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Important steps and policies toward GECOL's vision and objectives for a secure and reliable Libyan power system

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SUMMARY

Libyan sectors including the power industry have been affected by the political and military conflicts in Libya since 2011. GECOL's assets including generation, transmission and distribution networks, are severely damaged either by military conflicts or delayed maintenance and overhaul of GECOL assets, which cause frequent partial blackouts and power cuts to the final consumers. GECOL has started, in addition to the urgently undertaken actions to recover generating units and maintain damaged transmission system, a series of activities aimed at achieving its medium and long terms' policies and objectives, including efficient deployment of the huge potentials of Renewable Energy Resources (RER). This paper presents the main activities undertaken by GECOL with the support of Eni North Africa and CESI to achieve this goal, in particular:

<u>System modelling</u>: the prerequisite to perform detailed dynamic network studies is to have an accurate model of the network allowing to perform time-domain simulations. A significant activity of data collection from different sources and modelling has been performed to update the NEPLAN software model of the Libyan power system.

<u>Regulatory aspects</u>: a significant contribution in the process of unbundling the power sector is made by the development of a National Grid Code (NGC) and the review of internal practices. In this perspective, GECOL has undertaken a set of actions to develop a NGC, which has been approved and published by GECOL in 2021.

<u>RERs integration</u>: Libya has a huge potential for renewable energy, especially solar and wind. The proper implementation of this kind of generation would allow to mitigate the current deficits of the generation fleet and at the same time to increase the generation capacity of the Country in a sustainable way. A study for the integration of a large PV plant and the analysis of its impact on the network has been performed.

KEYWORDS

Power System Modelling, Network dynamic behavior, Fault Induced Delayed Voltage Recovery, RERs integration, Grid Codes

1 BACKGROUND AND INTRODUCTION

General Electricity Company of Libya (GECOL) is a state-owned company that has been running the power industry in the Country including generation, transmission and distribution since its establishment in 1984.
Libya is almost 100% electrified and it has one of the most robust power systems in Africa. Libyan national grid is divided into four operating areas with a total of 10 GW of generation installed capacity, with 15 power Plants containing 85 generating units of various sizes, technologies and ages. The Libyan power transmission network is distributed across the Country with a total length of about 16,000 km, with voltage levels of 400 kV, 220 kV and 132 kV. This transmission system is considered as a backbone to transfers the power to fed domestic, commercial agriculture and industrial Libyan power load demand of a total of about 8 GW [1].

The power industry and in particular GECOL's assets have been seriously affected by both the political and military conflicts in the Country since 2011 and the delayed maintenance. Such combination of factors is the cause of the frequent partial blackouts and power cuts to the final consumers.
To re-establish the operability of its assets, GECOL, in addition to the urgent actions undertaken to recover generating units and maintain damaged transmission system, has started a series of activities aimed at achieving its medium and long terms' policies and objectives to ensure an effective access to energy to the Libyan communities.
In this contest, Eni North Africa[1], the main international producer of gas for the Libyan domestic market, in line with the sustainable development goals (SDGs) which are part of Eni objectives to support the host countries, decided to promote the initiatives launched by GECOL and involved also CESI, which is a world-leading technical consulting and engineering company in the field of technology and innovation for the electric power sector.
Accordingly, since 2019 GECOL has started a series of studies namely: (1) system modelling, (2) regulatory aspects, (3) renewable energy resources (RERs) integration.

<u>System modelling</u>

Transmission and Distribution System Operators (TSOs and DSOs) consider power system modelling as a crucial part of network planning, management and operation. In principle, all the investments in power networks are approved based on the results of analyses performed using static and dynamic system modelling.
Network operators in GECOL are using network real-time EMS applications as well as offline power system tools to carry out different power system analysis studies, where wide ranges of commercial power system tools are used based on the required study. The accuracy of the results is in direct correlation with the quality and accuracy of both data entree and the system modelling. Therefore, model validation and verification is very important and should be carried out periodically as the power system changes [2]. Accordingly, GECOL has attempted within the frame of such initiatives to build-up and validate a static and dynamic model of the Libyan network, integrating in one modelling base software selected NEPLAN [3], the available static model (already available in NEPLAN) as well as the dynamic model built in the past in SICRE (patent software by Terna, developed by CESI), ensuring its validity in order to simulate the behaviour of

[1] The Libyan affiliate of the Italian based International Energy Company, Eni

the Libyan system after the recent changes in the infrastructure and newly added assets to the system.

Regulatory Aspects

The Grid Code is a set of documented rules which are established to govern the operation, maintenance and development of the transmission system, and it specifies the procedures for governing the actions of all transmission system users.
Grid codes are mainly concerned with transmission system voltage and frequency variations, fault events, reactive power capabilities, safety, and security.
The grid code compliance ensures that all users are treated transparently and equitably [3] ensuring a competitive market in the local power system growth in line with the upmost updated international standards and power sector best practices.
Although the Libyan national grid is planned and operated in accordance with the standards and set operation rules, GECOL is willing within the initiatives supported by Eni North Africa to develop a National Grid Code taking the chance to review the internal operative practices.
The target of such initiative is firstly to properly regulate the interactions between the power sector stakeholders on technical matters and secondly to adapt practices of the system operator to the new sector arrangement. In this perspective, GECOL has undertaken the following actions:

1. Development of a Libyan Grid Code on the basis of the international best practices on the matters of General Conditions, Connection Code, Transmission Planning Code, Operation Code, Scheduling and Dispatch Code, Data and Information Exchange Code, Metering Code;
2. Development of Roadmaps for the revision of GECOL internal procedures for Planning and Operation.

Renewable Energy Resources (RERs)

In 2013, the Libyan Government launched the *Renewable Energy Strategic 2013-2025 Plan*, which aims to achieve 7% renewable energy contribution to the electric energy mix by 2020 and 10% by 2025. This threshold is planned to be reached thanks to power coming from wind, solar photovoltaic, solar heat and concentrated solar power.

Yet, this promising vision is being jeopardized by the political conflicts and the lack of a dedicated renewable energy fund.

GECOL has set a strategy to “go green” and to be prepared to accommodate a huge penetration of renewable energy. The first step in this strategy is to define suitable sites across the Country which are technically and economically feasible to install large scale photovoltaic systems. Accordingly, supported by Eni North Africa, GECOL target to define realistic approaches and methodology to assess the proposed sites in terms of its readiness to accommodate securely the power generated from the solar power plants and to advise for any additional requirements that allows the using the existing GECOL infrastructures while ensuring system security and reliability.

2 SYSTEM MODELING

GECOL is currently using different tools to perform static and dynamic analyses in the framework of planning and operation studies.

In order to set a unique software basis for the modelling of its High Voltage Network, GECOL worked with CESI to develop on NEPLAN software platform [1] the static and the dynamic network model and, in order to validate the software release with the real network performances, performed its tuning using the most recent information available and validating the model against the comparison of the real network behavior during past disturbances.

Generators modelling

Starting from the available documents and information, different generators models and their controls have been selected from the NEPLAN standard library and implemented, as summarized in **Table 2**.

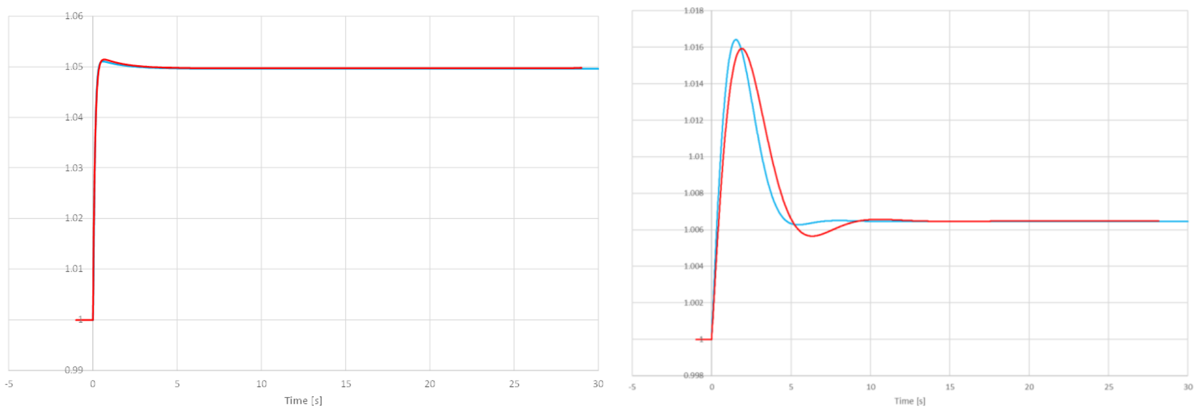
Table 1 Library models adopted for the generator's modelling

Generators	Turbine Governors	Automatic Voltage Regulators	Power System Stabilizers	Over-Excitation Limiters	Under-Excitation Limiters
NEPLAN Subtransient Model	IEESGO	EXPIC1	IEE2ST	MAXEX2	MNLEX3
	IEEEG1	SEXS	PSS2A		
	GAST	TYPE WK	PSS2B		
	Constant torque	ST1A			

The validation of the implemented models has been done by simulating standard tests on the machines and comparing the dynamic response against recordings coming from trusted data sources. More in detail, the following tests have been performed:

- Voltage Reference Step: the generators were at no-load condition (and were regulating the voltage at the controlled node. An event was set at t = 1 s to modify the reference voltage by applying either a positive or negative step of having 5% amplitude
- Load step: the generators have been isolated the rest of the system on a busbar feeding a load. The initial power output has been set to 80% of the active rated power. At t = 1 s a simulation event was set to increase / decrease the load by creating a consequent variation in the generated power

The validation tests allowed to fine-tune the models to have a good match with the available reference recordings (Figure 1).



Field voltage following a voltage reference step *Mechanichal power following a load decrease*

Figure 1: Comparison between NEPLAN model response (red color) and reference recordings (blue color) for standard tests on Automatic Voltage Regulators and Governors

Load model

In recent times, some disturbances which affected the Libyan system have been triggered by an initial fault after which the loads affected by the voltage dip have experienced a slow voltage recovery behavior. Low voltage conditions lasting for seconds negatively affect the dynamics of the system already stressed by the initial fault. For this reason, the proper representation of the load behavior is an important aspect to be considered in the model development.
This phenomenon, known as Fault Induced Delayed Voltage Recovery (FIDVR), refers to unexpected delay in the recovery of voltage to its nominal value following the normal clearing of a fault.
The need to develop dynamic load models adequate for FIDVR studies, and appropriately customized for local use by grid planners, was addressed in [5].
The most known model capable to represent this phenomenon in dynamic simulations is the WECC Composite Dynamic Load Model (CMPLDW), represented in Figure 2.

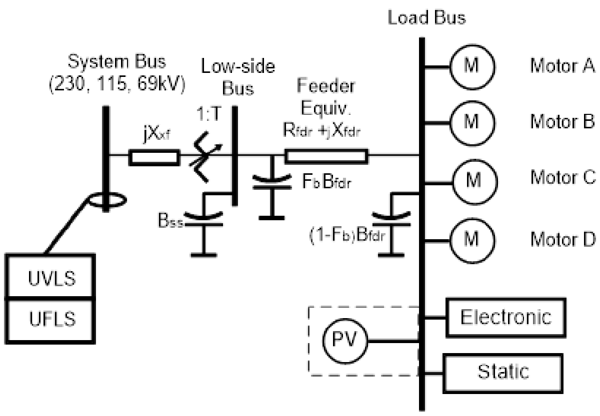


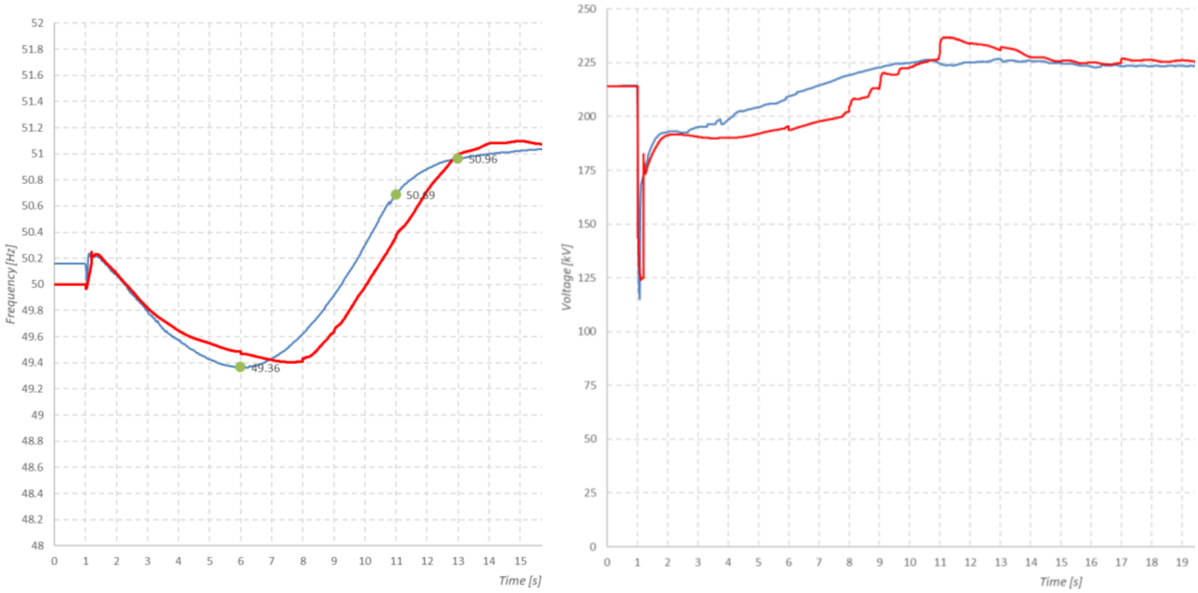
Figure 2: Comparison WECC Dynamic Composite Load Model (CMPLDW)

The WECC Composite Dynamic Load Model was not available in the NEPLAN Library. Due to this reason, a model has been developed in Symdef language of NEPLAN, on the basis of the literature available in the industry [6][7][8]. This has been developed particularly to reproduce the behavior of single-phase A/C motors, which are among the main causes of FIDVR.

Validation against real disturbance recordings

The developed NEPLAN mode has been validated and fine-tuned by simulating the real sequence of events related to real disturbances which affected the Libyan network in recent times.
One of the considered disturbances, here presented, has been triggered by a three-phase short circuit on the high voltage side of a transformer which evolved in a sequence of cascading events who lead to a significant loss of generation in the network. The reconstruction of the dynamic behavior of the system focused on the first 15 s, time range, where a quite accurate sequence of events was available.

In Figure 3, the comparison between the recordings of frequency and voltage in a bus nearby the faulty substation is reported.



(a) (b)

Figure 3: Frequency (a) and voltage (b) trends around the faulty substation – Real measurements (blue) and simulated (red)

The frequency trend has an offset of about 0.2 Hz due to the fact that at the time of the disturbance the frequency was slightly higher than the nominal value, while in the simulations in initial conditions it can only be equal to the nominal. From the voltage trends it can be observed the Fault Induced Voltage Delayed Recovery (FIDVR) phenomenon which delays the recovery of the voltage of about 10 s after the fault clearance. The developed load model is fully capable to represent the effect of the delayed voltage recovery and this is very important because due to the nature of the real loads this phenomenon can be observed quite often during faults.

3 REGULATORY ASPECTS

In order to provide a significant contribution in the process of standardization and unbundling the power sector, GECOL run through CESI all the necessary steps to develop a National Grid Code [9] [10] and to review the internal operative procedures.

- The electricity Grid Code of a TSO or a Country sets out the operating procedures and principles governing the relationship between the TSO and all Users of the transmission system, be they Generators, Consumers, DSOs, or any other entities which are connected to and make use of the transmission system. The Grid Code usually specifies provisions for both planning and operational purposes and covers both normal and exceptional circumstances [11].
- Internal procedures are designed and applied by the TSO for the planning and operation of the transmission system in accordance with its statutory duties (and according to the Grid Code), defined in terms of quality of the power supply and the customer loads [12]. The Grid Code does not report all these procedures as they do not directly involve the Users. These constitute internal documents of the TSO

which shall be designed by the TSO itself to correctly discharge its obligations and duties.

In this perspective, GECOL has undertaken the following actions:

- to review the current draft version of the Libyan Grid Code and contribute to further develop it for the following themes: General Conditions, Connection Code, Planning Code, Operation Code, Scheduling and Dispatch Code, Data and Information Exchange Code, Metering Code.
- to make a qualitative analysis of GECOL internal procedures for Planning and Operation supporting the identification of potential improvements and to propose a roadmap for their implementation.

The approach adopted for the execution of these two actions is given in Table 2.

Table 2 Approach for GECOL Grid Code and Internal Procedure developments

	Phase 1 Gap Analysis	Phase 2 Development
• General Conditions • Connection Code • Planning Code • Operation Code • Scheduling and Dispatch Code • Data & Information Exchange Code • Metering Code	**I. DATA COLLECTION** Primarily available documents are collected: surveys and interviews **II. ANALYSIS OF EXPECTED TARGET** Analysis of international best-practices (ENTSO-e), local guidelines (EAPP, MEDTSO, PAN-ARAB) and GECOL targets. **III. DRAFTING OF CONTENT INDEX** Contents indexes are drafted together with justifications aiming at highlighting the analysis between the available GECOL documents and the reference documents.	Development of full code contents according to the index as per Phase 1: • Review and integration of already available contents • Development of new contents
Internal procedures for: • System planning • System operations		According to the identified content index, a roadmap is developed aiming at defining specific steps, timeline and required effort to achieve the revision and development of GECOL internal procedures documents for system planning and system operations.

Emphasis is given to the development of the Grid Code which has been approved and published by the General Electricity Company in 2021 for the first time in its history.

Furthermore, it is important to highlight that although the GECOL Grid Code finds its full application in an unbundled electricity context, it still represents a valuable document to apply also to the current monopoly structure of GECOL. In this regard, the perspective for the development of the GECOL Grid Code is in the liberalization of the electricity sector. This means that the structure of the Code, its terminology, and the relationships between the Parties are the ones typical of a complete unbundled sector (e.g. “Generator Owners”, “TSO”, “Grid Users”). At the same time, awaiting the liberalization of the electricity sector, the applicability of this Grid Code is still valid also in the current monopoly structure, and it shall be intended as a collection of “internal procedures" for GECOL to be followed and acknowledged in order to operate its power system more efficiency and aligned with the best practice of the power sector.

An overview of the contents which are addressed by the GECOL Grid Code is reported in the following Table 3.

Table 3 Overview of GECOL Grid Code Contents

General Conditions
The General Conditions covers such topics that do not pertain specifically to one or more subsets of codes. It sets out the over-riding principles to be considered in the operation regarding such specific events that are not covered by the relevant Code (e.g. Unforeseen Circumstances, Force Majeure), and it governs the management of the code and the acknowledgment of its contents by its beneficiaries.
Connection Code
The Connection Code includes such connection requirements that specify the minimum technical, design and operational criteria which must be complied with by GECOL at connection sites and by Users connected to or seeking connection with the transmission system. Users are both power-generating modules (including renewables) and large demand facilities.
System Planning Code
The Planning Code describes the objectives, Planning criteria and methods on which the TSO bases its decisions about the developments of the Grid, considering a period of five (5) years. Planning development activities of the Grid requires TSO to obtain Data and Information about Users connected to the Grid and, where applicable, about other Parties.
System Operation Code
The Operations Code contains the provisions and regulations covering all relevant aspects of Power System Operation. The Operation Code governs the day-today control, management and short-term planning functions needed to ensure the satisfactory performance of the Power System.
Scheduling and Dispatch Code
The Scheduling and Dispatch Code sets forth the responsibilities and obligations of the TSO and Users regarding Scheduling and Dispatching of Generating Units. Also, it describes the process for providing information by the Users to the TSO, the TSO's preparing and issuing of Generation Schedules, and issuing of Dispatch Instructions.
Data & Information Exchange Code
Within a national Grid Code, the Data & Information Exchange Code define the sets of data and information to be exchanged between the TSO and the Users to properly carry out system planning and system operations tasks. Accordingly, the objective of the Data & Information Exchange Code is to make formal the procedure for the exchange of Data and Information from the User to the TSO and vice-versa.
Metering Code
The Metering Code is unique to other codes in the sense this is where Technical, Legal and Commercial operational matters coincide. For a vertically integrated power sector undergoing restructuring the changes this infers have widespread implications.

4 RERS INTEGRATION

Starting from the NEPLAN model developed and tuned as discussed in Section 2, GECOL through CESI developed a dedicated study to determine the hosting capacity for connecting a photovoltaic (PV) solar park to the 400 kV grid of the Libyan system and its impact to the grid has been performed. The pilot verification was run in the area of Zliten industrial district (160 km East of Tripoli).
The main tasks of the study are summarized in Table 4.

Table 4 PV plant integration study tasks

Connection of PV plant to the Point Of Interconnection (POI) – ZLITEN industrial area
The photovoltaic plant is inserted in the model in single independent bulks of 50 MVA – cos φ=0.95 (lagging), all connected to a 30 kV common busbar, which is connected to the grid via step-up transformers. The size of the PV power plant under study ranged between 50 MVA and 250 MVA, therefore the plant was represented by 5 bulks of 50MVA. These 50MVA elements can be connected and disconnected according to the analyzed target power scenario.
Model development
Power flow and dynamics models are required to properly represent the all functionalities required in the Grid Code. To this purpose, the WECC PV power plant generic dynamic model has been adopted for the analyses, as this is recognized as one with suitable characteristics for the evaluation of the impact of large PV plants in the GECOL network. The main components of the WECC Generic Model as shown in Figure 4.
Static Security Assessment (SSA)
To determine the maximum rated power of the PV plant, a contingency analysis has been performed to identify any violation of the electrical quantities with respect to the operational limits (mainly voltages and currents) stated in the Grid Code. The analysis has been performed considering different power injections from the PV from 50 MVA up to 250 MVA and allowed to determine the maximum PV power output allowing to operate the grid in accordance with the security criteria.
Dynamic Security Assessment (DSA)
Considering the most critical contingencies identified in the SSA, the same contingencies have been simulated to assess the stability of the system.
Short Circuit Currents Assessment
In the evaluation of the impact of the connection of a new plant to the grid, the modification of the short circuit currents due to new active elements has also to be assessed, to verify if the values of short circuit currents obtained exceeded the withstanding values of the existing elements.
Behavior during abnormal voltage conditions and LVRT capability requirements
According to the GECOL Grid Code [14] and also to current international practice, in case of transient voltage variations due to Faults on the Grid, Generating Units must be capable of remaining connected to the Grid and continue to operate in a stable manner, when the actual course of the phase-to-phase voltages at the Connection Point, during a Fault, is maintained over a Fault-Ride-Through voltage-against-time profile (Figure 5), specific for Inverter-based Generating Units. The same Grid Code, states that the TSO has the right to specify case-by-case that Inverter-based Generating Units be capable of providing Fast Fault Current at the Connection Point in case of balanced (3-phase) and unbalanced (1-phase or 2-phase) faults. This is achieved through a reactive current (Iq) injection by the inverter. Tests of the response to a voltage variation like that depicted in Figure 5 imposed in NEPLAN have been carried out.
Reserve and frequency control
According to the worldwide adopted practices, PV plants above certain ratings must be equipped with the FSM Frequency Sensitive Mode (FSM) functionality. Of more importance, for this kind of plants, is the Limited Frequency Sensitive Mode (LFSM), that is the operating mode which will result in active power output reduction / increase in response to a change in system frequency above / below a certain value. This is normally actuated when the spinning reserve is over. The dynamic behavior of the frequency with and without Power Frequency Control support from the RE generation has been evaluated.

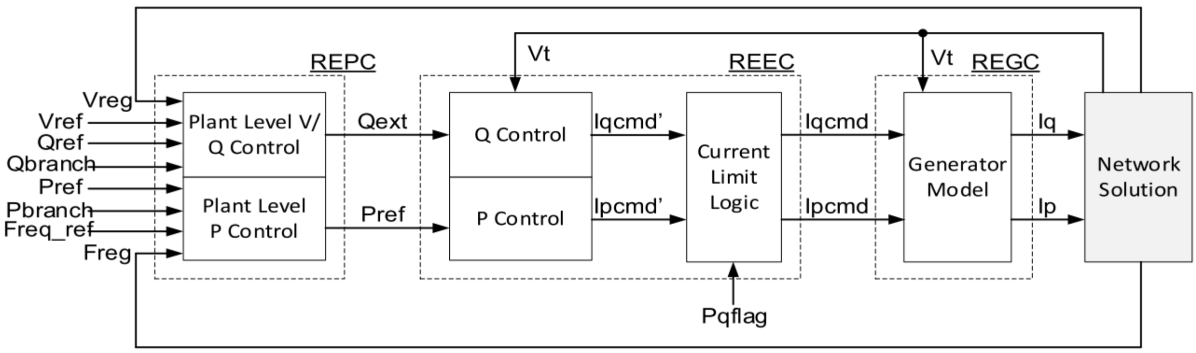
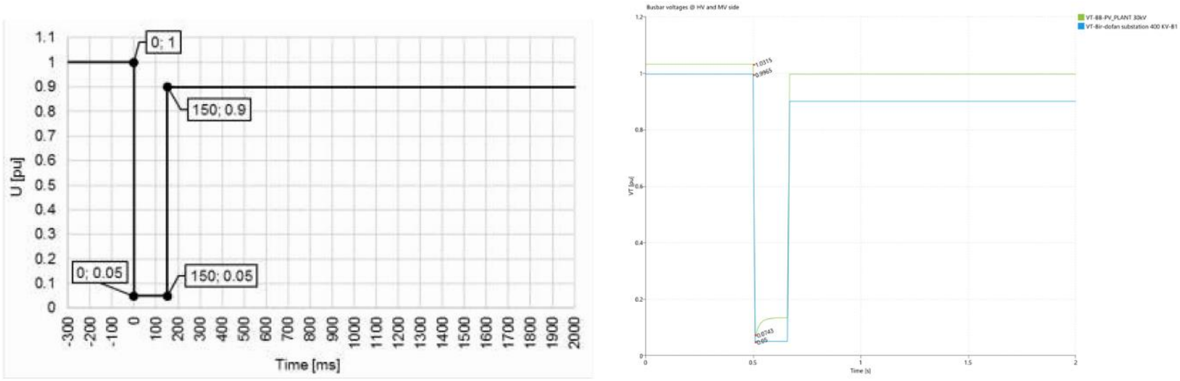


Figure 4: Block Diagrams of Different Modules of the WECC Generic Models (source [13])



(a) (b)

Figure 5: LVRT V-t profile (a) as per GECOL Grid Code [14], and tests results (b)

The results of the study carried out on the GECOL grid to evaluate the impact of the connection of a solar PV plant in Zliten with size up to 250 MVA to the 400kV network in the near future, can be summarized as follows:

- Static Security Assessment showed that considering the near future network reinforcements, the PV plant can be operated at the maximum power output (250 MVA)
- The Dynamic Security Assessment showed that the PV plant does not contribute to worsen the dynamic condition of the system, as it does not lead to system instability
- The sudden loss of the plant when at its maximum power of 250 MVA do not significantly affect the dynamic stability of the grid, as the frequency is regulated by the remaining groups and does not exceed dangerous values

5 CONCLUSIONS

This paper describes the successful achievements of **GECOL** in various initiatives launched since 2019 in order to robust and enhance the Libyan power sector with the base target to ensure an effective access to energy to the Libyan communities.
These activities were actively supported by **Eni North Africa**, the Libyan affiliate of the Italian based international energy company Eni and technically developed by the high qualified competences of **CESI**, worldwide leader in engineering and technology consulting for the electricity sector.

GECOL has currently fulfilled its main target to publish in early 2021, for the first time in its history, the National Grid Code that includes connection code, transmission planning code, operation code, scheduling and dispatch code, data and information exchange code and the metering code.
Moreover, GECOL has successfully endorsed an integrated static and dynamic model of the High Voltage distribution grid which allows to address the recent changes in the network infrastructure and plan properly the inclusion of any new assets to the system. A practical example of the fruitful usage of the new model is the verification of the integration of Renewable Energy Resources into the grid, that has been firstly elaborated by GECOL in the industrial area of Zliten for a solar park up to 250 MVA installed capacity. This initiative runs in the direction of the "go-to-green" strategy that GECOL is willing to lead for the benefit of the Libyan country.

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