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LOAD FREQUENCY CONTROL AND VOLTAGE REGULATION IN POWER SYSTEM BASED ON ALGORITHMIC FORMULATION OF POWER DISTURBANCE AND REJECTION

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ABSTRACT

As part of a power system's load frequency control (LFC) and voltage regulation, an ADRC is being developed. A three-area linked power system underpins the ADRC for LFC. Maintaining a nominal frequency (60 Hz in North America) and a planned tie-line power flow are the control goals. As a supplemental controller for voltage regulation, the ADRC is used to a static var compensator (SVC). When used in conjunction with ANSI C84.1, it is designed to keep voltages on adjacent buses within 5 percent of the maximum allowed. As a result, the SVC system was developed using an alternate ADRC that has lower controller gains than traditional ADRC. Shocking load fluctuations, transmission failures, equipment failure/failure, and other factors may create major or minor disruptions to voltage and frequency regulation systems. Studies based on simulations and theoretical analyses show that ADRCs are successful in compensating disturbances and meeting control objectives. Future power networks will have a frequency management problem as they integrate additional renewable energy supplies. A study and evaluation of potential problems and innovative techniques of frequency management in future power systems are presented in this article. Review of different kinds of loads and distributed energy resources (DERs). For the demand-side frequency response, a model of a population of water heaters is explored. These DERs use battery energy storage systems (BESSs), such as for charging smart electric vehicles (EVs), large-scale BESSs and residential and nonresidential DER BESSs, and are represented as models. They were tested on a Nigerian power system and a 14-machine Bus System . In future power systems, these novel techniques have the potential to be very successful in restoring the frequency responsiveness that has dropped.

Keywords BESS, distributed energy resource (DER), Battery energy storage system (BESS) in the home, and large-scale BESS aggregates Demand side response, Frequency control, and Markov chains are all examples of demand side response.

1.0 Introduction

Among the components of an energy system are the following: generation, transmission, distribution and load. Electricity is most often transmitted across long distances using three-phase AC electricity. Resistive components of an RLC load absorb and supply active power, which is measured in watts (W), whereas capacitors and inductors absorb and deliver reactive power, which is measured in volt amperes reactive (var), a unit of measurement (Apostolov AP (2011)). In a transmission network, the active and reactive powers are independent of one another and are regulated independently. Modifications to the active power have an impact on the system's frequency. In order to keep up with load fluctuations, the frequency of generation deviates from the plan. As a result, active power and load frequency management are linked (LFC). Bus voltage is affected by changes in reactive power. In this way, reactive power and voltage regulation are related. Power systems cannot operate continuously if generator frequencies and bus voltages are not maintained within tight limitations, as mentioned in the article.(Chapman AC, Verbic G (2019))Are responsible power systems must also stay intact and resist a broad range of disruptions, such as rapid load fluctuations, transmission system faults, equipment loss or failure, and soon.. In order to guarantee that power systems operate reliably, LFC and voltage control are used. (Cheng M, Sami SS, Wu J (2019))The efficacy and resilience of LFC and voltage control, which maintain a balance between load and generation, determine the dynamic performance of a power system. Power system outages are likely to occur if the equilibrium is upset. The 2003 North American blackout was related to short-term system instability (between 10 and 50 hours) caused by disturbances. For this reason, a dependable power system must include a strong control system that can withstand disruptions (Georgiev M, Stanev R, Krusteva A (2019)). A modern electric power system is made up of several control regions that are linked via tie lines. Any unexpected load disturbance in a control region may cause a power system's normal operating point to deviate from its specified values. (Ghafouri A, Milimonfared J, Gharehpetian GB (2015))Therefore, there is a departure from the operational point, such as the nominal system frequency and the planned power exchange with the rest of regions. Consequently, the LFC is employed to stabilize the system frequency at approximately 60Hz (the standard frequency in North America) and to maintain planned tie-line power flows. The area control error is defined as the linear combination of frequency deviation (f) and net power interchange error (P tie) (ACE). LFC's primary goal is to regulate the ACE. By driving ACE to zero, LFC also drives TIE, FIE, and PIE to zero. LFC has been studied in the literature for over five decades. As far as the power sector is concerned, the PI/PID based LFC is the most well-established option. Because of its simplicity, PI/PID controllers do not offer acceptable dynamic performance in the face of a variety of load fluctuations. Overshoot and a long time to settle are the two biggest problems with PI/PID controllers. (Huang S, Wu Q, Liu Z et al (2014))With the integration of a significant number of renewable energy sources, distributed generation, and demand response, today's power networks are experiencing unprecedented changes. As a result of these developments, power system control is subject to considerable uncertainty and disruption.

2.0 Materials and Method

In its initial nonlinear form, Han's ADRC was redesigned by Gao into a linear form for ease of implementation and wide application. Moving, Micro-Electro-Mechanical Systems, web tension, automobiles and power systems are just a few of the domains where the linear ADRC (with linear ESO) has had great success. nth-order system with m inputs and external disturbances is considered in this section. According to this equation, the typical form of an nth order system is

$$Y(s) = G(s)U(s) + D(s) \qquad (1)$$

There are three Laplace transformed variables in the system: output(Y(s)), input(U(s)), and external disturbance (D(s)). The plant transfer function (TF) is represented by G(s) in this equation:

$$G(s) = \frac{b_m s^m + ... + b_1 s + b_0}{a_n s^n + a_{n-1} s^{n-1} + ... + a_1 s + a_0} \qquad (2)$$

G's constant coefficients are ai I = 0...,n) and bi I = 0...,m) in (2). (s). For (1), the differential equation model may be written as follows. (Obaid ZA, Cipcigan LM, Muhssin MT (2017))

$$\begin{aligned} & a_n y^{(n)}(t) + a_{n-1} y^{(n-1)}(t) + ... + a_1 y(t) + a_0 y(t) \\ & b_m u^{(m)}(t) + b_{m-1} y^{(m-1)}(t) + ... + b_1 u(t) + b_0 u(t) \\ & a_n d^{(n)}(t) + a_{n-1} d^{(m-1)}(t) + ... + a_1 d(t) + a_0 d(t) \end{aligned} \qquad (3)$$

System inputs are u(t), y(t), and d(t). (3) may be integrated by multiplying m by both sides.

$$y^{(r)}(t) = bu(t) + f\left(y(t), u(t), d(t)\right) \qquad (4)$$

In this case, where b = bm/an, r = n−m, and f(y(t),u(t),d(t)) (or f) is the generalized differential equation (GD) that contains all terms except for bu(t) and y(r) is defined as: (t). For example, we could select state variables as follows: x1 = y, x2 = ˙y,...,xr = y(r−1),and xr+1 = f. For example, let's say f may be differentiated within the range of the interests, and that h = f second state-space model is given by (4), where

$$\begin{cases} X = AX + Bu + Eh \\ \quad y = CX \end{cases}$$

Where $X = [x_1, x_2, ..., x_{r+1}]$ (5)

$$A = \begin{bmatrix} 0 & 1 & 0 & \cdots & 0 \\ 0 & 0 & 1 & \cdots & 0 \\ \vdots & \vdots & \vdots & & \vdots \\ 0 & 0 & 0 & \cdots & 1 \\ 0 & 0 & 0 & \cdots & 0 \end{bmatrix}_{(r+1)\times(r+1)}, B = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ b \\ 0 \end{bmatrix}_{(r+1)\times 1} \quad (6)$$

$$E = \begin{bmatrix} 0 \\ 0 \\ \vdots \\ 1 \\ 0 \end{bmatrix}_{(r+1)\times 1}, C = \begin{bmatrix} 1 & 0 & 0 & \cdots & 0 \end{bmatrix}_{1\times(r+1)} \quad (7)$$

For a conventional ADRC, an ESO is utilized to estimate both system states and the GD (or f).The ESO is represented as

$$\begin{cases} Z = AZ + Bu + L\left(y - \hat{y}\right) \\ \qquad y = CZ \end{cases} \quad (8)$$

Where the observer state vector $Z = \left[z_1, z_2, ...,, z_r, z_{r+1}\right]^T$ with $z_1 \approx y,\ z_2 \approx y^{(r-1)}$, and observer gain vector $L = \left[\beta_1, \beta_2, ..., \beta_r, \beta_{r+1}\right]^T$ .The observer gains β1,...,β r+1 are selected in such away that the characteristic equation of the ESO will be (s+ωo)r+1 where ωo is a positive observer bandwidth. We have (Rui Y, Yingchen Z (2019))

$$\beta_1 = \frac{\left(r+1\right)!}{i!\left(r+1-i\right)!}\omega_o^i,\ i = 1,...,r+1 \quad (9)$$

Zr+1 is used to approximate f, the GD. We chose a control that was a wasp nest.

$$u = \frac{-z_{r+1} + u_0}{b} \quad (10)$$

To calculate u0, look at the following equation: Assume zr+1 is a good approximation of f's value. (8) is obtained by substituting it in place of (4.)

$$y^{(r)}\left(t\right) = u_0 \quad (11)$$

A steady reference signal r is our control objective. Next, state feedback controller u0 may be used to regulate the simplified system (9), where k1 and k2 are controller gains.

$$u_0 = k_1\left(r - y\right) - k_2 y - .... - k_r y^{(r-1)} \quad (12)$$

Let z1, z2,..., zr be substituted for y, y, y(r-1) in (10) The control a was obtained by substituting (10) into (8).

$$u = -\frac{k_1 z_1 + ... + k_r z_r + z_{r+1} - k_1 r}{b} = -\frac{K}{b} Z + \frac{k_1}{b} r \tag{13}$$

Controller gain vector K is defined as K = [K1,K2,...,KR,1]. This is done by selecting controller gains in such a manner that (s+ωc)r is the characteristic equation of the feedback controller. We already have

$$k_i = \frac{r!}{(i-1)!(r+1-i)!} \omega_c^{r+1}, i = 1,...r \tag{14}$$

The ADRC has just two tuning parameters, as can be seen from the equation development above. It's ωc and ωo for the controller and observer band widths. (Wu D, Yang T, Stoorvogel A (2017))This makes ADRC implementation and tuning straightforward. In addition, the feedback controller actively compensates for unknown system dynamics and external disturbances. It is thus resistant to system uncertainty and disruptions. Natural energy, such as steam (for non-reheat and reheat turbines), is transformed into mechanical power (ΔPm) that is delivered to the generator by the turbine.

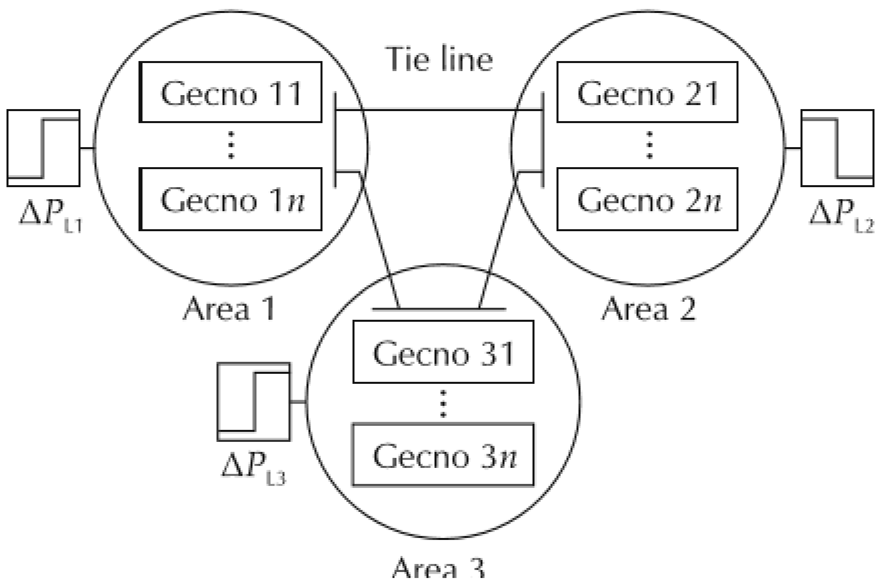

Figure 1 Schematic diagram of three-area power system.

Source: Yang J, Wang Y (2014)

For the ADRC-based LFC, we utilize a non-reheat turbine as an example. If GET(s) is defined as a method of transferring data from ΔPe(s) to ΔPM(s). The non-reheat turbine's GET(s) is a

$$G_{ET}(s) = \frac{Num_{ET}(s)}{Den_{ET}(s)} = \frac{1}{(T_g s + 1)(T_{ch} s + 1)} \tag{15}$$

Mechanical power from the turbine is converted to electricity via the generator. Systemwide, a change in frequency (Δf) reflects changes in the active power demand. Variations in frequency and tie-line power flow occur when generation tries to keep up with demand fluctuations. The area inertial constant M, and the area load damping constant DL, are defined as follows: Generator's power factor (TF) is

$$G_{Gen}(s) = \frac{1}{Den_M(s)} = \frac{1}{MS + D_L} \qquad (16)$$

As a result of changing active power loads, the purpose of the LFC (ADRC) is to control the frequency deviation (Δf) and tie-line power error (ΔPtie). Specific to ACE, it's used to set the value to 0. Measurement of the ACE is based on

$$ACE = \Delta P_{tie} + B\Delta f \qquad (17)$$

Where B is the setting for the area's bias in the frequency. A non-reheat turbine is shown in Figure 2.

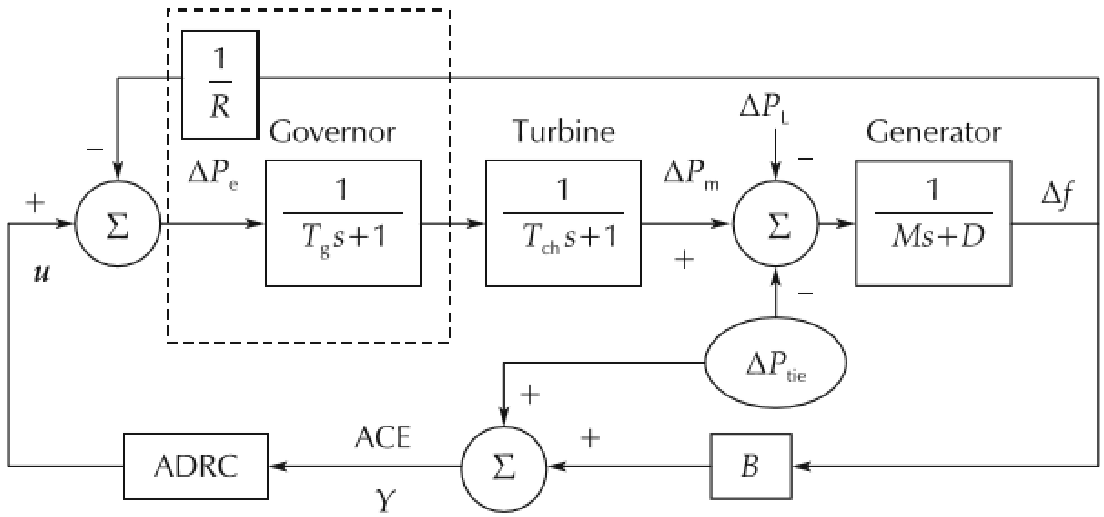

Figure 2: The block diagram of a generating unit with non-reheat turbine.

From Fig.2, the ACE output (or Y) is given by

$$Y(s) = G_p(s)U(s) + G_D(s)\Delta P_L(s) + G_{tie}(s)\Delta P_{tie}(s) \qquad (18)$$

Where

$$G_p(s) = \frac{RBNum_{ET}(s)}{Num_{ET}(s) + RDen_{ET}(s)Den_M(s)} \qquad (19)$$

$$G_D(s) = \frac{-RBDen_{ET}(s)}{Num_{ET}(s) + RDen_{ET}(s)Den_M(s)} \qquad (20)$$

$$G_{tie}(s) = \frac{Num_{ET}(s) + RDen_{ET}(s)Den_M(s) - RBDen_{ET}(s)}{Num_{ET}(s) + RDen_{ET}(s)Den_M(s)} \qquad (21)$$

Define

$$G_p(s)U(s) + G_D(s)\Delta P_L(s) + G_{tie}(s)\Delta P_{tie}(s) = D(s) \qquad (22)$$

It follows that (16) is equivalent to the generic form: Y(s) = GP(s)U(s)+D(s)) (1). The ADRC established in Section 2 may thus be used to regulate each generator. From (13) through (16), each generating unit's relative system order is three. To estimate the system states and GD for the generating unit, an ESO of fourth order may be used.

3.0 Result and Discussion

Figure 3 shows a simplified model of the Nigerian power system, which is used to aggregate different generating units. Official reports from the National Grid were used to determine generation and inertia values (the Nigerian system operator). The 2008 event sequence disruption in the Great Plains

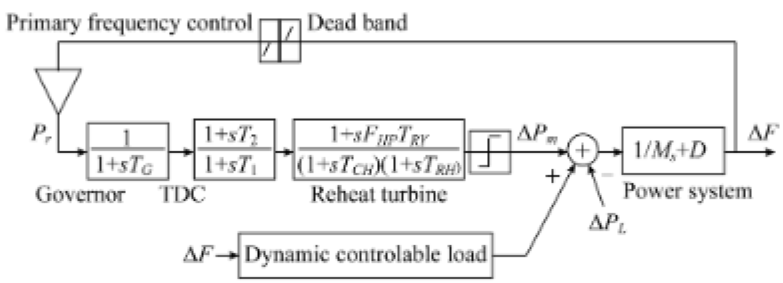

Figure 3: Simplified Nigerian frequency control model

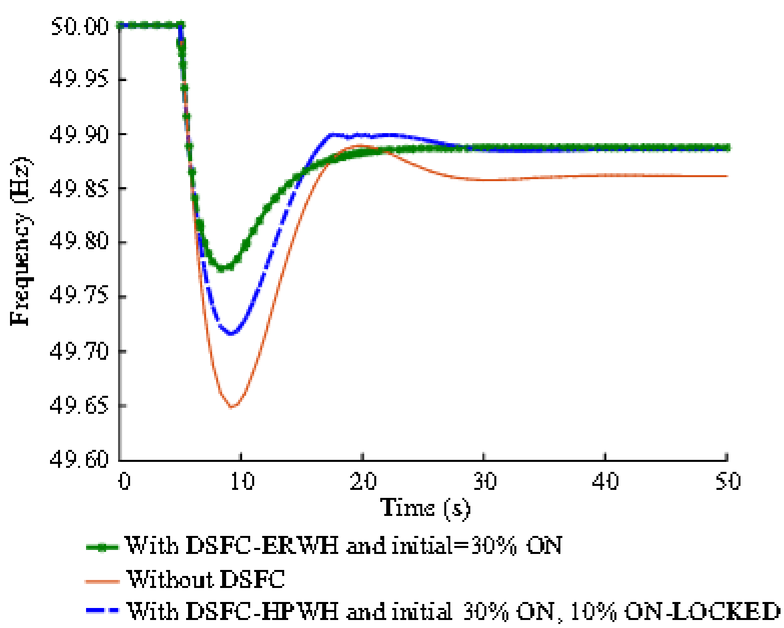

Figure 4: Frequency response of simplified Nigerian power system and DSFC

A calculation was made to determine the value of the British power system, which is equivalent to 0.03 p.u. In this part, we utilized the SOC-high starting condition from Table 1. When the DSFC is integrated, the frequency response in Figure 8 is shown, and in Figure 5, it is shown with the BESS integrated. Integrating such DERs has been shown to improve frequency deviation and inaccuracy.

The novel control methods were tested on the Southern and Eastern Australian system (Figure 5). The disruption that happened in the South Australian electricity grid on the 28th of September 2019 was deemed a major event (with load case 4 as in). The simulation experiments used disturbance sequences that resulted in the loss of roughly 311 MW of wind output at time t = 5 s. At B404, around GPS 4, this disruption appeared as a rapid rise in load.

Scenario 1: DSFC has a varied capacity It is possible to achieve this situation by using the DSFC of Table 7 in conjunction with the case studies for aggregated data.

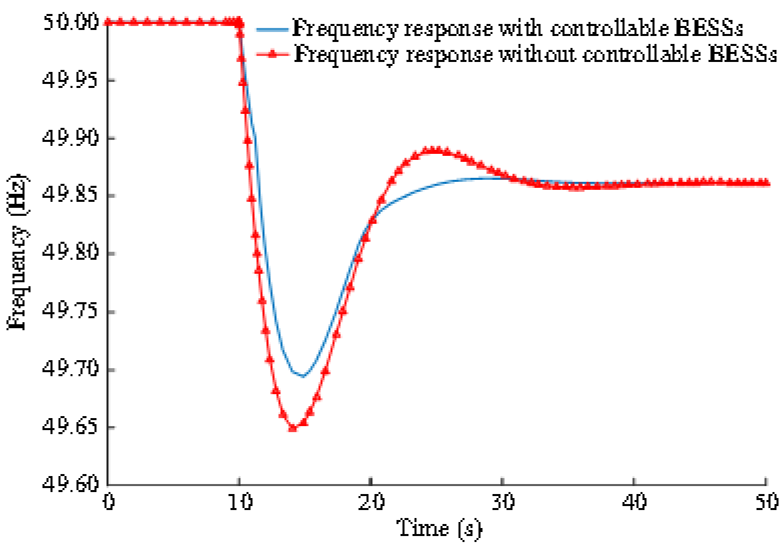

Figure 5 Controllable BESS and simplified Nigerian power system frequency response

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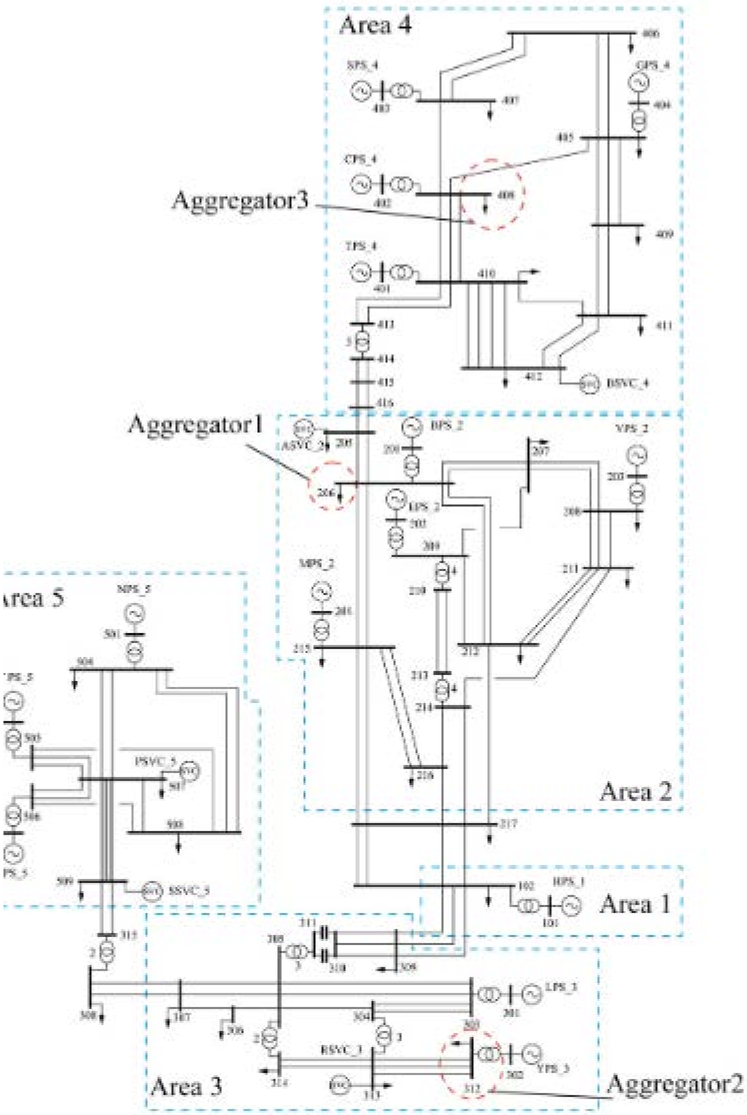

Figure 6 Nigerian power system

Table 8 shows the results of the analysis. Simulation findings of frequency response at various power units are shown in Figure 11. Increasing the number of aggregators and, thus, the number of users

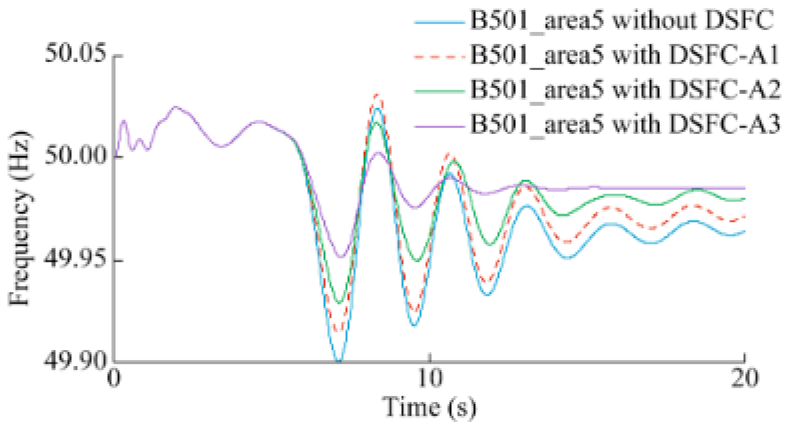

Figure 7: Power generating units at B501-area 3 compared to DSFC Scenario 1

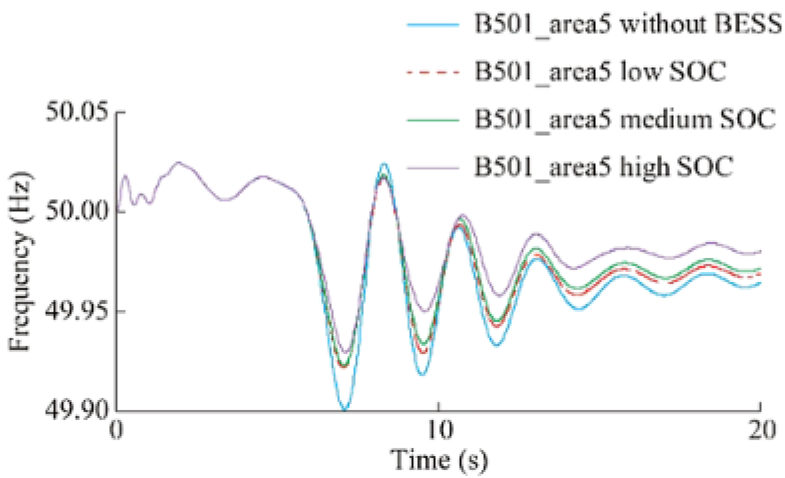

Figure 8: B501-area 3 power generating unit frequency response comparison with BESS Scenario 2

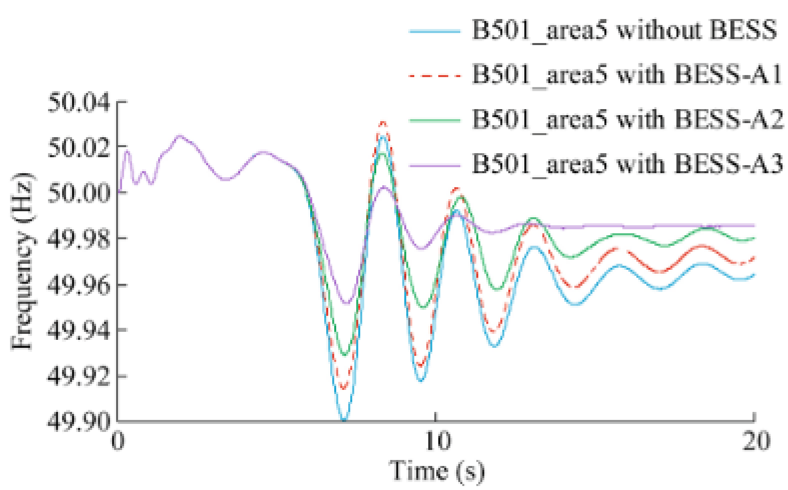

Figure 9: B501-area 3 power generating units compared to BESS Scenario 3

The frequency deviation is reduced as a result of the quantity of controlled DSFC. Figures 16, 18, and 21 show that the amplitudes of the traditional ADRC control signals are equal to those of the alternative ADRC signals, respectively. After a step disruption is added to the system, the alternative ADRC generates a significantly quicker settling period than the traditional ADRC (see Fig. 15 and Fig. 17). If c and 0 were raised in the traditional ADRC, the settling time would be shortened. However, the traditional ADRC control effort would increase. In real-world applications, when reducing power consumption is essential, a significant control effort (typically associated with a high cost) is not an option. There are overshoots in Figures 15 and 17, but they are within the permissible range of 0.05 p.u. Alternative ADRC also exhibits lower oscillations than conventional ADRC when there is a random disturbance.

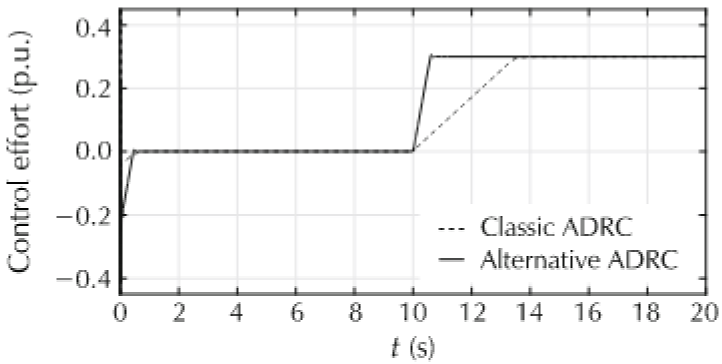

Figure 10: Step disturbances in the control signals are negative.

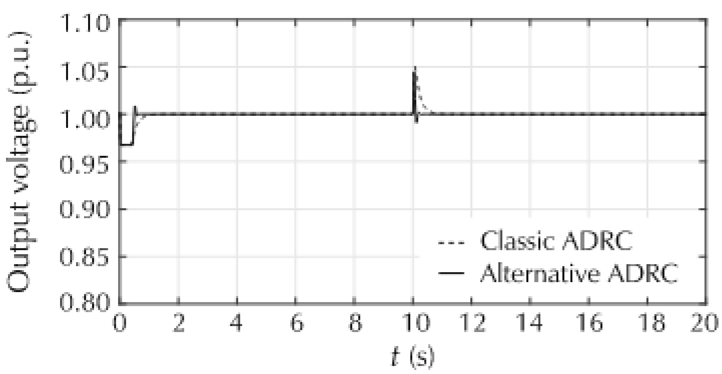

Figure 11: In the presence of a positive step disruption, SVC's system reactions change.

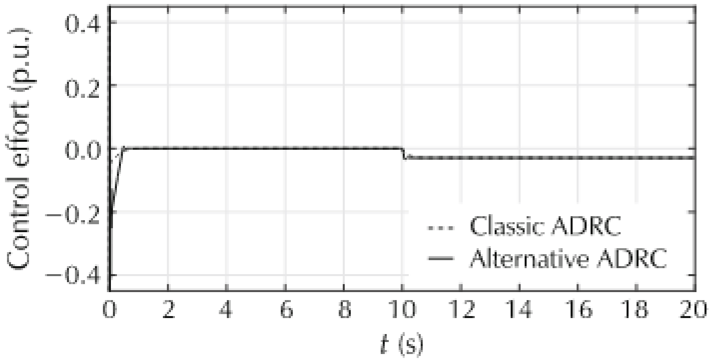

Figure 12: Positive step disruption may be used to control your efforts.

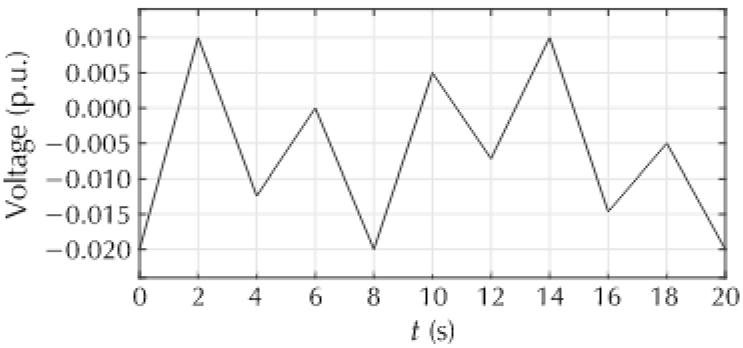

Figure 13: Unpredictable disruption.

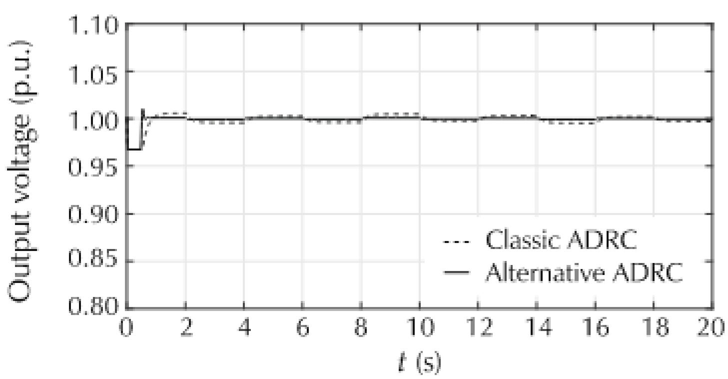

Figure 14: Random disturbances of the SVC system cause system reactions.

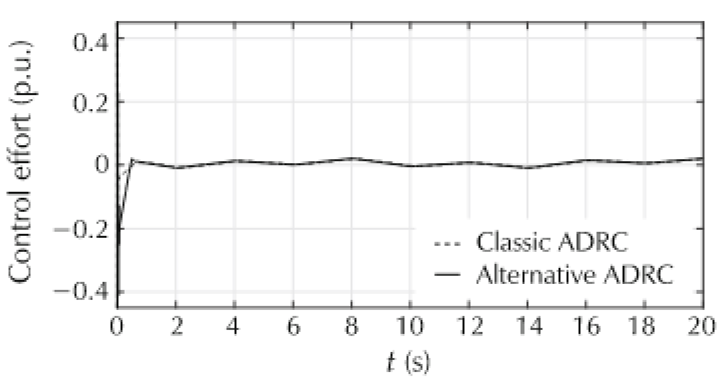

Figure 15: Signals of control with random fluctuations.

4.0 Conclusion and Recommendation

Quality of power supply and usage is highly dependent on frequency and voltage consistency. Voltage and frequency, on the other hand, vary from their nominal values from time to time owing to major and minor disruptions caused by abrupt load fluctuations, transmission system failures, equipment loss and malfunction, and soon. They impair the system's functioning and may lead to blackouts. An uncertain power system, which is continuously susceptible to step and random disturbances, lends itself well to the ADRC's resilience against disturbance. There are just two tuning parameters for the ADRC, and both of them are easy to determine. Voltage regulation (via SVC) and LFC are two important power system control loops that have been successfully used using the traditional ADRC. SVC and LFC have each been studied separately in literature, but they have never been studied together. In effect, the traditional ADRC pushes the ACE to zero. A review of the integration of DERs for frequency control in future power networks was given in the study. A study was conducted on the integration of demand-side frequency regulation and BESS as DERs. The literature-based models used to model the ERWHs and HPWHs aggregates were used. For example, residential-based BESS were aggregated with a large-scale BESS, and electric vehicles (EVs) were aggregated with either smart charging stations at home or at stations. In order to show the efficacy of the new techniques in regulating frequency, the Nigerian power system and the 14-machine Nigerian power system were used. We modeled many different scenarios for the availability of DERs and used real-world disruptions as inputs. Incorporating several DERs resulted in a significant improvement in frequency responsiveness. the Nigerian power system with 14.5 gigawatts of system demand was disrupted and water heater and BESS-based distributed energy resources were combined to minimize frequency deviation and error.

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