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Design of an ORBP-based fractional order controller for load frequency control in a multi-area power system with integration of RES

Abstract: *In the current situation of the power system, with the need to increase power to meet the availability of all types of loads, the quality of power is equal to the demand. On this day, there is no change and a demanding power supply with a stable and reliable power supply at all times. Therefore, to maintain the quality and power to meet the current reforms in the power sector and adapt to the changes in the industrial sector's demands, thus changing in frequency, an advanced controller is necessary. Change in frequency, there will be losses in the system stable, if appropriate control is not made. The most important of the power system from the controller. Based on the various analysis in the load frequency control area, the performance of various types of controllers used as load frequency controllers has been studied. It has been observed that certain crises such as damped oscillation, long stabilization time and maximum overshoot of frequency have been observed. In the present study, to overcome the above problems and improve the steady-state value, the frequency controller has been designed Optimum Resilience Power Balance (ORPB) controller. The performance of the ORPB controller is still good and has a faster settling time compared to other controllers. Due to the intermittent power generation of solar and wind power, the output power of PV and WT is not guaranteed. For this reason, the capacity of WT, solar photovoltaic panels, and battery systems are the parameters to be optimized and deliberately determined. The renewable energy system's optimized design ensures that there is enough power to be supplied to the EV charging station. The proposed ORPB controller will also provide appropriate PWM to the converter and inverter to maintain the stable power flow in the system; thus, ORPB plays an important role in maintaining constant frequency and voltage to ensure the reliability of power. The performance of the ORPB controller will be analyzed based on the parameters like settling time (sec), steady-state error (%), Integral Time Absolute Error (ITAE) (%), overshoot (%) and efficiency (%).*

Streszczenie. *W obecnej sytuacji systemu elektroenergetycznego, z koniecznością zwiększenia mocy w celu zaspokojenia dostępności wszystkich typów obciążeń, jakość mocy jest równa zapotrzebowaniu. W tym dniu nie ma zmian i wymagającego zasilania ze stabilnym i niezawodnym zasilaniem przez cały czas. Dlatego, aby utrzymać jakość i moc, aby sprostać obecnym reformom w sektorze energetycznym i dostosować się do zmian w zapotrzebowaniu sektora przemysłowego, a tym samym zmieniając częstotliwość, konieczny jest zaawansowany regulator. Zmiana częstotliwości spowoduje straty w stabilnym systemie, jeśli nie zostanie przeprowadzona odpowiednia kontrola. Najważniejszy w systemie elektroenergetycznym regulator. Na podstawie różnych analiz w obszarze sterowania częstotliwością obciążenia, zbadano wydajność różnych typów regulatorów stosowanych jako regulatory częstotliwości obciążenia. Zaobserwowano, że zaobserwowano pewne kryzysy, takie jak tłumione oscylacje, długi czas stabilizacji i maksymalne przekroczenie częstotliwości. W niniejszym badaniu, aby przezwyciężyć powyższe problemy i poprawić wartość stanu ustalonego, zaprojektowano regulator częstotliwości Optimum Resilience Power Balance (ORPB). Wydajność sterownika ORPB jest nadal dobra i ma szybszy czas ustalania w porównaniu z innymi sterownikami. Ze względu na przerywaną generację energii słonecznej i wiatrowej, moc wyjściowa PV i WT nie jest gwarantowana. Z tego powodu wydajność WT, paneli fotowoltaicznych i systemów akumulatorowych to parametry, które należy zoptymalizować i świadomie określić. Zoptymalizowana konstrukcja systemu energii odnawialnej zapewnia wystarczającą moc do dostarczenia do stacji ładowania pojazdów elektrycznych. Proponowany sterownik ORPB zapewni również odpowiedni PWM do konwertera i falownika, aby utrzymać stabilny przepływ mocy w systemie; w ten sposób ORPB odgrywa ważną rolę w utrzymywaniu stałej częstotliwości i napięcia, aby zapewnić niezawodność zasilania. Wydajność sterownika ORPB zostanie przeanalizowana na podstawie parametrów, takich jak czas ustalania (sek.), błąd stanu ustalonego (%), błąd bezwzględny czasu całkowania (ITAE) (%), przeregulowanie (%) i wydajność (%).* (***Projekt regulatora ułamkowego rzędu opartego na ORBP do sterowania częstotliwością obciążenia w wieloobszarowym systemie energetycznym z integracją OZE***)

Keywords: Multi-Source and Multi-Area Interconnected Power System, Load frequency control, Optimum Resilience Power Balance (ORPB).
Słowa kluczowe: Wieloźródłowy i wieloobszarowy system zasilania połączony, kontrola częstotliwości obciążenia, (ORPB).

Introduction

A good system frequency should always be maintained to provide a stable and reliable power supply. It should also be adjusted as needed to avoid generating a mismatched load. The frequency should also be maintained at its predetermined value to prevent deviations in the supply and the generator's speed. For the development of a stability system, it is necessary to identify the shortcomings of the existing methods. The concept of load frequency control (LFC) is a basic process that involves the coordination of the electrical power system components. The controller must function properly if the system has to provide high quality electrical power. This research aims to develop a high-sequenced differential feedback controller which can effectively manage the LFC problem.

It is essential to have an integrated power system in order to perform load frequency control (LFC). A well-designed controller is essential for ensuring consistent, high-quality electrical power by avoiding problems like regional frequency and tie-line power distortion. In order to address the LFC problem, this research constructed a high-sequence differential feedback controller (HODFC) and a MAMS power system [1]. Numerous factors contribute to the difficulty of energy management in Multi-Micro Grid (MMG) systems, including the generation unit's role in the power transaction between the grid and the MG, the MG's power exchange, and the distribution of individual MGs [2]. A huge power system and reality are both addressed by the central premise of this framework. A new strategy with the strategic purpose of giving support has been developed utilizing historical data in the comparative balance [3-5].

In a multi-regional setting, though, the electric power grid is essential for assessing costs and benefits and ensuring a sufficient supply of RES for transmission, storage, and synergy. In order to quantify renewable energy sources (RES) and storage capacity credit (CC), this study suggests a novel approach for a number of regional power agencies [6]. A brand-new electric system control system was recently suggested. When electricity generation is coupled with a high penetration of renewable energy, Economic Transmission (ED) and AGC) are integrated to keep economic performance stable [7–10]. Based on the findings of the aforementioned studies on the power flow transmission between various DEMS control centers, the

Border Bus State Fixed-Point Reconnaissance Program was developed to alter the external network evenly through data transfer [11]. Slashing the total cost of the system is the primary objective of the planning phase. It entails reducing operational expenses while maximizing the system's reliability. The planning difficulty of a multi-zone growth is subdivided into the planning problem of ensuring adequate yearly reliability. Two identical locations, one powered by solar/wind power and the other by EVs systems, are used to design and construct the modified Fractional Order Controller (FOC) framework, which is proposed in this study. An ORPB controller, which uses meta-heuristic technology inspired by nature, optimizes the controller's parameters. There have been three separate tests of the proposed technology's performance on MSUs in two different regions. A linear system is always presumed in the first scenario, while two linear and additional loads in the MAMS system are considered in the seco

Proposed system

In order to ensure the sustainable development of energy and reduce power quality problems, the power transmission of renewable energy and the proper maintenance of multi-energy resources. Therefore, proper design is required to prevent the power system from disconnecting the current and voltage grid power. The proposed energy management system is automatic, and it effectively regulates the power using the best Optimum Resilience Power Balance (ORPB)based fractional order controller. The thermal, wind, hydro and solar are the main energy generation of the proposed system. Electrical vehicle (EVs) energy management plays an important role in the MAMS. If the MAMS power generation is under fluctuation, the EVs-based energy management system will stabilize and produced a continuous power supply to the energy utility system. The EVs-based energy management is an additional advantage for the multi area power system; during the high power generation of MAMS, the EVs are charging mode. When the hybrid system is under fluctuations, the EVs will discharge and optimize the multi area power system. All these necessary actions are monitored and optimized by the proposed multi area power system generation to efficiently minimize the load frequency with the proposed system ORPB Controller. Hence the efficient energy is provided in the electrical vehicle under contrasting load changing conditions..

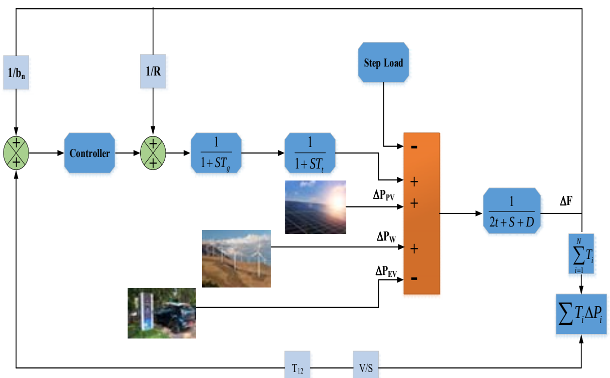

Fig : 1 proposed block diagram

Photovoltaic cell

The solar photovoltaic cells generate electricity similar to the sun's largest indescribable source of energy. There are numerous photovoltaic arrays in the cell to increase the overall current and the rated voltage of the battery. Experiential expression in a PV cell refers to the interpretation of power generation. Mostly it depends on the intensity of the sun's radiation and the ambient temperature of the sun's rays.

(1) $$P_{solar} = \eta . A . \Phi . T_A$$

The PV system is shown in the design and equations expressed in (2) by its equivalent transfer function;

(2) $$G_{PV} = \frac{\Delta P_{PV}(s)}{\Delta P_e(s)} = \frac{K_{PV}}{1+s.T_{PV}}$$

K_{PV}= gain, T_{PV}=PV system time constant

Wind turbine generator

The wind density and wind speed are a factor produced in wind power plants. Equation (3) shows how power is displayed in these two factors.

(3) $$P_{WIND} = \frac{1}{2} . \alpha . D . \beta . V^3$$

The T.F model of WTG

(4) $$G_{Wind}(S) = \frac{\Delta P_{Wind}}{P_{Win}} = \frac{K_{WTG}}{1+s.T_{WTG}}$$

Thermal Generator

The LFC study's thermal generator model consists of four parts. Generator, steam turbine, governor, and re-heater transfer functions refer to these parts. Figure 2 shows the heat generator's transfer function model, which includes all of the components.

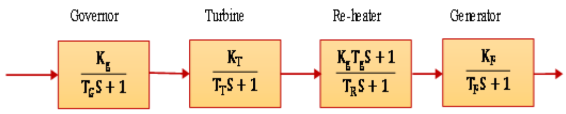

Fig 2 Transfer function model of the thermal generator

A total of two control loops in the heat generator's structure help regulate the frequency. It is possible to fine-tune the heat generation unit's governor frequency right from the offset of operation. Using this control loop is problematic due to the constant-level error in the frequency signal, even though the first cycle is helpful for observing huge frequency variances. The use of Area Control Error (ACE) secondary loop signals allows for the reduction of static error for this reason. Here is the mathematical expression of the ACE signal:

(5) $$ACE_i = \Delta P_{tie,i} + \beta_i \Delta f_i$$

The regional bias factor of the network connection, the tie-line power, and the frequency deviation of the i-th area are represented by β_i, ΔP_(tie,i), and Δf_i, respectively, in this study. The following section will explain the two frequency control loops that are integral to the heat generator's main structure.

Design of controllers

Internal Mode Control

A multi-area electrical system is a third-order system. Therefore, the use before entering the second row to use the IMC method can be minimized. In this work, the ORPB algorithm is presented in a low-order model that is easy to understand and very similar to the original system to minimize the functionality. Let us present the reduced-order model as follows:

(6) $$G_R(S) = \frac{a_0 + a_1 s}{a_1 s^2 + b_1 s + b_2}$$

Where a_j, j=0,1 and b_i, i=0,1,2 are constant co-efficient of s and $b_i > 0$.As for the LFC complex, the reduced sequence model obtained by the ORPB can be seen as a minimal phase structure. So, look at a_1 <0. If $a_1 \geq 0$, it can use a similar procedure as described below.

Equation (6) can be re-written as;

(7) $$G_R(S) = \frac{a_0 + (1 + a_2 s)}{b_0 s^2 + b_1 s + b_2}$$

Where $a_2 = \frac{a_1}{a_0} < 0$

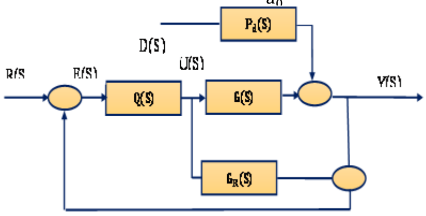

Fig 3 IMC Control scheme

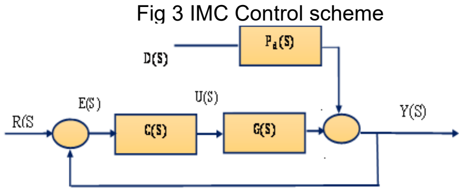

Fig 4 IMC Control scheme in conventional feedback

After receiving the reduced-order model, accept the LFC problem of the IMC scheme. Figures 3 and 4 show the traditional conceptual form of the basic IMC structure and IMC configuration block diagram, respectively. The implemented model is divided;

(8) $G_R(s) = G_R - (s)G_R + (s)$

Among them, $G_R - (s)$ and $G_R + (s)$ denote the minimum and minimum phase phases, correspondingly. Thus;

(9) $G_R - (s) = \frac{a_0}{b_0 s^2 + b_1 s + b_2}$

(10) $G_R + (s) = 1 + a_2 s$

Next, a filter equation is provided in the below expression;

(11) $F(s) = \frac{1}{(1+\delta_s)^k}$

Here, the delta adjusts arbitrarily. Where K the IMC controller is physically felt at the selected location. For this type of problem, consider K = 1.

Finally, the IMC controller provided:

(12) $Q(s) = F(s)G_{R-}^{-1}(s) = \frac{b_0 s^2 + b_1 s + b_2}{a_0 + (1+\delta_s)}$

In the standard feedback form, the PID controller can be written as follows;

(13) $C_{IMC}(s) = \frac{Q(s)}{1 - G_R(s)Q(s)}$

In modifying the values of $G_R(s)$ and $Q(s)$ from equations (8) and (12);

(14) $C_{IMC}(s) = \frac{b_1}{a_0\delta - a_1} + \frac{b_1}{a_0\delta - a_1}\frac{1}{s} + \frac{b_0}{a_0\delta - a_1}s$

Equation (13) can be re-written as;

(15) $C_{IMC}(s) = K_p + K_i + \left(\frac{1}{s}\right) + K_d s$

Where; $K_p = \frac{b_1}{a_0\delta - a_1}$, $K_i = \frac{b_2}{a_0\delta - a_1}$ and $K_d = \frac{b_0}{a_0\delta - a_1}$.

Therefore, the parameters of the IMC-PID controller have been obtained. In the following subsections, these parameters enable selecting the boundary of the FOPID solution space by the ORPB algorithm.

proposed system

The optimization of the method's performance is strongly related to the determination of random and rapid changes, which in turn impacts the system dynamics. Overshoot, minimum steady-state error, and vibration response are some of the designer-specified criteria that must be satisfied by the system when subjected to unexpected random fluctuations. When it comes to control engineering, an optimized, resilient power balance (ORPB) is a great tool for more accurate system modelling or for making control systems more robust and applicable in design. These are the steps of the ORPB algorithm, which stands for optimal elastic balance of power.

ORPB Algorithm Steps

Step1: Initialization of devices.

Step2: Initialize the ORPB parameters, set N, Ψ, maxi and 'iter' = 1. The lowest bound FOPID parameter is L = [p^{-1} K_p p^{-1} K_d p^{-1} K_i 0 0] and the upper bound U = [pK_p pK_d pK_i 2 2]. Here are the PID parameters calculated in (14). When μ∈(0,2). If,λ μ≥2 the resulting controller will be of a different order of magnitude higher than the traditional PID controller. The P factor is adjusted arbitrarily.

Step3: Define the objective function of the design variables for equality and inequality constraints.

Step 4: By generating a uniform random distribution with n candidate solutions. This stage of the Big Bang Phase (BBP) transition. Let the vector xi describing the position of the I-candidate solution. Thus, the element of x_i is thus formed;

(16) $x = L + (U - L)R, i = 1,2,\ldots,N$

Step 5: The computed fitness function of n candidate solutions matrix = $[f^1 f^2 \ldots f^N]^T$ where, $f^i = J(x_i)$, $f^i \in$ IR,i=1,2…N and J (x i) Function of the i-th candidate solution of the performance index.

Step 6: Set the Fitness value of its size in ascending order. Let the minimum exercise value be denoted by f^{iter}.

Step 7: To calculate the center of mass of a given candidate. This stage is called the large compression stage (LCP).

(17) $C^{iter} = \frac{\sum_{i=1}^{n}\frac{xi}{fi}}{\sum_{i=1}^{n}\frac{1}{fi}}$

Since our goal is to calculate the lowest value of the function, the algorithm uses the inverse function's fitness level. Therefore, the weighted average performance function of the candidate solutions is located at least in the area with its value dependencies.

Step 8: Next, after N creates new candidates, quality-based knowledge search using the center of the previous iteration calculation using (18).

(18) $x_i^{iter+1} = C^{iter} + \frac{r_i\Psi(U-L)}{iter+1}$

Here r_i is a normal random number that is distinctive to each candidate solution, forming r_i ∈(0; 1].

Step 9: Calculate the newly created fitness function value is generated in step 8. Then the candidate solution is set and go to step 6. Thus, repeated and continuous LCP phase BBP phase steps, until the stopping criterion is fulfilled.

Step 10: When number of iterations is maximum, also ordering the minimum fitness value in ascending order in step 4 and calculate the solution corresponding to the performance index's minimum value. Therefore, the solution with the lowest fitness value creates our best FOPID parameter.

Result and discussion

The research work of AC frequency regulation in grid-connected Multi Area-Multi Source (MAMS) power generation has been progressed through the improved version of MATLAB/Simulink software. Renewable energy power generation proposed a transfer function model based on the MAMS system in the Simulink environment. It suggested that the program development required for the optimization technology is built in the 2017 b MATLAB software environment M file. This part contributes to the effectiveness of various proposed methods in response to the frequency awareness of AC MAMS systems. The analysis of the proposed model has been progressed with different evaluation like (i) Frequency stabilization in MAMS system (ii) controller performance under dynamic test condition (iii) steady-state analysis (%) (iv) Settling time (sec) Overshoot (%), Integral Time Absolute Error (ITAE) (%), and efficiency (%).

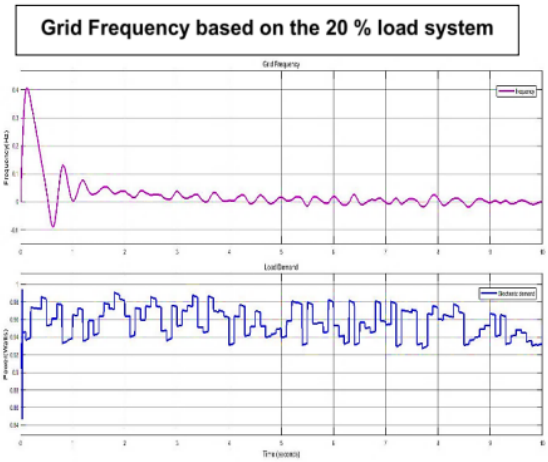

Fig 5 Grid frequency with 20% load varying system

Figure 5 shows the proposed grid frequency survey based on the ORPB algorithm; the exam is gathered with different stochastic load demands.

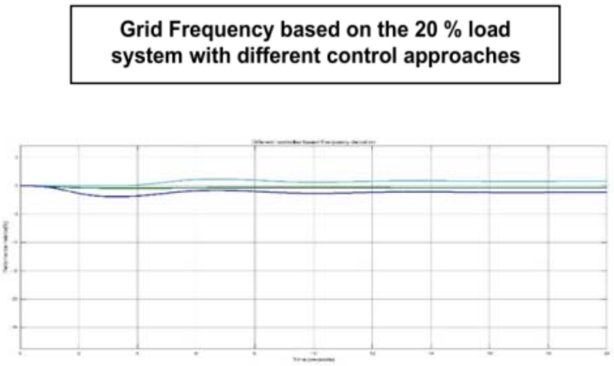

Fig 6 Grid frequency based on different control approaches

Figure e 6 clearly shows that the suggested ORPB will result in less frequency variation under 20% load conditions, in contrast to the system's dynamic load change, which will generate higher frequency variation.

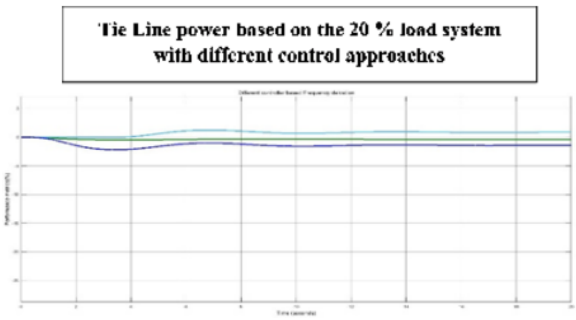

Fig 7 Tie Line power stability analysis

Figure 7 for the tie-line power stability analysis of the proposed multi source-single area interconnected model under dynamic load varying conditions. Comparing different controllers, the PI, PID and ORPB controllers. The ORPB produces a better result.

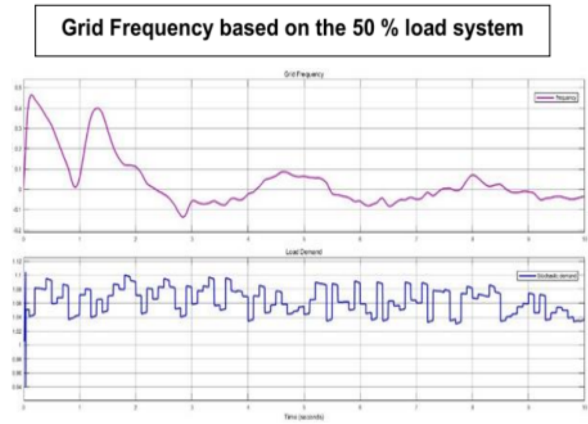

Fig 8 Grid frequency with 50% load varying system

Figure 8 shows the proposed grid frequency survey based on the ORPB algorithm; the exam is gathered with different stochastic load demands.

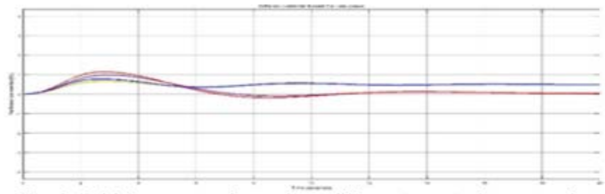

Fig 9 Grid frequency based on different control approaches

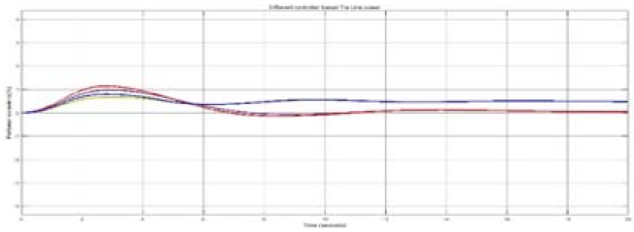

Fig 10 Tie Line power stability analysis for 50% load system

Figure 10 for the tie-line power stability analysis of the proposed multi-source-single area interconnected model for 50% load varying conditions. From the comparison of different controllers, the PI, PID and ORPB controllers. The ORPB produces a better result under 50% load varying conditions.

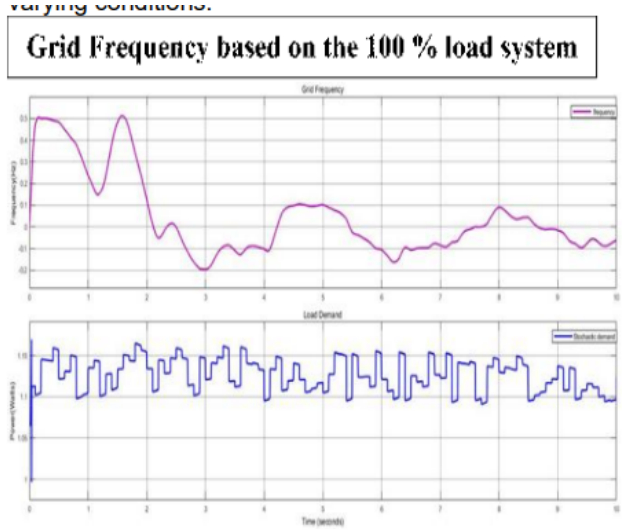

Fig 11 Grid frequency with 100% load varying system

Figure 11 shows the proposed grid frequency survey based on the ORPB algorithm; the exam is gathered with different stochastic 100% load demand conditions.

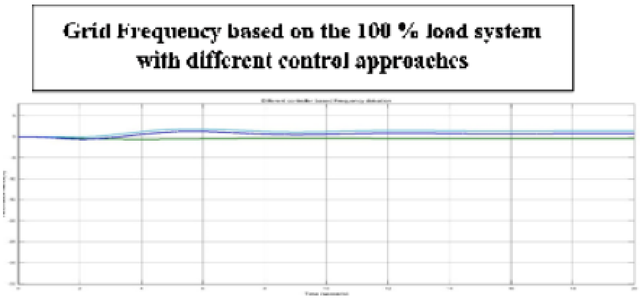

Fig 12 Grid frequency based on different control approaches

The system's dynamic load change will cause more frequency variation, but it is clearly shown in figure 12 that the proposed ORPB will produce less frequency variation during 100% load conditions.

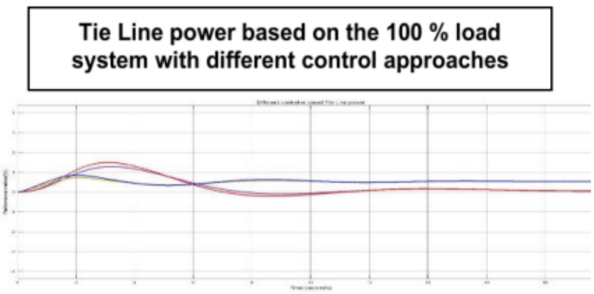

Fig13 Tie Line power stability analysis for 100% load system

As shown in Figure 13, the suggested multi-source-single-area interconnected model was tested for tie-line power stability under 100% load changing conditions. From the comparison of different controllers, the PI, PID and ORPB controllers. The ORPB produces a better result under 50% load varying conditions.

Table 1 Performance analysis of the proposed model based on different aspects

Variations	Parameters	PI controller	PID Controller	ORPB controller
Power system-1	Settling Time(sec)	0.58	0.46	0.39
	Peak Overshoot (%)	0.081	0.075	0.041
	Steady-state error (%)	0.7	0.64	0.46
Power system-2	Settling Time(sec)	0.56	0.41	0.37
	Peak Overshoot (%)	0.076	0.066	0.038
	Steady-state error (%)	0.65	0.50	0.39
Tie Line	Settling Time(sec)	0.55	0.42	0.37
	Peak Overshoot (%)	0.072	0.061	0.037
	Steady-state error (%)	0.63	0.48	0.35

Table 1 demonstrates the proposed Area-based Performance analysis of the proposed model. Based on the above parameters, Settling time (sec), Peak Overshoot (%) and Steady-state error (%), the proposed model produces an effective result.

Table 2 Performance analysis of the proposed model with and without the controller

Variations	Parameters	Without ORPB controller	With ORPB controller	% Improvement
Power system-1	Peak Time(sec)	0.72	0.39	33.21
	Peak Overshoot (%)	0.079	0.041	38.67
	settling time (sec)	0.72	0.46	24.36
Power system-2	Peak Time(sec)	0.70	0.37	33.65
	Peak Overshoot (%)	0.076	0.038	38.79
	Steady-state error (%)	0.69	0.39	30.64
Tie Line	Peak Time(sec)	0.69	0.37	32.16
	Peak Overshoot (%)	0.074	0.037	37.64
	settling time (sec)	0.64	0.35	29.33

Table 2 describes the performance analysis of the proposed model with and without the ORPB controller. Based on the analysis of the various parameters like peak Time (sec), Peak Overshoot (%) and Steady-state error (%), the proposed ORPB controller provide better result compared with without controller model.

Table 3. MSSA interconnected system Performance analysis function of proposed using ORPB and existing systems

Parameters	PI	PID	ORPB
Steady-state error (%)	1.8	1.2	0.7
Settling time (sec)	0.46	0.38	0.28
Overshoot (%)	0.079	0.045	0.02339
Integral Time Absolute Error (ITAE) (%)	0.0621	0.0458	0.02345
Efficiency (%)	88.1	89.7	93.1

Table 3 represents the proposed MSSA interconnected system's performance analysis function using different control techniques like PI, PID, and the proposed ORPB control systems; based on the analysis, the proposed ORPB techniques produce a better result.

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