Power System Analysis Using The ETAP Software: A Comprehensive Review

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With the increase in population and the amount of energy required, power systems have become more complex and extensive over time. Because of the development of new equipment and modern operation strategies, these system complexities are also continuously increasing. One of the most powerful tools to model, and analyze modern, and complex power systems is Electrical transient analyzer program known as ETAP software that was developed by ETAP, United States. Since the introduction of this software, its different versions were provided, and much research were conducted in power system field by using it. This research for the first time attempts to provide a comprehensive survey on different applications of this simulation tool. For this purpose, after addressing the research conducted using the ETAP software in power system, the classification of its different versions is presented. Then a general survey on addressed references in terms of publication year, publishers, different categories is mentioned. Detailing power system analysis in terms of different studies, and addressing the relevant works of each category is then presented. Furthermore, different case studies used in power system analysis in three categories of practical cases in different countries, standard grids, mainly IEEE systems, and some sample and typical grids are segmented. Ultimately, the work opens new views on the future directions.

keywords: *Arc flash analysis, Battery sizing, Contingency analysis, Equipment sizing, ETAP, ETAP real-time overview, eTraX analysis, Grounding system, Harmonic analysis, Load flow, Motor acceleration, Optimal capacitor placement, Optimal power flow, Optimization, Protection coordination, Reliability assessment, Short-circuit analysis, Transient stability analysis, Unbalanced load flow analysis.*

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1. INTRODUCTION

Privatization, and restructuring, as a turning point in energy efficiency and generation improvement, have significantly changed the traditional operation and planning strategies in power systems [1]. Furthermore, significant expansion of energy consumption leads to integrated management of natural energy resources, such as food, energy, water (FEW) to overcome different critical challenges in this regard [2]. In addition, the emergence of microgrids as self-sufficient energy ecosystems is one of the most important issues to deal with the energy challenges [3], which their optimal energy management brings new challenges to power system control, operation, and optimization [4].

Renewable energy resources, as one of the most suitable and deficient source to tackle the energy crisis, inject some fluctuations in power system because of their uncertain nature, which further complicate the power system analysis [5], [6], [7]. According to the mentioned cases, the necessity of using powerful tool for the analysis of today's complex power grids is inevitable, which can also be used as an educational aid, one of the important pillars of comprehensive education in electrical engineering, in addition to their ability in modelling the real industrial systems.

The ETAP software is introduced for the first time in [8] for power system analysis in steady-state, and transient conditions. Since its initial introduction, this software has experienced many changes compared to its latest version, for year 2023, or 22.5.

A. A brief review of previous review works

Here, the most important research on the comparative applications including the ETAP software, or the review papers which mentioned it are addressed. Providing this general background helps to find the neglected issues of the under-study concept.

Bam and Jewell [9], have presented some general data of different power grid simulation tools, including ETAP. They categorized the main analysis to availability of component models, contingency, DC system analysis, integration/reporting/database capabilities, optimal power flow, power flow, power market modeling tools and analysis, protection and coordination, reliability, short circuit, stability, and voltage control/AGC. They also launched ETAP for the design, simulation and resolution of energy production, transmission, distribution and energy markets, including different modules for cost analysis and integration of components. It also provides energy measurement, real time simulation, advanced monitoring, quality control, intelligent load shedding, energy efficiency, and protection coordination. It is a complete analysis tool for the design, management and operation of the energy grid in a completely graphical and virtual reality environment. Additionally, other versions of the software include ETAP PSMS for power plant management, ETAP STAR for equipment protection and coordination, and ETAP Panel System for panel are discussed.

Martinez-Velasco *et al.* [10] defined the DER as a combination of DGs, energy storage and demand-side measures to help the utilities for solving their different problems on distribution grids by improving voltage, reducing power losses, and increasing power quality, and reliability. They addressed the present status and future trends of simulation software, and tools for planning and analysis of distribution grids, considering DER. They presented a long list of needed studies for planning and design in distribution networks considering DER interconnection, including voltage support, loss reduction, fault analysis and protection, reliability, power quality, over voltages, system stability, and distribution planning. The authors mentioned the EATP as a suitable tool for load flow, fault-current analysis, protection, reliability, power quality, and stability of DER. For electromagnetic transients, and planning it was excluded from the list.

In [11], the ETAP tool is introduced as one of the used tools for software studies to teach power-system modeling and analysis in electrical and computer engineering (ECE) department at Charlotte university of North Carolina (UNCC) for modeling power system equipment (transformers, induction machines, etc.), load flow and other required analysis.

Selvan, and Anita [12], have compared different software, including MiPower, ETAP, EasyPower and PowerWorld in terms of bus limitations, cost, modeling of common equipment, modules available, special equipment and user friendliness. They addressed the key elements of power systems needed for simulation studies as: harmonic study, load prediction, load shedding strategies, online monitoring, optimal power flow considering transmission lines, power flow, or load flow, relay protection and coordination, short circuit analysis, SSR (sub-synchronous resonance), transient stability, unit commitment and voltage stability. They also provide a list of companies that produce different electronic simulation software, includes ETAP, presented by Etta company. Finally, they compered four software of MiPower, ETAP, EasyPower, and PowerWorld in term of: equipment, including generator (AVR modeling, multi swing bus option, governor modeling), transmission line, two winding transformer (phase displacement, OLTC), load (static load, lumped load, constant current, power, impedance load), series reactor, shunt reactor, capacitor, static Var compensator, current transformer, relay & releases; graphical user interface, including animation, bus coloring, display of cable length, and symbol; and modules available, including types of power flow (slack bus, frequency dependent, optimal power flow, power losses & dispatched, contingency analysis), short circuit analysis (modeling IEEE and IEC standards, topographical representation), and transient analysis (simulation of multiple events, and auto recloser).

Chun Hua [13], introduced models of major AC elements in ETAP PS 5.5.0 software, used data by different studies, applications, and contents of 3-D database. Also, it discussed some of the software capabilities, including power flow studies, short-circuit, transient stability, and motor starting and analysis through applied to Shanghai petrochemical power grid. The maximum load of this power system is over 500 MW, 1339 lines of buses, 938 cables, 83 capacitor banks, 4 transmission lines, 4 chargers, 1717 HVCB, 660 LVCB, 193 compound network, 18 generators, 19 fuses, 243 equivalent load, 18 synchronous motors, 570 induction motors, 443 2-winding power transformers and 8 three-winding power transformers.

Al-Sheikh, and Moubayed [14], reviewed the electrical simulation tools emphasizing on RES different applications. They divided the simulation tools into two main categories, including used for controlling and monitoring RES and tools used to design, model, and simulate. The tools used for control and monitoring are addressed as: operation technology based in Irvine, California, Shell wind energy, and Iberdrola renewables, SeaRoc group, Brighton, England, GridPoint, Arlington, Virginia, and LanMesh wireless, Vaughan, Ontario, Canada. Also, the main perspectives determining the effectiveness of a software for simulation and modeling re described as: deployability, simplicity of use, and modularity and expandability. For this purpose, some traditional tools, such as Eurostag, PSS/E, power system analysis package (PSAPAC), are mentioned. The modern tools are SaberRD, ETAP, Simplorer, DIgital SImuLation and Electrical NeTwork calculation program (DIgSILENT), and Matlab/Simulink. The authors introduced the ETAP 11 as an appropriate software for applications of PV, and WT, includes comprehensive models, different topologies of power converters integrated with PV array, including power system analysis for sizing, real verification, complete simulation, predicting analysis, and grid interconnection studies. Additionally, it manages the RES to maximize power output and increase efficiency by scheduling the power generation.

In [15], some design practices for harmonic analysis in industrial electrical distribution systems are detailed and the ETAP software is suggested as one of the commercially available software to model the electrical network.

Agrawal *et al.* [16], addressed the ETAP software, as an professional and educational software tools for power system simulation considering the FACTS controllers.

Mahmud, and Town [17], reviewed the computer tools for modeling EV energy requirements in distribution networks. They addressed 125 simulation tools, include ETAP, in this regard, and summarized their capabilities by availability, source, and application. They considered the molding of traffic, different vehicles, and power distribution grids in different applications. The authors addressed the ETAP as the commercial software used for electrical power grid modeling, studying, and optimization. They investigated the ETAP, with the capability of applications to V2G, electricity scheduling/pricing/, power grid planning, power distribution grids analysis, renewable energy sources, and distributed control. Against, it cannot handle the vehicle analysis/modeling/, EV control/energy management system, power train, and pollution. Moreover, they classified the advantages as follows: design, analysis, and optimization of power systems, and user-defined dynamic models; decentralized management of renewable energy using GIS tools. Disadvantages of the software are listed as not free to use (demo version available for free), lack of EV, HEV design and analysis and emissions analysis are not part of the tool. For handling different capabilities, ETAP uses the ETAP Data Exchange module (DataX) as a separate tool to export, import, and exchange information with a variety of external sources. It can connect the models with GIS, and AutoCAD applications, and uses a GIS tool for power grid single-line diagrams.

Kalair *et al.* [18], introduced the ETAP in list of more popular tools in utilities for harmonic modeling, which consider nonlinear loads, from 1990s. It simulates harmonic voltage and current source to determine harmonic distortion limit violation. ETAP completes low-frequency measurement and frequency scanning, which includes harmonic models with amplitude and phase angle as well as power frequency models, allowing users to take into account the difference between different and create a harmonic filter that changes resonance points according to a small hazard.

Mahmud *et. al* [19], addressed the ETAP battery sizing module for modeling and analysis of battery energy storage systems.

In a review of grid connected distributed generation using RES in south Africa [20], the ETAP software is mentioned as one of the most commonly used software for testing the optimal result obtained by different algorithms, analytical, numerical or genetic methods.

In [21], the ETAP was introduced as a user-friendly graphical user interface tool with various energy simulation modules for almost all aspects of power generation, transmission output, distribution, automation, monitoring, protection, energy efficiency, and power quality in power grids. It can handle short circuit, load flow, harmonic analysis, protection, and stability; integration and management of DERS; intelligent management of sub-stations, load-shedding, and load allocation, protection and switching optimization; and modeling of automation systems. Furthermore, it addressed some applications of this software, such as electrical load forecasting tool, and battery sizing module.

Gayathri, Sadagopan, Kumar, and Praveen [22], presented a survey on different studies in power systems by ETAP software, including power flow study considering UPFC, voltage profile improvement and electrical loss reduction, security and stability assessment, distortion of voltage and current, harmonic impacts on over current relay performance, optimal design of substation grounding system considering cost effectiveness and safety, the impacts of size and location of DG on voltage curve. They are also introduced ETAP, the first 32-bit power analysis program for Windows that is approved highly effective for use in nuclear power plants and is currently the world's largest power analyzer, which can meet client needs by incorporating the updated technologies, in real-time framework. Although this reference is one of the few references that addressed some very limited applications of ETAP software in 2018 (about 30 references), it did not provide any classification of software applications and in no way can it rule out the basic need to provide a review in this field in terms of the various applications of ETAP software.

In [23], the optimal capacitor placement (OCP) in distribution grids is investigated by applying three different methods of imperialist competitive algorithm (ICA), genetic algorithm (GA), and moth flame optimization (MFO). The authors implemented the OCP and LF studies with the help of the OpenDSS and ETAP software. The aims of study were the reduction of energy cost, and total losses, and savings maximization by reducing the voltage changes and power factor corrections, on an industrial 214-bus network in southern of Iraq. They compared different parameters such as candidate buses, total losses (MW), loss reduction (%), rated optimal capacitor size (kVAr), total kVAr, annual cost for kW power loss ($152/kW), annual capacitor cost ($/kVAr), savings (%), rated PF (%), mean voltage (p.u.), voltage deviation (p.u.), minimum and maximum voltages (p.u.). Finally, based on the performance speed and the accuracy of the results, GA method, is introduced as the best solution for handling the OCP problem.

Barra *et al.* [24], presented an overview of adaptive protection techniques of microgrids and distribution systems considering DGs, in which they addressed very limited works which used the ETAP software for simulation, without any classification on them.

Mehta, and Basak in [25], presented a survey of control techniques used for stability improvement in MGs, which identified the ETAP as a tool for MG simulation.

The overview of distribution system reliability assessment is presented in [26], in which the reliability assessment of a town was done by analytical approach using ETAP software [27] to assess the average outage duration, the average failure rate, and the annual outage time duration according to the basic load point (LP) indices.

Hakim *et al.* presented a minireview of techno-economic issues of substations in Indonesia [28], in which two types of 150 kV [29], [30] (provide benefits, and allowable voltage tolerance, respectively), and KA 1495 [31] (minimize power losses) substations are addressed, as the investigated projects by ETAP software.

Khalid, and Shobole [32], addressed a limited number of research based on ETAP simulation for adaptive smart grid protection.

Aruna *et al.* [33], introduced the ETAP software which is used for exploring real-time performance of power grid, and supports different electrical system analysis such as, electric supply substation simulation, generation security, wind and PV penetration studies, and reliability calculation of renewable energy systems. It also addressed some of the ETP applications in modern power system reliability assessment. Furthermore, investigating the failure rate, mean time to repair, mean time between failures, SAIDI, SAIFI, CAIDI, ENS, ASAI, and ECOST are the reliability factors which can be assessed by this simulation tool.

In [34], ETAP has been addressed as a commercial software and hardware simulation platform that provides various timestep interface models such as transmission lines or interconnect transformers for hybrid power simulation.

Verma and Verma [35], referred to some research which implemented the ETAP software to power quality in smart grid.

Shobole, and Wadi [36] is addressed some ETAP applications for hybrid multi-agent systems (MAS) based on overcurrent fault identification technique.

Buła *et al.* [37], addressed a limited references based on the ETAP applications for optimal active power filter placement and sizing problem.

In [38], the ETAP was introduced for analysis of the reliability in distribution system, which is also used to investigate the output by analytical methods.

Nkosi *et al.* [39], introduced the ETAP software for small signal stability analysis with the capabilities of voltage stability studies, or continuation power flow, electromagnetic transient, fault analysis, ground system, graphic unit interface, harmonic analysis, protection analysis and coordination, power flow, and time domain simulation. They addressed the ETAP which cannot handle the optimal power flow.

In [40], the ETAP is defined as an electronic analysis tool based on arithmetic and mathematical algorithms, which was developed in 1986, by Operation Technology, Inc. The purposes in energy distribution of its latest version, i.e., 19.0.1, are power system scheduling, power plant controller, microgrid controller, geospatial modeling, SCADA, ADMS, EMS, and distribution, and transmission grids planning.

Ref. [41], mentioned the ETAP as the simulation tool, which has employed to estimate the power flow analysis.

The scope of the ETAP for future electricity market modeling includes the unbalanced load flow, time series unified power flow, load allocation, short circuit, fault isolation and service restoration, reliability assessment of distribution grid, and AC high risk arc flash were discussed in [42]. It involves short to multi-year analysis. The used methodologies are scenario analysis with the capability of 100,000+ bus, and load growth analysis from one year to several years. The studies are classified into customer-based or assign parts into composite sectors. The time series plots capture voltage drop, current, power losses, load, and consumption in a defined stage. The approach is bottom-up and the coverage is multisectoral.

In [43], an standalone software for design the grounding system, based on IEEE standard, known as GSA (grounding system analyzer) is developed, and the results were compared by the ETAP.

In [44], the harmonic investigations, design and reduction techniques were reviewed, and it was confirmed that the ETAP software can simulate the current and voltage harmonic sources to specify harmonic distortion violations. It also mentioned that the PSS/E and ETAP software are more appropriate industrial tools for simulation studies and harmonic modeling, while academia mainly relies on Matlab/Simulink tools.

Gupta, and Akhtar [45], surveyed the smart power grid, includes the base-frames, strategies, security concepts, and solutions. They see the ETAP, as an energy management tool capable of real-time energy analysis, including at least 40 different types of integrated categories such as load, motor starting, short circuit transient stability, and harmonic study.

In [46], the ETAP software is introduced as one of the efficient tools for visual data representation in smart grids control and monitoring.

Ref. [47], illustrated different power systems analysis by MATLAB, and ETAP, in which some basic calculations such as power flow, short circuit, power system stability through some examples were addressed.

Agarwal, and Jain [48], studied the DER among the supportive integrated devices for optimal planning of power distribution grids. They claimed that ETAP is a comprehensive electrical engineering software platform for electrical energy analysis, ranging from modeling to real-time study of energy management.

Ref. [49], introduced the ETAP as one of the software for strategic urban grid planning tools for improving the smart grid resiliency, with capabilities of mathematical optimization, load forecasting, storage and generation modelling, islanding operation, case studies/scenarios/, contingency/outage simulations, power flow, and cost analysis.

In [50], the ETAP is introduced as the software to model power grids and GIC analysis especially for harmonic studies in the frequency area.

Ref. [51], mentioned that ETAP software is designed to provide a conceptual model of the interactions between systems in today's energy grids.

In [52], the ETAP software is introduced as a useful tool for determining the fault level, thermal conditions, voltage level and the assessment of dynamic behavior of equipment.

Ref. [53], listed the ETAP software in the simulation software for model the solar PV grid-connected systems, such as load flow and fault analysis.

In a sample substation, with a 60 MVA, 150/20 kV transformer, and 9 feeders, the bus voltages were analyzed and compared using the PSAT, and ETAP [54]. The difference between the PSAT simulation results and the bus voltage is approximately 0.663%, while the difference between the ETAP simulation results and the bus voltage is approximately 0.562%. Additionally, there is a 0.1% difference between the results of PSAT and ETAP simulations.

Ref. [55], listed the ETAP as one of the commercially available programs that rarely used for the sub-synchronous control interaction (SSCI) analysis.

Also, the ETAP is addressed as one of the used tools for tuning the power system stabilizers [56].

Some references have used the GA for optimal capacitor placement in distribution grids, incorporated to many commercial tools, such as ETAP software [57].

Table 1 provides a summary of the previous reviews contain ETAP software.

B. The reason for this study

Power system analysis is one of the most important challenges for planners, and operators in this field. The emergence of new issues such as the distributed generation, microgrids, renewable energy-based generation, and smart power grids has increased the importance of this topic. Various tools, and software have been proposed to achieve this goal. One of the most powerful applications and industrial software in this field is ETAP software, which in this research, its various abilities have been briefly examined from many aspects.

The review of the software used in power systems analysis has been reported in several researches. References [9], [58], [59], , [60] are some examples that can be mentioned in this context. Some softwares such as PowerWorld Simulator, SimPowerSystem, PSCAD, WindMil, PSS/E, GE PSLF, PSAF, RTDS Simulator, ETAP, ASPEN, ATP-EMTP, SPICE, EasyPower, PowerFactory, NEPLAN, SCOPE, CAPE, EDSA, QuickStab professional, SPARD® mp, DSA PowerTools, TRANSMISSION 2000, ABB AdviseIT GridView, Power* Tools SKM systems analysis, Inc., SynerGEE electric of Advantica Stoner, Micro-Tran of MicroTran power system analysis Corp., and interactive power system analysis (IPSA) software of IPSA power limited are introduced with their features in [9]. In [58], the abilities of steady state power system analysis, dynamic power system analysis, harmonic analysis, electromagnetic transient (EMT) analysis, real time simulation (RTS), hybrid simulation, and multi-domain analysis in some power tools include MATLAB (including Simulink and SPS/Simulink), DYMOLA, ETRAN (PSS/E and PSCAD), RTDS, Opal-RT, ATP-EMTP, EMTP-RV, EMTDC, DIgSILENT, ERACS, ETAP, IPSA, PSS Sincal, SKM Power Tools, DINIS, Power World, OpenDSS were investigated. In [59], power

Table 1. The summary of the previous reviews contains ETAP software

Ref.	The topic of study, or review including ETAP software
[9]	General data of some power grid simulation tools
[10]	The present status and future trends of simulation software, and tools for planning and analysis of distribution grids, considering DER
[11]	Using the ETAP tool for software studies to teach power-system modeling and analysis
[12]	Comparing MiPower, ETAP, EasyPower and PowerWorld softwares
[13]	Introducing models of major AC elements in ETAP PS 5.5.0 software
[14]	Reviewing the electrical simulation tools emphasizing on RES different applications
[15]	Design practices for harmonic analysis in industrial electrical distribution systems
[16]	An professional and educational software tools for power system simulation
[17]	Reviewing the computer tools for modeling EV energy requirements in distribution networks
[18]	The ETAP is in the list of more popular tools in utilities for harmonic modeling, which consider nonlinear loads, from 1990s
[19]	Battery sizing module for modeling and analysis of battery energy storage systems.
[20]	Grid connected distributed generation using RES in south Africa
[21]	ETAP was introduced as a user-friendly graphical user interface tool with various energy simulation modules
[22]	Different studies in power systems by ETAP software
[23]	The optimal capacitor placement (OCP) in distribution grids
[24]	Adaptive protection techniques of microgrids and distribution systems considering DGs
[25]	Control techniques used for stability improvement in MGs
[26, 27]	Power system reliability assessment
[28]	Techno-economic issues of substations in Indonesia
[32]	Adaptive smart grid protection
[33, 38]	Addressing some of the ETAP applications in power system reliability assessment
[34]	Introducing the ETAP as a commercial software and hardware simulation platform
[35]	Introducing the ETAP software to power quality
[36]	Hybrid multi-agent systems (MAS)
[37]	Optimal active power filter placement and sizing problem
[39]	Small signal stability analysis
[40]	Describing the ETAP abilities for energy distribution
[41]	Power flow analysis
[42]	The scope of the ETAP
[43]	Comparing the standalone software for design the grounding system, based on IEEE standard, known as GSA (grounding system analyzer) with ETAP
[44]	The harmonic investigations, design and reduction techniques
[45, 46]	The smart power grid
[47]	Power systems analysis
[48]	Optimal planning of power distribution grids, including DER
[49]	Strategic urban grid planning tools
[50]	harmonic studies in the frequency- area
[51]	Conceptual model of the interactions between systems
[52]	The fault level, thermal conditions, voltage level and the assessment of dynamic behavior of equipment
[53]	The simulation software for model the solar PV grid-connected systems
[54]	Comparing PSAT, and ETAP
[55]	Sub-synchronous control interaction (SSCI) analysis
[56]	Tuning the power system stabilizers
[57]	Optimal capacitor placement

system softwares of RETScreen, energyPLAN, HOMER, energyPRO, Polysun, TRNSYS, EINSTEIN, COMPOSE, INSEL were investigated. In [60], 19 softwares include HOMER, Hybrid2, RETScreen, iHOGA, INSEL, TRNSYS, iGRHYSO, HYBRIDS, RAPSIM, SOMES, SOLSTOR, HySim, HybSim, IPSYS, HySys, Dymola/Modelica, ARES, SOLSIM, and HYBRID DESIGNER with their main features and current status are studied.

As the review of studies confirms, there is no research works yet conducted to review the frameworks, different works, and the challenges posed by the ETAP software. The significant novelties of this work are classified, and highlighted as follows:

- Providing a comprehensive overview of research conducted using the ETAP software in power system, and classification the different versions of used,
- Describing a general survey on addressed references in terms of publication year, publishers, different categories,
- Detailing power system analysis in terms of different studies, and addressing the relevant works of each category,
- Segmentation the different case studies used in power system analysis in three categories of practical cases in different countries, standard grids, mainly IEEE systems, and some sample and typical grids.

It should be noted that the presented data in this work, is based on the information collected until 20 Dec. 2023. Since there is no comprehensive review of EATP software, the authors have attempted to provide a complete list of research in this area. We have also tried to provide complete information as well as details about each reference. According to this issue, the number of references was increased. Since there is no comprehensive review of EATP software, the authors have attempted to provide a complete research list in this area. We have also tried to provide complete information as well as details about each reference. According to this issue, the number of references was increased. There is really no criterion, or possibility to sift through some sources in this long list.

C. Paper organization

The rest of this research is organized as follows: Section 2 presents an overview of ETAP software. Section 3, surveys the addressed references in terms of number of research, publication year, and publishers. Section 4, reports different software versions used in power system analysis. Section 5, different categories studied of power systems in the studies using the ETAP software. Section 6, addresses different case studies in terms of practical cases in different countries, standard grids, mainly IEEE systems, some sample and typical grids. Section 7, concludes some important issues.

2. ETAP SOFTWARE: AN OVERVIEW, AND SOME APPLICATIONS

In this section, some general information on ETAP software is presented. The interested readers are referred to https://etap.com/ for further details. It should be noted that the presented overview for this software is extracted from the ETAP software instruction manual. Furthermore, some applications of the ETAP Software based on the reported references are addressed.

A. Main sections

The main sections of this software are as follows:

A.1. Engineering libraries

ETAP provides customized libraries based on standards, models and product information for a wide range of electrical equipment. By using the ETAP's library editors, additional devices can be added to each library. These libraries include cable, cable fire protection, transmission line, motor, transformer, fuse, relay, recloser, HV/LV circuit breakers, electronic controller, trip device, harmonic, overload heater, interruption cost, reliability, profile, control system, battery, and different renewable sources.

A.2. Menu bars

There are different menu types in ETAP, include start-up , one-line diagram , underground raceway system, cable pulling, dumpster, and ground grid.

A.3. Element editor overview

The main sections are: **AC elements:** buses and branches, including bus, node, bus duct, busway, transformers (two winding, three winding, open-delta, Scott-T, zig-zag), voltage regulator, cable, reactor, current limiting, transmission line, and impedance; Sources and loads, including power system (utility grid), power plant, synchronous, wind turbine generator (WTG), solar PV array, synchronous motor, induction machine, lumped load, static load, motor operated valve (MOV), capacitor banks, electrical panels, harmonic filter, phase adapter, remote connector, earthing/grounding adapter, MG set (rotary UPS), SVC (static VAR compensator), HVDC transmission; composites, including composite motor (AC & DC), and grid (AC & DC); protection system devices, including fuse, contactor, high/low voltage circuit breakers (HVCB/LVCB),recloser, overload heater, ground switch, inline overload relay, switches; reports and settings, including earthling systems, instrumentation toolbar, display options, and report manager **AC-DC Elements:** variable frequency drive (VFD), UPS (uninterruptible power supply), inverter, charger **Control System Diagram (CSD) elements:** bus, circuit breaker, contact, control relay, display options, double contact, fuse, general load, impedance, light, macro-controlled contact, node, pointer, push button, solenoid, switch, wire **DC Element:** branches: impedance, cable, converter; bus; composites: network and motor; protective devices: circuit breaker, fuse, switch, single/double throw; sources & loads: battery, PV array, motor, lumped and static loads, composite CSD. **Instrumentation:** current and potential transformers, ammeter, voltmeter and, multi-meter ; voltage , reverse power , frequency , MV solid state trip , motor , overcurrent , differential , multi-function , and distance relays, tag link Underground System Editor **ETAP data X (data exchange):** ETAP DataX provides a full set of customizable ETAP interfaces designed to bridge the gap between external software and ETAP. **Dynamic models:** dynamic lumped motor load, excitation system, governor-turbine, induction machine, mechanical load, power grid, PSS, SVC, synchronous machine, WTG. Also, there is user-defined dynamic models (UDM) program for defining new dynamic models.

B. Different analysis by ETAP software

This tool can simulate power systems to complete different issues of short-circuit studies, star protection and coordination studies, STAR view (TCC), arc flash analysis, unbalanced/balanced load flow, transient stability, motor acceleration, motor parameter tuning and estimation, generator start-up,

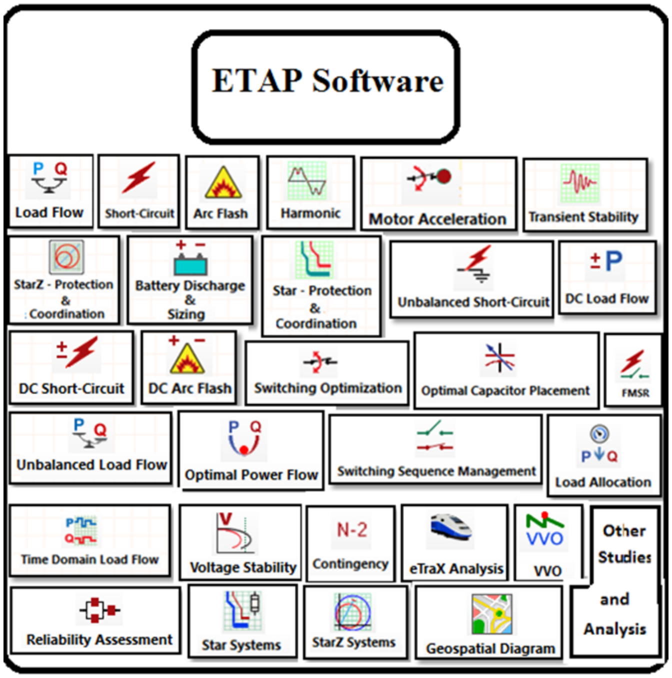

Fig. 1. Some capabilities of ETAP software in power system analysis

harmonic investigation, OPF, optimal capacitor placement, reliability analysis, Transformer sizing, transformer tap optimization, DC short-circuit, DC load flow, DC arc flash, battery sizing and discharge analysis, panel system, ground grid systems, grounding system and earthing types, cable ampacity and sizing, protective sizing & shock protection, underground raceway systems, cable pulling systems, switching interlock enforcer, switching sequence management, contingency analysis, StarZ protection and coordination analysis, MV and HV arc fault analysis, eTraX analysis, and time domain unbalanced load flow. Fig. 1, shows some capabilities of this software.

C. ETAP Real-Time System

The real-time system analysis in ETAP software re s following:

- Power system monitoring and simulation (PSMS), includes energy accounting, advanced monitoring, real-time simulation, load forecasting, and event playback.
- Intelligent load shedding (iLS), includes load restoration, load preservation, and load shedding validation.
- Energy management system (EMS), consists of AGC, ED, supervisory control, reserve management, and interchange scheduling
- Intelligent substation (iSUB), includes substation automation, load management, and switching management

D. Some Applications of ETAP Software

For the first time, the ETAP software is introduced in [8], as the mainframe tool was written for PCs as an interactive electrical grid design and analysis software, which can handle power grids contain 1000 buses, a load schedule tool tracks up to 10,000,000 load items, and reports the short-circuit current and voltage at the load terminals. Initially, it was included single-line diagram, short circuit, load flow, dynamic stability, motor starting, motor acceleration, cable rating, cable pulling, earthing grid design, parameter estimation of induction machines, induction machine slip/torque curve, and load schedule. Since then, different versions of this software have been developed with different capabilities, in such a way that now its capabilities have been significantly improved and extended to further issues. For example arc flash AC/ DC, load analyzer, harmonics, flicker meter, lightning risk assessment, microgrid controller simulations, reliability, voltage stability, battery sizing, transient stability, transformer sizing & tap optimization, optimal capacitor placement, and optimize power flow can be mentioned.

The simulation time step is 0.001 s and the processing time is 20·dt; where dt is the simulation time step. The maximum number of iterations to calculate the initial load flow is 2000, accuracy is 0.00001 and acceleration is 1.45 [61].

In [62], [63], a techniques to minimize loss reconfiguration in radial power distribution grids is proposed, based on finding the open/close switch states using calculating the active and reactive power line flows, and voltage at the buses, voltage deviation and real power losses . The authors compared the obtained results by the suggested method with the ETAP software, in term of voltage of buses.

In [64], the use of GA was proposed to solve the optimization problem of LTC and shunt capacitors in the presence of harmonics. The authors proposed a dynamic power flow function (DHPF) and performed a real-time comparison with ETAP software regarding the IEEE-18 bus.

In [65], to verify the suggested technique for decoupled harmonic power flow (DHPF) analysis in a large scale power grid considering nonlinear multiple loads the results were compared with ETAP software in terms of rms voltage, and THD.

In [66], and [67], a GA-based technique for the optimal allocation of DGs is proposed to voltage profile improvement and loss reduction. For evaluating the results correctness, the ETAP software is used.

Hegazy, and Galal [68], proposed a fuzzy system for power management during power generation and parallel operation of the power supply in large power plants. This system is supported by ETAP power measurement system software and can be considered as a widely used tool in monitoring the performance of large industrial plants.

Jabbar **et al.** [69], highlighted the power quality influencing factors caused by CFL in terms of THD of voltage, and current. They replaced all UET lighting with CFLs and created realistic models in the ETAP compatibility library, performing simulations including THDv and THDi to measure the required power quality.

The neural network methods need some data to train the framework. The data collection from real networks in faulty cases is not practical in different operating conditions. Therefore, modeling the real-world systems for providing input patterns using some software such as ETAP is needed. In [70], the ETAP software is used to model the system and generating training data set needed for a neural network-based technique suggested for protection scheme of a distribution system considering DGs. In [71], the load is randomly changed and the power production is calculated using OPF problem. The operating points are used for fault simulation in ETAP. Different contingencies are simulated to obtain the data needed to train the neural network classifier for security evaluation (secure or insecure line). The parameters include the rotor angle of each generator, the acceleration torque, and the power of each generator.

The goal of the capacitor placement issues is to reduce the total operating cost, including capacitor installation cost, capacitor purchasing, operation of the capacitor bank (maintenance and depreciation), and energy loss [72].

A comprehensive procedure for security and stability assessment in an Chines industrial plant is presented in [73]. Using the ETAP tool, typical operation points of power flow are set up as base case points for short circuit studies, static analysis, security, and stability assessment. Furthermore, transient stability analysis were conducted at each branch and each bus for fault contingencies.

Based on some sensitivity indices regarding the impacts of DGs on both reactive and active power losses, the size and location of DG with minimum losses are identified. Then by applying the ETP software, the performance of the proposed method is tested in terms of real power losses as well as voltage amplitude with or without DGs.

Due to the accessibility of the electric railway traction substation of 220kV Gongping Power Station, the compromise is greater than the standard value [74]. The voltage pollution is huge, and the substation has been operating at substandard voltage for a long time, so filter equipment needs to be installed. Installing the capacitor-series reactance branch to eliminate harmonic suppression is suggested for both the harmonic suppression and the reactive power compensation. Obtained results by ETAP software confirm the proposed strategy.

The ETAP can model different non-linear loads in the form of harmonic current source, including static load, uninterruptible power supply (UPS), converter/charger, VFD, and transformer. Items that can also be described as harmonic voltage sources include: main grid, inverters, synchronous generators, and static loads [75]. That research applied the GA to handle the optimal sizing of fixed capacitor banks in distribution systems by in three different loads of linear, light non-linear and completely non-linear.

Power flow during peak loading (using Newton-Raphson method), voltage profile, and power factor with and without the SVC are compared using the ETAP software, for enhancing the voltages, as the main objective [76]. The other objectives are minimizing the power system loss, enhancing the power transfer, and minimizing the branch current.

In [77], the ETAP library was updated to model the FLs, and CFLs . In general, lighting loads in the power grid constitute 10-12% of the total load. The current waveform spectrum of the high voltage side (HV) and low voltage side (LV) of the transformer distribution and the voltage waveform spectrum of different buses are compared in terms of THD of current and voltage in various locations.

A 1000 Ms/s TEXIO 60 MHz digital storage oscilloscope, 100-240 V ac is connected to a Pentium 4.0 computer: CPU 2.40 GHz, ATX,115-230 Vac, 2/1.5 A, monitor: Philips, 100-240 Vac,1.5/0.8 A [78]. Then the voltage, current spectrums and waveforms, were extracted using ETAP software.

In [79], some assumptions are used during calculations by ETAP, including: all loads are static, only the loads which their data available was considered, sort circuit calculation was applied based on IEC 909 standard, and the generation units are presented by one integral unit (including the step-up transformers). The overcurrent voltage controlled (51V), and directional overcurrent (67) relays are considered. The trip times for these relays, in terms of fault location, and distance from generator, were extracted from the simulation done by ETP.

Ref. [80], investigated the impacts of subsea cables on offshore power distribution grids in nine different scenarios, in terms of 6, 12, 18, and 24-pulse VFDs, with, and without harmonic filters). The grid is supported by some harmonic filters in different cases tuned 5th, 7th, 11th, 17th, by different capacities of 100-900 kAVrs, in 100 kAVr steps. Hairi *et al.* [81], mentioned different steps of coordination analysis procedures as one line diagram, short circuit analysis, protection curves and points (including the inrush point of transformer, and protection curve of transformer during fault based on ANSI), cable damage curves, and coordination analysis. Furthermore, they introduced the needed components for coordination analysis of overcurrent protection in different sections of overcurrent relays, the pick-up setting, time dial setting, time discrimination margin, relay characteristics, and time current characteristics (TCC) curve plot and interpretation.

Manio *et al.* [82], compared the sequential dynamic re-acceleration and acceleration of induction motors under three phase short circuit using the ETAP, and the electromagnetic transient program–restructured version (EMTP-RV), in terms of generator's mechanical power, active power, exciter voltage, terminal voltage, motor slip, speed, and the voltage stability based on. dip and rise of voltage. The generator unit is modeled using the machine's user-interface in both software. The exciter/AVR is built-in standard library model in both of them. The engine/governor is identified in ETAP by user-defined dynamic model (UDM), while in EMTP-RV is extracted from the control library. The induction motor dynamic model, and mechanical load are modeled by library user-interface in ETAP, while they are addressed in EMTP-RV by machine's user-interface, and control library, respectively. The results of using two-software in mentioned study cases were similar.

Ref. [83], proposed a sequential three-phase load flow using three-phase ZBus distributed factor (TZBD) for power calculation. The Quarter-hour load curves of transformers were obtained from customers' monthly energy consumption and load distributions obtained from the Consumer Information Center (CIS). Then, the implicit Z-bus Gaussian method, bus voltage, and line sensitivity are integrated to form a sequential three-phase flow equation.

ETAP's harmonics program provides an environment for modeling a wide variety of electrical and electronic components, including nonlinear behavior and frequency-dependent considering different harmonic sources. There are two min method of harmonic frequency scan and harmonic load flow for analyzing the harmonics [84]. By concurrent using of these two methods, different parameters can be calculated and compared with standard parameters.

In [85], a sample power system in Pakistan was analyzed by ETAP to investigate the over loaded transformers, voltage drop, and technical active power losses.

Shuqin *et al.* [86], have compared three different structures of power system to supply the auxiliary demand of 1000MW unit based. Finally, based on different investigations and calculations the authors proposed the second scenario, as the best of all.

Mostafa *et al.* [87], used the ETAP for generating the needed training data applied to PSO for coordination of overcurrent voltage controlled protection in an actual large power network.

In [88], power losses in distribution networks re minimized by applying different techniques, including restructuring, DG implementation, and capacitor placement. In all cases, the ETAP is used for simulations.

Different types of traditional starters used for induction motor are mentioned as using the auto-transformer, series stator resistor, series stator reactor, installing shunt capacitor, on the motor bus, installing shunt capacitor on the motor terminal, series rotor resistor, series rotor reactor, and star delta [89]. However, these starters have some disadvantages, such as torque pulsations, machine windings heating during starting period, high inrush current, low efficiency in low load, and drop in motor speed is more. To remove these drawbacks, different types of soft starters for induction motors, including current control, current limit, torque control, and voltage control, are proposed [89]. Control of starting current, improving the starting torque, Energy Saving, increasing the Input power factor, Minimizing the transients during starting are the main advantages of using soft starters. However, they suffer from reducing efficiency with load increasing, distortion the drawn currents from utility, and significant fifth harmonics.

Use of switches for protection of Electric Submersible Pump (ESP) installations, integration of protection devices for circuits upstream of ESP wells and optimization of protection settings equipment for large area protection and arc flash safety issues is addressed in [90]. Different relay settings, and arc flash hazards analysis are reported.

In [91], the motor starting is analyzed for large-capacity asynchronous motors of auxiliary industrial grid in three cases of self-starting, series, and group self-starting. Also, the impacts of current factor of locked-rotor on bus voltage, starting current, and terminal voltage during the motor starting is investigated in the range of 4-6.5 by ETAP software.

Some of the factors that should be mentioned in a ground-mat study are, including geometry of the grounding system, fault-current duration and magnitude, probability of contact, soil resistivity, and human factors such as standard assumptions on physical conditions, and body resistance [92].

The global performance index (GPI) as the weighted sum of reactive and active power loss indices (ILQ and ILP), voltage profile index (IVD), at maximum load, voltage regulation index (IVR), current-carrying capacity of conductors (ICC), transformer loading index (ICt), single phase to ground, and three phases short circuit indices (ISC1,ISC3,), and harmonic index (IH) is proposed to evaluate the distribution grids performance in terms of DG site and size [93].

Various techniques for transient analysis are [94], [95]: original and modified Euler methods, original and 2nd, 4rth, and Gill version of Runge-Kutta (R-K), equal area criteria, and implicit integration methods. Generally using the R-K-based methods is preferred due to their advantages in terms of required numbers of iterations, better accuracy, memory requirements, and simplicity [95].

In [96], the impacts of grid connected PV (GCPV) systems on voltage profile are investigated in three different cases of neglecting PV, with 14.4 kW, and 36 kW PV arrays stalled at all consumers. The area of each customer land is assumed 20x25 m2 with penalty roof space.

Single phase loads, and three phase rectifiers re introduced as the main sources of harmonic distortion [97]. Also, the harmonic consequences are mentioned as distorting the power factor, reducing the impacts of capacitor banks, motor heating, and overloading neutral conductors. The main methods for harmonic mitigation are mitigating the +ve sequence harmonics, mitigating the -ve sequence harmonics, and mitigating the zero sequence (triplen) harmonics [97].

The optimal capacitor placement study in ETAP software needs an objective function and the proposed strategy for power factor correction, and voltage regulation [98].

Liang *et al.* [99], proposed a mathematical framework of the system in the ETAP for solving some practical operation contents, including poor voltage profile, transformer overloading, power factor (PF) issue, harmonic concerns, and electrical submersible pump (ESP) installation failures. The needed data were gathered at key nodes of the grid, and the ETAP model accuracy is confirmed through comparisons of the measured and simulated data. Furthermore, different network operating modes and configurations are addressed to investigate the system performance operation.

When the THD is more than 20%, the performance of over current relay's will be significantly affected by increasing the malfunction [100]. By occurring a fault in the system, the over current relay may trip in an undesired way. So, based on the simulation the THD should be limited to below 20%.

Different measurement techniques are addressed case study of state estimation (SE), addition/elimination method, linearized state estimation process, root based algorithm, heuristic algorithm, GA, improved heuristic methods, PSO, and MCS [101]. This reference presented the plots of standard deviation, voltage versus bus using the ETP software with, and without DGs in different scenarios. It finally proposed the optimal bus location for measurement in order to complete state estimation of under studied systems to cover all possible operational cases.

Ref. [102], has analysed the impacts of DGs on power losses reduction, and voltage profile improvement in terms of location and size of DGs. The simulations verify that DG's power injection reduces the active power loss from 99.39 kW to 240.15 kW in some places.

Kasargode, Kannur, Kozhikkode, Malappuram, Palakkad, and Thrissur are the areas which are mostly affected by under-voltage subject in Kerala state power system, India [103]. These areas were investigated by applying different optimization techniques, including tap changing, compensation of reactive power, upgrading the substations, and upgrading the transmission lines.

Rusilawati *et al.* [104], addressed a technique to convert the multi-machine to single-machine infinite-bus (SMIB) by using the equivalent load, and an equivalent impedance (xeq and req). Also, the maximum generation of each generator units is specified as the steady state stability limit. The authors applied the radial basis function neural network (RBFNN) to calculate the maximum generation in different operating conditions. The ETAP tool was used to generated the needed data and verify the simulation results by the proposed technique.

In [105], by using the failure rate, repair rate, mean time to failure (MTTF), mean time to repair (MTTR), availability, and unavailability the reliability indices, including SAIFI, SAIDI, CAIDI, ASAI, ASUI are calculated for the case study. This reference predicts the reliability indices using the NN. An NN consists of several processing units, including input, hidden and output layers, interconnected in a predefined manner to build an appropriate pattern.

In [106], different calculations, including reliability indices (SAIFI, SAIDI, CAIDI), power flow, economy calculation, and short circuits analysis are done to determine the optimal wiring scheme for connecting the 2x600MW emergency power air cooling units.

Four models for motor starting, include direct, self-coupling-transformer current-control, and current-ramp are described in ref. [107].

Using the ETAP software for education purposes in Curtin

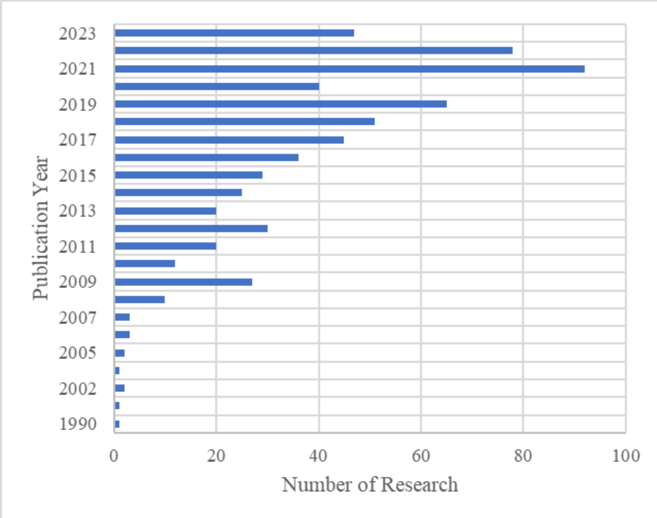

Fig. 2. Number of research per publication year

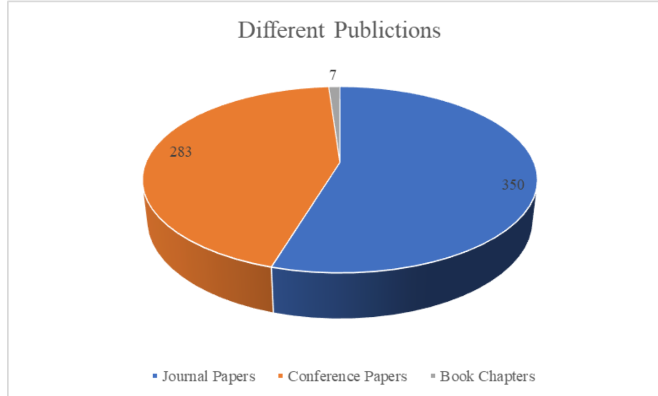

Fig. 3. Different categories of references

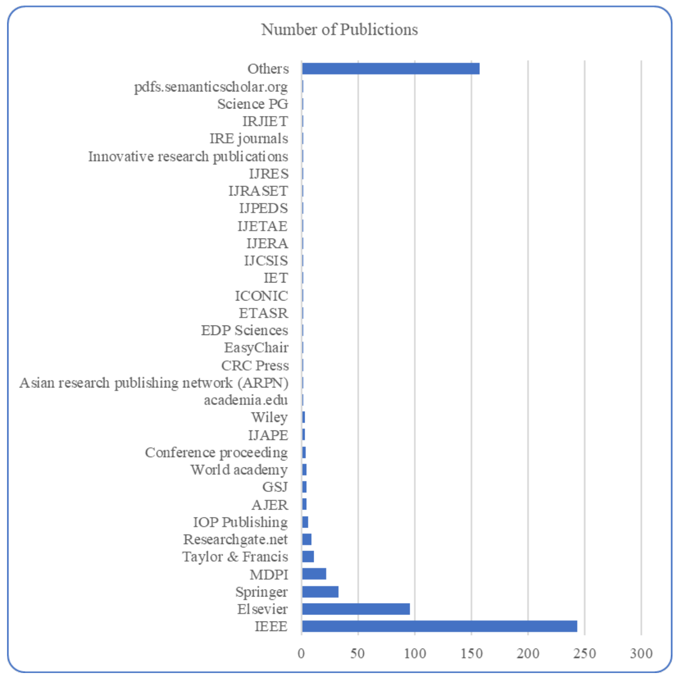

Fig. 4. Number of research per each publication

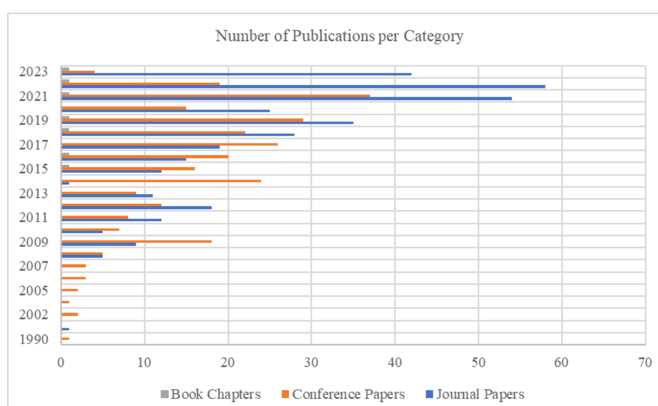

Fig. 5. Number of publications per category for years 1990-2023

University, Perth, Australia is reported in [108], in which two power system analysis tools, of PSCAD/EMTDC and ETAP are used to present the performance of overcurrent relays, protection coordination and transient analysis. The extended, and complementary version of this work is reported in [109].

The impacts of mesh conductors in a grounding system, as well as the mesh area, vertical rods, and conductor spacing on different potentials have investigated using different case studies in [110].

In [111], a unified platform (UP) is proposed to transfer power system circuit model data (PSCMD) between different software tools and create the same circuit in the second tool environment, including the ETAP.

Ref. [112] has used different IEEE models, include ST1 and AC5A excitation types, turbine governor types of ST, andST1, and IEEE general steam-turbine (STM) for different cases.

Analysis of the stability of the generator works best when SVCs are connected to the grid compared to FCLs [113]. SVC FACTS devices stabilize transmission lines with less line trip risks, and high transfer efficiency.

3. A GENERAL SURVEY ON ADDRESSED REFERENCES

The evaluations show that out of a total of 640 references, including 350 (54.68%) journal articles, 283 (4.21%) conference articles and 7 (1.09%) book chapters related to the topic, more 50% of them were published in 2019-2023 (see Figs. 2-3). Also, more than 14% of the works were published in 2021 (92 references from 640).

As the studies show, different versions of ETAP software were used for power system calculations. The list concludes the vast range from version 3.0 to version 20.6, as follows (see Fig. 6):

- Version 3.0: [114], [115]
- Version 4.0: [68], [75], [116], [117], Version 4.04: [70], Version 4.7.0: [65], [118], [119], [120]
- Version 5.0: [121], Version 5.0.3: [92], Version 5.1: [88], Version 5.5: [122], [123], Version PS 5.5.0: [13], Version 5.5.5: [124]

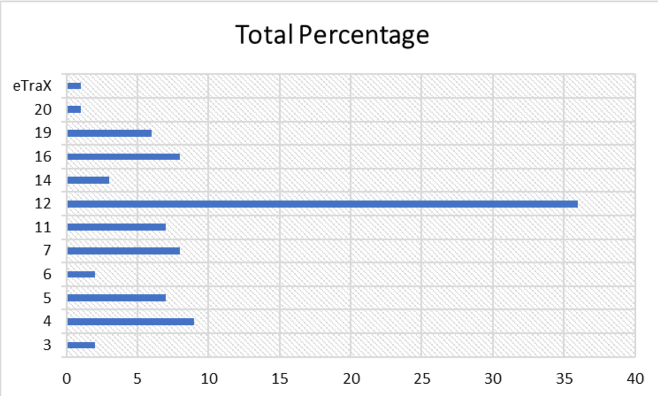

Fig. 6. The used versions of ETAP software in addressed references (%)

- Version 6.0: [102], Version 6: [125]
- Version 7.0.0: [126], [127], Version 7.0: [128], [129], [130], Version 7.1: [131], [132], Version 7.5: [133]
- Version 11: [14], [134], [135], [136], [137], [112], Version 11.1.1: [138]
- Version 12.0: [139], [110], [140], Version 12.5: [141], Version 12.6: [142], [143], [144], [145], [146], [147], [148], [149], [150], [151], [152], [153], [154], [155], [156], [157], [158], [159], [160], [161], [162], [163], [164], [165], [166], Version 12.6.0: [167], [168], [169], [170], [171], [172], Version 12.6.0H: [173]
- Version 14.0: [174], [175], Version 14.1: [176]
- Version 16: [177], [178], Version 16.0: [179], Version 16.0.0: [180], [181], Version 16.0.0C: [182], Version 16.00: [183], Version 16.1.0: [184]
- Version 19.0: [185], Version 19: [186], Version 19.0.1: [187], [188], [40], Version 19.5.0: [189]
- Version 20.6: [190]
- ETAP-eTraX: [191]

Fig. 6 shows that the most used version for power system analysis is version 12. It should be noted that in all of the referred works the software version is not addressed, and the presented numbers are only for 90 of 640 references, mentioning the software version.

4. DIFFERENT CATEGORIES STUDIED

In this section, different categories studied by addressed research are mentioned. As an important point, it should be not-ed that in almost all references, the power flow analysis has been performed due to its essential role in power system calculations. Hence, this issue is mentioned separately in this section, for the references that clearly focus on it.

The review of different research shows that the three topics of distributed generation (DG), renewable energy sources (RES), and power system protection, with 11.8%, 11.7%, and 9.9% have received the most attention.

Fig. 7, depicts the number of research for different studied categories by using the ETAP software.

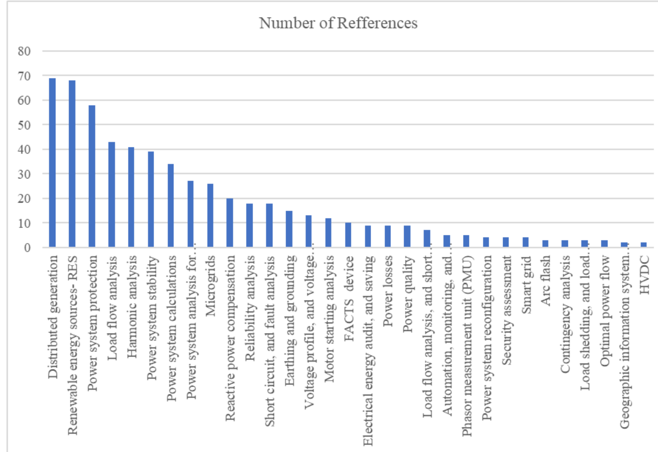

Fig. 7. The number of research for different studied categories

In the following, different categories are discussed in detail, alphabetically.

• Arc flash: [192], [138], experimental DC arc flash [189].

• Automation, monitoring, and metering: improving performance of underground MV distribution networks using distribution automation system [167], GUI of real-time system for intelligent automation of distribution and transmission grids [193], real-time monitoring and control system [194], Analysis of biogas net metering [195], single-phase net metering [196].

• Contingency analysis: Contingency studies include cables overloading, under voltage buses, equipment rating, protective device setting, LV power factor, considering load shedding, and capacitor banks [197], N-1 for offsite power system [198], for the AC-DC networks [199].

• Distributed generation:

- Modeling the system and generating training data set needed for a NN-based technique suggested for protection scheme considering DGs [70], generating data needed for islanding detection technique of DGs using discrete wavelet transform [200].

- DG impacts on power grids: using global performance index [93], [201], power losses and voltage profile [102], Newton Raphson load flow, voltage instability compared to the system with FACTS [133], multi DGs on power quality, and power flow [136], DG, SVC, and fixed capacitor [128], stability enhancement with modified AVR and PSS [202], protection coordination [125], load shedding schemes on isolated grids due to a natural disaster, load flow, loss reduction, and transient analysis-load shedding [139], reliability analysis with, and without passive failure rate, for SAIDI, SAIFI, CAIDI, ASAI, ASUI, and AENS [203], protection system [204], power losses and voltage profile [205], transient stability of frequency and voltage [206], proactive over-current protection [207], directional overcurrent relay characteristics [208], proactive recloser-fuse scheme for wind DG [209], adaptive overcurrent protection [210], reliability assessment [211], transient analysis of DG AC microgrid [212], bi-level multi agent based protection scheme, power flow [213], improving voltage profile and loss reduction in radial distribution grids [214], protection coordination [215], [216], [217], [218], [219], [220], [221], [222], [223], [179], [224], [225], reliability evaluation [226], [227], [228], [229], [230], arc flash hazard [231], power quality [157], power loss reduction [88], [232], [233], [234], voltage profile and power loss reduction [235], load flow [236], renewable DGs [237], overcurrent relays for reliability assessment [238], the voltage unbalance in distribution grids considering large scale interconnection of single-phase DGs [239], reliability analysis and demand side response [240], multi-agent based adaptive relaying [241], power system stability [242], static stability of operation mode [243], power system in steady state, power flow, harmonic analysis, short circuit [168].

- Optimal location, and sizing: reducing loss, improve voltage profile by GA [66], load flow, voltage profile improvement, loss reduction [244], DGs and SVC based on voltage stability indicator [245], congestion relief of transmission system by applying two identified parameters of sensitivity factor (SF), and severity index (SI) [246], the reliability of local distribution system [247], protection coordination [248], loss reduction by load flow [249], fault current limiters [250], solar SPVDG [251], multi-objective [188], voltage profile, losses, protection coordination and reliability calculations [252].

- PMU based power system state estimation [253].

- Community-based solar PV DG [254].

• Earthing and Grounding: earthling grid design [255], [152], [92] [119], [120], [182], [181],the effect of grounding grid configurations (triangular, rectangular, T, and L shapes) on the earthing system [140], electrical safety for residential and rural micro-grids, load flow, earth fault [256], transient, ground grid and short circuit analyses [257], substation grounding systems (based on IEEE standard 80-2000) [118], mesh optimization in a ground grid of EHV substation [110], Optimization design of ground grid mesh [258], [259], the ground impedance measurement [260].

• Electrical energy audit, and saving: [261], [262], [263], management and audit of lighting system in a commercial building [264], Energy usage analysis of industries, power flow [265], variable frequency drive for energy savings [184], energy consumption, emission and saving opportunities [266], [267], the impact of AC/DC voltage levels on energy efficiency [268].

• FACTS Device: TSC-TCR type SVC [269], unified power quality conditioner (UPQC) to eliminate the voltage concepts in power quality challenges include flickers, sags, and harmonics [270], the SVC [76], [271], the impacts of FACTS devices (TCSC, UPFC, and STATCOM) on voltage improvement and transmission loss reduction by using load flow [117], different FACTS controllers, including shunt reactor & SVC [272], FACTS devices (Static Var Compensator, SVC) on power flow [273], load flow, and voltage improvement using FACTS devices [274], improving the voltage level on the power factor by using SVC [275], the electromagnetic disturbances with or without SVC device, includes power flow, harmonic analyzing [143].

• Geographic information system (GIS): energy station identification and frequency analysis [276], optimal path routing for distribution grids [277].

• Harmonic analysis: sizing the harmonic filters [114], harmonic suppression [74], fixed capacitor banks optimal sizing in interconnected distribution systems by GA [75], multiple non-linear loads [65], decoupled harmonic power flow (DHPF) [64], harmonic parallel resonance introduced by subsea cables [80], distribution power system connecting small cogeneration facility Etan [278], [279], [97], HPF for optimum allocation of active filters [280], induction furnace modeling with real data by installation the passive harmonic filters [281], harmonic frequencies and HPF [282], HPF [283], HPF in an AC-DC hybrid microgrid [171], harmonic load modeling [284], harmonics analysis for rail transport load [285], HPF [286], harmonic impact of grid connected PV [287], harmonics estimation [288], harmonic analysis considering large-scale RES [289], harmonic analysis in hybrid power plant [290], harmonics analysis [291], [292], [293], [294], harmonic analysis in smart grids with passive filters [147], under voltage load shedding (UVLS) for sizing the harmonic filters prevent voltage collapse [61], real model of compact fluorescent lamp (CFL) to evaluate the required power quality parameters [69], the impacts of model of spectrum current waveform drawn by a PC, recorded using oscilloscope on distribution transformers [78], harmonic modeling, and a complete fundamental and HLF considering shunt filters to reduce the total harmonic distortion [84], power quality (harmonic analysis, and distortion power) with non-linear domestic appliances [295], harmonic mitigation for offshore systems by applying line reactor and active filter strategies [142], harmonic mitigation and optimization with capacitor banks [296], harmonic mitigation by using filters [297], harmonic mitigation of railway station by using single tuned filters [298], the effect of harmonic distortion levels [299], harmonic distortion [300], passive filter design to mitigate harmonics [301], HPF in radial distribution systems [302], harmonics mitigation [303], resonance characteristics for 11th order [304].

• HVDC: performance improvement of interconnected power systems by using HVDC link [305], HVDC in interconnecting power systems [306].

• Load flow analysis: [307], [145], [308], [309], [310], [311], [151], [312], [313], [175], [314], [154], [155], [315], [316], [317], [318], [319], [320], [321], [322], [323], [324], [325], [326], [327], [328], [329] [330], [331], [332], [333], [185], for verification the results of the proposed approach to load flow solutions in radial distribution systems [63], modeling, testing and optimization of power system using real data (Newton-Raphson) [103], using load data to obtain the load bus voltage magnitude needed for ANN to bus voltage estimation and optimal meter placement in distribution grid [123], [334], using Newton-Raphson technique to determine line currents [335], needed data by radial basis function neural network (RBFNN) for convert the multi-machine system to SMIB [104], the impact of adding the parallel shunt capacitor banks [336], three-phase calculation for radial distribution systems [83], comparing the accuracy of MATLAB self-coded, based on Newton-Raphson method [337], improved randomized model [161].

• Load flow analysis, and short circuit analysis: [338], [339], [340], [173], [341], to perform a pre-fault and post-fault load flow studies to estimate the fault resistance and location for SLG faults in multi-ring distribution grids by ANN [121], self-healing based on determining the optimal site of smart switches to interface with the control room (load flow, short circuit) [342].

• Load shedding, and load restoration: specifying the ranking of the load according to their importance level for applying the load shedding procedure [343], under frequency load shedding (UFLS), and the adaptive system frequency response (SFR) [344], sequential load restoration during station blackout [345]

• Microgrids: balanced/unbalanced power flow, harmonic study, and short circuit [346], over-current relay setting [347], adaptive protection with DER [348], protection [177], adaptive protection scheme with PV, wind [349], highly sensitive and fast protection [350], adaptive protection of phase/earth overcurrent relay [351], relay coordination [352], [353], [354], power flow study include wind energy [355], assessment framework [356], mitigating low fault current considering renewables-battery hybrid systems [357], power flows with renewable energy sources [358], operation of PV with an EESS [359], fault location in multi-voltage microgrids [360], techno-economic analysis of hybrid

RES [361], interconnection system simulation analysis of transient stability [362], microgrid analysis [363], Time series-based detection of firmware attacks [364], short circuit analysis with renewable energy sources [365], real time simulator [174], static-dynamic analysis of an LVDC smart [366], condition monitoring in a campus using smart sensors[367], integrated microgrid for strengthening the station blackout power supply [180], re-coordination of a distribution system using unidirectional fault current limiter (UFCL) [368].

• Motor starting analysis: induction motor starting analysis [89], large induction machine starting for auxiliary power grid [91], direct, coupling-transformer, self-transformer, current-control, and current-ramp [107], using VFD, capacitor, auto-transformer, and star-delta starter [369], using SVC [149], emergency generator sizing and motor starting analysis [370], verifying the proposed method for fast calculation of electromechanical transition processes in multi-machine systems [371], performance of the induction motor during direct-on-line (DOL) start in terms of different cable lengths[372], squirrel cage induction motors by variable frequency drive [373], frequency-dependent models for induction motors [190], starting industrial induction motor using VFDs [374], comparing EMTP-RV and ETAP tools for sequential motor dynamic re-acceleration and acceleration [82].

• Optimal power flow: [388], optimal PSS (power flow, short circuit, and transient stability) [389], optimal voltage control in the presence of the DFIG wind turbines and compensating devices [390].

• Phasor measurement unit (PMU): calculating the transmission line impedances for estimating the zero sequence impedance using phasor measurement units (PMU) [391], PMU full observation in radial balanced distribution systems [392], state estimation considering PV [393], micro PMU full observation [394], µPMU full observation in unbalanced radial networks [395].

• Power losses: losses in distribution networks of industrial cities [144], optimal allocation of transformer, loss minimization [396], HV transmission effects on ohmic losses [397], loss optimization in electric power distribution system [398], technical losses evaluation [399], power losses (active, and reactive) reduction in distribution grids [400], design and loss optimization, including current carrying capacity (CCC), voltage regulation, electrical losses, and efficiency [401], the effects of different methods to decrease the electrical losses, including changing the lengths of feeders, connecting sub feeders directly to the power grid, placing appropriate distribution transformers, placing compensation capacitor banks [402], power loss considering four typical induction wind turbine systems, include fixed-speed; variable slip with variable rotor resistance; variable speed DFIG with rotor-side converter; and variable speed with full converter interface [403].

• Power quality: the power quality between compact fluorescent (CFL) lamp and fluorescent light (FL) [77], enhancement by using SVC [404], monitoring and mitigation of an induction furnaces for steel making using Passive series and shunt filters [405], transient stability and power quality improvement [406], impacts of connected nonlinear loads on power quality [153], power quality impact assessment and governance [407], [408], power quality improvement using SVC [409], power quality analysis in railway [410].

• Power system analysis for special cases, or special strategies: AC/DC analysis [411], ship electric propulsion system [412], 80 floors high-rise building, power losses, and voltage profile [413], captive and cogeneration plant in sugar industry [414], enhancing transmission line capacity by using AC–DC converter [415], unequally spaced grids [416], web-based laboratory [417], enhancement of electric power supply [418], investigation of the self-starting process [419], demand response considering storage power systems [420], optimal operations of transformers in railway systems [191], evaluation of transmission distribution power outages [421], economic analysis of electricity system for residential loads [162], dynamic risk and safety assessment in the distribution grid [422], demand response in electricity markets [423], tune the power system stabilizer [424], comparing the performance of MATLAB software and ETAP software [67], to specify optimal voltage measurement points for SE, to reduce the deviation of voltage in buses which do not have a measurement [101], analyzing different cases to optimal design of emergency power supply in large dynamotor units [106], tuning the PSS using swarm based optimization by applying dynamic parameter estimation and tuning (DPET) algorithm [425], detection and management of large scale disturbances [426], combined sub-way traction substation considering traction load and consumers' auxiliaries [427], electric stock digital twin in a subway traction [428], power system optimization for industrial facilities [99], generation capacity [429], eTraXTM software package for AC traction power supply system [430], the effects of harmonic and negative sequence components on power system relay protection in a connected electrified railways to the main grid [431].

• Power system calculations: protective device coordination, harmonic, motor starting, load flow, short-circuit, capacitor bank calculation, and transformer protection [432], power flow, transient stability, short circuit, harmonic analysis [433], , unbalanced three-phase voltages, injected negative sequence currents, injected harmonic currents, and voltages [434], analyzing and monitoring of 132 kV grid for off-line monitoring including power flow, motor starting, and harmonic analysis [85], transient stability, load flow, and voltage profile [435], load flow, cable current carrying capacity motor starting, circuit protection, selectivity, design optimizations, and system availability [436], design of electrical power supply system, includes load analysis, sizing of transformers, generators, and dimensioning of transformers and generators, voltage drop limits, short circuit, relay protection, and relay coordination [437], comparative analysis of HV and LV distribution systems for rural agricultural loads (load flow, short circuit, voltage stability, reliability assessment, star protection and coordination) [438], vulnerability analysis for open phase condition (OPC), power flow, and relay protection [439], power flow, transient stability, short circuit, relay coordination [440], load flow, short circuit and load point reliability [441], power flow, motor starting, and short circuit [442], optimal load flow, motor starting analysis [286], design analysis, including load flow, and capacitor sizing [443], feasibility studies of the proposed developments [444], power flow, voltage profile, and short circuit analysis [445], [446], power system design and analysis [447], load flow, voltage stability & short circuit [448], power system analysis [449], [187], active power loss reduction, and voltage stability in distribution networks [122], comparing the power flow, reliability, short circuit, motor starting, and power consumption rate for three type configurations of auxiliary power for1000MW unit [86], intelligent load shedding (ILS), state estimation, load estimation in real-time, and transient stability analysis in SG, power management to minimal real power loss for ED, (AGC for MW sharing of all generators) [134], power flow, and losses, using N-R load flow method [116], load flow and transient system analysis [450], [451], evaluation the performance of 132kV sub-transmission system, power flow, voltage drop, power losses [148], load flow, and reliability analysis [452], power flow and voltage analysis [453], load flow and reliability evaluation [454], power flow analysis to define the problems of the existing grid include poor voltage levels, the power deficit, feeders' overloading, high power losses, and propose some solutions such as: increasing the voltage at the sending feeder, adjustment of transformers' tap setting, and installation of capacitor banks [455], load flow, short circuit, relay coordination [456], design an underwater hybrid transmission system [457].

• Power system protection: overcurrent [81], distance protection (long UHV transmission) [458], automatic line switches [459], motor starting module for influence of the inverter's setting protection on isolated grid operation with PV power plant [460], the effect of relay coordination and protection failure on some reliability index, including SAIFI, and SAIDI, and comparing the results with MCS method [461], protection upgrade [462], protection coordination [463], [464], [465], [466], [467], [468], [469], [470], [166], [471], [150], [472], [473], smart adaptive protection [474], online verification method of relay protection settings [475], protection assessment [476], using the overcurrent relays to improve earth fault protection scheme in a microgrid [477], directional overcurrent and under voltage relay protection [478], adaptive overcurrent protection [479], [466], [480], system integrity and protection schemes [481], improved lightning protection for LV [158], relay protection considering a local generation unit [482], Improving the synchro phasor based protection schemes [483], overcurrent relay of feeder protection [484], distance protection scheme and LVRT capability [485], improving the integrity protection schemes synchro phasor technology [486], capacity calculation of the protective device [487], study the arc-flash hazard in an oil-field distribution grid [90], adaptive fuse-saving protection [488], dynamic hybrid protection [489], relay protection setting for power transformer [490], integrating synchro phasor technology for improving the system protection schemes [491], using the ETAP software for generating training data set needed for a neural network-based technique proposed for overcurrent voltage controlled protection in power grids [79], coordination between directional overcurrent relays of transmission line and overcurrent voltages controlled relays of generator [87], digital directional and non-directional over-current relays [492], over current relays [493], [494], planning and coordination of relays in distribution system, including load flow, short circuit, CB and CT selection using time-current characteristics, and protection coordination to find the optimal critical clearing time [495], over current relays for phase and ground fault based on load flow [496], overcurrent relays coordination[497], forecast-based overcurrent relay coordination [498], over current relays setting considering transformer inrush current [499], directional overcurrent relays [500], [501], over-current relay tripping coordination [502], adaptive relay co-ordination [503], overcurrent relays [504], interphase fault relaying scheme [505], measuring the THD by adding an adaptive harmonic filter to improve the performance of over current relays [506], the impact of harmonics on the performance of over-current relays [100].

• Power system reconfiguration: [507], minimum loss configuration in a power distribution grid [62], mitigating voltage sags considering the load growth [508], capacitor switching with distribution system reconfiguration [509].

• Power system stability: [510], harmonic filter of power system stability [511], harmonic effect for voltage stability [512], transient stability (setting the relay for tie line tripping, and load shedding) [513], transient stability [514], [95], [515], [516], [517], [518], [519], [520], [521], [156], [160], [522], [523], dynamic stability [524], static stability [525], impact of SVC on transient stability [526], transient stability (adaptive load shedding, and conventional under frequency load shedding (ULFS) techniques) [527], application of principal component analysis (PCA) for (SG) data storage in different states of steady state, fault conditions: transient stability for loss of single generator, and for bus fault [528], stability studies [529], [530], [531], [532], [533], transient stability analysis (include power flow) of system with FCL (fault current limiter) and SVC (static VAR compensator) controller [113], transient stability assessment based on optimal critical clearing time in hybrid electrical grids [534], transient stability in a multi-machine system [535], transient stability enhancement using the SVC [137], [536], impacts of voltage instability and transient stability [537], improving the transient stability by using PSS, and SVC [538], short circuit and stability analysis of a multi-machine system considering wind turbine [539], enhancing power system frequency [141], Enhancing the voltage stability in power system by using the SVC [129], power flow, and voltage profile for distribution/transmission interface for enhancing power system stability [540], performance of different governor models and excitation sets on transient stability, power flow, short circuit, transient analysis [112].

• Reactive power compensation: [375], [376], [377], investigating the wind farm performance [378], power system reli-ability enhancement [135], [379], voltage improvement and total cost minimization in radial distribution grids [126], minimizing cost and power loss [380], modeling nonlinear loads [131], static VAR compensators (load flow analysis) [381], radial distribution systems of 11 kV, and 0.4 kV [146], reactive power compensation [382], [383], [384], current transformers' saturation error compensation [385], power quality improvement [386], impact of series/shunt capacitors on distribution network [387], power factor improvement [164], in distribution grids using GA [72], frequency response technique to improve the power factor [176].

• Reliability analysis: [541], [169], [542], [543] [544], using distribution automation based on wireless communications (ETAP : used for power flow and loss analysis) [545], prediction reliability indices, EATP, and NN are used [105], SAIFI, SAIDI, CAIDI, ASAI, ASUI, EENS, AENS) [546], ASAI, SAIFI, SAIDI, CAIDI [547], failure analysis[548], variable frequency drive [549], radial power distribution system using smart reclosers [550], distribution network [551], [552], power supply [553], reliability indices [554], Different reliability indices considering wind, hydroelectric, and solar power sources for three bus-bar schemes of ring, double bus double breaker, and a half breaker analyzed [555], investigation the electrical reliability of the system floating liquefied natural gas (FLNG) vessels, include power flow, short circuit, motor starting, and transient stability [556].

• Renewable energy sources (RES):

- Wind power plant: harmonic emission levels evaluation [557], DFIG-based, including short-circuit, power flow, harmonic analysis and filter design, reactive power and optimal load flow analysis [558], power quality enhancement [559], SCIG and DFIG [560], short circuit current, and offshore wind farm disturbance [132], improving transmission line voltage stability considering contingencies [561], impacts of wind energy [562], assessment of the wind power potential [563], assessment of DFIG on short circuits in distribution grids [564], operational modes, power losses, and voltage profile [565], load flow, and reliability [566], three-phase SCs [130].

- PV, or Solar: harmonic mitigation for multi-objective optimization of energy in rural distribution grids [567], offline penetration-free protection scheme [568], protection coordination [569], [570], [571], [572], transient stability of a hybrid grid-connected battery-PV [573], transient stability [574], solar panel penetration, power flow, and transient stability [575], impacts on grid [576], [577], [578], [579], [580], [581], [582], [96], [583], [584], feasibility study [585], impact of rooftop solar power systems on the LV distribution grid [586], optimal location and hosting capacity [587], impact assessment [588], a solar/biogas hybrid system [589], controlled electric vehicle charging [590], design [591], economic study for a DC residential distribution network [592], the EV parking integrated with PV roof mounted [593], the performance and quality of solar PV [594], design scheme for ring-based extra low voltage [595], reduction of central inverter number by MV capacitor banks [596], auxiliary services system in a transmission sub-station [597], power flow, and state load estimator (SLE) feature for analyzing the dynamics of integrated battery storage and PV [598], an integrated gas station with a solar unit [599], voltage stability evaluation [600].

- RES: harmonic estimation on a transmission system [601], impact of location and size of hybrid renewable energy systems (PV, and DFIG) on short circuit level of three-phase, LG, LLand LLG faults [602], reliability enhancement and voltage profile improvement considering the optimal sizing, and siting [603], transient stability [604], transient stability, and rotor angle stability [605], voltage stability considering FACTS [606], hybrid renewable energy [607], optimal placement [608], load flow [183], reliability assessment and feasibility study for an industrial facility [609], optimization and design of a sustainable industrial grid system [610], load flow, voltage profile, and power loss (DC/AC system to grid) [611], development of PV-wind, battery hybrid grid connected system, load flow [612], voltage regulation in the MV distribution [170], investigation the connected hybrid wind and solar systems [613], distributed power supply (wind, and solar) and micro-grid interconnection (voltage profile, and transient analysis) [614], fault current contribution [615], the feasibility study of frequency regulation in ESS [186], electric vehicle penetration modelling [616], three-phase power-flow solutions in smart grids considering the plug-in hybrid electric vehicles [617], the impacts of PV and wind penetration [618].

• Security assessment: steady security [115], obtaining the needed data for pattern recognition of dynamic security assessment (DSA) from simulation results [71], security and stability analysis of an industrial plant [73], real time security assessment, power flow [619].

• Short circuit, and fault analysis: [124], [620], [621], [622], [623], [624], ANSI-C37, and IEC 61363-1, IEC– 60909, standards [625], IEC 60909 [626], the impacts of repair-fault periods on MV feeders losses [159], fault current limiters [627], feasibility study of replacing traditional CTs inside gas insulated switchgears (GIS), with power current micro-sensors, three-phase, LLG, LL, and SLG faults [628], impacts of DFIG wind turbines on short circuit level in terms of unbalanced/balanced faults [629], short circuit studies using pu impedance techniques [630], short-circuit current reduction [631], short-circuit analyses in parallel/non-parallel transformer operations of railway [632], detectability of open phase [633], countermeasures of power system open phase conditions [163], fault clearing [634].

• Smart grid: protection through self-healing [635], analysis and management [636], reliability [172], stability [165].

• Voltage profile, and voltage regulation improvement: [637], [638], [639], [640], loss reduction [641], HVDC [178], effects of fault transients in the grid on nuclear power plant electrical system, in terms of voltage profile and frequency changes are analyzed [642], underground cable [127], local and remote control of AVR in distribution grids considering uncertainties [643], SVC [644], monitoring of large industrial plant parallel operation with grid, using a fuzzy technique for voltage control [68], comparing the curves of primary/secondary voltage controls (PVC/SVC), and optimal tracking secondary voltage (OTSVC) [645], the integrated SVC, and EAF (electric arc furnace) [646].

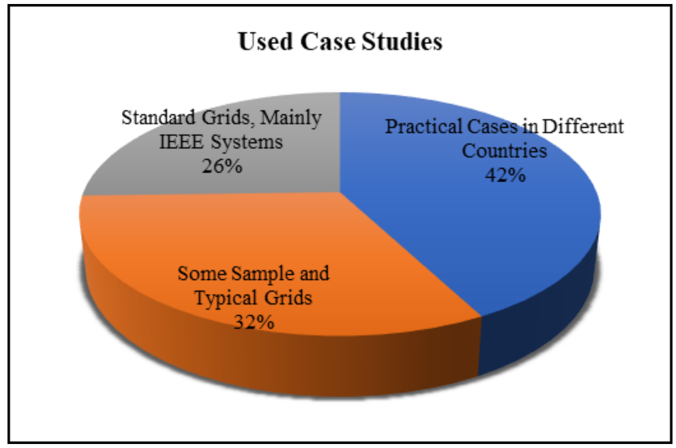

Fig. 8. The percentage of used case studies in different research

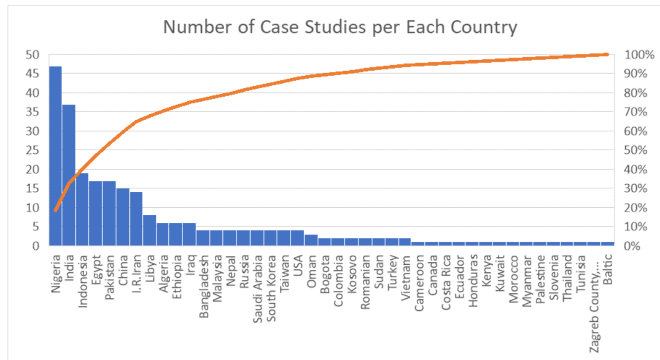

Fig. 9. The numbers of case studies used in different countries (total 256 cases).

5. DIFFERENT CASE STUDIES

The studies show that different case studies have been used for simulation in this software. These case studies can be categorized in three general groups, practical cases in different countries, standard grids, mainly IEEE systems, and some sample and typical grids. The share of these three classes are equal to 42%, 26%, and 32% respectively (from 605 case studies) (see Fig. 8.).

A. Practical Cases in Different Countries

Surveys show that most of cases studies used are practical systems in different countries. There are 43 countries in the long list of these cases. Nigeria, India, Indonesia, Egypt, Pakistan, China, and Iran are seven countries with about 65% of all cases in this category. Fig. 9 compress the numbers of cases studies used in different countries.

The detailed information for case studies of different countries is as follows:

• Algeria: GHAZAOUET 220/63/30 kV, an electrolysis plant power system, 30 MW, 63, 20, 5.5, and 0.4 kV, a 5.5 kV, 5 MVA steam turbine [445],[446],[341], a seawater desalination plant [449], Kaberten distribution grid, [524], a Saharian-Isolated area [366].

• Bangladesh: Dhaka grid, 71 buses (132, 230, 400 kV), 32 generators, 135 interconnecting lines, 47 loads and 4 parallel capacitors with the maximum demand of 5,525 MW [312], a 7.5 MVA (33/11kV) substation, 500 MVAsc, 2x2 MW generators [622], an isolated island: Swarna Dwip, 500 MVAsc, 10 MVA, 33/11 kV transformer, 11/0.4 kV, 4x2500 MVA, transformers [457], Teknaf Nayapara Rohingya refugee camp, 11/0.44 kV, 1500 kVA, with 3732 families [409].

• Bogota: CIPI building at the Universidad de Bogota Jorge Tadeo Lozano, 11.4 kV [168].

• Cameroon: The southern interconnected grid (SIG), the Ngousso, and the Oyomabang bus bars, 93 kV [587].

• Canada: Canadian urban benchmark distribution grid feeder with 4 inverter-based DGs [364].

• China: three different project configures [86], 600MW air-cooling and 1000MW thermal generator units [91], six connected zones by 110kV lines, high-speed 220kV rails [431], the Huozhou power system, 500kV, including three traction stations: Xinbao, Duping, and Guang Shengci [298], a certain island [614], electrified railway, 2×40 MVA, 220/27.5kV [407], the offshore platform group power grid, Bohai Sea [475], a real community power distribution network at WenLing, Taizhou, Zhejiang [422], Shanghai-Nanjing intercity railway, with high-speed railway (HSR) loads, 220kV.Jiangsu, including 5 traction substations, consists V-V connection transformer, supplied by 2 independent 220 kV feeders, 932 transformers, 229 generators, and 1345 transmission lines [434], 500 kV offsite grid, 1145 MW Hualong pressurized reactor (HPR-1000), [198], a power grid in China, consists of 470 buses (220/110/35/10/6/0.4kV), 12 overhead lines, 231 load nodes, 151 cables, 167 two-winding transformers, 2 three-winding transformers, 5 existing generator units (60/60/30/30/9MW), and 4 new units (each 60MW) [73], 220kV, 120MVA Gong Ping power station [74], Nanning power grid, 110 kV [285], the Ali grid large capacity motor starting when 4 hydro-generators (with 5MW output), 4 diesel-generators (with 0.4MW output), 2.4MW of PV, alpine remote areas [460], a multi-infeed AC/DC hybrid power grid, Shanghai, 4 inverter stations, 500kV and 220kV [304].

• Colombia: [636], A generation plant, 13.8 kV, 2x68.8 MVA generators, 13.8/69 kV, 2x60 MVA transformers, four 66 kV transmission lines [194].

• Costa Rica: [616].

• Ecuador: microgrid, San Cristobal Island, Galapagos, 1 MW PV, 2.095 MWh BESS, 6.39 MW diesel power plant, and 2.4 MW wind farm [177].

• Egypt: Zafarana wind farm [378], power distribution network in Rafah governorate, a Palestinian city located on the border of Palestine [455], Elgharbia 11 kV electricity grid: 75-bus, Kotour city, El Gharbia, total connected load of 6536 kVA, and maximum current of 344 A, two 1 MW DGs[125], main receiving substation (MRSS) of EZDK [646], an 5-buse, 3MVA, 11kV suburban distribution feeder, nearby Cairo city [578], 18 feeders radial distribution grid of Assiut university, [392], LV distribution networks, 350 MVAsc, 11 kV, 1 MVA, 11/0.4 kV transformer [231], distribution grid of El bareed-Youssef El sedeeq, Gharbia: 11 kV, 27 buses, 28 underground cables, total length of the network 8.37 km, 12.66 MVA, 3x300 kVAr capacitors [509], Behira 29-bus grid, two feeders, 28 underground cables and, 2x100, 6x200, 9x300, 9x500, 3x800 transformers kVA [159], Assiut 11 kV, 20 km, international airport long distribution feeder, 1x15 MVA, 66/11 kV, 2x2 MVA, 1x1.5 MVA 11/0.4 kV transformers [582], Borg El Arab city, 2x737 kW, dc, PV systems [591], the first nuclear power plant at El-Dabaa site (1200 MWe) [607], 66/11 kV distribution grid (Karot line), 16 water-pumps induction-motors [387], the Kafr Rabea feeder in Menoufia, a distribution network in the metropolitan area of Caracas [643], the East Delta network, the distribution network, 150 MVAsc., 11 kV [627], the 25-bus, 500 kV power grid [608], industrial power grid, united gas derivative company (UGDC), British Petrole-um, Gasco, Port Said [68].

• Ethiopia: Jimma Town, 132 kV, 132/33 kV 16 MVA, 132/15 kV 20 MVA transformers [169], Adegala-Hurso 230kV traction substation, Addis-Djibouti railway power grid [331], Bata 34 bus feeder, Bahir Dar power grid [172], the practical distribution network of Debre Markos city, 66, 33, 15, and 0.4 kV, with 10,670 customers, two incoming feeders with 6.32 MW and 2.972 MW [603], the 15kV distribution, Bata feeder, Bahir Dar city [277], Yirgalem town feeder, 47 bus [251].

• Honduras:[420].

• India: 132/11 kV substation, Hingna MIDC, Nagpur Zone, 132 kV incoming, 20 outgoing feeders of 33 and 11 kV, 40 buses, with 1x25, 2x20, 1x16 MVA power transformers [271], distribution substation132/11 kV, Hingna MIDC, Nagpur, Maharashtra, one incoming of 132 kV and 20 outgoing 33, and 11 kV feeders 1x25, 2x20, 1x16 MVA distribution transformers [644], Kerala state power system, 110, 220, and 440 kV, installed capacity: 2746.19 MW, maximum demand: 2998 MW, 220 KV lines circuit: 2701 Km, 110 KV lines circuit: 3970Km, 330 EHT sub stations: connected load: 15827.90 MW, no. of 220 kV substations: 17, no. of 110 kV substations: 123 [103], the 220 kV substations of Kerala [454], 33 kV Grid, located at thickly populated cities, like Bombay, Delhi, The 220 kV substations in Kerala [105], 2x11 kV feeders,1.829 MVA load, at Kerala, including 2x10 MVA, 66/11 kV, 10 lumped loads [342], three generating power stations of Tamilnadu (14-bus generation and transmission system) [515], Patna city, including 7 large substations, 100 feeders, 33kV/11kV, fed from 132 kV [402], Tamil Nadu, Southern Regional grid [642], A 400 kV substation [272], a 11kV three phase supply, 44 node urban distribution feeder, Vadodara, Gujarat [401], Surana steel plant, Tamil Nadu, including T 46 buses, in 6 voltge levels of 220, 110, 33, 11, 0.415 kV, with the demands of 23.336MW and 23.082MVAr [495], DEPZ plant: a small power plant (80MW, 11kV, and 33 kV), with 12 generators running in parallel, located at EPZ area SAVAR [517], a building in education and research institute, Chennai [264], an 11kV industrial feeder,at Chennai, Tamilnadu, 21 main bus systems, 21 11/0.44 kV transformers [265], 400 kV transmission network of southern grid system, two modified upcoming smart cities: Salem to Udumalpet and Madurai to Pugalur 2x400 kV to HVDC lines, together/independently [415], the Indian institute of technology Gandhinagar (IITGN) ring main distribution network, 11 kV, 500 kW solar power, 2x1000, 6x630, 2x315 kVA, 11/0.415 kV transformers [588], an educational institute in northeast, includes 285x75 W ceiling fans, 33 LED bulbs, 50 fluorescent tube lights, and 449 CFLs consuming 45.738, 396, and 1155.726 kWh, respectively, air conditioners consume 1376.76 kWh [266], a sample real time 50 bus test system [276], 400 kV EHV AIS, from 500MW Ukai generation unit, Tapi district, Gujarat, 250x250 ft2 [259], a cable manufacturing industry, Chennai [267], 66 kV substation, Trivandrum, Veli Kerala, 1x10 MVA, 2x8 MVA, 66/11 kV transformers [319], 3x660 MW super-critical thermal power plant, supplemented with a simulated 250.5 MW Solar PV system [290], 6 MW biomass power plant, 37 transports joining 35 burdens and 3 transformers, situated in Maharashtra [321], 132 kV 10-bus Manipur transmission system [641], Indian electricity board, TNEB 11 kV Distribution feeder [122], Maharashtra 33/11 kV distribution substation, Nagpur zone, two power transformers, each having capacity of 3 MVA, two outgoing feeders connected to each of power transformers [76], Indian 11kV electricity board TNEB distribution grid feeder [88], Tamil Nadu electricity board (TNEB) 45-bus [101], TNEB 140 bus system [123], The Kerala power grid [241], 33/11 kV, 3x5 MVA transformers, Harbour sub-station Ratnagiri [318], 11 kV Mancheery Feeder LVDS, 1500 MVAsc., 11 kV, and Mundramkattalai 250 kV[396], 132 kV substation, Hingna II, Nagpur [315], A substation of Bangalore institute of technology (BIT), campus, 4 incomings from 11 kV, 350 MVAsc, four 11/0.44 kV, 500 kVA transformers, and 0.44 kV outgoings [545], Amrita's power house-II university, Ettimadai, Coimbatore, 22kV, five load buses, 2x500 kVA, 250 kVA, 22/0.433 kV transformers [379], Engineering Institution Buildings in Maharashtra, 100 MVAsc, 500 MVA, 11/0.4 kV transformer [263].

• Indonesia: Jayapura system [435], Electrical systems in Surabaya Selatan, East Java [461], The power generation of ZULU [142], A process industry having the cogeneration facility [137], the transmission line 150 kV sub-system region III Yogyakarta [127], KSO Pertamina EP, Geo Cepu [145], Barru bus [429], Baubau power system, 30 MW, PV (5 MW) [573], The Sulselrabar electricity system includes 21 generating units, operating at 150 kV [183], 2x300 kW synchronous motor, energy storage, wind turbine, PV, inverter [362], Regent Resort & Holiday Inn Canggu, 50 MVAsc., 2x2000 kVA, 20/0.4 kV [164], 150, 158 kV modern railway system [410], The campus building of Medan area university, 20 kV, 100 MVAsc, 500 kVA [165], Rekind Daya Mamuju 2x25 MW [166], Manokwari electricity distribution system [102], The Titi Kuning power system, includes 6 power grids, one generator, 40 loads, 122 buses, 120 branches, 150/21/20/6 kV [157], The Saguling generator, in the Java-Bali 500 kV system [104], The MTs Parmiyatu school network system, a 630 MVA, 20/0.4 kV transformer, 4 load panels, laboratory, school building, kindergarten and mosque [585], Penyeimbangan Beban transformer distribution 400 kVA 20/0.40 kV Menggunakan [187].

• Iran: A part of Tehran distribution network, two synchronous DGs operating on PQ mode [200], Line 2 of metro, Tehran, three 63/20kV HV substations, 154 upstream feeders [380] ,[151], [548],The power distribution system of the Tehran metro [326],[327], [313], A real network in Esfahan [213], 1000 kW pump station, Tabriz [373], The 132/33 kV Payam power substation, 25x40 m2 [260], The Khoda Bande Loo feeder, Tehran distribution network, a MV feeder,13 bus 63/20 kV [66], A radial distribution network of a petrochemical plant in Bandar Assaluyeh, two DGs (500, and 250 kW) [70], The steel plant substation, Khoozestan, 13 MV CBs, 26 buses, 11 230/33 kV transformers, fed by 4 230 kV incoming lines, 5 induction furnaces (5 UPQC to manage power quality), induction motors, three distribution power transformers 3x89.6 MVA, 6x73 MVA, 1x120 MVA, 1x50 MVA [270], South Pars's third refinery, 75MW, 33 kV, 4x41.1MW gas turbine generators, and 2x4.5 MW emergency diesel generators [463].

• Iraq: Interconnected 400kV, 50Hz Kurdistan and Iraq power grids [305], An integrated solar combined cycle plant, with 2x250/250/75 MVA, 132/33/11 kV transformers [537], 12 substations, Kirkuk city [173], 132 kV, 36 bus, Kurdi-stan (Duhok, Erbil, Sulaimanaya) power system [178], F10 feeder, 11 kV, AL-Abasia distribution network [229], One of the feeders of Alkaherat distribution network: Abu-roayah feeder, Karbala 33kv distribution system. by distance around 10km, contains 20-bus, each supplied through transformer 11/0.4kV,250kVA [146].

• Kenya: Nairobi north distribution network, 220/66 kV, 1-5% PV penetration [583].

• Kosovo: A 35/10 kV substation, Malisheva [637], 110/35/10 kV Gjilani substation, Koznica [562].

• Kuwait: EHV system, 25-Bus, multi-machine grid, 5 lumped generating units300 kV, 25-bus, 59 branches (24 UGCs, 28 TLs, and 7 transformers), 5 step-up transformers, entire load of 6,160 MW [84].

• Libya: The Libyan regional distribution network at Benghazi, including five 220 kV buses with radial connection network [204], The 220 kV Eastern Libyan electric network, 7x30 kV, 5x11 kV, and one 11.5 kV DG bus connected to the grid [225], Real plant, 2000 MVAsc., 2x63 MVA, 220/30 kV [286], REBIANA village, 235 kW [592], 66/11 kV Al-Bayda city, with PV [320], Houn 220/66 kV substation [377], Zliten network [577], Benghazi distribution network, fed from 220/30 kV, 100MVA [207].

• Malaysia: an 11 kV, 286 MVAsc commercial building, southern [472], Mass rapid transit 2 (MRT2) [632], Mass rapid transit 2 (MRT2), 132/33 kV [191], electrical grid of Taylor's university, 4x 11/0.415kV transformers [197].

• Morocco: HV Grid (One 225/60/22 kV substation, two 2x70 MVA 225/60 kV power transformers and two 2×40 MVA, 60/22 kV power transformers, two 2x40 MVA, 60/22 kV power transformers.) to a 40MVA PV [640].

• Myanmar: 33/11/0.4 kV, 10 MVA Maubin distribution system [339].

• Nepal: Kathmandu valley network on integrated Nepal power system (INPS), 38 buses, 66 branches, 34 generators and 13 loads [566], Indushankar Sugar Industry Pvt. Ltd, 6 MW, 11, and 33 kV [414], Under construction hydropower plants, 1100 MW to 1188 MW demand increasing [314], A mini-grid, includes 6 MHP, 9, 12, 14, 22, 24, and 26 kW [476].

• Nigeria: full 330kV transmission network, including generators, transmission lines, transformers, and loads [514], 24-bus system [619], Ran feeder from Bauchi distribution network, (0.3 MVA, 11 kV) [226], 48-bus system[289], existing 28-bus, 330kV, consist of 9 power plants, and 29 transmission lines [117], 330 kV, 52-bus integrated power system, 11,000 km transmission lines, 17 power plants stations, 4 control centers, and 64 transmission lines, [116], 132kV Owerri transmission substation [129], 330 kV integrated power system, including 17 generating stations, 64 transmission lines, and 52 buses [529], 330kV transmission network [242], 330kV power system, 28-buses [624], The cities of Port Harcourt, Kano, and Lagos [144], 132/33kV substation, Alaoji [258], 5 distribution substations of Silver Bird, Secretariat, Water Works, school of Nursing injection, and UST with 15 load points, Port Harcourt, Nkpolu-Oroworukwo, Rivers State [547], 33 kV power grid, zone 4, Port Harcourt town, Rivers state [310], the power network, Port Harcourt sub-region, Rivers state [148], 132/33kV transformer substation, and 132/33KV network, Rumuola Injection to Afam substation Golden Lilly [540], 330kV transmission system, 27 buses [621], typical 15 bus network system Kastina town, two grid sources rated 132kV, 1250 MVAsc., 5x60MVA, 132/33 kV, 3x30MVA, 33/0.415kV, 1000 PV panels of 123 w, 2x3MW wind turbine generators [615], The power system network, 2000 MVAsc., 5x150 MVA, 230/132 kV, transformers [383], Egi-clan 33/0.415 kV distribution network, Nigeria [154], Elelenwo, 33/11 kV, 15 MVA, electric power grid [155], 330kV, 16 bus power grid [156], Opolo community in Bayelsa state, 2000 MVAsc, 33/0.415 kV [317], The distribution network of a university, the ABUAD, 1x5 MW, 33 kV, and 1x0.935 MW, 0.415 kV generators, 2x5 MVA, and 1x0.5 MVA, 33/0.415 kV transformers, and 17 feeders [288], Forcados power system (11/33 kV) network, 6x11.25 MVA, 11 kV generators, 2x25MVA, 11/33 kV, transformers, and 6.5, and 12MVA loads [630], Benin region, 330 kV transmission network [161], 330 kV power grid, 25 generating stations, 12,870 MW, 72 buses and 90 transmission lines [638], 330 kV power system, 48 buses [300], Afara feeder for 20% DG penetration [502], Ajaokuta steel company limited, Ajaokuta [542], The Okwuzi 33/11/0.415kV distribution network [294], The 330kV power transmission network between Afam and Port Harcourt [526], Borokiri 33/11 kV, 15 MVA injection substation, Port Harcour [322], 33 kV dstribution system, Calabar [543], Eket 132/33 kV transmission station [333], Harcourt 132/33/11 kV power grid [293], 80 MVA, 132/33 kV Ohia transmission substation [620], 132/33 kV substation, Benin city[324], Port Harcourt town 132/33/11 kV substation, with SVC, Nigeria [185], Port-Harcourt Town, 165 MVA 132/33 kV substation and 33/11 kV injection distribution grid [647], Port Harcourt distribution network, RSU 2X15MVA, 33/11kV injection substation [150], Total E & P in Port Harcourt, 33 bus system [158], Abuloma community in port Harcourt, 18 buses, 11 kV [418], 11 kV distribution network, marine base port Harcourt, 2x15 MVA, 33/11 kV transformers, 18 feeders [384], Four 11kV distribution feeders namely; Ojoto, Nsukka, Udi and Silverbird. 33/11 kV fed from 165 MVA transmission station, port Harcourt [398], Afam-Port Harcourt mains 132/33 kV transmission substations, 1200 MVAsc., 3x60 MVA transformers [421], 33 kV Abuja steel mill feeder [284].

• Oman: Mazoon electricity company (MZEC), 14 upgrading projects for existing substations or feeders, 17 constructing projects, 2 projects for shifting load among substations [400], the rural power system [355], Zone 3 of Muscat electricity network [72].

• Pakistan: A sample power system, two incoming lines of 132 kV, and six transformers (132/11 kV), with different type of industrial, offices, plazas, shops and domestic loads [85], A 11 kV distribution system (1500 MVAsc), 100 kVA 11/0.415 kV transformer, supplying 18 homes, located at Gujranwala electric power company (GEPCO) [295], A practical 500KV substation i.e. RA WAT [110], A radial 11kv feeder,Kohat Road, Peshawar [205], 132kV grid station [452], A radial distribution feeder, 6 buses operating at 11kV, located in Peshawar [565], An 132kV electric supply substation Abbottabad, Khyber PakhtunKhwa [456], A modified 11 kV, 14740 kVA, Rajewala radial feeder from 132 kV Eimnabad, Gujranwala [215], 132/11 kV grid station Bahawalpur region, 230, 115, 65 kV[274], Three radial feeders of Ismail Khani, Mandan-1, Mandan-2; 132/11 kV, 26 MVA, Bannu, Peshawar [232], NokKundi area [563], The centralized generation, Qadirpur Ran, a solar plant, an 10 biogas plant, three biogas plants of 2, 2, and 1 MW) [589], An islanded microgrid in a village [356], The IESCO distribution network, 16 buses, 200 kVA, 11/0.4 kV [196], Complete power distribution network of University of Engineering and Technology (UET) Lahore, 2 generator sets each rated at 1160 kW and two utility feeders as back up supply, 30 distribution transformers, total load 5250 KVA, maximum demand 2605 KVA, lighting load is 10% of the total load [69], Pakistan's power distribution system [234], power grid ,Rachna college of engineering & technology (RCET), 7 distribution transformers with capacities of 2x25, 1x50,3x100, and1x200 kVA [78].

• Palestine: A 22/0.4 kV, 630 kVA distribution substation, Al Fairoz residential area in the Gaza city [332].

• Romanian: A specific power system region, with the distorting consumers located at the Western side [282], A UHV DC integration, 220kV side and 500kV outlet of the six 500kV substation [417].

• Russia: Latvian power system 330 kV, and its connection with Estonian, Lithuanian and Russian power systems, contains 16 (17) 330 kV substations [243], The AC traction power system, 3810.512 MVAsc, 127 kV, 2x25 MVA, 127/15.67 kV transformers, and 111.803 MVA, 121.8 kV load, Moscow [430], 200 MW conventional gas turbine contains 4x50 MW, two power steam turbines, 65, and 75, MW fed by solar field and gas turbine exhaust, 400 kV, 30000 MVAsc. [599], 81-765/81-766/81-767 (Moscow), along with its mechanical and electrical characteristics [428].

• Saudi Arabia: 380 kV West–East inter-tie, reduced 37 bus [375], A residential network (through a 110/11 kV power transformer) with 3 feeders (step-down 11/0.38 kV), including 54, 42 and 48 load nodes [96], A petrochemical plant [114], [67].

• Slovenia: The Mavcice hydropower plant, 2x21.25 MW, 10.5 kV generators, 2x25 MVA, 10.5/119 kV transformers [531].

• South Korea: An industrial plant [556], the765 kV power grid of Korea's nuclear power plant [439], An standard nuclear power plant, 345kV switchyard, 345/21 kV, 1060 MVA transformer [633], An standard nuclear power plants, 345, 13.8, 4.16 kV [163].

• Sudan: Faroug 110 kV Substation, 2.94 MVAsc, 2x60/40/20 MVA, 110/33/11 kV transformers [275], A power sub-station, Khartoum (GARRI), with four generation sections, 11, and 220 kV [160].

• Taiwan: The Minsheng distribution substation, located at Taiwan Power Company (Taipower), including 3 distribution transformers, 6 static capacitances, 4 CBs, 2 tie CBs, and 18 FCBs, 161 kV bus-bar and 3x22.8 kV bus bars, The Fuyuan substation, 2 distribution transformers, 3 static capacitances, 2 CBs, one tie CB, 6 FCBs, 2x69 kV, and 2x22.8 kV bus bars [459], Wind farm in Penghu Island, 5 sets of two of 10x2 MW WTs, connected to 161 kV main bus, each set connected through a 60 MVA 23.9/161kV, with different heights of 10, 25, 50, 100, and 200 m [132], a cogeneration plant, Hsin-Chu Science-Based Industrial Park, one 36.6 MW steam turbine, and 3x45 MW gas turbines [513], ac-tual Taipower distribution system [617].

• Thailand: Wang Noi combined cycle 4 (WNCC4) [138].

• Tunisia: The 47-bus realistic distribution system, includes 42 lines and 47 nodes [230].

• Turkey: A 1350 MW combined cycle power plant, 6x138.8 MW gas turbine and 3x172.2 MW waste heat steam [433], Karabuk University'S grid-connected microgrid [408].

• USA: the 11kV Komag Sarawak operations (KSO) plant, 480, 433 or 280V, 12 transformers and 3 spare transformers, from 1000 to 2000 kVA [124], Byron Station, Unit 2, Ogle County, Illinois [623], An oil field system, supplied by 66kV, including different offshore and onshore load centers, with total normal demands 36 MW, including 16, 11, 2, and 7 MW, respectively, consist of 418 induction motors (mostly used for electrical submersible pump (ESP) motors), 67 6-pulse VFDs [99], Anclote plant, Florida state [462].

• Vietnam: A 75 MW wind farm with 25 wind turbines, Phuquoc Island [130], A case study in Ha Tinh province, 320 kVA, 22/0.4 kV, 5.22, 5.34, and 10 kW rooftop solar [586].

• Zagreb county, Croatia: A 35 kV substation with 35/10/10 kV, 8/4/4 MVA transformer, in Ivanic Grad [278].

• Baltic region: Power grid in island mode, and Latvian power system in different scenarios [141].

B. Standard grids, Mainly IEEE systems

The detailed information for standard grids, mainly IEEE systems are as follows:

• AC-DC networks: 10-bus [199], 13-bus [199],

• IEEE PSS2B-Dual-input PSS [425]

• 2-bus power system [426]

• 4-bus system [280] IEEE 4 node radial test feeder, include infinite bus, ground wye-ground wye transformer bank, two feeder segments, and a wye connected demand [83]

• IEEE 4-bus system, include 3x100 kW solar PVs[572]

• IEEE 4 bus system [376]

• IEEE 5 Bus System [115], [575], [241]

• A standalone 5-buses IEEE DC microgrid for a district zone [328]

• 6-bus IEEE power system including DG units, and A 16 kW, 11kV, system connected to a hybrid system of solar and wind, include 1x7 kW solar system, and 1x9 kW wind power plant [611]

• IEEE Garver's 6-bus test system [619], [289]

• IEEE 8-bus [501]76], with DGs [500], with 14 overcurrent relay network [335]

• IEEE 9-bus system [527], [532], [635], [352], [210], [393], [604], [237], for microgrid [353], modified [234], includes wind and solar power plants [206], 3 generators, 519.5 MW total power, and 330.618 load MW, 1x163.2 MW wind generator, a PV panel with battery (2552 AH, 143 V) [605], connected to a microgrid system, three wind turbine generators (WTG) [348], modified with wind farms and a typical wind-integrated substation, 220 kV, 25 MVA, 220/110 kV, incudes 9x225 kW, 0.4 kV, SIG wind turbines, 13 overcurrent relays [498], PV integrated hybrid power system [471], connected to PV system [350], modified without PV [584], connected to two PV plants [504]

• 9-bus radial distribution [510]

• IEEE-10 bus test system with solar PV [581]

• 13 bus microgrid, 500 MVAsc, 20 MVA, 115/12.47 kV, 3MVA, 12.47/0.48 kV transformers [363],

• IEEE 13-bus distribution test system [629], [617], [602] ,[349], [101], [303], [216], [499], with integrated SPP [593], expanded system [590], A modified unbalanced radial grid [188]

• IEEE 14 bus system [253], [579], [554], [503], with PV & wind [530], modified system [236]

• IEEE 15-bus test systems [501], with DGs [500]

• Radial 16-bus test grid [507]

• The distorted IEEE 18-bus system [64], [65], [302], [337]

• IEEE 20 bus distribution system [512]

• IEEE 21-bus [250]

• IEEE 24-bus system with RES, wind, PV [601]

• 28-bus distribution system [250]

• IEEE 30-bus [75], [506], [100], [135], [505], [219], [503], [423], [501], 33 kV [618], with a large-scale PV [574],[600], includes 111 number of SEPAM-2000 relays and 333 design variables with 726 inequality constraints[497], modified, one PV, inverter, wind generator, and 4 conventional power plants [534], grid-connected wind farms at buses 5, 7 and 10 [480]

• IEEE New England 30-bus system [61], [528]

• IEEE 33-bus radial distribution test system [62], [63], [564], [403], [302], [214], [226], [228], [488], [357], [224], [248], [218], [507], [608], [175], [244], grid connected to two PV plants [504], 32 branches and 32 load (static) radial distribution grid, with active load of 3.715 MW and reactive load of 2.3 MVAr [128], considering the reliability data of the IEEE Roy Billinton test system [569], modified with two DGs [223], [244]active network [220], with NTDC 220 kV real time grid system [376]

• IEEE 34-bus test system [233], [101], [617]

• IEEE 37 bus distribution system [122], [88], [617]

• IEEE 39-bus New England system (10-generators) [535], [491], embedded with HVDC link [486], [481], [483], 380 kV inter-tie network [536]

• IEEE 59 bus [113]

• 62 bus test system [179]

• IEEE 69-bus distribution network [608], [507]

• 85-bus with active and reactive power load of 2.57 MW and 2.622 MVAr [128]

• 118-bus radial test system [507]

• IEEE 123 bus system [617]

• Modified TNEB 140 and IEEE 202 bus systems [334], [123]

• 7-bus, 3-Machine test system [519]

• 10-bus multi-machine system with PV penetration [451],

• 9-generator power system, grid-connected operation [467],

• IEEE, WSCC 9-bus 3-generator system (multi machine) [71], [538], [291], [273], [648].

• 12-bus multi-machine with wind turbine generator [539],

• 4 machine 15 bus test system [202]

• Roy Billinton Test System(RBTS) bus-2 [252], [546], [544], [247], [227] RBTS, a 6-bus test system with 2 generator, and 5 loads[203]

• An RBTS 60 bus radial grid, 22 loads with consumption of 12.602 MW and 6.436 MVar, 24 transformers (2 transformers 33 kV, 22 transformers 11 kV) [126]

• ETAP library: 1200 MVAsc., 34.5 13.8, 4.16 kV (from ETAP library) [176]

• ANSI: The ANSI Model system [238]

• IEC: The benchmark microgrid (25 kV), four DGs (0.575 kV) with different technology types [347], A microgrid [477], [222], The IEC system [351]

• CIGRE: A distribution network, 14 buses, 11 feeders, 2x5 MW PV [571]

• International atomic energy agency (IAEA): Advanced power reactor 1400 MWe (APR 1400) medium voltage network section, 13.8 kV, 2000 A, 50 kA [385]

C. Some sample and typical grids

The details of used case studies in this category are as following: long transmission line 400kV, 380 km [269], a wind park, include 6x1.5 MW DFIG, connected to MV collector by a 0.575/25 kV transformer, then to the 120 kV grid by a 25/120 kV, 10 MVA transformer [645], [390], the electric ship propulsion system, 2x11MW, 2x6 MW generators, 4x12MW propulsion motors, include 2 redundant, 2x2.2 MW cargo pumps, and 1.5MVA service power loads [487], 90 units of FLs, with total load 42.16 kW, and 90 units of CFLs with total load 39.45 kW [77], a network consists of 10 generating stations, 33 substations at different voltage levels, 100 buses, 182 branches, and installed capacity 3,223.5 MVA [79], the oil company, fed by a 150-MVA power plant in area 1, an overhead transmission line (115 kV, 35-kM) transmits 20 MW to area 2 [121], An offshore grid with subsea cables on four platforms with mainly VFD loads (98% of the total load) [80], An isolated island, includes a diesel generator (1.87 MW, 0.85 Pf, with engine/governor and exciter/AVR controllers block models), six induction motors (225 to 400 HP) with mechanical torque presented in "A2" [82], A homogeneous electrical grid, include external power network and step-down transformer (equivalent resistance 0.012+j0.535 Ω), a 10.5 kV bus, cable lines (0.02+j0.008 Ω) to motors, and 10 induction drives, 4 MW [371], An actual large unified network, include 10 generating plants, 33 substations, 100 buses, 182 branches, installed capacity of 3,223.5 MVA [87], Three ESP wells of 38, 40, and 57 HP in an electric panel connected to a bus supplying large water injection pumps of 1500, and 1750 HP [90], A main substation, 34.5 kV, with total load 12.7MW [93], A main substation, 34.5 kV, with total load 12.7MW, in different cases of single DG (0.9 MW), two DGs (0.6, and 0.9 MW), three DGs (0.4, 0.6, and 0.9 MW) [201], An 9 bus, 220/132/33kV 220/132kV 200MVA and 100MVA, and 220/33kV 25MVA power transformers, an 220 kV incoming and six outgoing feeders (5x132kV, and 1x33kV) [95], The distribution system, fed from 34.5 kV, 1500 MVA SC utility supply, with a cluster of different linear and nonlinear loads including DC, and induction motors [279], A practical distribution system, consists of three voltage levels of 132, 33, and 11 kV, and different outgoing feeders [508], An urban substation (115/23 kV, 50 MVA), include an 477 MCM ACSR overhead line, an 750 MCM Al underground cable and an 3/0 AWG Al single-phase, the DG size is 25 kVA [239], A practical power system of 132 kV Grid, the sub-station in three voltage levels of 132,66, and 11 kV [257], an oil-field MCC (4.16-kV), consists of 2 water-injection-pump motors: 1750 and 1500 hp [374], The distribution network, larger interconnected 2x132 kV HV, 6000 MVAsc; Two HV /MV substations, include a 132/20 kV 40 MV transformer and a 20 kV MV bus bar; a feeder divided in 3 line sections of 3 km [131], A 21-buses power system connected grid, 2 generators, 10 WECC type, one wind generators, 4 PV arrays, 10 two-winding, and 2 three-winding transformers, 30 CTs, 20 PTs, 12 cables, 2 capacitors, 43 HVCB, 2 composite motors, 4 inverters, 32 different kinds of meters (amp-meter, multi-meter, and voltmeter), synchronous motors in 8 different sizes and 6 loads [134], The ITER power integrates the coil power, power grid and current drive and heating power systems, fed by the 400 kV French transmission grid, capable to supply 120MW power for auxiliary loads and 500MW pulsed power for plasma control and operation [436], A 400V industrial distribution power system, a 132kV loop network [492], A 33/11 KV distribution substation [381], A system of two buses and a transmission line of 100 miles [458], A steam plant include 35MW turbo generator, 15, 45 and 100 MVA transformers, shunt reactors, a transmission line, cables and the motor rating of 750 kW [389], A substation, 2x30MVA transformers, 161/11.95 or 23.9 kV [628], A power system supplied through a 132/11kV, 31.5/40 MVA power transformer, feeding 6 feeders include residential, commercial and industrial loads [281], The electrical system of a large oil storage terminal (OST), 2x66 kV incomings, 2x66/6.9 kV transformers, some outgoings, and two MCC switchgears (0.415 kV) [372], A 33kV, 100MVA grid, 20 bus distribution, 3 feeders at 33kV, 17 sectionalizing branch, 3 open points, and 8 lump loads [136], Drilling rigs, 8x5.2 MW generators [307], A 11kV, 16 kW power system, with a 9 kW wind tower and a 7 kW PV [613], the electrical grid of a large Oil storage terminal (OST), connected to public power company (PPC) at 2x66 kV, including different loads of Linear loads like lighting, heating, big motors, VFD, and soft starters [370], The 2x600MW emergency power air cooling unit [106], A paper pulp mill industry with 25 load points, including 2x120MW generators [343], The 132kV grid system (consists of 35 buses) of Bahamas island, include 16 isolated grids, with total population of 300,000 [139], A 66 kV incomer relay of a sample substation [493], A 110/11kV substation, 3 generating stations, 12 generators, 7 substations with step down transformers [516], A chemical industrial plant, supplied from a 69 kV system from two different substations. [494], A 220/132 kV substation [443], A small power system, including 1 incoming, and 4 outgoing feeders [296], A 2×30 MW thermal generation system [625], A typical power grid, 34 buses, 249 circuit breakers, and 186 cables, 3 generating units (20MW, 11kV) [344], An 42-node distribution grid, the lines length 26 km;, 7 industrial users, 5974 users, 2 power plant electricity loads, 5938 businesses or agricultural users [240], A part of radial 66 kV, 1218.5 MVAsc grid [469], A 220 kV power grid, with a peak demand of 50 MW, and a CHP with 35 MW [404], A typical power system, includes 46 buses, in 220kV, 110kV, 33kV, 11kV, and 415V; with the load of 23.336MW and 23.082MVAr [470], A 42 MW wind farm, including 20x2.1 MW turbines [558], A shipboard system operates as a double bus configuration, equipped with a three-phase, three-wire electrical power system, 690 V, 60 Hz, supplied by four diesel generators [283], An industrial plant, include the captive generation facility, 2 independent power supply lines, 11 KV/415 V, supplied by 12 MW, and 13 MW generators, national grid 132 kV, 7201 MVA [112], A Microgrid (include PV, wind generators, storage batteries and nonlinear/linear loads): 10kV bus connected to the utility grid with cable, 0.7kV, and 0.4kV AC buses connect to the 10kV AC bus with converter and transformer, respectively [171], A private grid, 54 MW generations, with 0.415/3.3/11 kV distribution levels and an 66 MW expansion [442], A real-time campus microgrid network, 2×33kV inputs, 2*17.5 MVA transformers, 11 kV switchgears and DGs [354], An extra high tension (EHT), 132 kV network [336], A 6.9 kV, 24.6 MW bus diesel power plant (DPP), with four diesel generators with 6,150 kW each [325], A combined cycle power plant [440], 20*2.1 MW WTG's (4 pole, 0.69 kV, 1500 rpm), the total capacity of 42 MW, connected to 132 kV bus through 2x56 MVA 0.690/33/132 kV transformers [560], A combined cycle power plant, 1240 MW, include 2x428 MW gas turbines and a 424 MW steam turbine, , 20/500 kV transformers [448], 11 kV Test feeder with and without the injection of a 2 MW DG to reduce the losses [308], Two induction furnaces of 3500 kW, 1000 Hz, and 350 kW, 700 Hz, 433 V [405], An 300 MVAsc feeder, connected to 20 kV bus, by a 20/0.4 kV, 250 kVA transformers [147], An 1000 MVA power grid, include a UFCL, a 50 MVA transformer, a transmission system, four overcurrent relays, two 1.5 MW DGs [368], 11/0.4 kV substation [438], A 66/11 kV substation, includes 1x10, 2x8 MVA transformers [309], An industrial load, with fixed load of 910 kW [609], A 23kV utility, 498 MVAsc. [192], A petroleum refinery plant, fed by 2x20kV incomings and the 12.5 MVA transformers with 6.3kV output voltage [437], A 20kV, 210 MVAsc, 2500 kVA, 20/0.38 kV [511], Combined cycle power plant, includes 2x36 MW steam turbine, and 2x34.5MW gas turbine generators, 33 kV,6.6 kV, and 415V [518], an 1.4 MW induction motor fed from two 11 kV incomings, 36, and 27 MW [149], An 20 kV radial, feeder [568], A 11 kV underground distribution network [167], The 0.415 kV, 315 and 16.2 kVA independent generators, with the area of 1800 m2 [140], Different load centers[441], A radial distribution feeder include DGs, 132/20 kV, 30MVA and 9% impedance transformer [208], 30 kV DN includes 220/30 kV substation, 63 MVA, 1.65 MW wind DG [209], A power system 11/0.433 kV, 630 kVA, 220 kVAR [382], 132 kV substation [406], Two feeders connected to a 63/20 kV substation, the loads are fed by 2x20/0.4 kV transformers, 4x10 MVA DGs [634], A system supplies 7.7 MW: 5.2 MW from the grid, and 2.5 MW from one generator, second generator is in maintenance, third one is standby, all 3 generators have same ratings (18% steady state reactance, 7.8 MW, connected to 6.6 kV), 2x25 MVA, 66/6.6 kV, Z=15.63%, transformers motor loads of 5.4 MVA and 4.5 MVA, 2x4 MVAr capacitors [496], The condensate pump motors of

APR1400 nuclear power plants, 3,432 kW, 13.2 kV [184], A substation, 16 MVA, 69/13.8 kV [464], A network: 315 kVA, 11/0.433 kV, 200 kW PV cell [287], A 132/33/11 kV substation, includes 25 MVA, 132/33 kV; 25MVA, 132/11 kV; 50 MVA, 132/33 kV; 25MVA, 132/11 kV transformers [340], 23MW gas cooling district plant, includes 66 buses, 2x10MVA transformers, 8x2.5MVA transformers, an 11.5MW generator, and 2x4.5MW generators [388], A 52.3 kW PV (three arrays, 2x11.6 kW, 1x23.1 kW) based micro-grid [212], A sample 11 kV power grid [612], A sample 220 kV, 850 MVAsc power grid, 400 MVA, 220/11 kV transformer [249], 66/11/0.415 kV, 3x15 MVA distribution transformers [413], An MG, 10-bus connected distribution system with DG, micro generator, PV cell [474], The 13-node power grid, includes, 11 generators (5 generating units), 27 power transformers [453], An 11 kV distribution industrial network [338], A hybrid power plant, 80 MW (12 parallel generators) coupled with a small solar plant [533], Condensate pump in nuclear power plant, the main grid: 1521 MW, 24 kV [549], A 230 kV HV substation, 200x200 ft2 [152], 65 MVAsc., 0.45 kV, 2x65 kW micro turbine, PV array, and motor loads [367], A 60/22 kV station, 2x10 MVA, 60/22 kV transformers [170], An experimental reactor developed (RDE) fuel handling system, (network data: 1000 kVA, 0.38 kV) [329], 11 kV, two transformers of 300, and 150 kVA, 5 buses, 30.415 kV feeder [330], Large induction motor pump set, 4x1 MW, a sea water desalination plant, operating through a microgrid [520], 2 sample 154 kV power systems [306], A real 132/32 kV radial network, includes two 3 MW CHP [217], A typical 500 MWe NPP, two 8000 MVAsc with the main grid, 220 kV, 70/35/35 MVA, 220/6.9/6.9 transformer [180], 130 VDC with 1.9 kA to 27.5 kA fault currents, and 12.7 mm (0.5 in) to 63.5 mm (2.5 in)bus gap distances [189], Metro railway station, 33 kV, 3x2 MVA, 33/0.435 kV transformers [639], 5x2.1 MW, 069 kV wind turbines, 3 MVA, 0.69/33 kV transformer [365], The microgrid, includes wind farm (250 kW), PV (73 kW and 62 kW), hydroelectric (150 kW), connected to 6 kV main grid, installed capacity of 34 kW (load 1), 170 kW (load 2), 85 kW (load 4) and 75 kW (motor) [358], A sample power system, includes 125, and 62.5 MVA, 11 kV generators, and three loads of 101.98, 50.99, 101.98 MVA, 11 kV [521], A sample power is system supplied by two independent sources: 345 kV, and 154 kV, each with a peak of 40, and 8149.58 MVAsc, 2x 345 kV/22 kV main transformers, 612 MVA generator, 53.5/26.65/26.65 (FA) MVA auxiliary transformers, and a 40/20/20 MVA transformer [186], A connected PV plant, with battery [597], A multi-wind farms system, 35/110 kV [557], A system includes, 3x4224 kW, and 1x1500 kW generator [412], A microgrid, 80 MVAsc., 11 kV, 1 MVA transformer [478], Balanced radial distribution grid, considering PV [394], A sample microgrid includes Li-Ion battery, PV, converter, and load [359], Multi-voltage level microgrid, includes wind, solar, battery in 11, and 0.4 kV [360], 1000 MVAsc., 2500 kVA, 11/0.4 kV distribution substation [316], A community microgrid, 39.54 MVAsc., 0.415 kV, wind, PV, generator [361], A sample radial distribution system, 1200 MVAsc., 132/15 kV, 20 MVA, 20/16/8 MVA, transformers, radial feeders, with smart reclosers [550], Comparing the ohmic losses in three separate voltages of 33, 132, and 330kV [397], Auxiliary network of traction substations, 2x10 MVA main transformers, 2x1.6 MVA, 20/0.4 kV transformers [631], A 132/33 kV substation with maximum grid current of 31.7 kA [181], An operational LV grid: 110, 250, 320 VDC and 220/380 VAC, 1000 MVAsc, 500 kVA, 33/0.415 kV, 16 feeders [411], A part of 22 kV distribution grid fed by a 110 kV grid through a 110/22 kV, 40 MVA, power transformer, includes 1x10 MVA 11/22 kV, 3x1 MVA, 22/0.4 kV, 2x2.5 MVA, 22/0.4 kV transformers [482], An 10 kV line, includes 20 transformers [553], A ship electrical grid system with S-CO2 Brayton cycle generation system integrated, a 9400TEU container, 9 refrigerated containers (940 kW), 6.6/0.45kV, and 0.45/0.23kV transformers [525], 460 MWe NPP, 2x30 MVA, 220/6.6 kV transformers [345], The 20 kV network, includes two main radially feeders, 22 busbars, three DG units, 10, 2x5 MW, 40% penetration of DGs [221], 460 MWe NPP, 2x30 MVA, 220/6.6 kV transformers [466], Two feeder ring distribution system, 9 buses, 7 transformers [399], An 9-bus MG, one generator, eight branches, and 3 PV arrays [570], HPR-1000 nuclear power plant connected to the national 500kV network [522], 2x36 MW, 2x34.5 MW turbine generators with different loads in 33, 6.6, and 0.415 kV [450], An PV integrated rural distribution network, 2x7.5 MVA, 33/11 kV, and five 11/0.433 kV transformers [567], Global-energy network over the world [523], A 200-MW PV plant connected to a 132 kV switching substation [596], A furnace oil-based power station [447], The Semiens 7SJ602 model (overcurrent and earth fault relay) [649], A nuclear power plant [468], An actual 10 feeder radial system [484], A DFIG based wind farm [485], The 11 kV feeder, 22 buses [195], the 33 kV feeders with 12-pulse rectifiers [292], 2x20 MVA, 11/6.6 kV substation, 80x70 m2 [255], 460 MWe, 21 kV, NPP [489], 11 kV distribution network [444], 500 kV busbar includes different switches [490], Sample 11kV feeder to supply a 0.415kV 250 HP motor [81], An 440 V, 3 HP, 50 Hz, 4 poles, 4.5 A, using direct on line (DOL), and auto-transformer starters [89], Three different cases, including the earth system network with the same intervals, optimum conductors land (a single variable optimization), a comprehensive multivariate optimization (the number of conductors, and earth rods network) [92], A 75x75 m2 substation [118], The 80x41, 65x65 m2 area substations [119], The 100x80, 80x41 m2 area substations [120], A 230kV, single circuit, single bundled, and un-transposed transmission line with two PMU module installed at its both ends [391], A 2000 kW motor [107], Some substations with different dimensions, and specifications [416], A simple power network, including 2 DGs [346], A residential house [262], A simple 20 kV power grid, includes a SVC device and two PV systems connected to the network by an 0.4/20 kV, 250 kVA transformer [143], A residential house, include different appliances [261], 6-, 12-, and 18-pulse harmonics analysis with VFD [297], Some simple power grids [541], The input required for SC calculation, parameters of all electrical equipment (transformer, generator, bus bar, etc.) and their sizing based on the SC calculation [626], Different wind turbine modeling [559], A 50hp, 480V, 3 phase induction motor [369], A three phase induction furnace [301], A synchronous machine connected to infinite bus, 18 MW, 21 kV; through 20 MVA, 21/132 kV [424], An 16 MW industry load [473], A sample electric vehicle charging [598], Validation the implemented models for generators [174], A microgrid [465], [256], A sample nuclear reactor case study [153], A typical home at 48 V, 220 V, and 380 voltages [268], A sample substation, 300x300 ft [182], A sample 6 bus, 220 kV network [479], An asynchronous motor, in the grid with 10 MVAsc, 6.3/0.4 kV, 0.75 MVA transformer, and 3x22, 1x30, 3x75, 1x100, 1x200 kW motors (all 0.4 kV) [419], 30 kW solar project [580], An unbalanced radial distribution sub-feeder [395], Different topologies of power system[595], A residential house, building area of 54 m2, with total energy consumption of 2384 Wh/day [162], A solar power model based on grid-tie [594], 7.5, and 25 kW induction motors [190], A sample 120/11.5 kV [606]. Other typical grids in [555], [193], [551], [552], [235], [610], [386], [576], [323], [254].

6. CONCLUSION

This work surveyed the applications of ETAP software in power systems. There is a long list of the applications of this powerful software in modeling, calculating, monitoring of power system in two modes of offline, and on-line. This research is the first attempt to introduce different research conducted using the ETAP software. For this purpose, initially, the review works which have mentioned this software, were addressed, and some important issues were addressed. Then an overview of ETAP software was demonstrated. Furthermore, some general investigations were addressed in terms of number of research, publication year, and publishers. The survey was reported different software versions, different categories studied of power systems and various case studies in terms of practical cases in different countries, standard grids, mainly IEEE systems, and some sample and typical grids. What is remained open is focusing on some dynamic analysis of power systems such as unit commitment, and modeling the new facilities of modern integrated and energy-hub systems.

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