Methodological Application to Integrate Renewable Energy Resource into Kuwait's Electrical Grid

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ABSTRACT

Kuwait's power system administrators are challenged for meeting future demands. Kuwait's electric sector capacity has been extremely slow to expand despite rapidly rising consumption rates over the past decade and persistent power shortages during peak demand periods. The country struggles to produce and import sufficient natural gas to meet peak demand, and as a result, depends on more expensive fuel oil. According to the estimates from the Ministry of Electricity and Water (MEW), in 2011, Kuwait had an installed electric generation capacity of 13.5 gigawatts (GW) [1] [2]. Derived by the high cost of fossil fuels, increasing energy demand, and environmental impacts, there is a dire need to increase the penetration of renewable energy (RE) as an integral part of Kuwait's electric network.

Renewable energy, as energy resources, possesses a variable and uncertain nature that significantly complicates the power grid balancing operations at all timescales. As a result, the power grid will experience fundamental changes in its physical structure and behavior that will consequently require enhanced and integrated control, automation, and Information Technology-driven management functions [3]. In this study, we present a methodology to assess the challenges and present a methodical solution for integrating renewable energy into Kuwait's power grid. The integrated grid must be able to respond to distributed system signals and events, and mitigate the fluctuation from renewable energy sources [4].

1. INTRODUCTION

The objective here is to identify the system integration challenges for renewable and distributed generation and propose standardized solutions for mitigating their impact on the network. In order to achieve this, a detailed network analysis was carried out to simulate the impact of the distributed generation sources on the grid and accordingly propose mitigation measures based on industry standard solutions that are cost-effective. A control method to minimize the impact of the distributed electricity generated on the performance, reliability, and stability of the electric grid was investigated [3]; followed by building the network model for the future study and then carrying out the network analysis. The analysis included steady state, short circuit, contingency, reactive compensation, dynamics and transient stability, and primary reserve frequency control analysis. Using the load flow analysis, both deterministic and probabilistic models were relevant, the study assessed system stability under predicted operating conditions and was set to identify any necessary network modifications. The network impact assessment and the subsequent required mitigation measures will include the following analysis: power flow analysis, stability analysis, and voltage and frequency fluctuation analysis as well as fault analysis for the integration of renewable energy (i.e., concentrated solar power plant, large-scale photovoltaic fields, large-scale wind farms, etc.) into Kuwait's electricity grid.

2. METHODOLOGY

The methodology for identifying challenges and proposes standardized solutions to integrate distributed electricity generation into the existing electrical grid are described here. Figure 1 shows a general overview of the applied methodology to identify network bottlenecks that need to be resolved when distributed generation (such as wind and solar) are integrated into the network within a certain period (i.e., short term and long term).

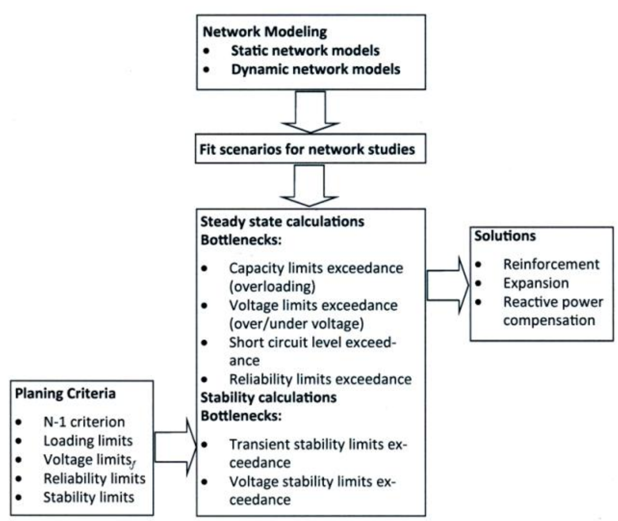

Figure 1: Overview of methodology to integrate distributed generation into the grid.

In fact there are three separate problems concerning an increased penetration of renewable energy: short-term fluctuations, medium-term fluctuations and network congestion [5]. As can be seen, power system calculations are executed to identify network bottlenecks and proposed solutions to relieve these bottlenecks. These calculations are carried out for several generation-load scenarios. To identify the consequences of renewable energy source (RES) integration, these scenarios contain RES scenarios on top of existing generation expansion plans. Proposed solutions and their effectiveness are calculated using the same network calculation methodology, as shown Figure 1. The most effective solutions (reinforcement, expansion, and/or reactive power compensation) will then be selected.

The methodology (framework) as discussed above is capable to address key questions such as:

- What is the impact of new conventional generation options including new renewable energy sources on the existing network?
- What network extensions and/or adaptions are needed to absorb and transmit electricity generated by these new generation options including wind and solar power plants to the consumers?
- What are the consequences of the intermittent nature of solar and wind power and concentration of solar/wind resources for power system operations (characteristic operating regimes) and control?
- Is reactive power generation control is required for solar and wind power plants? If so, in which parts of transmission network?

2.1 Network Model

Renewable energy introduces new dynamics into the power grid at all time scales [6, 7]. To perform network studies, a network model of the current Kuwaiti network is required. A model suitable for performing this study is currently available and is provided by MEW. This network model is adapted for executing both steady state and (dynamic) stability calculations. The supply-demand scenarios [2] are incorporated in the network model, by updating the generator and load data as appropriate. For the dynamic studies, dynamic models of a generator will be required ***(e.g.*** governor, excitation voltage controller, and power system stabilizer).

2.2 Steady State Studies

Load flow studies are carried out to identify capacity and voltage related bottlenecks in the network, while short-circuit studies attempt to identify any fault level issues. The network planning criteria of Kuwait is also considered when defining network bottleneck. This is performed as part of "contingency analysis". The planning criteria should include a description of the application of redundancy criterion (such as N-1), a set of contingency list (most credible contingencies) are considered in such contingency studies, redundancy during maintenance criteria, operating limits of the network devices, and preferred network configurations. Load flow and short-circuit studies are executed to study the effectiveness of solutions of identified network bottlenecks and ratings of related network components. More specifically, load flow analysis is performed to determine the operating limits and performance of the proposed future network extensions (new overhead lines, substations, and/or transformers) and/or proposed reactive power compensation. The load flow analysis is performed with the consideration of all of Kuwait's planning criteria with respect to outages, equipment loading, topology constraints, and voltage profile

In each of the considered scenarios, the capacity study is based on the following four cases:

- Peak load with low wind and solar
- Peak load with strong wind and solar
- Low load with low wind and solar
- Low load with strong wind and solar (critical case for regions with high wind power penetration)

Three-phase short-circuit calculations is executed to determine the maximum short-circuit level for the considered scenarios. Short circuit analysis is performed to study the effectiveness of the solutions of the identified network bottlenecks and ratings of related network components. The impact on the three-phase short circuit level is assessed on the transmission levels and sub-transmission levels. The short circuit current is computed according to the industry standard practices

The results obtained from the load flow and short-circuit studies form the basic for the basic design parameters for new substation and overhead lines. Only parameters related to steady state conditions are considered.

2.2.1 Steady state calculations

The objective of the steady state (load flow and short-circuit) calculations is to develop a network extension and reinforcement plan for the existing network based on the scenarios of demand growth and planned generation, both conventional and RES. For this purpose, the methodology as explained in Section 2.2 is applied, and related aspects are considered. The steady state assessment focusses on the adequacy of the grid thermal loading capacity and voltage -reactive power balance for a given period (short to medium term).

The following activities are carried out:

- Modelling of transmission network of Kuwait (including **400** kV, 275 **kV** and 132 kV network)
- Accommodate scenarios necessary for system studies in the network model: short term and

medium to long term scenarios are converted to input for the generation nodes and load nodes

- Establishing transmission network planning criteria of Kuwait as applied to steady state calculations
- Network development calculations (load flow and short-circuit) for the short and medium term: initial calculations and fine-tuning calculations are carried out.

The following study cases are considered:

- Peak load with low wind and solar conditions
- Peak load with high wind and solar conditions
- Low load with low wind and solar conditions
- Low load with high wind and solar conditions

The steady state calculations utilized internationally acknowledged power system analysis software: DIgSILENT PowerFactory. The short-circuit calculation will be based on IEC **60909**.

2.3 Impact of Distributed Electricity Generation (DEG) on Network Extension / Reinforcement

Load flow studies and short-circuit studies are carried out for current and future situations (short term 5 years and long term 10 years from the current situation). If bottlenecks are detected, solutions are considered to resolve these bottlenecks. This methodology is explained above. To assess the impact of DEG on transmission network **extensions/reinforcements,** these studies are carried without and with DEG plants. The focus on the analysis is set on estimation of the transmission network reinforcements needed in order to secure off-take of electricity produced by the DEG plants.

3.4 Power system stability

The stability calculations are shown in Figure 2. The shaded boxes in grey indicate the type of stability studies that are to be performed in this study: rotor angle stability, frequency stability and voltage stability. Conversely, types of stabilities indicated in the white boxes are not considered in this study and are mentioned here for completeness, namely: small-disturbance rotor angle stability and small-disturbance voltage stability. Small-disturbance analysis (or eigenvalue analysis) is generally for optimization control devices such as PSS which is not the main objective of this study.

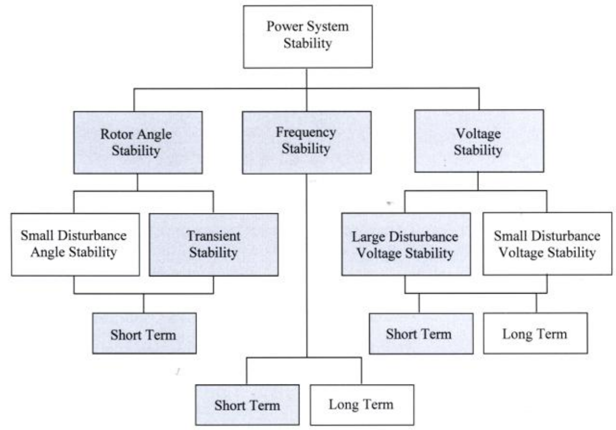

Figure 2: IEEE/CIGRE classification of Power System Stability [8].

3.4.1 Rotor angle stability/transient stability

The transient stability analysis deals with the question: will the power system remain stable right after a worst-case creditable contingency? To carry out this stability study, credible contingency scenarios (e.g. single or multiple outages), and stability requirements (e.g. derived from the Network Code). Single contingencies that can be considered in rotor angle /transient stability analysis are:

- three-phase short-circuit of a line;
- loss of a line;
- loss of a generating plant;
- loss of an interconnector.

Multiple contingency that can be considered are:

- loss of bus sections (of substation);
- circuit breaker failure; and
- tower failure (outage double circuit).

3.4.2 Frequency stability

Frequency stability refers to the ability of a power system to maintain steady frequency following a disturbance in the system resulting in a significant imbalance between generation and load. It depends on the ability of the power system to maintain/restore the balance between system generation and load, with minimum unintentional loss of load. Generally speaking, frequency stability problems are associated with inadequacies in equipment responses, inadequate coordination of control and protection, or insufficient power generation reserve.

To study frequency stability problems, the effect on the frequency of the following contingencies are studies:

- loss of the largest generator;
- disconnection of a large load;
- deviation between wind forecast and the actual wind (forecast error); and
- power fluctuations of the PV plants.

These studies are carried out for the scenarios that include DEGs.

The main outcome of this frequency stability study should be an evaluation (application of formalized metrics) of inter alia:

- Transient frequency drop - assessment of system inertia, initial frequency drop, and primary control response time;
- Steady state frequency deviation - assessment of primary reserve (volume) and activation time of primary reserve;
- Frequency back to nominal Frequency, area exchange according to schedule - assessment of secondary reserve (volume) and activation time of secondary reserve.

The assessment of the calculated frequency response is on the base of the requirements included in the Grid Code of Kuwait (e.g. compliance with quantitative metric "frequency response).

The minimum data set needed to execute the frequency stability study is discussed in Section 3.4.4.

3.4.3 Voltage stability/large-disturbance analysis

Voltage is the parameter in a power system that indicates whether there is a reactive power imbalance in an area of a system. In contrast to frequency, voltage can vary considerably between different substations. Hence, there are local and global voltage stability problems in power systems caused by small or large disturbances.

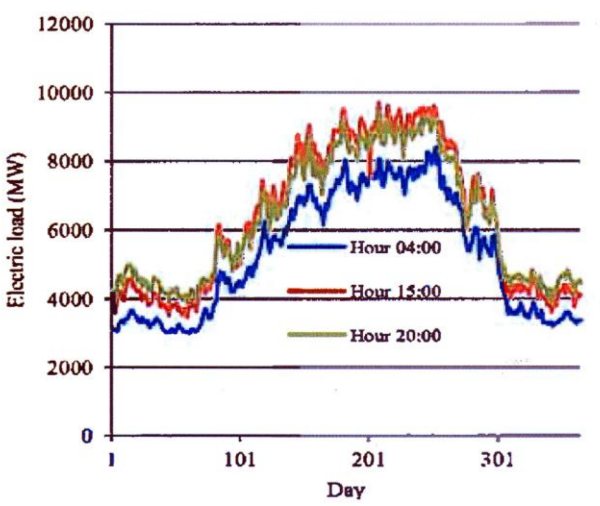

Figure 3: Typical load profile in Kuwait [9].

Voltage stability can be distinguished in short-term and long-term voltage stability (refer to Figure 3). This study only deals with short term voltage stability. Short-term voltage instability results from reactive power deficits or excess of active power transfers in the time frame of hundreds of milliseconds up to a several seconds. The time during which short-term voltage stability develops is linked to the time constants of fast controlling devices, such as Static Var Compensators and controllers of wind generators. In this study, the voltage stability study will address the same contingencies as considered on the rotor angle stability.

3.4.4 Stability calculations

The aim of this study is to verify whether the transmission system is stable. For this purpose, the following stability aspects are considered (as shown in sections 3.4.1, 3.4.2 and 3.4.3)**:** rotor angle stability, frequency stability and voltage stability. The power stability calculations in principle should only be carried out when the short/long term planning details of the transmission networks is established.

The following activities are carried out:

- Modelling of dynamic part of the power system (dynamic models of generation units, prime movers and control devices)
- Establishing transmission planning criteria as applied to dynamic calculations
- Power system dynamic calculations for three situations (existing, 5 years from existing, and 10 years from existing). The following simulations are carried out:
  - Rotor angle stability
  - Frequency stability
  - Voltage stability

  The maximum number of cases to be considered is related to:
  - Peak load with low wind and solar conditions
  - Peak toad with high wind and solar conditions
  - Low load with low wind and solar conditions
  - Low load with high wind and solar conditions

The power system stability calculations are carried out using internationally acknowledged power system analysis software: DIgSILENT PowerFactory.

4. CONCLUSION

Renewable energy sources differ by nature from conventional generators. Their technical capabilities are different and so is their operation, characterized by an almost inexistent marginal cost. Both reasons imply that specific requirements be established.

The first set of requirements regarding renewable energy sources is designed to keep those renewable power plants connected to the grid during normal operation as well as during system transients. They include normal range of operation regarding frequency and voltage, stability limits to withstand and fault ride through capabilities. These requirements can be different depending on the technologies involved.

The second set of requirements concerns the provision of ancillary services by renewable energy sources. Because of their null marginal cost, it is in most cases economically inefficient to ask renewable energy sources to provide frequency regulation. However, reactive power can be provided by almost every renewable energy technology, and with limited to no cost induced. Control strategies should be specified, differentiating large renewable power plants from distributed generation.

The last set of requirements is concerned with limiting the impact of renewable energy sources on power systems operations. They can include ramping capabilities, minimum power, the right to curtail or obligations from power plants operators to declare expected production for the next day.

Keywords: Renewable Energy; Electrical Grid; Power Flow Analysis; Stability Analysis; Voltage and Frequency Analysis; Fault Analysis.

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