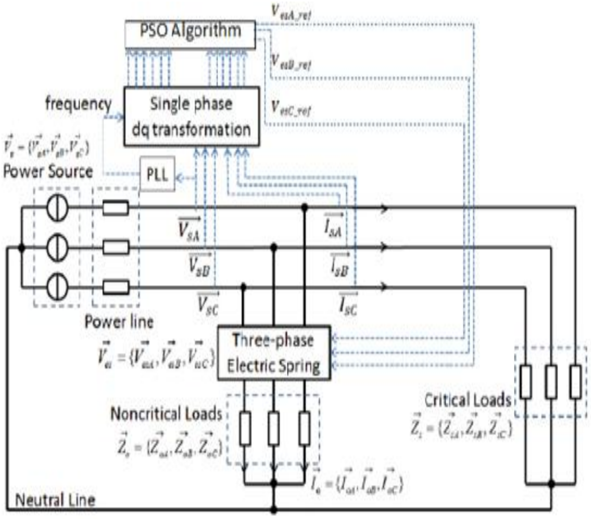


Fig.1 Implementation of Three Phase ES

A mechanical spring can expand and contract within a certain displacement only. Similarly an ES can regulate the line current within a certain range only [12] . Since the three-phase ES is typically a three-phase inverter with a constant DC voltage link, the output voltage of ES is limited by the DC link voltage. Thus the compensation voltage can vary in amplitude subject to the limitation of the DC link voltage V_{dc} and have a phase angle for 0° to 360° with respect to the reference vector which is usually the line voltage of phase A in a three-phase power system. The non-critical load is assumed as symmetric pure resistive and the critical load as symmetric resistive plus inductive load. In this system, it is considered that the critical loads are unbalanced among the three phases and the non-critical loads are balanced loads. The sum of power consumptions in the non-critical loads and critical loads represents the total power consumption. In the absence of compensation, the line currents are unbalanced due to the asymmetric load impedance of the critical loads and are given by

$$\left.\begin{aligned} I_A &= \left(\frac{1}{Z_{sA}}+\frac{1}{Z_{oA}}\right) V_{sA} - \left(\frac{1}{Z_{oA}}\right) V_{esA} \\ I_B &= \left(\frac{1}{Z_{sB}}+\frac{1}{Z_{oB}}\right) V_{sB} - \left(\frac{1}{Z_{oB}}\right) V_{esB} \\ I_C &= \left(\frac{1}{Z_{sC}}+\frac{1}{Z_{oC}}\right) V_{sC} - \left(\frac{1}{Z_{oC}}\right) V_{esC} \end{aligned}\right\} \quad (1)$$

The neutral current is the sum of the three line currents and is given as

$$I_{\text{neutral}} = \left(\frac{1}{Z_{sA}}+\frac{1}{Z_{oA}}\right) V_{sA} - \left(\frac{1}{Z_{oA}}\right) V_{esA} + \left(\frac{1}{Z_{sB}}+\frac{1}{Z_{oB}}\right) V_{sB} - \left(\frac{1}{Z_{oB}}\right) V_{esB} + \left(\frac{1}{Z_{sC}}+\frac{1}{Z_{oC}}\right) V_{sC} - \left(\frac{1}{Z_{oC}}\right) V_{esC}$$

(2)

ES voltage can be controlled to alter the line currents both in amplitude and phase within its operating limits, in response to the changing states of the critical loads. The limitations of the ES, is mathematically expressed as

$$\left.\begin{aligned} 0 \le |V_{esA}|, |V_{esB}|, |V_{esC}| \le V_{dc} \\ 0^0 \le \theta_{VesA}, \theta_{VesB}, \theta_{VesC} \le 360^0 \end{aligned}\right\} \quad (3)$$

The three-phase ES system includes a PLL (Phase Locked Loop) block, single-phase d-q transformation block and a Particle Swarm Optimization (PSO) based controller. In order to acquire accurate feedback, all variables in three-phase ES system should be synchronized under a fixed fundamental frequency. This is acquired by the installation of a PLL block which generates the fundamental system frequency and provides a reference vector with 0° phase angle. The line voltage of phase A is used as the reference vector. The single phase *d-q* transformation block decouples each current and voltage signal independently into *d* and *q* components. With the inclusion of PLL block, the decoupled voltages and currents are combined together into one *d-q* frame rotating at fundamental frequency of 50 Hz.

A. *Particle Swarm Optimizaion Based Controller*

Particle swarm optimization (PSO) is a population based optimization technique [13], [14]. Each member of the population is called a particle. All the particles have fitness values which are evaluated by the fitness function to be optimized, and have velocities which direct the flying of the particles. These particles fly through the problem space by following the current optimum particles. PSO is initialized with a group of random particles (solutions) and then searches for the optima by updating generations. In every iteration, each particle is updated by two "best" values. The first one is the best solution (fitness) the particle has achieved so far. This is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the overall population. This value is a global best and called gbest. After finding the two best values, the particle updates its velocity and positions.

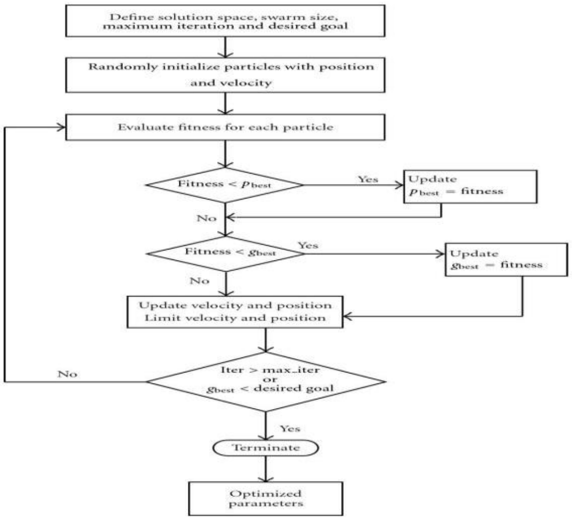


Fig. 2 PSO based Algorithm

B. *Hysteresis Current Controller for Harmonic Elimination*

Hysteresis current control is a method of controlling a voltage source inverter so that an output current which follows a reference current waveform[15]. This method controls the switches in an inverter asynchronously to ramp the current through an inductor up and down so that it tracks a reference current. Hysteresis current control is the simplest control method to implement.

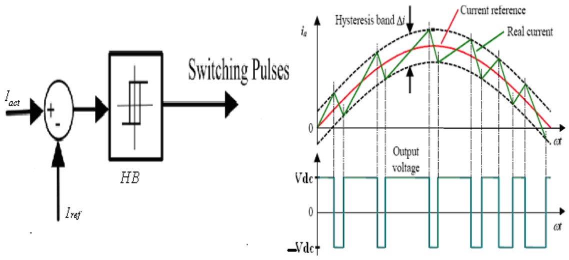


Fig. 3 Hysteresis PWM Current Control and Switching logic.

A hysteresis current controller is employed with a closed loop control system. An error signal, e(t) is used to control the switches of an inverter. This error is the difference between the desired current, I_{ref} (t), and the current being injected by the inverter, I_{actual}(t).When the error reaches the upper limit, the transistors are switched to force the current down. When the error reaches the lower limit the current is forced to increase. The range of the error signal controls the amount of ripple in the output current from the inverter and this is called the Hysteresis Band. The Hysteresis limits indicate directly to an offset from the reference signal and are referred to as the Lower Hysteresis Limit and the Upper Hysteresis Limit. The current is forced to stay within these limits even while the reference current signal is changing. The turn-on condition and turn-off condition for the inverter switches is

- Upper switch Off: (iact -ire f) > HB.
- Lower switch Off: (iact -ire f) < HB.

where HB denotes the Hysteresis Band. The width of the hysteresis band indicates the switching frequency of the inverter. According to the operating principle of the inverter, the output voltages of each phase depends on the switching pulses of the switches in each leg. As a result, the switching pulses for the active power filter can be obtained. The switching frequency can be altered by adjusting the width of the hysteresis tolerance band.

IV. RESULTS AND DISCUSSION

Fig.4 shows the simulation model for the implementation of a three phase Electric Spring for the reduction of neutral current in a secondary distribution system. The simulations are done in Matlab/Simulink software platform. The grid source is represented by three phase AC source. The non critical loads are represented as purely resistive or heating loads, and are balanced loads. The critical loads are represented as resistive cum inductive loads and are unbalanced loads. Two switches S_1 and S_2 are used for connectin the Electric Spring to the grid. Both the switches have a transition time of 0.2 seconds. i.e, switch S_1 is initially closed and S_2 is initially open. Therefore, the non critical loads are directly connected to the grid up to 0.2 seconds. At 0.2 seconds, switch S_1 is open and S_2 is closed. At that time, the non critical loads are connected to the grid through the three phase electric spring. The critical loads are directly connected to the grid.

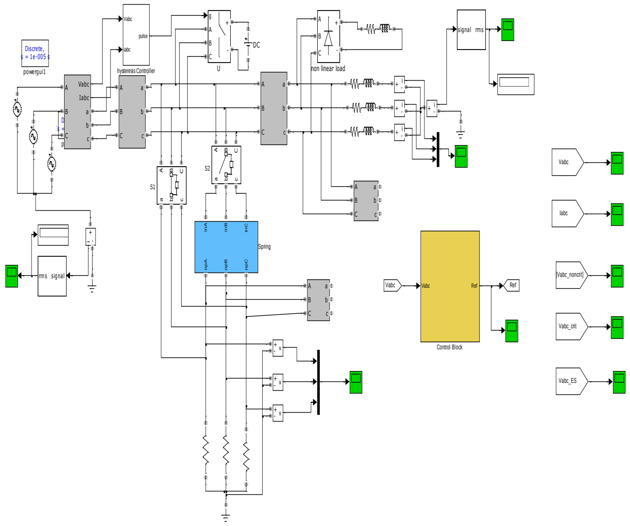


Fig. 4 Simulation Model for the Reduction of Neutral Current and Harmonic Elimination

The system parameter specifications are given in Table I.

Table I: System Specification

Grid Source Voltage	415 V, 3ø AC
Frequency	50 Hz

The Particle Swarm Optimization (PSO) Algorithm output gives the optimized values of three phase reference voltages of Electric Spring. Fig. 5 shows the Iteration vs Best Fitness plot of the PSO Algorithm.

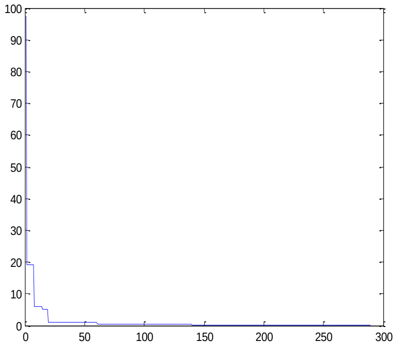


Fig. 5 Iteration vs Best Fitness plot

The performance of the system is observed by switching the Electric Spring for different loading conditions. The Electric Spring is connected to the grid at 0.2 seconds. From Fig. 6, it is observed that the supply side neutral current is reduced from 566.4 A to 0.8825 A with the introduction of compensation voltage V_{eS}.

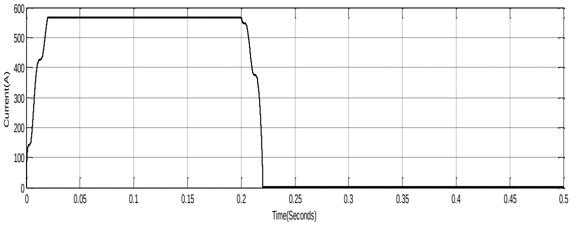


Fig. 6 Supply side Neutral current waveform

Fig. 7 shows the load side neutral current waveform. The load side neutral current waveform remains the same even when an ES is connected to the system.

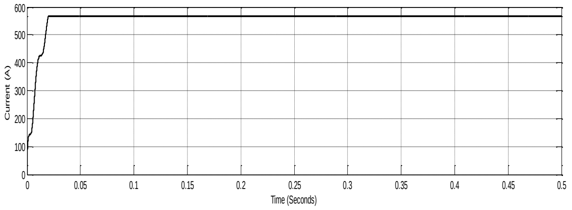


Fig. 7 Load side Neutral current waveform

Fig. 8 shows the voltage across the critical loads. It is clear that, the voltage drop across the critical loads maintains throughout the period.

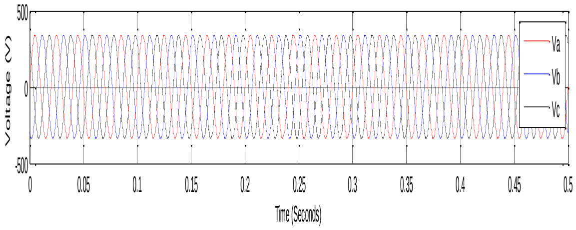


Fig. 8 Critical load voltage waveform

From Fig. 9, it is shown that the voltage across the non critical loads varies according to the Electric Spring voltage.

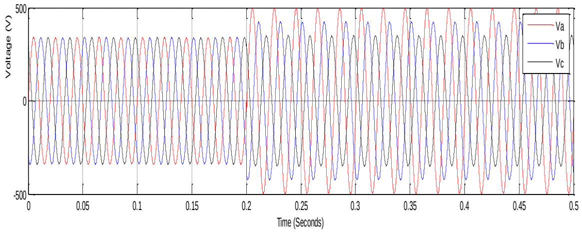


Fig.9 Non critical load voltage waveform

Fig. 9 shows the voltage developed across the Three phase Electric Spring in order to acquire neutral current compensation.

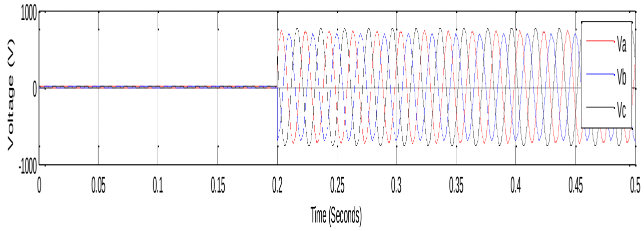
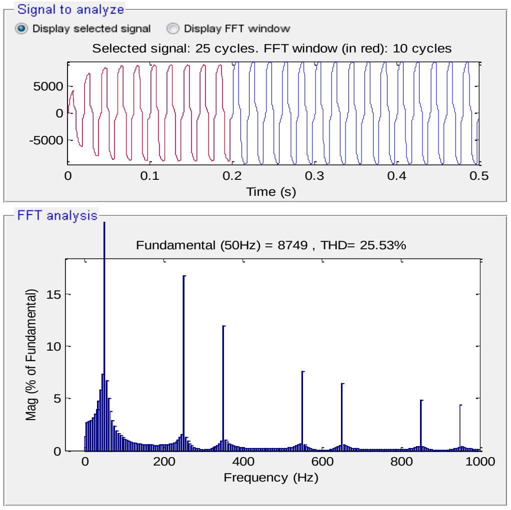


Fig. 9 Three phase Electric Spring voltage

Fig. 10 shows the harmonic analysis of the source current without Hysteresis Controller. The % THD of the system is shown as 25.53%.



Selected signal: 25 cycles. FFT window (in red): 10 cycles

Fundamental (50Hz) = 8749 , THD= 25.53%

Fig. 10 FFT Analysis : Without Hysteresis Controller

Fig. 11 shows the harmonic analysis of the system with Hysteresis Controller. It can be seen that the % THD of the system is reduced from 25.53% to 0.59% with the introduction of Hysteresis Controller in to the system.

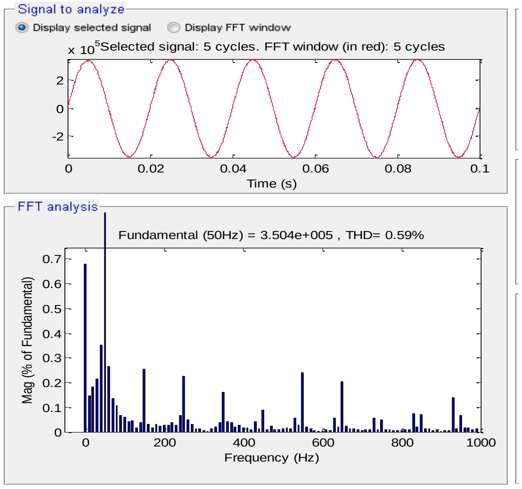


Table II shows the simulation results for first loading condition.

Table II : First Loading Condition

Non crit. Load(Ω)	Critical load (Ω)			Neutral Current (A)		%THD	
Ph A,B,C	Ph. A	Ph. B	Ph. C	ES on	ES off	Without Hyst. Control	With Hyst. Control
0.275	0.07+ 0.42j	0.15+ 0.29j	0.17+ 0.17j	566.4	0.88	25.53	0.59

Table III shows the simulation results for the second loading condition.

Table III : Second Loading Condition

Non crit. Load(Ω)	Critical load (Ω)			Neutral Current (A)		%THD	
Ph A,B,C	Ph. A	Ph. B	Ph. C	ES on	ES off	Without Hyst. Control	With Hyst. Control
0.5	0.5+ 0.5j	0.2+ 0.3j	0.1+ 0.8j	213.5	0.339	16.63	0.38

V. CONCLUSION

The neutral current in a three phase distribution system is the result of unbalanced load and third harmonic currents. The excess neutral current in the conductor degrade the overall performance of a three phase secondary distribution system. A three phase Electric Spring circuit is introduced in to the three phase distribution system for reducing neutral current. The Particle Swarm Optimization (PSO) algorithm based controller is used for generating the control signals of Electric Spring. A Hysteresis Current Controller based PWM inverter is introduced into the system for eliminating harmonics from the system. The simulation results verified the effectiveness of the proposed system for reducing neutral current and harmonics under different load conditions.

REFERENCES

[1] T. Gruzs, - A Survey of Neutral Current in 3 phase computer Power System", IEEE Trans.Ind.Appl.,Vol.26 , No.4, pp 719–725, July/Aug 1990.

[2] A. Liew,“ Excessive Neutral Currents in Three-Phase Fluorescent Light Circuits”, IEEE Trans. Ind. Appl., Vol.25, No.4, July/august 1989

[3] H.O. Aintablian and H.W. Hill,“ Harmonic Currents Generated by personal Computers and their effects on the Distribution System Neutral Current”, IEEE Trans. Ind. Appl., Vol.28, No.4, pp 340-345, Nov. 1993.

[4] F. Z. Peng, H. Akagi, and A. Nabae,“ A new approach to harmonic compensation in power systems-A combined system of shunt passive and series active filters,” IEEE Trans. Ind. Applicat., vol. 26, pp. 983-990,Nov./Dec. 1990.

[5] V. B. Bhavaraju and P. N. Enjeti, ‘‘Analysis and design of an active power filter for balancing unbalanced loads,’’ IEEE Trans. Power Electron.,vol. 8, no. 4, pp. 640--647, Oct. 1993.

[6] W. C. Lee, T. K. Lee, and D. S. Hyun, “A three-phase parallel active power filter operation with PCC voltage compensation with consideration for an unbalanced laod,” IEEE Trans. on Power Electron., vol. 17, no. 5, pp. 807–814, Sep. 2002.

[7] R. Apolonio, J. C. de Oliveira,and A. B. de Vasconcellos, “Three-Phase Electromagnetic Filter for Zero-Sequence Harmonics”, In Proc. of 11th International Conference on Harmonics and Quality of Power, 12-15 Sept. 2004, pp 613.

[8] S. Choi, and M. Jang, “Analysis and Control of a Single-Phase-Inverter Zigzag- Transformer Hybrid Neutral-Current Suppressor in Three-Phase Four-Wire Systems”, IEEE Transactions On Industrial Electronics, Vol. 54, No. 4,pp 2201–2208, August 2007.

[9] S. Y. R. Hui, C. K. Lee, and F. F. Wu, “ Electric springs - a new smart grid technology,” IEEE Trans. on Smart Grid, vol. 3, no. 3, pp. 1552-1561, Sep. 2012.

[10] S. Y. R. Hui, C. K. Lee, and F. F. Wu, “ Mitigating Voltage and Frequency Fluctuation in Microgrids Using Electric Springs”, IEEE Trans. Power Del., vol. 24, no. 4, pp. 2344-2352, Oct. 2013.

[11] Meo, S.; Perfetto,“ Comparison of different control techniques for active filter applications”, Proceedings of the Fourth IEEE International Caracas Conference on Devices, Circuits and Systems, P016–1 – P016–6, April 2002.

[12] C.K. Lee, S.C. Tan , and F.F. Wu,“ Use of Hookes Law for Stabilizing Future Smart Grid The Electric Spring Concept”, IEEE Trans. Smart Grid, vol. 4, no. 3, pp. 15581566, Sep. 2013.

[13] Kennedy.J and Eberhart, R.C.,“ Particle Swarm Optimization”, Proceedings of the 1995 IEEE International conference on Neural Networks, Perth, Australia, IEEE Service Center, Piscataway, NJ, IV:1942–1948.

[14] J. Kennedy, The Particle Swarm: Social adaptation of knowledge, Proceedings of the IEEE International Conference on Evolutionary Computation, Indianapolis, USA, 1997, pp. 303-308.

[15] Aredes M, Hafner J, Heumann K,“ . Three-phase four-wire shunt active filter control strategies ”, IEEE Trans Power Electron ;12(2):3118. Mar.1997.

BIOGRAPHY

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