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Frequency Regulation in Deregulated Power System Using Robust Firefly Swarm Hybrid Optimization

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Abstract
Frequency control is more delicate to the load variations in power system. So, it needs proper matching of generation and load demand. This work presents a hybridization of two optimization methods, combination of Particle Swarm Optimization (PSO) and Firefly algorithm (FA). In Automatic Generation Control (AGC), Proportional Integral Derivative (PID) controller is tuned by Hybridization of Particle Swarm Optimization with Firefly (HPSOFA). The proposed algorithm is tested for AGC of Two area multiunit power system include of both Solar and Wind. Area 1 and Area 2 contains of three non-reheat turbines and three reheat turbines respectively, along with solar thermal unit and Doubly Fed Induction Generator (DFIG). These two areas are interconnected by tie line. To validate the usefulness of PID controller, Integral of the Time Weighted Absolute Error (ITAE) performance index is considered and 1% step load variation is applied in area1 and Unilateral, Bilateral and Contract Violation are the three different cases observed for proposed deregulated power system. The resultant power system is exhibited in MATLAB/SIMULINK environment.

Keywords—Automatic Generation Control, Doubly Fed Induction Generator, Firefly Algorithm, Hybridization, load Frequency Control, Particle Swarm Optimization, Proportional Integral Derivative.

Introduction:
An AGC is a system for controlling how many generators at various power plants manage their power output in response to changes during the use and management of an electric power system, in load Maintaining zero steady state error in tie line power deviation and frequency deviation is the primary objective of AGC.

To improve the effectiveness, economy, and dependability of the connected power system, automatic generation control is used in conjunction with secondary regulators like PID. Particle Swarm Optimization (PSO), Firefly Algorithm (FA), Genetic Algorithm (GA), Artificial Neural Network (ANN), and Fuzzy Logic (FL) are a few examples of fine-tuning techniques. Several appliances employ PID controllers because of their reliability and simplicity. PID controllers enhance transient and steady state responses. Syed Mahboob discussed LFC of hybrid solar power systems in [3]. [4] discusses hybrid power systems that use LFC techniques and renewable energy sources. Deepesh Sharma concluded that LFC was very much essential for regulating voltage and frequency [5]. For a micro network power system, Hassan Mohamed introduced an adaptive load frequency controller in [6]. Sahani observed that FA based PID controller performs efficiently and effectively in [7]. In [8] the PSO Algorithm-based AGC of a multi-area power system with renewable energy sources was described by D. Gaurav. On load frequency control utilizing the DE algorithm, the effects of DFIG, SMES, and TCPS are discussed in [9]. AGC of multi area multiunit interrelated power system with DFIG wind turbine improved by TLBO discussed in [10]. Conventional PID & Fuzzy PID Regulator in Wind Integrated Power System explained in [11]. A reliable firefly swarm hybrid optimization for frequency regulation is described by

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Prakash K. Ray in [12]. In the literature survey, [1] discusses the principles behind load frequency and automatic generation regulation. For load frequency management, a variety of optimization techniques and control methodologies are proposed in [2].

Deregulated Power System

The power grid in question is often a regulated power system, meaning that the government sets the rules and regulates how the power grid must function.

All the rules and economic incentives are constrained in a deregulated power system and make the economic power manufacturing. The power system presently consists of GENCOs, TRANSCOs, DISCOs, PX, ISO, RESCOs, and customers as a result of deregulation. ISO is a reputable organization that ensures the reliability and security of the electrical system. It is a self-governing entity. PX operates mostly like a stock exchange, updating and posting Market Clearing Prices often (MCP). The price at which transactions are now occurring is known as the MCP. Electricity is purchased by RESCOs from GENCOs and sold directly to customers. In the end, consumers are the organizations that utilize power directly from GENCOs or through transactions conducted by ISO.

In this, GENCOs sells power to Discos. GENCOs are being contracted by the Discos of their own choosing for power. There are many different forms of transactions in a decontrolled power system, including unilateral, bilateral, and contract-violation transactions. The Disco Participation Matrix (DPM) makes it simple to imagine discos with GENCO contracts. The DPM's rows and columns, respectively, represent the system's total number of GENCOs and DISCOs. The ij in a matrix denotes the proportion of a matrix where the entire demand supplied by a disco j to a GENCO I adds up to one.

There are two control zones that are taken into account. Each control region has three GENCOS and three DISCOS, as shown in the figure. GENCO1, GENCO2, GENCO3, and DISCO1, DISCO2, DISCO3 are all located in Area 1. In Area2, you can also find GENCO4, GENCO5, GENCO6, and DISCO4, DISCO5, DISCO6.The equivalent DPM matrix is given by

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} & cpf_{15} & cpf_{16} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} & cpf_{25} & cpf_{26} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} & cpf_{35} & cpf_{36} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} & cpf_{45} & cpf_{46} \\ cpf_{51} & cpf_{52} & cpf_{53} & cpf_{54} & cpf_{55} & cpf_{56} \\ cpf_{61} & cpf_{62} & cpf_{63} & cpf_{64} & cpf_{65} & cpf_{66} \end{bmatrix} \quad (1)$$

The cpf is contract participation matrix.

System Modelling

As seen in Fig. 1, the study was conducted on a two-zone, multi-unit power system. Different PID controllers are occupied into account for individually unit. Eq. (2) provides the transfer function for the PID controller, and Eq. (3) provides the goal function for tuning using the hybrid algorithm (3)

$$PID = K_P + \frac{K_I}{S} + K_D S \qquad (2)$$

$$J = ITAE = \int_0^{t_{sin}} (|\nabla f_1|^2 + |\nabla f_2|^2 + |\nabla P_{tie}|^2) \quad (3)$$

An optimization problem can be expressed as a design problem. The conditions for this problem are given in equations 3 and 4.

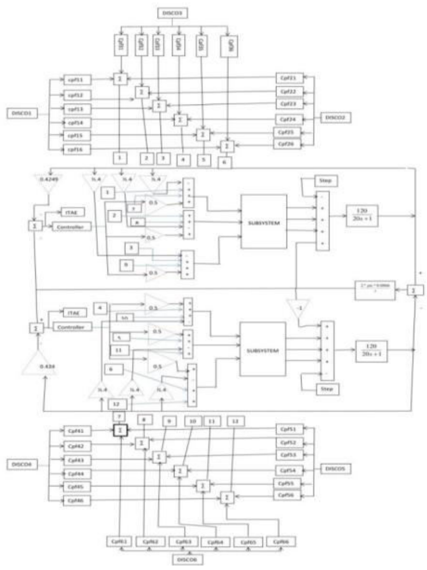

Fig. 1. Two area three unit deregulated power system.

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Minimize J Subject to $K_{P\min} \le K_P \le K_{P\max}$, $K_{I\min} \le K_I \le K_{I\max}$ and $K_{D\min} \le K_D \le K_{D\max}$ (4)

DFIG Model

In DFIG active power is one of the sources for frequency regulation and variable mechanical speed for the capable of generating electric power. As shown in Fig.2 is based on the inertia control by participating wind turbine to control active power from the modelling of DFIG. For simulation purpose the DFIG is modelled and control scheme is implemented in MATLAB. Table 4 below shows different power system parameters. From Fig.2, it is taken that the total active power, ΔPNC, introduced in given equation 5 by DFIG.

$$\Delta P_{NC} = \Delta P_f^{\,*} + \Delta P_\omega^{\,*}$$

(5) Where, $\Delta P_f^{\,*}$ is a function of frequency variation and rate of frequency range and $\Delta P_\omega^{\,*}$ is function of optimum turbine speed.

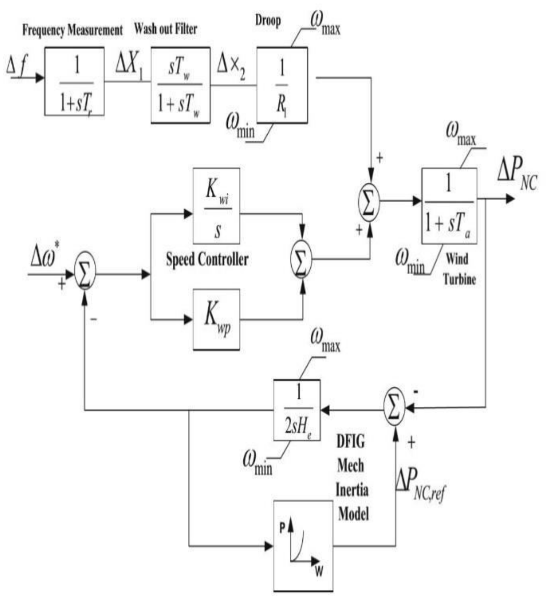

Fig. 2. DFIG model built on Wind Turbine inertia control

Modelling of Solar Thermal Unit

Light exists in nature in the form of solar energy. Clean energy, such as solar energy, is used to supply the system with consistent power. The steam produced by the heat-transfer apparatus turns the turbine's shaft, producing electricity. For the system design, a large number of heliostats (sun-tracking mirrors) are needed, and these mirrors reflect the incident sunlight into the heat exchanger. In the receiver, solar thermal energy warms the water or other fluids to a higher temperature up to 560 degrees Celsius where steam is produced, which drives the shaft that generates electricity. The model of solar thermal power system transfer function will be

$$G_{st}(S) = \frac{K_{st}}{1 + T_{st} S} \tag{6}$$

Where, Kst stands for gain of and Tst denote the time constant of solar thermal unit.

Hybrid Algorithm

Particle Swarm Optimization

In 1995, Eberhart and Kennedy released PSO. They took their cues from fish schools and the social behavior of birds. In PSO, the birds communicate using particles P that move at a constant speed V. Using Eqs. (7) and (8), they are updated by the particle's position (8). The speed among two elements, i and j, is represented by Eq. 8.

$$V_{ij}^{k+1} = w \times V_{ij}^{k} + c_1 \times r_1 \times \left(Pbest_{ij}^{k} - Z_{ij}^{k}\right) + c_2 \times r_2 \times \left(Gbest_{j}^{k} - Z_{ij}^{k}\right) \tag{7}$$

Equation 8 explains how to find the particles' new position

$$Z_{ij}(k+1) = Z_{ij}(k) + V_{ij}(k+1) \tag{8}$$

Firefly Algorithm

X.S. Yang established the firefly algorithm in 2008. The activities and flashing patterns of fireflies served as the basis for the creation of the firefly algorithm.The Eq. 9 provides the distance between one firefly and another firefly

$$r_{ab} = \sqrt{\sum_{k=1}^{d} \left(x_{a,k} - x_{b,k}\right)^2} \tag{9}$$

Eq. 10 is used to update the particle position when Firefly a's light intensity is lower than Firefly b's light intensity.

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$$x_a = x_a + \left[\beta(r)\right](x_b - x_a) + \alpha(rand) \quad (10)$$

HYBRIDIZATION OF PSO AND FA (HPSOFA)

Due to oscillatory behavior, Firefly algorithm does not give better solutions for the results obtained besides PSO with finely tuned control parameter is a fitness function dependent. The drawback of causing unbalance in exploration and exploitation in the FA algorithm can be conquered by combining FA with other troubleshooting techniques like PSO, the local search ability of PSO and global intellectual FA are combined in this HPSOFA to create a stability amongst local and global search capacity. Acceleration constant of PSO velocity equation is replaced with FA parameters.

$$V_i^{k+1} = wV_i^k + \beta_0 e^{-\gamma r_{ij}^2}(Pbest - Z_i) + \alpha\left(rand - \frac{1}{2}\right)(Gbest - Z_i) \quad (11)$$

IMPLEMENTATION STEPS OF HPSOFA

1. As size, alpha, beta and gamma set them as parameters.
2. Set the particle positions and speeds within the limits provided.
3. Obtain the pbest and gbest values by calculating the fitness and the distance between the firefly.
4. Use While loop.
5. Determine the new particle velocity using Eq (7)
6. Upgrade the position of the particles by using new velocity with the Eq(9).
7. Using the updated values, calculate the fitness function.
8. End while loop.

Simulation Results

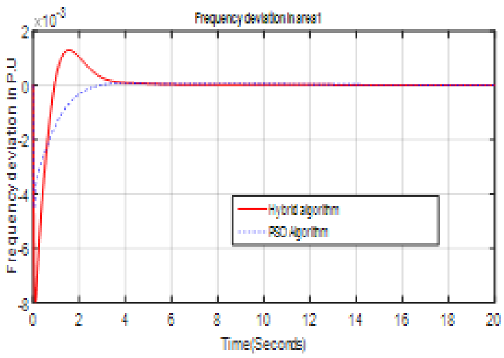

Fig. 3. For both PSO and Hybrid Algorithm, Area 1 frequency deviation

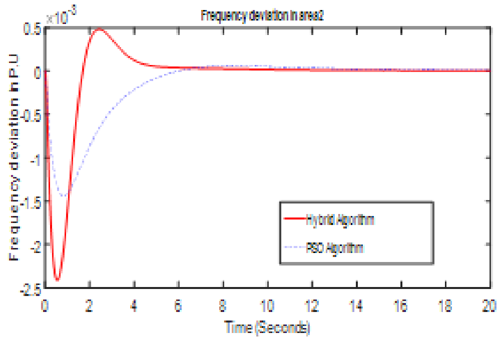

Fig. 4. For both the PSO and the Hybrid Algorithm, Area 2 frequency deviation

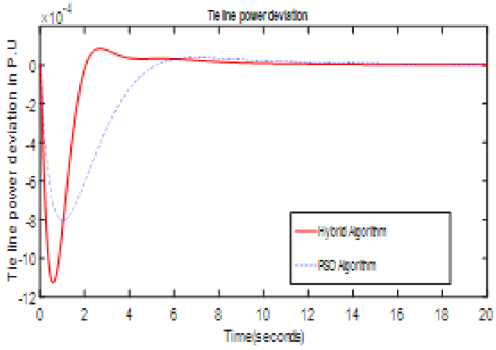

Fig. 5. Power deviation in Tie line for both PSO and Hybrid Algorithm

$$DPM = \begin{bmatrix} 0.333 & 0.333 & 0.333 & 0 & 0 & 0 \\ 0.333 & 0.333 & 0.333 & 0 & 0 & 0 \\ 0.333 & 0.333 & 0.333 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Frequency responses $\nabla f1$, $\nabla f2$ of area1, area 2 and power deviation in tie line $\nabla Ptie$ for both with and without renewable sources are shown in the figures 6, 7 and 8. The following table1 shows the PID controller's time domain specifications, including overshoot, undershoot, and settling time.

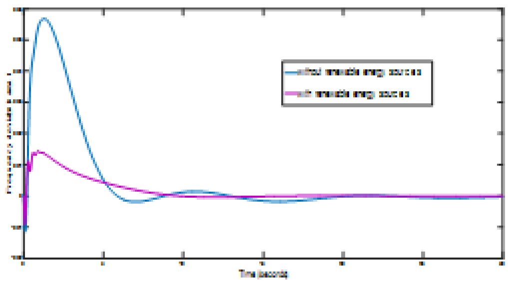

Fig. 6. Area 1 frequency variation

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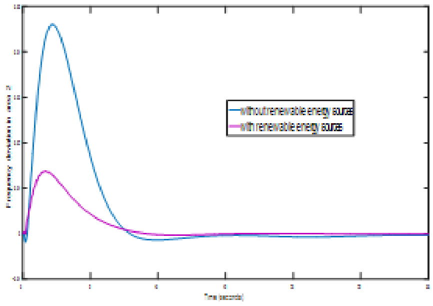

Fig. 7. Area 2 frequency variation

Fig 3 and 4 explains the frequency deviation for both Hybrid and PSO Algorithm, from the results it is noticed that the settling time for PSO Algorithm is more related to hybrid Algorithm.

Fig 5 explains the tie line power deviation for both Hybrid and PSO Algorithm, from this it is detected that settling time is 7 sec for Hybrid Algorithm which is less than 16 sec for PSO Algorithm.

A. Unilateral Contract

The area 1's generating and distribution systems are contractually bound in this instance. Assume that load variations and demand changes are exclusively influenced by the distribution systems of regions 1, 2, and 3.Distribution. Systems 3, 4, and 5 did not sign a contract with generating systems, hence there is no participation in the simultaneous cpfs.

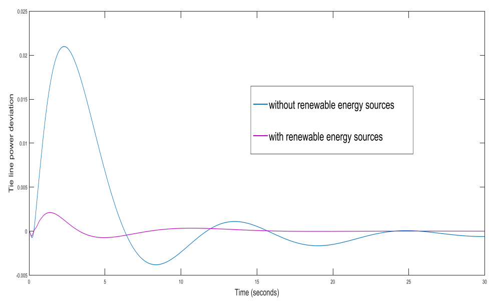

Fig. 8. Power variation in tie line

Table I. Time Domain Specifications of Unilateral Contract Case

Responses	Parameters	PID Controller	
		Without Renewable sources	***With Renewable sources***
∇f_1	US	-0.0001	-0.0009
	OS	0.055	0.015
	ST	29	12
∇f_2	US	-0.0001	0
	OS	0.0045	0.015
	ST	27	11
∇P_{Tie}	US	-0.004	-0.001
	OS	0.021	0.0002
	ST	30	12

B. Bilateral Contract

In this case, any generating system from any area, including the other area, is under contract with the distribution systems of both areas. The following DPM is in the contract between the distribution system and the generating system.

$$DPM = \begin{bmatrix} 0.2 & 0.25 & 0.6 & 0.2 & 0.1 & 0 \\ 0.2 & 0.15 & 0 & 0.2 & 0.1 & 0.1666 \\ 0.1 & 0.15 & 0 & 0.2 & 0.2 & 0.1666 \\ 0.2 & 0.15 & 0.4 & 0 & 0.2 & 0.3666 \\ 0.2 & 0.15 & 0 & 0.2 & 0.2 & 0.1666 \\ 0.1 & 0.15 & 0 & 0.2 & 0.2 & 0.1666 \end{bmatrix}$$

Frequency responses $\nabla f1$, $\nabla f2$ of area1, area 2 and tie line power variation $\nabla Ptie$ for both with and without renewable sources are shown in the figures 9, 10 and 11. Table 2 below shows the PID controller's time domain specifications, including overshoot, undershoot, and settling time.

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Responses	Parameters	PID Controller	
		Without Renewable sources	*With Renewable sources*
∇f_1	US	-0.01	-0.01
	OS	0.045	0.05
	ST	11	8
∇f_2	US	-0.005	0
	OS	0.035	0.045
	ST	10	9
∇P_{Tie}	US	-6	-1.9
	OS	0.5	2
	ST	27	11

Table II. Time Domain Specifications of Bilateral Contract Case

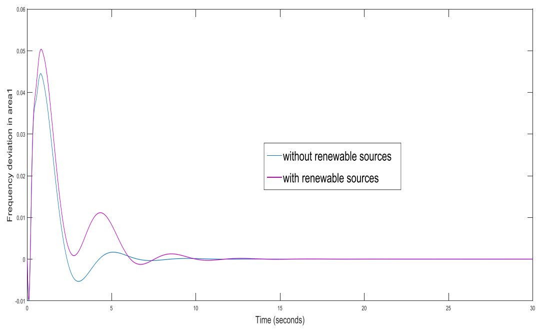

Fig. 9. Frequency variation in area 1

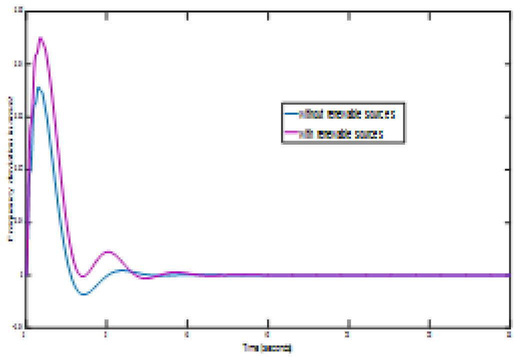

Fig. 10. Frequency variation in area 2

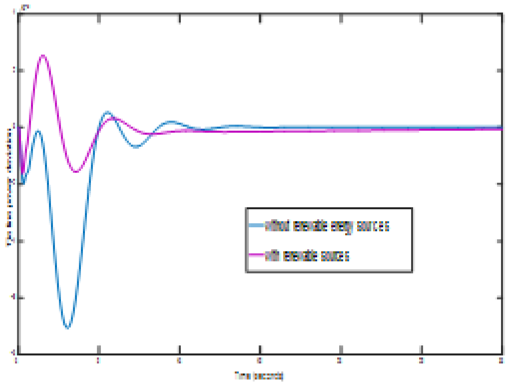

Fig. 11. Tie line power variation

C. Contract violation

In this case, DISCOS seek a surplus of uncontracted electricity demand in any location. The additional electricity must be provided by the GENCOs nearby the discos.

Change in load demand of the area1 is stated by

$\Delta P_{L1,loc}$ = load of Disco1(0.01) +load of Disco2(0.01) +load of Disco3(0.01) +0.01=0.04 pu MW.

The local load of area 2 and the DPM matrix remains parallel as in second case.

Frequency responses $\nabla f_1, \nabla f_2$ of area1, area 2 and tie line power deviation ∇P_{tie} for both with and without renewable sources are shown in the figures 12, 13 and 14.

Table 3 below shows the PID controller's time domain specifications, including overshoot, undershoot, and settling time.

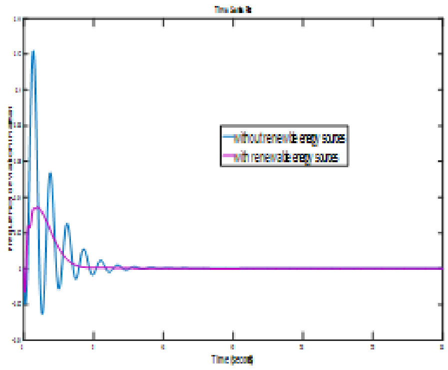

Fig. 12. Area 1 frequency variation

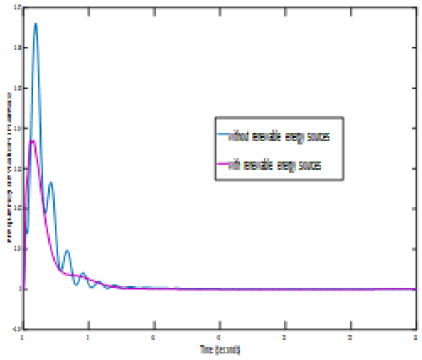

Fig. 13. Area 2 frequency variation

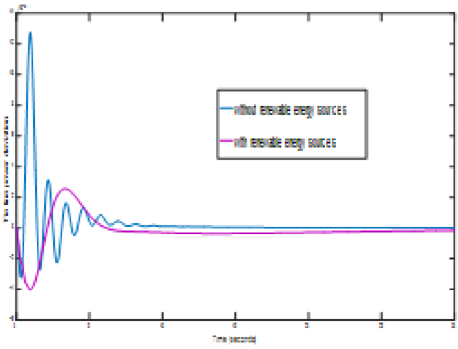

Fig. 14. Tie line power variation

TABLE III. Time domain specifications of contract violation case

Responses	Parameters	PID Controller	
		Without Renewable Sources	*With Renewable Sources*
∇f_1	US	-0.02	-0.01
	OS	0.12	0.03
	ST	10	6
∇f_2	US	0	0
	OS	0.07	0.035
	ST	10	7
∇P_{Tie}	US	-3	-4
	OS	13	2
	ST	30	11

From the findings, it can be inferred that the hybridization algorithm reduces the settling time for renewable energy sources in comparison to those without them. In addition, for the three examples, both with and without renewable energy sources are seen for the setup time.

Conclusions

The PSO and Firefly algorithms were merged to create a hybrid algorithm for PID controller tuning in a two-area, multi-unit power system using renewable energy sources. This method is simulated in the MATLAB/SIMULINK environment. This design has been tested for a 1% step load variation in area 1.

In all the three scenarios, such as unilateral, bilateral, and contract violation cases in a deregulated electricity system with renewable energy sources, hybridization performs better in frequency variations and tie line power variations compared to without renewable energy sources.

TABLE IV. Power System and DFIG Parameters

Parameter	Symbol	Value
Wind turbine inertia	H_e	3.5
DFIG turbine	T_a	0.2
Transducer time constant	T_r	15
Wash out filter time constant	T_w	6
Regulation	R_1	2.4
Gain of solar thermal unit	K_{st}	1.8
Time constant of solar thermal unit	T_{st}	1.8

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