Performance Analysis of Electric Springs in Reducing the Power Drawn From Supply System During Generation Uncertainties

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Abstract:-

This article deals about reduction of power drawn from the supply system in smart grid environment during un-certainties in the power generated by the source. Supply system in this work consists of an intermittent power source and a storage system, to support whenever there is deficit in power generation by the renewable generator.A micro grid systemis considered for thestudy which has critical and non-critical load present in it along with storage system and Electric spring. An attempt is made to study the performance of Electric spring in reducing the power drawn from the supply system under different non-critical loads during un-certainties or power deficit conditions of the source. The effect of reactive component in the non-critical loadis examined separately for the considered battery storage system. All the simulation models have been developed in MATLAB.

Keywords: Electric Spring; Micro grid; uncertainty; Non-critical load; Critical load

1. Introduction:

The major issue concerned with the Electrical energy is about its storage. Electrical power has its own limitations over its storage it can only be generated and consumed at the same instance of time.But during discrepancies in generation and load demand there is a necessity to match both. The following methods can be used to achieve the same. The first and traditional method for bridging the demand supply gap is by partial or full load shedding which is one of the methodologies used by many power utilities. There after scheduling the generators based on the probability and the available load data from the grid is reported in [1].The method shownin [1] is different from the traditional method because the generation scheduling considers the stochastic events occurring in the generation. Online scheduling of generators based on the load demand to match generation and load has been presented in [2]. The difference in the methods used in [1] and [2] is that,to carry out the methodology proposed in [2] telemetric and communication equipment are required to carry the required information to the generation station as the generation scheduling used is completely online. Apart from generation scheduling in the literature one other concept by name Demand side management (DSM) is also emerging in the recent past. Demand side management is a strategy where the generation from the utility is not varied but instead the price of the energy will be made dynamic. During deficits in power generation, in order to reduce the power drawn the price of electricity will be kept high and vice-versa. In order to benefit the consumers in planning and scheduling their demand a game theory approach which schedules the demand side equipment has been articulated in [3]. The method projected in [3] regulates the energy consumption of the consumers in optimal way through which consumers will be benefited and hence can be used in the future smart grids.

Some other optimization techniques like the Binary particle swarm optimization (BPSO) has been used in [4] for scheduling the demand side resources in an optimal manner. This method largely benefits the consumers because it uses a non-linear optimization methodology to solve the issue of demand side planning which works on the principle of random number generation. In [5] the author reported a method using game theory approach to shape the load curve in required manner. The main difference noticed in this paper [5] is that industrial, commercial and domestic loads are taken into account while scheduling the demand side resources. Taking into account the price fixed by the market utilities an hourly load demand adjustment model for the house hold consumers using linear optimization models has been reported in [6]. And up on the price prediction methodology the authors in [7] presented an automatic consumption model which schedules the equipment automatically in an optimal consumption manner. The works presented in articles [1]-[7]emphasizes either on optimal generation scheduling or load scheduling. So from the above it can be concluded that by using some or the other methodologies/techniques the demand and generation will be matched as tighter as possible.

Apart from the methods discussed above it is also advisable to add storage to the system to the possible extent in such a manner that whenever there is excess power in the grid the storage equipment can be charged and whenever there is deficit in the power generation this storage can act and support the system. The authors in [8]discussed about having different storage facilities along with generation units such as heating units and other mechanical ways of storing energy, so based on the storage availability and the available generation the consumers are charged. This means that the heat generated from furnaces and CHP will be stored whenever necessary and used to generate electricity whenever necessary. Battery operated Electrical vehicles can be used for storage of electrical energy during power surplus conditions and can act whenever necessary [9]. Further it was established in [10] that usage of secondary batteries i.e. the batteries which are obtained after their usage in Electrical vehicles can also be used for storage in grids which reduces the capital cost. For faster energy transactions i.e. to get better response from the storage system super capacitors can be used along with along with batteries [11]. From the articles [8]-[11] it can be understood that not only generation and load scheduling, storage systems also help the grid in maintaining the demand supply balance.

Advent of power electronics in Electrical Engineering has created some flexibility in controlling many parameters in power systems. For example use of FACTS devices in the power system made A.C power transmission flexible and easier. It can also be inferred that sometimes for example FACTS devices also help the generators in getting relieved from reactive power support which means that the real power generation is improved. So to a limited extent FACTS devices also help/support the system whenever necessary and useful in maintaining the demand supply balance. Apart from the FACTS devices present in the literature a new smart grid Technology by name Electric springs have been introduced to the field of Electrical Engineering in [12].

Electric Springs can be used for different applications in the power system domain, voltage regulation [13], three phase power balancing [14], mitigation of voltage and frequency fluctuations [15] and it is also proved that the performance of Electric Spring is better than that of the existing FACTS controllers like the STATCOM [16].

The concept of reduction in the battery storage requirement for the future smart grid using Electric Springs has been presented in [17] where the authors proved that by using Input control schemes like the Electric springs there will be a reduction in the Watt hour capacity of the battery, which is better than using series output voltage controllers for the active power flow control.

In this article an attempt is made to estimate the reduction of power drawn from the supply system using Electric springs. Hence the comparison of the power drawn is done by making Electric spring active in one case and by making it inactive in other case which is different from the comparison made with the output control devices as in [17].

For the usage of Electric springs, the loads present in the system are to be segregated into two types they are Critical and non-critical loads. Critical loads are those types of loads which are sensitive to the voltage fluctuations and non-critical loads can bare fluctuations in voltage over a larger range and other related explanation about the non-critical loads and their importance in saving the power drawn from the supply system is explained in the later stages of the article.

These Electric springs when used in series with non-critical loads save the power drawn by them and hence helpful in supporting the supply system to maintain demand supply balance to the possible extent during generation intermittence.

2.General Block diagram of the micro grid system with Electric spring:-

Electric spring is analogous to mechanical spring whichworks on basic principle of Hooke's law. Like mechanical spring Electric spring(ES) can be used for storing electrical energy and to damp oscillations in the input supply, whenever necessary. The peculiarity of the electric spring is that it stores electrical energy whenever required like the mechanical spring and releases the same whenever required as similar to mechanical spring.Electric spring constitutes input control scheme i.e. it regulates voltage from the supply side rather than output side.

An electric spring is a new smart grid technology which can be used in series with non-critical loads to reduce the power drawn from the supply system, whenever necessary by suppressing the voltage to a certain permissible extent

[17]. The general block diagram of the system considered is as shown in Fig.1

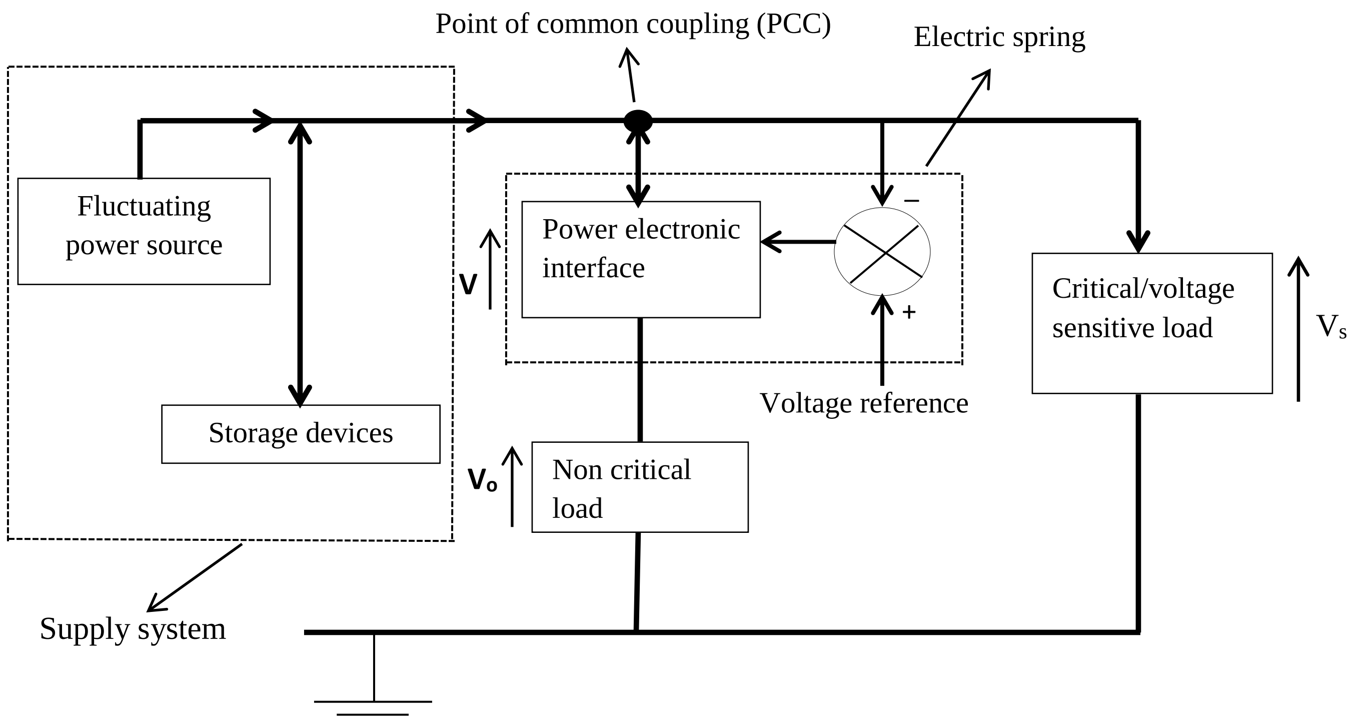

Fig.1 General Block diagram of the micro grid system with Electric Spring

Fig.1 shows the schematic diagram of the considered system and ES connected in series with the non-critical load. The Fluctuating power source block shown in Fig.1 may be any renewable energy source which has uncertainties in its operation i.e. the power supplied by it to the system is not constant (varies with respect to time at some instances). The storage devices shown in Fig.1 act and support the system only when there is deficit in power supplied by the fluctuating power source. The storage devices supply the deficit power and hence because of the action of storage devices during deficit conditions there will be always constant power at the PCC. The storage devices can be any type which are capable of supplying the required load, may be battery banks or super capacitors. The power Electronic interface is useful to reducethe voltage supplied to the Non critical load which in turn reduces the power drawn from the supply system.

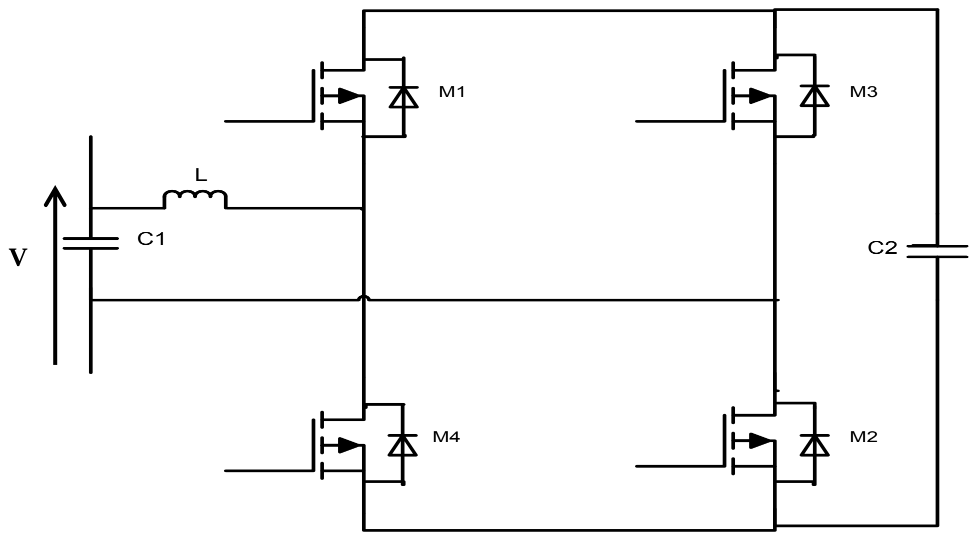

Fig.2 Details of power electronic interface block [17]

The details about the power electronic interface block are as shown in Fig.2, which is a simple rectifier/inverter circuit. During normal operation i.e. whenever the generated voltage is normal and has no voltage fluctuations then the power electronic interface block gets bypassed and the nominal voltage is applied across both critical and non-critical loads. Whenever there is uncertainty in the voltage i.e. the voltage falls beyond the tolerance level of the critical load the storage devices act and the deficit power is supplied to both the loads present in the system. The working of power electronic interface is as follows. Whenever there is abnormality in source voltage the diodes present across the switching devices in Fig.2 acts as a rectifier and charge the DC side bulk capacitor to certain a value. The switching devices or MOSFET's present in the rectifier circuit now are to be gatedusing firing techniques in such a way that they act as inverter and produce a controllable voltage across the capacitor 'C1' which in turn affects the voltage across the non-critical load.

In this condition due to the presence of controllable voltage(V) across C1 the voltage applied across the non-critical load (V_o) is as follows

$$V_o = V_s - V(1)$$

FromFig. 1,$V_s$is the voltage at the PCCor across the critical load

Hence assuming that the non-critical load used is purely resistive and has only real power consumption the power drawn (P_{nc}) from the supply system is as shown

$$P_{nc} = \frac{V_s^2 - V^2}{R}(2)$$

Where 'R' is the resistance of non-critical load

Therefore from the above equation during normal operating condition when the voltage across power electronic interface (Electric spring) is zero the power drawn will be different and during abnormal conditions when the Electric spring is made to act, the voltage across the capacitor is set to a certain value and hence there will be reduced power drawn from the supply system which in turn is an advantage during generation intermittence.

In the same way if the non-critical load present in the system is an impedance type of load(which means the load has both resistive and reactive components)then apart from Eq.1 the reactive power drawn(Q_{nc}) from the supply system can be written as

$$Q_{nc} = \frac{V_s^2 - V^2}{X}(3)$$

Where 'X' is the reactance of the non-critical load

3. Problem formulation:-

In the micro grid environment consisting of fluctuating energy sources there is a requirement of storage to compensate the power during deficit conditions. The Storage devices are supposed to act whenever there is deficit in power supplied by the sources. This work aims at reducing the power drawn from the Supply system (Both storage and power generator) during deficit conditions which in turn conserves some amount of power and relives the supply system during uncertainties. For a micro grid consisting of a renewable power generator, Storage system and loads the generated power and the power supplied by storage system should be equal to meet out the load demand. The loads present in the smart grid system can be broadly classified as

Critical and Non-Critical loads. Critical loads are those which are sensitive to voltage fluctuations and hence it is necessary to maintain the voltage across critical loads in prescribed tolerance limit.

Non critical loads in this work are those whose performance will not be affectedeven if there is voltage dip of around 40 volts (around 20%) from their rated value [18].

Hence,

$$S_g + S_s = S_l \quad (4)$$

$$S_t = S_l (5)$$

Where

S_g is the total power generated by the source.

S_s is the Power delivered by the storage devices

S_t is the total power drawn from the Supply system

$S_l$is the power fed to both critical and non- critical

loads

Now for understanding assume that critical and non-critical loads are purely resistive and there is no reactive component of power drawn.The total power drawn from the supply system can be written as

$S_l=P_c+P_{nc}$(6)

Where, P_c is the power drawn by the critical load which is almost constant because the voltage supplied to it at any case will be maintained within the permissible limits.

Now by substituting Eq.2 in Eq. 6 the equations becomes

$S_l=P_c+\frac{V_s^2-V^2}{R}$(7)

From Eq.7 it can be noticed that the power drawn by the noncritical load is largely dependent upon the voltage appearing across the Electric spring (V). Hence during normal operation, whenever the Fluctuating power source is supplying its full rated power the Electric spring will be in in-active state i.e. Voltage across the Electric spring(V) will be equal to zero and so the power drawn by the non-critical loadwill be equal to its rated value. Now assumingthat there is a dip in power supplied by the Fluctuating power source then the storage device supplies the deficit power and the objective now will be to reduce the power drawn from the supply system. This can be achieved by making the ESoperational which means there will be voltage (V) supplied by the ES. So by examining the Eq.7 if V is a finite value the total power drawn $S_l$will be reduced and hence reduces the burden on the supply system.In the same manner if the non-critical load has reactive component in it, the reactive power saving can be understood from Eq. 3

4. Performance evaluation and Case Studies:

For evaluating the performance of Electric springs in smart grid environment consisting of uncertain energy sources two different case studies were presented. The power output from the source is varied i.e. the source is preprogrammed to give different values of output voltage at different instances of time. The pattern of the voltage levels is as shown in the Fig.3. The values shown in Fig. 3 are not to be considered as the standard deviation profiles of any source. The pattern shown is only to understand the working of Electric spring at reduced voltage levels of the source.

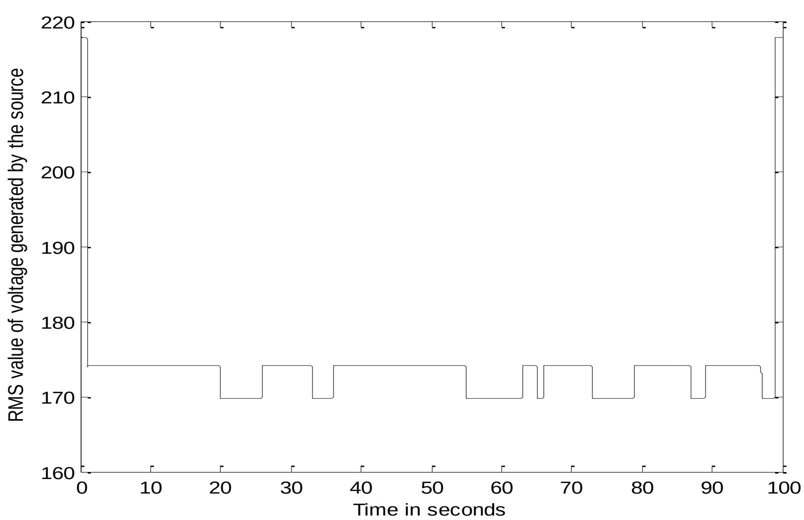

Fig. 3 Output voltage pattern of the source considered for the study

4.1 Control strategy adopted for the ES:

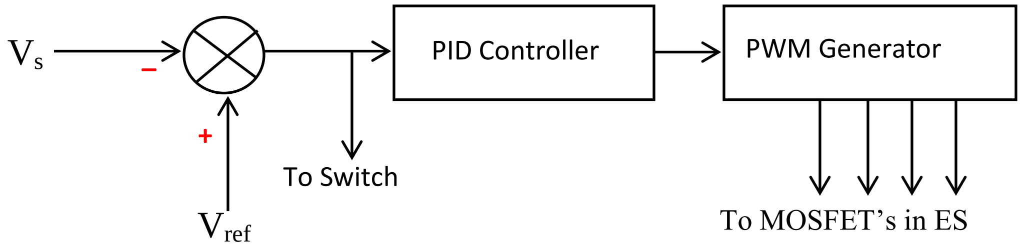

Fig.4 Control Scheme for Electric spring

Fig. 4 shows the control strategy adopted for the ES circuitry. The firing logic for the ES has been developed based on the output voltage of the Source (V_s). Whenever $V_s$is lesser the battery will act and support the system. So during this time the ES has to act and suppress some finite amount of voltage which is being applied to the non-critical load. The base value of system voltage is given as reference (V_{ref}) to the control circuit and an error signal will be generated whenever the source voltage falls down below a certain value and as a consequence of this an error signal gets generated which is feed to the PID controller and the PID controller processes the error signal generated and acts as a reference to the PWM pulses which will be generated by the PWM Generator based on the input given by the controller. These control pulses shall be fed to the switching devices present in the Electric Spring circuitry

Based on the error signal generated the Switch (Fig. 5) which bypasses the ES circuitry has to be opened to allow the conduction through the spring.Now because of the action of ESa controlled voltage is voltage is developed across the filter capacitor, C3 (Fig.5) and hence the voltage applied to the non-critical load is decreased and as a result the power drawn from the supply system reduces (Eq.7) for example. The PWM generator used here employs sinusoidal pulse width modulation technique. During the process of fine tuningthe PID controller it has been noticed that the value of the voltage appearing across C3 is largely dependent on the gain values of the controller.

The performance of the Electric Spring is evaluated in two different cases namely Case I and Case II where in Case I the non-critical load which consists of only resistive element is considered and in Case II the performance is evaluated considering the reactive component of non-critical load.

4.2 Case I:

The performance of Electric spring has been tested in the micro grid environment in the presence of battery storage considering the critical and non-critical loads. The load data and the rating of the system are as taken from [17].

The ratings of the system considered are as follows [17].In Case I the reactance part of the non-critical load is not considered in order to study the performance of Electric spring in the presence of pure resistive loading and battery storage. The system considered for simulation is as in Fig.1. The simulation model consists of 3 major blocks. The Fluctuating power source sub system has a programmable source which gives different time varying outputs based on the requirement and for this study preprogrammed fluctuations are considered for a period of 100 seconds. The Storage system block consists of a battery which is fully charged and supports the system only if the voltage from the power source falls below 220 volt (1 P.U.) and the ratings of the battery and other details are as in Table.1.

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Critical and Non critical loads are connected across the fluctuating power source and the storage system in such a manner that the power supplied to them is not affected even during generation un-certainties, as shown in Fig. 5. The Electric spring which is the key point of interest is connected to the non-critical load. During spring operation the "Switch" shall be in open state which means that the voltage appearing across the non-critical load will not be same as the critical load voltage.

The non-critical load voltage is regulated by controlling the voltage across the filter capacitor C3, by using electric spring circuitry. Under this case study the non-critical load is considered to be purely resistive and the storage system employs battery and the ratings of the same are as shown in Table.1.

With reference to Fig. 3 it can be noticed that the base value of voltage appears only for the first one second and for the last 2 second i.e. there were fluctuations in the voltage for 97 second. Even during the voltage fluctuations of the power source it can be seen from the results due to the support of the battery the voltage across the critical load is maintained in the tolerance limits and whenever there is a battery support the voltage across the non-critical load is reduced as per its tolerance standards and the same can be seen in the upcoming results.

In [17] or in any other work presented in the literature the authors considered an output pattern of the generator and based on that the non-critical load voltage is allowed to fluctuate and the voltage pattern considered is always in between 180 volt and 220 volt. In this work in order to analyze the power supplied by the supply system in a different way a pattern of voltage level which is always less than the tolerable level of non-critical load is considered as shown in Fig. 3

Table.1 System Data considered for the study

Nominal system voltage(RMS)	Details of non-critical load	Details of critical load	Battery capacity
220 volt	Resistance=27.5 Ω Reactance=23.5 Ω	Resistance=31 Ω	Output DC voltage=208 volt Rating = 45 Ah

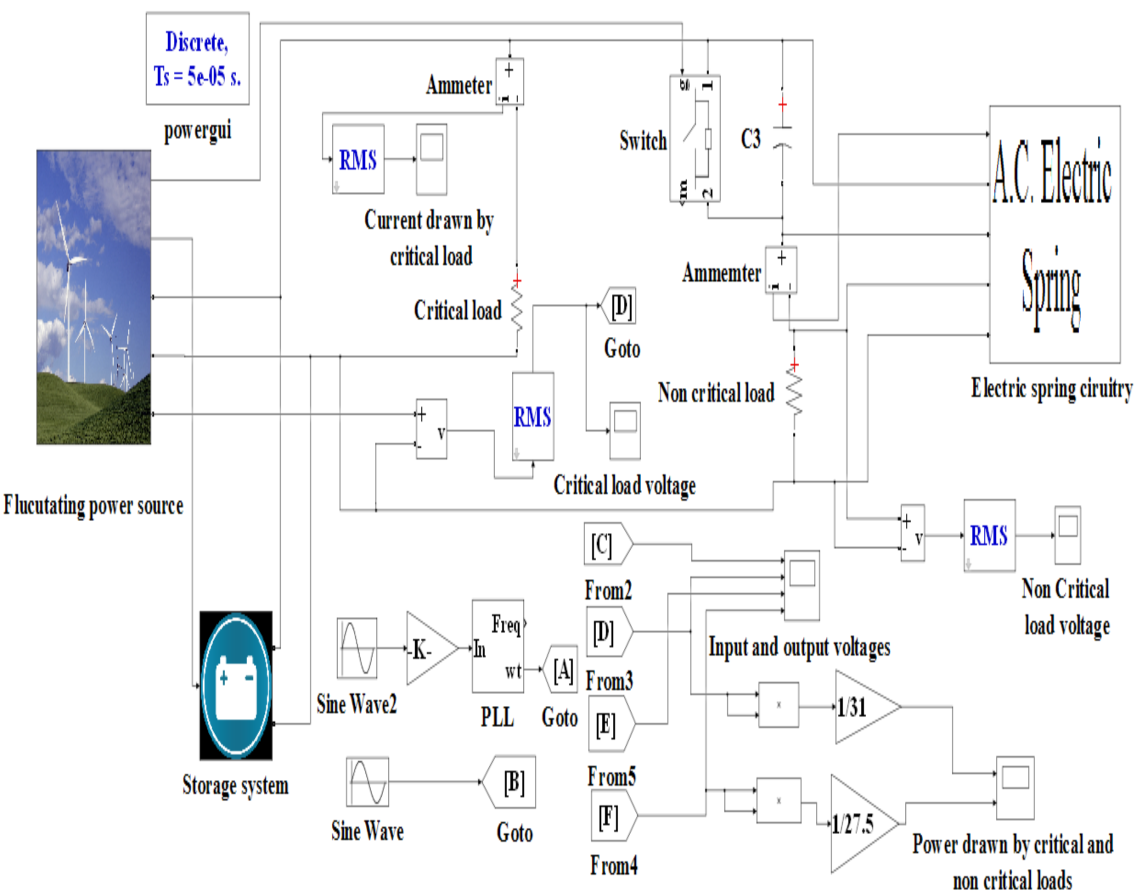

Fig.5 MATLAB Model designed for the study with Electric Spring

So as the level of voltage supplied by the source is always less than 180 volt, during un-certainties in generation the non-critical load is always operated at minimum level of voltage which is 180 volt and the voltage across the critical load is maintained at 220 volt with the help of battery support.

Fig. 6 projects the voltage levels at different points in the micro grid system. The voltage across the critical load, non-critical load and Electric spring as measured across the filter capacitor, C3 is presented.

It can be noted that during abnormalities i.e. whenever there is dip in the voltage from the power source the Electric spring acts and a controlled voltage is maintained across the filter capacitor,C3 and hence as a result the voltage across the non-critical load is reduced as per the Eq.(1).

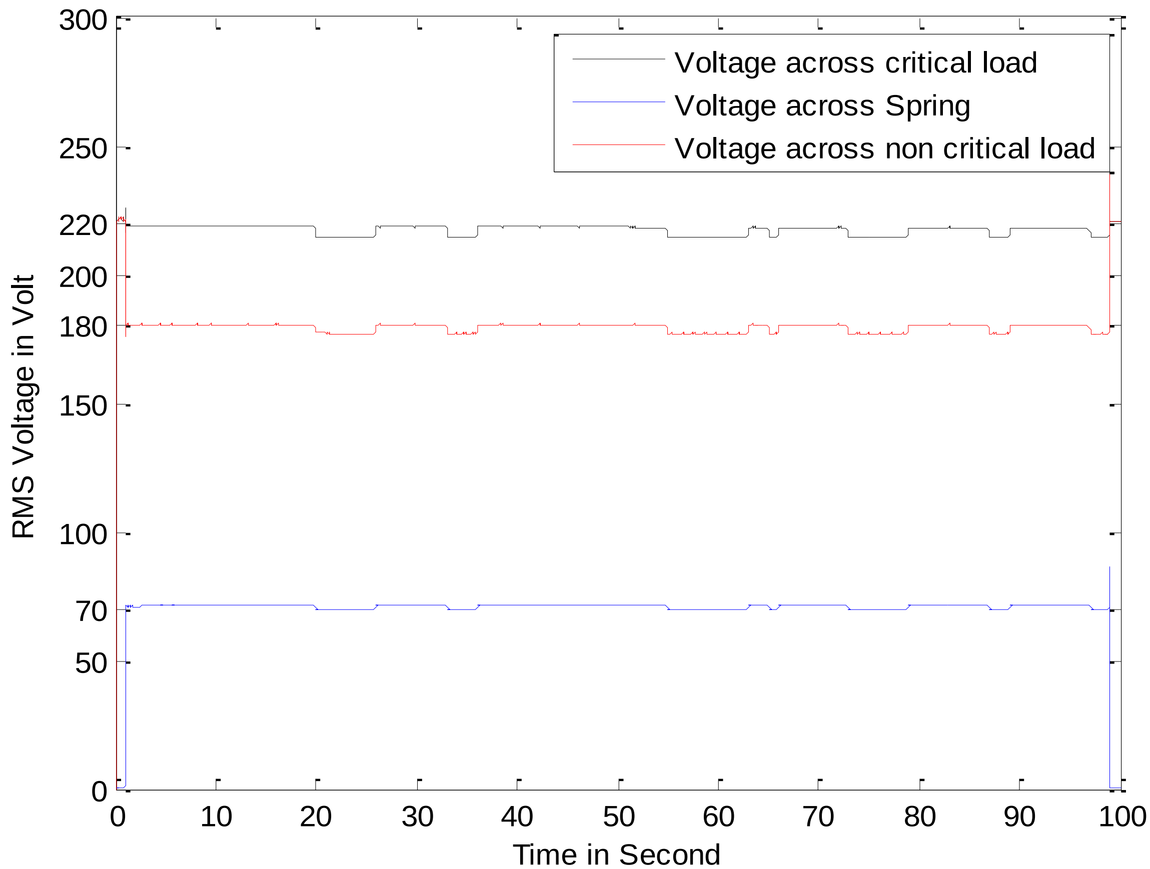

Fig.6. Voltages at different points of interest during with resistive non-critical load

During normal operating conditions i.e. until first second of the simulation time there are no fluctuations from the source and hence the spring does not act and hence the voltage across C3 will be zero, as shown in Fig. 6. After the end of first second there are programmed variations in the source and hence the Electric spring circuitry acts and will be helpful in suppressing the voltage across the non-critical load and also from Fig.6 it can be noted that after 98 seconds of simulation time the voltage across C3 falls to zero which means the Electric spring is inactive.

During the operation of Electric spring it can be noticed from Fig. 6 that the voltage across the non-critical load is being reduced to a much lesser value than the critical load which in turn results in reduced power consumption from the supply system (Including battery and the fluctuating power source). By comparison it can be seen that the voltage across the non-critical load during normal operating conditions is as same as critical load but has a larger differencewhen the Electric spring is operated i.e. during uncertainties in power generation by the source.

Now as the critical load considered for the study is pure resistive the real power drawn from the supply system is as shown in the Fig.7.The power drawn by the critical load during normal operating conditions is about 1580 watt and during power fluctuations with the battery support the power drawn also remains within the limit.

In this case study as the non-critical load considered is pure resistive, there will be only real power consumption. From Fig. 7 it can also be observed that the power drawn by the non-critical during generation sufficiency is around 1800 watt and during insufficiency the power drawn is reduced from its normal value and as a result of it the power drawn from the supply system gets reduced which relives the battery and the source during uncertainties.

Table.2 shows the energy supplied by the source and battery with and without the action of Electric spring. It can be established that due to the support of Electric Spring the power drawn from the supply system is less.

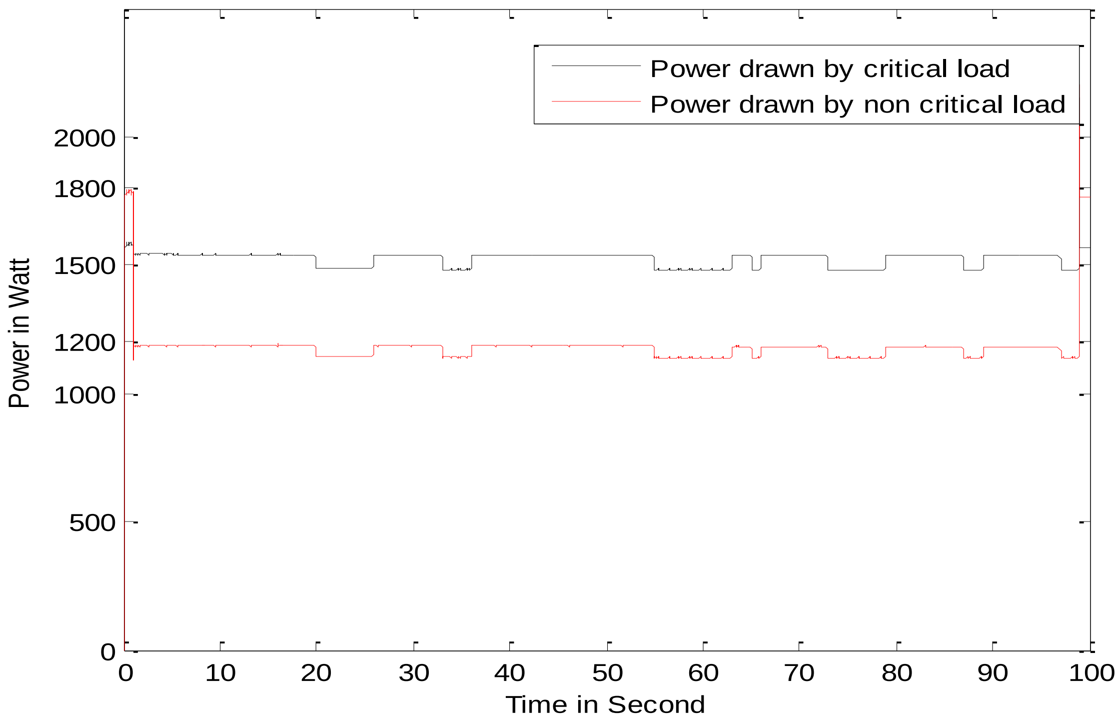

Fig. 7 Real power drawn by the critical and non-critical load

Table.2 Energy delivered by the source and battery with and without the action of spring

Energy levels with the action of Electric spring		Energy levels without the action of Electric spring	
Real power supplied by the source in terms of Watt hour	Real power supplied by the battery interms of Watt hour	Real power supplied by the source in terms of Watt hour	Real power supplied by the battery in terms of Watt hour
51	28	59	32

If the total power supplied by the supply system is considered the power supplied by the source and battery with and without the action of Electric Spring is about 79 Wh and 91 Wh respectively. Hence it can be established that there is15 % reduction in the energy supplied by the supply system which is good enough. If the objective is only the reduction of battery storage requirement it can be clearly noticed from Table. 2 that there is a reduction of around 14 % in the energy supplied by the battery which means that there can be substantial reduction in the battery size and capacity.

The results obtained in this case are different from other works in literature [17] because of the level of source fluctuations considered is distinct. Operation of the micro grid system without the action of Electric spring means both the critical and non-critical loads are supplied nominal voltage even during generation uncertainties, with the support of battery.

4.3 Case II:

This case aims at analyzing the performance of Electric spring in the presence of reactive component of non-critical load. Apart from this there will not be any other change in the system specifications. The design and implementation is similar to that of Case .1 and for the same uncertainties as considered in Case 1 the voltage across the critical load is maintained at required tolerance level.

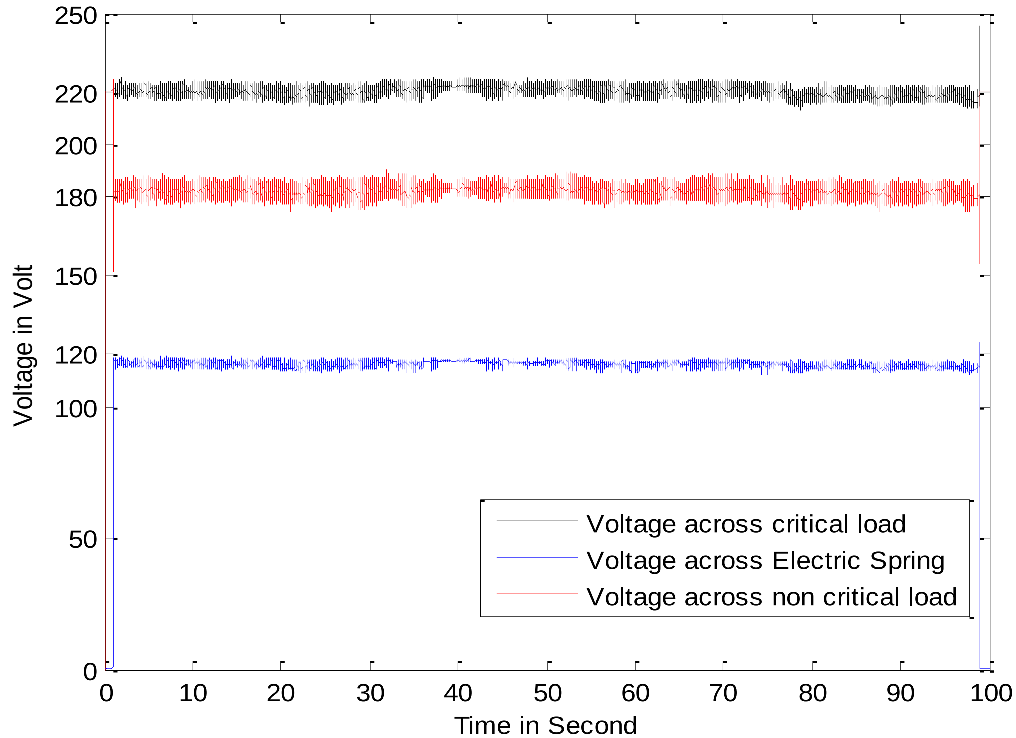

Fig.8 Voltages atdifferent points of interest with the presence of reactance in non-critical load

Fig.8 shows the voltage appearing across the critical load, electric spring and non-critical load for the considered simulation time of 100 second. In the same way during un-certainties in power generation the voltage across the non-critical load is suppressed to a lower value and the voltage across critical load is held within the tolerance value of 220 volt. The pattern of the real power drawn by the critical and non-critical loads during generation uncertainties is as shown in Fig. 9.

Fig. 9 gives the real power patterns of the critical and non-critical loads where in the power drawn by the critical load is always around 1580 watt in spite of fluctuations in the renewable generator. Then real power consumed by the non-critical load during generation sufficiency is around 1000 watt and during abnormality in the system the real power drawn is suppressed to around 700 watt because of the action of the electric spring. Apart from the suppression in the real power drawn, the reactive power supplied to the spring is also reduced during uncertainties and it is as shown in Fig. 10.

Fig. 10 shows the reactive power supplied to the non-critical load, which is also reduced during generation uncertainties and will be helpful in supporting the system. The reactive power drawn by the system during generation sufficiency is around 880 VAr and is around 600 VAr during generation deficits (Fig. 10). The real and reactive energy supplied by the source and the battery with and without the action of spring is as shown in Table. 3.

Table.3 gives information about the energy patterns of the source and battery with and without spring. In this case also whenever the spring is inactive it means that the non-critical load is also supplied its rated value (220 volt) with the battery support. Now it can be noticed from Table.3 that there is certainly a difference in the power drawn from the supply system as a whole with and without the action of Electric spring. Apart from the reduction of power drawn it was observed during the simulation process that during the action of Electric spring the renewable generator is completely relieved from supplying reactive power which in turn increases the real power supplied by the source which can be noticed from Table.3 which means that Electric spring provides reactive support to the system which can be useful in improving the system efficiency in terms of power factor correction. Although the generator is relieved from supplying reactive power it should also be noted that a little amount of reactive power is consumed by the source for its reactive support and this is being supplied by the Electric spring on a whole.

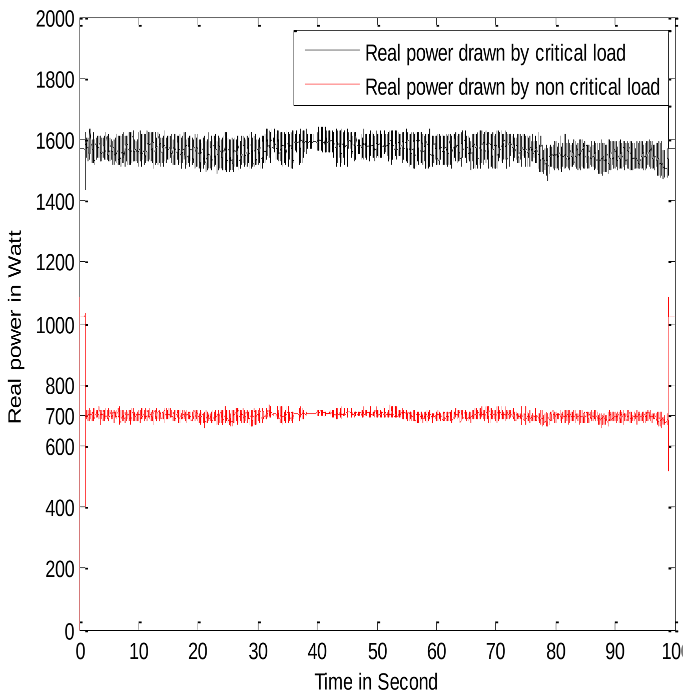

Fig. 9 Real power drawn by critical and non-critical loads

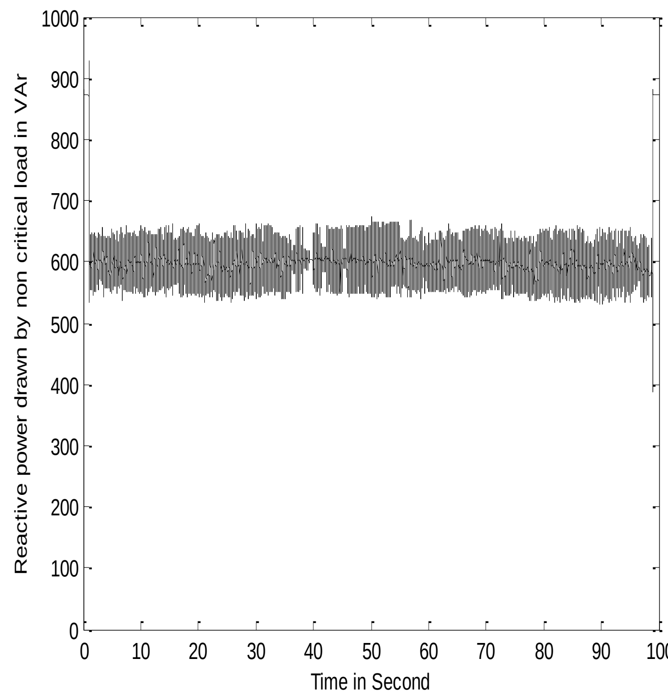

Fig. 10 Reactive power supplied to the non-critical load

Table.3 Energy delivered by the battery and source with and without the action of spring

Energy levels with the action of Electric Spring			Energy levels without the action of Electric Spring			
Real power supplied by source in terms of Watt hour	Real power supplied by battery in terms of Watt hour	Reactive power supplied by battery in terms of VAr hour	Real power supplied by the source in terms of Watt hour	Reactive power supplied by the source in terms of VAr hour	Real power supplied by battery in terms of Watt hour	Reactive power supplied by battery in terms of VAr hour
38.84	34	11	33	`11.58	37	13

Now as the system consists of reactive power loading the VAh supplied by the supply system with and without spring is 75VAh and 74 VAh respectively. Although there is no substantial reduction in the apparent power drawn from the supply system because of the action of spring he battery is relieved to certain extent because the VAh supplied by the battery with and without the action of spring is 35.73 VAh and 39.21 VAh respectively which is 10 % reduction in the volt ampere drawn from the storage system. And also with the action of Electric spring the real power supplied by the battery is also reduced by around 9 % and in the same way the reactive power supplied is reduced to around 18 % which can be treated as an appreciable saving in the battery power which in turn means that the necessity to have larger storage requirement will be reduced.

5. Conclusion:

In this work a comparative study is made on the performance of the Electric spring in reducing the power drawn by the non-critical loadsin the presence and absence of reactive component in the non-critical loads. It can be established from Case I that during pure resistive operation of the non-critical load and the action of Electric spring the net reduction in the real power drawn from the battery is around 14 % which is substantial enough to use less rated batteries for the micro grids which have to be operated on battery support during generation intermittence. It is also clear from Case II that Electric springs can operate even if the non-critical loads have a little inductive nature and also the reduction in the apparent power drawn from the battery storage system is around 10 % which is again a remarkable saving in battery storage requirement and so, if these type of smart loads are used in future smart grids the storage requirement may get substantially low which will encourage more investments in the field of Battery or super capacitor energy storage systems.Hence it is proved from the above results and discussions that usage ofElectric Springs in the existing grid environment is an effective solution to deal with the demand supply gaps in a grid system which consists of more renewable energy sources whose generation is highly uncertain.

References:

[1]Varaiya, Pravin P., Felix F. Wu, and Janusz W. Bialek. "Smart operation of smart grid: Risk-limiting dispatch." Proceedings of the IEEE 99.1 (2011): 40-57.

[2] Koutsopoulos, Iordanis, and LeandrosTassiulas. "Challenges in demand load control for the smart grid." Network, IEEE 25.5 (2011): 16-21.

[3] Mohsenian-Rad, A-H., et al. "Autonomous demand-side management based on game-theoretic energy consumption scheduling for the future smart grid." Smart Grid, IEEE Transactions on 1.3 (2010): 320-331.

[4] M. Pedrasa, T. D. Spooner, and I. F. MacGill, “Scheduling of demand side resources using binary particle swarm optimization,” IEEE Trans.Power Syst., vol. 24, no. 3, pp. 1173–1181, 2009.

[5] B. Saravanan, “DSM in an area consisting of residential, commercial and industrial load in smart grid,” Frontiers in Energy, 2015

[6]Conejo, Antonio J., Juan M. Morales, and Luis Baringo. "Real-time demand response model." Smart Grid, IEEE Transactions on 1.3 (2010): 236-242.

[7]Mohsenian-Rad, A-H., and Alberto Leon-Garcia. "Optimal residential load control with price prediction in real-time electricity pricing environments." Smart Grid, IEEE Transactions on 1.2 (2010): 120-133.

[8]Kienzle, Florian, Peter Ahcin, and GöranAndersson."Valuing investments in multi-energy conversion, storage, and demand-side management systems under uncertainty." Sustainable Energy, IEEE Transactions on 2.2 (2011): 194-202.

[9] A. Andreotti, G. Carpinelli, F. Mottola, Member and D. Proto, “A Review of Single-Objective Optimization Models for Plug-in Vehicles Operation in Smart Grids Part I: Theoretical Aspects,” IEEE power and energy society general meeting, pp. 1-8, 2012.

[10] Uttam Kumar Debnath, Iftekhar Ahmad, DaryoushHabibi, “Quantifying economic benefits of second life batteries of gridable vehicles in the smart grid,” Electrical Power and Energy Systems, Vol. 63, pp.577-587, 2014.

[11] Kanchev, Hristiyan, et al. "Energy management and operational planning of a microgrid with a PV-based active generator for smart grid applications."Industrial Electronics, IEEE Transactions on 58.10 (2011): 4583-4592.

[12]Hui, Shu Yuen, Chi Kwan Lee, and Felix F. Wu. "Electric springs—A new smart grid technology." Smart Grid, IEEE Transactions on 3.3 (2012): 1552-1561.

[13] Chaudhuri, N. R., Lee, C. K., Chaudhuri, B., &Hui, S. Y. R. Dynamic modeling of electric springs. Smart Grid, IEEE Transactions on,*5*.5(2014), 2450-2458.

[14] Yan, S., Tan, S. C., Lee, C. K., Chaudhuri, B., &Hui, S. Y. Electric Springs for Reducing Power Imbalance in Three-Phase Power Systems. Power Electronics, IEEE Transactions on, *30*.7(2015), 3601-3609.

[15] Chen, X., Hou, Y., Tan, S. C., Lee, C. K., &Hui, S. Y. R. Mitigating Voltage and Frequency Fluctuation in

Microgrids Using Electric Springs. Smart Grid, IEEE Transactions on, *6*.2(2015), 508-515.

[16] Luo, X., Akhtar, Z., Lee, C. K., Chaudhuri, B., Tan, S. C., &Hui, S. Y. R.Distributed voltage control with electric springs: Comparison with STATCOM. Smart Grid, IEEE Transactions on, 6.1(2015), 209-219.

[17] Lee, Chi Kwan, and Shu Yuen Hui. "Reduction of energy storage requirements in future smart grid using electric springs." Smart Grid, IEEE Transactions on4.3 (2013): 1282-1288.

[18] Lee, Chi Kwan, Sinan Li, and S. Y. Hui. "A design methodology for smart LED lighting systems powered by weakly regulated renewable power grids." Smart Grid, IEEE Transactions on 2.3 (2011): 548-554.