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SURVEY

A Comprehensive Survey on the Current Trends in Improvising the Renewable Energy Incorporated Global Power System Market

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ABSTRACT Power generation all over the world is slowly being taken over by the renewable energy technologies to alleviate the energy crisis, as well as provide clean and green energy. Therefore, in the foreseeable future, the renewable energy technologies most likely may compete on par level with the conventional energy generation. The near future holds the rebalancing of the global power system market, which mandates, the interpretation of the upcoming and current trends revolving around the power market, pricing and the supply-demand balance with focus on the various renewable energy sources. Levelised Cost of Energy (LCOE) is the present global evaluator that ensures the fair valuation of the generation costs and the grid parity achievement for the various generating technologies. With the power market rebalancing, both regulated and deregulated configuration, have a requisite duty of maintaining the power generation and demand balance. Therefore, this paper does an extensive survey on the recent trends and methodologies in the levelised cost estimation, demand-supply balance with focus on the various renewable generating sources.

INDEX TERMS Deregulated power system, levelized cost of energy, power system market, regulated power system, renewable energy generation.

I. INTRODUCTION

Power system and renewable energy coherence initiated since the adverse consequences of conventional and fossil fuel energy hit hard the global scenario economically as well as environmentally. With the implausible increase in necessity of power, the traditional power system generation which originated from fossil fuel sources is bound to face dead end with major downsides only to swerve the whole world towards renewable energy sources. Renewable energy development has been a parallel travel throughout the evolution of power system network since the vertical integrated system to the deregulated structure in late 90's.

To start off, during the 90s, the renewable sector was contemplated to be a small scale scheme due to various economic & financial limitations thereby investing in renewable energy generation arena was itself considered as a breakthrough. Also, hydro and wind were assumed to be the fruitful predominant options when compared to solar [1]. Ever since the signing of the Paris Agreement in 2016, the journey of renewable energy growth all over the world has been incredible. According to the IRENA 2022, the overall global renewable energy capacity is 3064GW with 9.1% growth at the end of 2020. With hydro power accounting for the major part of 1230GW, the next fair share is almost equally divided between winds and solar of 825GW & 845GW respectively. Bio, geothermal & marine energy have also finally managed to squeeze in a place for the remaining contribution towards the lime light [2]. Canada, Sweden, Denmark, Portugal, Chile, Germany, Spain, Italy, Ireland and the United Kingdom are the top ten supreme countries in renewable energy consumption and investment [3].

The usage of wind, hydro power and biogas has a substantial increase in India, Australia & USA as well while the European Union still requires improving on the target hit [4]. As per the Global Status Report 2021, despite of

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the COVID pandemic, China has managed to expand its online renewable capacity in 2020 than the whole world till 2013. While China leads in Bio power, Wind, Solar PV& Hydro power capacity, United States tops in Geothermal with Spain leading in Concentrating Solar thermal power (CSP) capacity [5].

Restructuring of the electric industry from the regulated model to deregulated design induced a major transition of delegating the collective power delivering services monitored by Independent System Operator (ISO) which attracted the renewable energy participation even better [6]. Hence, the Variable Renewable Energy Sources (VRES) play a major role in such a deregulated system and therefore will continue its strenuous journey as the future holds higher penetration of this renewable power generation. Also the equal competition of the renewable energy along with the conventional sources of generation is very much possible in the near future.

Grid parity is the term which is used to assess the participation of the renewable energy technologies along with the other available generating technologies. Achievement of grid parity promotes the competitiveness & subsidy issues of the renewable energy technology [7]. The Levelised Cost of Energy (LCOE) is termed as the universal standard tool employed for the energy pricing and assessing the grid parity achievement of various technologies. Furthermore, it asses the various available technologies and the decision to invest in the respective renewable energy generation by determining the market price of the particular generation. So, LCOE instigates in renewable policy making and futuristic changes in the electricity pricing market [8], [9].

Since the renewable energy may dominate the electricity market in the near future and its installed capacity is likely to increase tremendously, the variable renewable sources incorporated into the grid might become an intricate power network [10]. Successful operation of such a convoluted system requires transmission of energy which is to provide better generation-demand balance by sorting out the necessary ancillary services needed. Be the era before and after deregulation, matching demand with generation is one major responsibility of the electric industry. The load-generation matching also addressed as Regulation & Load Following ancillary services necessitates the operation of an effective power system rebalanced market [11].

A. MOTIVATION AND CONTRIBUTION OF THE SURVEY

The major motivation of the paper is to comprehend all the contemporary available techniques and methodologies emphasizing the changes in the global power system market pivoting around the renewable energy technologies. The goal of this literature survey paper is to enlist the ongoing trends towards integrating the renewables. Therefore, the survey is performed with respect to the global power system rebalancing, pricing and supply-demand balance. Hence forth, the contribution in this paper helps in identifying the pricing of renewable energy along with the control and modern power system operation in terms of traditional as well as deregulated system with various renewable energy sources in the market at the current scenario.

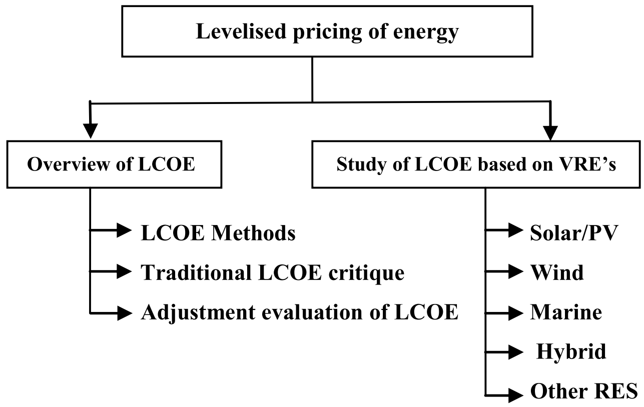

FIGURE 1. Depiction of LCOE study process.

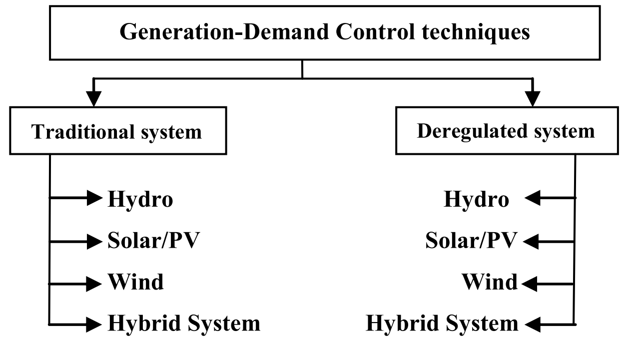

FIGURE 2. Depiction of frequency control survey with VRES.

B. ORGANIZATION OF THE REVIEW

The investigation is organized as two sections, namely studying the levelised pricing of energy and the generation-demand control techniques performed with respect to traditional (regulated) and non-traditional (deregulated) power system assimilated according to the various renewable energy sources. The illustration of the survey is represented is shown in Figure.1 and Figure.2

II. LEVELISED COST OF ENERGY CALCULATION

Levelised Cost of Energy (LCOE) is traditionally calculated from the current value of the capital investment costs divided by the energy generated for a particular technology i.e., Cost/kWh [12], [13].

A. OVERVIEW OF LCOE

As cost is the major constraint in power generation, LCOE is accepted as a common indicator in order to compare the cost between the various available generating technologies [9].

The levelised cost of energy calculation is most sought standard metric for the following reasons:

(i) Comparison of pricing of energy for the various renewable technologies [14], [15]
(ii) Various governments & inter government agencies for setting up the renewable energy policies [16]
(iii) Forecast & time-series analysis of a particular energy technology [17], [12]
(iv) Setting up the renewable energy policies [18]
(v) Determining the price value for the commercial & individual renewable energy produced [19]
(vi) Checking grid parity conditions for the profit of the respective renewable technology [20], [21]

The determination of LCOE in a simplified manner is considered from the total lifetime costs occurred divided by the total generated power delivered by that corresponding technology can be given by the following equation (1),

$$LCOE = \frac{Lifetim\ costs\ incurred}{Lifetime\ power\ generation(kWh)} \tag{1}$$

1) LCOE METHODS

LCOE is the unit cost of energy calculated considering the plant level costs and doesn't consider much of the system level effects like costs caused in the transmission & distribution part of the grid and also the additional investments with growth & need of demand [22].Hence, for the specific evaluation of the energy costs on a solid basis, the two methods identified for LCOE are suggested by the National Renewable Energy Laboratory (NREL), United States & Department of Business, Energy and Industrial Strategy (BEIS), United Kingdom which is (i) Annuity based LCOE (or) Simplified LCOE (ii) Discount based LCOE discussed in sections 2.1.1.1 & 2.1.1.2 respectively [16].

a: ANNUITY BASED LCOE (OR) SIMPLIFIED LCOE

The simplified LCOE suggested by the NREL is determined from the capital & fuel cost, operation & maintenance cost, performance cost based on the major financial assumption of Capital Recovery Factor ($CAP_{recovery}$) given by equation (2). It is the factor that helps in finding the present value of a series of equal annual payments for a particular length of time depending on the interest rate (ir) & number of years (or) annuities (n) [23].

$$CAP_{recovery} = \frac{ir\,(1+ir)^n}{(1+ir)^n - 1} \tag{2}$$

And so, the simplified LCOE projected by NREL is given by equation (3),

$$\boldsymbol{LCOE_s} = \frac{\boldsymbol{CAP_{overnight}} \times \boldsymbol{CAP_{recovery}} + \boldsymbol{O\&M_{fixed}}}{365 \times 24 \times \boldsymbol{C_f}} + (\boldsymbol{FC} \times \boldsymbol{HR}) + \boldsymbol{O\&M_{var}} \tag{3}$$

where, $CAP_{overnight}$ is the overnight capital cost; $O\&M_{fixed}$ and $O\&M_{variable}$ is the fixed and variable operation & maintenance costs respectively; FC is Fuel Cost (cost/Btu); HR is the Heat Rate (Btu/kWh); C_f is the Capacity factor of the plant (based on the generation ranging between 0-1) and product of 365 × 24=8760 gives the no of hours in a year.

Therefore, the LCOE calculated from the eqn. (3) proposed by NREL denotes the energy price of a corresponding energy technology to meet its service costs and part of capital costs for that respective year.

b: DISCOUNT BASED LCOE

The discount based LCOE offered by the BEIS, UK represents the lifetime costs along with the depreciation of the particular technology to the lifetime power generated by that particular technology. Also, it is defined as the ratio of Net Present Value of the lifetime costs (NPV) to the Net Present Value of Energy (NPVE) [24].

The discounted LCOE is given by the equation (4),

$$\boldsymbol{LCOE} = \frac{\boldsymbol{NPV\ of\ lifetime\ costs}}{\boldsymbol{NPV\ of\ energy}} = \sum_{t=1}^{N} \left\{ \frac{\left(\frac{CAP_t + FOC_t + VOC_t}{(1+r)^t}\right)}{\left(\frac{G_t}{(1+r)^t}\right)} \right\} \tag{4}$$

where, N is the total number of years (or) lifetime of the project; CAP_t is the capital cost of the project; FOC_t is the constant operating cost for the period; VOC_t is the variying operating cost during the period; $(1+r)$ stands for the discount rate for the period 't'; G_t is the power generated for the corresponding duration. The levelised cost calculated from the above formula yields a fixed revenue for energy generated equal to the discount rate considered for the overall lifetime of the project [16].

The LCOE cost calculation methods offered by the NREL and BEIS is most likely the same, apart from the discounted cash flow assumption in the discount based LCOE by BEIS. Both the methods calculate the LCOE with respect to cost per generation (cost/kWh). It is evident that both the methods implicit neither good nor bad impact over LCOE, as it is necessary to scrutinize the evaluation of LCOE with respect to uncertainties.

B. SUMMARY OF TRADITIONAL LCOE CRITIQUE & PRECISION EVALUATION WITH VARIABLE RENEWABLES

Assessing and evaluating renewable energy generation is quite challenging as they are intermittent in nature. And also, since the sources of renewable energy are inconsistent, the generation is non-dispatch able [25]. Consequently, there are various system level costs apart from the net present value costs for every renewable generation technology which actually requires consideration while calculating the LCOE. Therefore, the traditional method of LCOE determination needs certain modifications for the inclusion of the uncertainties and variability's for each individual technology.

The major input parameters for the traditional LCOE calculation are listed as follows:

(i) **Capital/Investment Costs** – Total costs for the overall installation, construction, mounting, equipments for the total lifetime of a respective project/ renewable technology [9].

(ii) **Operation & Maintenance Costs** - The costs incurred due to the maintenance after the installation including the operation which depends on the type of the renewable technology. The total costs spent over monitoring, running, scheduled/ unscheduled servicing of the equipments fall in this category which is annual over the total lifetime of the project [9].
(iii) **Capacity Factor** – The Capacity factor defines the energy performance or the energy retrieved from a respective renewable technology annually with respect to the total life of the generation. This factor varies with the type of technology, source of generation & intermittent nature [9].
(iv) **Discount rate** – The future cash flow value determined by the present value factor depending on the performance, location and lifetime of a renewable energy generation [26].
(v) **Lifetime of a project** – The total healthy period of time (in years) for which a particular renewable energy technology is able to generate electricity irrespective of minor deficiency [27].

Apart from these variables, the traditional LCOE calculation needs further improvement as the variable renewable energy technology is uncertain in nature with stochastic variables which not considered in the original LCOE calculation and therefore may not give satisfactory performance.

The major shortcomings of traditional LCOE may be identified as follows:

(a) Precise price variations are not considered for the exact comparison of RES over the conventional generation technologies.
(b) Assumption of constant values over the lifetime of a particular technology leads to non reliable results.
(c) Costs ensued in the renewable energy technology due to the integration, grid interface, ancillary services obtained and the type of storage has to be included for the better balanced solution.
(d) Grid parity analysis for spotting the profit of a respective renewable energy.
(e) Lacking inclusion of the contracts declared with the renewable energy providers which limit their participation in the whole electricity market.

With high chances of renewables finding a better place in the future, it is necessary to modify the traditional way of calculating the LCOE with the apposite costs & stochastic variables incurred in the respective RES technology to achieve better comparison results and reliability [28].

Assumption of constant values is one of the major setbacks for the traditional way of LCOE calculation which in the case for the variable renewable energy sources proves to be fallacious. And hence while choosing values for capacity factor and lifetime, it fair enough to consider the specific data for the corresponding technology while evaluating the levelised cost [9]

For the comparative study of LCOE for the various electricity generating technologies, it is mandatory to include the precise details such as the cost incurred in the green house gas emissions into the system costs. Hence these additional costs, for example the carbon pricing is included in the traditional LCOE calculation for a fair and evaluated study of renewables over the conventional sources of generation [29].

$$Cost_{co2} = C_{price} \times Heat\ Rate \times K_{GHE} \times C_f \times 365 \times 24 \times 10^{-9} \tag{5}$$

Eqn.(5) gives the annual payment of CO_2 which for the life span of the project is calculated to a net present value from the eqn.(6). K_{GHE} defines the Greenhouse gas emission coefficient, C_{price} is the carbon price and 10^{-9} is the factor for conversion of MMBtu to Btu.

$$NPV_{co2} = \sum_{i=1}^{N} \left\{ \frac{\left(Cost_{co2} \times \frac{(1+d)^{N-1}}{d}\right)}{(1+r)^N} \right\} \tag{6}$$

NPV_{co2} computes the future annual CO_2 payments, where the $d=(r+k)$ signifies the sum of interest rate and the variable carbon price increase respectively and N is the total number of years of the project. And so, the carbon pricing adjusted LCOE is given by eqn.(7) [9].

$$\boldsymbol{LCOE} = \frac{(\boldsymbol{CAP}_{overnight} \times \boldsymbol{NPV}_{co2}) \times \boldsymbol{CAP}_{recovery} = +\boldsymbol{O\&M}_{fixed}}{365 \times 24 \times \boldsymbol{C_f}} + (\boldsymbol{FC} \times \boldsymbol{HR}) + \boldsymbol{O\&M}_{var} \tag{7}$$

The extended LCOE modification comprising of the cost incurred from the commissioning to decommissioning of a project is given by eqn.(8) [30].

$$ExtLCOE = \sum_{i=1}^{N} \left\{ \frac{(CAP_t + OM_t + F_t + CC_t + D_t) \times (1+r)^{-1}}{G_t \times (1+r)^{-1}} \right\} \tag{8}$$

where, OM_t is the overall operation and maintenance costs, F_t is fuel cost, CC_t is the carbon cost, D_t is the decommissioning costs for the respective year 't'.

Renewable energy credits are the prime ticket for the numerous renewable energy suppliers to participate in the electricity market. Thereby, the energy delivery by the power providers, surveilled by the Power Purchase Agreements (PPA's) and the taxes paid is also to be added in the variable renewable LCOE computation. The cost or penalty arising during the conveyance of power at its highest or lowest limit is calculated from the penalty at minimum energy delivered (PC) and the production losses (PN) where the penalty is determined eqn.(9) [31].

$$Pen_n = PC_n + PL_n \tag{9}$$

Therefore, the PPA modified LCOE is given as per eqn. (10), where $TaxC_t$ is the tax credits to be paid in the year't'.

$$\boldsymbol{LCOE_{PPA}} = \sum_{i=0}^{N} \times \left\{ \frac{(CAP_t + OM_t + F_t - TaxC_t + Pen_{nt}) \times (1 \,\mathcal{C}\, r)^{-t}}{G_t \times (1+r)^{-t}} \right\} \tag{10}$$

Price variations within a specific time period changes corresponding to the demand and supply of the power in the grid are to be included in the basic LCOE calculation for the authentic analysis [32]. This tuning is performed by the correction factor called "Co variation coefficient". The composed capacity cost given by eqn.(11), where CAF_i is the capacity adjustment factor [10].

$$Cost_{cap} = \frac{(Const\ initial CAP_{cost}/unit)}{8760 \times C_f \times \sum_{i=1}^{N} \{CAF_i \times (1+r)^{-i}\}} \tag{11}$$

The modified LCOE is given by eqn. (12), where K_{TF} is tax factor which is the net summarized value of the overall income taxes.

$$\boldsymbol{LCOE_m} = \left\{ \left(\frac{Variable\ Cost}{KWh_{gen}}\right) + \left(\frac{Time\ Avg\ fixed\ O\&MCost}{KWh_{gen}}\right) + \left(Cost_{cap} \times K_{TF}\right) \right\} \tag{12}$$

If the levelised cost of energy is less or equal to the present value, then they don't require subsidies anymore and therefore, it is necessary to adjust the value by recalculating the capital costs along with the loan interest over the period of time. The energy price adjusted levelised cost calculation is given by the eqn.(13), as shown at the bottom of the next page, where, dr is the degradation (or) deterioration rate (in %) [8].

To emphasize the economic costs and value of a particular generating technology, the integration and variability costs is included and the modification is termed as the System LCOE which is given by eqn.(14), where the marginal integration costs is determined by the pace of change of the integration costs with respect to the change in generation of the renewable source [33].

$$\boldsymbol{System\ LCOE = Marginal\ gen\ costs + Marginal\ integration\ costs} \tag{14}$$

The Value Adjusted Levelised Cost of Energy (VALCOE) is the modified form of traditional LCOE for three parameters namely, energy, capacity and flexibility premeditated from the hourly electricity market models. The VALCOE is given by the eqn.(15), where K_E is the energy adjustment factor, K_C is the capacity adjustment factor and $K_F$is the flexible adjustment factor [28],

$$VALCOE_i = LCOE_i + K_E + K_C + K_F \tag{15}$$

The additional supporting costs that need to go into the compilation of LCOE for the extended LCOE studies are [34]:

(i) Capacity and type of flexible and available generation/demand
(ii) Maximum power/demand to be delivered.
(iii) Participation of the renewable suppliers
(iv) Storage technologies employed.
(v) Standards and reliability of the supply.

C. STUDY OF LEVELISED COST CALCULATION BASED ON VRES

The summary of LCOE survey is registered based on the types of VRES namely, solar, wind, marine, hybrid and other sources of generation in the following sections.

1) SOLAR PHOTOVOLTAIC GENERATION

Evolution of LCOE is exhibited by the learning curve approach and discounted cash flow process for a PV-CSP combination for duration of 2010 to 2050 [35]. LCOE optimization by genetic algorithm with seeking the optimal values of three design variables for a transformer including the inductor cost for a 200kW PV generating technology is customized [36]. Economical performance analysis of organic Rankine turbines driven by the concentrated Photovoltaic thermal generation system is estimated by the LCOE evaluation [37], [38]. Realization of grid parity achievement based on LCOE estimates in small developing states, particularly considering the financing constraints is emphasized for the investment and business perception of RE projects [39]. Impact of the tilt angle and its monthly modification based on a precise assortment is said to decrease the levelised cost of energy, thereby dipping its capital investment's return time [40]. Importance of space optimization for residential and agriculture PV energy harvest is learnt through the levelised cost calculation estimated for onshore photovoltaic and agro-photovoltaic [41]. Concept of Grid parity is rebuked for the PV system through the existing Feed in Tariff (FIT) and for the future expansion causes, the fixed investment costs are to be reclaimed by retail tariff reposed by modified additional tariff for the electricity from the grid [42]. Integration the design variables and magnetic losses for a cascaded modular PV inverter framework into the optimization engine gives back better operable parameters the same to minimize the LCOE [43].

Traditional LCOE is segregated into two components based on the cost and energy and reformulated as effective LCOE and validated for PV generation in three cities namely, Phoenix, Kansas, and New York [44].The levelised cost calculation for 20MW utility scale PV in three different regions in United States (US) is suggested through certain key modifications such as conversion of real discount rate to a nominal one by inflation factor, taxes paid & subsidies and system degradation rate is fed into a Monte Carlo solution [45].Impact of PV plant capacity factor and the associated factors in the levelised cost calculation is identified by evaluating the same for five PV power plants from United States of America [46]. LCOE case studies for a benchmark PV and updated PV consisting of an isolated solid transformer with inverter service is compared and studied for San Antonio, Denver & Baltimore [47]. The LCOE analysis of commercial photovoltaics power generation system is investigated using the System Advisor Model by NREL for three regions in Phoenix, Atlanta, and Boston, United States [48].

A stochastic new conditional approach called Conditional Value at Risk-LCOE (Cvar-LCOE) is suggested for 20 micro PV generation cities in Brazil to prove its pessimistic nature [49]. A case study of showcasing the efficiency of a hybrid PV-diesel, a typical off grid power generation in a small village from the Santiago province is performed by the LCOE evaluation [50]. Case studies of investigating LCOE for three 50MW power plants, PV, CSP and hybrid PV-CSP in the northern Chile is performed to recognize the scope of abundant solar resource in the near future [51]. A new metric for evaluation based on the output efficiency of PV generation in Brazil, identified as annual Yield factor (Y_f) and other associated parameters are optimized for the reduction of LCOE [52].

LCOE modeling for various PV technologies with technological and meteorological characteristics is composed by the method proposed by NREL with checking the grid parity for a case study in Egypt [53].Simulation of LCOE though SAM software proposed by NREL based on Egypt's feed in tariff for the Benban solar power park in the south of Egypt for the futuristic scope of the respective CSP projects is investigated [54]. Economical, environmental and energy aspects of LCOE analysis for polycrystalline, monocrystalline and microcrystalline built PV systems installed in the rooftop of 20 different locations in the Morocco city is analysed [55]. For a CSP plant in Tata city in Morocco, the minimization of LCOE is performed by optimizing five parameters namely, direct normal irradiation, solar multiple, mirror efficiency, absorber and power cycle efficiency by response surface model and ANN model [56].

The levelised cost calculation for the three districts of Italy was investigated for the concept of grid parity through the LCOE value, whose estimated time to achieve the same is done along with energy and economic assessment [57]. Real time operational, irradiation, economical and financial data taken from a grid connected PV plant in western part of Romania is employed for the LCOE calculation for the analysis aspects [58]. Profit of photovoltaic generation systems in urban areas is deployed by the LCOE study in Spain [59]. New Fresnel based concentrator for the CSP technology is said to reduce the LCOE estimate in case of solar thermal generation with significant potential in the Europe market [60]. Possible future for the floating photovoltaic farm for Spain in three dam reservoirs, the Borboll'on, La Pedrera and Guadalcacín, emphasizing the water depth limits is investigated by the LCOE estimation [61]. Reducing the LCOE costs predominantly in the solar PV is crucial due to the additional storage costs, which is therefore analysed for three conditions namely, with battery, short term forecasting and combination of both for the experimental data taken from Iberian Peninsula [62].

China seems to be an appealing case study due to comparatively small learning rate of PV which may achieve grid parity in Solar PV by 2020-2030 as per the prediction modeling [63].The benefits of integrating CSP solar PV into the grid is worth allowing for as it increases investment potential in spite of increased LCOE compared to other RE technologies for a advancing market structure in China [18], [64]. Two factor learning based LCOE model for the PV power generation connected to China's grid to achieve the grid parity condition in the near future and accessing the economic benefits is proposed [65]. A critical analysis of LCOE estimation over Turkey's Renewable Energy Resource Zone auctions for advancing the photovoltaic and wind technologies is carried out to conclude that Turkey can get better in its auction models [66]. Four different PV technologies in the Thailand science park with different degradation rate analysis is carried forward for the LCOE estimation [67].

2) WIND ENERGY SYSTEM

Expanded deterministic cost function models of LCOE for the offshore wind farm with traditional capital and operating costs along with other generation constraints in wind farm such as gross demand factor, total losses, availability, decommissioning costs are included [68]. LCOE evaluated from site cost, incentives, wake losses, recurring costs and cost of money is used in the auction market with subsidies for the strike and consumer price is proposed [69]. Power Purchase Agreements define the maximum and minimum energy delivery limit which in case of failure leads to penalty. A penalty check & default model is developed and included in the traditional LCOE calculation for a wind farm with annual C_f of 0.4 [70]. Modified LCOE with the power purchase

$$\textbf{Energy LCOE} = \sum_{i=1}^{N} \left\{ \frac{\left(\textbf{Payment in 'N'yrs} \times (1+r)^{-t}\right)}{\left[\left(\textbf{Gen}_{\textbf{initial}} \times (1-\textbf{dr})^{i-1}\right) \times (1+\textbf{energy price})^{i} \times (1+r)^{-t}\right]} \right\} \tag{13}$$

and contract limits included is imposed for the Maryland's Offshore Wind energy project to minimize the cost of bundles Renewable energy Credits (REC) and Public-Private sector signed PPA's [31].

The uncertainties of the wind farm fed into LCOE evaluation is further more scrutinized by the Omega ratio called as the Omega LCOE method which aims in robust benchmark [71]. Cost models optimized by two AI methods, genetic algorithm & artificial neural network is done to reduce the overall price of the off shore wind turbine system in order to minimize the cost of LCOE [72].

Case study of audited data from the United Kingdom's offshore wind farm costs show increase in the cost calculation study than the ones imposed by bids offered by government financial support using contracts [73]. Learning rate qualified from the following methodologies, technology diffusion curve, Experience curve approach and bottom-up cost modeling is employed for the estimation study of offshore wind energy in Europe and UK [74]. Off shore floating wind farm generation potential for the future scope is analysed by LCOE for a case study in Ireland [75]. LCOEs of 83 offshore wind power generating projects data that are linked to the China's grid during 2013–2020, and learning rates estimated by learning curve model for the accomplishment of grid parity is studied [76]. Case study of 10 year old off shore wind farm in the New York state is taken up for the LCOE prediction for the ongoing potential participation of the same in the market [77].

3) MARINE ENERGY SYSTEM

Political, economical, social, technological, legal and environmental aspect of LCOE analysis is carried out for ocean energy technology [78]. Reversed levelised cost calculation for five classes of wave energy technology with a fixed value of LCOE and unknown current value of capital and operating costs [79] is done by eqn.(16),

$$\begin{aligned} \textbf{\textit{Net Current value of}} \\ &= \textbf{\textit{LCOE}} \times \textbf{\textit{Energy produced}}\ (\textbf{\textit{MWh/year}}) \\ &\times \textbf{\textit{CAPEX \& OPEX costs}} \end{aligned} \tag{16}$$

Forecasted levelised cost calculation performed by two staged Monte Carlo simulation with LCOE estimate variables and uncertainties in one factor learning rate compared between European and United States dept of wave energy [80]. A MATLAB mapping based tool for the optimal source identification and execution through the levelised cost evaluation for the spatial and temporal variability of tidal steam energy in the promising areas of UK is done proving that the capital & operating costs play major than the power coefficients [81].

Detailed LCOE evaluation for the tidal wave energy with wide turbine in Messina Strait, Italy is done to prove its betterment over solar and wind energy technology [82]. Energy and economic analysis of the extensive coast ocean energy technology for two different wave energy converters in three regions of Brazil to determine the levelized costs then compared to the solar energy [83]. Levelised cost of energy and Internal Rate of Return (IRR) are evaluated based on the location, type, capacity and electricity tariff of a wave energy generation system located in the North West Spain [84].

4) HYBRID GENERATING TECHNOLOGIES

Australian National Electricity Market (NEM) is modeled and analysed for the levelised cost calculation with photovoltaics and wind additionally with the pumped hydro energy storage system. The levelised cost calculation is determined from the weighted average cost of generation (LCOG) and capital, operation costs (LCOB) for the same given by eqn.(17) [85],

$$\textbf{\textit{LCOE}} = \textbf{\textit{LCOG}} + \textbf{\textit{LCOB}} \tag{17}$$

The updated NEM with the hourly specifics of the wind, solar and Concentrated Solar Power are captured for the cost calculation with the additional costs imposed due to increased minimum share of renewable energy supply, a limit on the CO2 emission and an increased penalty for CO_2 emission [86]. The LCOE's of eleven different generation technologies for both conventional and non conventional projects taken from the LAZARD, IRENA, IEA, EIA and NREL is calculated and the maximum, minimum and median values of the very same is studied which reveals that the benefits of renewables and the hazards of non renewables should be considered for improving the economic value of RES [87].

Research and Development prospects of six various generating technologies through regression analysis & LCOE foresight model is carried out proving that the LCOE foresight results outrun the regression analysis [88]. LCOEs is computed for six combinational technologies of solar and wind simulated by HOMER software on standalone FIT payments based on the site of location and share of the generation between the RE power plants [89].Optimization of green house gas emissions by HOMER software is investigated through the outputs such as LCOE, initial capital cost, current value, back payment and rate of return for various generating technologies [59]. Collective generation of marine energy from tidal, wave and offshore wind and their potential competition in the electricity market is evaluated accurate prediction costs [90]. Optimized Multi RE generation system with less LCOE absolutely satisfies the demand on the electricity grid with high utilization efficiency, better power grid stability, low generation costs & less CO2 emissions [91].

Levelised cost of energy and Social cost of energy is composed, assessed and criticized for the floating offshore wind and ocean energy technology in the fields of Scotland and Portugal [92]. The LCOE of various electricity projects (both renewable and non renewable) in US is analysed with modification of traditional LCOE being included with the system costs and carbon pricing through the greenhouse gas emission for the lifetime of the projects [9].

The Electricity Generating Costs (EGC) spreadsheet model of LCOE calculation is used for studying the seventeen multiple power plants in China, revealing that the fixed infrastructure investment costs affects the levelised cost and therefore, additional short term subsidies are necessary for healthy RE competition in the China's electricity market [19]. LCOE analysis through learning rate by segmented regression process for utility scale solar and wind hybrid generation system in United States is exhibited [93]. Concept of marginal LCOE for a green VRE i.e., improving the level of participation levels (20%-80%) for the various renewable generating sources in a case study in Europe is performed [94].

Economical operating crossover point for the traditional diesel generation and hybrid wind-hydro power generation in the island of El Hierro which is the world's first island wind and pumped-storage hydroelectric facility called as modified levelized cost of energy [95]. Bottom-up energy system model based LCOE methodology is applied to a case study for the grid parity examination of solar PV and onshore wind technologies in the Korean electric power market [96]. Case study of Pulau Tioman island diesel power generation replaced with mini hydropower and solar PV is proposed and future expansion is suggested through the LCOE valuation [97].

5) OTHER RE TECHNOLOGIES

(i) Biomass

Economical and potential analysis of a Rankine cycle turbine biomass power plant driven by the rice straw as fuel in Egypt is performed by System Advisor Model (SAM) LCOE studies for future policy making [98].

(ii) Geothermal

Comparative study of the levelised price for the geothermal energy source over the other renewables such as solar, biomass and wind is performed with the following inclusions in the LCOE calculation [99]:

(i) Costs incurred in identifying and exploring the desirable fount.
(ii) Cost of drilling.
(iii) Generation Costs.

III. GENERATION CONTROL TECHNIQUES WITH VRES

Good quality of power is ensured by the frequency and voltage maintenance along with the balance of demand and generation. Hence, the frequency control process evolves with respect to the changes in power network [100]. The survey in the following sections summarizes the load-frequency control techniques under regulated and deregulated scenario.

A. REGULATED (TRADITIONAL) POWER SYSTEM WITH VRES

Load frequency control or Automatic generation control problem in the regulated or traditional system with the coalescence of renewable energy resources (RERs) reduces the overall dormancy of the system thereby making the operation and control a bit tedious. Various advanced control techniques are available and also applied in such vertical structures for better frequency regulation [101].

1) HYDRO POWER GENERATION

The usage of Hydro Power Plants (HPP) in the managing of Primary Load-Frequency Control (PLFC) with regulating the set points of the generating units and electrical analogy for elementary element of penstock & tunnel along with the process modeling of the linearized hydro system is explained [102].

A Classical Genetic Algorithm (GA) tuned PID controller using a combination of ISE and ITAE as main objective, with scheduled power generation matched to either thermal or gas under 1% step load perturbation in the respective areas is proposed [103]. Fuzzy Logic claims to be efficient for non linear systems. Thereby, Fuzzy logic tuned PID controllers are employed in a three area system.The study is extended for additional single SMES/TCSC incorporated for better AGC performance [104].

Evolving from basic PID controller, an Integral Proportional Derivative (I-PD) controller is optimized through a latest nature-inspired Fitness Dependent Optimizer (FDO) for a diverged source interconnected power system (IPS) is more pragmatic [105].

Model Predictive Control (MPC) based frequency control proves to have faster response & better stability against nonlinearities and constraints which is tuned by Bat Inspired Algorithm (BIA) effectively applied to a two control area system with backlash value of 0.05% for thermal and dead band value of 0.02% for hydro system [106]. A Imperialist competitive algorithm(ICA) based cascaded fuzzy-proportional integral derivative filter based (PIDN)-fractional order PIDN (FPIDN-FOPIDN) controller is expressed as a better solution with lesser settling time & performance index to mitigate the issues of AGC in Interconnected Power System (IPS) [107].

Intelligent controlling techniques are essential in tracking & updating the parameters for the control gain calculation in the frequency control. An Adaptive Neuro Fuzzy Inference System (ANFIS) using neural network back propagation method process is employed for the power network with four interconnected hydro and thermal locale better dynamic response [108].

A classical PID governor controller with single tuning parameter method called Internal Model Control (IMC) is proposed for hydro power plant inclusive of the water hammer effect is checked for supplying an isolated/grid connected load [109]. An Adaptive Model Predictive Control (AMPC) based control in two control area with hydro-thermal is developed in the incidence of load disturbance/deviation and nonlinear constraint [110].

The major downside of PID controller is that the variables are always evaluated for the critical operating point which lacks insufficiency whilst operating away. A Model Predictive controller where the linear prediction parameters are validated based on the operating point of the frequency oscillations, is implemented to the controller in mini lab hydro power plant's governor [111].

For managing the rapid demand changes as in to overcome the unbound variation in conventional controllers, a linear quadratic regulator (LQR) structure is introduced. For better efficacy, the weight Q matrix of the LQR is optimized through the new & sturdy Jaya optimization algorithm for a hydro-hydro interlinked via AC tie line power delivery system [112].

The gains of a plant level PI controller are updated by Ziegler Nichol's technique and Genetic Algorithm for multi hydro-thermal control area. Fine tuning of PI controllers using Fuzzy Logic scheduling for gain-disturbance adjustment, also accomplishes the switching from P to PI controller for better performance [113].

While discussing the LFC of hydraulic turbine system, the variation of water starting time ($T_w$in secs) and load damping ratio (D in pu-Mw/Hz) are usually ignored while the dynamics are represented as minimally represented. A fresh approach of Desired Time Response Specification (DTRS) technique based on the input guide vane servomotor (IGVS) considering the variation of T_w andD with active load variation is proposed and studied [114].

Hydro dominating energy system models in the study of LFC are scarcely available. One such system model is considered for the study of PID controller based on newly merged bacteria foraging reliant particle swarm optimization (BFO-PSO) algorithm [115]. Cascaded hydro power stations in hydro power domination models are under limelight throughout the world. The challenges in regulating such system under high dynamical situations for better delivery of power are studied in two regulating modes whilst the prototypes of West-East Electricity Transfer Project of China and Colombia power system [116].

Generation control is improved by establishing a coordination between Gate Controlled Series Capacitor and Automatic Generation Control optimized by the fuzzy fine tuning process which is proved better over the various other optimization algorithms [117].

2) SOLAR/PHOTOVOLTAIC GENERATION

The assorted nature of the Renewable energy sources specially with Photovoltaic and EV integration necessitates the need for better response feedback system and controllers for better frequency control and regulation. Hence, For a three area model, a Fuzzy Logic based PID controller is discussed [118].

The influence of PV on LFC is that for every 10% contribution from PV requires 2.5% increase in frequency regulation for conventional system. For this, a mathematical small scale model of photovoltaic generation is taken and applied for sunlight patterns gathered from Tokyo metropolitan area [119].

Multi area control area with PV penetration experiencing time delays in communication channel is explored through a newly proposed feedback loop approach for tuning of the PI/PID controllers for a realistic four area system obtained from the Arab-Gulf region [120]. Transmitting measurements to control centre has practical communication delays which may cause lag in the dynamic performance of LFC as delay margin which is included for study & analyzed using Fuzzy logic control for the same system with PV [26], [27].

Owing to the advantages of Bacterial Foraging Algorithm (BFA), for a interconnected control area, a classical PI controller is designed using the same [122]. A robust and efficient Imperialist Competitive Algorithm cum Fuzzy controller handles the uncertainties thereby eliminating the steady state error satisfactorily [107].

To increase the performance of the integrated control area, an ANFIS tuned neuro-fuzzy controller is designed. Two separate FLC controllers are taken for optimizing the isolations and different membership functions [123].

Two unequal Solar-Thermal plant systems with nonlinearities of GDB and GRC is considered for the analysis while the PID, FOPID, PIDN-FOPID cascade controllers gains along with the output parameters of Model Predictive Control (MPC) method are manipulated using Salp Swarm Algorithm (SSA) for various cost functions too [124].

Cooperative distributed model predictive control (C-DMPC) strategy edges over the MPC method by interacting with more local controllers through WAMS for better performance, by applying the proposed strategy to the distributed solar thermal AC/DC interconnected three area power system [125]. With effect of dynamic PV nature, an artificial neural network by means of the radial bias function is trained for the control process through the real time data collected from a PV power plant in Aswan, Egypt [126].

For achieving better time response in the frequency control, a one plus fractional order integral-derivative (1-FOID) controller is optimized by a very recent evolutionary technique called as Harris Hawks Optimization (HHO) which uses exploitation and exploration phases [127].

Utility scale solar photovoltaic system with site dependent variable frequency droop curve provision to realize better operating condition. The machine learning based FD when compared to the linear FD proves that the Neural network based structure is capable of accurately mapping and adaptive for different loading levels [128].

An uncomplicated fuzzy logic control method is discussed for a PV-Diesel system depicting Okinawa, one of Japan's southern prefectures with hundreds of remote islands mostly dependent on diesel generation moving towards PV generation owing to its subtropical climate [129]

For the PV generation to meet the demand in spite of the dynamic variations faced, it is necessary for the PV generation to possess an adjustable Active Power Control

(APC) without any storage devices like battery. A neural network based Maximum Power point estimator is devised for better tracing with step variable modified P&O algorithm under various constraints [130].

With more uncertain factors considered in photovoltaic generation like grid-tie inverter parameters, and resonance, frequency fluctuations happens which requires a better control strategy of load frequency control with double equivalent-input-disturbance (EID) controllers [131].

3) WIND POWER GENERATION

Among the renewables, wind power has always been an unsaid promising source of power generation however has its set of uncertainties such as varying wind speed and natural impacts. Therefore integration of wind power and operation of load frequency control issue is solved by fuzzy logic controller for a DFIG integrated two area system and the variations impact of wind on the LFC characteristics with varying step load disturbances is analyzed to improve the performance [132].

A digitally modeled decentralized LFC established through Particle Swarm Optimization (PSO) algorithm tuned optimal PID Controller for an Egyptian Power System comprising of non linearities inclusive conventional generation & wind power units is stated [133].

Post a large scale blackout or outage, the contribution of the renewables to the grid restoration is intermittently concentrated these days due to their flexible operation. Before going on to the moral support, the controller parameters that are optimized & the additional active power provided by the $P(f)$-control of the ENERCON WPP where in the K_p and K_i gain value of the control are increased or the $P(f)$-curve slope of the WPP controller is deduced for satisfactory performance [134].

DFIG based Wind Turbine Generators (WTGs) when connected to weak grids affect the performance due to voltage instability is rectified by SMES where the energy exchange is controlled using hysteresis current-fuzzy logic controller [135].

Wind power consumption as the active power compensator to regulate frequency with the control logic developed using Dig SILENT Simulation language (DSL) is discussed. The frequency stability analysis for various case studies is performed on the modified IEEE 14 Bus Network [136].

In case of large scale wind power penetration, the LFC is regulated by a newly optimized Grey Wolf Optimizer-PID controller coordinated support through Redox Flow Batteries (RFB). The investigation was carried out for two-area interconnected IEE Japan East 107-bus-30-machine system [137].

The two-degree of freedom (2DOF) based 2DOF-Hybrid secondary controller in the New England 39-bus system modified as two control areas for regulating the AGC and RFB. Modified sine–cosine algorithm is used for the hybrid combination of the fractional-order proportional-integral-derivative (FOPID) controller & tilt-integral-derivative (TID) controller [138].

Frequency regulation model of DFIG-based wind power is created in which the wind turbine do not operate with de-loading, so the dynamic response characteristics is obtained with the controller design using model predictive control (MPC) [139].

The WTGs faces difficulties in tracking the load change, due to intrinsic intermittence chances in wind power generation. This is formulated as control objective for the DMPC that takes care of the special dynamics for the same to optimize the wind power depending on the demand change with the availability for different modes of operation [140].

The significant noise factor happening by switching of loads in frequency measurement makes the feedback loop of the controller tricky in interconnected thermal and wind system which is solved by a noise sensitive controller entitled as modified proportional integral derivative (MPID) controller adjusted by internal model control (IMC) [141].

Rather than time consuming traditional and heuristic optimization technique for MPC controllers, a new speeder Chimp optimization algorithm (ChOA) achieves optimal solution within short span of time. The new robust control approach binds the MPC and linear quadratic Gaussian (LQG) for frequency stability [142].

During post fault recovery, a power-balancing coordinated control strategy of the wind power and the demand side response is developed for the coordinated control of the system. As EVs are emerging controllable sources on demand side and owning to its flexibility, it is proposed to provide additional power support on the grid for balancing the power. Based on the available wind active power recovery and the power of the demand side response, regulation may be done effectively [143].

Based on Lyapunov–Krasovskii (LK) functional approach, new $H\infty$ delay dependent stabilization criterion results in terms of linear matrix inequality (LMI) considering both time-delay and actuator saturation in the IPS dynamics [144]. Fault-tolerant load frequency control (LFC) proposes as a distinct model as the communication time-delay is taken into the area control error (ACE) signals. The asymptotic stability settings are consequential in the LMI's outline by utilizing the Lyapunov – Krasovskii functional (LKF) method and inequality technique of Wirtinger [145]. In a non-fragile control modeling, *D*-stabilization is transformed into asymptotical stabilization and then, the criterion of *D*-stability & *D*-stabilization has been resolved by the linear transformation [146].

To prove the efficiency of the modified Jaya optimization algorithm with proposed weight parameter change for the online LFC of two area wind integrated system is performed by linearized model and Δf tolerance methods with case three extended to modified IEEE 39 New England test bus system in a real time laboratory setup *x*PC target board [147].

4) HYBRID POWER GENERATION SYSTEM

For the effective utilization of multi generation hybrid models, technical & economical aspect analysis is mandatory for the integrated operation of diverged sources of renewable energy [148].

A traditional PID controller whose values are fine tuned in MATLAB environment for frequency deviation control in hybrid environment for sustained power generation [149].

The multi area system with interconnection of renewable & nonrenewable combination is studied for the dynamic fluctuations in frequency for disturbance through including PI, PID and Fuzzy Controllers for the comparative analysis of better results [150]. Firefly algorithm (FA) applied Proportional-integral differential (PID) controllers adopted for regulation of LFC [151].

The very same controller optimized through Differential evolution (DE) reaches frequency regulation in the multi hybrid power system with solar and wind integration [152]

To overcome the frequency instability, a grasshopper optimization algorithm (GOA) technique based secondary fuzzy PD-PI cascade controller is developed [153].

Single area power system employing thermal interconnected with solar and wind setup is presented and aims to reduce the frequency fluctuations by utilizing a very new optimization algorithm called Jaya optimization technique [155]. Model predictive control technique based frequency control with the impact of varying wind turbines with uncontrolled solar & thermal power is manipulated [168].

Two tilt-based cooperative controllers migrated through modified hybridized particle swarm optimization - genetic algorithm (MPSOGA) for the LFC function standing by the virtual inertia control (VIC) in to the renewable energy system [156].

An Evolutionary Imitation Curriculum (EIC)- Multi Agent Deep Deterministic Policy Gradient (MADDPG) algorithm combines imitation and curriculum learning to extract the coordinated control process in a multi-area integrated energy system (IES) on the Southern China Grid [169].

A hybrid amalgam of the Fractional order PID & Tilt integral derivative controllers incorporating superconducting magnetic storage system is designed based on the optimization of LFC parameters through Manta Ray Foraging optimization algorithm [158]. The fractional parameters & gains of the FOPID controller is attuned for minimal Integral Time Absolute Error through physics motivated Atom Search optimization algorithm which is validated using Real Time Digital Simulator [157].

Biogeography-based optimization (BBO) technique for the generation control in a hybrid control area assuming dish stirling solar-thermal system along with wind model is studied with Integral controller (I), Proportional-Integral (PI) & Proportional-Integral-Derivative (PID) controllers to study the step and random load perturbation effects [170].

The ballast adjustment for load change is done through the basic Integral, PI & PID controllers, whose parameters are tuned with the Particle Swarm Optimization (PSO)

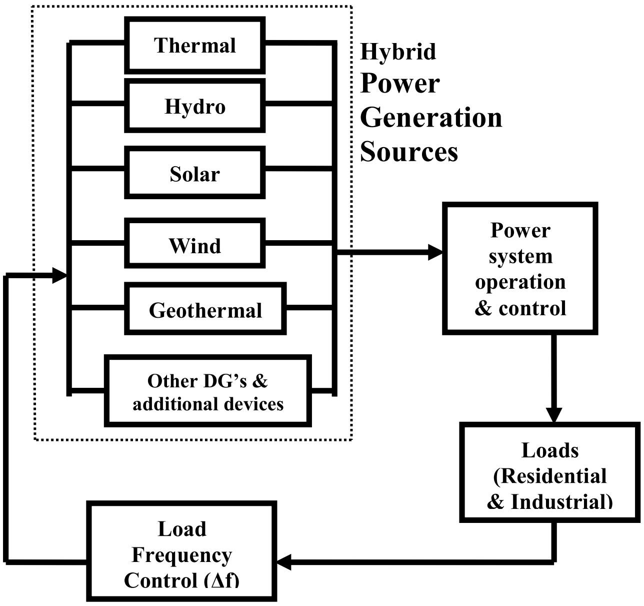

FIGURE 3. Hybrid model of frequency control in traditional power system.

technique. The ongoing proposal is conducted on a hybrid Solar Photovoltaic (SPV)-Wind Generation (WG)-Micro Hydro (MH) based generation plant for National Institute of Technology, Meghalaya at Sorha [171].

The synchronous inertia and the wind speed fluctuations is suggested to be eliminated by adding the VSWT rotational speed variables & frequency dynamics as additional feed to the hydro-power governor units. The case study recorded for an isolated power system in El Hierro at Canary Island, Spain [172].

A novel LFC control of Multi-verse optimizer - Model predictive control (MVO-MPC) in a substantial hybrid system comprising of six renewable energy system [166]. An extremely recent Improved Sunflower Optimization Algorithm (ISFO) technique tuned Adaptive Type-2 Fuzzy PID (AT2FPID) structure is designed for frequency adjustment of hybrid distributed power systems. The study is extended to applying an AT2FPID controller in the same system [159]. A hybrid power system (HPS) is considered for the LFC control through the amalgamation of fractional order calculus integrated proportional–integral– derivative controller & fuzzy logic controller tuned by quasi-opposition harmonic search (QOHS) algorithm [167].

A multi area hybrid system generation control, wherein an attempt of integrated geothermal power plant (GTPP) is achieved by secondary cascaded Fractional order (FO) proportional integral (PI) –Fractional order proportional-integral-derivative controller whose gains are tuned by the powerful Sine Cosine Algorithm is proposed [164].

Mathematical model of Thermal, PV with MPPT, Wind developed and investigated as two different systems with two & four generating units respectively, where in the load frequency control is done through the Adaptive Neuro

Fuzzy Inference System processed by Ant-Lion optimizer (ANFIS-ALO) for a Proportional Integral controller [165]

The superiority of coyote optimization algorithm (COA) is exhibited by using it over to tune PDn-PI cascaded controller for hybrid power system consisting of thermal and PV with wind system in a two area model [163]. Cascaded PID controller for the multi area non conventional system having thermal, hydro, MPPT based solar, wind, gas & battery storage is analysed with consideration of communication time delay through hybrid Teaching Learning Based Optimization- Differential Evolution optimization technique [161].

Dual loop internal model control with two control loops internal & external for suppressing disturbance & oscillations respectively is proposed & proved by analyzing the same for two, three and four area systems employing combinations of hydrothermal, solar with irradiance factor, wind with speed constraint and fuel cells [173].

Marine predator algorithm tuned classical PID controller is employed for a hybrid solar and wind along with two energy storage systems such as SMES and battery. The realistic implementation is done by real wind speed variation taken from a wind site at Zaffarana in Egypt [174].Self tuning controller with recursive type estimator is used for the frequency control of the wind dominating two area system with thermal and hydro power plants termed as self tuned automatic generation control significance proved over conventional controller LFC [162].

B. DEREGULATED POWER SYSTEM WITH VRES

Post Deregulation the research aspect of renewables in the frequency control with respect to generation has gained more importance. Delegated power system operation and control along with the differing dynamic renewable sources is challenging because of the complex structure [175]. The frequency control becomes the paramount problem with the renewable energy integration and the developing & advanced control strategies may lead to a promising future for better performance in spite of the dynamic nature [176].

1) HYDRO POWER GENERATION

A unique LFC control strategy is stated to swap the one overall PI controller with separate PI controllers in each control area, whose parameters are tuned using ZN method for a two GENCOs and DISCOs system under the contract and violation with desired load sharing [177].

In a multi-sources multi area system, the LFC problem is solved using a PID controller tuned using Social Spider Optimization algorithm under deregulated environment for all possible contracts i.e., bilateral, poolco or violation of these contracts [178].

As a maiden attempt, for composite combination of six hydro & reheat thermal with three gas generating units where in the auto generation control is modeled by a

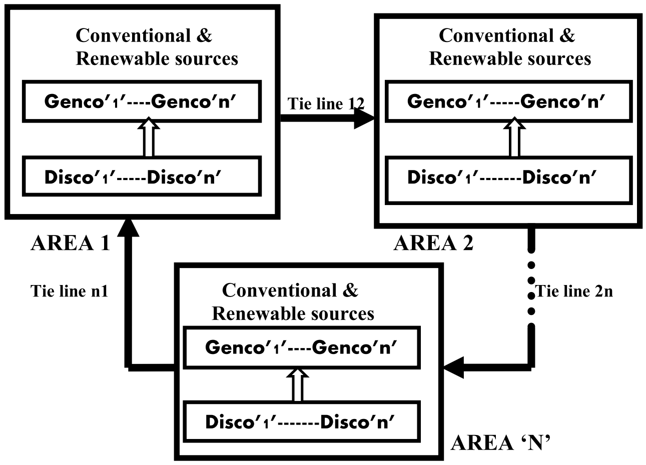

FIGURE 4. 'N' area deregulated power system with renewable & non renewable sources.

quasi-oppositional harmony search algorithm(QOHS), as an optimizing means for the proportional–integral–derivative controller is signified [179]. Modeling a novel output feedback controller state space model for a modified LFC of multi-source power generation is proposed in delegated environment for the market transactions [180].

The state space model for generation control of a two-area AC-DC parallel tie line interlinked power system under restructured atmosphere employs optimal PI regulators intended to conjure up all power market contracts. The DISCO participation matrix (DPM) is subjugated for all available transactions [181].

A coordinated control strategy for 3 area system posses a fractional order PI controller along with FACT device is connected to diminish the overall tie-line oscillations under poolco and bilateral market [182]. The AGC of multi-source six unit two control area using an objective function as ITAE criterion for tuning the fuzzy PID controller through Firefly Algorithm (FA) is proposed.

The stable steady-state and dynamic transient behavior of the system is analyzed for the case scenarios where the state space model is simulated with automatic generation control and SMES [184]. The capacitive energy storage system & thyristor-controlled phase shifter in the two area frequency control is investigated by developing proportional-integral (PI) controller using sine-cosine algorithm for better optimal gains [185].

Differential Evolution (DE) algorithm with ITAE as objective criterion with important physical constraints included, tunes the filter optimized PID (PIDF) controller to a six units two area hydro thermal system [186].

For better system response, the frequency error & its derivative is reticulated by an adaptive neuro –fuzzy hybrid (ANFIS) process [187]. Craziness based particle swarm optimization algorithm (Crazy-PSO) & hybrid modification of Bacterial foraging optimization algorithm (hBFOA)-particle swarm optimization (PSO) algorithms is compared

TABLE 1. Survey of hybrid system in regulated system with vres.

Ref No	Sources of generation	No of areas	Performance Index	Non-linearities	Additional devices	Type of Controller	Merits
[154]	Thermal, Wind, Solar	Single	--	GDB, GRC	--	RPID based ILAPO	Robust such as stability restored in less settling time.
[155]	Thermal with reheat, Wind, Solar	Single	--	--	--	Jaya optimized Integral controller	Better result compared with conventional integral controller.
[156]	Thermal, Hydro, Wind, Solar	Two	ISE	--	SMES	TID/TIDF	Frequency enhanced through the co-optimized process.
[157]	Reheat thermal, Wind , Solar thermal	Two	ISE, IAE, ITAE, ITSE	GDB and GRC	Fuel cell, AE, Plug in EV	FOPID	Remarkable reduction of error in the performance indices.
[152]	Thermal with reheat, Wind, Solar	Two	ITAE	GRC	--	DE-PID	Parametric variations minimized with large load variations.
[158]	Thermal, Hydro, Wind, Solar	Two	--	GRC	SMES	Hybrid FOPID- TID	40%-50% minimum overshoots & settling times achieved.
[159]	Thermal, Wind, Solar	Two	--	--	FC, HAE, MTG, BESS and DEG	ISFO- AT2FPID	Minimum objective function value achieved over other methods.
[156]	Thermal, Hydro, Wind, Solar	Two	ISE, ITSE and IAE	GRC	EV	Hybrid FOPID- TID	System oscillations dampened with less number of EV's.
[160]	Thermal, Hydro, Wind, Solar	Two	ITSE	GRC, GDB, TD	--	AOA based I-TD controller	Better convergence & very much minimum overshoots, settling time.
[161]	Thermal, Hydro, Wind, Solar with MPPT, Gas	Two	ISTSE	TD	Battery system	Cascaded PID	Outer & inner loop of the controller design leads to the fastest response.
[161]	Thermal, Wind, Solar-thermal	Two	ISE	GRC, GDB	SMES, BESS	MPA-PID	Output responses rise and fall within adequate bound abided by European grid regulations
[162]	Thermal, Hydro, Wind	Two	ISE	--	--	Self tuned LFC controller	Recursive type controller adjusts dynamics and provides better response.
[163]	Thermal, Wind, PV	Two	ITAE	--	--	COA-tuned PDn-PI	Maximum frequencies & tieline power deviations do not exceed 0.4% relating
[153]	Thermal, Wind, Solar	Three	ITAE,ISE	--	--	GOA-PI	Transient performance of this controller is better than others with/without RES.
[164]	Thermal, hydro, wind, solar, geothermal	Three	--	GRC	BESS, FESS, CESS, SMES, UC, RFB	FOPI-FOPID	SCA helps in simultaneous optimization of the controller parameters.
[165]	Thermal, Wind, Solar with MPPT	Four	ITAE	--	--	ANFIS	ALO trained ANFIS gives optimum solution with best fitness function.
[150]	Reheat Thermal, Hydro, DFIG	Four	--	--	--	Fuzzy PID controller	Better results over other conventional controllers
[166]	Thermal, Hydro, Wind, PV, Diesel	Multi system	ITAE		SMES	MVO-MPC	Better results due to non convergence of controlling parameters in local optima.
[167]	Thermal, Wind, Solar	Multi system	--	--	FC, HAE, MTG, BESS, FESS and DEG	FO-Fuzzy-PID controller	Mitigates the oscillation during the load and wind perturbations, solar irradiation.

in the PI frequency regulators in AC-DC parallel tie line links [83], [84].

An extensive study on the bacterial foraging optimization (BFOA) algorithm employed fuzzy inspired PI/PID controller in frequency control of multi-area systems is comparatively analyzed with the various other techniques such as firefly algorithm, particle swarm optimization and pattern search (PS) algorithms [189].

ANFIS rule based load frequency control to comply as per NERCs standard BAL-001-2 for reducing the frictional damages in the generating equipment apart from regulating frequency system with thermal & hydro GENCOs is discussed. The proposed controller is tested for the data from load center of Indian Regional Grid [190].

An uncommon two area deregulated system with Combined Cycle Gas Turbine - Thermal-Hydro plant system is analysed for load frequency control through classical controllers tuned using Stochastic Fractal Search algorithm which offers better global optimum solution & simplicity [191].

2) SOLAR/PHOTOVOLTAIC POWER GENERATION

An advanced Artificial Bee Colony (ABC) algorithm is employed for a stout solar power stabilizer which reconciles the recurrence and tie-line deviations successfully [192].

Two control areas are mathematically formulated from solar PV arrays & electric vehicle aggregate units which is considered as system with four GENCO and DISCO is studied for trial and error method compiled PI controller parameters [193].

Deregulated multi area Electrical Vehicle (EV) incorporated Solar cum Thermal Power Plant (STPP) is designed & controlled by Fractional Order ANN (FOANN) controller. The performance of the FOANN controller is tested on the devised system considering the bilateral market contract transaction [194].

In a two areas restructured power system, PI controller is used as the secondary control whose parameters are pre specified. The DISCO participation matrix acts in the poolco based and bilateral contract with contract violation [195]. A two area system with a total power rating of 2000 MW in which the Solar-thermal generation as two GENCOs and four DISCOs with two DISCOs in each area are considered respectively. The classical PID controller gains are updated by the new improved grey wolf optimization technique [196].

Selection of optimal secondary controller is very much essential for the AGC system to have better transient and steady state responses. The Integral, PID and cascaded PI-PD act as secondary controllers for each area consisting of two GENCO & DISCO. They are tuned by the classical, population based PSO algorithm [197].

A new and novel Quasi Opposition based Whale Algorithm (QOWOA) modifying the parameters of PIDN-FOPD controller is proposed for the frequency correction of two areas under poolco transaction only [198].

3) WIND POWER GENERATION

Doubly fed Induction generator based wind turbine and its inertial support issues necessitates the need for reducing the dynamic deviations. Fuzzy logic control scheme taking frequency error to provide express active power hold up by supplying the available kinetic energy on varying load conditions [199].

A five area load frequency model is designed as one DISCO & two GENCO's and each microgrid control area include three GENCOs connected to form a ring feeder configuration. Particle Swarm Optimization and Fuzzy based hypothesis effectively optimizes the PID controller. [200]. An additional control scheme comprising of Artificial Bee Colony algorithm (ABC) computes the parametric values of the wind energy machine side converter, enabling them to partake in frequency control minimizing the active power deviation [201].

Linear matrix inequality technique (LMIs) based stability criterion is recognized in terms of the relationship between time delays and decay rate and the resultant controller gains. A robust load frequency controller to reduce the inertia effects based on the latter caused by integrating wind power is designed [202].

PI controller tuned by Fuzzy Gain Scheduling (FGS) method is proved to outrun Ziegler Nichols (ZN) method. The former controller is installed in the secondary LFC loop which sets the set point of the governor in the relevant area [203].

Recent developments in the demand-side response (DR) have paved way to idolize the controllable loads which are fitting for deferment or transposing the load power demand to off-peak duration with no disturbance in operation [204]. Wind plants containing differing speed turbines includes a supplementary control of frequency feedback loop causative to boost total system inertia together improves the system frequency performance [205].

The Fuzzy logic based DFIG controller is found to have quicker response than the rest of the system which may delay the reaction time of the conventional generators post disturbance [206]. During the frequency dips and transients, the fuzzy logic inspired control is scrutinized considering frequency error as input feed for spontaneous active power support and balance in the tie-line power during the transient period [207].

The EPSO based LFC scheme is premeditated for the multi-control area with wind model. The composite feedback controller from the measurable state estimates of the LFC system attenuates the wind energy disturbance in the output [208].

Modeling of precise wind turbine system, the frequency control studies is performed using fractional order proportional integral &integral order integral derivative with filter tuned by the crow search algorithm subjecting to a new performance index namely, hybrid peak area integral squared error [209].

4) HYBRID POWER GENERATION SYSTEM

Frequency control and load following coined as Automatic Generation Control (AGC) in deregulated system is an important ancillary service. A deregulated three area hybrid model utilizes the classical Proportional Integral Derivative controller (PID) whose parameters are tuned and proved superior by Cultural Algorithm (CA) [210].To decrease this

TABLE 2. Survey of hybrid system in deregulated system with vres.

Ref No	Sources of generation	No of areas	Performance Index	Non-linearities	Additional devices	Type of Controller	Market transactions	Merits
[212]	Thermal, Hydro, Wind, Gas	Two	ITSE	GRC, GDB, TD,BD	RFB,TCSC	FOI-PD	Poolco, bilateral, contract-violation	Effect of zeroes is overcome and enhances the response of the system.
[213]	Thermal, Hydro, Wind, Geothermal	Two	ITAE	GDB, GRC	DEG,AE, FC, BESS	CC-TID	--	Prior estimation of fast-changing profile utilizing disturbance observer
[214]	Thermal, Gas, DSTS, WTS, EV	Two	ISE	GDB, GRC, BD	RFB, SMES	QOLOA-TPID	Bilateral	50% improved result with renewable using proposed controller.
[215]	Thermal, Solar, Wind, Biogas	Two	ITAE	GDB, GRC	DEG,AE,FC, BESS,FESS,EV	LADRC	Poolco, bilateral, contract-violation	Disturbance need not be modeled mathematically for the proposed controller.
[216]	Thermal, Hydro, Wind, Diesel	Two	ITAE	GDB, GRC, BD	UPFC, RFB	hDE-PS-MID	Poolco, bilateral, contract-violation	Proposed hybrid technique has the global exploring capabilities of DE & local exploitation ability of PS.
[217]	Thermal, Hydro, Gas, Geothermal, DG	Two	ISE	GDB, GRC, BD	AE,FC	2-DOF-PI-FOPDN	Poolco, bilateral	INEC strategy is implemented and better transfer capability in HVDC tie-line.
[218]	Thermal, Solar, Wind	Two	ITAE	--	DPFC, TCSC, UPFC, SSSC,UC	2DOF PID-FOPDN	Poolco, bilateral, contract-violation	Greater response by minimizing the changes in the system over studied approaches
[219]	Thermal, PV with MPPT, Hydro, Wind	Two, Three	ITAE, IAE, ITSE, ISE	GDB, GRC	SMES	MPC	--	Proposed control achieves the best performance index value for non linear system.
[220]	Thermal, Hydro, Gas, Geothermal, DG	Two, Three	ISE	GDB, GRC, BD	--	2-DOF (FOPIλD)-PDN	Poolco, bilateral	30-40% improvement in deviations with parallel HVDC tie line.
[210]	Thermal, Hydro, Solar, Wind	Three	ISE	--	Battery system	CA-PID	Poolco	High derivative gain by CA counterbalances the oscillation due to error.
[221]	Thermal, Solar, Wind, Geothermal	Three	ITAE	GDB, GRC	RFB	STFOFPID	Poolco, bilateral, contract-violation	Real time validation of SSA tuned controller in OPAL-RT 4150.
[222]	Thermal, Hydro, Wind, Natural gas, Diesel	Three	IAE, ITSE, ISE	GDB, GRC	RFB	PFM-PID	Bilateral, contract-violation	Frequency adjustment and disturbances damping are significantly improved

frequency fluctuation an Automatic Voltage Regulator (AVR) prepared by Power System Stabilizer (PSS), FACTs devises and PID controller is used and the PID controller parameters are updated by Imperialist Competitive, genetic and PSO algorithm and the success of Imperialist Competitive algorithm is displayed [211].

Fractional Order Integral (FOI) combined Proportional Derivative (PD) controller involving six-generation unit incorporated two area model with the insertion of all available non-linearities is optimized by the Improved Fitness Dependent (I-FDO) optimizer is evaluated [212].

A hybrid multi source multi area power system's frequency regulation performance is compared for different controllers namely, PI, PID with filter, two and three degree of freedom (2DOF-PID & 3DOF-PID), fractional order PID, cascaded PI–PID, Tilt integral derivative and cascaded TID that are optimized by Crow search algorithm with chaotic mapping. Furthermore, state space transfer function model of Geo thermal power plant is included in pole-zero form for realistic approach [213].

Sooty terns optimization algorithm (STOA) optimizes a model predictive control (MPC) for an interconnected system which aims to minimize the error by considering GRC and GDB in PI controller [219]. Improved Frequency Regulation (IFR) in a deregulated system is established through hybrid modeled fuzzy inspired Proportional Integral (FPI) cum linear active disturbance rejection control tuned by a fresh Quasi opposition-Artificial electric field (QO-AEFA) algorithm [215] A multi-source power system is frequency regulated through a Modified integral derivative controller optimized by a hybridized Differential evolution and Pattern search (hybrid DE-PS) outruns by its desirable performance for all three market contracts [216].

AGC in stable operations under unexpected situations for the SESCO-West Kalimantan power system interconnection in Indonesia and Malaysia with biomass power as a huge predominant is proposed by the distributed power generating resources based process, targeting supply-demand balance [223].

Gains of the cascaded fractional order 2-DOF (FOPI$^{\lambda}$DN)-PDN optimized by Volleyball premier league algorithm is planned for the generation control scheme comprising of DGs. Also, the inertia emulation strategy incorporated modified AC tie line parallel to HVDC tie-line to retract the inertia control [224].

A tilt proportional integral derivative controller equipping Integrated Square Error (ISE) as objective for Quasi opposition lion optimization (QOLOA) algorithm with numerous hybrid storage units is used to reduce the frequency oscillations [214].

A multi area restructured system AGC is dealt with Area I comprising of thermal, DG, GTPP while Area II has thermal, hydro & gas plants as the GENCOs respectively. System is investigated for various controllers optimized through Volleyball Premier League (VPL) algorithm [217].

Automatic voltage control of thermal reheat, solar and wind interconnected to form the hybrid system under the restructured scenario is performed by the Firefly algorithm tuned Fractional order PID controller & validated by in real time through Typhoon hardware in-the loop (HIL) 402 [225].

For verifying the superiority of the moth flame optimization algorithm over the others such as Cuckoo search and Bat algorithm, the recent two degree of freedom- proportional integral derivative-fractional order proportional derivative with filter is tuned by all the above stated algorithms for two area system [218].

Unequal areas are assumed for the study and so, a modified PID controller coordinated by the predictive functional control fine tuned by grass hopper optimization algorithm is proposed under restructured scenario for a hybrid system comprising of multi sources [222].

IV. CONCLUSION & INFERENCES

The present paper reviews the very recent trends and impact of renewables in electricity market in terms of LCOE as well as the load frequency control in overall electrical power system. The survey is done based on the major transition in the power network i.e., deregulation and therefore the annotations of the contents are organized by including and excluding of deregulated structure. The detailed extensive study reveals the following important observations and inferences:

- Traditional LCOE requires furthermore précised calculation for the justified assessment of renewable participation.
- Lack of a standard LCOE methodology for all the generating technologies especially with the VRES.
- Apart from Solar PV, the research and development for the estimation of levelised cost for the other renewable sources is challenging and still has a long way to go.
- Improvement of LCOE is required in terms of the overall risk related costs, losses and uncertainties for VRES projects.
- The stability and reliable grid operation is another important aspect to be considered in the LCOE evaluation of VRES.
- Inclusion of inherent input parameters for LCOE evaluation paves better way for the policy makers regarding futuristic growth of renewable energy integration.
- Accurate LCOE estimation for VRES technology leads to better investments by public and private players.
- Irrespective of regulated or deregulated power system, the impacts of renewable energy sources are dynamic in the load frequency control due to their natural intermittent nature.
- Even after the advancements in the intelligent techniques, the operation of LFC/AGC with Renewables integrated is still challenging especially under deregulated scenario.
- The sporadic nature of renewable resources which is termed as the drawback can itself be turned over as an advantage by employing them for quick power support to ensure reliability.
- Renewable energy resources participating in the load frequency control of the deregulated power system is still at stake, with which their growing penetration needs to be explored for the active participation.
- In practice, lack of non linearities inclusion for a realistic system study in both traditional & restructured system tends to make the system study negligent and unrealistic.
- Comparing the control techniques, methodologies and research studies available in non deregulated structure impregnated with solar, wind and hybrid systems, deregulated structure with renewables needs more precise & distinct control techniques through research.
- Furthermore efforts and research focus on the frequency regulation & load following ancillary services of the restructured power system with renewable energy penetration both individually and collectively is required.
- The active and dynamic participation of renewables in frequency control needs further exploration & control methods innovation as a beneficial aspect in the near future.
- Development and contribution towards the robust energy management, operation & control methods in hybrid

power system needs to emphasized for the effective progress of the multi source restructured system.

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