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Application of Capacitive Energy Storage Unit for Automatic Generation Control of Two Area Two Unit Power System

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Abstract: This paper is about the application of Capacitive Energy Storage unit (CES) to two area two unit powersystem to improve dynamic performance of automatic generation control. Simulation is done without CES, with CES unit by taking frequency error as control input and with CES unit by taking Area Control Error (ACE) as Control input. Simulation studies show that CES units are capable of reducing the settling time of the responses. Simulation study also reveals that the dynamic responses with frequency deviations as feedback to CES are better than that obtained with ACE as feedback to CES unit and far superior than that without CES units.

Index Terms: Automatic generation control, capacitive energy storage, Area control error, generation rate Constraint, Area participation factor, Power Conversion System, a super capacitor or a cryogenic hyper capacitor

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INTRODUCTION

Electric power consumption is highly dynamic, changes randomly at every instant. Hence electric power generation must match with consumption at every instant to maintain the system in its nominal state. Nominal state is characterized by nominal frequency, voltage profile, and load flow configuration. But 100% equilibrium can't be met, in reality there is always generation-consumption mismatch. This mismatch causes a deviation of system frequency and tie line power from their scheduled values. To make the deviations to zero utilities prefer integral or proportional integral controllers in their system. How fast the deviations can be brought to zero is the point of concern.

Some of the energy storage devices are designed to meet these needs are fly wheels, battery storage, compressed air, pumped hydro, fuel cells, superconducting magnetic energy storage (SMES), etc. Most of these technologies store electrical energy in other forms in addition to their own inherent disadvantages pointed out by [1]-[2]. Reference [3] has shown that the relative merits of Capacitive Energy Storage (CES) which outweigh Superconducting Magnetic Energy Storage (SMES).

The main objectives of present work are modeling of CES and its control logic, compare the dynamic responses of frequency deviations, tie line power deviation, and change in generated power without and with CES units in two unit two area two unit power system.

Two Area Two Unit Power Systems:

When the system is exposed to small change in load during its operation, a liberalized model is used to represent the system. Block diagram model of the two area power system is as shown in Fig.1. Area 1 consists of two reheat units and area 2 consists of two non-reheat units. A limit is present to the rate at which the output power of steam turbines can be changed because of the thermodynamic and mechanical constraints. This limit is known as Generation Rate Constraint (GRC). Now for this network, a GRC of 3% per min. for reheat units and 10% per min for non reheat units is considered for each unit in areas 1 and 2 respectively as in [4].The ACE participation factors in area 1 are apf_{11} and apf_{12} and the ACE participation factors in area 2 are apf_{21} and apf_{22}. Note that $apf_{11} + apf_{12} = 1.0$ and $apf_{21} + apf_{22} = 1.0$. A small rating CES unit of 3.8 MJ storage capacity is fitted to both the areas 1 and 2 to examine its effect on the power system performance. A step load disturbance of 0.01 per unit is considered in area 1 for investigation. The control signal to the CES unit can be frequency deviation or the Area Control Error (ACE). In this paper, both the cases are studied.

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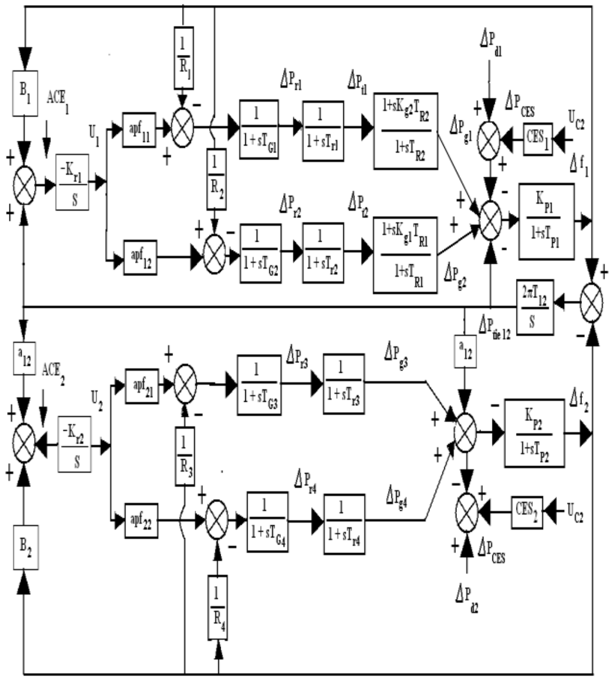

Fig.1 Model of two Area two unit interconnected Power System with CES units

Modeling of Capacitive Energy Storage Unit:

A Capacitive Energy Storage (CES) consists of a super capacitor or a cryogenic hyper capacitor (CHC), a Power Conversion System (PCS) and the associated circuitry. Capacitive energy storage unit is as shown in Fig. 2.CHC has a peak dielectric constant of 77K.

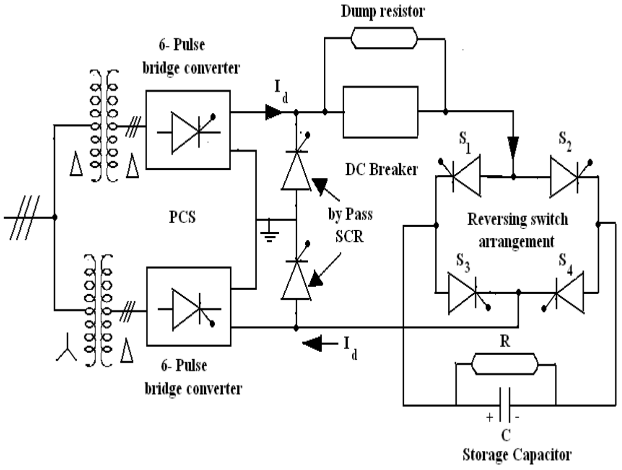

Fig. 2 Capacitive Energy Storage Unit

The resistor R is connected in parallel across the capacitor represents dielectric and leakage losses of the capacitor bank. The PCS forms an electrical interface between the capacitor and the power system, consists of ac to dc rectifier and a dc-to-ac inverter. The thyristors provide a path for current I_d to bypass and the dc breaker allows current I_d to be diverted into the energy dump resistor R_d if the converter fails. Assuming the losses to be negligible, the bridge voltage Ed is given [5]

$$E_d = 2E_{d0}\,cos\alpha - 2I_D R_D \qquad (1)$$

The voltage across the capacitor E_d can be varied from its maximum value to minimum value by changing the phase angle ∝.The firing pulses are given in appropriate timings and hence the voltage E_d and power P_d is defined by the value ∝.Thus, without any switching operation, reversibility and magnitude control of the power flow is achieved by continuously controlling the firing angle α and it is controlled by an algorithm. A firing angle is calculated and transmitted to the firing circuit based on the voltage across the capacitor. As the response time of the control and firing circuits is very short, a new firing angle is chosen within a few milliseconds for the very next SCR to be pulsed. This rapid response to power demand is the major capability of CES relative to other energy storage systems. The change of direction of the current in the capacitor during charging (rated load period) and discharging (during peak load period), can be provided by the reversing switch arrangement since the direction of the current through the bridge converter (rectifier/inverter) cannot change. During the charging mode, switches S1 and S4 are on and S2 and S3 are off. In the discharging mode, S2 and S3 are on and S1 and S4 are off. The operating point of capacitor is such that the total energy which is absorbed is equal to the total amount of energy discharged. If E_{d0} denotes the set value of voltage and E_{dmax} and E_{dmin} denote the maximum and minimum limits of voltage respectively, then,

$$1/2CE^2{}_{dmax} - 1/2CE^2{}_{d0} = \quad 1/2CE^2{}_{d0} - 1/2CE^2{}_{dmin}$$

and hence,

$$E_{d0} = \left[\frac{E^2_{dmax} + E^2_{dmin}}{2}\right]^{\frac{1}{2}} \qquad (2)$$

A low limit is imposed on capacitor voltage i.e., 30% of the rated value is used to overcome the voltage fluctuations which occur due to a sudden disturbance. Initially capacitor is charged to its set value E_{d0} .At this position ∝ value will be 90^0 and now CES is ready to operate. When load is raised suddenly, the stored energy is released immediately through the PCS to the grid as pulsed AC. As the governor and other control mechanisms start working to set the power system to the new equilibrium condition, the capacitor charges to its initial value of voltage E_{d0}.Similar action takes place if load is reduced. The capacitor immediately gets charged towards its full value, thus absorbing some portion of the excess energy in the system, and as the system returns to its steady state, the absorbed energy is released and the capacitor voltage attains its normal value.

The power flow into the capacitor at any instant is P_d $=E_d.I_d$ and the initial power flow into the capacitor is P_{d0} = $E_{d0}.\, I_{d0}$ Where E_{d0} and I_{d0} are prior to the load disturbance. When a load disturbance occurs, the power flow into the coil is

$$P_{d0} + \Delta P_d = (E_{d0} + \Delta E_d)(I_{d0} + \Delta I_d)$$

The term Ed0.Id0 is neglected since $E_{d0} = 0$ in the storage mode to hold the rated voltage at constant value. So that the incremental power change in the capacitor is

$$\Delta P_d = (I_{d0}\, \Delta E_d + \Delta E_d\, \Delta I_d) \qquad (3)$$

Block Diagram of CES:

After any load disturbance the set value of CES voltage has to be restored so that the CES is ready to act for other load disturbance. For this, the capacitor voltage deviation can be sensed and used as a negative feedback signal in the CES control loop so that fast restoration of the voltage is achieved as shown in Fig.3

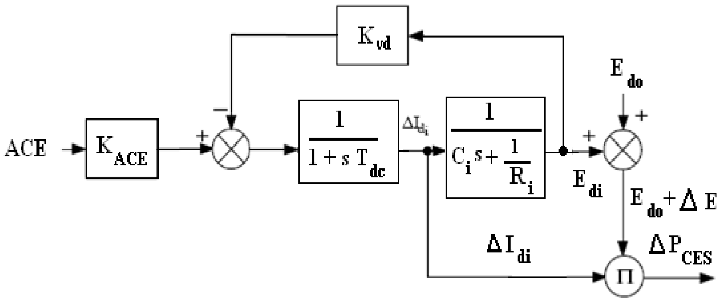

Fig.3 CES block diagram with capacitor voltage deviation feedback

CES Control Logic:

E_{di} is continuously controlled in accordance with the control signal. The control signal of CES unit can be provided either by Area Control Error (ACE) or frequency deviation. For the i_{th} area, if the frequency deviation Δf_i (i.e., $\Delta error_i = \Delta f_i$). of the power system is used as the control signal to CES, then the deviation in the current, $\Delta I_{di}$is given by

$$\Delta I_{di} = [\frac{1}{1+ST_{DCi}}][k_{CESi}\Delta f_i - k_{vdi}\Delta E_{di}] \qquad (4)$$

If the tie-line power flow deviations can be sensed, then the Area Control Error (ACE) can be fed to the CES as the control signal (i.e., $\Delta error_i = ACE_i$).As a function of tie-line power deviations, ACE as the control signal to CES, may further improve the tie-power oscillations. Thus, ACE of the two areas is given by

$$ACE_i = \beta_i \Delta f_i + \Delta p_{tieij,i,j=1,2} \qquad (5)$$

Where Δp_{tieij} is the change in tie-line power flow out of area I to j. Thus, if ACE is the control signal to the CES, then the deviation in the current ΔI_{di} would be

$$\Delta I_{di} = [\frac{1}{1+ST_{DCi}}][k_{CESi}\Delta ACE_i - k_{vdi}\Delta E_{di}]\ ;\ i,j=1,2. \qquad (6)$$

Simulation Results:

To obtain the dynamic responseof the two area system 0.01p.u. step input is given as load disturbance in area 1. The area participation factors are taken as $apf_{11} = apf_{12} = 0.5$ and $apf_{21} = apf_{22} = 0.5$.The system is simulated for a time of 80sec without CES unit, with CES units having Δf_1or ACE_1 as the control logic signals. From results as shown in figure 4, it is evident that the dynamic responses have improved significantly with the use of CES units. It is observed that with the use of Δf_1 feedback to the CES control block, the dynamic responses are better than those obtained with ACE_1.As the load disturbance has occurred in area 1, at steady state, the power generated by generating units in area 1 are in proportion to the ACE participation factors. Therefore, as in Fig. 4(d),(e),(f)and(g) at steady state, $\Delta P_{g1ss} = \Delta P_{d1} \times apf_{11} = 0.01 \times 0.5 = 0.005$ p.u. MW and $\Delta P_{g2ss} = \Delta P_{d2} \times apf_{12} = 0.01 \times 0.5 = 0.005$p.u. MW. Similarly, $\Delta P_{g3ss} = \Delta P_{d2} \times apf21 = 0 \times 0.5 = 0$ p.u.MW and $\Delta Pg4ss = \Delta P_{d2} \times apf_{21} = 0 \times 0.5 = 0$ p.u. MW at steady state.

Conclusions:

In this paper, the responses of a two-area interconnected thermal power system with reheat and non reheat units have been studied. Responses show that Capacitive Energy Storage units are capable of consuming the oscillations in area frequency deviations and tie-line power deviations of the power system. Further, CES units reduce the settling time of the responses. Two different control logic signals for CES units are employed and it was found that, the dynamic responses with frequency feedback to CES are better than that obtained with ACE feedback to CES units and far superior than that without CES units. Hence, it may be concluded that CES units are efficient and effective for improving the dynamic performance of AGC of interconnected power systems.

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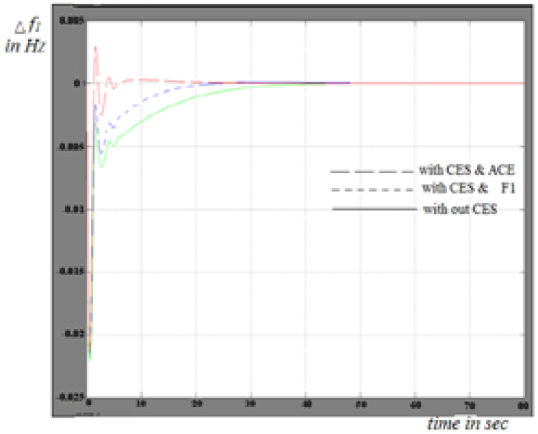
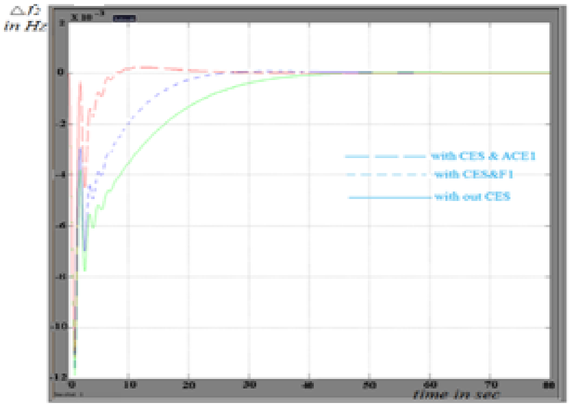
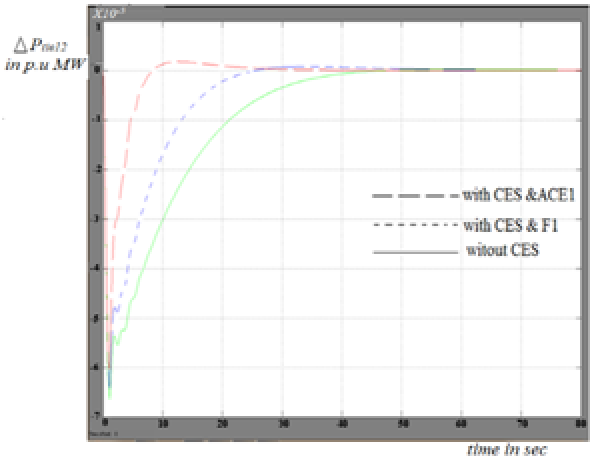


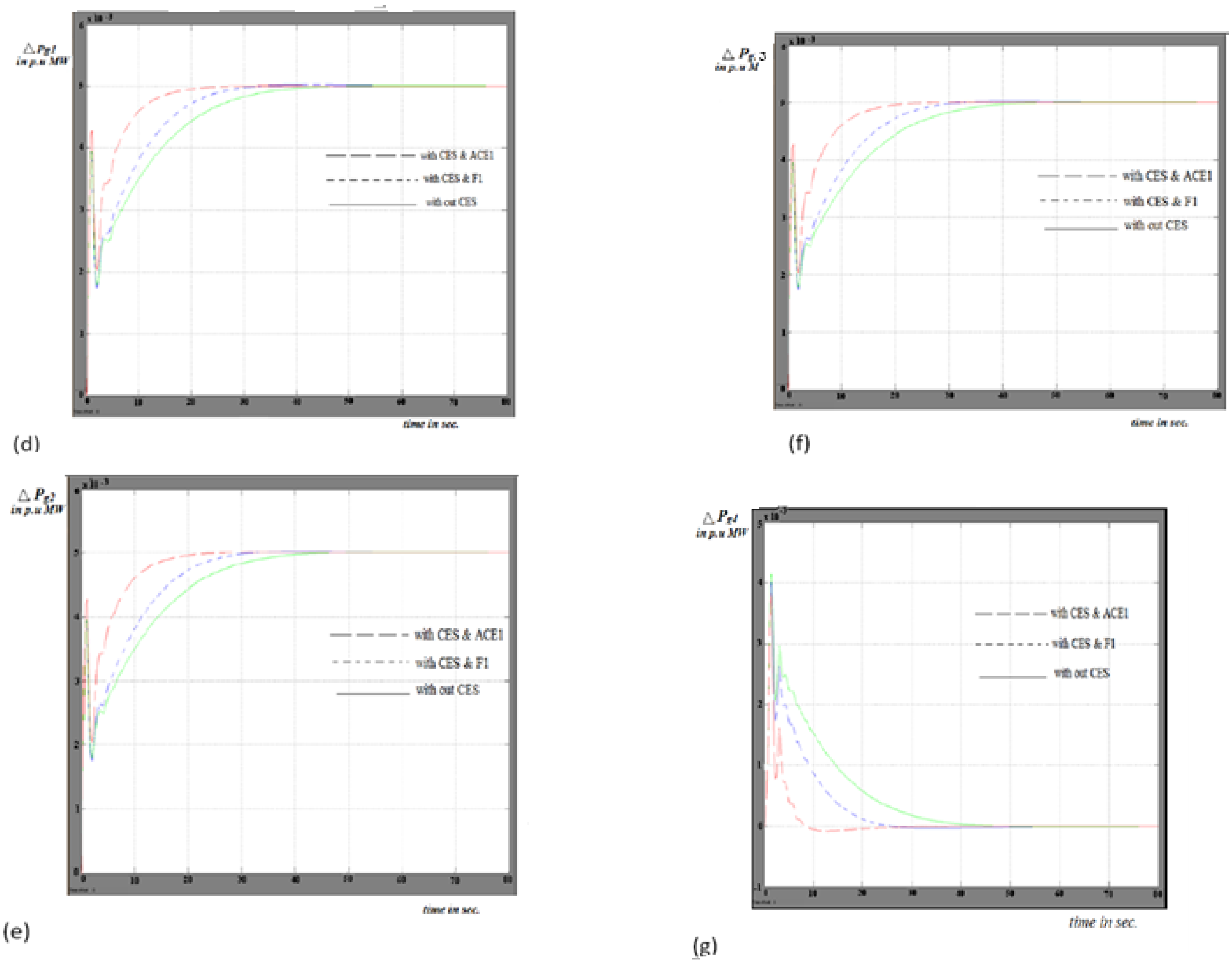
(a)



(b)



(c)



(d) (f) (e) (g)

Fig. 4 Dynamic responses considering a step load disturbance of 0.01 pu in area-1.
(a)Δf_1(b) Δf_2(c) ΔP_{tie12} (d)ΔP_{g1}(e)ΔP_{g2}(f) ΔP_{g3} and (g) ΔP_{g4}