Danish Energy Agency

ERAV
Electricity Regulatory Authority of Vietnam

Prefeasibility Study on Inertia for the Vietnamese Power System

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EVNNLDC

ENERGINET
ASSOCIATED ACTIVITIES

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Acronyms

The below table lists acronyms used in this document.

DEA	Danish Energy Agency
ENTSOE	European Network of Transmission Systems Operators for Electricity
EVN	Electricity of Vietnam
ERAV	Electricity Regulatory Authority of Vietnam
FCR	Frequency Containment Reserves
HVDC	High Voltage Direct Current
NLDC	National Load Dispatch Centre (Vietnam)
PMU	Phasor Measurement Unit
PV	Photo Voltaic (Solar Power)
ROCOF	Rate Of Change Of Frequency (sometimes abbr.: RoCoF)
WAMS	Wide Area Monitoring System
WP	Wind Power

1. Introduction

The rapid increase of variable renewable energy in Vietnam such as wind and solar power could become a challenge to the system stability. One parameter determining the system stability is inertia. In this study NLDC and Energinet cooperates on assessing the level of inertia today and in the future. NLDC needs more knowledge about the challenge they might be facing in the years to come, with the increased variable renewable energy but NLDC already have some ideas on the possibilities to handle these challenges.

Particularly NLDC worry about an increase in 5 GW PV over the course of only a few months in 2019, and how it affects the level of inertia in the system. Over the next two decades more than 50 GW of variable renewable energy production capacity is expected to be installed in the Vietnamese grid (Reference 7). The fact that the Vietnamese grid is stretched over a long longitudinal distance, about 1,500 km, amplifies the challenges.

Inertia is however not the only parameter relevant for the dynamic stability. Small signal stability as well as angle stability must also be taken into consideration when assessing dynamic stability of a system.

Especially the long trajectories of transmission lines small signal and angle stability might be the dominant parameters for securing the dynamic system stability. Angular stability monitoring via PMU monitoring at strategic grid system locations can in some settings be more relevant than monitoring the level of inertia.

2. Inertia formulas

The inertia constant H describes the inertia of an individual turbine-generator:

$$H = \frac{1}{2}\frac{J{\omega_n}^2}{S_n} \quad [s]$$

Where

J is the moment of inertia of a generator and turbine [kg·m^2],

ω_n is the rated mechanical angular velocity of the rotor [rad/s],

S_n is the rated apparent power of the generator [VA].

The inertia constant is given in seconds and it can be interpreted as the time that energy stored in rotating parts of a turbine-generator is able to supply a load equal to the rated apparent power of the turbine-generator (Reference 6). In other words, inertia is an attribute of a generation unit.

The total kinetic energy stored in turbine-generators in a synchronous power system $E_{k,sys}$ is the sum of the contributions from each individual turbine-generator, which in turn is the product of inertia constant H (characteristic for groups of types of generators) and the apparent power of that specific turbine-generator, i.e.

$$E_{k,sys} = \sum_{i=1}^{N} S_{ni}H_i \quad [Ws]$$

Evidently being a measure of energy [Ws = J], which is both intuitive and convenient for the use and interpretation of the resulting number.

3. Critical system inertia

It is important to remark that a system also gets contributions to inertia and stored kinetic energy from electrical motors connected to the system. In this report we only look at the contribution from the generator side.

We will use the above to calculate the contribution to stored kinetic energy from all the generating plants in the system. For this we will use inertia constants identical within groups of types of generators. This is a value that we look up, e.g. for all hydro plants we use the same inertia constant H_{hydro} = 2.4 seconds.

The critical level of inertia in the system must be calculated based on the dynamic simulation model of the Vietnamese grid system including the current generation and demand portfolio and cannot be inherited from other grid systems. Yet it is out of scope to perform dynamic simulations in this study.

This report can be considered a simplified approach to assessment of the level of inertia in the Vietnamese system but no important decisions should be based on these results. For a thorough study to base decisions on one would need to include specific inertia constants from each individual power plants and furthermore assess the critical level of the inertia in the system by dynamic simulation.

As a start we compare the critical system inertia in other systems.

Johnson et al. (Reference 1) found theoretically that the Texas grid with a peak demand of 73.0 GW has a minimum inertia demand of 105 GWs. Texas has occasional wind penetration of 40 %, and overall 30 % production from variable renewable energy sources, at the time of the study.

According to two ENTSO-E studies (references 2 and 3) the Nordic countries, which comprise one synchronous area excluding western Denmark, has a peak demand of 73.1 GW and an estimated minimum inertia demand of 100-120 GWs depending on model and anticipated model accuracy. The Nordic countries has 30 % of demand covered by variable renewable energy.

A simple, linear comparison of these numbers suggests that the Vietnamese grid, with a peak demand around 40 GW in 2019 has a minimum inertia demand around 57 GWs. Vietnam has lower variable renewable energy penetration than the examples, but it is growing fast. The variable renewable energy production in Vietnam today corresponds to 4.6% of the consumption on an annual average.

4. Actual inertia levels in different load situations

The decided first approach to evaluate the situation in Vietnam was to calculate the amount of inertia bottom-up; meaning to add all the contributions from the production side.

From actual recent historical operation data, we calculate the inertia at specific points in time. To do this we need a list of the plants running, their type and their apparent power. Finally, we need each plant's inertia constant H. We have decided to use table values, as this will not add significant error considering the generic level of this study. We use the H values for different power plant types illustrated below, taken from Johnson et al. (Reference 1).

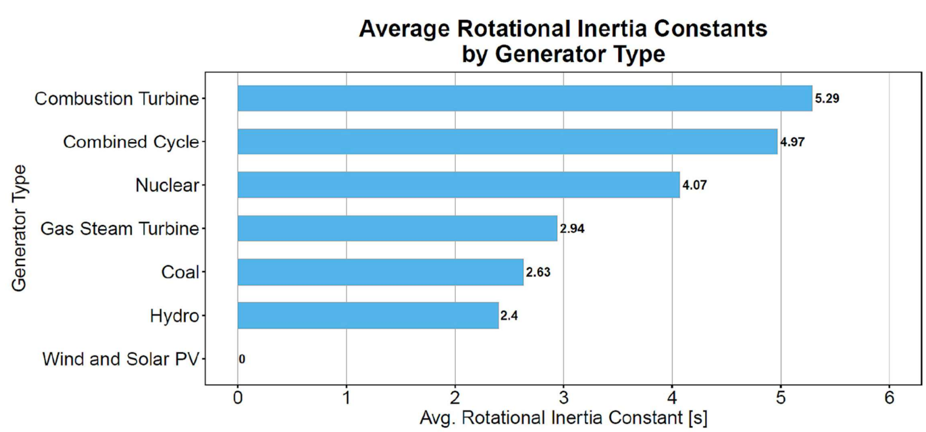

Figure 1. Average Rational Inertia Constants by Generator type

We have operational data from three different operation hours in January the year 2020, i.e. peak hour, off peak hour and a noon hour. The noon hour is chosen because solar production on average is highest in that hour. The inertia in these three situations is shown below.

[GWs]	Noon	Off peak	Peak hour
January 2020	104	105	117

Table 1. Inertia calculated from real operation data in 2020

We can use the same bottom-up method with model data, if the model gives accurate information about the production fleet. This opens the possibility to use development projections to predict future inertia. What we are doing is we perform an adequacy study in a five-year time frame. See for instance the ENTSO-E system adequacy monitoring concept (Reference 5). For estimates on future inertia we use the simulations performed for the Energy Outlook report (Reference 7). In this work the Balmorel model has been used to calculate optimal dispatch patterns to match the load in each hour under certain constraints of the power plant fleet and the grid. Each power plant is represented in the model by a simple input-output relation and production potential depending on plant type. The model can be set to calculate hourly values, and we have taken such sets of values from 2025 to calculate expected inertia in this year. We have chosen the hours 'noon', 'off-peak' and 'peak hour' for comparison with the actual operation data we have from 2020.
To have an impression of the validity and possible bias of the model we have even taken some data from 2020, to compare with the 2025 data. The results are shown below in Table 2.

The Vietnam Energy Outlook report is available online, e.g. on the DEA website:
https://ens.dk/sites/ens.dk/files/Globalcooperation/vietnam_energy_outlook_report_2019.pdf

[GWs]	Noon	Off peak	Peak hour
Balmorel model 2020	89	62	116
Balmorel model 2025	143	107	203

Table 2. Inertia calculated from model data in 2020 and 2025

Current inverter technology for wind and PV can provide synthetic inertia. But it is not always the case so in all the calculations in table 1 and table 2, it is assumed that the inertia contribution from wind and PV is zero. I.e. we look at actual inertia here and not synthetic inertia.
The results show that system inertia is significantly different in the two chosen situations, the modelled system in 2020 and 2025. System inertia strongly depends on the number of generators connected to the grid. The calculation shows an increase in inertia from 2020 to 2025. The primary reason for this is that the consumption and production of electricity in Vietnam increases about 10 % per year. This is off course input to the Balmorel model, and it leads to a larger production fleet and hence a larger inertia contribution.
We assume an approximate linear relation between the production and the critical system inertia level, so the critical 57 GWs calculated for 2020 above corresponds to 92 GWs in 2025, at the current and foreseen development rate.
Further, the comparison between Table 1 and 2 shows that it is right now the noon hour that is most challenged, but it will be the off-peak hour in 2025. This reason is probably that PV is the predominant renewable technology today, but that wind power will be the predominant renewable in the future. We also see that the foreseen development in the production fleet, the input into the Balmorel model, does not significantly worsen the inertia situation. Even when we calculate no inertia contribution from inverters, which is a very conservative assumption.

The system inertia calculated here results from production side only. It does not take into account load side and small generation contributions. In addition, bottom-up calculations use predetermined look-up values, so that it does not reflect the actual inertia constant of each individual generator in Vietnamese power system.

5. ROCOF and trip events

Inertia in the system protects it from collapse when a unit trips – either production unit or demand unit. ROCOF protects the generation unit. The inertia represents an amount of stored kinetic energy. When a trip occurs, an immediate inertial response fills in a part of the gap between production and load.

Another contribution to fill in the gap between production and load, comes from the nature of load, giving that when the frequency decreases or increases, the load decreases or increase with it, at a rate characteristic to the actual configuration and state of the system, x %/Hz.

The other way around, the behavior of the frequency in the case of a trip, indicates the amount of inertia in the system. See these three examples below from Vietnam April 2020.

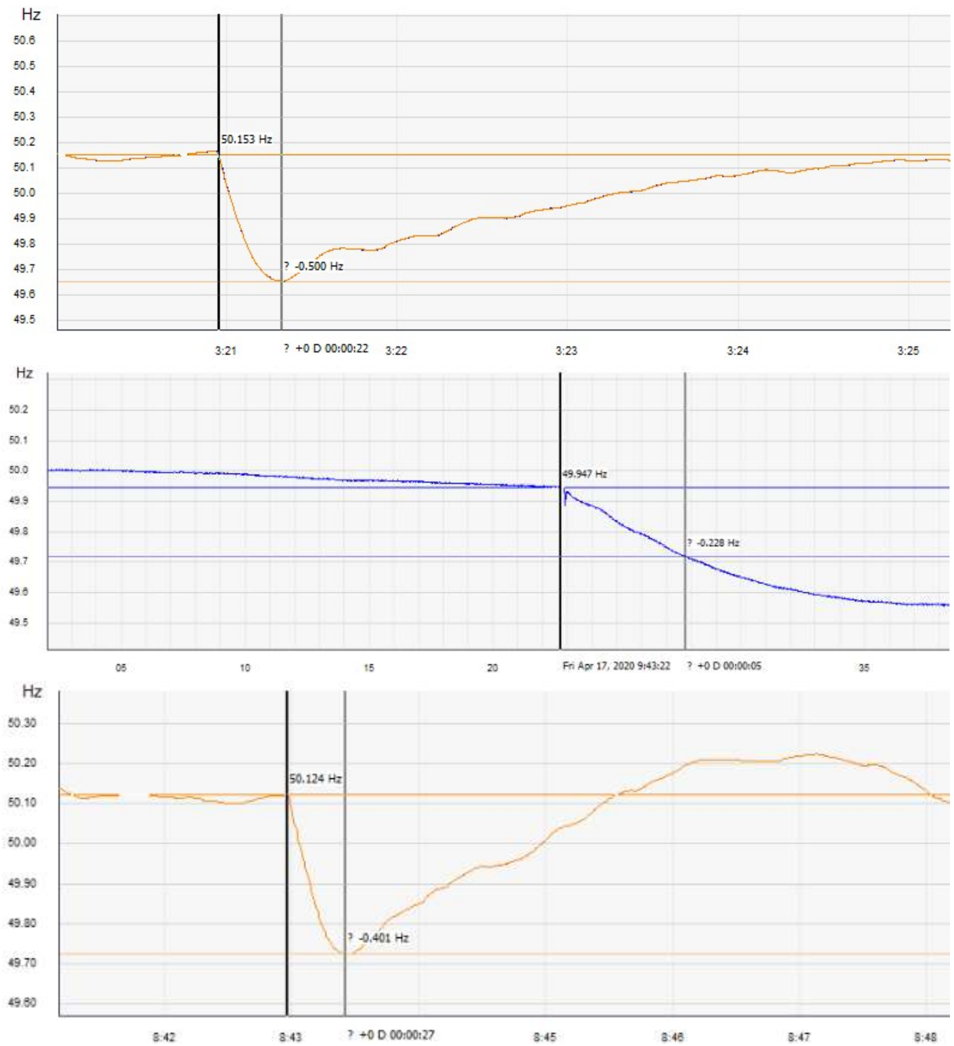

Figure 2. Frequency disturbance from the tripping of Vĩnh Tân

The first of the three graphs above depicts the frequency disturbance from the tripping of Vĩnh Tân I, an instant loss of net 338 MW production capacity. This response is very classic; frequency declines sharply, the decline slows down and reaches a minimum, and the frequency climbs slowly to a stable level near pre-trip level, depending on the amount of reserves employed.

The second trip event above is also Vĩnh Tân, the third is a trip event at Nghi Son.

We can derive useful frequency response indicators: minimum instantaneous frequency (f_{min}), maximum frequency deviation (Δf), time to reach minimum (Δt), and rate of change of frequency (RoCoF, $\frac{df}{dt}$).

See schematic illustration below for examples.

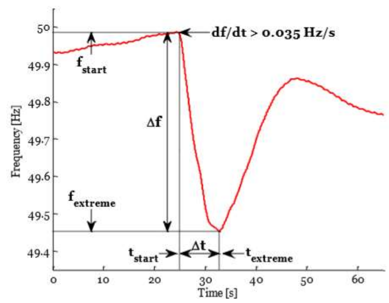

Figure 3. RoCoF schematic illustration

We assume in this report that the frequency center (Ref. 4) is at the tripping plant, whereby we can reasonably derive an estimate of system inertia from the frequency response indicators. We assume that:

$$E = \frac{f_n}{2} \cdot \frac{\Delta P}{RoCoF}$$

Where f_n is the nominal frequency (50.00 Hz) and ΔP is the size of the trip event in [W]. Earlier in this paper we have referred to this way to estimate inertia as the top-down method. When applied on the trip at Vĩnh Tân I shown above we get an estimate of stored kinetic energy that equals 186 GWs. In table 3 is shown the stored kinetic energy in connection to a number of different trip events.

Event	Trip size (ΔP) (MW)	ROCOF	E = system inertia
Vĩnh Tân S1 3:21am	338+15=353	0,0474	186 GWs
Vĩnh Tân S3 1:05am	588	0,0606	243 GWs
Nghi Son S2 8:43am	274+22=296	0,0230	322 GWs
Duyen Hai S2 9:43am	450	0,0456	247 GWs
Cam Pha S2 12:10pm	300	0,0324	231 GWs
Vĩnh Tân S1 6:44am	1200	0,1174	256 GWs
Duyen Hai 3 S1 17:12pm	578	0,0560	258 GWs

Table 3. Trip events from March-April 2020 and the deduced system inertia.

In Figure 4, we look at the amount of stored kinetic energy related to time of the day. From the data, which is rather limited, there seem to be no correlation.

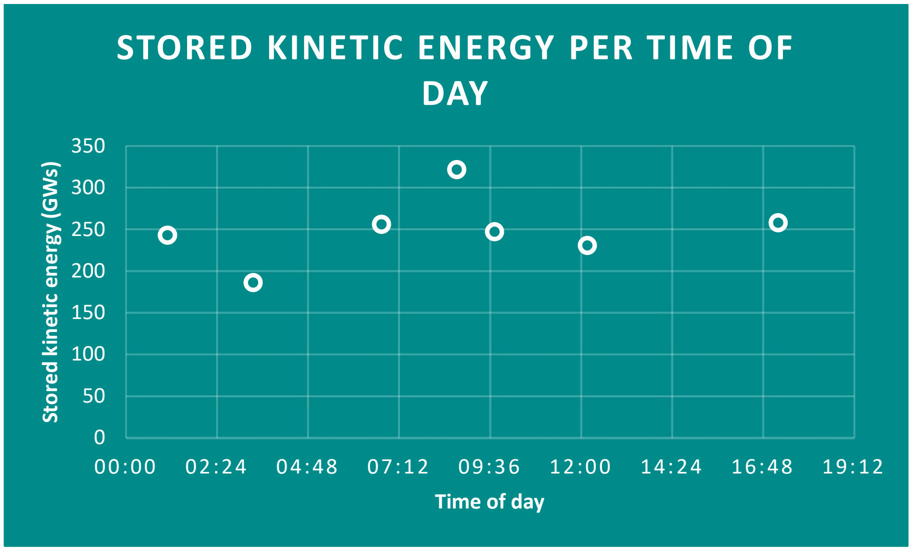

Figure 4. The relation between 'stored kinetic energy' and time of the day.

6. Mitigations and solutions

With the configuration of the Vietnamese transmission grid in mind, including the development pace and stage, below is given some possible actions to take pertaining to inertia level. The list is not prioritized, but some pros and cons are suggested. Some of the actions will work together while others not so well.

Non-synchronous generation can provide synthetic inertia. In fact, it is standard requirement for all current generation wind and solar power plants. Note that in all the above calculations in this paper, the contribution from wind and solar is set to zero. If all new wind and solar will contribute with synthetic inertia, shortage can at least be postponed a considerable number of years. To secure this, requirements for solar and wind to supply synthetic inertia, must be considered in future amendments of the grid code.

Even if requirements for inverters to deliver inertia are not included into the grid code, or in the period until the grid code is amended, NLDC still has the possibility to require this ability and in addition to be very specific about details according to where in the grid the new non-synchronous capacity is installed. Specific requirements are i.a. determined by other system demands e.g. it is important to note that, if these attributes are wanted, they must be explicitly specified one way or another. Ideally, it is specified in the grid code.

In any transmission grid, Phasor Measurement Units (PMUs) perform real time measurements of different electrotechnical parameters on the active equipment. PMUs deliver data to the almost real time monitoring of the system. When several PMUs are combined, a Wide Area Monitoring System (WAMS) can be established. NLDC has around 23 PMUs in the system today. Data handling sets a limit for increasing the number of PMUs right now. One possible step towards better information on inertia, and possibility to react in low inertia situations, is to optimize the distribution of the PMUs data are taken from.

Transmission systems are usually operated with a comfortable margin of inertia supply, and only ex-post inertia estimates with a relatively wide time interval. Then when indicators alert the operator, more attention is given to the inertia level. A high share of variable renewable production is an alert indicator, albeit with synthetic inertia from inverters it is not necessarily the most critical indicator. Other factors influencing inertia is load distribution, production distribution and grid topology. If a system often is close to critical (low) level of inertia, it is increasingly widespread to implement real time monitoring of inertia, as an alternative to measurements that increase the level of inertia. Real time inertia measurement can allow operation closer to the limits. It is mostly an analysis of small changes in the frequency. Real time measurement is costly to implement but can be an instrument to avoid other more expensive measures. But it is important to remember that real time inertia measurement, is not a solution that increases inertia in the system.

A less intensive or coarse granulated inertia information system can be established with information and equipment that NLDC already has today. This could be inspired by the calculations presented in this paper. A self-developed system most likely cannot deliver real time information, but this is not necessary if the system operates with a large margin. If NLDC develops a system in-house, then it can be upgraded according to actual need for information, and the competences and knowledge are kept in the company.

If a synchronous area receives power from outside the synchronous area via a HVDC line, then the converter can inject inertia into the AC grid. The converter must be of the type 'Voltage Source Converter' and the power source must come from outside the synchronous area. Embedded HVDC lines (internal) cannot increase the inertia in the system.

Synchronous Condensers deliver some inertia and they can be built with an extra heavy wheel to deliver extra mechanical inertia. The downside to synchronous condensers is i.a. that they are expensive and that they are permanently geographically fixed. Note also that normally the main purpose of synchronous condensers is to deliver dynamic voltage regulation and short-circuit power.

Obviously, there is a possibility to establish a market for inertia, where plants are activated to minimum production. It could even be in the form of a regular energy activation market i.e. already existing, with special rules favoring more units with little production before large production volumes on fewer units. Operator could also simply just activate to meet whatever demand is the highest, power or inertia.

Hydro units running with air in the turbine house produce inertia to the grid. This effect has been used in Sweden during inertia droughts. It is a relatively cheap solution especially suitable for extraordinary emergency inertia deficit. Vietnam also has dispatched some hydro units to operate at this mode, but the reasons currently are voltage regulation and active power reserve.

Batteries can provide both synthetic inertia and FCR, if it is specified in the grid code. This could either be from batteries installed and operated by the system operator or a power company, or it could be procured as a market product utilizing batteries on the demand side.

7. Conclusion and recommendations

A priority is to include precise requirements for synthetic inertia in the next grid code revision. This should preferably be in the grid code C25 and C39 where general requirements for generators are set.

As to the current situation, this study shows that there is no need for additional inertia before 2025 considering the Vietnam Energy Outlook report scenario. As a consequence of this, we recommend the solution that NLDC do the bottom-up calculation of inertia once a year, and in connection to that evaluate the foreseen development one year ahead. This calculation should be done following same systematic each year, with identical principles for collecting data and calculation the levels of inertia et cetera. It should be done for more different situations than in this report, i.e. more different hours representing time of day, season, calendar events and more. To accompany this calculation, an exact statistic of

the transmission grid and production fleet should be provided. This statistic can be fairly simple, presenting a number of key parameters, bearing in mind that a single number of inertia cannot represent the dynamic system stability.
Having these data year by year, collected in an identical way, will allow NLDC to follow the development. If eventually signs of near critical levels of inertia occur, NLDC can take further steps to establish a more intense monitoring program.

We believe that the level of inertia in the Vietnamese grid at this point, and some years into the future, is adequate and by no means near critical. For this reason, we believe that the different real time measurement solutions are not yet urgent. It would anyhow be wise and economically optimal during other grid extension/development, to have the real time solution in mind and build it up gradually. For instance, when new PMUs are installed due to other demands, to set them up to be able to deliver the relevant input to the WAMS. It is necessary to have a clear strategy for applying the PMUs for this purpose, and the expected outcome must be specified. Which parameters to monitor for what purpose. Too many parameters can cause data pollution, and confusion.

Finally, we recommend that this study is extended with more hours and higher data quality and a precisely defined systematic. This could aim to be the NLDC yearly report on inertia, as recommended above. It should include all system stability aspects – small signal, angle stability and inertia.

8. References

#	Description
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