Ambition
to
Action

Grid integration in Indonesia

Contribution of variable renewable power sources to energy and climate targets

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ECN › TNO innovation for life

Executive Summary in Bahasa Indonesia

Kontribusi energi angin dan energi surya pada bauran energi listrik diperkirakan masih tetap rendah di tahun tahun mendatang dan proses menghubungkan listrik dari sumber energi terbarukan yang bersifat variabel ini ke jaringan (*grid integration*) mungkin tidak menimbulkan hambatan untuk mencapai target pengurangan emisi NDC dan target kebijakan energi terbarukan. Tetapi, pengurangan biaya akibat perkembangan teknologi atau peningkatan tekanan kebijakan yang berhubungan dengan iklim dapat mempercepat pemanfaatan energi terbarukan-khususnya energi surya. Gagasan dan strategi yang bertujuan untuk meningkatkan fleksibilitas dalam menjaga sistem pembangkit tenaga yang terpercaya, andal dan berkesinambungan meskipun memiliki bauran energi dari angin dan surya yang besar. Indonesia berada dalam posisi yang menguntungkan dalam menyiapkan bauran energi yang besar bahkan lebih besar dari sumber energi terbarukan yang bersifat variable karena struktur dari sistem dan perkembangan pesat di tahun tahun mendatang; kegagalan dalam mengantisipasi dan mempersiapkan dapat mengakibatkan kehilangan kesempatan dalam memanfaatkan sumber energi masa depan yang murah dan rendah karbon seperti angin dan surya sebab biaya penyambungan ke grid yang tinggi dan biaya yang tinggi untuk transformasi sistem daya.

Abstract / Synopsis

Shares of wind and solar power in the Indonesia electricity mix are expected to remain low in the coming years and grid integration of variable renewable sources is unlikely to pose an obstacle to reaching the NDC emissions targets and the Energy Policy renewable energy targets. However, further technology cost reductions or increasing climate policy pressure can accelerate the uptake of renewable energy – especially solar photovoltaic. Best practices and strategies point to increased flexibility to keep power systems reliable, affordable and sustainable even with large shares of solar and wind power. Indonesia is in a favourable position to prepare for large(r) shares of variable power because of the structure of the system and the growth trajectory for the coming years; failure to anticipate and prepare could lead to missed opportunities from future cheap low-carbon supply sources like wind and solar because of high integration cost and the cost of power system transformation.

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Introduction

Indonesian president Joko “Jokowi” Widodo inaugurated the nation’s first operational wind turbine park on July 2nd, 2018: the *Sidrap Wind Park* (75 MW) in South Sulawesi. A second of its kind, the *Tolo 1 Wind Park* (72MW), is expected to start operations any time soon in the same region. Together, these parks amount to just over 5% of the total installed power capacity in South Sulawesi. Integrating this amount of variable renewable power into the grid is new for PLN and amidst enthusiasm there is also hesitation[1] to expand further beyond 5-10% in relatively small grids like that of South Sulawesi. With ever increasing competitiveness of solar and wind power, integrating large amounts of variable power into the grid is becoming more and more relevant. For policy makers, the important question is whether and when integration of variable renewable energy is likely to become an obstacle to achieve energy diversification ambitions (National Energy Policy) and climate targets (Paris Agreement).

This policy brief presents a number of considerations related to integrating variable renewable power into a power grid, looks at how these relate to the Indonesian energy context, and offers direction to prepare for future integration of significant levels of solar and wind energy in emerging power grids.

Integrating variable renewable energy (VRE)

To an operator of a power grid, some renewable sources are controllable (geothermal, biomass, hydropower) and do not require a very different approach than fossil sources (coal, oil, gas). Other renewable sources are less controllable and fluctuate due to natural variability. This last category is called **variable renewable energy (VRE)** and includes solar, wind, and wave energy. Hydropower can be variable under special circumstances such as droughts or floods but is normally not counted as VRE.

There are a number of issues with VRE. First, production depends on weather conditions with actual electricity output changing in seconds (for example when clouds pass by) and on longer (even seasonal) timescales as a result of weather and climate fluctuations. Wind and solar output variations can be **challenging for grid operators** when they result in an abundance or scarcity of electricity at certain times and location in power systems. Because electricity supply and demand need to be balanced all the time, and the ability to transport electricity is typically limited because of losses and grid constraints, abundance and scarcity can lead to balancing issues and congestion, which in turn can lead to system outages. Second, variable renewable sources are non-synchronous and unless properly handled this can impact the stability of the power system (again leading to outages). Third, as a consequence wind, solar, and wave power have limited ability to deliver grid support services such as frequency support. Therefore, the integration of large wind and solar plants into traditionally designed and operated hierarchical power systems can be less straightforward than the integration of other (renewable) sources like coal, gas, geothermal or hydropower.

Behind the deceptively simple link between weather conditions (or day and night) and power generation, reality is not as straightforward as it seems and there are quite a number of **myths surrounding VRE**. Although variable renewable energy integration does have its challenges, a number of frequently mentioned **claims turn out to be false** when compared to practical evidence. Myths that turn out to be very well manageable with modern technologies, range from ‘weather driven short-term variability is unmanageable’, ‘variable renewables require 1:1 back up’, to ‘storage is a must-have’ (see for elaborate discussions: IEA,

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[1] *There is no firm source for this ‘perceived wisdom’ that wind and solar should be kept within 5-10%; it has been mentioned consistently by different independent experts in Jakarta during interviews in September-November 2018 and is echoed in recent PLN tender documents, which mention a penetration of 10% of the daytime peak load of the power system.*

2017, 2018, IEEJ 2017). Real world examples from countries such as Denmark and Ireland show that **very large penetration rates are possible** (see Figure 1), but that this does require technical and operational changes to the system in order to remain reliable, sustainable, and affordable.

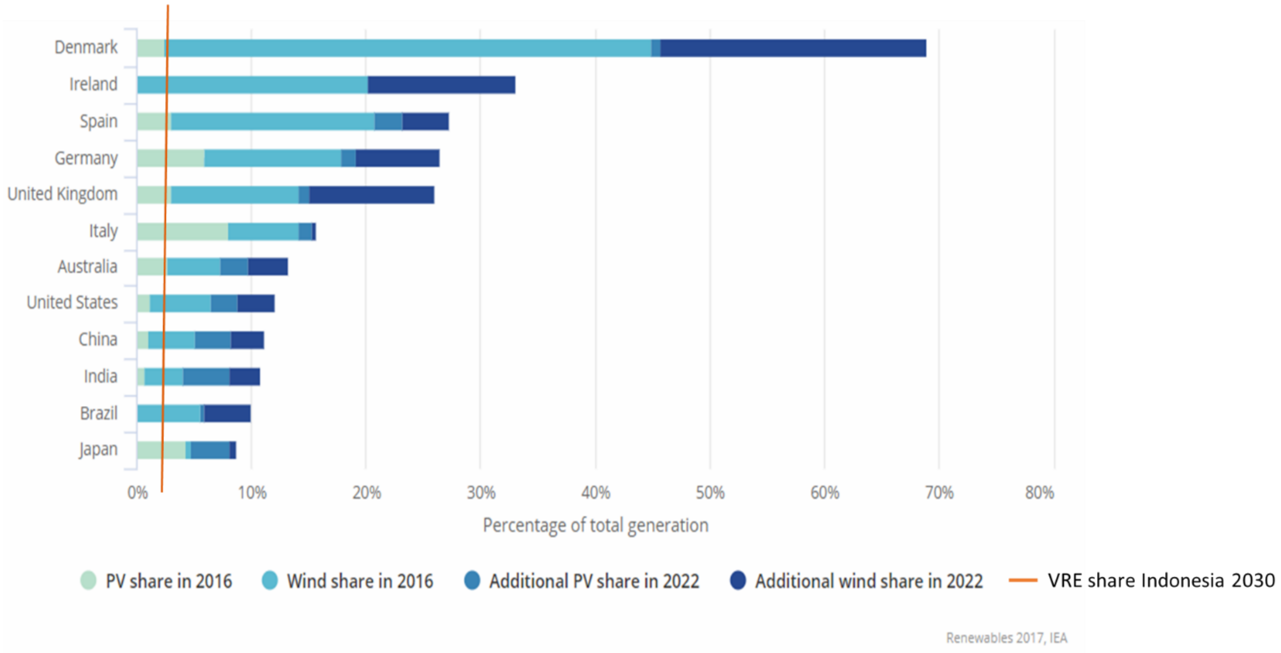

Figure 1: Share of wind and solar in annual electricity generation (IEA 2017a)

Is VRE integration an obstacle to reaching energy and climate targets?

In the coming decades, the share of renewable energy in the electricity generating mix is expected to increase significantly in Indonesia Driven by the National Energy Policy (KEN) and motivated by energy security through diversification, the target share of renewable energy should be at least 23% in 2025 and at least 31% in 2050 (GoI, 2014). Reaching this 23% target is far from trivial and many challenges remain (IISD, 2018).

The National Energy Council (DEN) is assigned by the Ministry of Energy and Mineral Resources (EDSM) to develop long-term supply and demand projections. The DEN scenarios in the 2016 Indonesia Energy Outlook are currently most representative and are consistent with the National Energy Policy (KEN). The national electricity company PLN publishes their annual update to their 10-year electricity supply business plan (RUPTL). The RUPTL is consistent with national and regional electricity plans (RUKN/RUKD) and provides detailed information on demand and capacity projections.

According to both the RUPTL 2018-2027 (PLN, 2018) and the National Energy Outlook Indonesia 2016 (DEN, 2016), **variable renewable energy (solar and wind) capacity is not expected to rise above 2.5%** of the total installed capacity in Indonesia up to 2030 (see Figure 2). Other renewables (mainly geothermal and hydro power) will have a more prominent role towards reaching the 23% target in 2025. The detailed regional plans of PLN (2018) show that in the largest and most robust electricity system in Indonesia, the Java-Bali and Sumatera systems, the share of VRE will remain around 1%, which is even below the national average of 1.5% of the RUPTL 2018.

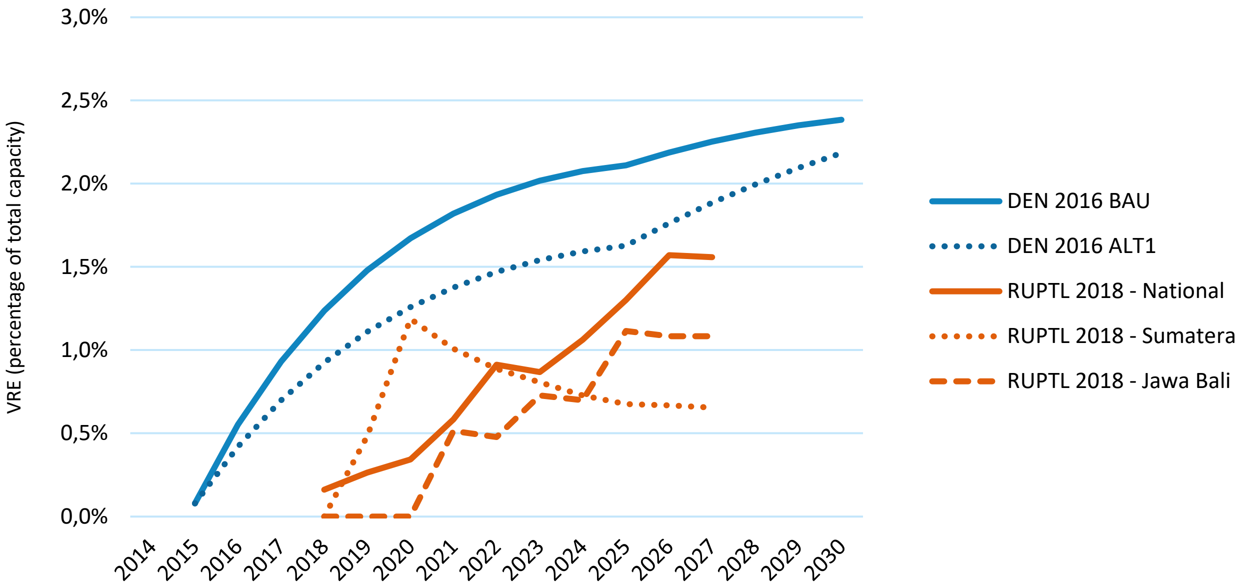

Figure 2: Share of wind and solar in Indonesian power sector scenarios

Indonesia's domestic emission reduction target is 26% reduction in 2020, as unilaterally stated by the former President of Indonesia Susilo Bambang Yudhoyono (SBY) to the G20 meeting in Pittsburgh in 2009[2]. The implementation of this domestic mitigation target is covered in the RAN-GRK climate action plan. To date the RAN-GRK has not had significant traction on investment decisions in the energy sector and it does not pose an additional incentive towards more (variable) renewable energy. Indonesia's first Nationally Determined Contribution (NDC) to the Paris Agreement, submitted in 2016, does explicitly reference the energy sector but it does not introduce additional constraints or guidance for the energy sector; the NDC refers to the KEN for setting the pace of energy sector mitigation. There is no straightforward way to determine whether the current NDC requires changes to power sector planning and target setting. National and sector emissions targets communicated in the first NDC are broadly aligned with (or even based on) existing power sector projections and plans and are **not expected to affect the generating mix** (van Tilburg and Donker, 2018).

Comparing the maximum projected percentage of 2.5% VRE capacity in Indonesia in 2030 with other countries who have already been capable to include much higher percentages today (see Figure 3) would suggest that integration of solar and wind will not be a major obstacle. Note that 2.5% VRE capacity (kW) results in an even lower percentage of total generation (kWh) due to typically low capacity factors for solar and wind.

Based on PLN projections in the RUPTL, the eastern part of Indonesia will see a somewhat higher deployment of VRE in the coming years than the national average. In remote regions, where high-cost diesel-based power generation is a common occurrence, renewable technologies such as solar are already cost-competitive. Distributed technologies such as solar PV are especially popular because they can play an important role towards energy access, electrification, and economic development in remote regions. However, as PLN rightly points out in the case of South Sulawesi, **deployment of VRE in small power systems can have a relatively high impact on (local) grid stability**.

In terms of power output and greenhouse gas emissions, the eastern part of Indonesia is modest compared to the Java-Bali and Sumatera power systems in the west of Indonesia. The current installed power supply

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[2] *https://www.reuters.com/article/idUSSP495601*

capacity on the Java-Bali grid (36 GW of the total of 55 GW in entire Indonesia) places it in the top 30 largest power systems worldwide and above the average of European countries [3].

IEA (2017a, 2017b) identified, based on the share of VRE generation of a country, different phases of grid integration. Based on the recent scenarios Indonesia would stay in *Phase One* up to 2030, stating variable renewable energy has **no relevant impact at the systems level and no concerns with variable renewable outputs** and their variability should be expected. The impact, if any, will be local at or near the point of connection (IEA, 2017a). However, as Indonesia consists of about 17 thousand islands and has many unconnected isolated power systems, comparing Indonesia's national average numbers to countries with often single and highly connected grids only has limited value.

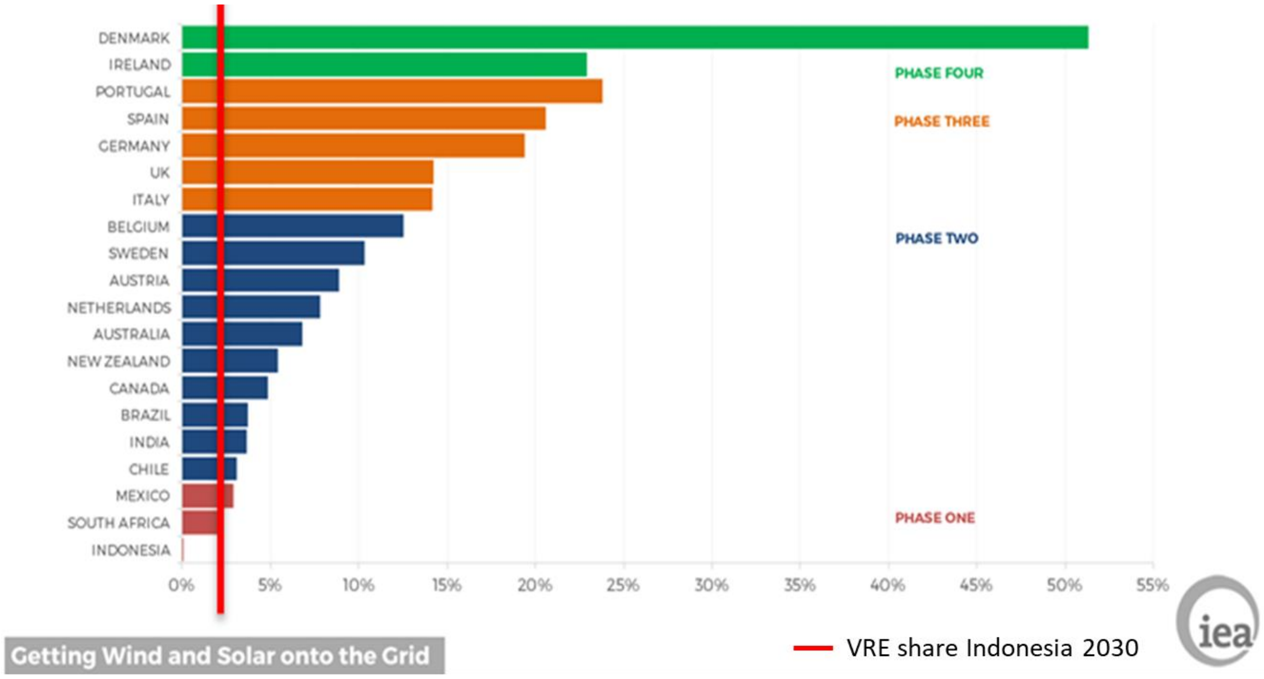

Figure 3: Four phases of VRE generation (IEA, 2017a)

Looking ahead

Power systems across Indonesia, in eastern and western provinces, have in common that, in contrast to most European systems, they are expected to grow significantly in the coming decade. Most projections show that installed capacity triples or quadruples by 2030, compared to 2010. Accommodating large amounts of new capacity requires major power grid reinforcements and extensions, independent of whether new capacity is based on variable renewables or not. Power grid extensions that support or prepare for variable sources are somewhat different, but not necessarily more expensive. With strategic planning and power system development, integrating higher amounts of variable renewable energy would therefore not necessarily lead to additional investment requirements beyond the cost of normal system development. **Based on current projections, integration of variable renewable energy sources is not expected to lead to major challenges in the short- and medium term.** Challenges on local level in for example distribution grids, or small and very small power systems can occur. However, the (growth) assumptions underlying the current projections may not materialise and external factors may change. Power demand projections in high-growth contexts are notoriously hard to predict, and small changes in assumptions can have large consequences. For example,

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[3] *https://www.cia.gov/library/publications/the-world-factbook/rankorder/2236rank.html*

PLN’s 10-year projections changed significantly from 2017 to 2018, reducing demand with 20% and renewable energy capacity with 36%.

Two important factors that could drive larger amounts of solar and wind energy, are cost reductions and climate considerations. The costs of renewable energy technologies, and in particular for solar photovoltaic, have dropped rapidly over the past years and analysts expect that further cost reductions are possible. Against the backdrop of PLN’s continued focus on affordability, it is very well possible that solar PV will become the most economic viable technology available in more and more investment decisions. A second driver is the Paris Agreement on climate change. According to a recent IPCC report, best available science tells us that staying well below two degrees global warming (i.e. the goal of the Paris Agreement) is still possible but would require all counties to reach net zero emissions by 2050 or shortly thereafter (IPCC, 2018). As a consequence, fossil fuels will need to be phased out much faster than is currently planned (over half of energy supply is fossil based in the 2050 KEN targets). As the ambition mechanism of the Paris Agreement gets its bearings, this is likely to translate to calls for more ambitious renewable energy targets. Against this background of opportunity and increasing pressure, it is only prudent to continue exploring what it would take to accommodate much larger shares of variable renewable energy in the mid- and long-term future.

Focus on flexibility

Solutions to accommodating large shares of VRE cover the whole chain of operation of the power system: supply, demand, markets, and grids. The solutions are often a mix of procedural, technical, and policy interventions. Most solutions focus on increasing **flexibility**, which is defined as the ability of the power system (actors, technologies, processes, measures and markets) to **respond reliably and rapidly** to large fluctuation in the supply and demand balance (IEA, 2018b).

There are various strategies to avoid lock-ins and take precautions to make future integration easier. Annex 1 below presents an overview based on analyses by the International Energy Agency. Timing is an important consideration in planning for flexibility. Most energy infrastructure built today in Indonesia (especially coal and gas power plants and grids) are designed to operate for many decades and will be part of the power system in the long-term. Current decisions on new capacity that increases *stiffness* of the power system, such as new coal-based power plants that are required to run at full capacity, or long-term take-or-pay contracts, can lock the power system into a potentially unfavourable pathway for a long time. Failure to anticipate and prepare for VRE integration, could lead to less benefits from future cheap low-carbon supply sources like wind and solar because of high integration cost and/or the cost of power system transformation.

Flexibility has always been an important feature of power systems and grid operators typically must respond to highly variable demand patterns on a daily basis. Even without a need to accommodate large shares of VRE, power grids around the world are made more flexible in anticipation of opportunities that further digitalisation and automation bring (e.g. sophisticated demand response).

Integrated power planning offers a solid step towards increasing flexibility and control, and towards avoiding VRE hotspots and grid congestion (IEA 2018a). Integrated planning includes geospatial aspects, a diversity of supply and demand resources, generation and (inter-regional) network planning but also planning between the power sector and other sectors like industrial development, heating and cooling and transport (IEA 2017b). The fact that Indonesia has a vertically integrated monopolistic managed power system with expected massive expansions, offers a unique opportunity to increase flexibility and anticipate further integration of solar and wind. Therefore, the Indonesian grid of the future should be able to incorporate more ambitious VRE deployment.

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Annex 1: Addressing grid integration issues

Most grid integration solutions focus on increasing the flexibility of the energy system; the ability of the power system (actors, technologies, processes, measures and markets) to respond reliably and rapidly to large fluctuations in supply and demand balance (IEA, 2018b). The combination of all measures and processes which ensure that energy input and energy uptake are always equal, thereby making for a stable system, is herein defined as 'balancing'. There is not one single sort of flexibility: needs and supply options of flexibility do vary in time (seconds until months), size and level of scale (household until international). As each power system must manage fluctuations in the demand and supply balance, flexibility has always been necessary in power systems (Donker *et al.*, 2015). Below short descriptions of grid integration and/or flexibility options are provided, predominately based on IEA literature.

A. Operation

Optimize dispatching: optimizing the (process of) output of power plants to meet electricity demand in a power system

- *Aim for short dispatch intervals and frequent scheduling updates*: By doing this, system operators gain more knowledge of the operating state and have more possibilities to act on that information. For example, by controlling plants output close to and during real-time operations reduces VRE generation forecast errors, allowing more accurate and efficient operation. VRE production forecast are depended upon weather forecasts, which become far more reliable near real-time, reducing production forecast errors.
- *Avoid locking in power plants over long term*. Take Or Pay contracts with Independ Power Producers (IPPs) and long fuel purchase contracts for power plants are examples that can lead to lock in effects on the dispatching of power plants. It can lead to must run facility which can disturb the technical and economic dispatching decisions of the System Operator. This decreases the level playing field and potential of other supply sources like VRE. An increase of the contractual flexibility of fuel and PPA is estimated to provide a greater operational cost savings to the system (IEA, 2017).
- *Forecast of VRE output*. In case System Operators have oversight of VRE data, they can better predict plant behaviour and make more accurate forecasts on VRE output. Data can include weather related data and VRE system data. Via a grid code or Power Purchase Agreement, System Operators can require that VRE generators provide them information on their systems.

Extend balancing grid: Enlarging the balancing area can create the (1) benefit of scale (2) smoothening output (of VRE) over a wider grid network, (3) and fluctuations that balancing each other out. This can require both physical changes like developing interconnections (transmission lines) with adjacent balancing areas and operational and process changes for among others system operators of these balancing areas.

Improve Grid code: Revising the grid code provides System Operators the possibility to include evolving needs of the power system as the share of VRE increases (IEA, 2018a). Grid codes includes requirements for grid connection of all generators. Requirements can include contribution to balancing and ancillary services or providing forecasting data. Due to technological advances VRE are more and more able to provide power system stability services as well.

B. Power Markets

Liberalization (move away from single-buyer model): Short-term markets are the foundation of all market-based electricity systems and have been proven to be a valid approach to cost-effective integration of high shares of VRE. Recent years have seen growing interest in the establishment or strengthening of such markets to improve the operational efficiency of the power system and better incorporate higher shares of VRE. (IEA 2018b)

More real-time markets and higher resolutions of E program: Improvements to the design of short-term markets focus on: (1) enabling trading closer to real time, (2) improving pricing during periods of scarcity, (3) reforming markets for procurement of system services, (4) allowing for trade over larger geographical regions, (4) better incorporating distributed resources and (5) increasing the time resolution of markets (to five minutes). Hereby, the need for flexibility in the system will be economically (in prices) better reflected, thereby improving market operation. (IEA 2018b).

C. Power Supply

Enhance flexibility of current fleet and new thermal plants (also via IPP): Next to contractually elements, the technical flexibility of the current fleet can be increased by retrofitting existing thermal plants. Existing thermal generation fleet, particular coal plants, have proved that they can operate in a relatively flexible manner, after modification. Coal plants have traditionally been designed to operate continuously (base-load), however new thermal plants are able to provide increased operational flexibility (Henderson, 2014). Although technical constraints remain, new thermal plant design should take into account the (future) need for operational flexibility.

Enhance flexibility and system services through new (VRE) deployment: Decisions on new power supply technologies should consider the (future) need for flexibility, balancing options and grid services. Specific supply technologies can be chosen and/or plants can be designed in such a way that they are able to provide (future) flexibility, balancing options and grid services. As mentioned before, due to technological advances VRE are more and more able to provide power system stability services as well.

Reduce variability and system impact of new VRE plants by design, geographical spreading, forecasting data, and ancillary services: Orienting of a solar system to encourage greater production later in the day, and lower wind speed turbines resulting in smoother production, are examples of Time of Delivery factors in VRE design to reduce the variability and system impact of VRE plants. Geographical spreading of VRE plants around the footprint of the existing grid can allow a greater installed capacity of VRE before additional measures are required. In addition, due to different weather conditions in different parts of the country or region the aggregated output of VRE plants is smoothened, minimizing variability and thereby system impact (IEA, 2017a).

Technology mix / Hybrid utilization: Other (renewable) power supply sources and VRE generation can be complementary to each other. The output of wind and solar power is complementary in various parts the world. Hydro plants and VRE can also complement each other. On more local scale, combined connection of complementary (VRE) supply sources to a substation can increase the sum of VRE capacity at a substation (IEA, 2018b).

D. Power Demand

Flexibility of demand involves consumers of electricity adapting their needs within certain limits regarding the quantity or the timing of supply. If there is little electricity supply available in the system, they can reduce their consumption, and vice-versa. This involves a shift in the timing of the requirement for energy, not a lowering of consumption levels. Large (industrial sector) consumers of electricity to can provide interruptible load, by delaying certain industrial processes at moments of low electricity supply. Various technologies influence demand for electricity for smaller customers, such as cooling systems, air conditioning, thermal pumps, and the charging of electric cars. The development of intelligent steering should make it increasingly easy for consumers to move the time when electricity is used. Demand management can play an important role in stabilizing the energy system when a significant proportion of it is based on variable production. It can also help smooth out peaks in demand (Donker et al, 2015).

E. Power grid

Improved usage of existing grid: Before investing in grid reinforcement, various grid solutions can defer these investments by increasing the efficient usage of the existing grid capacity. Dynamic line rating technology, special protection schemes and active network management are examples of grid solutions to improve the usage and capacity of the existing grid (Miller *et al.* 2013)

Grid expansion and reinforcement: Grid reinforcements and expansion can be essential to accommodate all kinds of new power supply capacity, both fossil based and renewables, but also new or increased demand, as both can require more need for transmission and distribution of power. More recently attention on limited grid connection capacity and the need for reinforcement and expansion is focused upon the penetration of VRE. VRE tend to be deployed in a much more distributed fashion, have fluctuating output and are frequently built far from load centres and in areas where the existing grid is not yet prepared for the accommodation of this new power supply. This can result to bottlenecks in the grid, due to limited capacity of a line or substation at certain times, that may constrain the transmission of power from supply sources to demand centres. Grid reinforcement and grid expansion can be solutions to overcome these issues and increase transmission and distribution capacity.

Integrated planning of grid reinforcements and expansion: Integrated long-term planning for power production, transmission and distribution should take into account the role of VRE and other new technologies. This includes the alignment of expansion and reinforcement planning with the VRE deployment planning or procurement (technologies, location, sizes), to reduce system cost.

> *“Traditionally, the primary focus of power sector planning was on expanding supply infrastructure (generation, transmission and distribution networks) to meet projected electricity demand, based on assumptions of economic growth over the next 20 to 30 years. However, with the changing landscape of the power sector, due to increasing deployment of VRE and other new technologies, as well as increasing consumer participation, planning for a future power system needs to become more sophisticated by taking account the role and impact of these developments”*
>
> *“Sound long-term planning for power production must recognise that the optimal mix of flexible resources is likely to evolve over time. The need for strong co-ordination applies most notably in dynamic power systems where demand growth warrants investment in generation and transmission capacity. In this context, a transparent process with clear rules and procedures can ensure that new VRE capacity is introduced at the right time and place, using the technologies that have the highest system value. Aligning transmission expansion with procurement of VRE can reduce overall system costs.” (IEA, 2018b).*

Interconnection: Transmission of electricity between various power systems of regions or countries can allow for greater aggregation of VRE and increased flexibility of both power systems. Due to greater geographical spreading of VRE production with different weather conditions, variability can be reduced. Secondly, due to the benefits of scale, the connected power systems are able to deal better with relative smaller disruptions and fluctuations that balance each other out. In addition, it can provide (short-term) balancing support (see operation).

F. Storage & conversion

The storage of energy is an ideal source of flexibility, allowing the production and utilization of energy to be separated in time. In addition, it can be applied on all levels of the power system. The various possibilities for storage should of course be connected to technologies that are actually capable of realizing these adaptions. Three things are important here: energy density, response time, and storage time. Energy can be stored by electrical, mechanical, thermal, chemical or electro-chemical means; each one with different specifications and conversion pathways with certain efficiencies. It is to be noted that electrochemical means – batteries – allow for quickly loading and discharging energy over long periods and are therefore currently are seen as most suitable for power and volume applications.

G. System Integration

The energy system does not consist of the electricity network alone. Energy systems can include gas and (local) thermal infrastructure as well. Combining these systems would increase the size of the overall system and also increase utilization of the existing infrastructure (Donker *et al*,. 2015).