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REVIEW OF VOLTAGE MANAGEMENT IN LOCAL POWER GENERATION NETWORK

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ABSTRACT

Electric energy consumption shows the living standard of people of any country. In country like India, there are many places where no electricity is available. A huge population live without access to electricity, possibly the reason may be the location, non-feasibility of the grid connection or due to any political issue. Microgrid/distributed generations (DGs) are big alternative of the utility supply to provide electricity for such regions. If renewable resources of energy are used to generate electricity, it will offer great operating flexibility in such situations. The DGs can operate in grid connected as well as isolated mode from the existing utility grid. Voltage and power management are the main technical challenges in renewable based generation. When generated power depends mainly upon the renewable resources, frequency and voltage variations become more frequent. This draws the attention of the researchers to develop control strategies to establish smooth voltage profile and power sharing among the different units participating in the generation. The control strategies are employed at different level in the microgrid control architecture to control voltage and frequency errors within acceptable limits. The voltage and frequency deviations reflect the necessity of reactive power and active power balance respectively. This paper presents a literature review of various frequency and power sharing control strategies implemented in the microgrid.

KEYWORDS: Microgrid, distributed generation, Load frequency control, power management.

I. INTRODUCTION

Electric energy consumption reflects the people standard of any country. There are many places where no electricity is available [41, 52] till date. Beside availability of power, quality of power has also become an important concern [59-64]. Micrograids are just like the main grid having small scale power generation to serve the load within a small span. Microgrids have their own control center, a load to be served and locally available fuel required for generation. Fig. 1 shows the basic diagram of the microgrid [1]. A microgrid is defined as a group of multiple loads interconnected to each other in conjunction with distributed generation energy resources (DERs) within limited premises of clearly specified electrical boundaries. In other words, it is said that a microgrid is a low-level power grid which operates either independently or connected with the power grid. These two modes of operation are known as “Islanded mode” and “Grid connected mode” respectively. The distributed generation may include solar generator installed on the roof of a large/small building, wind power plant, small hydro power plant, tidal power plant, micro-turbine, combined heat power plant etc.

The distributed generation may be incorporated with any energy storing device such as a battery energy storage unit, a super capacitor and flywheel energy storage etc. When connected to the main grid, it provides distinct benefits to main grid such as loss make up, reliable supply, increased capacity, better service and quality [42-51]. Microgrids are also used to supply back-up power for the main power grid during periods of high loads. It can further assists the main grid by providing ancillary service support required for the active power management [41], frequency stabilization, voltage stabilization and many more.

The fuels used for the generation purpose in microgrid are generally renewable sources of energy. Intermittent nature of such kind of energy resources needs a very keen watch to regulate the generation. As microgrid has to fulfill the load specification and it also has to maintain the grid code standards, a proper coordination between

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the renewable based generation and storage device is required to properly balance the active power demand [53, 54] and generation. All the generating units are connected to the system common bus through their converter along with its storage unit if any. The control strategy is implemented by the converter to ensure the power specification required specified by the system operator. The development of the control strategy is the challenging prospective in the microgrid architecture. A good controller/control technique must be capable to control the power flow from the various resources by generating power sharing signal according to the rating of individual units to share the load accordingly. AC loads are very sensitive to the power variations. If frequency of the supply is not maintained as per the requirements, it will harm the connected load and the accessories used for generation and control [56, 57]. Therefore, proper control becomes the essential requirement in the safe and smooth operation of the microgrid and its various components.

Figure:

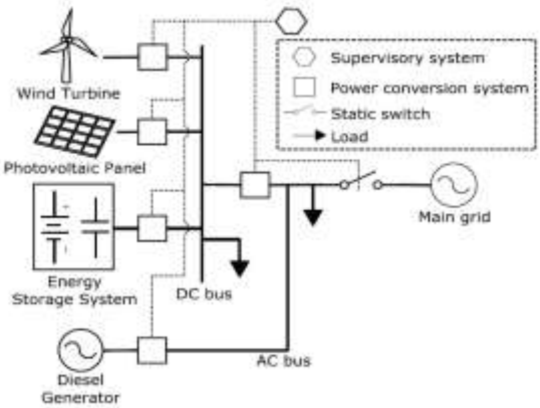

Figure 1. Architecture of a Microgrid

II. MICROGRID CONTROL OBJECTIVES

DGs participating in the microgrid generation may generate AC or DC power depending on the type of the load. The connected load requires power as per its rating, so, microgrid has to fulfill the load requirements also. Also, the control objectives must include the microgrid mode of operation, i.e., grid connected and standalone mode. The various control objectives are listed below:

- Reliable and secure operation of the whole structure.
- Voltage regulation within specified limits.
- Frequency regulation within specified limits.
- Accurate power sharing among all DGs, respective to their ratings.
- Coordination between all resources to achieve the lowest cost of operation.
- Capability to handle transients either caused by change in operation mode or any other variations.
- Meeting the load specifications.

In this paper, literature review is targeted for the different frequency control strategies adopted to limit the frequency within acceptable limits in the microgrid.

III. ACTIVE POWER AND FREQUENCY CONTROL IN LOW VOLTAGE MICROGRID

The transfer of power from sending end to receiving end depends upon the line impedance. Fig. 2 shows a generator connected to a load through transmission line. Power flow from sending end bus (S_b) to receiving end bus (R_b) through the transmission line can be calculated as follows:

The complex receiving end power is given by

$$S_R = (V\angle 0)I^* \qquad (1)$$

$$I = \frac{E\angle\delta - V\angle 0}{Z\angle\theta} \qquad (2)$$

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$$(V\angle 0)I^* = V\angle 0\left(\frac{E\angle -\delta+\theta - V\angle\theta}{Z}\right) \tag{3}$$

Equation (3) yields

$$S_R = \frac{VE\angle -\delta+\theta - V^2\angle\theta}{Z} \tag{4}$$

Real and Reactive power can be calculated as

$$P_R = \frac{VE\cos(-\delta+\theta)}{Z} - \frac{V^2\cos\theta}{Z} \tag{5}$$

$$Q_R = \frac{VE\sin(-\delta+\theta)}{Z} - \frac{V^2\sin\theta}{Z} \tag{6}$$

Figure:

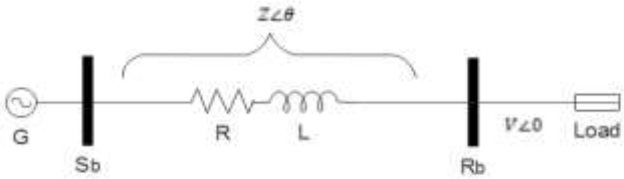

Figure 2. Power transfer to load

The active and reactive power transmitted over transmission line depends upon the (Z∠θ) impedance angle 'θ'. The value of impedance angle depends upon the transmission line and its operating characteristics, e.g., operating voltage, frequency and length etc. In low voltage transmission lines, the line resistance has high value and can't be neglected and the value of line impedance angle lies between (0°<θ<90°). This couples the active and reactive power together as it can be seen from equations (5) and (6). While in high voltage line, where line impedance is mainly inductive, the value of resistance can be neglected and θ≈90°. The active and reactive power can be compensated individually as seen from equations (7) and (8).

Real and reactive power is given as:

$$P_R = \frac{VE\sin\delta}{Z} \tag{7}$$

$$Q_R = \frac{VE\cos\delta}{Z} - \frac{V^2}{Z} \tag{8}$$

For small value of power angle (δ), equation (9) and (10) may be written as:

$$P_R = \frac{VE\delta}{Z} \tag{9}$$

$$Q_R = \frac{V(E-V)}{Z} \tag{10}$$

To achieve the different control objectives, the control strategies are implemented at multiple levels in microgrid control architecture. These control levels are namely, 1) Primary control 2) Secondary control 3) Tertiary control. These control levels are shown in the hierarchical order in Figure 3 [2].

IV. FREQUENCY CONTROL TECHNIQUES USED IN MICROGRIDS' LITERATURE

The active power deviation causes the change in the system frequency. When active power demand increases more than the generation, the system frequency reduces. If active power generation is not increased in same

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respect, the system frequency will be at lower level than the required. Renewable sources of energy are not continuous in nature [55, 59], their availability varies throughout the day sometimes weather conditions also impose negative effect on the generation, based on renewable sources. To reduce the impact of intermittency of renewable resources, energy storage units are required. The renewable based DGs may also be incorporated with conventional fossil fuel based generators such as diesel generators, to meet the demand under deficiency of power from renewable generation resources. In microgrid, some units generate DC power (e.g. solar cell, fuel cell etc.) and some generate AC power (wind, small hydro etc.). The control strategies are intended to balance generation and demand within acceptable range of frequency while incorporating the all type of DGs.

In literature, for the control of active power generation according to demand and managing the power sharing between DGs, authors used wide variety of controller design and control strategies. These strategies can be categorized in different ways with respect to their level of intelligence, operating time, adaptability, complexity, controller design technique, control parameter, algorithm used and system requirement etc. To study the impact of these factors a wide variety of papers are selected for review. The selected papers reflect the importance and issues of the frequency control in renewable based generation systems. The process to achieve good control within a specified period of time, involves tedious workforce. The different schemes used to deal with the voltage and power variations, are not able to handle them under different environmental conditions. Generally, renewable based generation is highly based on weather conditions which necessitate the requirements of energy storage elements. This literature provides enough understanding that how to coordinate the different units along with the storage units to compensate the power imbalance. In this paper, it has been tried to segregate some of the controllers on the bases of techniques used.

Figure:

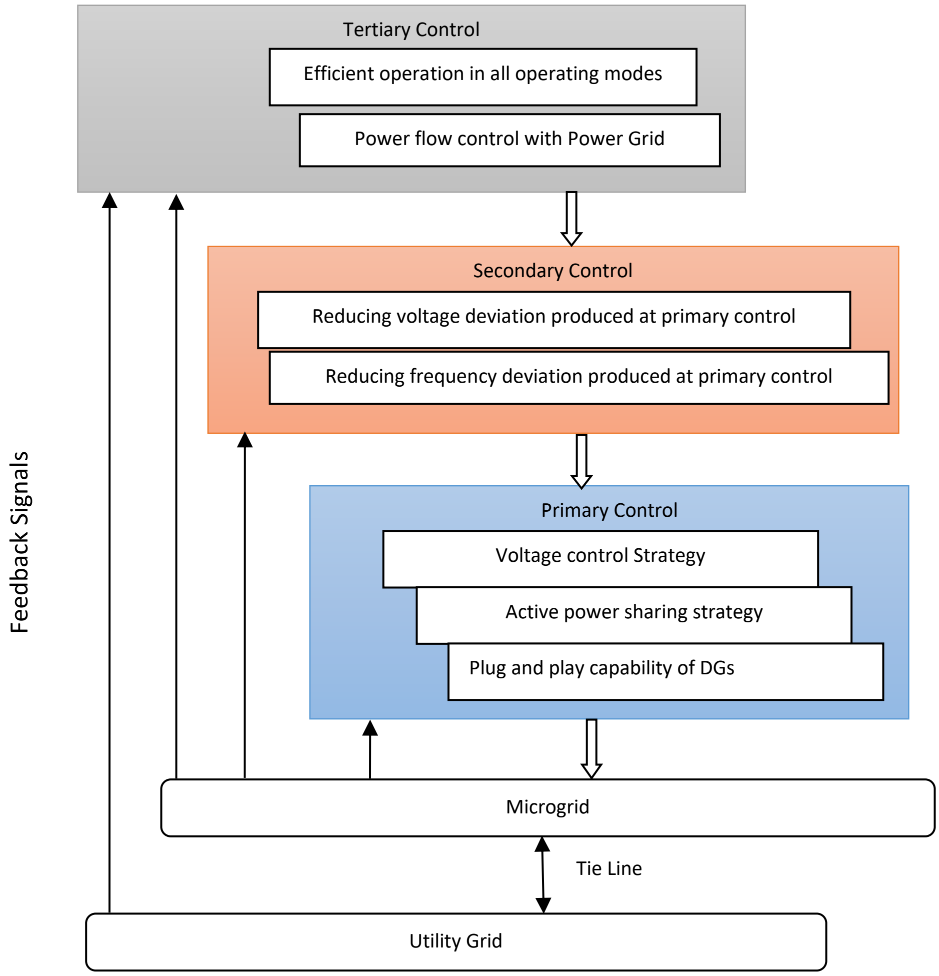

Figure 3. Hierarchical Control of Microgrid

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Recently proposed techniques

Any change in the active power demand directly reflects the change in the frequency of the system. To control the frequency in wind based generation plant, T.S. Bhatti et al. used integral square error (ISE) control technique to control the pitch of the blade of wind turbine and regulated the frequency of wind power generation [1]. Integral square error technique is used by S.K. Aditiya Das and D. Das to accommodate the frequency control through battery energy storage (BES) system [2]. Dr. S.K Kalyani and S. Nagalakshmi [3] also controlled the frequency using BES and shown that battery energy storage system has quite good performance, feasibility and reliability. Koichiro Shimizu et al. [11] controlled the frequency of microgrid using V2G concept. The customer convenience is considered and state of charge (SOC) method is used to calculate the vehicle's charging and discharging process. Jin Yang et al. [6] presented load frequency control of islanded micro grid. They proposed multivariable generalized (MGPC) theory and developed a simulation model for micro grid using electric vehicles. P.M. Rocha Almeida et al. [40] also proposed technique for load frequency control by electric vehicle stored energy. They focused mainly on the contribution of electric vehicle, while considering intermittent nature of renewable energy sources (RES). Yinliang Xu et al. [12] proposed a new technique for maintaining the supply and demand balance, based on cooperative control of distributed energy storage system of the grid. Anne Mai Ersdal et al. [35] controlled the frequency of a wind energy based power plant using robust nonlinear model predictive control technique. G. Shankar and V. Murkherjee et al. [36], presented a novel technique for load frequency control. This technique was based on quasi-oppositional search algorithm (QOHSA). Binod Kumar Sahu et al. [38] presented a novel technique for load frequency control. This technique was based on hybrid LUS-TLBO optimized fuzzy controller. Sheetla Prasad et al. [31] presented non-linear sliding mode controller (SMC) with matched and unmatched uncertainties for the LFC application in three-area interconnected power system. The proposed controller has ability to vary closed-loop system damping characteristics according to uncertainties and load disturbances present in the system. The frequency deviation converges to zero with minimum undershoot/overshoot, fast settling time, significantly reduced chattering and ensures asymptotic stability. Yi Zhang et al. [32] controlled the frequency using distributed model predictive control technique. N. J. Vinoth Kumar et al. [33] applied a new designing approach of dual mode type-2 controller for of load frequency control in AC-DC tie line. The proposed controller is capable to handle the uncertainties of complex power system.

The control strategies adopted for frequency stabilization are highly dependent on the network topology; any variation in the system architecture disturbs the system operating characteristics. Further, the system must be capable to facilitate plug and play feature, this requires the control strategy to be adaptable to the system parameter variation. System complexity is another issue which gives rise to high settling time and computationally intensive results. Development of artificial intelligence, instant and reliable results can be achieved. These techniques are not only able to handle non-linearities in the system but also their quick response protects the sensitive loads connected to the microgrid.

Fuzzy Logic based Techniques

In microgrid environment, the changes in the system parameters are not certain. The changes are not only generated from the load side but also from the generation side due to irregular availability of the renewable energy. So, the controller has to take decision accordingly; for this to achieve efficiently and quickly, the artificial intelligence based controllers are designed. These controllers are capable to shift the system operating point with respect to the variation from either side. Fuzzy logic control technique is one of the artificial techniques used for this purpose. The main advantage of the fuzzy logic based control is that they can handle nonlinearities and uncertainty of the system very effectively.

Pedro Albertos and Antonio Sala [13] analyzed the role of fuzzy logic controllers. They analyzed that fuzzy control technique provides flexible operation and knowledge based design. Nilesh N. Karnik and Jerry M. Mendel [10] discussed about the T2 FS. They concluded that the T2 FS gives better performance than T1 FS. [28]. Mukesh Singh, Praveen Kumar and Indrani Kar [21] presented a new technique using vehicle to grid infrastructure. The technique used fuzzy control and optimized the flow of energy between electric grid and electric vehicle. Manoj Datta and Tomonobuoj Senjyu [4] presented load frequency control using fuzzy control of distributed photovoltaic (PV) inverter in conjunction with electric vehicle. They concluded that the proposed technique gives good performance and reduces tie line power fluctuation efficiently. Dongrui Wu [23] approached for reducing the computational cost of Interval T2 FLC. Interval T2 FLC gives better performance to manage uncertainties than T1 FLC. T. Bharath Kumar and Dr. Muma Vani [20] presented an ANFIS controller and produced better results than other conventional controllers. Hassan Yousef et al. [37] discussed about adaptive fuzzy control technique for controlling the frequency of a multi-area power system. They concluded that the proposed controller is capable to handle more variables compared to other controllers of a

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closed loop system. Surya Prakash and Sunil Kumar Sinha [19] controlled the frequency using ANFIS controller. The proposed ANFIS controller provided quick response and low setting time of the multi-area power system. Kamel Sabahi et al. [22] presented their work on adaptive T2 FLS for the controlling the frequency. The T2 FLC was designed to amend the system performance. Saber Falahati et al. [39] presented frequency control of microgrid by controlling the charging and discharging of electric vehicles through fuzzy logic controller. N. J. Vinoth Kumar et al. [33] applied a new designing approach of dual mode type-2 controller for load frequency control in AC- DC tie line. The proposed controller is capable to handle the uncertainties of complex power system.
The reliability of the fuzzy logic based controllers highly depends upon the training data used to train the controller. Further, rule base used for membership function design, is the choice of the designer which may vary from problem to problem. These issues can be eliminated by adaptive techniques which can learn and modify its parameters with application and implementation. Fuzzy logic with conventional control methods produces much better results.

Miscellaneous Techniques

Hongwei Wu and Jerry M. Mendal et al. [14] presented their work for Interval T2 FLS. They used Karnik-Mendel iterative technique for the type-reduced set calculations. M. Guzelkaya et al. [27] tuned the fuzzy logic controller using relative rate observer technique. This new technique adjusts the scaling factor of input signal and output signal. Willett Kempton and Jasna Tomic [5] implemented the load frequency control technique on multiple sources together. This new strategy calculated the amount of power needed to balance the solar energy power in peak load periods and wind energy power for base load periods. Asim Ali Khan and Nishkam Rapal [24] presented the designing and tuning of fuzzy PID controller using Ziegler-Nichols tuning rule. They concluded that fuzzy controller reduces settling time and peak overshoot. Feilong Liu [29] presented a new strategy for the α- plane representation and reduced the computational time of general T2 FLS. Simon Coupland and Robert John [15] introduced T2 fuzzy logic system which reduces execution time. Nilesh N. Karnik and Jerry M. Mendel [10] discussed about the T2 FS. They concluded that the T2 FS gives better performance than T1 FS. H. Bevranj et al. [16] controlled the frequency of ac microgrid based on particle-swarm-optimization (PSO) technique and briefly reviewed the microgrid and their control loop. This technique was based on tuning of parameters of membership function of the FLC. Dongrui Wu [23] approached for reducing the computational cost of Interval T2 FLC. Interval T2 FLC gives better performance to manage uncertainties than T1 FLC. Engin Yesil [8] controlled the frequency using Interval T2 fuzzy PID controller. Mohammed Hassan Khooban and Taher Niknam [9] presented fuzzy tuning based intelligent technique for load frequency control. The proposed strategy was based on self-adaptive modified bat algorithm (SAMBA) algorithm. Human brain emotional learning technique is implemented by Mohammad Reza Khalghani et al. in [7] for frequency control. This controller has self-tuning properties to reduce the system difficulties. The proposed controller provided suitable control over change in system structure and uncertainties. Moharamad Hassan Khooban et al. [26] controlled the frequency of solar and wind based distributed generation using V2G technique. They proposed a new idea of combining the GT2FLS and modified harmony search algorithm (MHSA). M.H Khooban et al. [30] presented a new technique for load frequency control and utilized the energy stored in electric vehicles.

Tables:

Table 1. Summary of Literature survey along with merits and demerits

S. NO.	AUTHOR NAME	YEAR	METHODOLOGY	CONTROL PARAMETER	MERIT	REMARKS
1	T.S Bhatti et al.	1997	ISE technique	Blade-pitch control of wind-diesel hybrid system	Gives better dynamic performance	High settling time, continuously running diesel generator
2	Pedro Albertos and Antonio sala	1998	Fuzzy logic control Introduction	Fuzzy Controller design	Flexible operation and knowledge based design	Not perfect for more complex system

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3	Nilesh N. Karnik and Jeery M Mendel	2001	Centroid and generalized centroid of fuzzy set	Implementation of T2 fuzzy logic system	Type-2 fuzzy sets gives better performance	Computationally intensive
4	S.K.Aditya and D.Das	2001	Integral Controller gain optimization through ISE technique	Active power sharing control between two areas	Improves the system dynamic performance	High settling time and high peak overshoot
5	Hongwei Wu and Jerry M. Mendel	2002	KM iterative technique	Reduction fuzzy set type	Useful for real time application	Reduction from higher level to lower level fuzzy set
6	M.Guzelkaya et al.	2003	Relative rate observer technique	Tuning of Fuzzy PID controller	More efficient tuning method	Fails to handle systems having more uncertainties
7	Willett Kempton and Jasna Tomic	2004	V2G concept	Grid Power Control	Provision of ancillary services	Smart metering and two way communication required
8	Asim Ali Khan and Nishikam Rapal	2006	Ziegler-Nichols technique	Tuning of FLC	Reduces overshoot and settling time	Problem in handling all the complex problems
9	Juan R.Castro et al.	2006	IT2FL technique	Evaluation of IT2FLS	IT2FLS can solve all the problems on the different applied areas	Used for tool application introduction
10	Feilong Liu	2007	Centroid type reduction technique	α-plane of GT2FLC	Decrease computational complexity	Reduced type reduces implementation complexity of controller
11	Simon Coupland and Robert John	2007	Weiler-Alherton algorithm	Computational Geometry of T1 FS and T2 FS	Reduces the execution time	Issue of defuzzification not covered
12	Jerry M. Mendel et al.	2009	Karnik- Mendel algorithm	α-plane of T2 fuzzy sets	Easily communicate about the geometry of T2FS	provides a novel way to carry out set theory operations for GT2FS
13	Koichiro-Shimizu et.al	2010	SOC synchronization technique	Total energy model of electric vehicle	Convenience of EV user's and effective control of LFC	Only local control is considered
14	Mukesh Singh, Praveen kumar and Indrani kar	2012	Fuzzy logic control technique	Electric vehicle	Increases voltage stability and peak power management	Membership function and selection of particular membership function

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15	Dr. S. Kalyani et al.	2012	Battery energy storage using ISE technique	Frequency control of interconnected power system	BES replaces conventional controllers	Inter area oscillations and huge capital cost investment
16	H.Bevrani et al.	2012	Online PSO-based fuzzy tuning technique	Membership function parameter	Intelligent frequency control of the micro grid	Technique may converge optimally but influenced by the inertia of weight
17	Dongrui Wu	2013	KM algorithm	Computational cost of IT2FLS	Reduces the computational cost	Enhanced KM algorithm implementation
18	Manoj Datta and Tomonbu Senjyu	2013	Fuzzy logic control technique	PV system and EV system parameters	Provides frequency control and reduces tie-line power-fluctuation	Only active power is controlled
19	Engil Yesil	2014	BB-BC algorithm	Tuning of scaling factors and FOU of membership function of IT2FLC	High convergence speed and minimize frequency deviation	Scaling factor optimization technique can change the system output
20	Dongrui Wu	2014	Interval type-2 fuzzy logic technique	MATLAB implementation	Reduces the computational cost IT2FLS	Implementation procedure of Fuzzy logic control difficult
21	T.Bharath kumar, Dr. M.Uma. Vani	2014	Adaptive neuro-fuzzy technique	Load frequency control	Minimizes all the performance indices of the power systems	Five layers for ANN make system more complicated.
22	S.Prakash, S.K.Sinha	2014	Neuro-fuzzy computational technique	Load frequency control	Minimizes setting time and peak overshoot	Reduces settling time and peak overshoot
23	Hassan Yousef	2014	Adaptive fuzzy logic control	Frequency and tie-line power	Controller is superior over the classical PID controller	Type-II Fuzzy Logic produces more accurate results
24	Jun Yang and Zhillizeng	2015	MGPC technique	Energy stored in Electric vehicles to manage LFC requirements	Improves systems' frequency stability	Difficulty to handle more complex uncertainty occurring in the system
25	P.M Rocha et al.	2015	Combination of inertial emulation and droop control technique	Active power control	Reliable frequency control is done	Useful for hydro and wind generation units
26	Yinliang Xu et al.	2015	Co-operative control of distributed energy storage system	Charging/discharging of BESS	Maintains the active power balance and minimizes	Inertia of rotating machines are not considered

					power loss	
27	Mohammad Hassan Khooban and Taher Niknam	2015	SAMBA algorithm	PI Controller parameter tuning	Good performance against uncertainties caused by external disturbances	Can't handle more complex system
28	Sahaj Saxena and Yagesh V.Hote	2015	Kharitonov's theorem	Tuning of PID	Effective controller and stable for all admissible uncertainties	Reduced error, transient and dynamic stability issue
29	Surya Prakash and Sunil Kumar Sinha	2015	Neuro-fuzzy hybrid intelligent technique	Frequency control of the power system	Combines the advantage of FLC as well as quick response of ANN	Efficient results, less uncertainty, High speed
30	Anne Mai Ersdal	2015	MPC technique	Load frequency control of power system	Better coordination with AGC	If combined with fuzzy will produce better results
31	G. Shankar and V. Mukhherjee	2015	QOHSA technique	Gain of conventional controllers	Improves overall dynamic performance	Data synchronization & collection problem, communication b/w all units
32	Binod Kumar Sahu et al.	2015	Novel hybrid LUS and TLBO technique	Scaling factor of the Fuzzy-PID Controllers	Optimized controller gives superior performance	High cost and complex algorithm
33	Mohamad Reza khalghani et al.	2016	Human brain emotional learning	Load frequency of AC microgrid	Capable of maintaining balance between generation and demand	Problem dedicated controller and may sacrifice system security based on training
34	Kamel Sabahi et.al	2016	Adaptive type-2 fuzzy logic technique	Frequency control of grid	Better efficiency than other conventional controllers	Modulated the fuzzy controller in good manner
35	Saber Falahati et al.	2016	Optimized fuzzy logic control	Charging/Discharging of EV is controlled	V2G concept useful for grid frequency control	EV can replace huge battery bank
36	Mohammad-Hassan Khooban et al.	2016	Combination of GT2FLS and MHSA technique	Tuning of PI controller	Proposed controller is quite simple and has no complexity	Implementation of GT2FLS is computationally expensive

37	N.J Vinoth Kumar et al.	2016	Dual mode type-2 fuzzy logic technique	AC-DC tie line	Robust stability and gives good performance	Capacitor possess high cost, continuous energy loss
38	M.H Khooban et al.	2016	Combination of GT2FLS and MHSA technique	Load frequency control of micro-grid	Reduces the effect of power fluctuations	GT2FLS is more complex
39	Sheeta Prasad et al.	2017	SMC technique	LFC of two area	Controller has ability to vary closed-loop system damping characteristics according to load fluctuations	Intermittency is more in DG rather than conventional generation, small single stability issues
40	Yi Zhang et al.	2017	DMPC technique	LFC of multi-area	reduces impact of intermittence of wind turbine	Topology changes the constrains, computational complexity

V. CONCLUSION

Based on the comprehensive Table 1, it is apparent that there are many control techniques like fuzzy logic technique, vehicle-to-grid interaction techniques, Integral Square Error based techniques, Ziegler-Nichols technique etc. which are present in the literature for the purpose of frequency control. In the category of fuzzy logic control, various strategies have been employed for load frequency control, for instance, dual mode T2 FLC, interval T2 FLC, adaptive T2 FLC, general T2 FLC etc. But every technique has its pros and cons. For example, in fuzzy logic control techniques, selection of particular membership functions for different inputs and outputs and range selection, demand careful attention and proper insight into the system behavior. Moreover, different variants of FLC like interval T2 FLC and general T2 FLC produce less efficient results due to higher controller complexity.

On the other side, controllers like P, PI, PD and PID lack the capability for handling nonlinearities in the system, though, these controllers perform well in case of linear systems and are easy to implement. Therefore, due to incapability of handling the system uncertainties and non-linearity, these controllers can't be fully relied upon. Thus, there is a need of a controller that can provide the benefits of FLCs but simultaneously can also deal with the problem of correct selection of membership function and can train the fuzzy inference system adaptively according to the system requirements.

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