



A COORDINATED V2G CONTROL FOR LFC OF MULTI AREA POWER SYSTEM WITH HVDC LINK IN DEREGULATED ENVIRONMENT

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Abstract

This paper presents a robust coordinated V2G control strategy with FOPI (Fractional Order PI) controller for frequency control of multi area power system in deregulated environment. EVs are integrated in each control area to reduce frequency deviation of each control area. The penetration of EVs (V2G Control) supplying power during peak loads to reduce low frequency oscillations. The control action of the controller shall take care of high frequency oscillations by tuning the gains of FOPI controller. Simulations are performed using Matlab-simulink by simulating two control areas with V2G penetration by considering bilateral transitions. The penetrations of V2G with FOPI in two control areas are demonstrated with simulation result.

Key Words: Electical vehicle, State of Charge, Load frequency control, Fractional order controller, Deregulated power system

1 INTRODUCTION

In power system, due to change of load on system causes frequency deviation, this problem called Load Frequency Control (LFC) problem [1]. This frequency deviation causes the saturation of power system transformers and damages of turbine blades. These deviations are caused when the load demand on the consumer side is more than the generation side. The primary LFC loop is not much effective to control the frequency [1]. The secondary frequency control loop via LFC controller is necessary for frequency stabilization. The design of load frequency controller is not complex for integrated conventional power system. In a Deregulated Power System (DPS) there are multiple power distributors for the consumers [3, 4]. The entire system is monitored by Independent system operator (ISO) this will ensure the contacted powers and their regulation to the particular power distributors (DISCOS). Since the system contains a cluster of distributor it is important to ensure the power system stabilities at regular intervals. In deregulated environment design of load frequency controller is more complex due to rapidly varying load demands on DISCOMs. EVs are integrated in each Control Area (CA) with hydro-thermal generation in DPS [3, 4]. As the modern technologies are bringing revolutionary changes to the transport system the Electrical Vehicles (EVs) are used extensively because of low-cost charging, environmental friendly and zero tail gas emission. These cars have been using extensively by the consumers as per the latest reports released by the International Energy Agency [15]. There were more than two-millions EVs on road around the world in 2016 [16]. This numbers are growing rapidly by upcoming technologies in manufacturing the batteries to make these vehicles run for long distance and charge quickly [16]. The new reforms taken by many cars manufacturing companies are starting to produce more number of electric cars per year. Also in china it is approximated that by 2050 there will be 200 million Electrical Vehicles on the road [17]. These EVs are charged during the night at which the power prices are low. Therefore when

these vehicles are fully charged their power can be transferred to the power grid through the charging station by the technique known as V2G(Vehicle to Grid) to compensate the power imbalances during the load frequency deviations[18].

The V2G control is based on average battery SOC deviation control to compensate the LFC problems of power system. This V2G technique ensures the two-way of charging vehicle from the grid and discharging the power from V2G. In normal scenario the vehicle is used for small interval of time on an average of 30 km and they are plugged in to the charging stations at remaining times. This shows us that most of the time these vehicles are plugged in to stations that are available in offices or at home outlets. These charging stations provide us with the V2G control over the charging and discharging of the vehicles. As the technologies in battery are improved the time taken for charging is decreased [19]. There will be a lot of time for the vehicles to stay plugged in the stations these will charge the vehicles smartly depending upon the SOC for the battery of electrical vehicle [20]. In this way charging station ensures vehicles to be charged at maximum level before usage. The electrical vehicle pumping power to the grid through the V2G technique. In this paper first time EVs are integrated in deregulated environment to achieve the objective of LFC [21].

2 System Modeling for LFC

Each CA consisting of two DISCOMs. The transactions made by the GENCOs with DISCOMs is called bilateral transactions. This is represented by DPM matrix [5-7]. As a result, total of entries of column belongs to DISCOs of DPM is. The corresponding DPM to the considered power system having three areas and each of them including two DISCOs and two GENCOs is given as follows[7-8].

$$DPM = \begin{bmatrix} cpf11 & cpf12 & cpf13 & cpf14 \\ cpf21 & cpf22 & cpf23 & cpf24 \\ cpf31 & cpf32 & cpf33 & cpf34 \\ cpf41 & cpf42 & cpf43 & cpf44 \end{bmatrix}$$

3 V2G control scheme

The frequency deviations are caused by the difference in the power generated and power demanded by the load. This causes to the frequency fluctuations in power grid [15]. In order to supply the battery power to the grid from all of these vehicles there should be a relevant parameter that decides the amount of power to given for the power system, here the V2G output can be controlled by the droop characteristics against the frequency deviations (Δf) as

$$P_{V2G} = \begin{cases} K_{V2G} \Delta f & (|K_{V2G} \Delta f| \leq P_{max}) \\ P_{max} & (P_{max} < |K_{V2G} \Delta f|) \end{cases}$$

The power that can be given from a car battery to the grid is determined by V2G gain and the frequency deviations present in the system. K_{V2G} is V2G gain tuned by considering the V2G effect and the battery SOC. The State of charge of the vehicle battery is called SOC (State of charge). When the vehicle is plugged into the charging station for a long time the charging of the vehicles take places in a smart way by charging the vehicle initially through considering the SOC of the vehicle. Most of the vehicles are charged at higher SOC then the battery starts to supply its energy to grid until it reaches the low SOC. When the Battery reaches the low SOC the charging station starts to charge the vehicle. In this way a cycle of discharging and charging takes places. battery present inside these vehicles also compensates the inductive load present on the system during the fluctuation period[15].

Where P_{max} is determined by the maximum amount of power that can be drawn from car battery. It can be given by considering that the parameters of the plug-in station are 200V and 25 Amps. By the following In view of these considerations of the stations a total of 5000W or 5KW power can be drawn from a car battery. Then the K_{V2G} can be computed by

$$K_{V2G} = K_{max} \left[- \left(\frac{SOC - SOC_{low(high)}}{SOC_{max(min)} - SOC_{low(high)}} \right)^n \right]$$

Where SOC_{low} , SOC_{min} , SOC_{high} , SOC_{max} , n are the low battery SOC, minimum battery SOC, high batter SOC, maximum battery

SOC and design parameter respectively. Where as K_{max} is the maximum V2G gain. The battery is maintained around 50% as shown in fig.1.

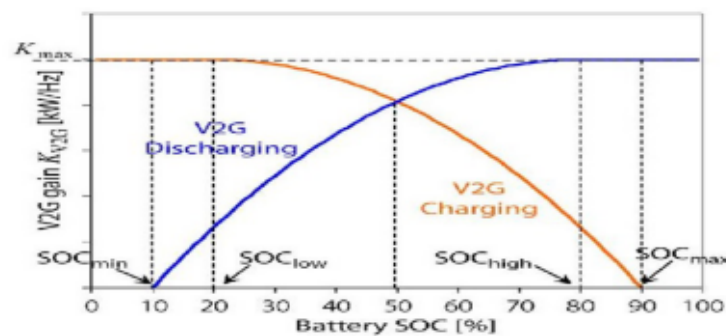


Fig.1 State Of Charge control of Battery

The mathematical model of the Electric Vehicle (EV) is shown in fig.2.

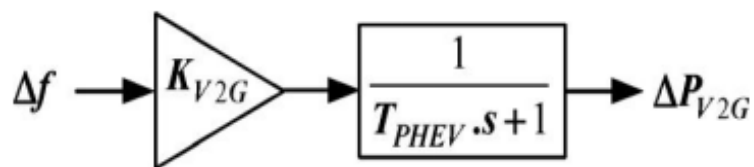


Fig.2 Block model of V2G

4 FRACTIONAL-ORDER PI CONTROLLER

The concept of fractional order controllers deals with differential equations using fractional order calculus. The fractional calculus is nothing but the generalization of the ordinary calculus [22, 23]. The commonly used definition for the fractional differ-integral is given by Riemann-Liouville (R-L) definition. The R-L definition for fractional derivative is given by

$${}_a^D{}^\alpha f(t) = \frac{1}{\Gamma(n-\alpha)} \frac{d^n}{dt^n} \int_a^t (t-\tau)^{n-\alpha-1} f(\tau) d\tau \quad (1)$$

Where $n - 1 \leq \alpha < n$, is an integer and $\Gamma(.)$ is the Euler's gamma function.

The R-L definition for fractional integral is given by below equation

$${}_a^D f(t) = \frac{1}{\Gamma(\alpha)} \int_a^t (t-\tau)^{\alpha-1} f(\tau) d\tau \quad (2)$$

Where D^α is fractional operator. The Laplace transformation of Riemann-Liouville definition (1) for fractional derivative is given by equation (3).

$$L {}_a^D f(t) = s^\alpha F(s) - \sum_{k=0}^{n-1} s^k {}_a^{D^{\alpha-k-1}} f(t) \quad (3)$$

For $n - 1 \leq \alpha, n$ where $Lf(t)$ indicates the normal Laplace transformation. This means that when zero initial conditions are assumed, the system with dynamic behavior described by differential equations including fractional derivatives give rise to transfer function with fractional order of s.

The fractional derivatives or integers D^α can be approximated by well-known transfer function proposed by Oustaloup in the pre-specified frequency range using a recursive distribution of poles and zeros is given by equation (4)

$$s^\alpha = K \prod_{n=1}^n \frac{1+s/\omega_{z,n}}{1+s/\omega_{p,n}} \quad (4)$$

K is an adjusted gain so that if $K=1$ then the given is zero db for a 1 rad/sec frequency. The number of poles and zeros N is chosen in advance: low value resulting in simpler approximation but causes ripple in both gain and phase behavior. Such ripples can be removed by increasing the values of N but it will make approximation complex [24]. Frequencies of poles and zeros are given by equation (5)

$$\omega_{z,l} = \omega_t \sqrt{n} \quad (5)$$

$$\omega_{p,n} = \omega_{z,n} \varepsilon, \quad n = 1 \dots N \quad (6)$$

$$\omega_{z,n+1} = \omega_{p,n} \sqrt{n} \quad n = 1, \dots, N-1 \quad (7)$$

$$\varepsilon = \omega_h / \omega_l^{V/N} \quad (8)$$

$$n = \omega_n / \omega_l^{1-V/N} \quad (9)$$

The most common form of FOPI is the PI^λ where λ is the non-integer order of integrator and can be any real number. The transfer function has the form given by (10)

$$G(s) = Kp + \left(\frac{Ki}{s^\lambda} \right) \quad (10)$$

If λ , then classical PI is obtained. The differential equation of fractional order PI controller is described in equation (11)

$$u(t) = Kp e(t) + Ki D^{-\lambda} e(t) \quad (11)$$

The main advantage associated with FOPI controller is its extra tuning parameter than FOPI that provides more flexibility in achieving control objectives, thus the PI^λ controller is less sensitive to the changes of parameter of a controller system. The merits of fractional order controllers have gained popularity in various fields of design and control.

In order to create a fractional order function there is Filter Approximation to Fractional Order Differentiations. In this two types of filters we can use

- Oustaloups Recursive Filter.
- A Refined Oustaloup Filter.

A. Refined Oustaloup Filter

A new approximate realization method for the fractional-order derivative in the frequency range of interest $[\omega_b, \omega_h]$ Our proposed method

here gives a better approximation than Oustaloups method with respect to both low frequency and high frequency [24,25]. Assume that the frequency range to be fit is defined as $(\omega b, \omega h)$. Within the prespecified frequency range, the fractional-order operator can be D^α approximated by the fractional-order transfer function as

$$K(s) = \left(\frac{1 + \frac{bs}{d\omega_b}}{1 + \frac{ds}{b\omega_h}} \right)^\alpha$$

Where $0 < \alpha < 1$, $s = j\omega$, $b > 0$, $d > 0$, and

$$K(s) = \left(\frac{bs}{d\omega_b} \right)^\alpha \left(1 + \frac{-ds^2 + d}{ds^2 + b\omega_h s} \right)^\alpha$$

In the frequency range $\omega b < \omega < \omega h$, by using a Taylor series expansion, we obtain and

$$p(s) = \frac{-ds^2 + d}{ds^2 + b\omega_h s}$$

It is then found that

$$s^\alpha = \frac{(d\omega_b)^\alpha b^{-\alpha}}{\left[1 + \alpha p(s) + \frac{\alpha(\alpha-1)}{2} p^2(s) + \dots \right]} \left(\frac{1 + \frac{bs}{d\omega_b}}{1 + \frac{ds}{b\omega_h}} \right)^\alpha$$

Truncating the Taylor series to 1 leads to

$$s^\alpha \approx \frac{(d\omega_b)^\alpha}{b^\alpha (1 + \alpha p(s))} \left(\frac{1 + \frac{bs}{d\omega_b}}{1 + \frac{ds}{b\omega_h}} \right)^\alpha$$

Thus, the fractional-order differentiator is defined as

$$s^\alpha \approx \frac{(d\omega_b)^\alpha}{b^\alpha(1+\alpha p(s))} \left(\frac{1+\frac{bs}{d\omega_b}}{1+\frac{ds}{b\omega_h}} \right)^\alpha \quad (12)$$

Expression (12) is stable if and only if all the poles are on the left-hand side of the complex s-plane. It is easy to check that expression (12) has three poles:

- One of the poles is located at which is a negative real pole since $\omega_b, \omega_h, d > 0$;
- The two other poles are the roots of the equation

$$d(1-\alpha)s^2 + a\omega_h s + d\alpha = 0$$

Whose real parts are negative since $0 < \alpha < 1$. Thus, all the poles of (12) are stable within the frequency range (ω_b, ω_h) . The irrational fractional-order part of expression (12) can be approximated by the continuous-time rational model.

$$k(s) = \lim_{n \rightarrow \infty} \prod_{K=-N}^N \frac{1 + s/\omega'_K}{1 + s/\omega_K}$$

According to the recursive distribution of real zeros and poles, the zero and pole of rank k can be written

$$K(s) = \left(\frac{bs}{d\omega_b} \right)^\alpha \left(1 + \alpha p(s) \frac{\alpha(\alpha-1)}{2} p^2(s) + \dots \right)$$

as

$$\omega'_K = \left(\frac{d\omega_b}{b} \right)^{\frac{\alpha-2k}{2N+1}}, \quad \omega_b = \left(\frac{b\omega_h}{d} \right)^{\frac{\alpha+2k}{2N+1}}$$

Thus, the continuous rational transfer function model can be obtained as

$$s^\alpha \approx \left(\frac{d\omega_h}{b} \right)^\alpha \left(\frac{ds^2 + b\omega_h s}{d(1-\alpha)s^2 + b\omega_h s + d\alpha} \right) \prod_{k=-N}^N \frac{s + \omega'_k}{s + \omega_k}$$

Through conformation by experimentation and theoretical analysis, the synthesis approximation can obtain the good effect when

$b = 10$ and $d = 9$. Through the approximation method, the fractional-order system may be approximated as the very high integer-order system. The block diagram of a two-area deregulated hydro-thermal system with plug-in EV's are shown in fig.3

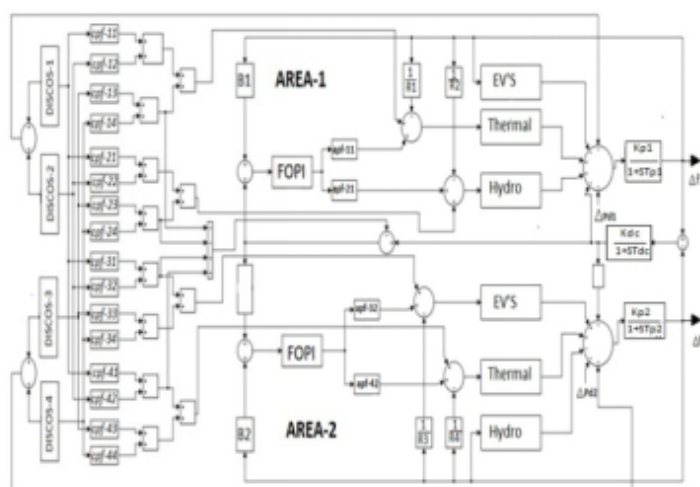


Fig.3 Two-area hydro-thermal power system with HVDC link with EV's

SIMULATION RESULTS:

The frequency deviations that caused by the power imbalances are minimized by introducing new power input to system by the use of a battery powered vehicle. This power will be taken from Electric vehicles by V2G control method by considering the SOC of the battery of the Electrical vehicle. The amount of power drawn from EV's through a charging station is completely depending upon the current SOC of the batter. When the power demand is reduced by the EV's remaining LFC is done by the FOPI controller. The simulation results are displayed when N numbers of cars are used to supply power and K_p , K_i , are the proportional, integrator and lambda parameters of the FOPI (Fractional order PI) controller.

The contract scenario of the deregulated system is considered as the following matrix.

$$\begin{bmatrix} 0.5 & 0.3 & 0.1 & 0.3 \\ 0.1 & 0.2 & 0.6 & 0.2 \\ 0.4 & 0 & 0.2 & 0.1 \\ 0 & 0.5 & 0.1 & 0.4 \end{bmatrix}$$

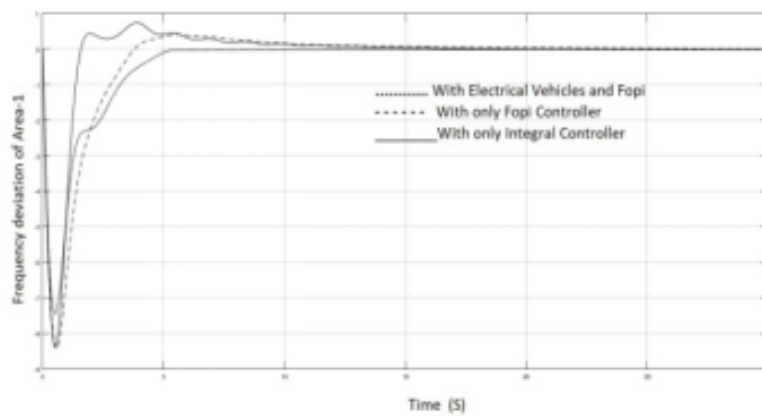


Fig.4 Shows Frequency response of CA-1 with FOPI and EVs compared to FOPI and I controller without EVs

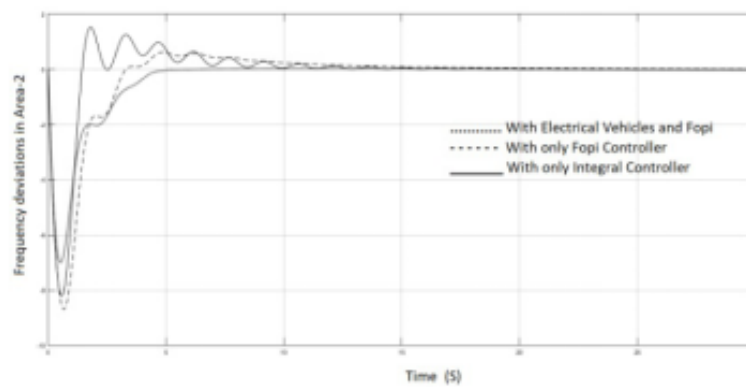


Fig.5 Shows Frequency response of CA-2 with FOPI and EVs compared to FOPI and I controller without EVs

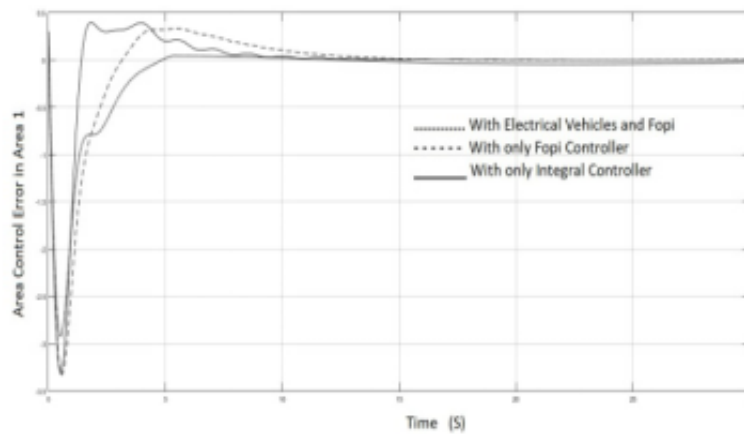


Fig.6 Shows Area Control Error(ACE)of CA-1 with FOPI and EVs compared to FOPI and I controller without EVs

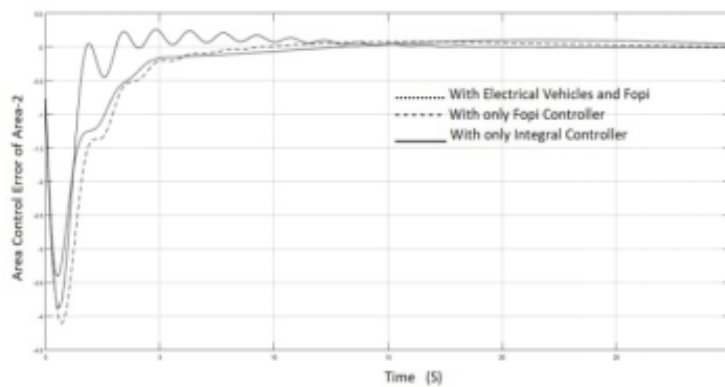


Fig.7 Shows Area Control Error(ACE)of CA-2 with FOPI and EVs compared to FOPI and I controller without EVs

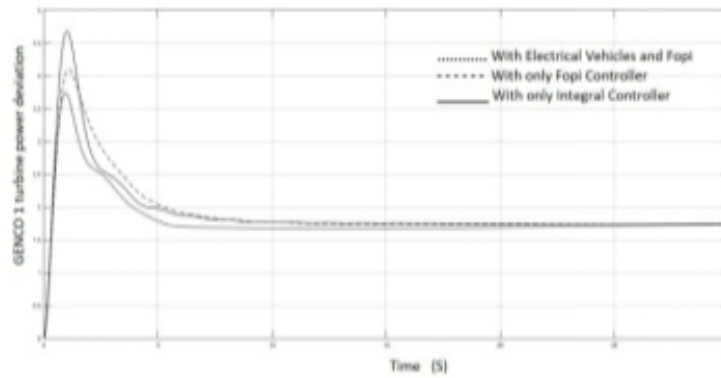


Fig.8 Shows Power Output of GENCO-1 of CA-1 with FOPI and EVs compared to FOPI and I controller without EVs

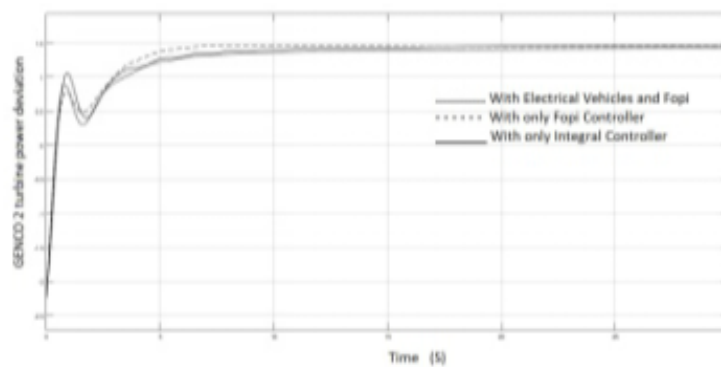


Fig.9 Shows Power Output of GENCO-2 of CA-1 with FOPI and EVs compared to FOPI and I controller without EVs

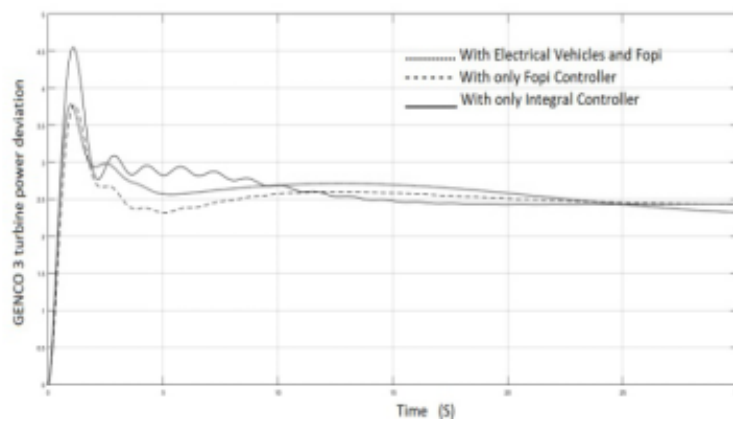


Fig.10 Shows Power Output of GENCO-3 of CA-2 with FOPI, EVs compared to FOPI and I controller without EVs

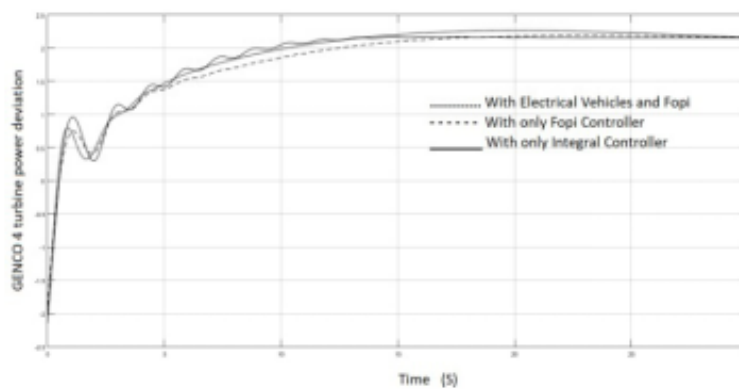


Fig.11 Shows Power Output of GENCO-4 of CA-2 with FOPI, EVs compared to FOPI and I controller without EVs

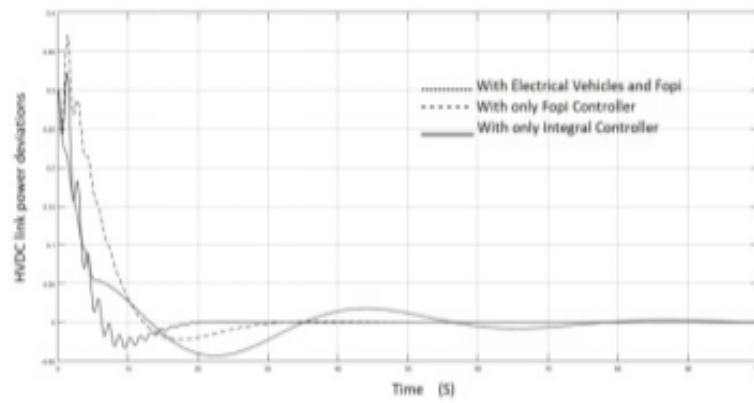


Fig.12 Shows Power Output of GENCO-4 of CA-2 with FOPI, EVs compared to FOPI and I controller without EVs.

5 Appendix

The power system parameter are given in table 1, 2 and 3

Table 1: GENCO parameters for Thermal plant

GENCO parameters	AREA-1		AREA-2	
	GENCO 1	GENCO 2	GENCO 3	GENCO 4
$T_T(S)$	0.32	0.30	0.33	0.32
$T_C(S)$	0.06	0.08	0.06	0.07
$R(HZ\ pu)$	2.4	2.5	2.5	2.7

Table 2: Control Area parameters

Control Area Parameters	Area-1	Area-2
$K_p(\text{pu/Hz})$	102	102
$T_p(\text{S})$	20	20
$B(\text{pu/Hz})$	0.425	0.396

The V2G control parameters of the system is given below

Table 3: V2G parameters

Parameters	Area 1	Area 2
Max V2G power ($P_{\max}$) (kW)	5	5
Max V2G gain ($K_{\max}$) (kW/Hz)	200	200
n , $\text{SOC}_{\min}$, SOC_{low} , SOC_{high} , $\text{SOC}_{\max}$ (%)	2,10,20,80,90	
Delay time (T_{ev}) (s)	0.05	0.05
Number of EV's	60000	60000

6 CONCLUSION

In this proposed work two CAs modeled in deregulated environment and connected with HVDC link, integrated with EVs(V2G control) in each control area (CA) to reduce frequency deviations. A new coordinated control strategy proposed to address LFC by considering bilateral transactions. This scenario simulated and tested using MATLAB simulink for one possible contract scenario. The coordinated control strategy of EVs ((V2G control) with FOPI reduces frequency deviation of each control area effectively compared to FOPI and conventional integral controller

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