DC ELECTRICAL DISTRIBUTION SYSTEMS IN BUILDINGS

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Abstract

With the gaining of popularity of concept of distribution generation (DG) and sustainable development, DG with renewable energy (RE) sources is one of the possible ways for building energy supply in the future. The current "DC-AC-DC" route from DG to DC loads via inverters may not be rational from the viewpoint of system simplicity and energy efficiency, a review on the current electrical distribution systems should be made. This paper reviews and evaluates possibilities of using DC electrical distribution systems with increasing RE resources and DC loads. There is potential of increasing energy efficiency and power quality. Drawbacks and merits will also be identified.

Keywords: distributed generation, building distribution system, energy efficiency, DC system, renewable energy

INTRODUCTION

AC system has been a standard for electricity distribution in buildings for a long time. It is rational to use AC rather than DC as traditionally most of the loads (such as motors, lighting) adapt AC very well and it is convenient to distribute power from power plants, which are also AC in nature, over long distance. However, with the gaining of popularity of concept of distribution generation (DG) and sustainable development, it is clear that DG with renewable energy (RE) sources is the way for building energy supply in the future. From the supply side, DG is constituted by small size local generators and storage systems that generate DC, such as photovoltaics (PV) and fuel cells. These DC systems use grid-connected inverters to interface with the AC grid. From the demand side, number of electrical apparatus which use DC is increasing due to rapid development of electronics technologies. Examples include cell phone chargers, computers and network equipment, UPS and emerging LED lighting technologies which is believed to be for the future interior lighting. For example, Kurtz [1] stated that LED lighting and PV have similarities and have potentials to save enormous amount of electricity.

Currently all these devices use PWM-based AC-DC converters to interface with the AC grid. The "DC-AC-DC" route from DG to DC loads may not be rational from the viewpoint of system simplicity and energy efficiency.

There is an incentive to look for alternative distribution systems, which have been suggested in various literatures. Larruskain et al [2] has pointed out that DC transmission has more advanatages such as stability, controlled emergency support and no contribution to short circuit level. Brush's survey [3] indicated the trend of switching from centralized power to distributed power architectures. Local DC distribution network with DG resources has also been proposed by Brenna et al [h], therefore a review on current electrical distribution systems should be made to adapt the trend.

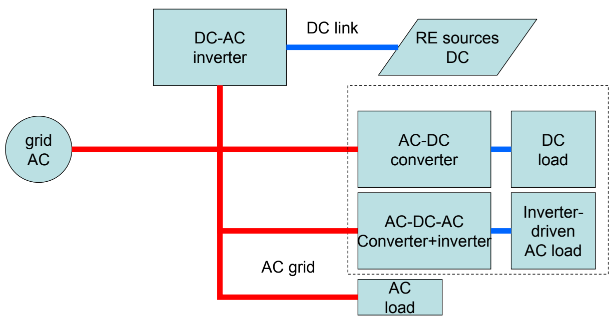

Fig.1: Schematic of current building's distributions system

THE APPROACH

As both the energy source and loads are getting towards DC, it is logical to have a preliminary analysis on a DC distribution system for a building as the first step of investigating alternatives of electrical distribution systems in buildings.

An analysis on the impact of changing from existing AC system to DC system has been performed by a case study. In order not to complicate the analysis and serves as a preliminary study, we assume the existing 220V (380V peak) 3-phase AC system is replaced by a corresponding centralized DC system rated at 400V and evaluate potential energy savings that can be achieved by loss reduction in distribution system of a 30-storey (100m) high building, which is typical in Hong Kong.

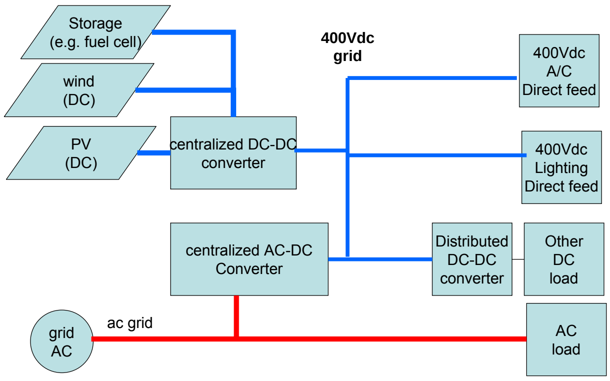

Fig.2: Schematic of proposed distributions system

Efficiency improvement on distribution system

A schematic of a building's electrical distribution system is shown below:

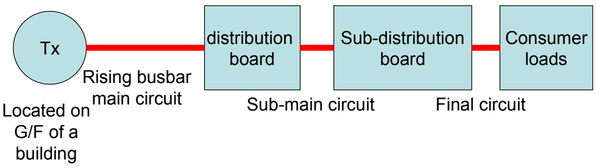

Fig. 3: Illustration of main circuit and sub-main circuit of a building

Main circuit (100m running from Tx to roof)		
System	3-phase 4-wire 380V 400A	400Vdc 380A 2-wire system
CSA (mm^2)	185	185
Voltage drop (mV/A/m)	0.21	0.23
Distribution loss	2.2%	2.2%

Table 1: Comparison of distribution loss between AC and proposed DC system in main circuit

At this point, there is no significant difference in terms of energy loss. Then the situation in sub-main circuit was analyzed:

Sub-main (40m running from main to distribution board)			
System	1-phase 2-wire 220V 100A	400Vdc 55A 2-wire system	
CSA (mm^2)	35	16	35
Voltage drop (mV/A/m)	1.25	2.8	1.25
Distribution loss	2.27%	1.54%	0.69%

Table 2: Comparison of distribution loss between AC and proposed DC system in sub-main circuit

Distribution loss has decreased in DC system, and no significant amount of copper could be saved, so is the case in final circuit:

Final circuit (20m running from distribution board to socket)		
System	1-phase 2-wire 220V 15A system	400Vdc 8A 2-wire system
CSA (mm^2)	2.5	2.5
Voltage drop (mV/A/m)	78	78
Distribution loss	2.45% loss (5.4V drop)	0.74% loss (2.97Vdrop)

Table 3: Comparison of distribution loss between AC and proposed DC system in final circuit

The overall distribution loss is found by integrating three sub-systems into one:

Efficiency (1-loss)	220Vac	400Vdc
1. Main	97.8%	97.8%
2. Sub-main	97.79%	99.31%
3. Final circuit	97.55%	99.26%
Overall (1)x(2)x(3)	92.3% (7.7% loss)	96.41% (3.59% loss)
Difference $\Delta\eta_{db}$	4.11%	

Table 4: Overall distribution loss comparison

Reduction of distribution loss is mainly contributed by the sub-main and final circuit, overall a 3% improvement can be achieved.

Efficiency improvement on converters

Both AC-DC and DC-DC systems require converters or inverters. They play a key role in determining overall efficiency of a distribution system. A simple survey of efficiency of different converters/inverters at different power ratings available in commercial market has been done.

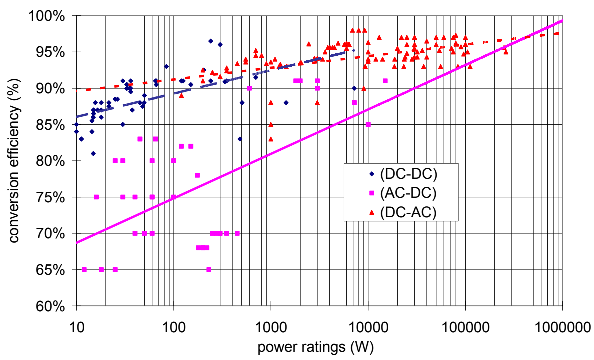

Fig. 4: Efficiency against power ratings for different converters in the commercial market

From the graph, it is observed that:

(1) both DC-DC and AC-DC converters efficiency increase with power ratings.

(2) Efficiency difference between DC-DC and AC-DC converters decreases as power ratings increases

Load type and distribution

Secondly we analyze energy usage in different sectors in Hong Kong [5]:

Usage	Air conditioning	Office equipment	Lighting	Others
Commercial				
Office	47.8%	21.8%	18.9%	11.45%
Others	17.91%	2.7%	11.4%	67.9%
School*	30.9%	NA	NA	NA
Residential housing				
Public	22.85%	NA	19.95%	NA
Private	25%	NA	24.15%	NA

* data provided by Ma Wan Primary school

Table 5: Energy usage by different sectors in Hong Kong

It is clear that air-conditioning consumes most of the electricity in Hong Kong in various sectors. Most of the consumers in Hong Kong have been trying hard to cut down consumption from air-conditioning in various ways either by using inverter-driven split-type air conditioners (for residential consumers) or replaces window-type air-conditioners to central HVAC systems.

Nasution et al [6] stated that air-conditioning systems originally operating on a constant speed mode can be retrofitted with an inverter-driven system and the energy saving is estimated to reach 25.3%. Reviews by Mitsubishi Heavy Industries draw a similar conclusion [7] which estimated a saving of 38% can be done. It can be seen that improving air-conditioning system has big potentials in improving energy efficiency. In addition to this, one may regard air conditioners, shifting from AC-operated constant-speed mode to DC-operated inverter-driven mode, are "retrofits" since the inverters used are composed of AC-DC and DC-AC conversion. It is clear that the system can be simplified by eliminating AC-DC part if the energy source is already DC.

Similar cases happen in office equipments, computers and lighting. Currently there is a mismatch between the source and these equipments as they all consume DC. Although modern AC-DC converters attached with these equipments are all PWM-based but from Fig. 1 it is clear that DC-DC conversion has a higher efficiency.

It is interesting to understand efficiency improvement on these loads by changing the distribution system. A simple survey and analysis has been done with the information from Fig. 4

Equipment	AC network	DC network	Change.
Inverter-driven Air-conditioner 2kW (1)	AC-DC-AC 83% x 93%=77%	DC-AC 93%	16%
Inverter-driven Air-conditioner 10kW (2)	AC-DC-AC 87% x 95%=83%	DC-AC 95%	12%
Office system equipment (3)	AC-DC 78%	$400V_{DC}$ - $?V_{DC}$ 92%	14%
Lighting (4)	AC-DC-AC 70% x 87%=60.9%	DC-AC 87%	26%

(1) typical residential air-conditioners in Hong Kong
(2) typical commercial air-conditioners in Hong Kong
(3) Assume a typical 300W AC-DC converter of PC
(4) typical 20W fluorescent tube in Hong Kong office

Table 6: Potential efficiency improvement of different equipment by switching from AC to DC network

Efficiency improvements on each type of equipment are now available and incorporated with the weight factors from Table 5 to estimate the final efficiency improvement ( ) on different building sectors:

	Load	A/C	O/E	Lighting	Others
Office	Weight	0.48	0.22	0.19	0.11
		12%	14%	26%	0%
Public housing	Weight	0.18	0.027	0.114	0.679
		12%	14%	26%	0%
Schools	Weight	0.309	0.27	0.22	0.19
		16%	14%	26%	0%
$\Delta\eta_{db}$	+4.11%				

Type	Office	Residential	Schools
$\Delta\eta_{db}$	17.7%	9.49%	18.7%

Table 7: Efficiency improvement of different building sectors considering the weight of different electrical loads used

A simple case study

As mentioned earlier, a DC system provides advantages for renewable energy systems as it may simplify grid-connection issue. It is worthwhile to study the potential savings of a building with RE resources. The Ma Wan Primary School in Hong Kong is a school with a 40kW rated PV system, 33756kWh of DC electricity [8], or 8.7% of the school's total consumption, has been generated from September 2004 to August 2005.

An quantitative analysis has been done to see the potential savings in financial terms:

Type	Consumption	Improvement
A/C (2kW)	121.8 MWh	23.1MWh (16%)
O/E	106.3	18.0 (14%)
Lighting	90.5	23.5 (26%)
Others	75.1	0(1)
Total per annum	393.7	64.7 MWh
tariff=HKD0.964/kWh		HKD 62416

(1) assume no improvement on other loads

Table 8: electricity consumption in Ma Wan Primary School and potential improvement

16% of electricity can be saved if the generic DC distribution system replaces current 3-phase 4-wire AC system. Also, it helps boosting PV performance by improving performance of power conditioning unit, which will be a DC-DC converter instead of a grid-connected inverter:

Annual generation (DC)	33756kWh
Annual generation (AC)	29637kWh
DC-AC efficiency	87.8%
DC-DC efficiency if DC system is used (assume 4x10kW)	95%
Improvement	2430kWh

Table 9: summary of potential improvement of PV system performance

OTHER MERITS AND DRAWBACKS

From the results illustrated above, it is observed that energy efficiency can be achieved by alternating current electrical distribution systems in a building. In additional to this major advantage, other benefits should not be neglected,

Savings in material cost and capital equipment

From the analysis listed above concerning the main circuit, it is noted that potential material saving can be achieved by replacing a 4-wire system. Suppose a 2-wire DC system is chosen, then at least 50% of conductor material can be saved and thus the cost. As the DC system eliminates the AC-DC part in inverter-driven loads, there should be savings in materials in the products as no rectification or power correction front end is needed. Reduction of building distribution system cost may be achieved by simplifying the whole distribution network. However, this is only the case for new buildings. Existing buildings with AC distribution network may require high capital cost to retrofit a DC network or switch from AC to DC network. Also there may be extra cost for DC protection equipment (compared with AC of same power rating).

Power quality issues

As the distribution system is now in DC, there should be no low order harmonics in the building distribution system.

Reliability

There is potential increase of reliability of DC system over AC system. DC system can interface more easily with large-scale storage facilities such as fuel cell and other types of batteries. “Premium power”, in terms of quality and reliability, can be provided. This is also beneficial to the utilities as Asahara et al [9] pointed out that stable power supply to customers is the most basic service and maintenance works, which causes outage, are constantly required.

System simplicity with RE

Although grid-connecting a RE system to the grid is accepted worldwide, some countries and regions still have no relevant experiences or laws to encourage such installations. Utilities in these regions may be conservative to grid-connection. It is believed that a local DC distribution network can facilitate the “grid-connection” of a RE system by providing a DC interface, which may not be part of the utility network. However, this has to be further explored as this involves the arrangement of metering by the utilities.

Other potential issues

Although the proposed generic system has a similar voltage to the existing distribution system, safety issues such as insulation requirement is also a matter of concern. Contact corrosion, although outside the scope of electrical engineers, is also a major issue that should not be neglected.

CONCLUSION

In this paper, a generic DC distribution system within a building has been proposed and the possibility of replacing existing AC distribution system has been discussed. It is concluded that in general DC system can improve energy efficiencies by simplifying system structures and improving conversion efficiencies of various converters. Other potential benefits and drawbacks have also been discussed.

It has to be stressed that the proposed generic DC distribution system is not a finalized proposal as this only serves the purpose of exploring alternatives of distribution systems. For example, determining appropriate voltage level, relevant safety issues should not be neglected. The proposed system not only involves enormous changes in designing building electrical distribution system but also in designing electrical appliances. If the change really occurs, there may be potential chaos in transitional stage, therefore more researches should be done to investigate the practicality of this proposed system before a long-term and profound change is made.

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