PV, BATTERY STORAGE AND ENERGY CONVERSION SYSTEM FOR MEETING PEAK LOAD IN A SUBSTATION

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ABSTRACT

Out of firm (OOF) conditions at a distribution substations may last for several hours and it is quite common in a rapidly growing distribution system like the one at Kahramaa (Qatar). Dealing with such a condition is a big challenge for network planners. Combination of renewable, power electronics and advent of more efficient storage systems can give innovative solutions to similar challenges. This paper describes a methodology of using energy storage system, including photo voltaic and battery storage, to provide energy during the peak hours of the day to avoid N-1 violation of reliability criteria. The methodology would be implemented at a selected substation, and the implementation process is also outlined in the paper. The application is inline with Kahramaa strategic plans to comply with Qatar National Vision 2030.

INTRODUCTION

Distribution grid can actually operate in unbalanced loading conditions and subject to overloads during peak hours. Custom power electronic devices have capacities to be integrated with battery storage or superconducting magnet storage and such integrations can allow a voltage injection with varying angles. The successful application in power electronics is due to the evolution of silicon voltage source converter (VSC) technology. The recent technology progress unveiled the advent of more techno-economic silicon carbide-SiC, which is expected to make some applications feasible for actual development that will serve the power utilities.

Battery storage integrated with solar Photo Voltaic (PV) is one of the most beneficial approaches of providing solutions to existing network. Storage devices are capable of assisting in the distributed generation power which can be useful in implementing renewable energy to power systems and also facilitate the implementation of smart and micro grids. Such DC generation systems need to be combined with DC/AC conversion using a suitable means of power electronics commutations.

Qatar General Electricity & Water Corporation (Kahramaa) is the sole responsible utility of transmission and distribution of electricity and water. Kahramaa, due to high and rapid growth in the electricity demand, is facing a big challenge to meet the load requirement at the distribution level following the reliability criteria. There are reasonable number of 66/11 kV distribution substations in Qatar Power System (QPS) with loading exceeded their firm N-1 capacities (25 or 40 MVA). While there is a five years statement plan to upgrade these substations or divert some loads from these substations to newly committed/commissioned substations, however, due to long lead time in implementing the projects, Planning Department of Kahramaa intends to investigate the potential application of renewable energy storage system integrated with the distribution substations to help shaving and balancing the peak loads at that substation.

The objective is to investigate the use of a mini-scale renewable in the form of solar cells integrated with storage battery system to produce power in the range of 5 to 10 MVA with a suitable power factor during the peak hours. The space at the roof of substation and free area available within the fence could be utilized efficiently for PV panels' installation. Qatar has the advantage that the peak hours occur mainly during the day time (peak time between 2:00pm – 3:00pm) and use of PV would be an ideal choice.

DAILY LOAD BEHAVOIUR AT SELECTED SUBTATIONS DURING SUMMER

Kahramaa distribution network is primarily fed from 66/11 or 132/11 kV substations with 25/40 MVA firm capacity. Many 66/11 kV substations known with out of firm (violating N-1 criteria) are considered for installation of the energy conversion system. Figure 1, shows the load profile of some of the substations during the day of 2011 system peak. As can be seen these substations remain out of firm (OOF) for many hours during the peak time and their load profiles make them good candidates for PV and energy storage application.

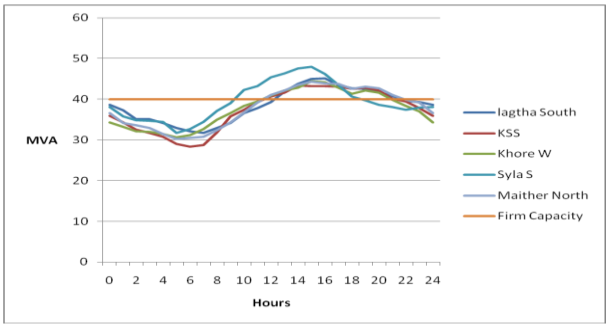

Figure 1: Load profile of some OOF substations during the day of 2011 system peak.

The task is to select a substation having an OOF condition within the range of 4-8 MVA and lasts for 6 to 10 hours. Also, the space availability and age of the substation equipment are key factors to be considered for selecting the candidate substation. Considering the above, Maither North substation seems to be a potential candidate for this project. The peak load recorded for this substation in summer 2011 was 44.5 MVA against a firm capacity of 40 MVA.

PHOTO VOLTAIC

Solar Energy Mapping of Qatar

Qatar is quite rich in terms of solar energy radiation since most of the year the weather is clear. The solar resource spatial distribution map for Qatar is developed under the project, *Qatar national food security program* [1] with average DNI as shown in Figure 2.

Figure 2: Solar resource spatial distribution [1].
Source: Satellite-based analysis for the time period 1999-2005 (7 years) using DLR-SOLEMI algorithm Data produced by DLR 2009.

According to the DLR map the DNI conditions are quite good in Qatar since annual cumulative DNI would be than 2075 kWh/(m²a) or higher in most places in Qatar. This indicates that there is a huge potential of taping solar energy through PVs and other similar solar technologies for electrical energy generation.

This project would be a stepping stone in entering to this field of energy conservation and getting experience with green field technologies through this first time pilot project on utility level in Qatar.

Land Requirements for PV Panels

Benchmarking with similar projects in other countries reveals that PV cells designed to produce 4 MW required an area of 45000 m² [2]. The land requirement is also studied for efficient solar panels commercially available in the market. It is found that a high efficiency commonly available panel of about 315W_p (262W_{max}) requires a dimension of 1.65x1.31 m^2. This implies that to have 1 MW of solar power, the solar panels area only would require at least 7000 m^2. Considering 40 % additional requirement for inter panels spaces and access corridors, the total area requirement comes around 9800 m^2/MW. Since, it is unlikely to have such a spare area available in an existing substation; it is intending to feed at least the substation auxiliary load from PV under this project.

Control of PV Panels

There are different types of PVs controls researched and developed in different applications depending upon the scale of energy required. There are PV controllers based on satellite data acquisition, while there are PV inverters rating up to 12 MW for VAr and dynamic controls. Some manufacturers introduced a wireless PVs monitoring and control system solution for individual panels tracking, unlike most residential PV systems. Complete monitoring and control solutions for PVs are available in the market including asset management and solar tracking.

If the PV panels are attached with batteries then another sort of control is required to prevent batteries over-charging and also to prevent reverse current from the batteries to the PVs during the night. The upcoming PV control will comply with statutory regulations for efficient and safe PV installation.

BATTERY STORAGE SYSTEM (BSS)

Battery storage system (BSS) is probably the oldest method of grid energy storage system which was in place during the direct current electric power networks. With the advent of very efficient, high energy density, high power and long life batteries, the BSS is having many grid applications including power, frequency and voltage stabilization. Sodium Sulphur and Vanadium Redox batteries are mainly used for grid energy storage. The BSS would require DC/AC (and vice versa) power conversion system (PCS) from the battery voltage to distribution voltage level (11 kV in this pilot case). Both BSS and PCS form a compact energy storage system (ESS).

Selection of Battery Type and Capacity

Figure 1, indicates that most of the substations were remained OOF for about 8-10 hours and the maximum loads were 4-8 MVA in excess of their firm capacities. In order to avoid OOF condition in future, it is estimated that a BSS of 8 MW/48 MWH would be sufficient. Mitsubishi has proposed containerized ESS of capacity 0.5 MWH with Lithium-Ion (LI) MHI batteries [2]. However, this system delivers ac power at 300 V, requires a lot of space and seems not suitable for KM application. Also, the LI batteries seem more suitable for fast load smoothing rather than load feeding for long time.

Sodium-Sulphur (NAS) batteries are relatively inexpensive, have high power, high energy density (3 times compared to conventional batteries) and have fast response (2 milliseconds), while they occupy third space footprint [3]. Therefore, it is conceived that NAS batteries are best suited for the application and are recommended to be used for the project.

Land Requirements for BSS and PCS

The typical installation area for NAS batteries is about W15mXD2.3mxH4.5m for 1 MW block (area of 34.5 m² for 1 MW and 138 m² for 4 MW (0.5 MW X 8 units) [3]. 34 MW of NAS battery system was installed for a wind and battery hybrid system in Japan in an area of 82mX33.5m [3] comprising of 17 units of 2 MW each. However, we believe that instead of splitting the batteries into many units and housing them in separate buildings it is more economical to house all the units in one building considering the limitation of available space.

Figure 3, shows a tentative layout of BSS for a 4 MW unit which is housed in a 21mX40m building [3]. In order to install 8 MW of BSS a similar layout could be used in the second floor of the building, however, since the substations are in the residential area and there are limitations imposed on the maximum height of buildings, it is more suitable to have a single story building with an area of about 2x(21mX40m) and have PV panels installed on the roof of the building.

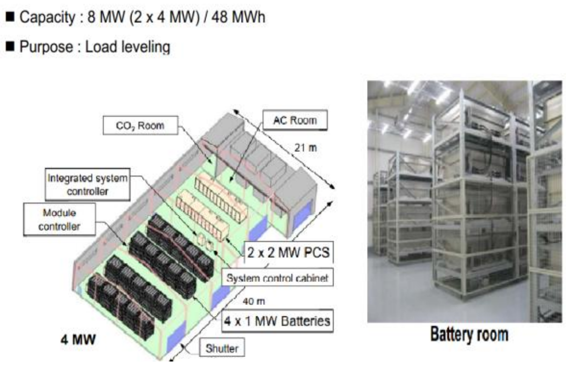

Figure 3: Lay out of a typical 4 MW BSS.

PROJECT PLAN

The layouts of the candidate substations were carefully reviewed for assessing the available area in the yard, at the roof and within the building for any required switchgear expansion. Considering the energy requirements, available land and substation's life, Maither North is selected for this PV and battery storage system project.

The total area of the selected substation is about 6900 m^2 and the empty space available for solar panels and battery storage system is about 5000 m^2. The estimated power output by solar panels utilizing this area would be in the range of 250-350 kW. It is, therefore, recommended to install an 8 MW/48 MWh BSS for load levelling and a PV solar energy system to feed the auxiliary load of the substation during the day with an integrated control system.

Figure 4, gives an overview of the available resources within the substation for energy conversion system. A conceptual layout of solar panels and BSS building is also shown in Figure 4. With this arrangement of solar panels it is expected to install at least 1000 panels with an expected output of about 262 kW (315 kWp) which is the required auxiliary load of the substation.

Figure 4: Conceptual layout of solar panels and BSS building in Maither North substation.

Maither North is a 66/11 kV 40 MVA feeder transformer substation.. Provision is available to add two bays at the existing 11kV switchgear which would be used to connect the BSS to the 11 kV busbar. The SLD of the substation is shown in Figure 5.

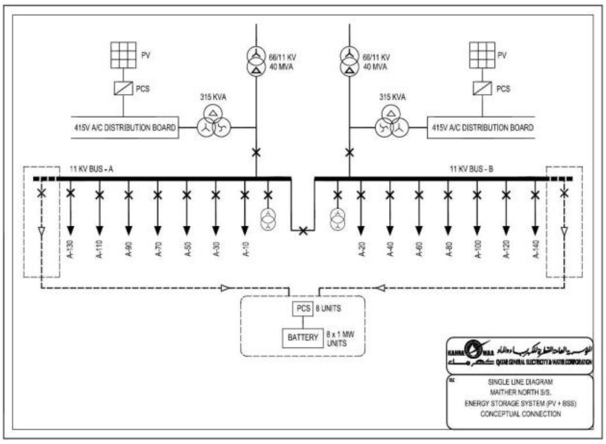

Figure 5: Single line diagram of the Maither North substation with conceptual connections of PV & BSS.

At present the auxiliary supply for the substation is taken from the earthing/auxiliary 11/0.415 kV 315 kVA transformers. It is recommended to connect the solar power output to the 415 V distribution board to feed the auxiliary load with suitable control.

CONTROL METHODOLOGY

Normally two kinds of control are available in the PCS, one is 'load following control' and the second is 'constant output power control'. In load following control the battery output follows the load profile and is adjusted to provide the additional power required for load levelling (in our case to avoid the OOF condition) as shown in Figure 6. In constant output control, a constant power of the battery is delivered during the peak hours irrespective of the load requirements as shown also in Figure 6.

Although, constant output control may be useful from overall system point of view when there are also some limitations on the generation side. However, in this case where there is a surplus generation available in the system, the load following control is more suitable considering battery life, longer discharging time window, etc. and is recommended for the project.

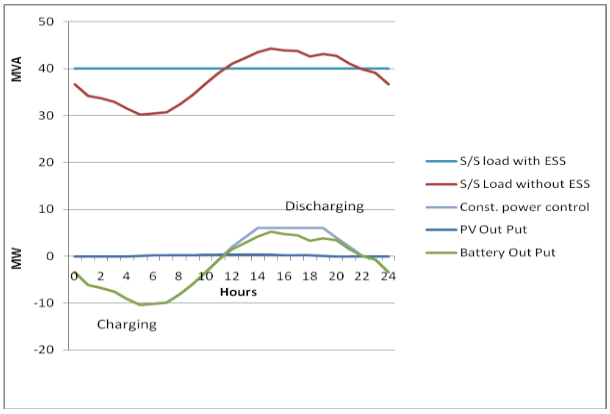

Figure 6: Battery output for load following and maximum output control philosophies.

Although the aspect of load levelling is considered only in this project, however other applications like voltage and frequency stabilization can also be included in the integrated control system to enhance the grid system performance when required [4, 5].

GENERAL COST OVERVIEW

A tentative cost analysis is described in this section. The market indicates that the NAS-BSS costs about $300/kWh on average [6]. The estimated energy requirement for this project is 48 MWh (8 MW output power) which makes the total tentative cost (EPC) for this project to be about $14.4M (52.5MQR), i.e., about 6.6 MQR/MW. This is almost three times the cost incurred on a standard distribution (66/11 kV) substation per MVA. However, to avoid OOF condition, Kahramaa needs to build a new substation with 40 MVA capacity. Also, the ESS is a generation rather than a distribution system, which might support the justification for new investment. Moreover, this ESS is a new technology, usually characterized as more expensive; however utilities would like to embark in new smart applications on pilot cases.

CONCLUSION

Electrical energy storage using integrated batteries and PV system, is rapidly evolving technology and is being accepted as a viable source and essential part of electricity delivery system. Its use in power as well as energy oriented applications is quite promising in the modern power system of the future. This batteries and PV system application, although small, satisfies part of Kahramaa long term objectives to utilize renewable energy as well as in the best use of energy conservation to minimize the total dependence on conventional fossil fuels. Kahramaa is in the process to align its long term strategies with the 2030 Qatar National Vision for renewable, including solar energy parallel to the energy conservation measures.

The concept for this energy storage system will be further studied for potential implementation. The basic concept report for the project will be prepared shortly for management approval.

REFERENCES

[1] Sogreah, March 2010, "*Qatar National Food Security Program-Consultancy service for detailed preliminary feasibility assessment*", Sogreah, France.

[2] Mitsubishi Heavy Industries Ltd. Presentation at Kahramaa, Oct. 2011, "Energy Storage System with Lithium-ion Battery".

[3] NGK Presentation at Kahramaa, Oct. 2010, "Application of Sodium-Sulfar (NAS) Batteries".

[4] Mitsubishi Heavy Industries Ltd. Presentation at Kahramaa, Oct. 2011, "Size estimation of Energy Storage System for Renewable Energy".

[5] Mitsubishi Heavy Industries Ltd. Presentation at Kahramaa, Oct. 2011, "Pre-Feasibility Study on Qatar *National Food Security Program*-Exchanging of Views with Kahramaa for Study on Energy System".

[6] Sandia National Laboraries, 2002, "Boulder City Battery Energy Storage Feasibility Study", SAND2002-0751.