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# Smart Load Primary Frequency Control Contribution Using Reactive Compensation

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**Abstract -** *By the growing penetration of asynchronous inverter interfaced generation (wind, solar etc.), the effective inertia of future power systems is expected to scale back drastically. These would make the primary frequency management far more difficult than what it is currently. Frequency-dependent loads inherently contribute to primary frequency response. Primary frequency control based on voltage dependent non-critical (NC) loads that may tolerate a large variation of voltage is analyzed. A smart load (SL) includes of a voltage compensator connected in series between the mains and a voltage-dependent load which may tolerate a wider variation in supply voltage. Such a load is henceforth referred to as NC load. By using a series of reactive compensators to decouple the NC load from the mains to create a SL, the voltage and hence the active power of the NC load can be controlled to control the mains frequency. The effectiveness of SL is presented by incorporating it in an IEEE 37 node test feeder.*

***Key Words***: Compensator, Demand-side management (DSM), Non – critical load (NC), Primary Frequency control, Smart load (SL), Voltage control.

## 1. INTRODUCTION

For the safe operation of power system there should be balance between generation and load. Frequency control plays important role in maintaining balance between generation and load. Frequency control maintains the frequency of power system tightly around its nominal value when demand or supply fluctuates. Three levels of frequency control (i.e. primary frequency control, secondary frequency control and tertiary frequency control) are generally used to maintain the balance between generation and load. . Three levels differ as per their time of response to a fluctuation and the methodology adopted to realize the fundamental operating philosophy of maintaining reliability and overall economy.

This paper deals with primary frequency control on demand side. Frequency control on demand side is generally done by switching off/on of loads which is known as demand side management (DSM) [1]-[3]. The loads supplied through adjustable speed drives have constant power characteristics over large voltage range. The voltage control with in allowable limits can be done based on optimization of reactive power consumption [4]-[6]. It is possible to control active power consumption by controlling supplying voltage for certain type of loads like electric heating, lighting, small motors with no stalling problems (e.g. Fans, ovens, dishwashers, and dryers). So, without interrupting such loads frequency control is done by implementing smart load (SL) configuration.

## 2. CONCEPT OF SMART LOAD

Generally the frequency control with respect to demand is done by changing speed governor, which is known as secondary control which takes 30 seconds to 15 minutes to restore the frequency. Primary frequency control gives quick restoration of the frequency which takes 0 to 30seconds after disturbance of balance between generation and demand. Thus, a smart load configuration is introduced to get quick control of frequency. A smart load consists of a voltage compensator, critical load, non-critical (NC) load and controller as shown in Fig. 1. This system can be connected at the distribution level. That is low voltage (LV)/medium voltage (MV) feeders.

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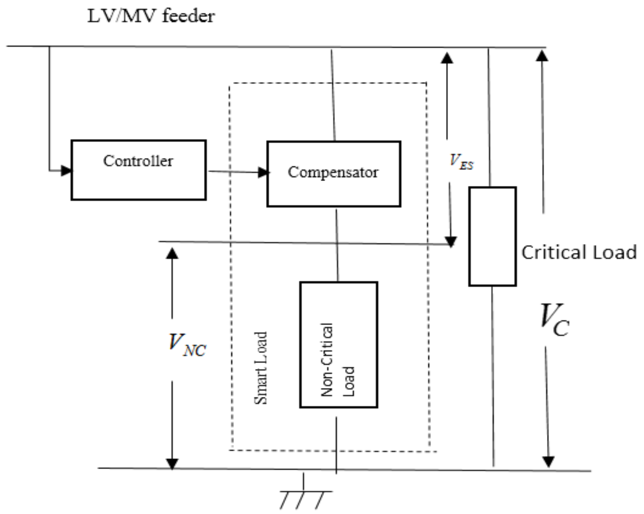
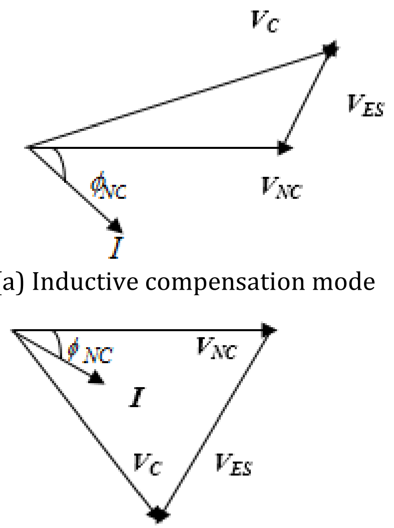



**Fig – 1**: Smart load configuration

The compensator used in smart load is a STATCOM (Static Synchronous Compensator) [7]. The effect of smart load on frequency control is explained in section 3.

## 3. MODELLING OF SMART LOAD

By controlling the compensator injected voltage ($V_{ES}$) and the voltage across the non-critical load ($V_{NC}$), power consumption of total load at the point of connection, is controlled. In this paper, the type of loads used is of resistive-inductive (R-L) nature. The compensator used here is a STATCOM which has two compensating modes i.e. capacitive and inductive compensations where the phase angle is ± 90⁰. The phasor diagrams for the smart load with the compensations are shown in Fig. 2.



(a) Inductive compensation mode

(b) Capacitive compensation mode

**Fig – 2**: Phasor diagrams of compensation modes of STATCOM

From the phasor diagrams, the relation between compensator voltage, non-critical load voltage and mains voltage can be expressed as Eq. 1

$$V_C \angle \theta_C = V_{NC} \angle \phi_{NC} \pm V_{ES} \angle \theta_{ES} \qquad \text{Eq. 1}$$

The positive and negative corresponds inductive and capacitive modes respectively. Since one can need to provide voltage support from the compensator, $V_{ES}$ in terms of mains current and voltage is expressed as Eq. 2 and Eq. 3 for inductive and capacitive compensation modes respectively.

$$\left. \begin{aligned} V_{ES} &= -IZ_{NC} \sin \phi_{NC} \pm \sqrt{V_C^2 - (IZ_{NC} \cos \phi_{NC})} \\ &= -F(I, V_C) \end{aligned} \right\} \qquad \text{Eq. 2}$$

$$\left. \begin{aligned} V_{ES} &= +IZ_{NC} \sin \phi_{NC} \pm \sqrt{V_C^2 - (IZ_{NC} \cos \phi_{NC})} \\ &= +F(I, V_C) \end{aligned} \right\} \qquad \text{Eq. 3}$$

Compensation modes used depending upon the change in frequency. Frequency is directly related with active power consumption. The capacitive compensation ($\theta_{ES} = -90$) reduces active power consumption of smart load $P_{SL}$ while inductive compensation increases $P_{SL}$. The control architecture of compensator connected in smart load is as shown in Fig. 3.

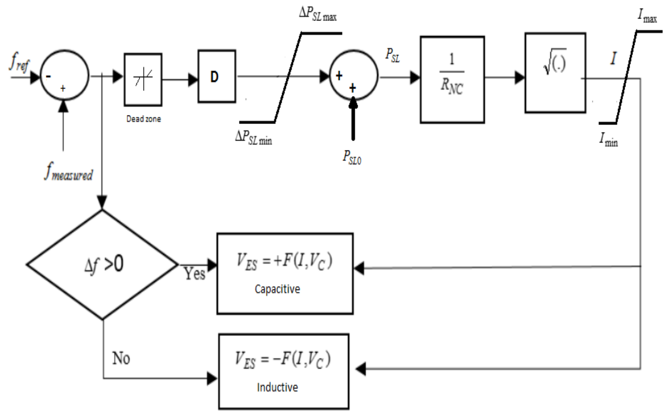



**Fig – 3**: Control architecture of smart load

The reference frequency ($f_{ref}$) and measured frequency ($f_m$) are compared. The change in frequency ($\Delta f$) is sent through dead band (± 0.01). According to the change in frequency, compensation modes are applied. To give appropriate compensation modes, current $I$ and voltage of compensator ($V_{ES}$) are required. A change in power of smart load ($\Delta P_{SL}$) is obtained by sending $\Delta f$ into droop gain (0.215/$P_{SL}$). $\Delta P_{SL}$ is limited between $\Delta P_{SL\max}$ expressed in Eq. 4 and $\Delta P_{SL\min}$ expressed in Eq. 5 [8].

$$\Delta P_{SL\,\max} = \frac{V_C^2 \sin\phi_{NC} \tan\phi_{NC}}{Z_{NC}} \qquad \text{Eq. 4}$$

$$\Delta P_{SL\,\min} = -\frac{V_C^2 \cos\phi_{NC}}{Z_{NC}} \qquad \text{Eq. 5}$$

The change in power is added with nominal smart load power ($P_{SL0}$) to get the total power of smart load. The maximum and minimum currents can be obtained by Eq. 6 and Eq. 7 respectively as shown in Fig. 3.

$$I_{\max} = \frac{V_{NC\,\max}}{Z_{NC}} \qquad \text{Eq. 6}$$

$$I_{\min} = \frac{V_{NC\,\min}}{Z_{NC}} \qquad \text{Eq. 7}$$

The current and compensator voltage ($V_{ES}$) are compared to give particular type of compensation.

## 4. SIMULATION AND RESULTS

The practical evaluation of smart load is evaluated by incorporating it in an IEEE 37 node test feeder. This feeder is an actual feeder in California, with a 4.8 kV operating voltage. It is characterized by delta configured, all line segments are underground, substation voltage regulation is two single-phase open-delta regulators, spot loads, and very unbalanced. This circuit configuration is fairly uncommon. Simulation of the IEEE 37 node test feeder with smart load is done in MATLAB (Matrix Laboratory)/Simulink platform. The equivalent single line diagram of the total system is shown in Fig. 4.

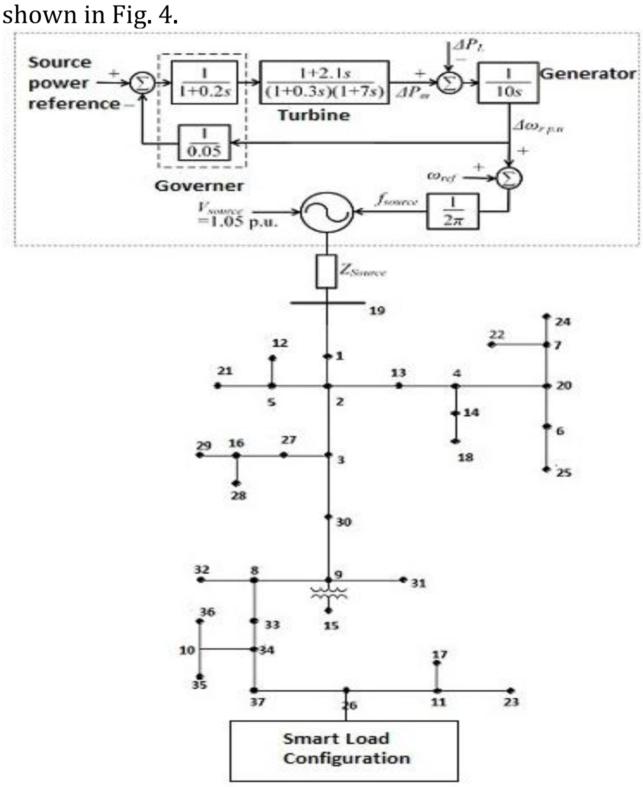



**Fig – 4**: Single line diagram of IEEE 37 node test feeder

The capacitive and inductive modes given in Fig. 3 are modelled in Simulink platform are shown in Fig. 5 and Fig. 6 respectively. When change in frequency ( $\Delta f$ ) is greater than zero then capacitive compensation mode is applied. Inductive compensation is applied change in frequency ( $\Delta f$ ) is less than zero.

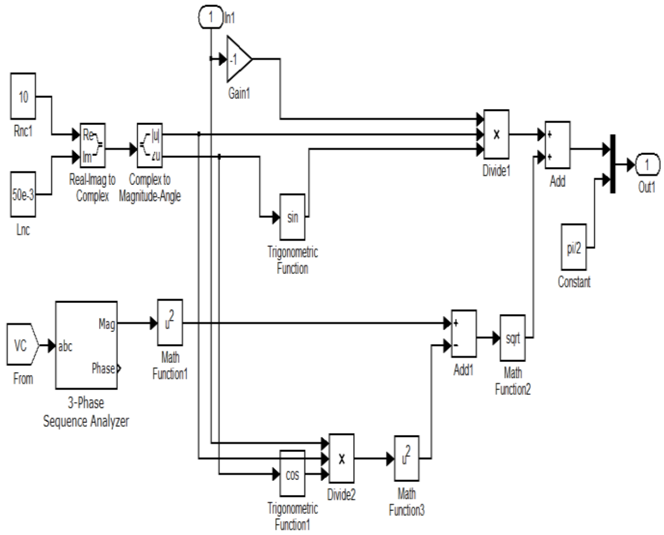



**Fig – 5:** Simulink model of capacitive compensation mode

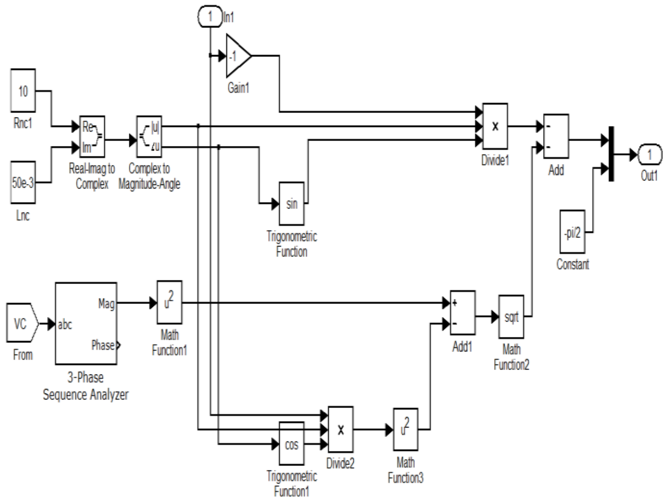



**Fig – 6**: Simulink model of inductive compensation mode

Simulation is done for both increasing and decreasing frequencies. IEEE 37 node test feeder data is taken for the simulation of distribution network [9]. Results for both decreasing and increasing frequencies are presented in section 4.1 and 4.2 respectively.

### 4.1 Results for Frequency Decreasing Mode

The system frequency decreases demand is greater than generation. Primary frequency control is faster control which re-establish a balance between generation and demand within the synchronous area at a frequency different from the nominal value within 0 to 30 sec after disturbance of the balance between generation and demand. By using smart load instead of normal load, the frequency deviation is less which is shown in Fig. 7.

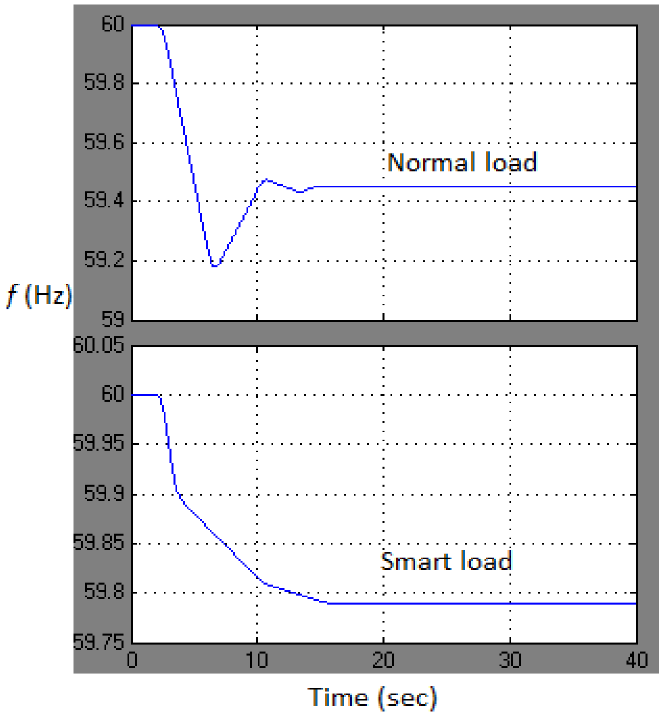



**Fig – 7**: Supply frequency variation

Supply voltage and active power variations at the mains for normal and smart load are shown in Fig. 8 and Fig. 9 respectively.

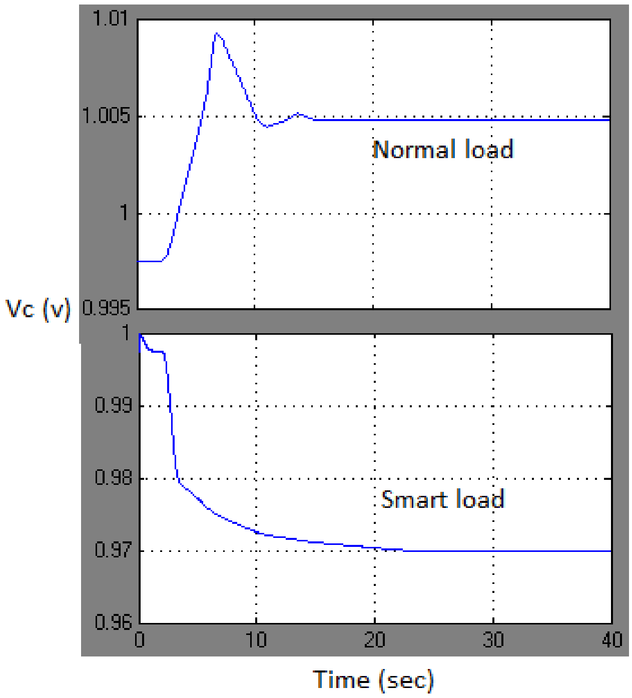



**Fig – 8**: Supply voltage variation

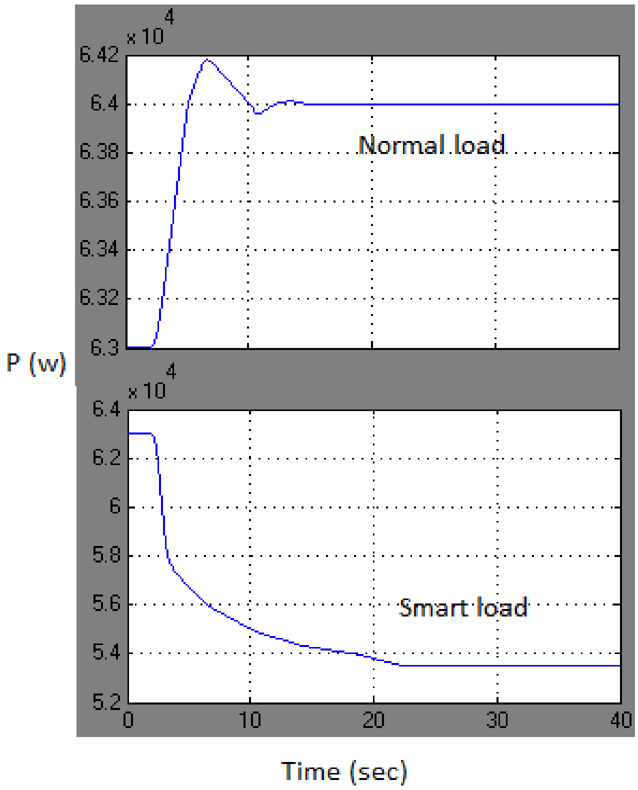



**Fig – 9**: Active power variation

### 4.2 Results for frequency increasing mode

The system frequency increases when demand is less than generation. Supply frequency variation of normal load and smart load for increasing mode is shown in Fig. 10.

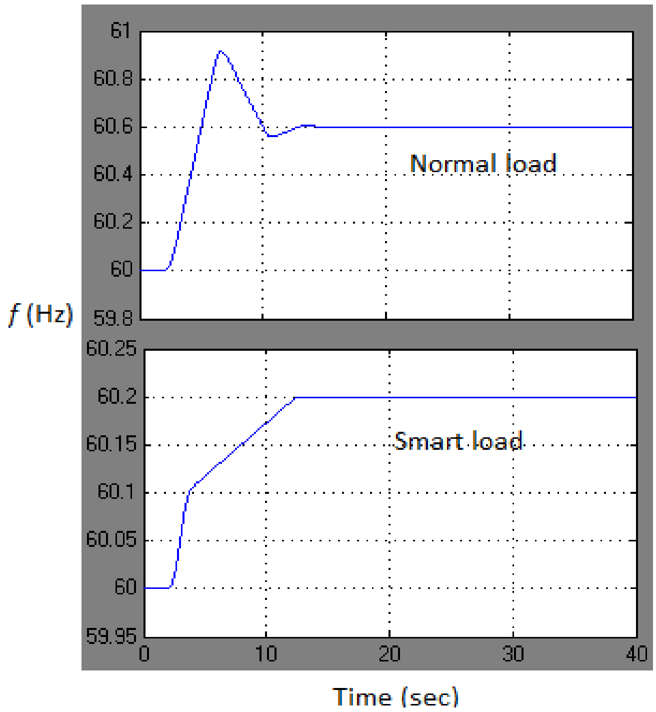



**Fig -10**: Supply frequency variation

Supply voltage and active power variations at the mains for normal load and smart load are shown in Fig. 11 and Fig. 12 respectively.

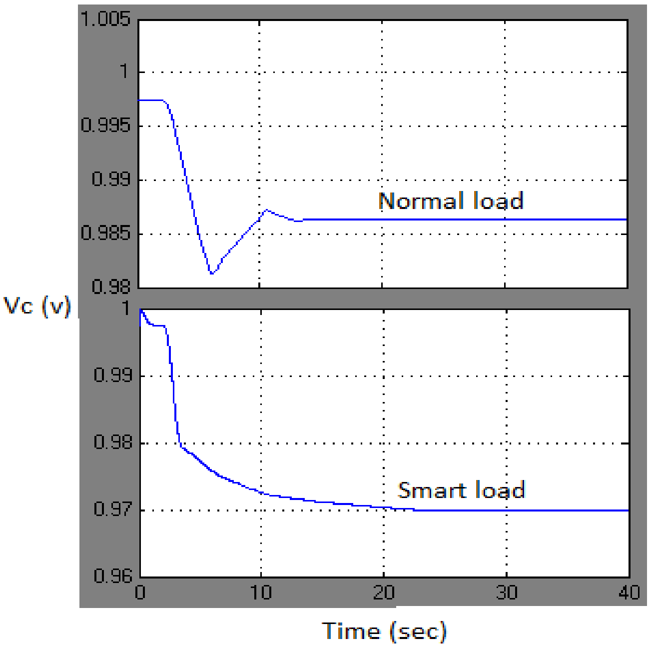



**Fig -11**: Supply voltage variation

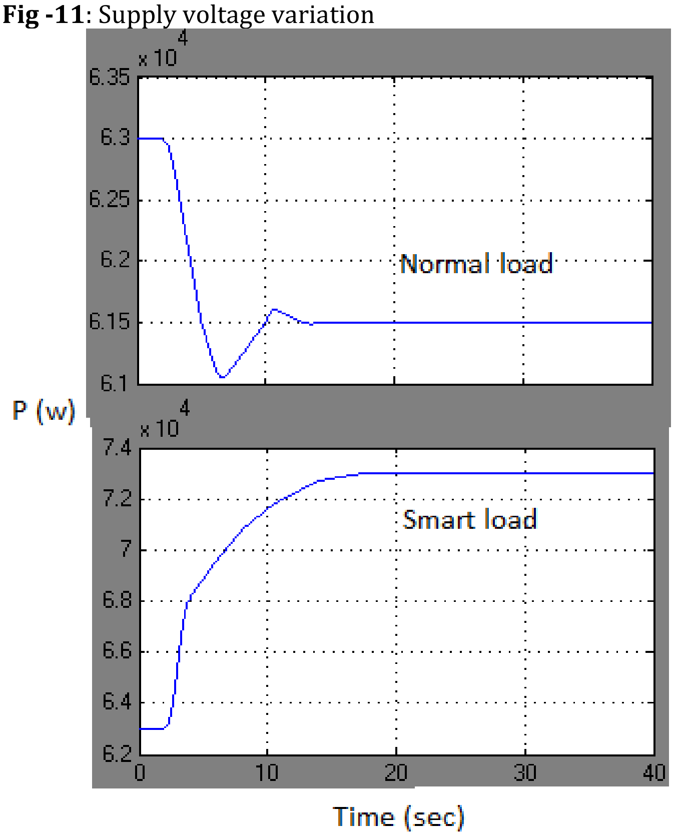



**Fig – 12**: Active power variation

The frequency of normal load is decreased below 59.5 Hz which is shown in Fig. 7. By introducing smart load, frequency is brought back to 59.79 Hz. By using smart load configuration, the frequency is brings back to 60.2 Hz from 60.6 Hz which is shown in Fig. 10.

## 5. CONCLUSION

Frequency control in a power system is an important aspect for safe operation of power system. Frequency control can be done at both generation and load side. Generation side frequency control takes longer time i.e. 30 seconds to 15 minutes. In order to support the frequency in short time, demand side control is chosen i.e. primary frequency control. Demand side control (DSM) is generally used for frequency control on load side, but some loads with constant power characteristics cannot be disturbed. In this paper smart load concept is used to control load power consumption through voltage variation using shunt reactive compensation device like STATCOM. The effect of smart load on frequency regulation of mains is evaluated by simulating IEEE 37 node test feeder using MATLAB/Simulink. The results shows that the frequency variation is less for both capacitive as well as inductive compensation using smart load configuration compared to a normal load.

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