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Secondary Control of Microgrids: A Brief Review

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***Abstract*—** Among RESs, PV has come out as one of the most important DGs owing to the reduced cost in current years. For incorporating PV sources, the conception of PV-storage MG was extensively analyzed, and storage is an auxiliary component for the power supply-demand stability. The chief benefit of MG development is to offer the best solution to contribute power in case of an urgent situation and power outages throughout power disruption in the main grid. MG's encompasses low voltage distribution system with DERs, namely, PV power system and wind turbines, along with storage devices. Hence, this survey intends to review various topics related to secondary control of MG's. Accordingly, the algorithmic classification for the surveyed papers were analyzed and portrayed. In addition, the performance measures and the maximum performance achievements are also analyzed and demonstrated in this survey along with the research gaps and challenges.

***Keywords*—** *Secondary control; MG; Performance measures; Research gaps.*

Nomenclature

Acronyms	Description
RESs	Renewable energy sources
PV	Photovoltaic
DGs	Distributed Generators
DERs	Distributed Energy Resources
DCC	Distributed Cooperative Control
SVC	Secondary Voltage Control
DTSMC	Distributed Terminal Sliding Mode Controller
EM	Electricity market
ESUs	Energy Storage Units
RoP	Ratio of Power
SC	Secondary Control
SoC	State of Charge
SOFC	Solid Oxide Fuel Cell
DCS	Discrete Consistency Scheme
BESS	Battery Energy Storage System
V/F	voltage-frequency
FLC	Fuzzy Logic Controller
PI	Proportional-Integral
MSC	quasi-master-slave control frame
MVS	Master Voltage Sources
CCVS	Current Controlled Voltage Sources
SMES	Superconducting Magnetic Energy Storage
FC	Frequency Control
SOTS	Second-Order Tracking Synchronization
I/O	Input-output
FL	feedback linearization
DAPI	Distributed Averaging PI
CAPI	Centralized Averaging PI

I. INTRODUCTION

The conception of MG has newly been commenced as the major resolution for introducing the desires to systematize the DESs [1]. A MG duplicates the power system that includes the capability to detach from the chief grid to function in islanded mode and coordinate with foremost grid to connect again [2] [3]. On the other hand, DCC structures are appropriate substitutes for the SC of MGs. DCC is currently established in power systems, to normalize the power of numerous PV generators [4] [5].

The RESs [32] with uncertainty and variability offers great confront to electrical functions [6]. A MG as a small-scale distribution and generation system usually incorporates ESUs, loads, and DGs [7] [8] [9] [31]. In deregulated EM's, MGs are approved to take part in subsidiary services namely, demand response and power support to achieve supplementary income. With the intention of facilitating their market contribution, MG operators [10] [11] have to synchronize the ESUs, loads and DGs reasonably [12] [13]. For long-time scale, the most favourable bidding and functioning scheme is originated to capitalize on the gains in EM [14][15].

Numerous methods subsists for the modelling of secondary control MGs, specifically, droop control scheme, dynamical design of inverter-based DGs [16] [17], SOC equalization, feedback linearization etc. For previous decades, power market has attained much consideration owing to their computational effectiveness and feasibility [18] [19] [20] . The dynamics of DG's in MGs were non identical and; nonlinear. I/O FL is utilized to convert the nonlinear dynamics of DGs to linear one [21]. Therefore, the SVC is altered to a SOTS [22] crisis [23] [24]. The major drawbacks of the preceding techniques are that they cannot provide assurance for robust stability when facing un-modelled dynamics [29], parametric suspicions, or interruptions [25].

This survey has reviewed various works related to the secondary control of MG's. Here, various algorithmic classifications, which are adopted in the surveyed papers, are demonstrated along with their maximum performances. Along with it, the performance measures examined by the reviewed works are also portrayed in this survey. The paper is organized as follows. Section II analyzes the various related works and reviews done under this topic. In addition, section III describes the various analyses on secondary control of MG's and section IV presents the research gaps and challenges. Finally, section V concludes the paper.

II. LITERATURE REVIEW

A. *Related works*

In 2017, Amin *et al.* [1] have proposed the secondary control scheme which was engaged to relate the SoCs of the DESs, distribute the power mismatch, and control the voltage and frequency of the MG. The proposed system has DCC structural design, and it utilizes a PI controller and it also exploits DTSMC for the state regulators. Finally, the simulation results have verified that the proposed scheme offers fast transients, finite-time convergence and enhanced robustness.

In 2013, A. Bidram et al. [2] suggested a SVC of MGs depending on the DCC of various systems. The suggested SC was entirely distributed; every DGs merely necessitates its individual data along with the data of various neighbours. The distributed arrangement performs the desires for a controller in multifaceted network that further develops the reliability of the system. The efficiency of the implemented technique was moreover confirmed from the simulation outcomes.

In 2017, Ni et al. [3] introduced a SVC and FC system depending on multi-agent systems of DCC. The suggested SC was executed by means of a communication network having communication links in one-way. Here, the required network was designed by a digraph. The introduced SC model was distributed entirely, in such a way that all DGs necessitates only its individual information. At last, the execution outcomes verify the efficiency of the implemented SC when distinguished with conventional schemes.

In 2017, Dehkordi et al. [4] have suggested a novel DCC for both V/F reinstatement of an islanded MG with inverter-based DGs. The entirely distributed controllers reinstate the MG V/F magnitudes to their reference values for the entire DG units without considering of parametric suspicions and interruptions when offering precise real power sharing. At last, a inclusive execution was conducted in MATLAB and it was confirmed that the implemented method offers better control scheme presentation.

In 2017, Huang et al. [5] has established a DCC technique to control the discharging / charging performance of multiple ESUs to hold back the PCC's active power fluctuation. With the implemented technique, the entire ESUs function in the similar RoP and SoC and therefore the uneven degradation of ESUs is evaded. In the DCC building, the network resource was able to be saved as the control centre immediately corresponds to the elements of ESUs. Finally, the experiments were carried out on an archetypal MG, and the efficiency of implemented technique is authenticated by various outcomes.

In 2018, Gao and Ai [6] suggested a optimal DCC technique depending on the DCS to recognize the large-scale dissemination of RESs in an AC MG. Moreover, the implemented process was performed through a DCC design and the adopted control technique offers better flexibility and reliability in the AC MG control, and just necessitates a restricted communication among neighbouring representatives to comprehend a global optimization. At last, the efficiency of the implemented approach is established from the simulation outcomes.

In 2016, Khan et al. [7] has developed a new multi-agent dependent distributed EUS structural design in this paper. The DG system is included of numerous group of loads and DER's. A multi-agent system depending on decentralized control framework was generated with the intention of offering control to the complicated management energy in DG system. Subsequently, game theory was exploited for the coordination multi-agent systems. The experimental outcomes demonstrate that the operation of the new EUS was known to provide improved performance and reliability than traditional centralized EUS's.

In 2016, Chang and Wei [8] has offered a novel DCC structure to organize inverter-interfaced in island MGs of DERs. Accordingly, beneath the bounded load uncertainties, the implemented control technique was portrayed which could steer the MG to a looked-for steady state in the network and equal contribution of reactive and active powers between the inverters. Executions depending upon a variety of MG performances were moreover offered to illustrate the efficiency of the implemented scheme.

In 2016, Vigneysh and Kumarappan [9] have introduced a scheme, where the improvement and simulation of PV, SOFC and BESS dependent MG were concerned. The MG system was functioning in autonomous manner to supply the loads. For controlling the MG V/F efficiently and to attain better flow of power among the production and utilization, V/F control dependent on FLC was suggested here. For demonstrating the efficiency of the introduced FLC over the traditional schemes, the system was executed by means of PI controller and the required outcomes were evaluated.

In 2018, Yang et al. [10] has established a PV-storage scheme, which enhances independent allocation of PV-storage. For this configuration, a new MSC was established devoid of communication. Storages attempts to work as MVS and PVs function as CCVS. In addition, the small signal constancy of whole system was investigated to model the physical and control factors. Therefore, PVs can attain highest energy consumption and the V/F parameter simultaneously.

In 2013, Kim et al. [11] has proposed a scheme based on functioning features of SMES for the frequency controlled MG operation. A test MG comprises of a load, a PV system, wind power generator and a diesel generator to check the possibility of SMES for regulating the frequency throughout islanded function in addition to the transient state. At last, the outcomes demonstrate that the SMES serves well for FC in the islanded function.

In 2015, Simpson et al. [12] has introduced novel distributed controllers for SVC in islanded MG's. Motivated by methods from cooperative control, the introduced controllers exploit localized data to carry out secondary control performance. In addition, the adopted scheme do necessitates any knowledge of the MG topology. The distributed structural design permits for redundancy and flexibility, eradicating the requirement for a central MG controller. Finally, wide-ranging investigational results were presented that confirms the effectiveness of the adopted scheme.

In 2014, Shafiee et al. [13] has established a novel wireless robust approach for the DSC of MGs. Here, the errors occurring in transmission were absorbed via an averaging process carried out in every local controller, consequential in an increased reliability. In addition, transmissions from every DG were periodic and in such manner, conflict over the shared wireless medium could be evaded. At last, investigational outcomes were offered so as to calculate the probability and robustness by the established scheme. The outcomes point out that the established algorithm was very robust in terms of random packet losses and packet delays.

In 2013, Bidram et al. [14] has adopted a SVC of MG's depending on the DCC of multi-agent systems. The adopted SC was found to be completely distributed and each one of it necessitates its own data and the data of certain neighbours. The distributed structure prevents the requirements of multifaceted network, which enhances the system consistency. I/O FL was deployed to transfer the SVC to a linear second-order issue. Moreover, the control constraints could be adjusted to attain a required response speed. Finally, the efficiency of the established control method was confirmed by the execution of a MG test system.

In 2013, Bidram et al. [15] has suggested a SVC method depending on the DCC of multi-agent systems. The established SC was executed via a communication network. The necessary communication network was then designed by a digraph. Accordingly, the necessities for a composite network and central controller were prevented, and the system consistency was enhanced by the implemented scheme. Finally, the efficiency of the established control method was confirmed by the execution of a MG test system.

III. VARIOUS ANALYSES ON SECONDARY CONTROL OF MG'S

A. Algorithmic Classification

Various algorithms are adopted in the reviewed work are described by Fig. 1, which comprises of techniques such as, DTSMC, FL algorithm, graph theory, droop control, quasi M&S framework, SMES algorithm, Game theory algorithm, consistency algorithm, consensus algorithm and droop coefficient algorithm. From the review, the DTSMC approach was adopted in [1] and FL algorithm was implemented in [2] [4] and [14]. Accordingly, graph theory was implemented in [3] and [15] and droop control was implemented in [8]. In addition, quasi M&S framework was suggested in [10] and SMES algorithm was implemented in [11]. Game theory algorithm was adopted in [7] and consistency algorithm was implemented in [6]. Likewise, consensus algorithm was implemented in [5] and droop coefficient algorithm was adopted in [12] and [13].

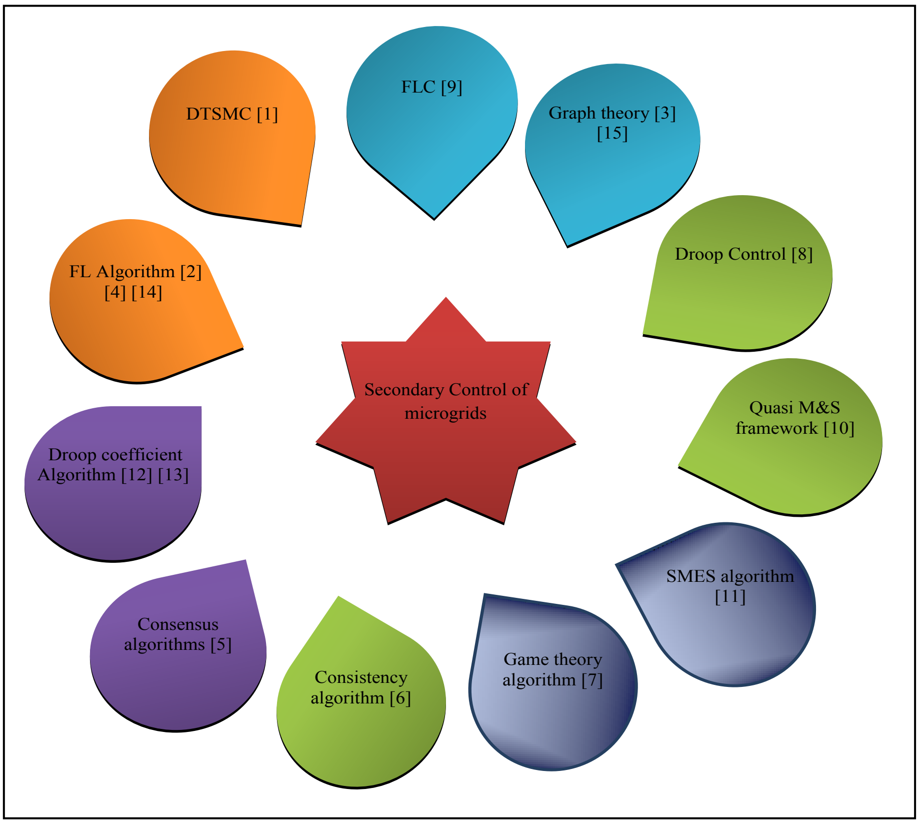

Fig. 1: Algorithmic classification of the reviewed works

B. ***Maximum Performance Achieved***

The maximum performance achieved by various performance metrics is given by Table I. From the table, the efficiency measure adopted in [7] has attained a higher percentage of 90%. Nominal frequency implemented in [11] has attained a higher value of 50Hz and Voltage magnitude implemented in [8] has attained a higher value of 1.005p.u and Active power implemented in [10] has attained a higher value of 2.5KW. Accordingly, Filter capacitance and Nominal voltage has attained a higher value of 25µF and 325.3V respectively. Also, Load demand and Frequency has presented increased values of 4.5KW and 60.2Hz, which were determined in [10] and [1]. Likewise, Current was measured in [9] and it has adopted a value of 100A. Similarly, Resistance and Inductance was deployed in [1] and they have attained optimal values of 380V MW and 59KW. Moreover, SoC has presented increased values of 52.5%, which was determined in [5].

TABLE I. MAXIMUM PERFORMANCE ACHIEVED BY THE REVIEWED WORKS

Sl. No	Measures	Maximum value	Citation
1	Efficiency	90%	[7]
2	Nominal frequency	50Hz	[11]
3	Voltage magnitude	1.005p.u	[8]
4	Active power	2.5KW	[10]
5	Filter capacitance	25µF	[11]
6	Nominal voltage	325.3V	[11]
7	Load demand	4.5KW	[10]
8	Frequency	60.2Hz	[1]
9	Current	100A	[9]
10	Resistance	380V	[1]
11	Inductance	59KW	[1]
12	SoC	52.5%	[5]

C. *Performance Measures*

The performance measures of the reviewed works are given by Fig. 2. Various measures such as efficiency, nominal frequency, Voltage magnitude, active power, filter capacitance, nominal voltage, load demand, frequency and current were obtained from the reviewed works. Accordingly, efficiency was measured in [7] and nominal frequency was measured in [12] and [13]. In addition, voltage magnitude was measured in [8] [11] [14] and [15] and active power was analysed in [1] [3] [6] [8] [10] [11] [12] [13]. Also, Filter capacitance was analysed in [12] [13] and nominal voltage was measured in [2] [3] [4] [5] [7] [9] [12] [13]. Moreover, load demand was examined in [4] [12] [14] and frequency was examined in [1] [8] [11] [15]. Also, current was analyzed in [9] and others was examined in [2] [5] [7] [8] [10] [12] [13].

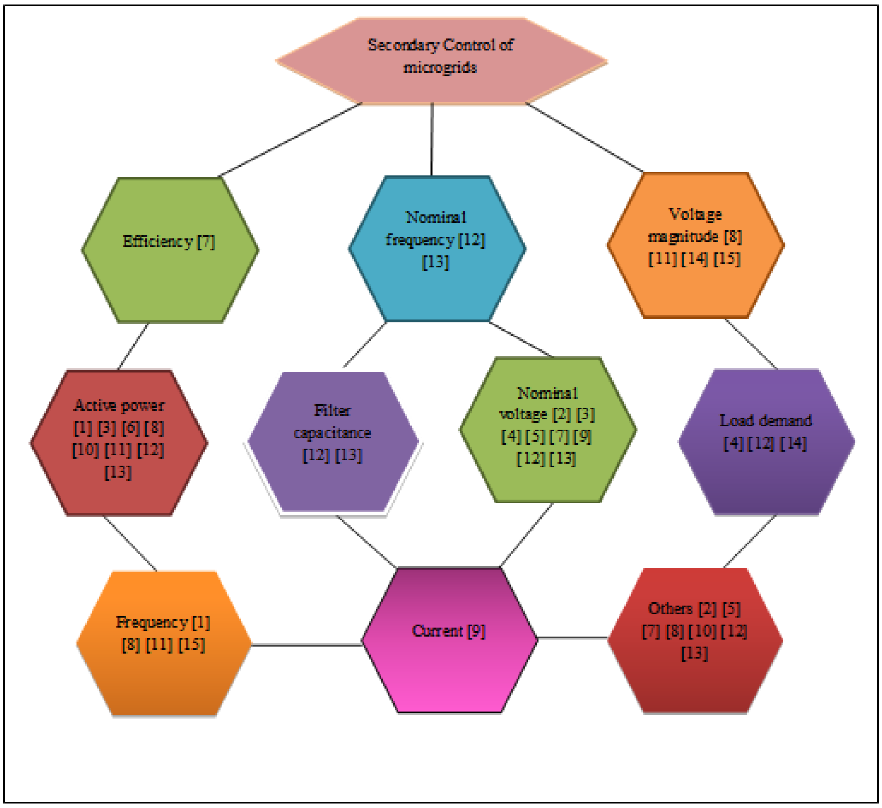

Fig. 2: Performance measures of the reviewed works

D. *Renewable resources*

The renewable sources attained by the reviewed works is given by Table II. From the survey, solar energy was exploited in [1] and fuel energy was exploited in [2] and [4]. In addition, wind energy was deployed in [5] [6] [7] and fuel energy was employed in [9]. Also, in [10], solar energy was exploited and in [11] and [12], wind energy was deployed. Accordingly, fuel energy was exploited in [14].

TABLE II. RENEWABLE SOURCES ACHIEVED BY THE REVIEWED WORKS

Citation	Solar	Wind	Fuel
[1]	✓		
[2]			✓
[4]			✓
[5]		✓	
[6]		✓	
[7]		✓	
[9]			✓
[10]	✓		
[11]		✓	
[12]		✓	
[14]			✓

IV. RESEARCH GAPS AND CHALLENGES

The manipulation of better parametric conditions for the subsistence and reliability of steady state in lossy primary-controlled MG remains as a demanding and open issue. It could be confirmed that the secondary controllers DAPI controller and CAPI controller were accurately executed, i.e. they adjust the frequency of the system to its nominal value in the existence of random losses. Anyhow, the stability analysis devoid of any predictions on the conductances was also a demanding and open issue. Furthermore, it remains uncertain whether traditional droop control was appropriate in most cases for the stabilization of a dominantly resistive MG.

Numerous current works have adopted secondary control approaches for MG's. Anyhow, till now no single control model was capable to present a flexible, plug-and-play framework assuring voltage and frequency regulation when sustaining accurate reactive and active power distribution between dissimilar DGs. At present, this arrangement of intentions seems impossible with decentralized control by means of information such as, power, voltage, etc. at every DG. Likewise, communication between DGs was recognized as a major component in attaining these intentions while discarding a centralized control framework. In addition, a centralized secondary controller was established to get rid of the voltage variations. Anyhow, if there is a malfunction in the supplementary centralized controller, the operation of voltage restoration could not be attained.

V. CONCLUSION

MG's was a small-scale power system that offers the effectual integration of DGs. Appropriate control of MG's was a requirement for constant and cost-effective functions in smart grids. Secondary control of MG's can function in both islanded and grid-connected functional modes. Traditional secondary controls of MG's presume a centralized control configuration that necessitates a multifaceted communication network in several cases, with two-way communication links. This can unfavourably have an effect on the system consistency. Accordingly, in this survey, various papers were analyzed and the corresponding techniques adopted in each surveyed paper were described. In addition, the performance measures concerned in each paper were illustrated and along with it, the maximum performance measures attained were also illustrated. Thus the survey provides the detailed analysis of the secondary controls of MG's from the reviewed papers.

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