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Power Mismatch Estimation in Smart Grid Using Distributed Control

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ABSTRACT One of the major challenges in the area of smart grids is the management of power between consumers and generators. Traditionally, the power mismatch is managed in a centralized fashion which has major shortcomings of complexity, requires large bandwidth, ineffectiveness, and unscalable. To address these problems, this paper presents a novel distributed mismatch technique in smart grids. In this algorithm, every generation and consumer unit, has to estimate the total power that has been generated, the total load and the power mismatches. The coordination and control of power nodes is achieved through distributed manner. The proposed technique achieves through consensus algorithms. Such distributed technique prevails task sharing, surviving on single link failure, efficient decision making, the fastest convergence, and autonomy for the global power nodes. The technique is suitable for all types of grid in islanded and connected mode. We evaluated optimization factors: rapid convergence, fast computation, scalability and effectiveness. The proposed distributed network examined power systems using random, unreliable, unpredicted, and arbitrary topologies. It explores distributed node convergence, optimality, and status sharing through Graphs and Matrix theories. The communication reliability, link stability, privileges distribution, comparative cost, and adoptability of propose distributed technique has been assessed. Moreover, the proposed scheme is evaluated under different communication topologies and experimental testbed results to explain the effectiveness of the algorithm.

INDEX TERMS Power mismatch, consensus algorithms, multiagent systems, smart grid, distributed control.

I. INTRODUCTION

Researchers and engineers in the field of power systems propose the integration of renewable energy sources to balance supply of power in accordance with the increase in power demand. The current architecture of power management is in centralized fashion through which each power node is connected to a central entity. It acquires highly computational resources and results in transmission delays at central location [1]. It inherits architectural complexities, extensive computations, cooperative constraints, and scalability complications. Among the major challenges of the centralized power management system, power mismatch is an emerging and hot issue [2]. The computation of power mismatch is important in order to estimate substantial changes of power flow during peak hours. The rapid increase and decrease of power demand could not accurately be estimated through existing methods [3]. In the existing system, the collection of information from power generators and demand side accumulate and process. The system becomes inefficient in case of link failure and transmission delays [4]. Moreover, system upgradation, scalability, and complexities are inherited issues in the existing power system management.

Smart grid technology provides scalable, manageable, and easy interfacing platform for power systems management and control. It has the capability to manage the dynamically changing attributes of power systems and reconfigure itself. Smart grids overcome communication link constraints, exist in centralized fashion power systems [5]. Smart grid possesses adaptable, efficient, consistent, and ingenious attributes for the management of power generation and demand sides. The communication and interfacing

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architecture of smart grid provides redundancy, stability, reconfigurability, and fault tolerance [6]. In contrast to centralized control, the transmission delays and links failure issue and cope in smart grids. In smarter grids, frequency control and distributed energy resources proposed for coordinating real-time issues of power management systems [7].

The distributed control mechanisms of power system management efficiently implement for power nodes cooperation and ancillary services. It handles different types of power grids, energy systems, transient stability constraints, inverter-based microgrids, frequency and voltage regulation, faults handling, and service restoration issues [8]–[10]. In contrast to centralized management systems, the distributing system efficiently computes power mismatch issues in a coordinated and control manner. This paper presents an effective approach to estimate power mismatch using consensus algorithms. This approach needs not architectural changes and explicit protocols for implementations. It replaces the centralized mechanism of computation power mismatch with distributed control systems. Such system collects information from closely neighbor power node to estimate power mismatch. The proposed approach is easily converging, scalable, fault tolerant, reliable, resilient, stable and economic.

The novel approach of this paper contributes globally optimal control of power system effectively. It synchronizes power nodes on the network for managing power mismatches. By implementing this technique, power management runs in an intelligent way without centralized control. Additionally, distributed energy resources can easily integrate in power system without substantial architectural modifications. In addition, the coordination and control burden of centralized power management reduced and locally manage on each power station. The mismatch issues overcome in this approach by introducing microgrids in decentralized fashion grid. Moreover, power delivery to local costumers, energy localization, reduction of power transmission losses, and cost-effective benefits are included in this method. This paper proposes a resilient technique which interconnects whole network and operates under unreliable communication without interrupting the whole network.

The rest of the paper is organized: section II describes related work incorporated to this paper, section III presents the mathematical preliminaries of graph theory and communication links, modeling of proposed distributed systems described in section IV, the problem formulation and power mismatch issues are elaborated in section V, the proposed algorithm and main results are presented in section VI and VII respectively, the case studies and experimental setup are analyzed in section VIII, the conclusive remarks and future work draw in section IX.

II. RELATED WORK

The literature of power system management and its emerging issues are addressed from different perspectives. A novel approach of consensusability and distributed control are proposed for economic dispatch, problem formulation, optimal power flow, and energy storage systems of smart grids in [11]–[14]. The multiagent based distributed control mechanism is considered in [15] for predicting delay constraints and packets drop out of the power network. The droop control, cascade failure reduction, and accurate estimation of imbalance power sharing are discussed in [16] by implementing consensusibility and decentralized approach [17]–[18]. The load restoration, fault identification, and isolation techniques [19], the unit commitment of electrical energy retailing [20], and designing of self-healing microgrids [21] are investigated through agent-based distributed system to assess various constraints and its management. The hierarchal microgrid [22] and efficient energy management of sensor network [23] are proposed for the computation of real-time interoperability issues through economic dispatch and potential game approach [24]. The distributed approach of routing regional market demand examined in [25] and trendy applications of multiagent in [26] are analyzed. The power network control optimization, islanding LV network, and voltage regulation, by implementing multiagent systems [27]–[30].

The coordination and control of multi microgrids considered for adjustable power demands and response under contingent [31], unreliable and various models of communication networks in [32]–[34]. The service restoration of distributed grids [35], transmission impairments [36] and optimal power flow [37] deliberated for the energy management of a smart grid and distributed control. The optimal control of energy storage grids, AC microgrids, and optimal dispatch of decentralized power systems scrutinized under lossy and unreliable communication environment of the multiagent network [38]–[41]. State estimation and smart grid power nodes management assume using the novel approach of multiagent systems [42] and network convergence algorithms [43]. The various types of multiagent algorithms are proposed in [44] and [45] for the computation of decentralized based intelligent systems. The communication reliability is proposed random, unreliable, reconfigurable and fixed. The resiliency of proposed algorithms examines under contingent and irregular model distributed networks.

This paper assumes power management and optimal control of smart grid in an intelligent way. The featured work of paper includes distributed pattern of multiagent based power systems, power dispatch problems, synchronization of agents through consensusability mechanisms, communication reliability of networks, shaping the centralized architecture of power systems to the distributed pattern, and distributed optimization using random communication links. The investigated paper work closely relates to adoptive modeling of energy storage systems of decentralized and active distribution networks [2]. The multiagent stability evaluation [4], cooperative control [6], real-time coordination [7], economic dispatching [11], predictability of packet loss during information exchange [15] and optimizing consensus algorithms [25]. We aim to frame and optimize distributed pattern, agent synchronization, communication reliability, optimum dispatching, and contingency conditions. To do so, we are shaping centralized architectures [1] with distributed design [4]–[6] through distributed control [7]–[13] of consensus algorithms [14]–[17] and multiagent approach [19]–[21]. In [4]–[6], consensusability of agents implemented for faults handling, voltage control, and stability constraints while the feasible approach of power handling and mismatch issues considered in the paper. In contrast to [14]–[17], our approach focuses on smart grids of all types with optimum factors and applications. Associated with [15], [31] and [36], we focus random, unreliable, unpredicted, and a limited number of communication links among agents to converge and evaluate power mismatch. For redundant links, we advise robustified first gradient approach for reducing extensive computation and efficient utilization of resources. In contrast to [39]–[42], the communication network of the proposed multiagent network in smart grid investigated for fixed, dynamic, and unreliable topologies. Moreover, the autonomy of participating agents, link capacity, computational processes, fast convergence, and operational cost are considered and benchmark with centralized power systems management. In last, experimental results of distributed control of agent controller and consensusibility processes exemplified to validate optimality of the proposed technique.

In short, decentralization approach is implemented for handling generator dynamics, transmission efficiency, fault tolerance, frequency and voltage regulation, storage systems, self-healing capabilities, economic dispatch issues and energy management systems. The communication link reliability, link constraints, delay response, and cost effectiveness are examined for distributed systems. This paper will focus on distributed pattern energy management system under numerous topologies. The novel distributed algorithm evaluated and assess resiliency for managing mismatch problems. The propose work is track towards the intelligent control of distributed grid to tackle hot issues that persist in existing grid operation.

III. MATHEMATICAL PRELIMINARIES

For distributed systems, graph properties, communication network modeling, and links reliability are important to understand the prior proposed approach.

A. GRAPH PROPERTIES

The network model, connections, and exchange information of nodes are framed by means of graph theories. The distributed network connect each node through a link termed as edge $\mathcal{E}$ while nodes term as vertices v. The graph $\mathcal{G}$ represents the combination of interconnected nodes through direct or indirect communication links as $\mathcal{G} = \{v, \mathcal{E}\}$ [24]. The $\mathcal{N}$ number of nodes $\{v_1, v_2, v_3 \ldots v_n\}$ connected through a bi-directional links $\mathcal{E} = \{v \times v\}$. The nodes of i and j index adjacent to other is $\mathcal{A} = [\mathrm{e}_{i,j}]$ for all $\left[\mathrm{e}_{i,j}\right] > 0$ if $(v_i, v_j) \in \mathcal{E}$ and $\mathrm{e}_{i,j} = 0$ otherwise. Now the neighbor nodes v_i and v_j are represented as $\mathcal{N}_i = \{v_j : (v_i, v_j)\}$ and $\mathcal{N}_j = \{v_i$: $(v_j, v_i)\}$ respectively. Now the degree matrix shows number of links $\mathcal{E}$ connected to each node v_i and v_j as $\mathcal{D} = diag[d_1, d_2, d_3 \ldots\ldots d_n]$ with $d_i = sum(\mathrm{e}_{i,j})$ which is row sum of $\mathcal{E}$ [36]. The connectivity of nodes ensures through Laplacian Matrix $\mathcal{L} = \mathcal{D} - \mathcal{A}$. It define communication paths among the nodes of v_{i1} to v_{ik} is links $\mathcal{E}$ sequence $(v_{i1}, v_{i2}), (v_{i2}, v_{i3}), (v_{ik-1}, v_{ik})$, with $\left(v_{i-1}, v_{i,j}\right) \in \mathcal{E}$ or $\left(v_{i,j}, v_{i-1}\right) \in \mathcal{E}$. Any Laplacian Matrix having eigenvalue set consist of single zero represents undirected connected graph of distributed network. The bi-directionality B of graph satisfied the condition of $\mathrm{e}_{i,j} > 0 = \mathrm{e}_{i,j} > 0$ or $\mathrm{B} = \left[\mathrm{e}_{i,j} > 0\right] = \left[\mathrm{e}_{i,j} > 0\right]^{\mathcal{T}}$. The eigenvalues of bi-directional and balance graph of distributed network has $\lambda_i e_{i,j} = \lambda_j e_{j,i}$ [38]. The reversibility of balance graph of the nodes is pertinent to Markov Process.

B. COMMUNICATION NETWORK

From previous discussions, the pairs of communication links among node i and $j \in \mathcal{E}$. To avoid self–looping connections of node i and j, we suppose (j, j) and $(i, i) \notin \mathcal{E}$. Although each node i and $j \in v$ such that each node process self–state in the network [41]. The communication path of nodes i is kth number such that $(i_n, i, j) \in \mathcal{E}$ for $j = 1, 2, 3 \ldots k - 1$. The communication network of nodes satisfies Adjacency with neighbors, Degree, and Laplacian Matrix theories. The graph $\mathcal{G}$ of node i and j connected if it holds Adjacency $\mathcal{A} = [\mathrm{e}_{i,j}]$ conditions express as follow,

Lemma 1:

$$\mathrm{e}_{i,j} = \begin{cases} 1, & \text{for } (v_i, v_j) \in \mathcal{E} \\ 0, & otherwise \end{cases} \quad 1a$$

Now the participant node exists in communication network represented with Degree matrix $\mathcal{D}$ of graph $\mathcal{G}$ theory as $\mathcal{D} = diag[d_{ij}]$ as:

Lemma 2:

$$\mathcal{D} = \begin{bmatrix} d_{ij} & \cdots & 0 \\ \vdots & d_{ij} & \vdots \\ 0 & \cdots & d_{ij} \end{bmatrix} \quad 1b$$

The d_{ij} is positive integer value for the number of links exist among i and j nodes in the communication network.

It is important for the connected nodes in a communication network that ensured through eigenvalues of Laplacian matrix $\mathcal{L}$. The Laplacian matrix achieved through

$\mathcal{L} = \mathcal{D} - \mathcal{A}$ express as:

Lemma 3:

$$\mathcal{L} = \mathcal{D} - \mathcal{A} = \begin{bmatrix} d_{ij} & \cdots & 0 \\ \vdots & d_{ij} & \vdots \\ 0 & \cdots & d_{ij} \end{bmatrix} - \begin{bmatrix} e_{ij} & \cdots & e_{ij} \\ \vdots & e_{ij} & \vdots \\ e_{ij} & \cdots & e_{ij} \end{bmatrix} \quad 1c$$

C. LINKS RELIABILITY

The link reliability of distributed systems is considered a partially and strongly connected node in the network. The strongest reliability of link $\mathcal{E}$ defines each i and j nodes

TABLE 1. The list of symbols.

Symbol	Description
$\mathcal{E}$	Edge or Link
$\mathcal{N}_{ij}^{out}$	Neighbor i and j transmitting link
$\mathcal{N}_{ij}^{in}$	Neighbor i and j reciving link
$\mathcal{A}[e_{i,j}]$	Adjacency matrix of i and j
$\mathcal{D}[d_{ij}]$	Degree matrix of node i and j
$v_g \times v_d$	Generator and Load node
$\mathcal{G}$	Graph of multiagent network
$\mathcal{L}$	Laplacian matrix of agents
p_i^t	Instantaneous power of generator
L_i, C_f, L_c	State Space variables
$\mathcal{P}_i(k)$	Initial state of generator for k iteration
$\ell_i(k)$	Initial state of load for k iteration
$\mathcal{Z}_a(k)$	Initial state of nodes for k iteration
$\mathcal{C}_{i,j}(\tau;\mu)$	Convergence of node i and j for time τ
α, β and Υ	Matrix weight for converging graph
$\mathcal{M}(k)$	Exchange value of neighbor generators
$\mathcal{N}(k)$	Exchange value of neighbor loads
$\mathcal{Y}(k)$	Exchange value of all nodes
$\Delta\mathcal{P}$	Power mismatch of distributed graph
$\mathrm{T}_i(k)$	Total iterations of i nodes

connected with each other having $\mathcal{D}(max)$ for all v_i and v_j. Let assume that $\mathcal{N}_{ij}^{in}$ and $\mathcal{N}_{ij}^{out}$ are the in and out neighbors of nodes v_i and v_j [36].

Lemma 4:

$$\mathcal{N}_{ij}^{in} = \{i, j \in v| \, (i,j) \in \mathcal{E}\} \quad 2a$$
$$\mathcal{N}_{ij}^{out} = \{j, i \in v| \, (j,i) \in \mathcal{E}\} \quad 2b$$

The partial connectivity of nodes v_i and v_j with limited bi-directional links $\mathcal{E}$ hold $\mathcal{D}(min)$ of graph connectivity.

Lemma 5:

$$\mathcal{N}_{ij}^{in} = \{i, j \in v| \, (i,j) < \mathcal{E}\} \quad 2c$$
$$\mathcal{N}_{ij}^{out} = \{j, i \in v| \, (j,i) < \mathcal{E}\} \quad 2d$$

The symbols list we use in this paper is given in table 1 as following.

D. MOTIVATING EXAMPLE

Let a distributed network of four random nodes associated each with communication link that converge and update their status in distribution pattern. The distributed systems implemented through consensus algorithms in which nodes initial states and estimated states maintain via consensus variable. The nodes (generators/loads) exchange their consensus variable with corresponding neighbor. The information exchange among the nodes is possible only if all nodes are connected with each other. In every iteration, every participating node exchanges its initial state and updates the consensus variable in the next iteration. The information exchange depends upon the number of edges/links of nodes. As the number of links increases, the consensus will be achieved rapidly in fewer iterations. Figure 1 is representing as a distributed graph of four nodes.

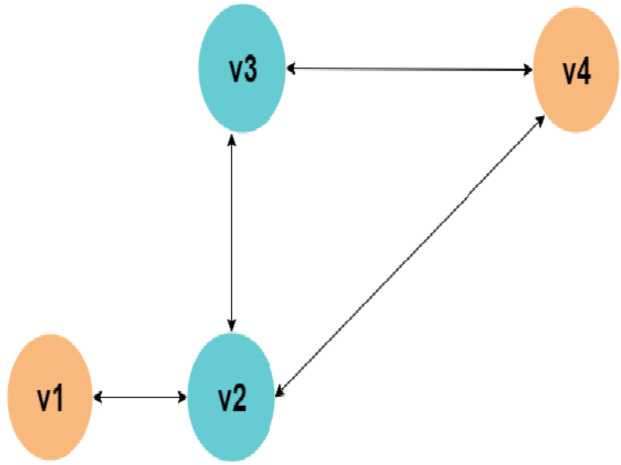

FIGURE 1. The communication network of four nodes.

Let $\mathcal{E}$ is link/edge set of v nodes express as:

$$\mathcal{E} = \{(v_1, v_2), (v_2, v_3), \ldots\ldots\ldots\ldots (v_3, v_4)\}$$

The neighborhood nodes of figure 1 are:

$$\mathcal{N}_1 = v_2$$
$$\mathcal{N}_2 = v_3, v_4$$
$$\mathcal{N}_3 = v_2, v_4$$
$$\mathcal{N}_4 = v_2, v_3$$

The calculated adjacency matrix $\mathcal{A}_{g,d}$ of the graph is express as

$$\mathcal{A}_{g,d} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix} \quad i$$

The link association and degree of graph illustrate as

$$\mathcal{D}_{g,d} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 3 & 0 & 0 \\ 0 & 0 & 2 & 0 \\ 0 & 0 & 0 & 2 \end{bmatrix} \quad ii$$

The connectivity of v_g and v_d nodes achieve as

$$\mathcal{L}_{g,d} = \begin{bmatrix} 1 & -1 & 0 & 0 \\ -1 & 3 & -1 & -1 \\ 0 & -1 & 2 & -1 \\ 0 & -1 & -1 & 2 \end{bmatrix} \quad iii$$

IV. MODELING PROPOSED SYSTEM

The modeling attributes exemplified in terms of generator dynamics, generator controllers, and communication networks.

A. MODELING GENERATOR DYNAMICS

The dynamics of i_{th} distributed generators considered for a single phase of n_{th} numbers. The state–space model of i_{th} distributed generators are given as:

$$I_i = -\frac{R_i}{L_i} i_i + \frac{1}{L_i}(v_i - v_o) \quad 3a$$

$$V_o = \frac{1}{C_f}(i_i - i_o) \quad 3b$$

$$I_o = -\frac{R_c}{L_c} i_o + \frac{1}{L_c}(v_o - v_i) \quad 3c$$

Here i_i, v_i, v_o, and i_o are generator variables for controlling input/output while R_i, L_i, R_c, C_f, and L_c are generator parameters [40].

The frequency and phase of i_{th} generators are to be set as:

$$\omega_i(t) = \int_0^t \varphi_{\omega i}(\tau)\, d_\tau + \omega_i(0) \quad 4a$$

$$\vartheta_i(t) = \int_0^t \omega_i(\tau)\, d_\tau + \vartheta_i(0) \quad 4b$$

Here $\varphi_{\omega i}$ is frequency control input of the generator.

The power assumes as instantaneous and active for real and reactive power of i_{th} generators as:

$$p_i^t = v_i^t i_i, \quad q_i = \frac{1}{\sqrt{3}}\phi(v_i \times i_i) \quad 5$$

Now by applying a low–pass filter for filtering high-frequency harmonics and achieve active and reactive power as:

$$\dot{\mathrm{P}}_i = \omega_c\left(p_i^t - P_i\right), \quad R_i = \omega_c(q_i - Q_i) \quad 6$$

B. MODELING CONTROLLERS

The controllers of power mismatch network composed of generators and loads. The primary commands of generators are voltage and frequency that propose to optimize in secondary droop control. For active power delivery, we transform primary control attributes of frequency and voltage to a secondary control parameter. The reactive power does not include in consensusability and power mismatch. Let ω_i and v_i is generator and demand frequency and voltage. The system expresses as:

$$\dot{\mathrm{w}}_i = \begin{cases} \omega_c\left(\omega_i - \omega_{avg}\right) & |\omega_c| < w_i \\ 0 & |\omega_c| \geq w_i \end{cases} \quad 7$$

$$\dot{v}_i = \begin{cases} \omega_c\left(v_i - v_{avg}\right) & |\omega_c| < v_i \\ 0 & |\omega_c| \geq v_i \end{cases} \quad 8$$

C. PROPOSED COMMUNICATION NETWORK

The distributed generators and loads view as a multiagent network of $\sum N$ generators and loads. The distributed nodes consist of v_g generators and v_d loads. The graph of nodes splits in two types of having adjacency and consensusability. Let $\mathcal{G}_g = \{v_g, \mathcal{E}_\tau\}$ and $\mathcal{G}_d = \{v_d, \mathcal{E}_\tau\}$ for distributed generators and load respectively. Assume bi-directional links for both graphs will be $\mathcal{E}_\tau = \{v_g \times v_d\}$. Let the adjacencies of v_g and v_d express as $\mathcal{A}_{g,d} = [e_{g,d}(\tau)]$. The degree of nodes is maximum link connecting each node in the graph as $\mathcal{E}_\tau = \{v_g \times v_d\}$. The entire connectivity of distributed generators and loads ensure as $\mathcal{L}_{g,d} = \mathcal{D}_{g,d} - \mathcal{A}_{g,d}$. In this way, consensusability among v_g and v_d achieve through each time instant τ in the multiagent network.

V. PROBLEM FORMULATION

This paper introduces a novel approach of consensusability of distributed control of power mismatch estimation using random communication links. The deployment and implementation cost of the proposed technique are the same as centralized. Whereas, optimized power management is more efficient than centralized control systems. The consensusability inspired in control [17], [36] and autonomic computing [21], [30], [32], [35] applications are mostly implemented in this paper. The network consists of several distributed nodes reaching an agreement of mutual interest of initial state variable. Our approach focuses on active power generation, load, and estimation of power mismatch in real-time. The power mismatch is estimated by unreliable and random communication links. The power assumed as active power as state variable for considering a more realistic case. The limit of generated power and power consume collectively defined from initial state variables of nodes. The consensus among nodes proposed to perform explicitly among distributed generators, loads, and total participating nodes. The status of each node updated in an iterative mechanism of the consensus algorithm. The mismatch of power approximated in the smart grid through average consensus algorithms. The communication model of distributed nodes is supposed to be uncertain and unreliable. The pattern of the communication network is considered a random and limited number of links.

Let transform consensusability theories into power mismatch condition for analyzing and optimizing results. The generator node v_g and demand response v_d of index $n = 1, 2, 3 \ldots n$ and total participating nodes or $v = vg \cup vd$. The convergence of smart grid network consists of generator and load of i and j nodes for $k = 1, 2, 3 \ldots n$ iteration represents as:

$$\mathcal{P}_i(k+1) = \mathcal{P}_i(k) + \alpha \sum_{j \in \mathcal{N}_i} [\mathcal{P}_j(k) - \mathcal{P}_i(k)] \quad 9a$$

$$\ell_i(k+1) = \ell_i(k) + \beta \sum_{j \in \mathcal{N}_i} [\ell_j(k) - \ell_i(k)] \quad 9b$$

$$\boldsymbol{\Delta\mathcal{P} = \ell_n - \mathcal{P}_n} \quad \mathbf{9c}$$

In addition, total participating nodes of consensus-based network illustrate as:

$$\boldsymbol{\mathcal{Z}_a(k+1) = \mathcal{Z}_a(k) + \Upsilon \sum_{b \in \mathcal{N}_a} [\mathcal{Z}_b(k) - \mathcal{Z}_a(k)]} \quad \mathbf{9d}$$

VI. PROPOSED ALGORITHM

The fundamental approach to achieve a consensus of nodes holding homogeneity, communication reliability, link redundancy, and linearity. It is analyzed and computed through state space differential equations of $\mathbf{9}a$, $\mathbf{9}b$, $\mathbf{9}c$, and $\mathbf{9}d$. The complication urges in consensusability of nodes with unreliable communications, limited communication topology, heterogeneity, and nonlinearity attributes. It is an inflexible approach to apply linear convergent approach on nonlinear time dependent situations.

Let the contingent condition among smart grid nodes modeled on the probabilistic approach of nonzero probability. Let the contingent communication initiated from node *i* to *j*. The intermittent communication model of the distributed network is $(\chi, \mathcal{K}) \in \mathcal{E}$. The convergence of nodes indicated as $\mathcal{C}_{i,j}(\tau;\mu) : \chi \rightarrow \{0,1\}$ for communication of node *i* to *j* be establish or not. From this assumption, let the updates node *i* received by node *j* is $\mathcal{C}_{i,j}(\tau;\mu) = 1$ and node *i* lost communication with node *j* is $\mathcal{C}_{i,j}(\tau;\mu) = 0$. For each interval τ and edge $\mathcal{E}$, $\mathcal{C}_{i,j}(\tau:\mu)$ is define to *i* to *j* nodes. Let consider a random vector and arbitrary communication links for all variables $\mathcal{C}_{i,j}(\tau:\mu) : (i,j) \in \mathcal{E}$. The contingent communication assumptions for $\mathcal{C}_{i,j}(\tau:\mu)$ is following,

i. The nodes of $\mathcal{C}_{i,j}(\tau:\mu)$ are independent.
ii. The link reliability preserved in limits of $1-\mathcal{C}_{i,j}(\tau:\mu) < 1 : \{0.1 \rightarrow 0.9\}$.
iii. The nodes of *i* to *j* uniformly distributed in the network.

The proposed algorithm explicitly exchanges information among heterogeneous nodes to compute state information. The nonlinearity of nodes deals with Lyapunov candidate function and intermittent communication through the nonzero probabilistic approach. The information exchange for each node updated on every iteration. In this way, the algorithm achieves consensusability among nodes under contingent communication network. Moreover, the optimization of proposed algorithm focused in term of limited iterations for consensusibility and fastest convergence of nodes than $\mathbf{9}a$, $\mathbf{9}b$, $\mathbf{9}c$, and $\mathbf{9}d$. The power mismatch proposed algorithm of converging heterogenic nodes under intermittent communication scenario is exemplified as:

$$\Delta\mathcal{P} = \begin{cases} \ell_i(k) - \mathcal{P}_i(k) + \dfrac{1}{\mathcal{C}_{i,j}(\tau:\mu)} \\ [\mathcal{M}(k) - \mathcal{N}(k)] \quad \forall 1 - \mathcal{C}_{i,j}(\tau:\mu) < 1 \\ \mathcal{Z}_a(k) + \dfrac{1}{\mathcal{C}_{i,j}(\tau:\mu)}[\mathcal{Y}(k)] \\ \quad \forall 1 - \mathcal{C}_{i,j}(\tau:\mu) < 1 \\ 0 \quad \forall 1 - \mathcal{C}_{i,j}(\tau:\mu) > 1 \end{cases} \tag{10}$$

Proof of Algorithm: The mismatch of power network having load ℓ_n and distributed generation power $\mathcal{P}_n$. The mismatch estimated linearly as Eq.10.

$$\Delta\mathcal{P} = \ell_n - \mathcal{P}_n \tag{10a}$$

Let the consensusability among load is

$$\ell_i(k+1) = \ell_i(k) + \beta \sum_{j\in\mathcal{N}_i} [\ell_j(k) - \ell_i(k)] \tag{10b}$$

Let the input of load systems

$$\mathcal{M}(k) = \sum_{j\in\mathcal{N}_i} [\ell_j(k) - \ell_i(k)] \tag{10c}$$

So $\mathbf{10}b$ became

$$\ell_i(k) = \ell_i(k) + \mathcal{M}(k) \tag{10d}$$

Let expand $\mathbf{10}d$ matrices as

$$\ell_i(k) = \begin{bmatrix} \ell_1(k) \\ \ell_2(k) \\ \dots \quad \dots \\ \dots \quad \dots \\ \ell_n(k) \end{bmatrix} \tag{10e}$$

And

$$\mathcal{M}(k) = \begin{bmatrix} \mathcal{M}_1(k) \\ \mathcal{M}_2(k) \\ \dots \quad \dots \\ \dots\dots \\ \mathcal{M}_n(k) \end{bmatrix} \tag{10f}$$

After a single iteration of information exchange

$$\ell_i(k+1) = \begin{bmatrix} \ell_1(k+1) \\ \ell_2(k+1) \\ \dots \quad \dots \\ \dots \quad \dots \\ \ell_n(k+1) \end{bmatrix} \tag{10g}$$

Let the input $\mathcal{M}(k)$ received by node from their neighbor ℓ_j become $\mathbf{10}c$

$$\mathcal{M}(k) = \sum_{j\in\mathcal{N}_i} [\ell_j(k) - \ell_i(k)] \tag{10c}$$

Expand $\mathbf{10}c$ in a global matrix form of Adjacency and Laplacian is

$$\mathcal{M}(k) = \left(\begin{bmatrix} d_{ij} & 0 \\ 0 & d_{ij} \\ \dots & \dots \\ d_{ijn} & d_{ijn} \end{bmatrix} - \begin{bmatrix} e_{ij} & e_{ij} \\ e_{ij} & e_{ij} \\ \dots & \dots \\ e_{ijn} & e_{ijn} \end{bmatrix} \right) \ell(k) \tag{10h}$$

Now, for the connected graph of nodes, the algorithm must meet the condition of the nonzero probabilistic model.

$$\mathcal{C}_{i,j}(\tau:\mu) : \chi \rightarrow \{0,1\} \tag{10i}$$

We proposed random connectivity in which the values of $\mathcal{C}_{i,j}(\tau:\mu)$ for each interval time τ is not constant. So $\mathbf{10}h$ became:

$$\mathcal{M}(k) = \left(\left[\mathcal{D}_{i,j} - \mathcal{A}_{i,j} \right] \right) \ell(k) \tag{10j}$$

Using Lemma 3,

$$\mathcal{M}(k) = \left(\left[\mathcal{L}_{i,j} \right] \right) \ell(k) \tag{10k}$$

Let the matrix weight β represents random topology of connected nodes in systems is

$$\beta = \frac{1}{\max\{\mathcal{C}_{i,j(\tau:\mu)}\chi \rightarrow \{0,1\}} \tag{10l}$$

Now, by combining $\mathbf{10}c$ and $\mathbf{10}g$, the distributed load will be $\mathbf{10}b$.

$$\ell_i(k+1) = \ell_i + \frac{1}{\mathcal{C}_{i,j}(\tau:\mu)}[\mathcal{M}(k)] \tag{10b}$$

The same approach adopted for distributed generator nodes of **9*a*** which became

$$\mathcal{P}_i(k+1) = \mathcal{P}_i + \frac{1}{\mathcal{C}_{i,j}(\tau:\mu)}[\mathcal{N}(k)] \qquad \mathbf{10}m$$

Our proposed algorithm for estimation of power mismatch is illustrated in **10*a*** as

$$\Delta\mathcal{P} = \ell_n - \mathcal{P}_n \qquad \mathbf{10}a$$

Rearranging **10*b*** and **10*n*** for **10*a***.

$$\Delta\mathcal{P} = \ell_i(k) - \mathcal{P}_i(k) + \frac{1}{\mathcal{C}_{i,j}(\tau:\mu)}[\mathcal{M}(k) - \mathcal{N}(k)] \qquad \mathbf{10}a$$

The above algorithm is valid for $\forall 1 - \mathcal{C}_{i,j}(\tau:\mu) < 1$ where the maximum degree of convergence in range of 0.1 to 0.9.

Now, the next step of the algorithm is to estimate a total number of nodes n participating in smart grid network irrespective of their status. Another assumption is proposed in algorithm as

$$n = \mathcal{Z}_a(k) + \frac{1}{\mathcal{C}_{i,j}(\tau:\mu)}[\mathcal{Y}(k)] \qquad \mathbf{10}n$$

The convergence conditions and link reliability of all participating nodes are the same.

However, when the communication between node loss and could not able to exchange information with a neighbor, the power mismatch and total participated node estimation become false as $\forall 1 - \mathcal{C}_{i,j}(\tau:\mu) > 1$. Using piecewise function and linear algebra, we combined proposed algorithms as eq. 10.

$$\Delta\mathcal{P} = \begin{cases} \ell_i(k) - \mathcal{P}_i(k) + \dfrac{1}{\mathcal{C}_{i,j}(\tau:\mu)} \\ [\mathcal{M}(k) - \mathcal{N}(k)] \quad \forall 1 - \mathcal{C}_{i,j}(\tau:\mu) < 1 \\ \mathcal{Z}_a(k) + \dfrac{1}{\mathcal{C}_{i,j}(\tau;\mu)}[\mathcal{Y}(k)] \\ \qquad \forall 1 - \mathcal{C}_{i,j}(\tau:\mu) < 1 \\ 0 \quad \forall 1 - \mathcal{C}_{i,j}(\tau:\mu) > 1 \end{cases} \qquad (10)$$

VII. MAIN RESULTS

To effectively manage power mismatch estimation through robustified consensus algorithms, we optimized distributed based consensus algorithms. The consensusability of smart grid power mismatch is consider for random, fixed, and unreliable communication links. After that, node connectivity and convergence are confirmed with the positive probabilistic multiagent model.

A. CONSENSUSABILITY AND ALGORITHM RESILIENCY

The consensusability of node for different variable of generators, loads, total participating nodes, and packets drop are investigated. The information is exchanged explicitly among generators $\mathcal{P}_i(k+1)$, loads $\ell_i(k+1)$ and total participating nodes $Z_i(k+1)$ under link intermittence $\mathcal{C}_{i,j}(\tau:\mu)$. Nodes are iteratively update their status with neighbor $\sum_{j\in\mathcal{N}_i}$ and estimate total power. The updated information of nodes $[\mathcal{P}_j(k) - \mathcal{P}_i(k)]$, $\mathcal{L}_j(k) - \mathcal{L}_i(k)]$ and $[Z_j(k) - Z_i(k)]$ is stored in system memory. The matrix weights α, β and Υ corresponds to $\frac{1}{\max \mathcal{C}_{i,j}(\tau:\mu):\chi\to\{0,1\}}$ of distributed power network. Link contingency $\frac{1}{\max \mathcal{C}_{i,j}(\tau:\mu):\chi\to\{0,1\}}$ is optimized to $1-\mathcal{C}_{i,j}(\tau:\mu) < 1 : \{0.1 \to 0.9\}$. The bi-directionality B of nodes satisfies $e_{i,j} > 0 = e_{i,j} > 0$ or $B = [e_{i,j} > 0] = [e_{i,j} > 0]^{\mathcal{T}}$. The information of $\mathcal{P}_i$, $\mathcal{L}_i$ and Z_i update when nodes i and j are linked successfully. The nodes broadcast their running state with neighbor after next iteration and sum-up converging values, i.e.$\mathcal{P}_i(k+1)$, $\mathcal{L}_i(k+1)$, $Z_i(k+1)$ and $\mathcal{C}_{i,j}(\tau:\mu)$. After that, j node updates itself after receiving latest information from neighbor. The averaging process continue until node status become same and hence consensus is achieved. Finally, the results of $\Delta\mathcal{P}$ computed for estimation of power mismatch.

Remark 1: The proposed algorithm of 9*a*, 9*b*, 9*c*, and 9*d* robustly computed power mismatch estimation in distributed pattern. The centralized mechanism replaces by proposed algorithm and network efficiently converge through unreliable link contingency for $\mathcal{P}_i(k+1)$, $\mathcal{L}_i(k+1)$, $Z_i(k+1)$, and $\Delta\mathcal{P}$.

Remark 2: The resiliency of consensus-based algorithm investigates under intermittent communication scenario for each interval τ and edge $\mathcal{E}$ of $\mathcal{C}_{i,j}(\tau:\mu)$ for node i and j.

B. DISTRIBUTED SYSTEM CONVERGENCE

The convergence of nodes under the contingent condition of proposed algorithm evaluated here. For each node of $\mathcal{P}_i(k+1)$, $\ell_i(k+1)$, $Z_i(k+1)$ and $\Delta\mathcal{P}$ converged to an optimal state. After that, the node consensusability computed. We focus convergence analysis and optimization in order to compute optimal consensus values.

For convergence analysis and optimizations, the preliminary theorems of 9*a*, 9*b*, 9*c*, and 9*d* are necessary to explored for optimum results of proposed algorithm. The average consensus among explicit nodes of power nodes and total participated nodes under unreliable communication networks:

1. **Input:** $\mathcal{P}_i(0) = 0$, $\ell_i(0) = 0$, $Z_i(0) = 0$, $\forall \mathcal{N}_{ij}^{in} \in \mathcal{E}$
   For $k \geq 0$
2. **Compute:**

$$\sum_{j\in\mathcal{N}_i}[\ell_j(k) - \ell_i(k)]$$
$$\sum_{j\in\mathcal{N}_i}[\mathcal{P}_j(k) - \mathcal{P}_i(k)]$$
$$\sum_{b\in\mathcal{N}_a}[Z_b(k) - Z_a(k)]$$

3. **Broadcast:** from $\mathcal{P}_i(1)$, $\ell_i(1)$, $Z_i(1)$ to all on $\mathcal{N}_{ij}^{in} \in \mathcal{E}$ in network.
4. **Receive:**

$$\mathcal{P}_i(k+1)$$
$$\ell_i(k+1)$$
$$Z_i(k+1)$$

on $\mathcal{N}_{ij}^{out} \in \mathcal{E}$.

5. **Set:** $\frac{1}{max\,\mathcal{C}_{i,j}(\tau:\mu):\chi\to\{0,1\}}$ for α, β and Υ.
6. **Compute:**

$$\sum_{j\in\mathcal{N}_i}[\ell_j(k)-\ell_i(k)]$$
$$\sum_{j\in\mathcal{N}_i}[\mathcal{P}_j(k)-\mathcal{P}_i(k)]$$
$$\sum_{b\in\mathcal{N}_a}[Z_b(k)-Z_a(k)]$$

7. **Compute:**

$$\mathcal{P}_i(k+1)$$
$$\ell_i(k+1)$$
$$Z_i(k+1)$$

8. Estimate: $\Delta\mathcal{P}$ and $Z_a(k)$ for $\forall 1-\mathcal{C}_{i,j}(\tau)<1$.

VIII. CASE STUDIES AND EXPERIMENTAL TESTBED

The effectiveness of our proposed algorithm for power mismatch estimation is investigated in subsections using various communication topologies. The different case studies focus on realistic problems and variable which should be emphasized like fast convergence, algorithm resiliency, CPU processing, and link speed. The communication reliability considered under the proposed algorithm. The simulation of unreliable communication topologies considers under Monte Carlo simulation. The error tolerance value of each scenario kept as minimum as 10^{-10}. The total number of iterations considered for power mismatch estimation and node computation is represented in eq.11.

$$\mathrm{T}_i(k)=\sum_{j\in\mathcal{N}_i}\left|\mathrm{x}_j(k)-\mathrm{x}_i(k)\right| \quad \forall k=1,2,3\ldots\mathrm{n} \qquad 11$$

A. DYNAMIC TOPOLOGY OF NODES

The node positions under this topology are changing continuously with time and each iteration. As the change in nodes topology produced a degree of the graph in real-time as discussed in 10*h* and 10*j*. Subsequently, the adjacency of nodes and graph connectivity become complex in order to achieve consensus for estimating power mismatch and nodes computations. In such scenarios, the cooperation among nodes, information exchange, dynamic nature of the link and convergence become complex. The number of nodes and their initial states are unknown in the network. Moreover, the communication links dynamically change after each interval τ. Our proposed algorithm optimistically computed and estimated mention issues in an efficient manner. The dynamically changing graph of twenty nodes equally distributed among generators and loads in this case. In contrast to [43], the convergence time and values is more optimistic to run algorithm in limited number of iterations as table 2 shows.

The node communication network, total generated power, total load, and number of participating nodes shown in figure 2–5 respectively.

TABLE 2. Parametric results of consensus achieved in dynamic topology.

Nodes	$\tau(10^{-6})$ sec	CPU(MHz)	$\mathrm{T}_i(k)$	$\mathcal{C}_{i,j}(\tau;\mu)$
Generator	0.035	2.21	160	0.060
Load	0.031	2.36	148	0.060
Total	0.037	2.42	143	0.060

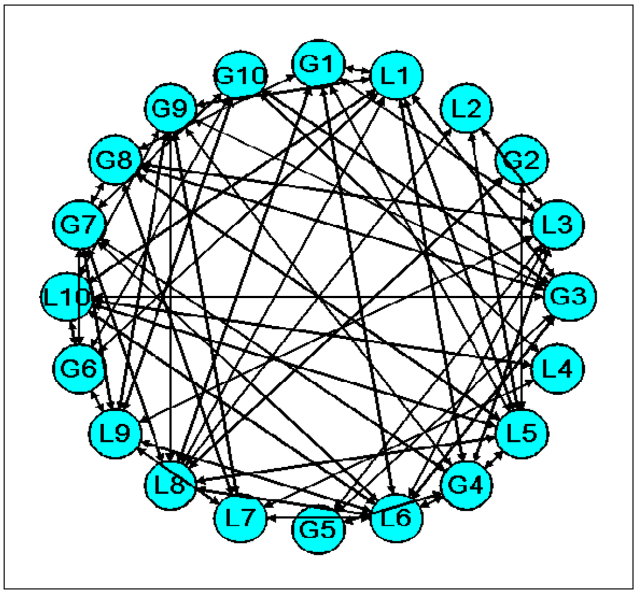

FIGURE 2. Consensusability of 20 nodes using dynamic topology of smart grid network.

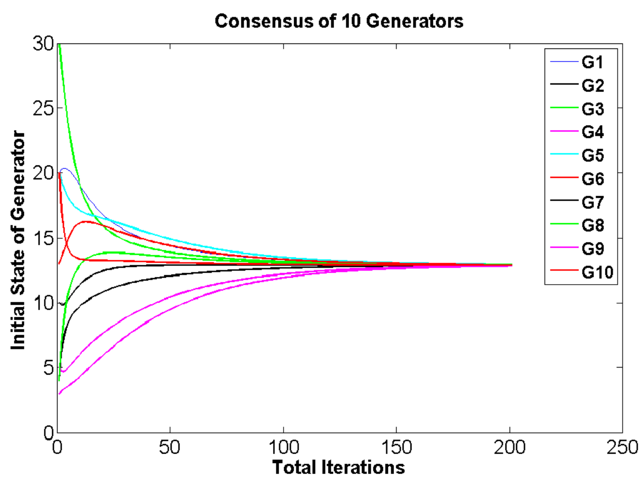

FIGURE 3. Consensus among generators through dynamic topology of communication.

Figure 2 represents the dynamic topology of twenty nodes of equally distributed among generators and loads. The communication links considered bi-directional $\mathrm{B}=[\mathrm{e}_{i,j}>0]=[\mathrm{e}_{i,j}>0]^{\mathcal{T}}$ and avoid self–looping connections of node *i* and *j*, we suppose $(i,\,i)$ and $(j,\,j)\notin\,\mathcal{E}$. The parameters examined for the analysis and optimization consensusibility of random topology in table 2. Figure 3–5 illustrate the consensus of

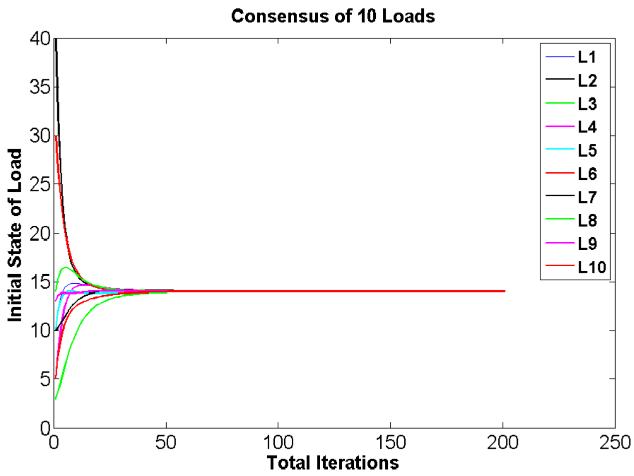

FIGURE 4. Consensus among loads through dynamic links of communication.

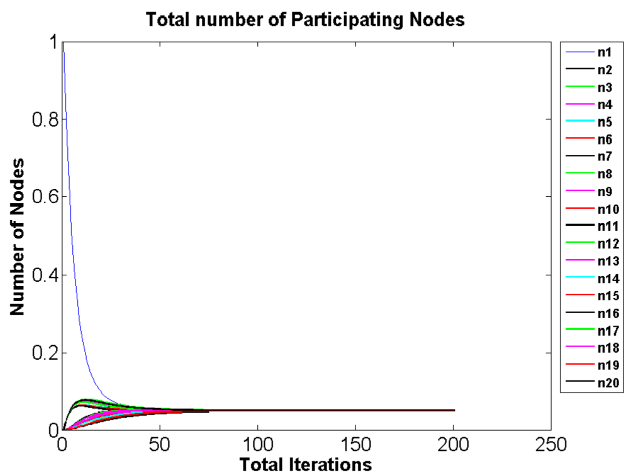

FIGURE 5. Estimation of participating nodes of the smart grid using dynamic communication links.

generators, loads, and total nodes of the smart grid. The consensus values depend on the initial states of nodes. The convergence $\mathcal{C}_{i,j}(\tau : \mu)$ of the fully connected random topology of distributed network observe as 0.060. It exemplifies the proposed algorithm is efficient, promising, and effective for estimation of power mismatch and distributed control applications.

B. FIXED TOPOLOGY OF NODES

The investigations in this case, explore node communication through the fixed and fully meshed topology. In such conditions, the convergence value of nodes considered as peak as discussed in section IV and 10g. The redundancy of edges on $\mathcal{N}_{ij}^{in} \in \mathcal{E}$ and $\mathcal{N}_{ij}^{out} \in \mathcal{E}$ considered among the nodes. The massive processing and memory required for updating status and exchange information on each edge after every single iteration. The cooperation and consensusability of nodes accomplish in very limited iterations, however, the link cost and communication interfacing become a significant issue in

TABLE 3. Parametric results of consensus achieved in fixed topology.

Nodes	$\tau(10^{-6}$) sec	CPU(MHz)	$\mathrm{T}_i(k)$	$\mathcal{C}_{i,j}(\tau;\mu)$
Generator	0.011	24.46	29	0.10
Load	0.009	26.77	28	0.10
Total	0.014	23.74	26	0.10

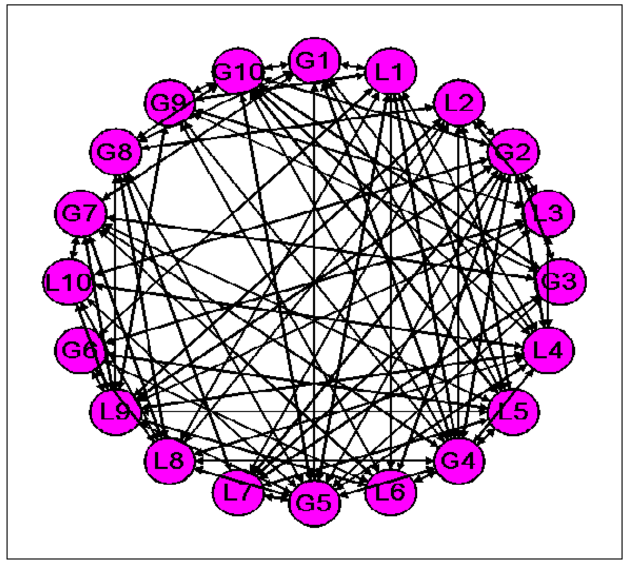

FIGURE 6. Consensus control of 20 nodes in fixed topology of smart grid network.

such cases. The remaining variables of this case is similar as the random topology of communication network such as bi-directionality $e_{i,j} > 0 = e_{i,j} > 0$, initial status of nodes, time interval τ and number of iterations. The probability of link failure does not affect consensusability and computation of participating nodes in fixed topology fully connected network. In contrast to [44], the convergence among the nodes is efficiently achieved in limited number of iterations. The convergence efficiency is approximately three times better as table 3 illustrate.

The fixed topology of nodes in which total power, total load, and total nodes shown in figure 6–9 correspondingly.

The distributed network of fixed topology of smart grid is represented in figure 6. Apart from self–looping connections, the communication links $\mathcal{E}$ and convergence value is high as investigated in 10h and 10g. Figure 7–9 illustrate consensus control of generators, loads, and total participating nodes of the distributed smart grid. As a result, the power mismatch estimation and node computation achieve in few iterations through consensus control algorithm. The performance parameter of a fixed communication network given in table 3. The computational power and processing are urged due to complex and fully meshed network. The convergence $\mathcal{C}_{i,j}(\tau : \mu)$ of such type of communication network optimum than random topology network. The convergence time τ in this case is highest than other communication topology of distributed networks. Moreover, the resiliency and

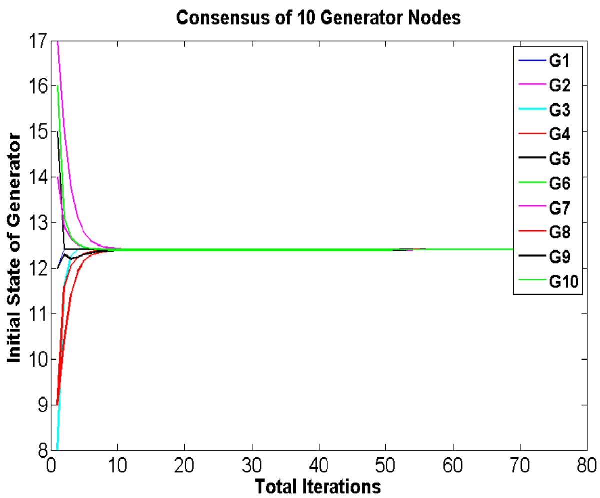

FIGURE 7. Consensusability of generators in the fixed topology of the communication network.

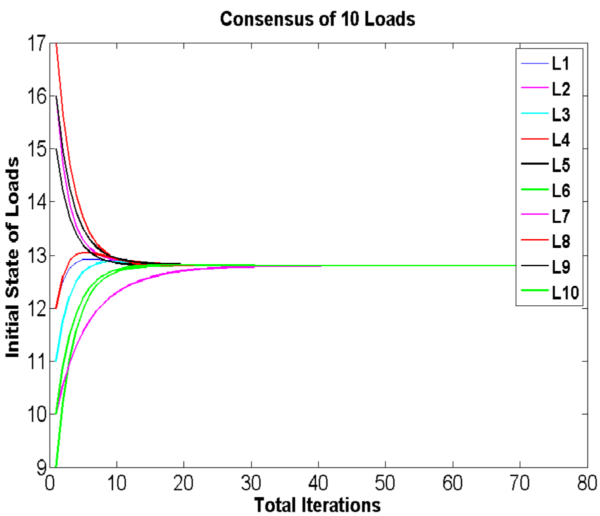

FIGURE 8. Consensusability of Loads in the fixed topology of the communication network.

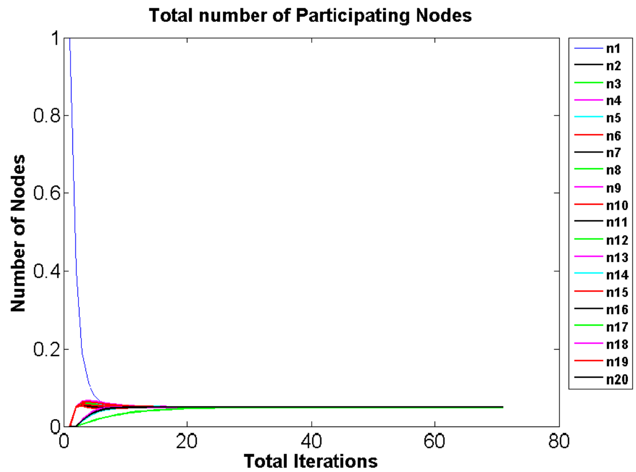

FIGURE 9. Estimation of participating nodes of the smart grid using the fixed topology of communication links.

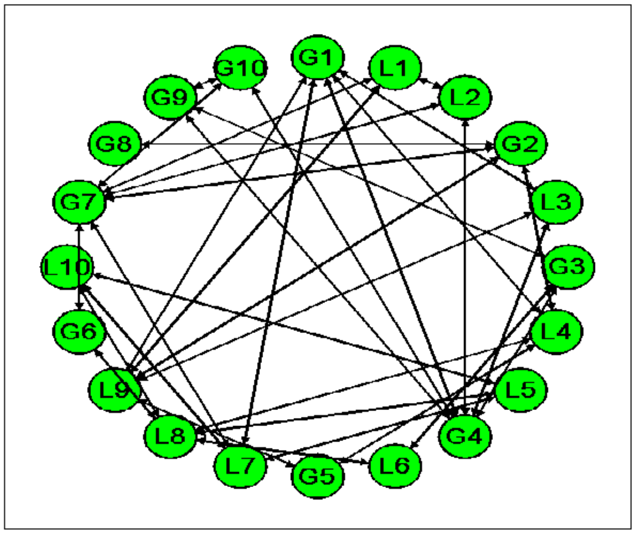

FIGURE 10. Consensus control of 20 nodes under unreliable communication topology of smart grid.

adoptability of proposed algorithm remain the same as for random communication network. The realistic results of the proposed algorithm are implemented in various distributed control applications.

C. CONTINGENT TOPOLOGY OF NODES

In such a case, the communication links and edges randomly change and reduces. The cooperation and consensus control under such a contingent environment is crucial and resource consuming. The limited number of links and reliability of $2a - 2d$ implemented such that we focus $\mathcal{N}_{ij}^{in} < \mathcal{E}$ and $\mathcal{N}_{ij}^{out} < \mathcal{E}$ for communication network. The degree of such graph directly linked with $\mathcal{E}$ and neighbour nodes. The dependencies of available links and node connectivity assumed intensive for this type of topology. The cooperation and information exchange of generators and loads under such contingency became complex and required highly computational resources. The convergence $\mathcal{C}_{i,j}(\tau : \mu)$ state is the lowest in such case while the required iterations $T_i(k)$ is higher than fixed and random topology of the distributed network. In contrast to [43] and [44], the CPU processing and total iteration become high to achieve convergence among the nodes because of limited number of connections. It shows the resiliency of proposed algorithm under contingent topology as shown in table 3.

The contingent topology of node communication assumes in figure 10 in which total generated power, total required power, and total nodes as shown in figure 11–13 individually.

Figure 10 illustrates the contingent topology of smart grid network comprise of twenty nodes equally distributed among generators and loads. The link reliability is worse such that node may exchange information with neighbor sometimes and loss link after time τ and iterations $T_i(k)$. The reconfigurable processes of converging distributed network last until it is fully connected. The distributed convergence

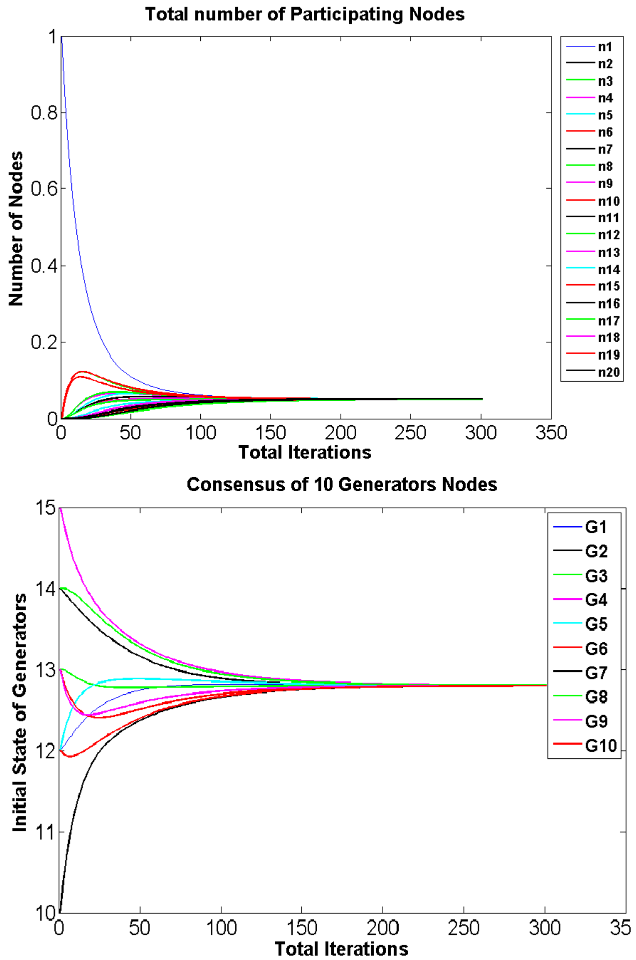

FIGURE 11. Consensus control of generators under contingent of communication network.

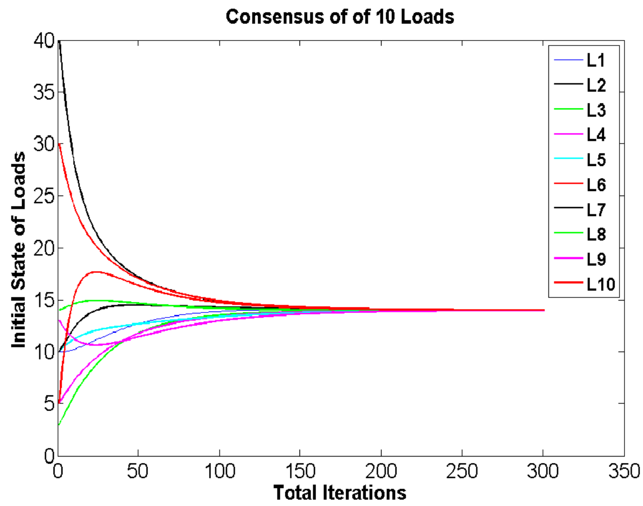

FIGURE 12. Consensus control of loads under contingent Communication network.

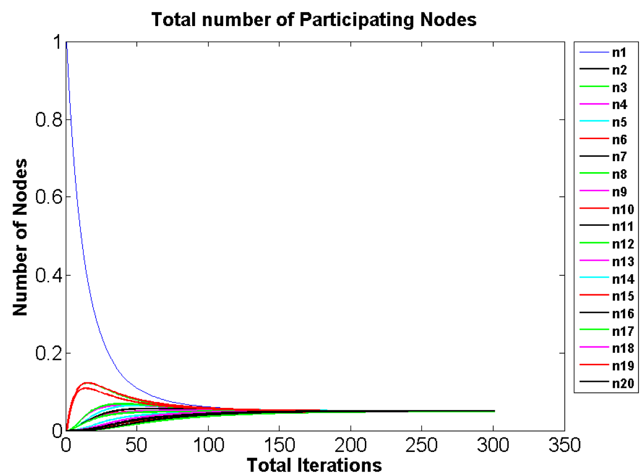

FIGURE 13. Estimation of participating nodes of the smart grid under contingent of communication network.

and node dependencies investigated in section VI and VII. Figure 11–13 illustrate generators, loads, and total nodes consensus considering unreliable communication links. Table 4 represents the performance and optimization parameters of distributed consensus using contingent communication topologies. As discussed in V and VI, the consensus of the node through limited communication links required more iterations for the network to converge that ultimately acquire enormous computation and CPU processing. The link failure does not halt the proposed algorithm from being converged; however, it extended the convergence time and iterations. The resiliency of the proposed algorithm inspected in all cases of communication topology. The proposed algorithm may be implemented for sensor network clock synchronization, islanded smart gird frequency synchronization, and prevention of cascade shedding of smart grid.

TABLE 4. Parametric results of consensus achieve in contingent topology.

Nodes	$\tau(10^{-6})$ sec	CPU(MHz)	$T_i(k)$	$C_{i,j}(\tau;\mu)$
Generator	0.065	134.10	260	0.025
Load	0.061	137.16	250	0.025
Total	0.068	139.19	265	0.025

D. EXPERIMENTAL TESTBED AND RESULTS

The validation and implementation of the proposed distributed algorithm experimentally proved by using smart controllers and radio frequency (RF) communication channels. The configuration of RF channels between controllers programmed random and unreliable to investigate the proposed algorithm performance and convergence. The experimental setup comprises of following tools:

- Arduino controller.
- RF Controller (NRF24L01).
- Arduino IDE
- Arduino Libraries.
- Embedded C for coding proposed algorithm.

1) ARDUINO

The Arduino is cross-platform technology implements the innovative application of smart sensors, communication

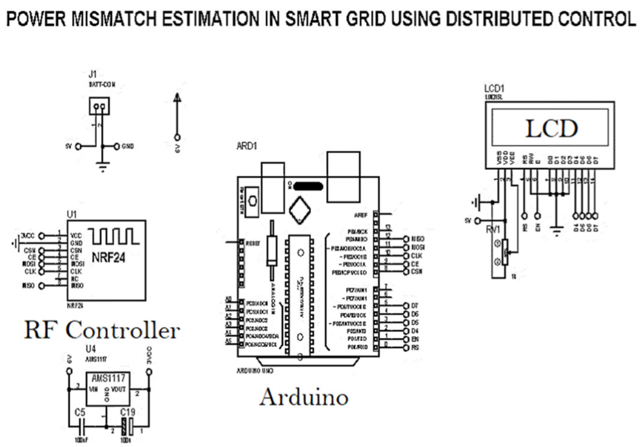

FIGURE 14. Schematic of proposed controller for estimating power mismatch.

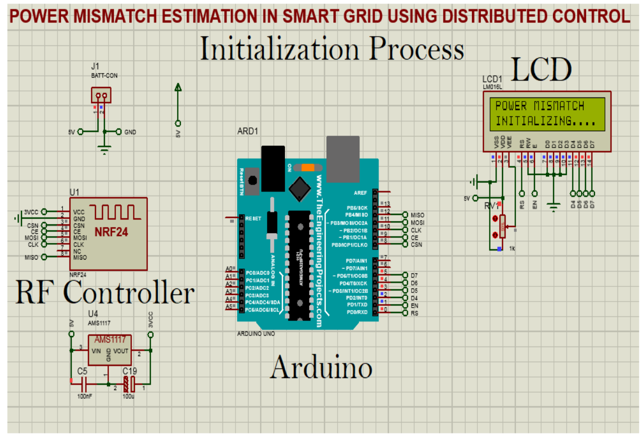

FIGURE 15. Power mismatch Initialization among the nodes.

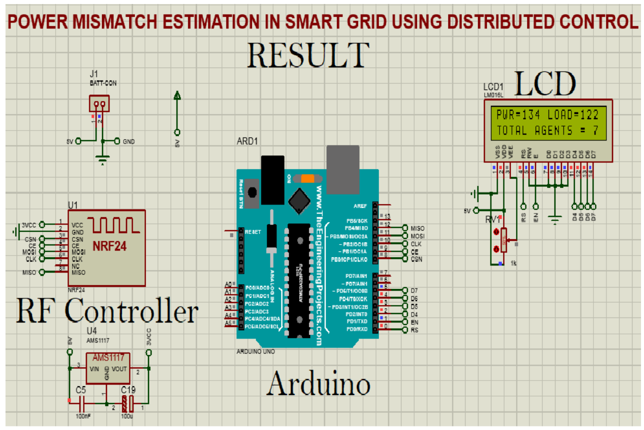

FIGURE 16. Power mismatch estimation result among the nodes.

controllers, and activating input/output devices. The purpose of using Arduino is flexibility, cross-platform adaptability, and easy configurations. The Arduino used microcontroller that considered brain for Arduino. The compatibility and plug/play feature, 32KB flash, 20 MHz clock, and PWM ports of Arduino board meet experimentation requirement for testing the proposed algorithm of multiagent. The seven controllers considered in this case which distributed in four generator controllers and three load controllers.

2) RF CONTROLLER

The RF controllers NRF24L01 are used in the testing module. It consumes the lowest power and operates on 2.4GHz ISM bands. Its data rates range is 250kbps–2mbps. It operates on 2–3.6 V supply. The frequency range starts from 2400 MHz to 2550 MHz having 1 MHz spacing and produced 125 RF channels. Each channel holds six addresses that capable each controller communicates with six other controllers simultaneously. Three SPI port used for full-duplex communication between RF controllers.

3) CONFIGURATIONS

The configuration of the Arduino board, RF controller, and other components accomplish as follow:

- Install Arduino IDE and associated packages before configuration.
- Used Proteus application for virtual connections of proposed modules.
- Embedding proposed algorithm code in Proteus.
- The same procedure repeated for the rest of six modules.
- The RF channel pattern does not configure in 6/6 mode.
- The channel configuration of RF assumes random.
- The initial state values of generators and load program statically.
- The total power generated, load, and participating nodes assessed.
- If the controller communication lost, the consensus among the nodes repeats and converge the whole network again.

Figure 14 represents schematic and figure 15–16 illustrate simulations of nodes controller for testing proposed consensus algorithm among the node to estimate power mismatch.

IX. CONCLUSION

In this paper, an energy management system is proposed to implement in distributed fashion. The significance of proposed approach is to improve the efficiency of power transmission and utilization. In such way, distributed power system localizes power utilization to near loads and avoid long transmission to reduce power losses. Additionally, the fault-resiliency evaluated in case of communication link failure among the nodes. The cost of centralized and proposed model evaluated to prove that the distributed pattern of power system control is more efficient. The proposed algorithm is resilient that can be implemented and require connectivity of power generation and consumer nodes. In addition, the distributed approach in this paper is scalable in nature which introduces grid integration for reducing power mismatch. The simulation shows power nodes communication and convergence to optimal value efficiently. The information sharing of distributed power nodes achieved through consensus technique. The results explore optimal convergence, distributed processing, nodes scalability, global autonomy of power nodes. We assessed control coordination of power nodes through random, fixed, contingent communication link successfully. To validate simulated results, a pilot-scale experimental testbed presented to prove the effectiveness of proposed algorithm. The future work of this paper extends to manage cascade shedding problems of power management system in which power network collapse due to centralized distribution of load in an inefficient way.

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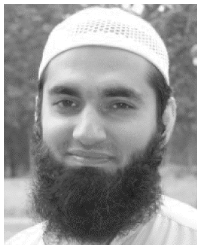

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