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Impact of Distributed Generation Technologies on Generation Curtailment in Pakistan

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ABSTRACT

Distributed Generation (DG) in Pakistan is being operated both privately and publicly and integrated in the main distribution network. This paper presents the distribution technologies impact on the 11KV distribution network of Water and Power Development Authority (WAPDA) Pakistan. A reference network, based on the existing WAPDA network has been considered, which consists of generation dominated areas. This network is used to examine the effect of a new DG connection to an existing network or a bus bar. DG associated parameters such as DG contracts; the capacity factor and the levelized cost of electricity generation are considered in this paper. The load flow analysis has been carried out in ETAP software which shows that mixing of DG technologies have a profound impact on the quantity and the cost of generation curtailment.

Keywords: *Distributed generation, DG contract, Capacity factor, Levelized cost of electricity generation, Generation curtailment*

1. INTRODUCTION

Distributed Generations (DG) currently have a very low penetration in electricity distribution networks of Pakistan. The Government of Pakistan has taken some positive steps in order to increase the addition of DGs in the existing distribution network. This initiative of the Government towards DGs development has encouraged the private investors and numerous projects have been launched in both private and government sector. Introduction of supporting regulations and mechanisms will attract more people, individuals, groups, communities or businesses, to further invest in DGs [1].

The new DG connection to an existing distribution network directly affects the power flow in the network. In a generation dominated area, new DG connection will cause the additional power flow form generation dominated area to the network which will increase the use of the network capacity. On the other hand, in a demand dominated area a new DG connection will reduce the power flow on local network because the output of connected DG will be directly passed to the local demand. It means the use of network capacity is curtailed as electricity is directly transferred from the network to the demand dominated area. While the addition of DG in generation dominated area leads to excess capacity of the network. Hence, generation curtailment is required—a method to reduce the output from generations in order to match the network capacity.

A number of studies and researches have been conducted related to generation curtailment, especially wind energy curtailment [2, 3]. Also to facilitate generation curtailment some mechanisms have been introduced, such as voltage constraint management, active network management [4, 5] active power flow management [6] and a decentralized voltage control mechanism [7].

This paper discusses an important factor i.e. how DG technologies affect generation curtailment. There are three parameters associated with the DG technologies, i.e. the types of DG contract, the capacity factor and the levelized cost of electricity generation, to determine the quantity and the cost of generation curtailment.

2. DISTRIBUTED GENERATION IN PAKISTAN

2.1 Current DG Technologies

DG has many kinds of technologies, including Wind, Biomass/Waste, CHP and Micro-generation. Micro-generation is a type of smaller generation with capacities measured in kW (less than 50 kW), mostly consists of renewable generations, such as small hydro, wind, solar power, and smaller Combined Heat and Power [4].

Total installed capacity in Pakistan is 21.375 GW, which consists of 7.097 GW hydel power against the potential of 45 GW, while 13.507 GW thermal power generation, 665 MW nuclear power generation and 106 MW wind power generation. Pakistan has rich potential of more than 100 GW from solar energy, wind potential ranging from 10 GW to 50 GW. Initiatives have been taken by the government of Pakistan in order to attract more investors to invest in DG due to which number of DGs projects have been launched such as Jhampir Wind Energy Project and Foundation Wind Energy limited etc. while numerous DG projects are in pipeline and are in different stages in wind, solar, small biomass and small hydro power generation [1, 8]. These DG power plants have already added substantial amount of power in the existing network while more will be added in near future. But still large efforts are required to exploit these DG sources to their peak.

2.2 Types of DG Contract

In order to provide the DG power to consumer every DG developer needs a new connection to a distribution network, so they need to sign a contract with the Distribution Network Operator. There are three types of DG contracts in the Pakistan, i.e. Base Load Contract,

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Day Time Contract and Night Time Contract. Generators with base load contracts will produce their output on a must-take basis for 24 hours. The Daytime Contract will allow generators to be operated during daytime between 7am and 7pm (12 hours). The Night Time Contract generators will operate during night time hours, between 7pm and 7am (12 hours). The division of DG contract types is based on the load shape in the day [9].

2.3 DG Capacity Factor

The capacity factor is the generator's actual energy output for a given period of time divided by the theoretical energy output when the generator is operating at full rated power for the same period. This factor indirectly is an indicator of the reliability of supply. The capacity factor of various electricity generation types is given in Table I [10].

Table 1: Generation Capacity Factor

Type of Generation	Capacity Factor
Offshore wind [8]	32%
Hydro (run of river) [15]	60%
Hydro (reservoir) [15]	65%
Solar PV [11]	16.8-17.5%
Biomass [16]	50%
CHP [18]	60%

2.4 Levelised Cost of Electricity Generation (LCG)

Levelized cost of electricity generation is the ratio of all associated costs to generate electricity from a power plant over its lifetime [10]. The value of LCG is expressed in Rs./kWh and it varies for each power plant, as presented in Table II [10].

Table 2: Levelised Cost of Electricity Generation

Technology	LCG (Rs./kWh)	Technology	LCG (Rs./kWh)
Wind [12]	12.6	10 MW Gas CHP [17]	11.74
Small Hydro[14]	9.08	CCGT CHP [10]	10.87 – 12.95
Solar PV [11]	16.30-17	Small Biomass CHP [16]	10.62

The above tariff has been worked out on the basis of PKR/US$ rate of Rs.100.0

3. CASE STUDY

3.1 Reference Network

A reference network is used to find out the effect of a new DG connection to an existing line or network. Five voltage levels are used in the reference network, i.e. 220kV, 132kV, 33kV, 11kV and 0.4kV. The reference network is depicted in Figure 1. There are sixteen bus bars on the network which consist of one 220kV bus bar, one 132kV bus bar, three 33kV bus bars, seven 11kV bus bars and four 0.4kV bus bars. These bus bars will supply five demand dominated area bus bars and three generation dominated area bus bars.

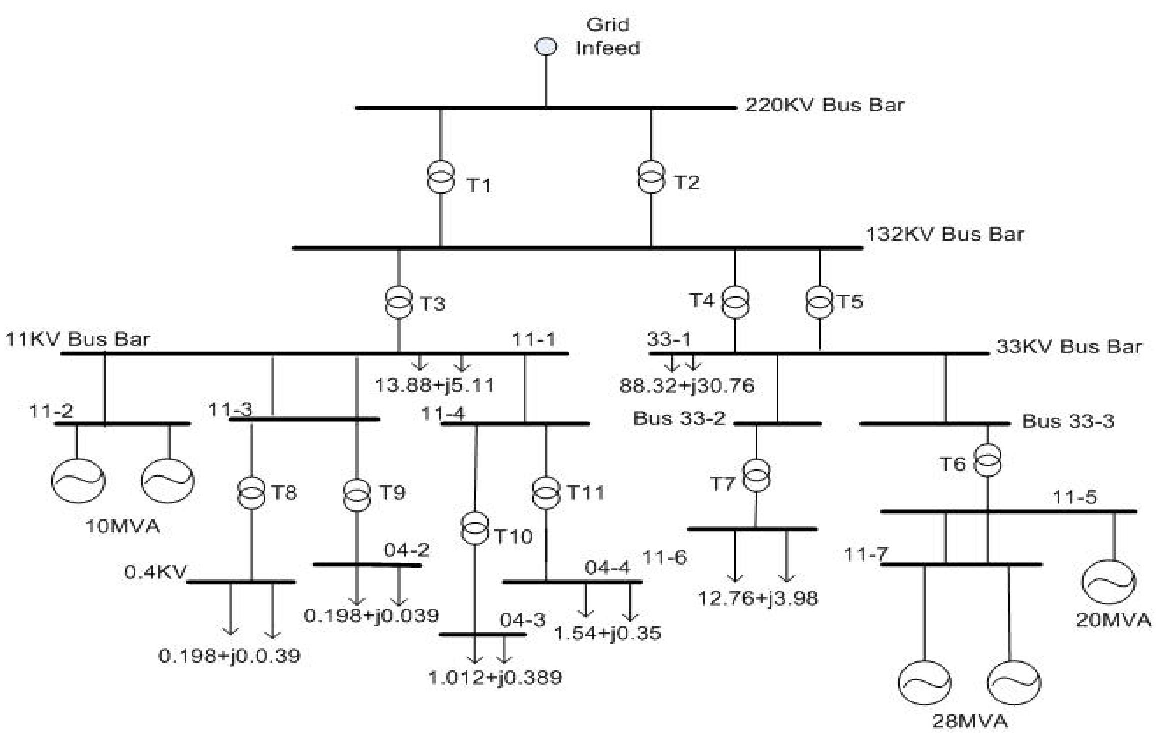

Fig 1: The reference network

The lines data and the transformers parameters are presented in Table III and Table IV, respectively.

Table 3: The Lines Data

Form	To	Ratings (MVA)	Resistance (pu)	Reactance (pu)
Grid	220kV BB	100	0.000123	0.000119
33-1	33-3	20.860	0.018014	0.018003
33-1	33-2	20.860	0.018014	0.018003
33-1	33-2	20.860	0.018014	0.018003
11-1	11-3	14.860	0.005900	0.017300
11-1	11-4	14.860	0.039875	0.130011
11-1	11-2	14.860	0.039875	0.130011
11-5	11-6	14.860	0.039875	0.130011
11-5	11-7	14.860	0.039875	0.130011
11-5	11-7	14.860	0.039875	0.130011

Table 4: The Transformers Data

	MVA	R (pu)	X (pu)	R_0 (pu)	X_0 (pu)
T1	75	0.00215	0.0324	0.00114	0.0287
T2	75	0.00215	0.0324	0.00114	0.0287
T3	45	0.00600	0.1249	0.00500	0.1075
T4	45	0.00600	0.1249	0.00500	0.1075
T5	26	0.00375	0.0675	0.00250	0.0585
T6	26	0.00723	0.1308	0.00651	0.1177
T7	26	0.00723	0.1308	0.00651	0.1177
T8	0.25	5.99800	17.990	5.80000	16.300
T9	0.25	5.99800	17.990	5.80000	16.300
T10	0.25	5.99800	17.990	5.80000	16.300
T11	0.25	5.99800	17.990	5.80000	16.300

Table V shows the percentage of line's capacity used by all generation-dominated bus bars in the network, i.e. Bus 11-2, Bus 11-5 and Bus 11-7. These results are obtained by running the load flow analysis program in ETAP software
.

Table 5: Load Flow Results for The Initial Network

Rating Exception Load Flow Results				
From	**To**	**Power Flow (MVA)**	**Standard Rating (MVA)**	**Line's Capacity Used**
Bus11-1	Bus 11-2	12.899	14.860	86.80%
Bus33-3	Bus11-5	17.879	20..863	85.70%
Bus11-5	Bus11-7	14.010	14.860	94.30%
Bus11-5	Bus11-7	14.010	14.860	94.30%

3.2 A New DG Connection

A new DG will be connected to one of three generation-dominated bus bars, i.e. Bus11-2, Bus11-5, and Bus 11-7. The new DG is a 6.7MVA CCGT CHP generation with a capacity factor of 60.0% [10] and a power factor of 0.9. The impact of this new connection changes the power flow as shown in Table VI.

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Table 6: Load Flow Results after Connecting a New Dg

Targeted Bus bar	Rating Exception Load Flow Results				
	From	**To**	**Power Flow (MVA)**	**Rating (MVA)**	**Exceeded Capacity (%)**
11-2	11-1	11-2	17.990	14.860	21.1%
11-5	33-3	11-5	21.980	20.863	5.3%
11-7	33-3	11-5	21.770	20.863	4.3%
	11-5	11-7	17.740	14.860	19.4%
	11-5	11-7	17.740	14.860	19.4%

The results in table VI show that due to new DG connection in generation dominated area the network capacity exceeds from the available network capacity. Therefore output of connected DG is required to be curtailed in order to match the existing network capacity.

For generation curtailment, the case of a new DG to 11KV bus bar i.e. bus 11-2 has been chosen for further study & analysis in this paper

3.3 Generation Curtailment

Generation curtailment is used to minimize or reduce the output capacity of existing generation so that addition of new DG connection may not cause the line capacity to exceed from the available network capacity.

To analyze the effect of DG technologies on generation curtailment, three configurations of DG technologies are used, as shown in Table VII. The capacity of all DGs is assumed to have 6.7 MVA with a power factor of 0.9.

Table 7: Dg Technologies Mixes

DG Technologies Mixes			CF	LCG (Rs/ KWh)	Contract Type
Configuration 1	DG1	Offshore Wind	32.0%	12.6	Daytime
	DG2	Offshore Wind	32.0%	12.6	Daytime
	New	CCGT CHP	60.0%	12.95	Daytime
Configuration 2	DG1	CCGT CHP	60.0%	12.95	Nighttime
	DG2	CCGT CHP	60.0%	12.95	Nighttime
	New	Offshore Wind	32.0%	12.6	Nighttime
Configuration 3	DG1	Offshore Wind	32.0%	12.6	Base load
	DG2	Offshore Wind	32.0%	12.6	Base load
	New	CCGT CHP	60.0%	12.95	Base load

Two options are taken in to account in the generation curtailment:

1. Output of a new connected DG will be curtailed only
2. Output of all DGs will be curtailed proportionally

In order to obtain required generation curtailment per year (MWh), in Table VIII, multiplication of four parameters associated with the DG technologies have been carried out, i.e. the curtailed capacity, power factor, capacity factor and the operating hours of each power plant . The calculation is based on the data for DG technologies mixes in configuration 1.

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Table 8: Generation Curtailment Calculation

Capacity		Connected	Curtailed	CF	Curtailment/ Year
(MVA)					(MWh)
Only the new added DG curtailed					
Line	14.86				
Offshore	6.70	6.70	-	32.0%	-
Offshore	6.70	6.70	-	32.0%	-
CHP	6.70	1.46	5.24	60.0%	12,393.648
Total	20.10	14.86	5.24		12,393.648
All DG curtailed proportionally					
Line	14.86				
Offshore	6.70	4.95	1.75	32.0%	2,207.52
Offshore	6.70	4.95	1.75	32.0%	2,207.52
CHP	6.70	4.95	1.75	60.0%	4,139.10
Total	20.10	14.86	5.24		8,554.14

Then, costs of the generation curtailment is obtained by multiplying the amount of generation curtailed with the levelized cost of electricity generation (LCG) of each generation technology, as shown in Table IX.

Table 9: Generation Curtailment Costs Calculation

	Generation curtailment (KWh)	LCG (Rs/KWh)	Generation Curtailment Cost (Rs)/year
Only the new added DG curtailed			
Offshore	-	12.6	-
Offshore	-	12.6	-
CHP	12,393648	12.95	160,497,741
Total	12,393648		160,497,741
All DG curtailed proportionally			
Offshore	2,207520	12.6	278,147,52
Offshore	2,207520	12.6	278,147,52
CHP	4,139100	12.95	536,013,45
Total	8,554140		109,230,849

Same calculation procedure is applied in order to find out the quantity of generation curtailment and the generation curtailment cost of each DG technologies configuration connected to Bus 11-2. The results are presented in Table X and table XI, respectively.

Table 10: Generation Curtailment Calculation for all Dg Technologies Mixes

	Curtailed Capacity (MVA)		Generation Curtailment/Year (MWh)	
DG Technologies Mixes	Only new DG curtailed	All DGs curtailed	Only new DG curtailed	All DGs curtailed
Configuration 1	5.24	5.24	12,393.648	8,5541.40
Configuration 2	5.24	5.24	6,609.946	10,485.70
Configuration 3	5.24	5.24	24787.296	17,108.28

Table 11: Generation Curtailment Cost Calculation for all Dg Technologies Mixes

	Generation Curtailment Cost (Rs)/year	
DG Technologies Mixes	**Only new DG curtailed**	**All DGs curtailed**
Configuration 1	160,497,741	109,230,849
Configuration 2	832,853,19	135,017,442
Configuration 3	320,995,483	218,461,698

The amount of capacity curtailed is obtained by subtracting the rated capacity of the targeted bus bar from the total connected DG capacity, i.e. 20.10 MVA, minus the rating of the line or the targeted bus bar, i.e. 14.86 MVA. Hence, the amount of capacity curtailed is always the same for all chosen configurations, i.e. 5.24 MVA, no matter the reduction is done, either by the curtailment of only new added DG or all DGs curtailed proportionally.

Although the amounts of curtailed capacity are equal for all configurations, the calculation of generation curtailment for one year period of time, as well as the cost needed for generation curtailment, has different results. This is due to the mixing of DG technologies along with their associated parameters, i.e. the type of DG contract, the capacity factor and the levelized cost of electricity generation, which are used in each configuration.

4. CONCLUSION

a. A new DG connection may cause excess in line capacity above the targeted bus bar capacity. The output of connected DGs must be curtailed, either by curtailing only the new added DG or by curtailing all connected DGs proportionally in order to match the targeted bus bar capacity.

b. Mixing of DG technologies and their associated parameters, i.e. the type of DG contract, the capacity factor and the levelised cost of electricity generation, have a significant impact on the quantity and the cost of generation curtailment.

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