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Negative Effects and Processing Methods Review of Renewable Energy Sources on Modern Power System: A Review

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Abstract- Extremely penetration of Renewable Energy Sources (RES) into modern power systems inflicts many challenges when it comes to achieve optimal performance out of overall system. One of the potential issues is that RES are electromagnetically de-couple from the rest of the system as they are interfaced through power electronics with the traditional grid, which gives rise to synchronization problems and improper control of rate of change of frequencies (ROCOF). Moreover, variations in weather and operating conditions adversely effect their non-linearity performance, which causes their insufficient participation towards frequency regulation along with other conventional synchronous generators. Furthermore, uncertainty associated with RES because of their intermittent nature introduces different dynamic characteristics, which increases complexity of control systems and operation. Some other concerns are degraded system inertia, high fault current, low power quality, high uncertainties, and low fault ride through capability. As a solution to these RES integration problems, cutting edge technologies including different control strategies, inertia emulation techniques, optimization techniques, energy storage devices, and fault current limiters are being practically adopted. This paper is intended to provide a comprehensive overview of challenges faced by modern power systems because of the rapidly rising RES penetrations. Further, this literature presents some practical approaches and solutions to conquer these challenges. Overall, this paper is an intensive source of information about the operational strategies and challenges of modern smart power systems including various kinds of RES as their constituents.

Keywords Renewable energy sources (RES), RES integration challenges, solar photovoltaic (PV) systems, non-synchronous generators, RES power quality.

1. Introduction

The penetration of renewable energy sources (RES) is highly appreciable to meet the rapidly increasing power demand of the modern world. Also, negative impacts caused by traditional ways of power generation such as carbon emissions, air pollution and climate changes are further paving the way towards utilization of RES. Recently, deployment of RES such as solar, wind, tide, and geothermal is being rapidly increasing all over the world because of their natural availability in environment with minimal pollution factor.

According to statistics, RES penetration in conventional power systems will grow up to 48% in most European countries and 35% in China by 2030. Figure 1 presents the roadmap of RES penetration into traditional power systems for some of the leading world countries by 2030 [1].

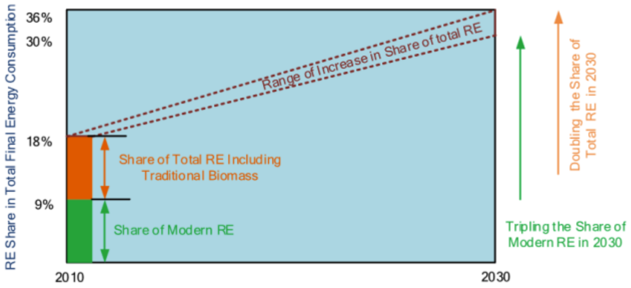

Fig. 1. A roadmap for renewable power generation by 2030 [1].

Modern power systems are hybrid solutions incorporating both conventional synchronous generators and renewable energy sources (RES). Conclusively, the performance and philosophy of modern power systems have been changed from passive networks to active networks with low inertia and dynamic characteristics. The main challenges associated with such modern power systems are degraded system inertia, reduced stability margin, low reliability, and poor control of rate of change of frequency (ROCOF), larger frequency deviations. In addition, high uncertainties, low fault ride through capability, high fault current, low generation reserve, and low power quality are other red flags to optimal performance and operation of modern power systems [1, 2]. To overcome these challenges, many solutions have been presented and are being practically implemented. For example, enhancement of grid inertia with the inclusion of synchronous condensers, ultra-capacitors. Flywheels and batteries in power system. Efficient control strategies with state-of-the-art optimization techniques can be utilized to improve stability and reliability issues. Further, effective and costly power electronic conversion systems can be designed to magnify the quality of power production. Similarly, fault current limiters can be included to enhance low fault ride through capability [2, 3].

As smart grids would be ubiquitous in future because of their multiple benefits over traditional grids, such as human-centered, more effective distributed topology, coordinated infra-structure, and facilities of load-shaping, remote monitoring, communications, self-healing, flexibility to customer choices. Smart grids predominantly generate their output power from various kinds of RES, therefore there is an utmost need to study, invent and overcome difficulties regarding RES integration into traditional grids. Research, developments, and innovations in this scientific field are highly welcomed all over the world [4].

This paper provides a comprehensive understanding of challenges associated with modern and hybrid power systems because of ever-increasing RES penetration into their network. Also, this literature delineates some of the practical remedies and solutions to overcome these challenges. The next **Section 2** includes all the negative effects caused by increasing RES penetration into the modern power systems in detail. **Section 3** explains inertia and frequency control techniques in modern power systems. Later, **Section 4** deals with the practical solutions and methodologies to overcome the negative impacts of RES penetrations.

2. Negative Effects Review of RES on Modern Power Systems

Increasing penetration levels of RES in modern power systems are causing many performance issues in recent years. Degradation of system's inertia leads to frequency instability, increasing levels of short circuit currents, intensive uncertainty, and deterioration of power quality. These issues represent challenges for the operators of modern power systems, designers of modern power systems, modern power system planners and the researchers [5]. The main objective of this section is to briefly review these issues while describing them in a simple understandable manner.

2.1. Inertia Modeling of Modern Power Systems

The inertia is the significant property of modern power system operation. It describes the sensitivity of modern power system towards abrupt power miss matching. The equivalent inertia constant H_{eq} of modern power systems is composed from two parts as indicated in Eq. (1). The first part is the synchronous inertia constant HS which is coming from conventional synchronous generators, while the second part is the emulation/virtual inertia constant HEV which is coming from RES as shown in Fig. 2.

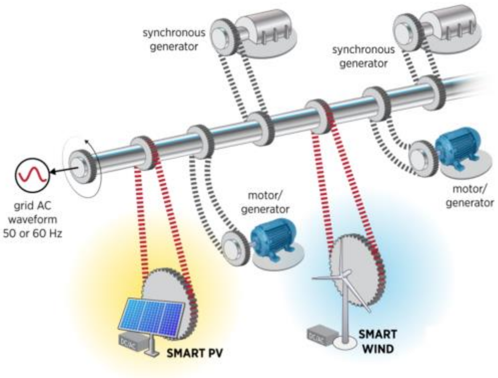

Fig. 2. Equivalent inertia constant components of modern power system [1].

The swing equations of modern power systems are written as follows [1]:

$$H_{eq} = \frac{\sum_{i=1}^{GCPC} H_i \, . S_{base,i} + \sum_{i=1}^{EVG} H_{EV.j} \, . S_{base,j}}{S_{base}} \tag{1}$$

$$\Delta\omega_r = \frac{\Delta P_{in} - \Delta P_L}{2H_{eq} * s + D_{eq}} \tag{2}$$

Where:

i is the serial number of synchronous generator,

j is the serial number of RES unit,

GCPS is the total number of synchronous generators coupled to the modern power systems,

EVG is the total number of RES units connected to modern power systems through emulation/virtual inertial of control system for modern power system,

Hi is the inertia constant of i-synchronous generator in second,

$H_{EV,j}$ is the inertia constant of j-RES unit in second,

$S_{base,i}$ is the base power of i-synchronous generator in kVA or per unit,

$S_{base,j}$ is base power of j-RES unit in kVA or per unit,

S_{base} is the base power of modern power system in kVA or per unit,

Δωr is the difference of angular frequency in rad/s,

ΔPin is the miss-match of the input power in kW or per unit,

ΔPL is the miss-match of the load power in kW or per unit,

D_{eq} is the equivalent damping factor, and s is the s-domain of Laplace transform.

Equation (1) shows that, H_{eq} of modern power systems is no longer constant as in conventional power systems but depends mainly on RES penetration levels in power systems. So, the modern power systems become low inertia system because of high penetration levels of RES in grid network. The degradation of inertia in modern power systems is due to low inertia of wind turbines and no inertia of both photovoltaic and fuel cells generation systems. H_{eq} is reduced in many European countries during last recent years. The statistical reduction in H_{eq} during last decade of 1996-2016 in European countries is shown in Fig. 3 [1].

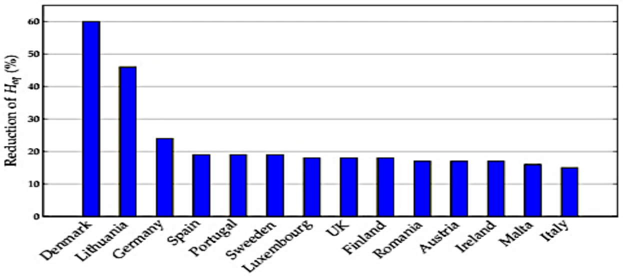

Fig. 3. H_{eq} reduction of European Union during 1996-2016. [1].

The inertia degradation of modern power systems causes many issues such as instability problem, faster rate of change of frequency (ROCOF) with more frequency deviation, degradation of power quality, and black out.

Furthermore, the frequency deviations in modern power systems are being caused by substituting of reserve generating units and depletion of reserve power [1, 5].

2.2. Fault Ride Through (FRT) Capability Issues of Modern Power System

Instantaneous or quick tripping of RES from modern power systems because of faults or disturbances causes stability problems. So, RES must remain connected with modern power system grid for a certain time period according to grid code of the specified country. FRT capability should be enhanced with properly control systems to achieve relay settings to satisfy this ability [5].

2.3. Uncertainty Issues of Modern Power Systems

Uncertainty of modern power systems represents inaccurate parameters of the system at 100 % certainty. Normally, uncertainty results of non-smoothing in operation and performance of the modern power grid. Therefore, RES represent the main sources of uncertainty due to their intermittent nature. So, RES integration cause abrupt operation of modern power system in case of un-remedy of uncertainty [5].

2.4. Degradation Power Quality of Modern Power Systems

Harmonics are the main sources of degradation power quality. Power electronics devices and systems control of RES which ate linked with power grid represent the main sources of harmonics in modern power systems. Harmonics are causing lot of issues in modern power systems such as resonant phenomenon which are causing over-voltages or over currents, increasing loss, mal operation of protection power systems [5, 6].

3. Negative Effects Review of RES on Modern Power Systems

The remedy methods for negative effects of RES in modern power systems are listed as follows:

[1] Enhancing low inertia techniques [1,2, 7]

[2] Processing methods of frequency regulation [1, 7].

[3] Processing methods of enhancement fault ride through (FRT) capability [5].

[4] Remedy methods of uncertainty in modern power system [5].

[5] Remedy methods for improving power quality of modern power system [5, 8, 9]. Various technologies were developed to enhance power system's inertia, provide prompt response to power imbalances, and decrease ROCOF in the power system. Diminishing ROCOF will ultimately improve the frequency stability of power system. Many techniques were proposed in the literature to overcome of reducing inertia in modern power systems such as synchronous condensers, compressed air energy storage, pumped hydroelectric energy storage, ultra-capacitors, flywheels, and batteries are being presented [7].

3.1. Methods of Enhancing Inertia in Modern Power Systems

There were many various available developed techniques in the literature to enhance power system's inertia, provide prompt response to power imbalances, and decrease ROCOF in power grid. Diminishing ROCOF was ultimately improved the frequency stability of power system. Also, there were many proposed technologies available in the literature to overcome of reducing inertia of modern power systems such as synchronous condensers, compressed air energy storage, pumped hydroelectric energy storage, ultra-capacitors, flywheels, and batteries [2, 7].

3.1.1. Synchronous condensers

A synchronous condenser is a freely spinning synchronous machine connected to modern power network to improve its power factor and enhance its performance for voltage regulation through controlling its field current [10]. The synchronous condenser is controlling the reactive power by absorbing or releasing it according to the requirement of voltage regulation. In case of an emergency or power imbalance, the frequency regulation will be steadily through providing inertia of synchronous condenser that typically lies between 1 and 1.25s [2, 7].

Therefore, the synchronous condensers will overcome the reducing of inertia problem and provide the modern power system that linked with RES with the following performance:

➢ Decreasing of ROCOF values and frequency fluctuations.

➢ Reducing the fault level.

➢ Increasing the short circuit ratio.

➢ Ameliorating the frequency nadir.

However, coastally the installation and operation cost of synchronous condenser with difficulties in controlling swiftly for the abrupt load changes [2, 11].

3.1.2. Demand-side management

Security of traditional power system can be controlled by balancing between power generation and load demand. However, the increasing penetrations of RES in modern power systems leads to uncontrollable in generation side whatever an imbalance arises between generation and load demand that causing to frequency deviations. To avoid this situation, a proper control over either generation or demand side should be installed. Nowadays, the modern power systems with RES integration employ demand-side-management techniques. These techniques are realizing self-regulated loads to manage frequency deviation via contributing the active power at the consumer's sides to resolve frequency regulation and its ROCOF [7, 11].

Air-conditioners and refrigerators are examples of self-regulated loads that are capable of these appliances [12]. The devices of frequency regulations and ROCOF should be setting up to provide a promising solution to overcome low-inertia issue irrespective of high initial cost for these modifications and possibility of breaking down its communication system for controlling process [7].

3.1.3. Pumping hydroelectric energy storage (PHES)

PHES can be implemented to store hydroelectric energy in load balance. PHES stores electric power by moving water between upper and lower of reservoir [13]. In case of excess energy, the water is pumped to an upper reservoir to compensate the excessive of energy in grid system, while in case of high load demand, the water is released to lower reservoir for purpose of electrical generation. Both generating and pumping modes of a PHES are controlling grid's inertia with increasing penetration of RES into grids. The rapid growth installations of PHES will be 59 % by 2030. The PHES are providing modern power system with inertia constant (H) of between 2 and 4 second to realize of 100% RES penetrations [14]. PHES can also behave as a synchronous condenser to provide the modern power systems with reactive power and inertia support. Moreover, other ancillary services such as voltage regulation, spinning reserve and inertial response can also be provided by PHES for slower response purposes as compared to flywheels and super-capacitors [7].

3.1.4. Compressed air energy storage (CAES)

CAES technology deploys pressurized air to store potential energy to facilitate large-scale RES penetration in modern power system. It is a promising technique due to its high performance efficiency with long life. The air is compressed when excess power is presented in the grid and is decompressed for delivering required power to the grid. It enhances grid inertia with inertia constant between of 3 and 4seconds via voltage and frequency support. In practice, Australia's 5 MW CASE installation is used its modern power systems to overcome negative effects of RES and providing support performance to its grid networks [7, 15].

3.1.5. Flywheels

The flywheel is a mechanical equipment to store power in kinetic energy for applications of absorption or injection of an electrical power to enhance grid's inertia. It has the following advantages over other techniques:

➢ Its storage capacity is independent of aging.

➢ It is the most suitable option for continuous charging and discharging requirements.

➢ It doesn't possess any geographical constraints and its installation process is quite easy.

➢ It exhibits round trip efficiency and quick ramping capability [7].

➢ It also provides ancillary services such as frequency regulation and inertia controlling [16].

As flywheels are coupled to the grid through power electronic interfaces, so its capability of storing energy is quite low [7].

3.2. Batteries and Ultra-Capacitors

Batteries are used to store electrical energy in DC form. Therefore, power electronic converters should be used to link them with grid network to back up inertial response and frequency stability of low inertia power system with fast response time [7, 17, 18]. Also, ultra-capacitors are stored and released a large amount of electrical energy in a short period with fast response. A combination of ultra-capacitor with a battery is effectively deal with abrupt power imbalances to provide primary frequency regulation [19].

4. Remedy of Frequency Regulation and ROCOF in Modern Power Systems

Researchers have developed of new controllers to back up the increasing of penetrations of RES in modern power systems. These controllers have capability to deal with the characteristics of both synchronous generators and RES for both frequency response and regulation to enhance system's stability. The inertia and frequency control techniques for wind turbines and solar systems in the literature are indicated in the block diagram of Fig. 4 and being discussed in the following sections [5, 8, 20].

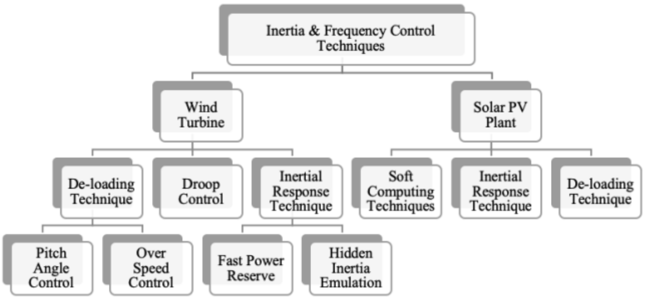

Fig. 4. Block diagram of inertia and frequency control for both wind turbines and PV systems [1].

4.1. Wind Turbine

Wind turbine is a promising technology for converting mechanical wind energy into electrical power. The wind turbines are classified into two main types as follows [20]:

- ➢ Fixed speed wind turbines coupled with induction generators which are connected directly to the power grid. These types of wind turbines are directly sharing with grid inertia and frequency regulation systems.

- ➢ Variable speed wind turbines coupled with double fed induction generator (DFIG) or permanent magnet synchronous generators which are connected to the power grid through power inverters. These types of wind turbines are decoupled from power grid and sharing its inertia and frequency regulation through specific control systems.

The swing equations of wind turbines are written as follows [5]:

$$P_m - P_e = J\omega \frac{d\omega}{dt} \tag{3}$$

$$H = J\frac{\omega}{2S} \tag{4}$$

$$\frac{df}{dt} = f\frac{P_m - P_e}{2HS} \tag{5}$$

Where:

P_m is the mechanical input power of wind turbines in kW or per unit,

P_e is the electrical output power of wind turbine in kW or per unit,

J is the moment of inertia of wind turbines in kg-m^2,

H is the inertia constant of wind turbines in second,

S is the total power of modern power systems in kVA or per unit,

ω is the angular frequency of modern power system in rad/second,

(df/dt) is the rate of change of frequency (ROCOF) in HZ/Sec

f is the frequency of modern power system in Hz.

The sewing Eqs. (3-5) share the frequency regulation, the rate of change of frequency (ROCOF) and inertia control either directly coupled with the grid or through specific wind turbine control systems as shown in block diagram of Fig. 4. The characteristics of power-speed wind turbines for different pitch angles is shown in Fig. 5 [21].

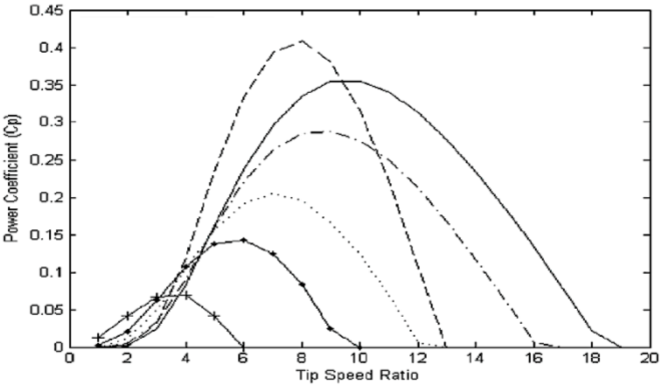

Fig. 5. Power-speed characteristic curves of wind turbines at different pitch angles [21].

4.1.1. Control of inertia response

The Kinetic of synchronous generator can be controlled automatically through prime mover, while in wind turbines are not satisfied. The available satisfied wind turbines two control techniques in this regard are:

- ➢ Inertia Emulation: The control loops were intended to deal with the kinetic energy reserved in turbine's rotating blades for controlling its inertia with constant (H) in the range of 2-6s [9, 22] during power imbalances for setting frequency regulation. There exist generally two kinds of inertia responses based on the number of control loops:
  - o One-loop inertia response: It exhibits one control loop, which depends on ROCOF.
  - o Two-loop inertia response: It deployed two control loops based on frequency deviations and ROCOF.

- ➢ Fast Power Reserve: In this technique, frequency deviations of multi-mechanism to face amount release during power unbalancing in short period with low inertia time response [22].

4.1.2. Droop control

The active output power of a wind turbine is regulated by the frequency change according to the following equation [21]:

$$\Delta P = P_1 - P_0 = -\frac{f_{means} - f_{nom}}{R} \tag{6}$$

Where: ‘R’ is Droop Constant, ‘f_{means} and P_1’ are the new operating points (namely frequency and output power of wind turbine); ‘f_{nom} and P_0’ are the initial operating points. According to Eq. (1) the output active power of wind turbine is raised from P_0 to P_1 to back up the frequency deviation [23].

This type of controller has the following advantages:

➢ It significantly ameliorates frequency nadir.

➢ It efficiently recovers frequency after power disturbances [22].

4.1.3. De-loading control

Normally, the output power of wind turbines is extracted at an Optimum Power Extraction Curve to ensured maximum efficiency or transferring from this optimum point in case of de-loading. A wind turbine captures mechanical output power is given as follows [22]:

$$P_m = \frac{1}{2} pAC_P(\lambda, \beta) v^3 \tag{7}$$

Where: ‘A’ is the rotor’s sweep area, ‘p’ represents air density, ‘β’ is the pitch angle, ‘λ’ is the tip speed ratio, ‘v’ indicates wind speed, ‘CP’ is the power coefficient.

Equation 7 shows that, the turbine’s output power depends on two important parameters: tip speed ratio ‘λ’ and pitch angle ‘β’. De-loading techniques deploy these two parameters as control signals. The de-loading techniques cab divided into the following process controls:

➢ De-loading by speed control: In this strategy, tip speed ratio ‘λ’ is being modified by transferring the turbine’s operating point either left or right to the maximum power point (MPP).

➢ De-loading by pitch angle control: In this approach, the angle of turbine’s blade is increased for de-loading purposes. Such a control is being opted when either speed of turbine’s generator is reached at its rated value or over-speed controller is unable to execute this operation [22].

4.2. Solar PV Plant

On grid solar PV plants can regulate system’s frequency during only positive excursion of frequency. When generation is greater than demand, then system frequency increases to decrease the PV’s frequency, while there is no regulation during negative excursion of frequency due to absent reverse margin when operating point is MPP. The following techniques are used to support the frequency regulation during negative excursion of frequency [5].

4.2.1. Inertial response techniques

Inertia emulation techniques provides frequency control of PV system via DC/DC converter to regulate the power of the PV system according to Eq. (8) [24].

$$P_{pv}^{ref} = (1\text{-}r).\,p_{max} - \Delta P_{freq}^{ref} \tag{8}$$

Where, r is the reserve power, which is adjusted by system operator. P_{max} is the maximum available power and △P is the output of frequency controller [5, 25].

4.2.2. De-loading control

PV de-loading techniques provides reserve power for supporting system’s frequency response beyond the MPP as shown in Fig. 6 [5]:

$$P_{reserve} = P_{max} - P_{de\text{-}loaded} \tag{9}$$

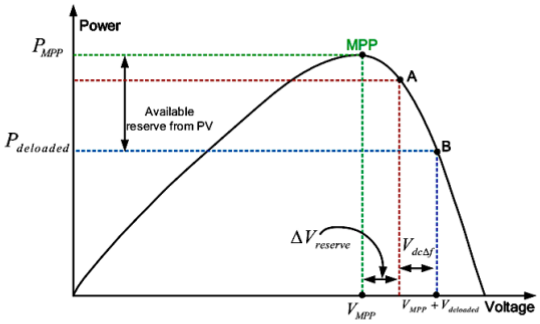

Fig. 6. De-loading power-voltage curve for PV systems [5].

4.2.3. Soft computing techniques

When the output power of a PV system fluctuates because of weather variations, it tends to frequency deviations at higher scale. Certain soft computing methods were developed to diminish these power fluctuations by ameliorating system’s frequency response. A fuzzy logic controller was suggested to generate output power command by frequency deviation. This approach is found to be better than de-loading technique due to PV system is normally operated near MPP [26]. Moreover, fuzzy logic controller can further be combined with particle swarm optimization for better system efficiency [3].

4.3. Review Processing Methods for Enhancement Fault Ride Through (FTR) Capability

RES should be maintained in connection with modern power grid during its disturbance time interval to enhance its reliability during contingency. To satisfy this goal, modern power systems were equipped with different control strategies, and many auxiliary devices for controlling and monitoring of RES installations. According to the types of RES installations in modern power system, the control strategies were divided into three categories such as PV system, wind system, and hybrid PV/wind systems. Figure 7 shows control strategy with different techniques for hybrid PV/wind system with and without auxiliary devices [5].

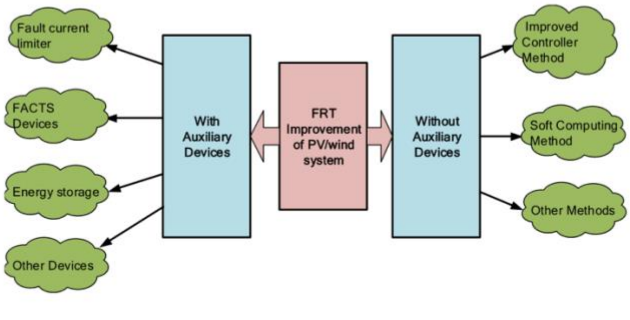

Fig. 7. Hybrid system PV/Wind control techniques for improvement FRT capability of modern power systems [5].

4.3.1. Classification of techniques for improving FRT capability

The different techniques for improving FRT capability can be classified into:

4.3.1.1. Auxiliary devices control techniques for improvement FRT of hybrid system

Different auxiliary devices are shown in Fig. 7 for improving FRT of modern power system capability. These auxiliary devices are known as fault current limiters (FCLs), energy storage devices, and flexible alternating current transmissions (FACTS) devices. FCLs are normally used and employed due to their costless, less in loss in stand-by mode, and high voltage withstand capability. FCLs have different types as shown in Fig. 8 such as bridge type fault current limiter (BFCL), series dynamic braking resistance (SDBR), modified BFCL, super-conducting FCL, and variable resistive FCL [5].

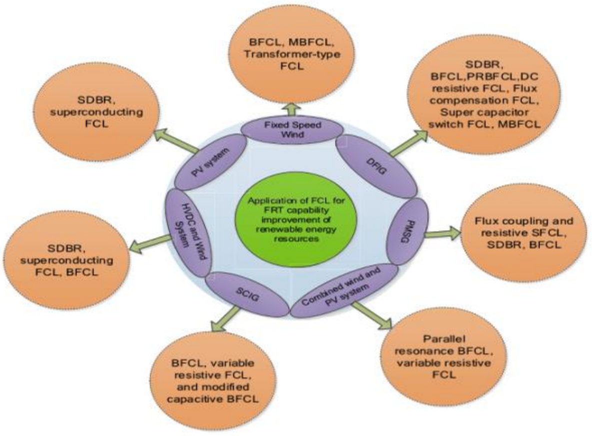

Fig. 8. FCL Techniques for improvement FRT capability [5].

4.3.1.2. Non-auxiliary devices techniques for improvement FRT capability

Non-auxiliary devices and soft computing techniques as shown in Fig. 7 were improved in the literature for enhancement FRT capability. Non-auxiliary devices for control systems of Fig. 7 are composed from improved controller method, soft computing method, and other methods. The improved controller methods were listed in a surgeon fuzzy logic controller which has low overshoot and steady state error. Soft controlling algorithms for other methods to improve FRT capability were presented in the literature [5, 27].

4.3.1.3. Alternative techniques for improvement of FRT capability

Alternative technologies using FACTS methodologies such as static VAR compensator (SVC), thyristor-controlled series capacitor (TCSC), static synchronous compensator (STATCOM), and storage devices such as battery, super capacitor, and flywheel are also employed to enhance FRT capability of modern power grid. These devices were increasing the capability of FRT of modern power system with higher cost and more complexity in controlling methods. Also, there were other alternative remedies with less cost and fewer control methodologies for small scale PV system were presented in the literature such as Dynamic current limitation method [5].

4.3.2. Review of remedy methods for minimizing uncertainty RES effects on modern power systems

Alternative technologies using FACTS methodologies such as static VAR compensator (SVC), thyristor-controlled series capacitor (TCSC), static synchronous compensator (STATCOM), and storage devices such as battery, super capacitor, and flywheel are also employed to enhance FRT capability of modern power grid. These devices were increasing the capability of FRT of modern power system with higher cost and more complexity in controlling methods. Also, there were other alternative remedies with less cost and fewer control methodologies for small scale PV system were presented in the literature such as dynamic current limitation method, uncertainty mitigation methods are shown in Fig. 9 [5].

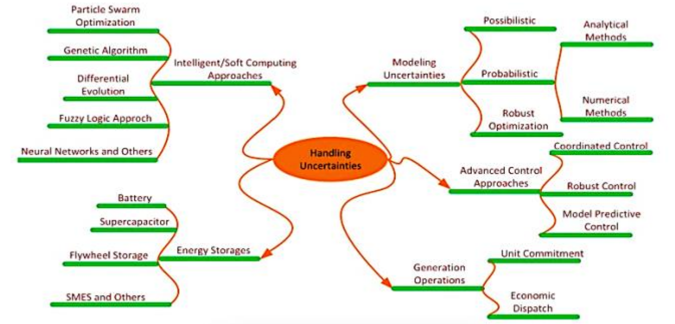

Fig. 9. Remedy methods of minimizing uncertainty [5].

➢ Uncertainty Modeling: This methodology is required for daily uncertainty. It represents the uncertainty by uncertainty set according to representative days with respect to measuring load and RES power generation for the modern power grid to ensure smooth operation at all its operating conditions [5].

➢ Intelligent Generation-Operation of Power Grid: This is done through economic dispatch (ED) and unit communication (UC) with implementing many optimal algorithms such as optimal power flow, state estimation, and commitment methodologies between RES and power grid which equipper generating plant of fast starting in operation [5].

➢ Power Grid Operation under Advanced Control: There were several approaches in the literature to minimize uncertainty of high level RES penetrations in power grid. These approaches were considering control approaches to ensure smooth operation of output wind power with minimum power fluctuation. The power grid which it is linking of solar energy sources is equipped with a robust non-linear control techniques for reducing uncertainty effects and ensure its reliability [5].

➢ Intelligent/Soft computing techniques: Uncertainties of RES were managed by intelligent soft computing algorithms such as genetic algorithm-particle swam (GA-PSO), and artificial neural network (ANN). The soft computing algorithms were used for power grid which equipped with hybrid of wind turbines and solar energy systems. The power grid performance has load uncertainty and random change of demand [5].

➢ Energy Storage using for Grid Performance: Several approaches were used for improving the power grid performance and reducing its uncertainties of RES. The techniques of hourly demand response, energy storage devices, and fast ramping unit were used to minimize uncertainty effects on modern power systems. The literature shows that the energy storage systems are the main core for mitigation uncertainty of power grid at all operating and weather conditions [5].

4.4. Review of Processing Methods for Improvement Power Quality of Modern Power Systems

Figure 10 shows that, the processing methods for improvement power quality of modern power systems are categorized into five groups such as filters, converter control for harmonics, flexible AC transmission systems (FACTS) devices, energy storages, and other methods. Each group can be sub-categorized into multi-different techniques. These technologies were used to minimize harmonic content according to harmonic standards of IEC61000-3 and IEE519. The harmonic standards were employed to determine harmonic levels for each voltage level of power grid [5, 8, 9].

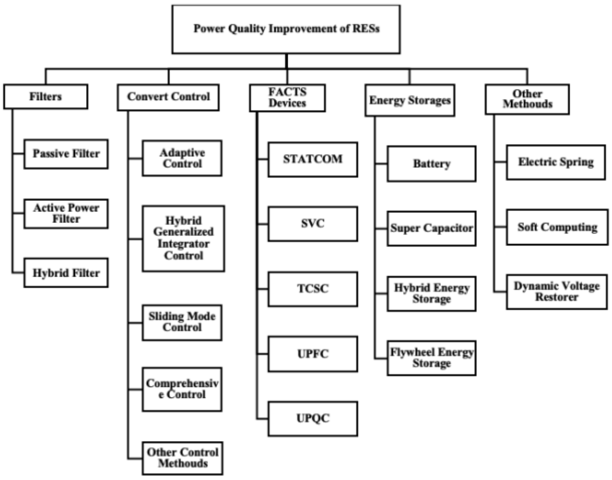

Fig. 10. Remedy methods of minimizing uncertainty [5].

The processing methods are summarized as follows:

➢ Harmonic Filters: Harmonic filters are classified into passive filters, active filters, and hybrid filters. The main functions of harmonic filters are concerned with minimizing harmonics to improve power quality and power factor of power grid.

➢ Converter Control for Harmonics Mitigation: The processing methods under such circumstances are divided into:

a. An adaptive and hybrid control for improving high frequency rejection technique with hybrid generalized integrator controller. This type of controller eliminates both sub-harmonics and inter-harmonics with minimizing disturbances of modern power grid.

b. Sliding mode control for dynamic state estimation for power grid linked with wind farm system to improve power quality.

c. Comprehensive control for mitigating harmonics of hybrid RES systems.

d. Comprehensive and other method controls for improvement of power quality with harmonic compensation and fundamental load extractive by advanced least mean mixed norm (LMMN).

➢ Flexible AC Transmission System (FACTS) devices: FACTS have advanced different aspects of power quality such as harmonic mitigation, improvement power factor, minimizing oscillations of electrical quantities, and reducing voltage dips. These processing methods in the literature were done by several FACTS devices such as thyristor-controlled series capacitor (TCSC), static VAR compensator (SVC), and static synchronous compensator (STATCOM).

➢ Energy Storage Devices: Power quality improvements were done in the literature by various energy storage devices such as batteries, super capacitors, and flywheels energy storage. The storage devices in the literature were used to smooth operation of power grid, mitigation over voltage at points of common coupling (PCC), support in wide ranges of reactive power, and reducing fluctuation of grid power.

➢ Other Methods for Improving Power Quality: The improvement of power quality for modern power system was done by other processing methods such as economic optimization, super conducting magnetic energy storage (SMES), high temperature super conducting (HTS) coil, electric spring, dynamic voltage restorer (DVR), soft computing-based method, fuzzy logic control, modulated multi-level converters (MMC), and multi-phase synchronous generators [5].

5. Conclusion

Penetration of RES into traditional power systems is highly encouraging in recent years because of their environmental benefits and availability in nature. RES can replace conventional synchronous generators for power generation in an effective way. On the other hand, technical challenges associated with their integration into modern power systems are troublesome. Some of them are lower system’s inertia, fault ride through (FRT) capability, uncertainties, increasing fault current levels, system instability and poor power quality. An extensive amount of research and collaborative efforts worldwide have been made to come up with innovative and efficient approaches to conquer the technical difficulties in this regard. Some of the popular ones are being discussed in this literature in simplest possible manner. However, the developed practical technologies and strategies so far are insufficient to accommodate current penetration levels of RES into modern power system. To facilitate higher penetration levels of RES (nearly 100%) to realize the future concept of smart grids, intensive studies and research must be conducted to overcome these challenges and to achieve robustness, stability, and reliability in modern power systems.

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