

Virtual Power Plant in Industry 4.0: The Strategic Planning of Emerging Virtual Power Plant in Kazakhstan

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Abstract— Today, in the era of Industry 4.0 with total automation of the cloud data bus and domestic energy production the concept of the Virtual Power Plant (VPP) is entering global power sector to facilitate the integration and management of distributed power units relying on real-time communication and uniform control. The motivation behind VPP is to solve a problem of variable profile and uncertainty of power generated by DG units that is found to be challenging when building reliable DG-aided power plant. This paper aims to propose the potential location for the VPP in Kazakhstan and to recommend roadmap planning for its realization based on the results and estimates conducted in the scope of simulations. It was revealed that there is promising possibility to locate VPP on the territory of South Kazakhstan, Jambyl and Almaty regions due to concentration of high capacity renewable energy plants and efficient operation of Energy Management System (EMS) revealed from the simulation results. Emergence of the VPP may contribute to further development of the renewable power grid provided financial aid to facilitate technologies and to promote the prosumer status of households is attracted.

Keywords— Virtual Power Plant, Industry 4.0, renewable energy sources, distributed generation, energy market, Kazakhstan

I. INTRODUCTION

Nowadays with a quick growth of population and the consecutive energy demand increase, the fossil energy scarcity is becoming a real issue. On the contrary, the usage of conventional energy sources such as coal, oil and gas inadvertently addresses serious environmental problems. To reduce the rate of pollution and save the environment, renewable energy technologies take a leading role in energy supply. Alternatively, these technologies can be referred as Distributed Energy Resources (DER) and constitute of renewable energy sources like solar panels, wind turbines, biomass as well as energy storage systems like batteries and electric cars [1].

High penetration of distributed power sources introduce dramatic changes in conventional aspects of energy production and supply. Obviously among the positive effects one can find increased availability of distributed energy and efficiency of energy generation. However, power system stability is disturbed due to instability and randomness of distributed power generation [2].

The electricity system containing DERs requires intelligent power networks to provide stability in generation and demand and maintain security of power systems. This issue can be solved by centralizing control over generation units. This concept can be referred as Virtual Power Plant [3]. VPP can control aggregated units as well as manage the flow between them [4],[5].

This paper is focused on exploring the concept and historical background behind the VPP, identifying the role of VPP in Industry 4.0, and familiarizing with VPP requirements and conducting resource assessment on Kazakhstan land to decide whether the arrangement of VPP in Kazakhstan is feasible. The rest of the paper is structured as follows. Section II and Section III present theoretical background behind the concept of VPP and basic requirements for VPP. Section IV explores the current grid condition in Kazakhstan in terms of renewable resource assessment on the territory of Kazakhstan. Section V examines the global VPP market and particularly focuses on Australia's VPPs. Section VI discusses the feasibility analysis for Kazakhstan and provides model and simulation results. Finally, concluding remarks are shown in Section VII.

II. BACKGROUND FOR VPP

A. Definition of the VPP

VPP concept was first introduced in 2005 in the content of the FENIX (Flexible Electricity Network to Integrate the Expected Energy Evolution) project and stated basically for integration of DERs for the energy system operation and energy market transactions [1], [6]. Till today, the interpretation of VPP varies from combinations of DGs, fixed and variable loads integrated via communication links and real-time control techniques [7], [8] to Energy Management System (EMS) acting as a real power plant in the electricity market [9], [10]. VPP manages units independently, this is due to EMS that helps to establish the link between distributed power units from centralized to decentralized control modes [5].

VPP can be defined as a single big power plant that connects, controls and envisions dispersed generators via an information communication technology (ICT) structure. Fig. 1 portrays the virtual power plant basic structure. The

application of the VPP concept encourages reconciliation of discontinuous sustainable power sources, settling their stochastic power output. Likewise, it optimizes existing energy framework and upgrades the grid performance [11], [12].

Following three are the main functions of VPP [13]:

- 1) Dispatch and optimization
- 2) Management and control
- 3) Integration of DGs and renewable energy resources

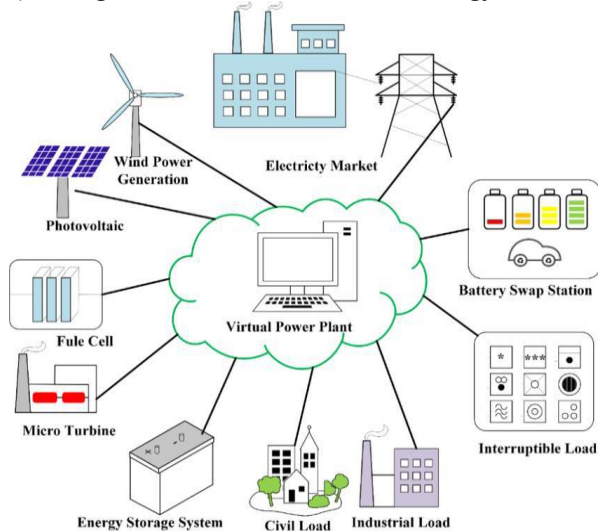


Figure 1. VPP structure [12]

VPP is able to diminish the burden in the power system because electricity is produced and consumed locally without transmission to long distances. On top of that, for the better operation of VPP energy storage should present [13].

B. VPP Digitization in Industry 4.0

Over the recent decades digitization of energy systems has received broad attention. There have been significant advancements in information and communication technologies, cloud-based computing and the Internet of Things all of which can have considerable impact to the power sector. Digital technologies can provide optimal solutions to integrate renewable energy sources to existing power grids. The digital system monitors and efficiently manages generation, distribution and consumption from different dispersed energy sources for covering the fluctuating demand of end-users. Also, it allows flexibility required to integrated renewables into electricity networks on a broad scale [14].

Concept of Industry 4.0 on VPP may be understood as integrated technology infrastructure by software service which forecasts, analyses, monitors, and optimizes a system to create true value for effectual DER software [4]. It includes some systems like embedded computing (effective control of physical systems); cloud computing (software platform for optimization); data networking; big data analytics; adaptable and computable control algorithms. The software server makes the primary drivers to all estimates, continually observes and shares data of actual energy stock level. Then if the problem is arisen it alters demand levels and delivers

supply making sure of quality market and purchase [15]. Among the challenges of Industry 4.0 in VPP digitization are data security, a continuous update of storage servers, availability and interoperability.

III. BASIC REQUIREMENTS OF VPP

Communication within VPP plays a vital role in proper operation. There is a need for standardized and reliable communication language and the simple exchange of information between VPP, measurement systems, market and the system operator. The way each party can communicate with each other is different and is defined with respect to standard protocols. One can find such a look-up table for communication protocols for the Germany energy market operation [3], where IEC can be referred as international standard defined in International Electrotechnical Commission.

To ensure control center contains the data about the real-time status of each unit of the system VPP is operated within unified Energy Management System(EMS). In this way it is vital to give the correspondence infrastructure for information stream and exchange. A few viewpoints must be considered on this matter. The system is better to sustain a local character, have the least delay, and have the capability to augment newly entering devices. Based on the quantity of units, the hierarchy structure of the infrastructure should be changed. An excessive number of nodes connected with the EMS can back off the operation of the system or cause overstress in the communication medium. Due to that a portion of the information from units should not be transmitted individually to the EMS. They might rather be processed as a bunch of alike units. Obtained data has to be in predetermined format and sent utilizing identified protocol. A reconcilable information stream from several units and further extension of the system should be assured. One example of the suggested and utilized protocols in a VPP approach is IEC 61850 [16].

In addition to the establishment of proper communication links between players it is required to properly manage power unit scheduling. This is essentially critical for the estimation of power demand in case of critical situations, the daily forecast of power supplied by parties and optimal market participation [3]. By expedient power scheduling one can understand the well-coordinated operation of power units which in turn contributes to smoother profile and reliable functioning.

IV. KAZAKHSTAN GRID CONDITION

Any feasibility analysis should include the study of current status of resources to be applied. In case of the feasibility of arrangement of VPP in Kazakhstan the situation in renewable energy sector was examined in terms of assessment of RES availability that may be varied according to location and specificity in environmental conditions. For this purpose, the existing and potential distributed power technologies of Kazakhstan are to be investigated.

Regarding conventional energy resources, Kazakhstan is known as one of the fossil fuel rich countries in the world with considerable reserves of coal, oil and natural gas. This fact

makes Kazakhstan one of the twenty global producers of primary energy resources according to the World Energy Council [17]. In 2013 the Government of Kazakhstan employed a law, On Supporting the Use of Renewable Energy Sources, that facilitates the penetration of renewable energy technologies such as biomass, solar, wind, geothermal and hydropower into the energy system of the country. Even though the features mentioned before are dominant in Kazakhstan, thanks to environmental conditions it has potential to employ renewable energy technologies as wind and solar that are already existing ones. Regarding the biomass generation one can claim that it is planned to contribute up to 300 MW electricity capacity that is one thousand times less than the wind generated currently, but still it has promising potential to be implemented in Kazakhstan [18].

According to Karatayev, et. al., the First Wind Atlas containing wind data for all 14 regions of Kazakhstan was published in 2014. It is revealed from the study of statistical data that in 2013 the wind capacity from a single wind farm in South Kazakhstan was about 5.6 MW. It is estimated that by 2020 the cumulative wind capacity will reach 1787 MW [18],[19]. Upper map of Figure 2 depicts wind profile in Kazakhstan. The central and western part experience continual and faster winds, thus making those regions potential for future wind power plants.

Regarding solar energy generation within the territory of Kazakhstan one can evaluate sunlight thrown to territory of Kazakhstan as 2200-3000 h per annum with solar irradiance of 1300-1800 kWh/sq.m. This tendency forms a steady solar profile and contribute to 0.5 MW of solar capacity generated in two solar panels located in the southern part of Kazakhstan. It is planned to increase the capacity to 713.5 MW by 2020 [18].

Hence regarding location preference one can suggest the Atyrau and Akmola regions of the country as most viable for the wind energy generation, while the southern realm: Kyzylorda and Shymkent regions have higher potential in solar energy production.

Today less than 1% of total power generation is contributed by renewable technologies, it is estimated that by 2050 this percentage will reach 50% due to sufficient capacity of DERs that may potentially satisfy the growing electricity demand [19].

V. VPP AROUND THE WORLD

A. Global VPP Market

Virtual power plant market is growing rapidly. As from the prediction, its market is going to rise from 191.5 million from 2016 to 1,187.5 million by 2023 [20],[21]. Major drivers are shift from centralized generation to distributed, wide integration of renewable energy sources and rising demand for cloud-based energy management systems [22]. Related to the global market geography, it constitutes of four major regions: North America, Europe, Asia Pacific and Rest of the world (mainly Middle East and Latin America). North America is a world leader in the gross value VPP market with a share of

exceeding 40%. The U.S. and Canada have been installing all types of renewable energy sources and adopting technologies for power distribution efficiency with minimum energy wastage. Also, these countries implement smart grid technologies for the advancing power evacuation infrastructure. The U.K. and Germany are forefronters in the European continent. By contrast Asia Pacific region is the fastest growing market due to rise in industry that adopts VPP solutions. Other emerging nations such as India, Brazil and Indonesia witnessed common power shortages due to the low quality of energy infrastructure. The fast economical rise in these nations has helped to fund the electricity sector to assist business and industrial activities. The developing investment in the energy area has ended in opportunities for modern solutions like VPP, which might be wished for a long time sustainability of newly evolved energy initiatives. Hence, an advancing power sector in emerging nations provides opportunities for the increase of the VPP market [23].

The global providers of VPP services are Siemens AG, ABB LTD, Enbala Power Networks, Autogrid Systems Inc, Sunverge Energy Inc and others. You et. al. [21] report that major inhibiting factors are of high capital costs for software control systems as well as adverse health effects due to Radio Frequency(RF) exposure.

B. Australia's VPP

Australia is one of the world's leading countries in VPP solutions and projects as now will be discussed in this section. Moreover, the country is similar to Kazakhstan in terms of geography, population density and energy generation. Hence, it is reasonable to study VPP projects of this country to analyse the feasibility of deployment VPP in Kazakhstan. As it can be seen from Table I, major energy patterns of two countries are relatively similar [22],[23].

TABLE I. AUSTRALIA VS. KAZAKHSTAN

	Australia	Kazakhstan
Population density(people/ sq.km)	3.14	6.62
Area (sq.km)	7,686,850	2,724,902
Electricity price per kWh	25 cents	5 cents
Energy generation	Coal – 63% Gas – 20% Hydro – 6% Wind – 4.7% Solar – 2.7%	Coal – 72% Gas – 14% Hydro – 12% Wind – 0.5% Solar – 0.5%
Energy consumption	Electricity supply - 28.5% Transport – 27% Manufacturing – 18.4% Mining – 10% Residential – 7.5%	Industry – 69.7% Households – 9.3% Service – 5.6% Transport – 5.6% Agriculture – 1.2%

The largest virtual power plant of the world is planning to be deployed in South Australia by Tesla company. The company plans to incorporate 50,000 homes fitted with sunlight based boards and Powerwall 2 home batteries [22],[25]. The project is intended to bring down private power rates and give grid stability. The 5kW sun oriented PV and 5kW/13.5kWh Powerwall home energy framework is relied upon to give a huge extent of households energy utilization. A self-powered home joins solar energy and Powerwall to autonomously supply a home. Amid the day, the sunlight based PV may deliver more electricity than the home consumes. Powerwall stores that abundance energy and makes it accessible when needed, even after the sunfall. Tesla application allows to observe each household energy use. In case if the house expends more power than is accessible from the energy framework, it will take from the main grid. All power devoured by the household (regardless of whether from the energy system or the grid) will be metered and charged for through the family unit power bill. The advantage for the household in being a part of the virtual power plant is that it will be charged an altogether diminished rate for its power utilization. Investigation by Frontier Economics demonstrates the VPP is relied upon to bring down electricity bills for participating households by around 30% [25].

VI. FEASIBILITY ANALYSIS FOR KAZAKHSTAN

A. Integration of DERs

First and the most important precondition for implementing VPP is existence of multiple distributed energy generation sources located near to the loads that they are serving. Moreover, the distance between each DER should not be very far in order to avoid transmission losses and operation maintenance. Figure 2 depicts current renewable power plants in Kazakhstan.

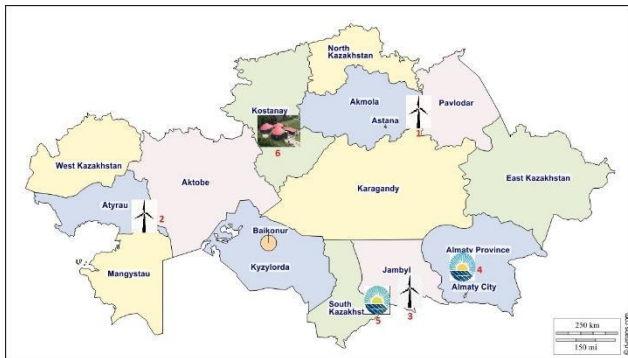


Figure 2. Renewable energy power plants in Kazakhstan

As it can be seen there are 6 such plants: 3 wind stations, 2 solar plants, 1 biogas plant with generating capacity more than 1MW. The territory of Kazakhstan is vast, so the viable areas for each type of renewable power plant vary. The distance between each power plant is more than 200km, except the 3rd and 5th stations from Figure 2. So in order to introduce VPP in Kazakhstan, there should be more of distributed energy units. Provided more distributed sources, there arises issue of

improving power reliability, maintaining voltage level, balancing supply and demand. EMS of VPP handles the above mentioned issues. The south-east part of Kazakhstan has high potential in both solar and wind energy generation. Furthermore, government has plans to construct 4 more alternative energy power plants in following decade in that region [21]. Thus, south-east Kazakhstan is the most adequate location for VPP emergence within Kazakhstan. This area includes South Kazakhstan, Jambyl and Almaty regions. It is also worth to consider the small scale power sources. Microgrids with own power generating capabilities play an important role in VPP system. Mostly such sources in a microgrid are solar panels and battery systems in residential. In Kazakhstan there are no such grids with multiple solar panels, because of high price for PV arrays and low price of grid electricity. For the improvement of generating capacity in a microgrid, more residents should own solar panels. Government should incentivize people to become prosumers. Prosumers are those who at the same time can produce and consume electricity (producers+consumers) [13]. Feed in tariff (FIT) introduced by government in 2014 incentives people to have own electricity generating sources. Excess energy can be sold to the grid at 10 cents/kWh [26]. This is twice as price of electricity from the grid. Such initiative would increase number of households with own energy source, consequently rising the demand for VPP system.

B. Electricity Price

Grid price for electricity in Kazakhstan is lower than most of the industrialized countries. From Table II it can be seen that in Kazakhstan on average 1 kWh costs 5 US cents. In Australia the price is five times higher, which equals to 25 cents. According to Mountain [27], before 2008 the electricity price in Australia was similar with US and average of EU. Nevertheless, starting from the year 2008, electricity price in Australia steadily increased. The dramatic rise in energy price causes more households to become prosumers because of concerns about saving on their electricity bills. Starting from 2016 Australia experienced realization of huge VPP projects like Tesla in South Australia and Origin in Victoria [25]. Private companies invest and deploy VPPs, in exchange to make profits by providing energy management services as well as by selling PV panels and batteries. If company as well as participating households forecast payback of investments after 5 years for running VPP project in Australia, in Kazakhstan since grid price is 1.5 times lower than in Australia even considering FIT, the payback period will be equal to 12.5 years. Therefore, low electricity prices inhibit the emergence of companies deploying VPP systems.

C. Simulation

This paragraph discusses simulation of possible VPP in Kazakhstan. As viable location Burnoye village was chosen which is located in Jambyl region of Southern Kazakhstan. There are two renewable power plants nearby, the first one is “Muzbel” wind station and the second one is “Burnoye solar” solar power plant. The demand of the village is 12 MW, and it is assumed that 800 households have energy storage systems

for demonstration purpose. The total capacity of batteries add up to 4MW and VPP considers it as a single BESS. EMS manages the power flow of given electrical network. The model is built on Simulink tool and is shown in Figure 3. Simulation plots are shown in Figure 4. Each of five rows in Figure 4 represent power profile output. They are from top to down: output of solar station, output of wind station, total power delivered from main grid, load demand and BESS output power. All the power profiles are in MW scale, while y-axis represents time in seconds. The plots are divided to 9 columns. First 8 columns are in 10^4 seconds duration, while last column represents 6.4×10^3 seconds duration, thus making total duration of 8.6×10^4 seconds (24 hours duration). The simulation is run with corresponding wind profile, solar irradiance and load demand. EMS of VPP gives priority to wind and solar stations in covering the load demand. Then the rest demand is supplied from the main grid. See the first plot (the top) in Figure 4, at time $t=4.32 \times 10^4$ seconds ($t=12$ hours, 5th column), partial shading was introduced, reducing the output of solar generation by 30%. In this case, part of the energy is supplied from the battery and is able to cover the deficient supply (see fifth plot corresponding to battery profile). Now consider the case when wind speed is

assumed to be high enough to temporarily shut down the wind station. See the second plot in Figure 4, at time $t=8 \times 10^4$ seconds (8th column) the output of wind station is zero, and EMS again allows injection from BESS to maintain the energy balance.

Overall, EMS proved to efficiently manage the complex grid system of Burnoye village with multiple power sources. It first gives priority to renewable power stations to consider the environmental factors and reduce the dependency from main grid. Also during sharp changes in the output of renewables, EMS allows batteries to provide deficient energy.

VII. CONCLUSION

Virtual Power Plant is one of the bright examples of digitization of energy in the scope of Industry 4.0 concept. Unified control over all units of VPP and intelligent coordination of power distribution to dispersed loads contribute to building a web-based networking of distributed power units based on advanced communication, cloud-based computing and IoT technologies. VPP can be useful in development of RES and increasing of their contribution to net power generation. This is extremely important considering the ever increasing electricity demand and primary energy sources depletion.

The arrangement of VPP in Kazakhstan may bring significant benefits in terms of transition to more efficient and environmentally friendly energy generation which is always a prior scenario. In this regard the resource assessment over the vast territory of Kazakhstan revealed existing and potential locations of wind and solar plants. Although the renewable energy plants are located in a dispersed way throughout the country, one can find South Kazakhstan, Jambyl and Almaty regions as ones where the plants are concentrated and subsequently the potential location of VPP can be pointed. The placement of VPP on the areas of these three regions may further trigger the construction of new renewable energy sources and handle the control over the complex becoming electrical grid. The case study was performed on “Burnoye solar” and “Muzbel” plants located in Jambyl region. The simulation results exhibit the efficient management of the complex grid due to priority-based load feeding: the power abrupt in one unit can be compensated by others giving lowest priority to the main power grid.

Actions to be taken to initiate the VPP arrangement in Kazakhstan should definitely include promotion of domestic energy generation ruling by the government and attraction of financial aid for development of renewable energy plants and advanced communication technologies with reasonable RoI period.

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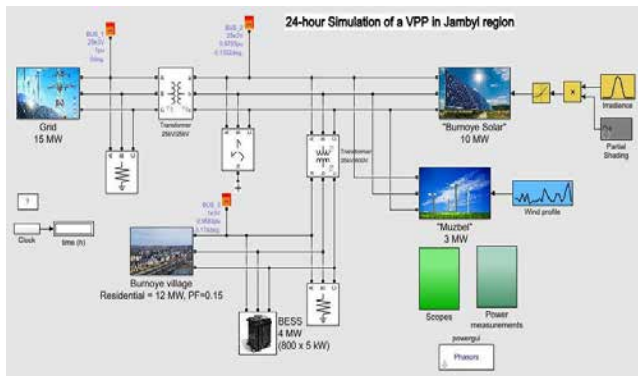


Figure 3. Model of the VPP system

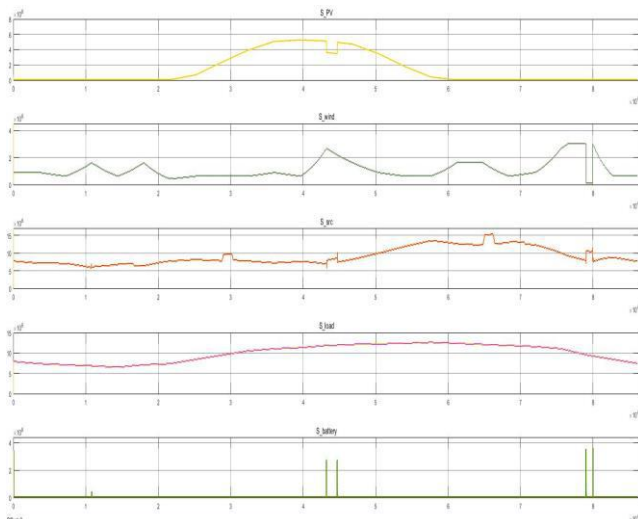


Figure 4. 24 hour simulation results

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