COST-BENEFIT ANALYSIS OF INTEGRATION DER INTO DISTRIBUTION NETWORK

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ABSTRACT

The large integration of DER into distribution system has significantly changed the approach to planning, design and operation of distribution networks. Based on the cost and benefits of three sides (distribution network owner, EDR provider, and electricity user), this paper proposes a ***elemental calculation approach*** *to analysis the costs and benefits when DER is token as an alternative on network investment to meet special needs for special customer. A test example is used to verify the efficiency and effectiveness of the approach.*

INTRODUCTION

The basic task of power system is to provide the uninterrupted energy supply to every customer with reasonable price and reliability. The present policies framework worldwide is to encourage the integration of DER, from which the benefits for the sustainable socio-economic development include: reduce greenhouse gas emission (GHG), use of renewable energy, better to make energy conservation, and reduce environmental pollution.

The definition of distributed energy resources (DERs) in this paper consist of: (1) distributed generation (DG): uncontrollable Renewable Energy Resource (RES), controllable micro-turbine (nature gas); (2) electrical energy storage (EES) like pump storage, battery, etc; (3) electric vehicle (EV) and (4) demand side integration (DSI).

Originally, controllable DG and EES are applied in case of large scale power system could not provide the special reliability needed. That is, the time of interruption for energy not supply (ENS) should be less than one minute or better because the cost of interruption even for such a short time is quite high, almost ten times higher or above than the cost of regular electric tariff. There are many traditional schemes to prevent interruption of large scale power system for special customers to arrange the controllable DG and EES.

It is well know that distribution network means huge investment, and in the present stage, DER is still in small percentage to be integrated into distribution network. But looking into the near future, **DER make benefits on network investment such as**, an economic alternative to network reinforcement, increasing operational reliability, including power delivery, reduce electrical network loss, leading automation and control to improved network access for DG/load customers. The integration of distributed energy resources (DER) into the distribution network has significantly changed the approach to planning, design and operation of power system.

The large integration of DER make great impact on distribution network in the near future and make the distribution networks to change from passive into active. Based on 2008 WG C6.11: "Active distribution networks (ADNs) have systems in place to control a combination of distributed energy resources (DERs), defined as generators, loads and storage. Distribution system operators (DSOs) have the possibility of managing the electricity flows using a flexible network topology. DERs take some degree of responsibility for system support, which will depend on a suitable regulatory environment and connection agreement."

Based on the cost and benefits from three sides (power system, DER provider and electricity user), this paper firstly proposes a **elemental analysis approach** to analysis the costs and benefits when DER is taken as an alternative on network investment to meet special needs for special customer; secondly to analysis the impact of integration of DER on distribution system, thirdly to analysis the possible alternatives of DER; fourthly to give the evaluation procedure of cost-benefit of DER. Test examples are used to verify the efficiency and effectiveness of the approach.

THE GENERAL ANALYSIS APPROACH

The approach of cost-benefit analysis of integration DER into distribution network is proposed as follows [1]:

(1) **Analysis the impacts of DER on the existing network**: the conditions of existing network, the condition to improve reliability, Network Sel-healing Requirements
(2) **Analysis the possible alternatives of DER:** The access of distributed energy storage, the integration of DG, the interactive of load.
(3) **Set up the objective of integration of DER: Objective** function-1 is to minimize four kinds of cost: distribution network investments and operation cost as well as DER investments and its operation cost separately. Objective function-2 is to maximize the DER energy, by which the carbon emissions can

be as low as possible.

(4) **Set up constraints to integrate DER:** line power **balance** constraints, substation power balance constraints, Load growth exception, reliability requirement, DER constraints:

(5) **Evaluation of cost-benefits**: Evaluation methods should be judged that whether it is based on system approach and the principle of minimum cost or based on **the** project orientated approach. The system approach is in terms of quantity, quality and cost, emphasizing the maximization of the marginal cost-effectiveness for reliability. The project orientated approach is only to determine the amount of the total investment costs for each project. Especially, it is necessary to consider the cost benefits when improving the reliability of the network.

(6) **Decide the optimal alternative** for the specific user based on Cost/benefit marginal **analysis**.

THE IMPACTS OF DER ON THE NETWORK

The capacity of DG is limited when integrating into the distribution network, no matter controllable or uncontrollable, showing in Table.1

Table.1. Per unit range of DG in the voltage level

No.	Voltage level	Capacity
1	0.4kV	< 1.5MW
2	10kV	0.2-2MW
3	20kV	0.2-2MW
4	35kV	2-10MW

This section gives the positive and negative impacts of DER on the network as follows:

(1) Positive impacts:

- postpone the investment of network
- reduce the cost to enhance reliability
- decrease the loss of network because DER is locate near to load
- provide emergency power
- improve grid reliability standards

(2) Negative impacts:

- more investment for network to upgrade the capacity to integrate DER
- reduce the equipment ratio, to be backup for RES
- reduce the energy sales of the network during DER normal operation
- increase the complexity of operation scheduling, especially in small-capacity DER access, affect the safe operation of the distribution network (even cause personal injury) when scheduling and controlling DER access to and exit from
- increase the frangibility of lager disturbing

THE POSSIBLE ALTERNATIVES OF DER

As mentioned before, there are 4 types of DER in this paper: (1) DG: uncontrollable RES and controllable DG; (2) EES: pump storage, battery, etc; (3) EV, which may be taken as a type of EES; and (4) DSI, which may make load curve even, no matter which kind of DG.

EES can potentially smooth the variability in power flow from renewable generation and store renewable energy so that renewable generation can be scheduled to provide specific amounts of power, which can decrease the cost of integrating renewable power with the electricity grid, increase market penetration of renewable energy, and lead to greenhouse gas emission (GHG) reductions. Therefore, EES is analyzed in detail in this paper. Electric energy storage (EES) uses forms of energy such as chemical, kinetic, or potential energy to store energy that will later be converted to electricity.

EES provide many benefits, such as
(1) Decreasing peak demand by using electricity stored during periods of lower demand.
(2) Balancing electricity supply and demand fluctuations over a period of seconds and minutes.
(3) Deferring expansions of electric grid capacity.
(4) Promises other benefits unrelated to renewable energy, such as improved grid reliability and stability.
(4) Deferral of new generation and transmission investments, and other grid benefits.

THE EVALUATION PROCEDURE OF COST-BENEFITS OF DER

The load curves can be divided into two categories: even and uneven. For the even load curve, the DER can be integrated at any time; for the uneven curve, the integration of DER must be optimized according to the constraints of network, DER and operation.

To integrate DER into distribution network, three sides (distribution network owner, EDR provider, and electricity user) might pay different cost and obtain different benefits.The evaluation procedure of cost-benefits of DER is as following,

(1) Determine the cost of the system with DER
The cost consists of the following two parts:

- Cost of network

Including the construction cost of the base network.

- Cost of DER provider

Including the capital investment for equipment, the operation and maintenance cost, also for the necessary network enhancement.

(2) Determine the benefit of the system with DER
The benefit consists of the following two parts:

- Benefit of new energy by peak shaving

The new energy power generation can evidently reduce the maximum load, so the revenue of new energy by peak shaving is equal to the capacity of the maximum load reduction multiply the power supply invest.

- Benefit of interruption cost reduction

The integration of DER can evidently reduce the interruption cost, so the benefit of interruption cost reduction is equal to the interruption time reduction plus the every hour interruption losses.

- The environment benefit of new energy generation

The integration of DER can evidently reduce the carbon emissions, so the environment benefit of new energy generation is equal to the average annual generation capacity(kWh) multiply s the every kWh coal consumption (g/ kWh).

(3) Determine the marginal cost-benefit of the system with DER and without DER

The marginal cost-benefit of the system with DER and without DER can be determined by the following equation [2].

$$iB/C=\Delta B/\Delta C$$

EXAMPLES

Two examples are given here to validate the evaluation procedure of cost-benefit of DER. The first example is based on a small scale system with even load curve. The second example is based on the larger scale system with uneven load curve which has been optimized [3] by pump storage.

Small scale system

Taking one company in Wuhan as an example, the load of the whole company is 20 MW, of which the critical load is 2.4 MW. In order to improve the reliability of the critical load (reliability up to 99.9999999%), all of these critical loads are protected by the DC-BUS system. 3.3 MW solar panels are built in the roof of company building, the maximum output of this solar system is 3MW with average 1.6MW output.

The solar system can reduce 3MW of the maximum load, which means it can effectively eliminate 15% of the peak load. The average day generation is up to 7500kWh, and the average annual RES generation is 2.73 million kWh. The load curve with and without PV generation is shown in Fig.1 and the configuration of DC-BUS system is shown in Fig2.The cost-benefit analysis is as following:

(1) Determine the cost of the system with DER

- Total cost for network investment=24million

  Where：

  Total Cost=network capacity*cost of per KW =40MW*6000Yuan/kW = 24million Yuan

- Total cost of DER (5 years) =60 million

  Where：

  a. Capital cost of DC-BUS system = 6.5million

  b. (O&M) cost = 0.96 million (5 years)

  Note：O&M is Operation and maintenance

  c. The Capital cost of PV = 51.58 million

  d. O&M cost of PV =0.265 million.

- Interruption cost of user (5 years) = 156million

Where each voltage drop causes 8h production interruption, the cost of loss supply is at least 13 million. The cost of loss in 5 years is at least 156 million.

(2) Determine the benefit of the system with DER

- The benefit by peak shaving with DER =18 million

Where：

The benefit ＝capacity of peak shaving*cost per KW= 3MW*6000Yuan/kW*1000=18 million, which can delay the investment for distribution network.

- The benefit by PV generation=4777.5t coal

Where：

The environment benefit of new energy generation because of PV generation(5years) = PV annual generation(kWh)* coal(gram/kWh)*5years =2.73 million kWh * 350g/ kWh*5years= 955.5t coal (350g coal consumption/ kWh).

(3) Determine the marginal cost-benefit of the system with DER and without DER

The marginal cost-benefit of DER is：

ΔB=156+18=174million

ΔC=(24+156)-(24+60)=96million

Ratio of $\Delta B/\Delta C$=1.81.

Because the ratio of marginal cost-benefit of DER is greater than 1.0, which means that DC-BUS system with PV is a meaningful investment for the user with high reliability.

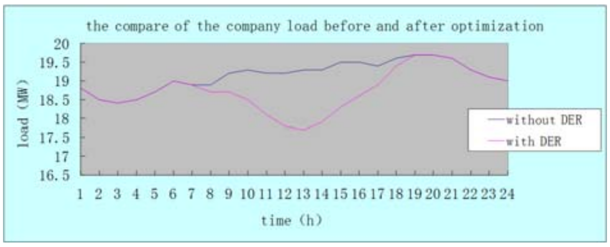

Fig1. Load curve with and without PV generation

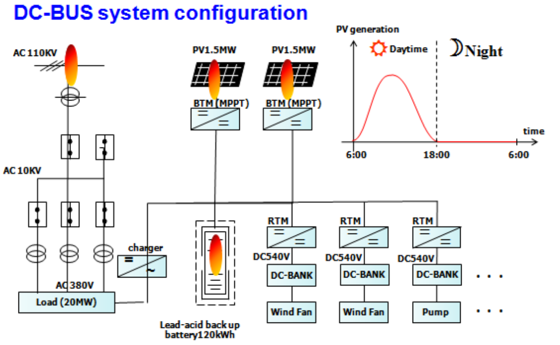

Fig.2 Configuration of DC-BUS system

Lager scale system results

This example is large-scale system with big capacity of pump storage. The installed capacity of thermal power is 10315MW, the hydropower is 924MW, and the pumped storage is 1200MW.

The maximum and minimum load before optimization is 7000MW and 4350MW respectively, and the maximum peak-valley difference is up to 2650MW. After the optimization, the maximum and minimum load is 5244MW and 4800MW respectively, and the peak-valley difference is reduced into 575MW which is less than one-fifth of the original. The load curve is shown in Fig.3. The peak shaving is about 1756MW (7000MW-5244MW), and the generation in peak hours is about 5000MWh and the generation in valley hours is about 7500MWh. The cost-benefit analysis is as following:.

(1) Determine the cost of the system with DER

- Investment cost of the system=6743.4million

Where cost of the system = capacity of generation unit * per KW cost of generation unit = (10315MW+924MW) * 6000Yuan/kW = 6743.4million Yuan

- Investment cost of pump storage=420million

Where cost of storage = storage capacity * per KW cost of storage = 1200MW * 3500 Yuan/kW = 420million

(2) Determine the benefit of the system with DER

- Benefit of peak shaving by storage= 500million

If the 1756MW by peak shaving is to be generated by the hot standby unit, then it requires 2000MW, that is to say, peak shaving can great delay the thermal installation investment. So the benefit of peak shaving by storage = capacity of peak shaving * cost of per kW by storage = 2000MW * (6000-3500) Yuan/kW = 500million

- Benefit of tariff reduction by storage =180million

Assume the peak tariff is 0.6Yuan/kWh, the valley tariff is 0.3Yuan/kWh and interruption cost for user is 1000Yuan/kWh, then the amount tariff benefit = (peak generation * peak tariff – valley generation * valley tariff) * interruption cost = (5000*0.6-7500*0.3) * 1000 Yuan/kWh = 0.9 million Yuan. Assume the maximum load utilization hour is 4800h, so the annual benefit/year = 200days * 0.9milliom = 180million. Even taking the operating cost into account, the investment can be covered in several years.

- Benefit of reliability for user =29million

Assume the forced outage probability of pumped storage and thermal unit is 0.1% and 0.39% respectively, the generation of the pumped storage units in peak hours is 5000MWh, then the day reliability benefit = Forced outage probability of (thermal unit - pumped storage unit) * peak generation by storage(MWh) * interruption cost for user (0.39%-0.1%) * 5000MWh * 10000Yuan/MWh = 0.145million, and the reliability benefit within 200 days of per year = 0.145million*200=29million.

(3) Determine the marginal cost-benefit of the system with DER and without DER

- The marginal cost-benefit of storage is
  Δ B=500+180+29=709million
  Δ C=420million
- Ratio of marginal cost-benefit = Δ B/ Δ C=1.69.

Because the ratio is greater than 1.0, it means a meaningful investment for the investment of pump storage. Therefore, for the benefits created either from the peak-valley tariff difference or from the thermal units commitment cost reduction, the economic benefits of this optimization result is very impressive

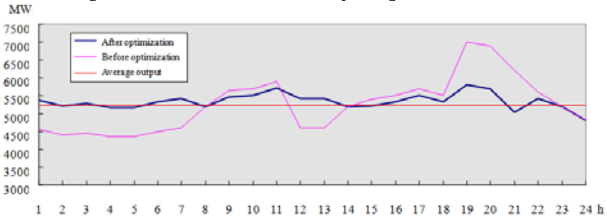

Fig.3 load curve with and without pump storage

CONCLUSIONS

Various considerations and impacts on the distribution planning to facilitate the transition towards active distribution networks (ADNs) were studied in detail. A comprehensive analysis approach with DER and without DER was proposed in this paper. The proposed approach was verified to be reasonable by two test examples. The study is a new attempt for the future study on ADNs planning.

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