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Smoothing Effect and Wind Power Variability of Moroccan Wind Farms

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ABSTRACT: Wind energy is growing fast, although the integration of this energy into the grid is still a major challenge. Several solutions contribute together to increase the integration rate of wind power into the grid. In addition to pumped storage plants, interconnections, the “smoothing effect” constitutes a key element to stabilize wind generation. The aim of this article is to evaluate the impact of the smoothening on the integration rate and the reserve capacity for Moroccan wind farms.

KEYWORDS: Smoothing Effect, Correlations, Grid Security, Geographic Dispersion, Wind farms, Intermittence.

I.INTRODUCTION

The international economy is marked by a global energy transition, which aims to ensure a green economic development with less greenhouse gases that are due to the generation of electricity. Morocco pilots its own energy transition which is based on the support and the massive introduction of renewable energies for its energy mix on one hand and the rationalization of energy consumption on the other hand. Such a transition will enable the Kingdom of Morocco to reduce its energy dependence and preserve the environment.

To make this energy transition a reality, Morocco has set a fixed goal of reaching 42% of its installed capacity of renewable sources by 2020. This can be achieved through the development of three electricity production programs (Wind, Solar and hydro 2,000 MW each). This ratewill be raised to 52% in 2030as announced during Conference Of Parties in Paris (COP21). Wind energy constitutes one of the pillars to achieve thisgoal with an operational capacity Of 787 MW in 2015. Morocco has sought to reach more than 5,000 MW of wind energy (4200 MW will be developed between 2016 and 2030 [1]) that will represent 20% of the total installed capacity. Such capacity will render the issue of energy integration, generated from renewable sources in the national power grid, indispensable [2].

Globally, wind energy intermittence has been analysed in depth and several solutions have been adopted including the hydraulic storage of surplus through Pumped Hydroelectric Storage Plants (PHSP).These plants can retrieve, if any, the excess of stored energy [3]. However, it is expensive as it requires heavy investment, it is limited given the few geographical areas that can shelter this kind of plants and it is not adequate for fast intermittence in short time intervals(i.e. In Germany, the production of wind energy can vary from 15 GW during 15 minutes[4]). As for the electrical interconnections between countries or inter-continentals, they can easily improve and increase the level of integration of renewable energy into the grid, this enhancement is conditioned by advanced management of these grids and also by a strong determination of interconnected countries (Energy Cloud in Europe)[5].

Morocco, with Spain and Algeria interconnections and PHSP realization and development (Afourar PHSP of 464 MW in operation and Abdel moumen, 350 MW in development) temporarily increased the rate of wind power integration into its grid. After the introduction of 10 GW from renewables by 2030, this rate will fall down and the stability of the grid may be unbalanced, whence the need to strengthen the interconnections and the PHSP development. Morocco must come up with other alternative to address the issue of wind power intermittence and to increase its integration rate.

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II.INTERMITTENCY OF RENEWABLE ENERGY AND ITS IMPACT ON THE GRID MANAGER

The intermittence of renewable energy is still considered a weak link in an energy production system based on wind, which generates power only when the wind blows. This locally varied wind can be nil, too low or too high and in this case the wind turbines cannot produce electricity (cut in and cut out wind speed). However, these local effects may be partly mitigated given the various climate environment of Moroccan regions, wind generation is not null at the same time. It is "Smoothing effect" of wind power, which is defined as the ability of a climate zone to smoothen or to offset the wind power generation of another area. According to this effect, the intermittent wind generation in a given region would be mostly offset by another region which itself would vary more or less in reverse giving the sum of productions more regular behaviour [6,7].

This article analyse the "Smoothing effect" to avoid an over-reserve capacity in Moroccan energy system and to improve the integration of wind energy. The wind farms studied, shown in fig 1, are grouped in three parks in the North and three in the South. The north and south groups are at latitudes 360 N and 280 N with the Atlas Mountains in between. Furthermore the north parks are exposed to Mediterranean wind which is not the case for the south parks. The northern region is characterized by a strong wind regime widely fluctuating while the wind regime in the south is more stable with moderate wind speeds [8, 9].

Fig. 1 Map of Moroccan wind farms

This analysis is based on the performance of 6 wind farms, listed in Table-1; the study period is defined from April 15th, 2014 to April 15th, 2015. The input data is the hourly generation of each wind farm during the study period and the total output of all wind farms.

	Maximum output (MW)	Capacity (MW)
North-1	132.00	140.0
North-2	35.52	50.0
North-3	49.22	50
South-1	228.36	301.0
South-2	50.00	50.6
South-3	98.99	100.0

Table 1: Moroccan Wind Farms

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With a large stock of fuel, the generation of power by conventional sources is linked solely to the energy requirement, unlike the generation by renewable sources. In addition to the energy requirement, renewable resources are also required; for instance, a photovoltaic panel cannot produce energy during the night even if energy demandis needed. It is also the case for wind. The abundance of wind is mandatory to generate power and therefore meet a demand. Moreover, if there is a lack of wind in a given area, the wind will blow in another one. It is the case of Morocco with an opening on both coastlines and mountain ranges, which make it an ideal location for uniform spatial and temporal distribution of wind.

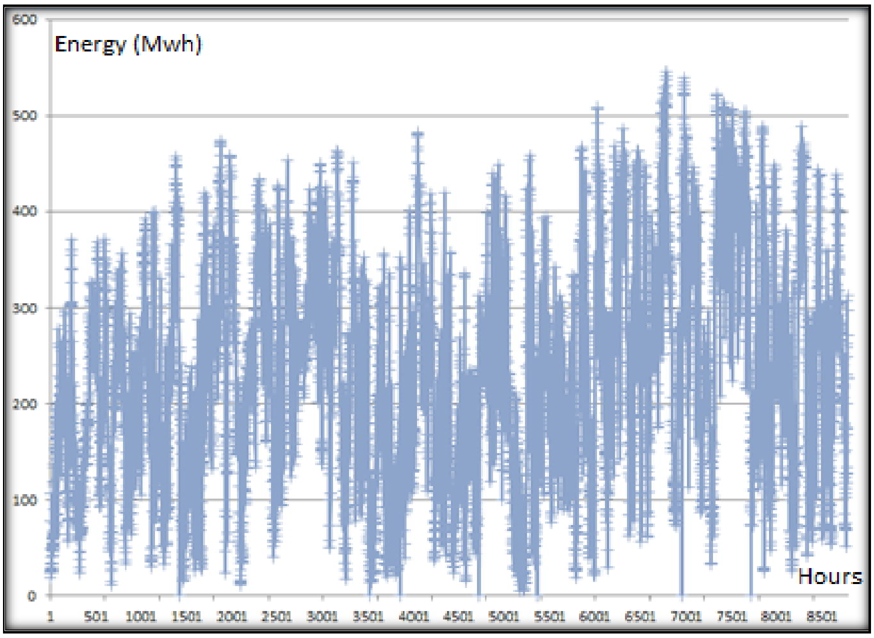

Fig. 2 Total Generated energy curve of all wind farms in Morocco (2014)

In the fig 2, it shows the graph of global generated energy from Moroccan wind farms during the study period, it illustrates that the minimum generation of all wind farms in Morocco is not null and it's around 40 MW.

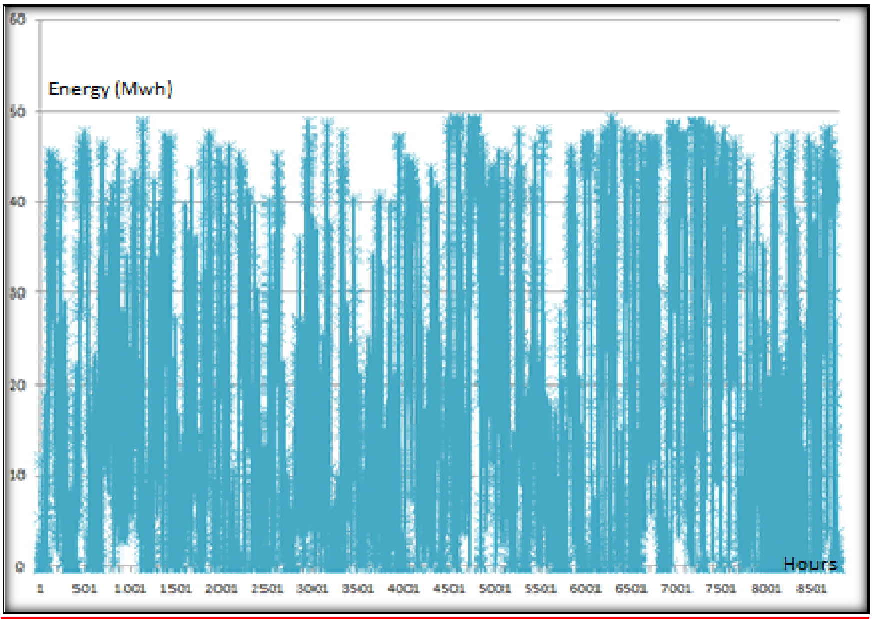

Fig .3 Generated energy curve of a single wind farm (North-3)

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In the fig 3, it shows the graph of energy generated from a single wind farms during the study period, the generated energy can be cancelled when there is no wind, so a sudden drop in wind generation of a country as a whole is unlikely.

III.PERFORMANCE OF WIND FARMS

In case of wind farms being located in the same climate zone (less than 120 km) analysis of two wind farms generation behaviour North-1 and North-3 compared to global behaviour of wind generation shows that both wind farms almost have the same trend shown in Fig.4.

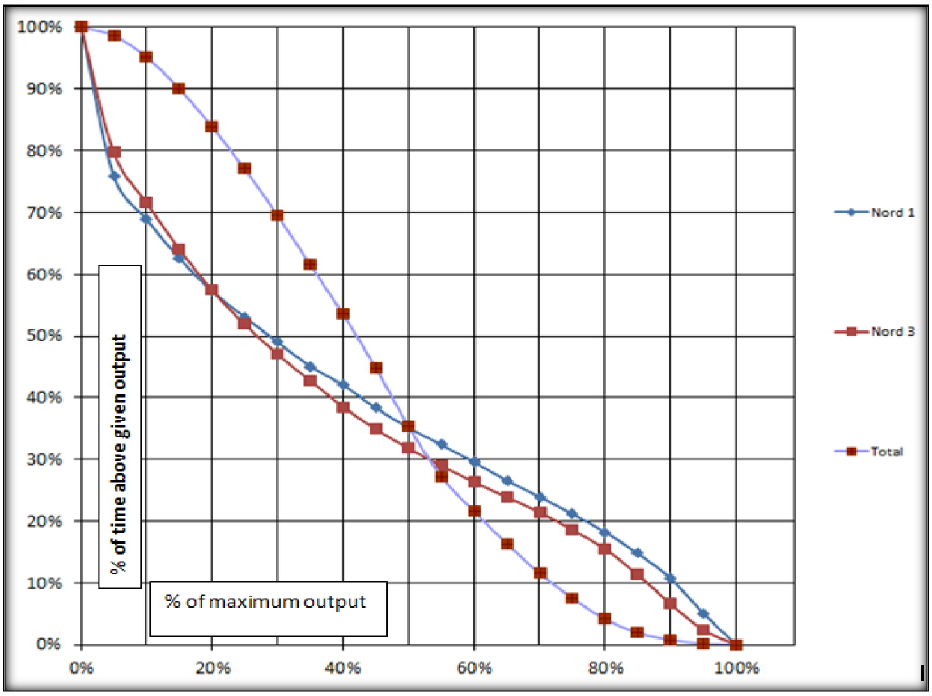

Fig. 4 Behaviour of two wind farms in the same climate zone

Fig 4 also shows that the northern wind farms produced more than 10 %of their nominal power during 70% of the time, while they produced more than 75% of their nominal power only for 20% of the time. As for the total output of all wind farms, 75% of the rated power is produced only for 9% of the time, while over 10% of the rated power is produced during 90% of the time. The northern wind farms produce energy more in terms of peak generation, while in terms of energy they contribute less in the energy balance. All the wind farms have managed to pool the north production including the wind farms located in a climate zone characterized by unstable wind. This pooling of capacity represents the smoothing effect.

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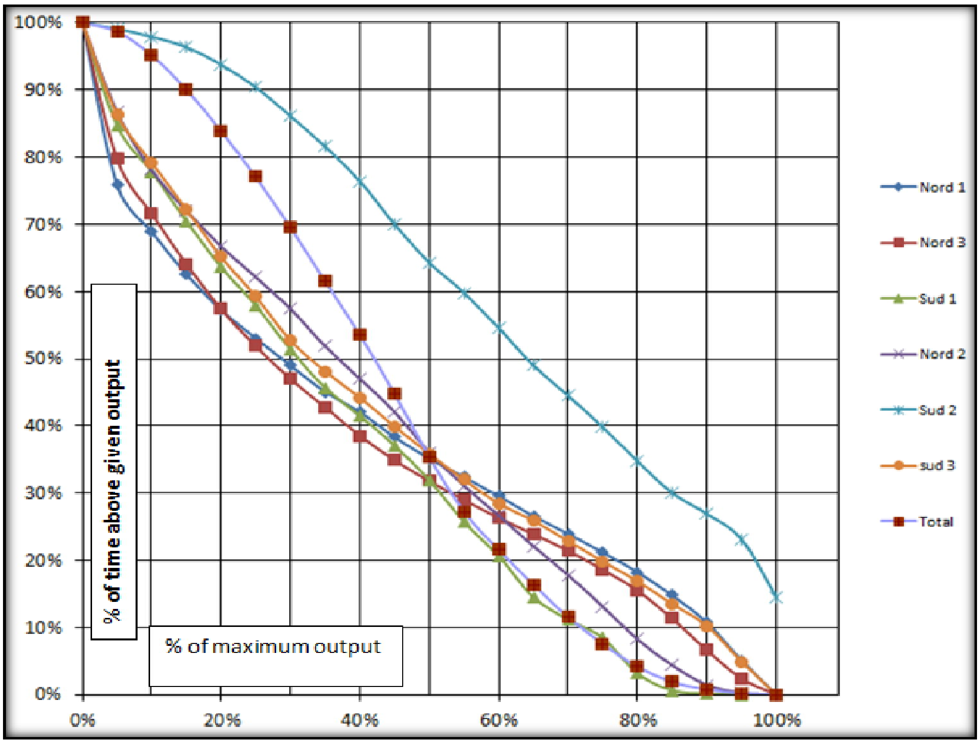

Fig .5: behaviour of wind farms in different climatic zones.

A spotlight on all wind farms (Fig 5) shows that the southern wind farms vastly improve the behaviour of the global wind generation. Wind farm “South-2” is dominant, with more than 85% of its nominal power produced at 30% of the time and over 45% of its nominal power produced for 70% of the time, so the climate zone of that area is characterized by strong and steady wind.

In the table 2, it shows the capacity factor, the reliability and the deviation of each farm, according to this table the capacity factor or load factor [10] has globally an average of 40 % for a total installed capacity of 517 MW, the monthly average of this factor is 46% generally supported by both wind farms South-2and South-1 with the capacity factors of 64% and 44% respectively. Installing new wind farms with low factors decrease the global factor, hence the need to take these criteria into consideration during the outline of new wind farms. The 90% reliability analysis expressed as a percentage of the maximum power produced by each farm [11], shows that the wind farm South-2 presents a reliability of 27% better than the other wind farms. The total reliability is 1% impacted by the wind farmwith a minimum reliability.

	North-1	South-1	South-2	North-3	South-3	Total
capacity factor	36%	44%	64%	35 %	40%	40%
reliability 90%	11%	1%	27%	7%	10%	1%
deviation	44,65	60,70	14,32	15,32	31,11	

Table 2: Performance of wind farms

IV.GEOGRAPHICAL SPREAD OF WIND FARMS

An analysis of partial correlations between different wind farms shows the existence of a certain complementarity between climate areas hosting concerned wind farms. Both wind farms North-1 and South-1 shows a high correlation with 82%, it’s a major indicator for the grid operator, a high complementarity between wind farms needs less intervention in terms of energy injected by the operator to balance Supply-Demand [12]. The correlation coefficients summarized in Table 3 provides a summary measure of the intensity of the relationship between different wind farms.

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Partial correlation	North-1	South-2	South-1	North-3	South-3
North-1	100%	-44%	-82,5%	77,1%	-58%
South-2		100%	22,3%	-39%	12,2%
South-1			100%	-73,5%	11%
North-3				100%	-49,8%
South-3					100%

Table 3: Partial correlation regarding the total generation between wind farms

V. RESULT AND DISCUSSION

To understand the hourly behaviour of wind generation, because his capacity factor is near to the global average, the power data of South-3 farm during 24 hours were analysed to draw this behaviour. Figure 6 presents the hourly output of the wind farm South-3 (April 15, 2014). During a period of 24 hours, the average wind power output is 30 MW, the largest fall down in output is around 6 MW (23% of the average of output) and the largest rise in generation is 31 MW (42 % of the average production).

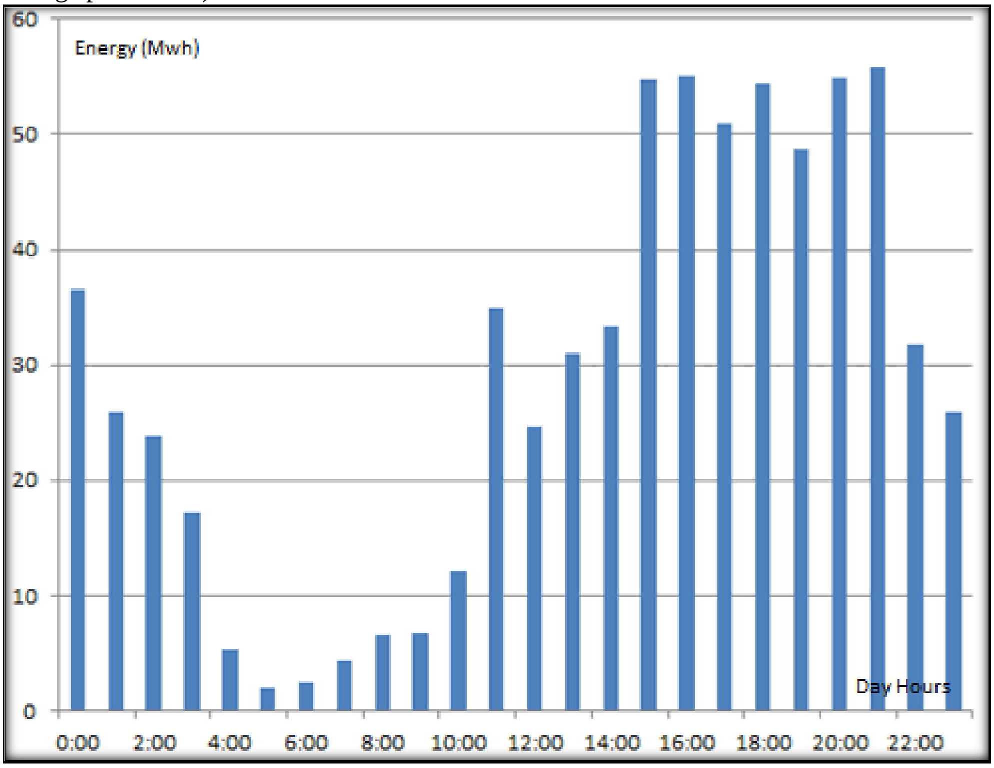

Fig 6: Time Analysis of wind generation wind farm south-3 (05.15.2014)

The variations average recorded is 8 MW (27% of the average daily production). The long-term data have maximum values of time variation of power, greater than the day of 05.15.2014, but the monthly average values are smaller.
Figure 6 shows also that a majority of wind generation from farm South-3 is produced during the time interval 3pm-10pm. This interval perfectly matches with the interval of peak hours in Morocco 6pm-10pm, so this wind farm comes to the supply of energy in the period of peak in which energy is produced at high cost (Use of combined cycle gas turbine and fuel oil), therefore with wind that costs nothing, it avoids costly consumption of fuel oil or natural gas.

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VI. CHRONOLOGICAL AND SPATIAL OFFSET OF WIND FARMS

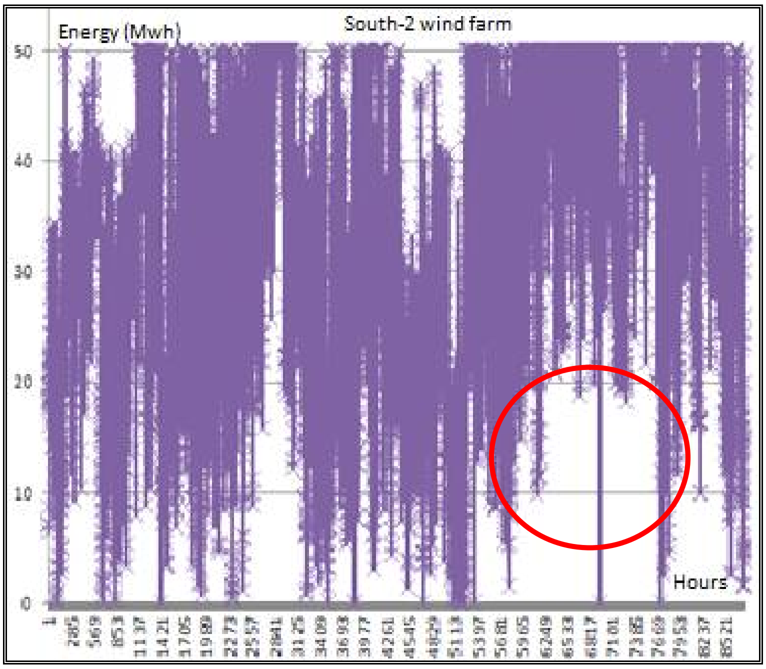

Fig 7: Hourly generated power from South-2 wind farm

The fig 7 shows the evolution of hourly production of the farm "South-2" during one year. This development is characterized by high output in full capacity (95-100% of total capacity) but it also has peak periods of power generation, which ask more the grid operator (Dispatching) to maintain the balance of supply-demand. The addition of wind farm North-3 in the grid (Fig 8) largely offsets the fluctuations of South-2 farm, and also it allows to limit off-peak wind generation.

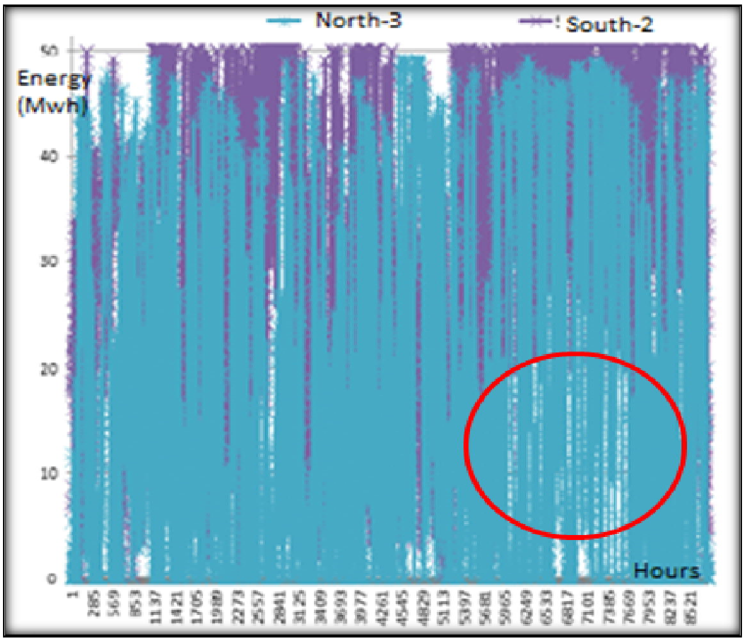

Fig 8: Hourly generated power from South-2 and North-3 wind farms

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Regrouping of the total production of wind farms smoothen and sharpen the power curves with an average production of about 40% of capacity (Figure 9)

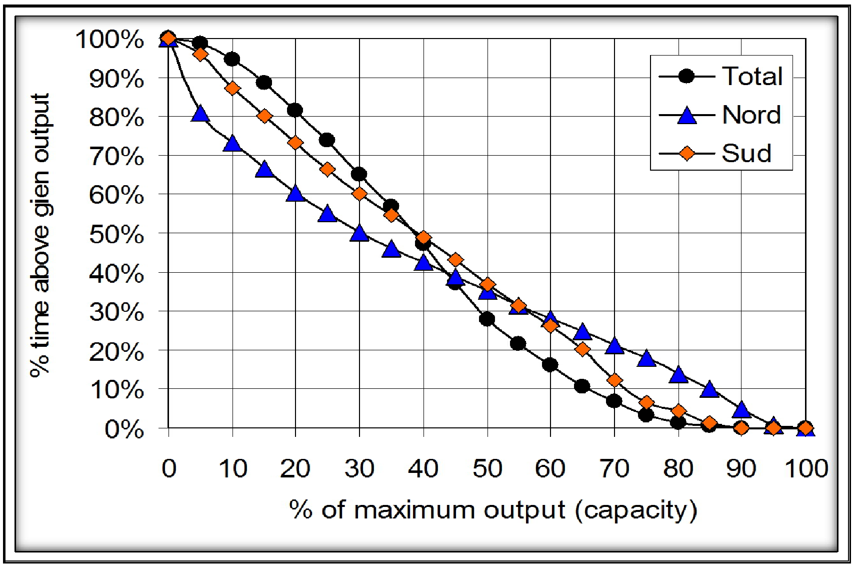

Fig 9: South-North Offsetting

VI.CONCLUSION

The intermittence of wind power (and generally renewable energy) is one of the major challenges of the power grids' managers. This article shows that the behaviour of a wind farm is nearly smoothened by the other wind farms through the smoothing effect. It's a compensation of non-produced energy by an overproduction of another region subject to partially or fully netted wind regimes. Such compensation is anchored to the geographical dispersion and the presence of different wind regimes associated with different geographical areas. Furthermore, with almost offsetting wind regions allows, after the development of more capacities, a smoothening of wind generation that will significantly reduce the effects of its intermittence. The total production curve still has a fluctuation with a minimum load factor close to 0% and a maximum of 75% while the average value is 33%. However, regarding the actual limited installed capacity, a heavy smoothening effect is not yet reached in Morocco, also before implementation of new wind farms; this effect must be evaluated during the choice of new zones to avoid a heavy investment en term of reserve capacity.

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