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Using Fuzzy Logic Control the Distributed Voltage Control with Electric Springs: Comparison with STATCOM



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Abstract

In this paper, a comparisonis made between electric springs (ES) and static compensator (STATCOM). A comparison is made between distributed voltage control using ES againstthe traditional single point control with STATic COMpensator(STATCOM) by using fuzzy logic controller. Here we are using fuzzy logic controller instead of using other controllers. For a given range of supply voltage variation, thetotal reactive capacity required for each option to produce thedesired voltage regulation at the point of common coupling (PCC) connection is compared.In this paper, it turns out that a group of ESsachieves better total voltage regulation than STATCOM with lessoverall reactive power capacity. Dependence of the ES capabilityon proportion of critical and NC load is also shown. Simulation was done by using MATLAB/Simulink software under various critical and NC loads.

A fuzzy logic-based controller is developed to control the voltage of the DC Capacitor. This work presents and compares the performance of the fuzzy-adaptive controller with a conventional fuzzy and PI controller under constant load. The total Harmonic Distortion, Individual harmonic content with respect to % of fundamental in Supply current, source voltage have been analyzed.

*Index Terms—**Demand response, electric springs (ES), STATicCOMpensator (STATCOM), voltage control, voltage regulation, Fuzzy logic controller.***

I. INTRODUCTION

Controlof voltage in medium voltage (MV) or low voltage(LV) distribution networks is typically exercised throughtransformer tap-changers and/or switched capacitors/reactors.Sometimes a STATic COMpensator (STATCOM) is usedfor fast and precise voltage regulation, especially for thesensitive/critical loads [1]. The novel concept of electric spring (ES) has been proposed as an effective means of distributed voltage control [2].The idea is to regulate the voltage across the critical loadswhile allowing the noncritical (NC) impedance-type loads(e.g., water heaters) to vary their power consumption and thuscontribute to demand-side response [3], [4] as well. This wouldallow and facilitate large penetration of intermittent renewableenergy sources without requiring huge amounts of energy storage to act as a buffer between supply and demand [5]. Thebasic proof of concept of ES has already been demonstratedthrough hardware experimentation with the developed prototypes [2], [6]. Distributed voltage regulation through collectiveaction of a cluster of ESs, each employing droop control hasalso been illustrated [7].

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A spring is an elastic object used to store mechanical energy. Springs are usually made out of spring steel. There are a large number of spring designs; in everyday usage the term often refers to coil springs.Small springs can be wound from pre-hardened stock, while larger ones are made from annealed steel and hardened after fabrication. Somenon-ferrous metals are also usedincluding phosphor bronze and titanium for parts requiring corrosion resistance and beryllium copper for springs carrying electrical current (because of its low electrical resistance). The concept of electric spring (ES) has been proposed recently as an effective means of distributed voltage control. The idea is to regulate the voltage across the critical (C) loads while allowing the noncritical (NC) impedance-type loads (e.g., water heaters) to vary their power consumption and thus contribute to demand-side response.

In this paper, the focus is to compare the effectivenessof single point voltage control using STATCOM against distributed voltage control using a group of ESs. The basis forcomparison is total voltage regulation [root mean square ofthe deviation of the actual voltages from the rated (1.0 p.u)values] achieved and the overall reactive capability requiredfor each option in order to achieve that [8], [9].

A number of papers [2], [5]–[7] have been publishedrecently on the ES concept and its control. However, noneof those papers have focused on the collective performanceof multiple of ESs considering realistic distribution networks.This paper demonstrates the effectiveness of multiple ESsworking in unison through case studies on an IEEE testfeeder network and also a part of a real distribution systemin Hong Kong. The voltage regulation performance and totalreactive power requirement of a group of ESs in case of distributed voltage control is compared against the single-pointcontrol using a STATCOM. In both cases, it turns out thata group of ESs achieves better total voltage regulation thanSTATCOM with less overall reactive power capacity.

II.ELECTRIC SPRING CONCEPT

Voltage control in LV and MV distribution networks and demand-side management (DSM) have traditionally been treated and tackled separately. Voltage control is usually achieved by control devices discussed in the previous section. Demand-side management on the other hand is employed in a more distributed fashion (often at the appliance level) and is predicated on intelligence or communication facility in the appliance [10-12]. Alternatively, an integrated approach to voltage control and aggregated demand action could be achieved by separating the loads into critical loads requiring constant voltage and uninterrupted supply and non-critical, impedance-type loads.

At times of generation shortfall or network constraint, the voltage of the non-critical loads is reduced while regulating the voltages across the critical loads. This addresses the generation shortfall or network constraint and also facilitates better voltage regulation of the critical loads through manipulation of the supply impedance voltage drop. Here for electric springs controller is needed, for that controller pulses are required to turn-on the converter switches. The pulses are provided by using PWM techniques along with using fuzzy logic controller.

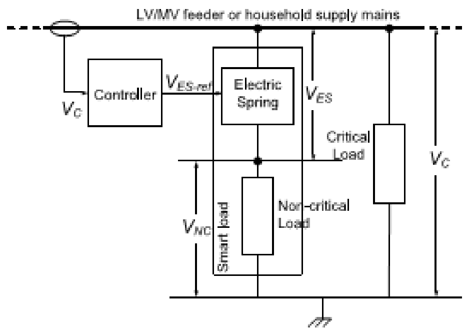

Fig. 1. Electric Spring set-up for Smart loads.

One way to exercise this control is to use the so called Electric Springs (ESs) which are power electronic compensators that inject a voltage with controllable magnitude VES in series with each non-critical load to regulate the voltage VC across the critical load as shown in Fig. 1. The voltage VNC across the non-

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critical loads is thus controlled (within allowable bounds) and the active power consumed by them modulated. The series combination of the ES and the noncritical load thus acts as a 'Smart Load' which ensures tightly regulated voltage across the critical load while allowing its own power consumption to vary and thereby, participate in demand side response. Adding the voltage VES in quadrature with the current flowing through the ES ensures exchange of reactive power only like conventional voltage compensators including STATCOM. For further details about Electric Springs the readers can refer to [2, 5].

III. ELECTRIC SPRING (ES) VS. STATCOM

A. Test System

In order to compare the voltage regulation performance of a single ES against that of a STATCOM, a simple test system as shown in Fig. 2 was considered.

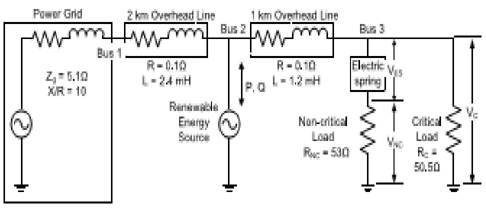

Fig. 2. Simulation set up with an intermittent source and an equivalent power grid.

It comprises of a power source acting as the main power grid and a separate controllable power source to emulate an intermittent renewable energy source. The controllable source is capable of injecting variable active and/or reactive power which causes the voltage across the critical load to fluctuate. For simplicity both critical and non-critical loads were represented by resistors although they do not have to be necessarily resistive. The parameters used for the system and the ES are the same as in [2] and are not repeated here due to space restriction.

The above system was modeled in Matlab/SIMULINK using a controllable voltage source representation for both ES and STATCOM. Modeling and control of ES is discussed in [13]. The magnitude of the controllable voltage representing the ES is controlled using a fuzzy logic controller to minimize the difference between the actual and reference values of the voltage across the critical load. Phase angle of the voltage source is locked in quadrature to the phase angle of series current to ensure there is no active power transfer. The STATCOM is modeled by a controllable voltage source in series with impedance. Its control circuit is very similar to that of ES except for the adjustments due to its parallel connection to the critical and non-critical load.

B. Voltage Suppress Mode

The voltage across the loads was increased above the nominal value (216 V) by reducing the reactive power absorption of the renewable source. This is to test the ability of an ES and a STATCOM to suppress the voltage and regulate it at the nominal value. At t=1.0 s, the reactive power absorption by the intermittent renewable source was reduced from 467 VAr down to 110 VAr. Without any voltage control, the load voltage increases from the nominal value of 216 V up to 224 V as shown by Fig. 3(a) & (b). Both STATCOM and ES are able to restore the voltage across the critical load back to the nominal value as shown by the overlapping blue and red traces in Fig. 3(b). The ES achieves this by injecting about 115 V in series with the non-critical load the voltage across which drops to about 185 V as shown by the blue traces in Fig. 3(c). In order to suppress the voltage, both ES and STATCOM absorbs reactive power (as indicated by positive sign of Q) from the system as shown in Fig. 3(d) with ES requiring to absorb about 100 VAr more than the STATCOM.

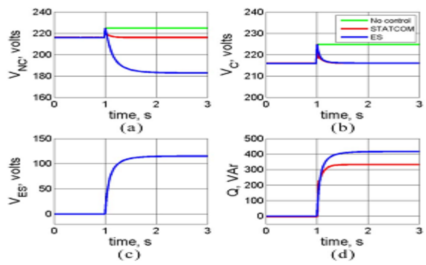

Fig. 3. System response following decrease in reactive power consumption of the intermittent source from 467 to 110 VAr

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It is observed that the reactive power consumed by ES to restore the critical load voltage to normal value is higher than the reactive power consumed by STATCOM to achieve the same voltage. This can be explained from Fig. 1. An increase in ES voltage will result in a decrease in non-critical load voltage. This causes a decrease in the active power consumption of the (resistive) non-critical load. In order to have a higher overall active/reactive power consumption for the smart load, ES has to consume more reactive power. Note that the X/R ratio is not large (about 2) in this case which is why both active and reactive power affects the voltage regulation.

C. Voltage Support Mode

To investigate the opposite effect of what was described in the previous subsection, the voltage across the loads was reduced by increasing the reactive power absorption of the renewable source. This is to test the ability of an ES and a STATCOM to support the voltage and regulate it at the nominal value. At t=1.0 s, the reactive power absorption by the intermittent renewable source was increased from 467 VAr to 1100 VAr. Without any voltage control, the load voltage is seen to drop from the nominal value of 216 V to slightly below 190 V as shown by the green trace in Fig. 4(a)&(b).

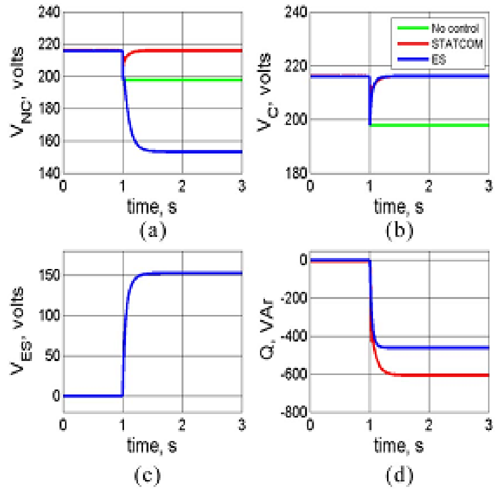

Fig. 4. System response following increase in reactive power consumption of the intermittent source from 1100 to 467 VAr.

As before, both STATCOM and ES are able to restore the voltage across the critical load back to the nominal value as shown by the overlapping blue and red traces in Fig. 4(b). The ES achieves this by injecting about 150 V in series with the non-critical load the voltage across which drops to about 150 V as shown by the blue traces in Fig. 4(a)&(c). In order to suppress the voltage, both ES and STATCOM injects reactive power (as indicated by negative sign of Q) into the system as shown in Fig. 4(d) with ES requiring to inject about 150 VAr less than the STATCOM. This is due to the fact that an increase in ES voltage will result in a reduction of non-critical load voltage which causes a decrease in active power consumption of the (resistive) non-critical load. Hence, the ES needs to produce less reactive power than an equivalent STATCOM to restore the system voltage due to the similar arguments about the X/R ratio as mentioned earlier for the voltage suppress case.

D. Proportion of Critical and Non-critical Loads

An ES injects a voltage is series with the non-critical load in order to regulate the voltage across the critical load. The proportion of the critical and non-critical load is therefore, quite important towards the effectiveness of an ES both in terms of its voltage regulation capability and also the amount of reactive power (and hence its rating) exchanged with the system. The reactive capability of an ES is governed by the product of the voltage it injects and the current flowing through it (which is the same as the current through the noncritical load). If the injected voltage increases, the voltage across the non-critical load and hence the current reduces which limits the reactive capability of an ES and thus its ability to regulate the voltage across the critical load. For low proportion of non-critical load, the fidelity of current is restricted which limits the capability of an ES compared to the case when the proportion of non-critical load is relatively high. To verify this, simulations were conducted with different proportions of non-critical (NC) and critical (C) loads. The results are shown in Fig. 5.

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It can be seen that for high proportion of non-critical load (NC:C=9:1) shown by the black traces, the critical load voltage is restored back to its nominal value, with only 80 V injected by the ES. This results in little change (from 216 V to 202 V) in voltage across the non-critical load. Voltage regulation is similar for equal proportion of critical and noncritical (NC:C=5:5) loads shown by magenta traces. However, the voltage across the non-critical load is lower (about 140 V) than before due to larger injected voltage (160 V) by the ES. Based on public statistics in Hong Kong [14], about 50% of loads (such as heaters, air-conditioners etc.) in domestics and commercial buildings can be considered as non-critical.

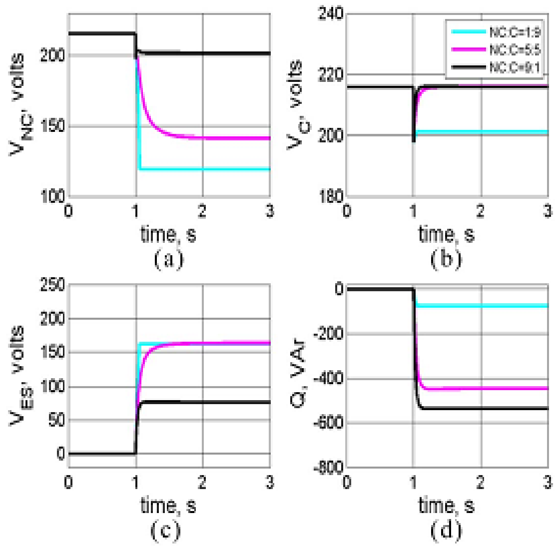

Fig. 5. System response for different distribution of non-critical and critical loads (NC:C). Disturbance is increase in reactive power consumption of the intermittent source from 467 to 1100 VAr.

For low proportion of non-critical load (NC:C=1:9), it is not possible to restore the voltage across the critical load back to its nominal value as shown by the cyan trace in Fig. 5(b). This is because of the low fidelity in current which restricts the reactive capability of the ES to less than 100 VAr (Fig. 5(d)) for a maximum possible ES voltage of 160 V. This demonstrates that the voltage regulation capability of an ES is dependent on the relative proportion of non-critical and critical load. Lesser the proportion of non-critical load, lower is the voltage regulation capability of an ES. As the second generation of ES with embedded energy storage [15] has emerged, there would be more flexibility in control which would be demonstrated in a future paper.

The reactive power exchange with the ES depends on the injected voltage VES and also on the impedance of the noncritical load. Consider the circuit shown in Fig. 1. For a resistive-inductive (R-L) type non-critical load with impedance ZNC∠θNC, the voltages VC, VES and VNC are shown on the phasor diagram in Fig. 6(a) when the ES is working in voltage support (i.e. capacitive) mode. From the phasor diagram we can write:

$$V_C^2 = (V_{NS} - V_{ES}\sin\theta\, NC)^2 + (V_{ES}\cos\theta\, NC)^2 \qquad (1)$$

$$V_{NC} = \pm\sqrt{V_C^2 - (V_{ES}\cos\theta\, NC)^2} + V_{ES}\sin\theta\, NC \qquad (2)$$

$$Q_{ES} = V_{ES} I_{NC}\sin(-90^{\circ}) = -V_{ES} I_{NC} = -\frac{V_{ES} I_{NC}}{Z_{NC}} \qquad (3)$$

$$Q_{NS} = V_{ES} I_{NC}\sin\theta\, NC = \frac{V_{NC}^2}{Z_{NC}}\sin\theta\, NC \qquad (4)$$

Here, QES and QNC are the reactive powers of the ES and the non-critical load, respectively. For a purely resistive noncritical load, the reactive power of the ES and the smart load will be equal. However, they would be different if the the noncritical is not purely resistive. If the ES is working in voltage support (i.e. capacitive) mode with a non-critical load of R-L type, the total reactive power of the smart load QSL is given by:

$$Q_{SL} = Q_{ES} + Q_{NC} \qquad (5)$$

$$Q_{SL} = \frac{-V_{ES}\left(\pm\sqrt{V_C^2 - (V_{ES}\cos\theta\, NC)^2} + V_{ES}\sin\theta\, NC\right)}{Z_{NC}} + \frac{V_{ES}\left(\pm\sqrt{V_C^2 - (V_{ES}\cos\theta\, NC)^2} + V_{ES}\sin\theta\, NC\right)^2}{Z_{NC}}\sin\theta\, NC \qquad (6)$$

Similarly, for the ES in voltage suppress (i.e. inductive) mode, we can write:

$$V_{NC} == \pm\sqrt{V_C^2 - (V_{ES}\cos\theta\, NC)^2} - V_{ES}\sin\theta\, NC \qquad (7)$$

$$Q_{SL} = \frac{V_{ES}\left(\pm\sqrt{V_C^2 - (V_{ES}\cos\theta\, NC)^2} - V_{ES}\sin\theta\, NC\right)}{Z_{NC}} + \frac{\left(\pm\sqrt{V_C^2 - (V_{ES}\cos\theta\, NC)^2} - V_{ES}\sin\theta\, NC\right)^2}{Z_{NC}}\sin\theta\, NC \qquad (8)$$

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From (3), (6) and (8) it is clear that the reactive power of the ES and the smart load are both dependent on non-critical load impedance (ZNC). A decrease in the value of ZNC (increase in the non-critical load) will result in an increase in reactive power. Hence, a higher proportion of non-critical load will increase the effectiveness of an ES.

E. Reactive Power Limit of Smart Load

For a fixed non-critical load impedance (ZNC∠θNC) and a target critical load voltage (VC = 1.0 p.u.), all the terms on the right hand side of (3), (6) and (8) are constant except the ES voltage (VES). Hence, QES and QSL can be expressed as functions of VES only. Fig. 6(b) shows the variation of QES and QSL versus VES for VC = 1.0 p.u., and ZNC =1.0 p.u. for two different power factor of the non-critical load. In all cases the ES is considered to be in voltage support (i.e. capacitive) mode as indicated by the negative sign of QES. For a purely resistive non-critical load, QES and QSL are equal and are shown by the black trace in Fig. 6(b). QES and QSL for an R-L non-critical load with 0.95 power factor are shown by blue and green traces respectively. The figure is drawn only for nonnegative values of VNC phasor represented by (2).

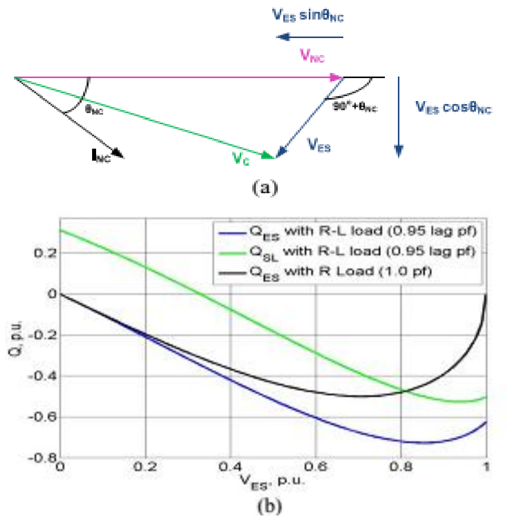

Fig. 6. (a) Phasor diagram showing relationship between voltages across non-critical load, critical load and ES, (b) Variation of reactive power of ES and smart load with respect to ES voltage for R-L and R non-critical loads.

It can be seen that beyond a certain point, increasing the ES voltage will result in a decrease in reactive power magnitude due to decrease of the current. Hence, it is essential to impose a limit on the output of the fuzzy logic controller which determines the ES voltage magnitude, so that the voltage injected by the ES does not go beyond the maximum reactive power (magnitude) point on the curves shown in Fig. 6(b). It may also be noted that the maximum values of the two reactive powers will occur at different values of VES if the noncritical load is not purely resistive. In such cases, the limits of the fuzzy logic controller should be based on the maximum value of QSL. Also, it can also be seen that the reactive power output of the smart loads would be maximum at different values of VES depending on the power factor of the non-critical loads.

F. Variable Active and Reactive Power from Renewable Source

In this subsection, the result of varying the reactive power absorbed and the active power generated by the renewable energy source connected at bus 2 (see Fig. 2) is shown. First, the reactive power absorbed is varied between 150 and 1100 VAr keeping the active power generation fixed at zero. Without any voltage control, the voltage across the loads reduces as the reactive power absorption increases. This is shown by the green trace in Fig. 7(a) about the nominal voltage of 216 V. For Q467 VAr, the actual voltage is less than the nominal requiring voltage support.

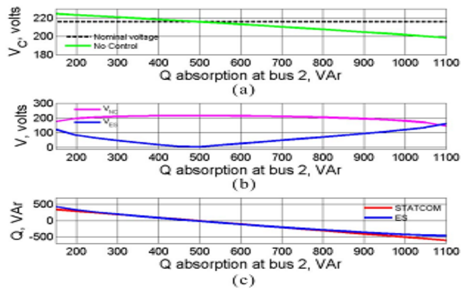

Fig. 7. Variation of voltages across the critical and non-critical loads and voltage and reactive power of electric spring as the reactive power absorption by the renewable source (at bus 2, Fig. 2) is changed from 150 VAr to 1100 VAr.

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Voltage injected by the ES and the voltage across the noncritical load are shown in Fig. 7(b). For Q=467 VAr, the voltage injected by the ES is almost zero while the voltage across the non-critical load is equal to the nominal value of 216 V. On either side of Q=467 VAr, the ES injects a positive voltage, resulting in a reduced voltage across the non-critical load such that the vector sum of the two equals the nominal voltage (i.e. 216 V) which is maintained across the critical load. The reactive power exchanged by the ES is compared against that of a STATCOM to regulate the critical load voltage at 216 V. It can be seen that for voltage suppression (Q467 VAr) they inject VAr into the system. It should be noted that over the range of variation of Q absorption shown in Fig. 7(c), the reactive power exchanged by the ES and the STATCOM are very similar. For higher levels of voltage support (Q>900 VAr), a STATCOM requires more reactive power than an ES with the difference between the two growing for larger Q absorption. For higher levels of voltage suppression (Q change in power consumption of the non-critical load (when ES is active) as explained earlier in Sections II.B and II.C.

Next, the reactive power absorption is fixed at Q = 467 VAr, while the active power (P) generated at bus 2 is varied from 0 to 900 W. Without any voltage control, the voltage across the loads increases with increase in active power generation (P) at bus 2 as shown by the green trace in Fig. 8(a).

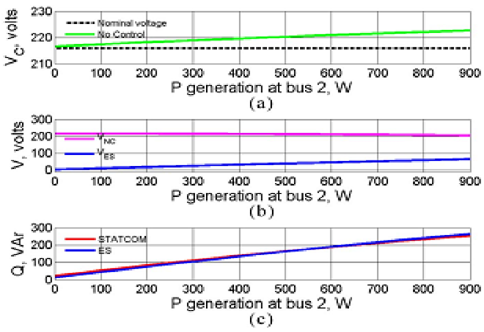

Fig. 8. Variation of voltages across the critical and non-critical loads and voltage and reactive power of electric spring as the active power generation by the renewable source (at bus 2, Fig. 2) is changed from 0 to 900 W.

One important point to note from Fig. 8(b) is that as power generation from the renewable source at bus 2 increases, the voltage across the non-critical load (and hence the active power consumed by it) reduces in order to regulate the voltage across the critical load to its nominal value of 216 V. In such cases, the non-critical load voltage has to be lower than its nominal value for a non-zero ES voltage. Hence the active power consumed by the non-critical load cannot increase above its nominal value. This restriction can be overcome if the load has non-unity power factor in which case the two voltages are not constrained to be in quadrature. Alternatively, the ES can be allowed to inject a voltage with any phase angle (not just ±90 degrees) with respect to the current requiring exchange of both active and reactive power with the system which is possible through incorporation of energy storage (i.e. a battery) into the ES. This type of ES with embedded energy storage is more versatile in terms of its capability to control the voltage while ensuring power balance and hence regulate the system frequency and is referred to as version 2 or generation 2 of ES (ESv2) [15]. The scope of this paper is limited to reactive power only version (ESv1) [5] to ensure a fair comparison against STATCOM which only exchanges reactive power with the system.

IV. FUZZY LOGIC CONTROLLER

In FLC, basic control action is determined by a set of linguistic rules. These rules are determined by the system. Since the numerical variables are converted into linguistic variables, mathematical modeling of the system is not required in FC.

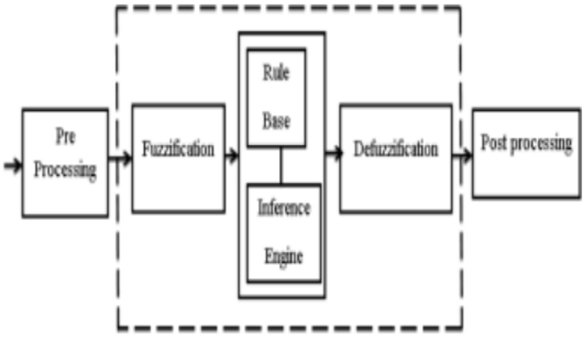

Fig.9.Fuzzy logic controller

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The FLC comprises of three parts: fuzzification, interference engine and defuzzification. The FC is characterized as i. seven fuzzy sets for each input and output. ii. Triangular membership functions for simplicity. iii. Fuzzification using continuous universe of discourse. iv. Implication using Mamdani's, 'min' operator. v. Defuzzification using the height method.

TABLE I:Fuzzy Rules

Change in error	Error						
	NB	NM	NS	Z	PS	PM	PB
NB	PB	PB	PB	PM	PM	PS	Z
NM	PB	PB	PM	PM	PS	Z	Z
NS	PB	PM	PS	PS	Z	NM	NB
Z	PB	PM	PS	Z	NS	NM	NB
PS	PM	PS	Z	NS	NM	NB	NB
PM	PS	Z	NS	NM	NM	NB	NB
PB	Z	NS	NM	NM	NB	NB	NB

Fuzzification:

Membership function values are assigned to the linguistic variables, using seven fuzzy subsets: NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium), and PB (Positive Big). The Partition of fuzzy subsets and the shape of membership *CE(k) E(k)* function adapt the shape up to appropriate system. The value of input error and change in error are normalized by an input scaling factor.

In this system the input scaling factor has been designed such that input values are between -1 and +1. The triangular shape of the membership function of this arrangement presumes that for any particular *E(k)* input there is only one dominant fuzzy subset. The input error for the FLC is given as

$$E(k) = \frac{P_{ph(k)} - P_{ph(k-1)}}{V_{ph(k)} - V_{ph(k-1)}} \qquad (18)$$

$$CE(k) = E(k) - E(k-1) \qquad (19)$$

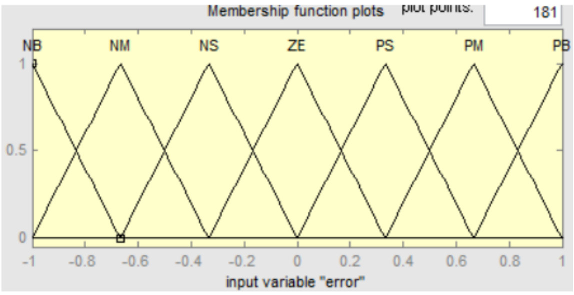

Fig.10.Membership functions

Inference Method:

Several composition methods such as Max–Min and Max-Dot have been proposed in the literature. In this paper Min method is used. The output membership function of each rule is given by the minimum operator and maximum operator. Table 1 shows rule base of the FLC.

Defuzzification:

As a plant usually requires a non-fuzzy value of control, a defuzzification stage is needed. To compute the output of the FLC, „height" method is used and the FLC output modifies the control output. Further, the output of FLC controls the switch in the inverter. In UPQC, the active power, reactive power, terminal voltage of the line and capacitor voltage are required to be maintained. In order to control these parameters, they are sensed and compared with the reference values. To achieve this, the membership functions of FC are: error, change in error and output

The set of FC rules are derived from

$$u=-[\alpha E + (1-\alpha)*C] \qquad (20)$$

Where α is self-adjustable factor which can regulate the whole operation. E is the error of the system, C is the change in error and u is the control variable. A large value of error E indicates that given system is not in the balanced state. If the system is unbalanced, the controller should enlarge its control variables to balance the system as early as possible. One the other hand, small value of the error E indicates that the system is near to balanced state.

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V. SIMULATION RESULTS WITH ES

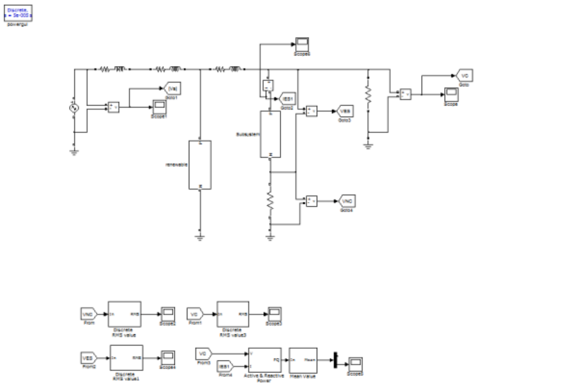


Fig.11.Matlabmodel of proposed system with ES

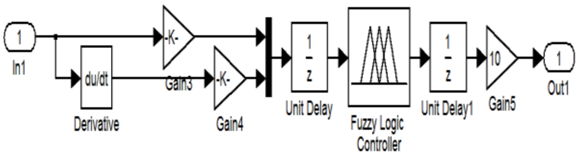
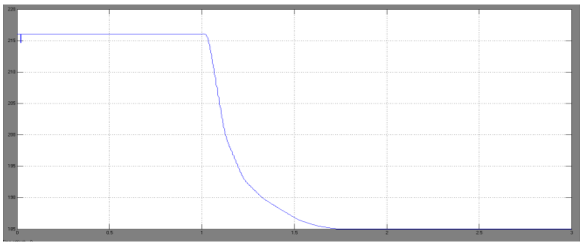
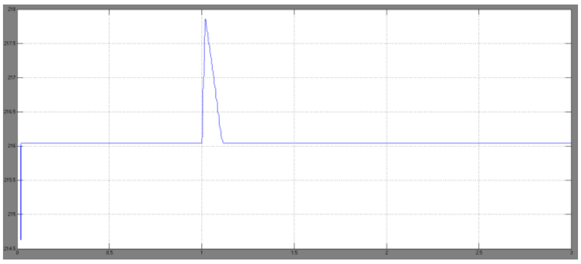


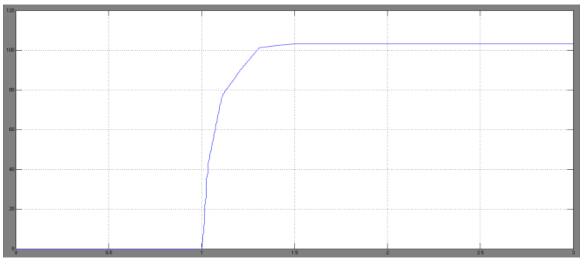
Fig.12. Fuzzy logic controller



(a)



(b)



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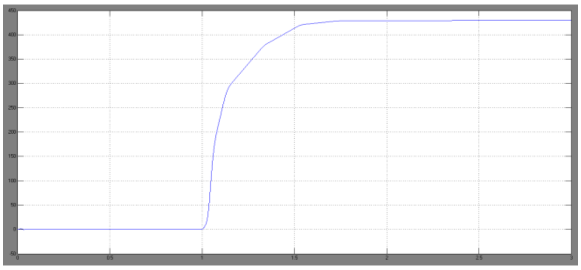
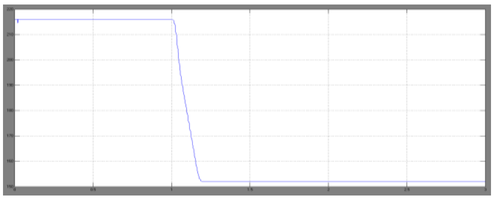
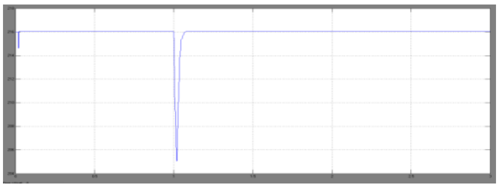


(d)

Fig. 13. System response following decrease in reactive power consumptionof the intermittent source from 467 to 110 VAr. (a) Non-critical load voltage.(b) Criticalload voltage. (c) Electric spring voltage. (d) Reactive power exchange.



(a)



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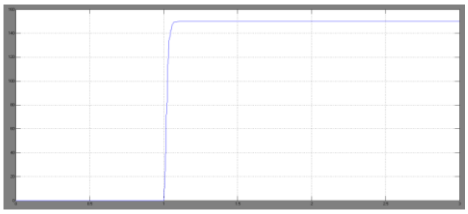

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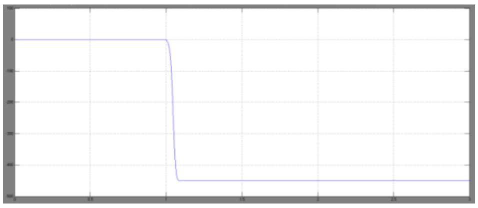

(d)

Fig. 14. System response following increase in reactive power consumptionof the intermittent source from 467 to 1100 VAr. (a) Noncritical load voltage.(b) Criticalload voltage. (c) Electric spring voltage. (d) Reactive power exchange.

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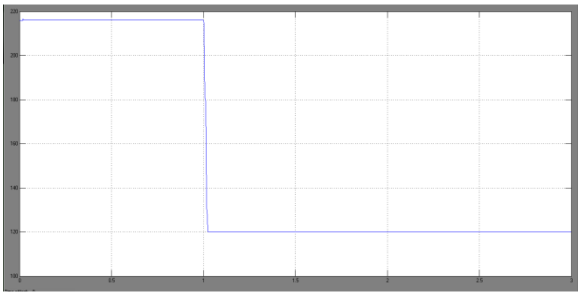
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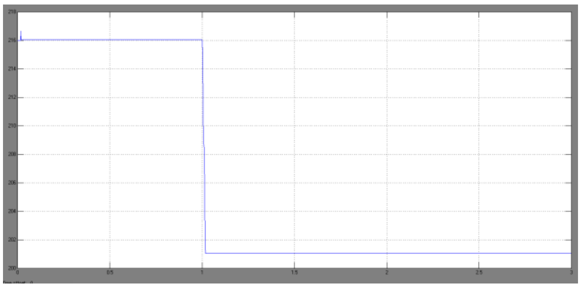
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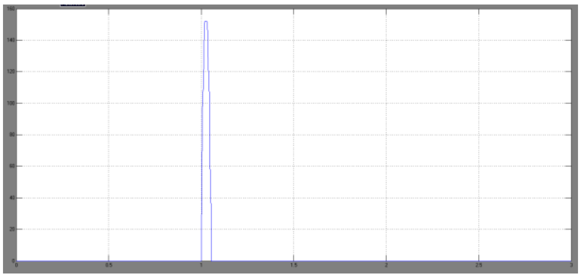
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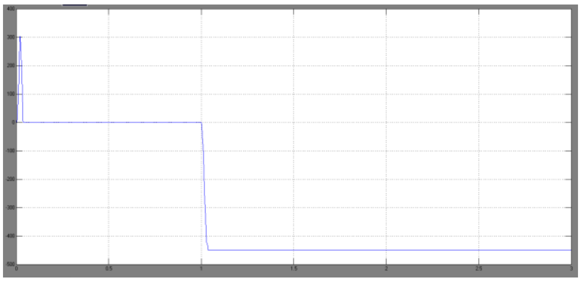
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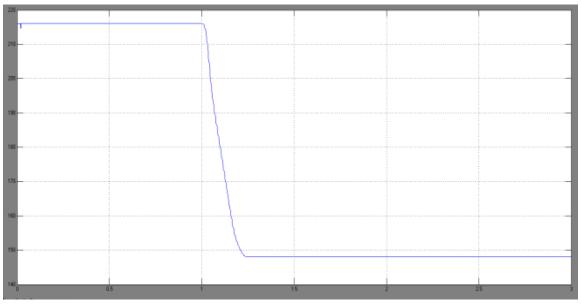
(i) NCC= 1.9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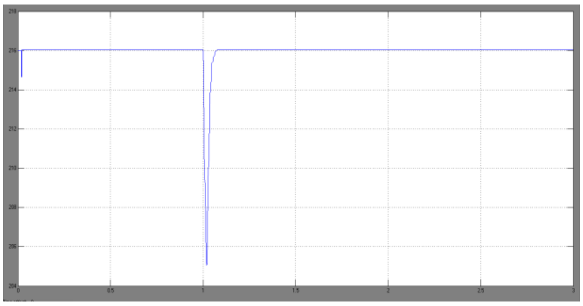
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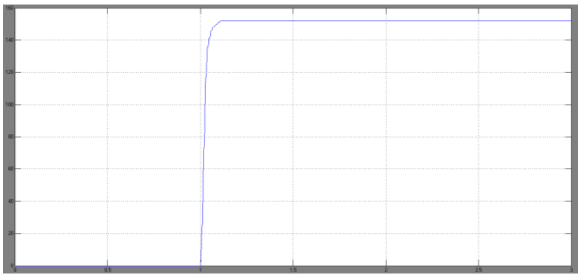
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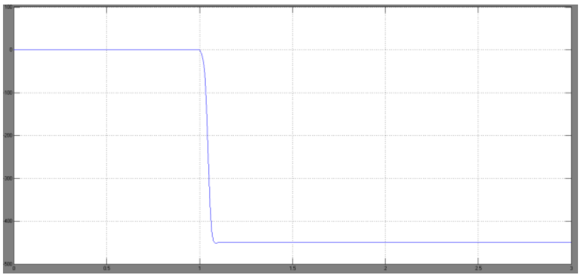
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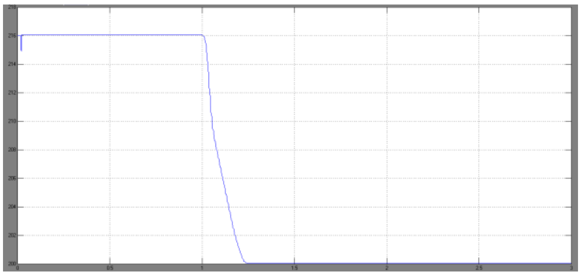
(ii) NCC=5.5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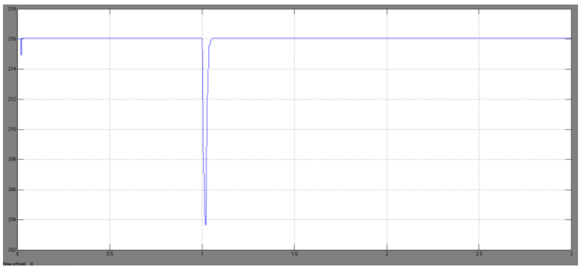
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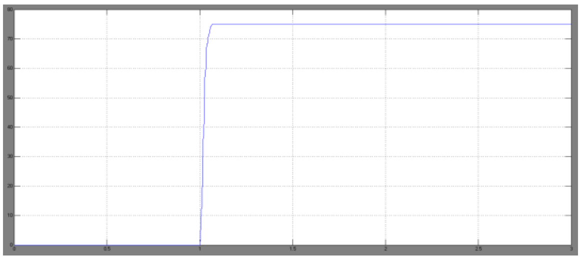

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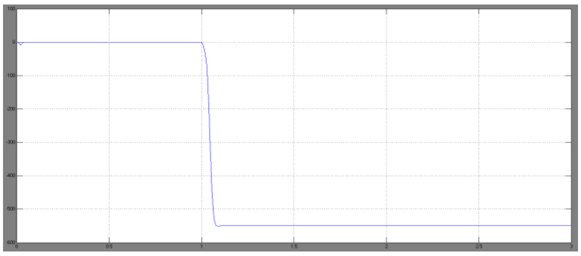


(d)

(iii) NCC=9.1

Fig. 15. System response for different distribution of noncritical and criticalloads (NC:C). Disturbance is increase in reactive power consumption of theintermittentsource from467 to 1100 VAr.(a) Noncriticalload voltage.(b) Criticalload voltage. (c) Electric spring voltage. (d) Reactive power exchange.

WITH STATCOM

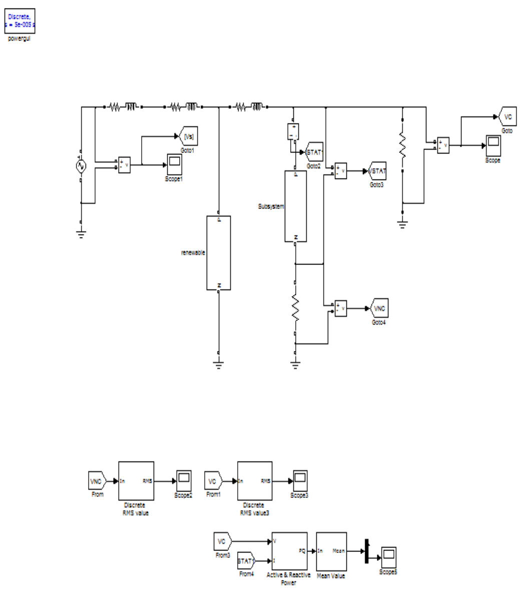
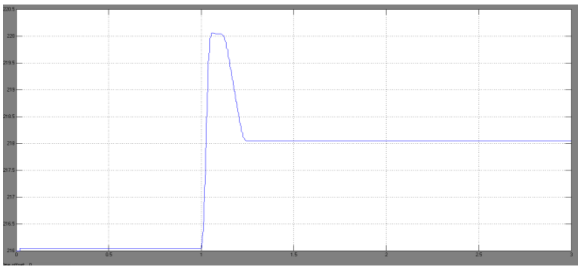
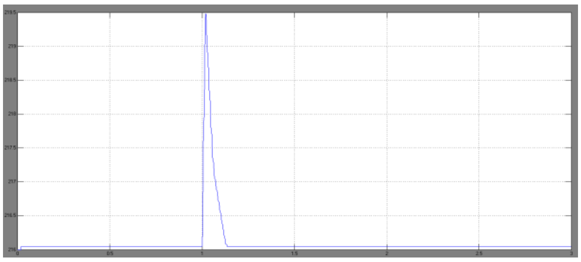


Fig.16.Matlab model of proposed system with STATCOM



(a)



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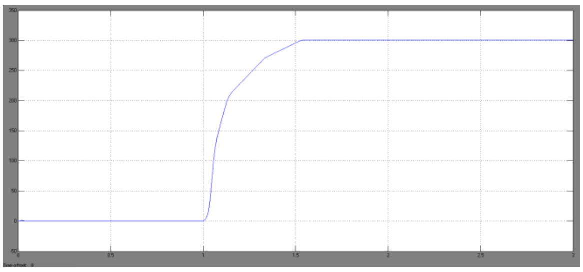
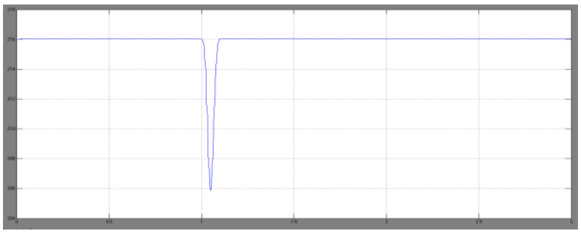


(c)

Fig. 17. System response following decrease in reactive power consumptionof the intermittent source from 467 to 110 VAr. (a) Non-critical load voltage.(b) Criticalload voltage. (c) Reactive power exchange.



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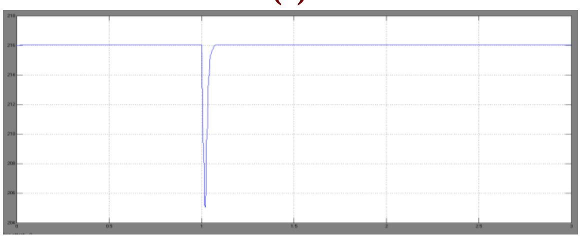

(b)

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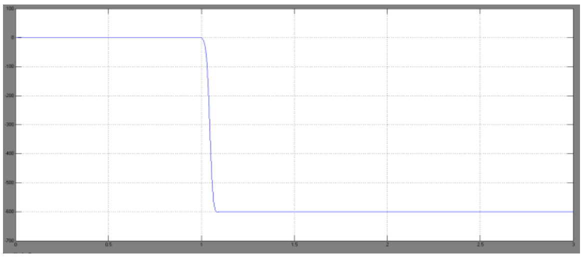


(c)

Fig. 18. System response following increase in reactive power consumptionof the intermittent source from 467 to 1100 VAr. (a) Noncritical load voltage.(b) Criticalload voltage (c) Reactive power exchange.

WITHOUT CONTROL

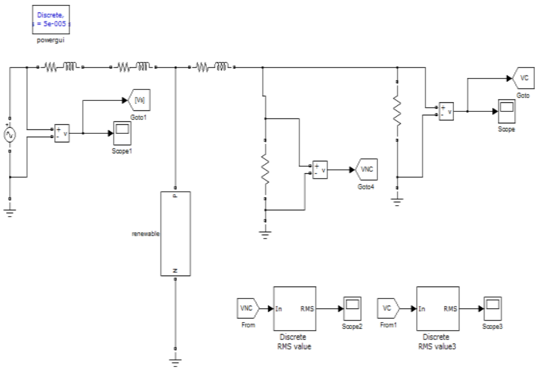
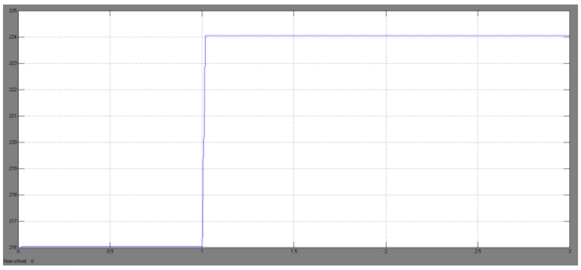
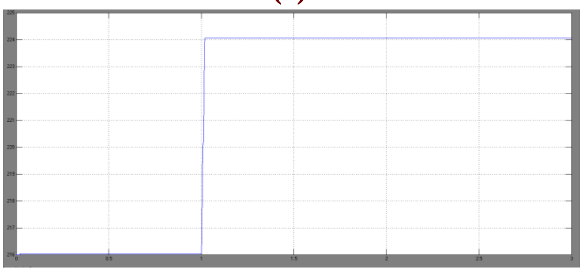


Fig.19.Matlab model of proposed system without any control

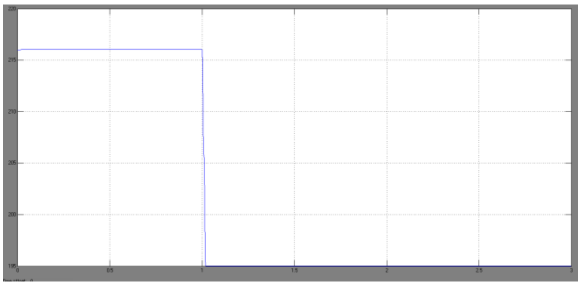


(a)

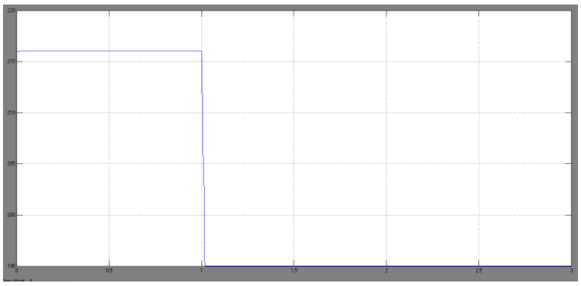


(b)

Fig. 20. System response following increase in reactive power consumptionof the intermittent source from 467 to 1100 VAr. (a) Noncritical load voltage.(b) Criticalload voltage



(a)



(b)

Fig. 21. System response for different distribution of noncritical and criticalloads (NC:C). Disturbance is increase in reactive power consumption of theintermittentsource from467 to 1100 VAr.(a) Noncriticalload voltage.(b) Criticalload voltage.

VI. CONCLUSION

In this paper a comparison is made between distributed voltage control using ES against the traditional single point control with STATCOM by using fuzzy logic controller. For a given range of supply voltage variation, the total voltage regulation and the total reactive capacity required for each option to produce the desired voltage regulation at the point of connection are compared. In this paper, it turns out that the ESs requires less overall reactive power capacity than STATCOM and yields better total voltage regulation. This makes electric springs (ESs) a promising technology for future smart grids where selective voltage regulation for sensitive loads would be necessary alongside demand side response. The

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simulation was done using MATLAB/Simulink software. The comparison was done between electric springs (ES) and static compensator (STATCOM).

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