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*Key words:*  
*Carbon emissions, wind offshore, HVDC, faults, machine learning, neural networks.*

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## **FAULT STUDY OF HVDC BASED WIND OFFSHORE INTEGRATION USING MACHINE LEARNING**

With the rise of carbon emissions, the paradigm of producing electrical energy is shifting from conventional sources to renewables. Among various renewable sources, wind offshore is attracting the researchers to work on, as wind speeds are higher in the ocean hence more potential to harness energy. To channel this energy towards the load centers, high voltage direct current (HVDC) technology is the way to go. This paper presents fault study (classification) of various fault conditions both on HVDC Link (SLG etc.) and converter station based on Machine Learning technique ‘Artificial Neural Network (ANN)’. The pattern recognition characteristics of ANN helps to decipher relationships and accurately classifies the type of fault present. The data gathering is done via simulation of Voltage Source Converter (VSC) based HVDC System on MATLAB® Simulink and ANN tool is also implemented on MATLAB® software.

### **1. INTRODUCTION**

Climate change has been the driving component of all the energy-related discussions, mainly because of the impact it possess on the human life. Most important area influencing the climate change is ‘energy sector’, solely because of the fact that conventional power plants are the main sources of increasing carbon footprints. Many nations around the globe are active to act on climate change initiatives, for example Germany is one of the few countries to propose a climate change plan 2030 and 2050 with the aim to substantially reduce carbon emissions. In 2019, the carbon emissions across the world were reduced 1.8% in comparison with the previous year [1]. Moreover, in Germany, we can see an influx of renewable energy integration in the grid, capturing 40% of the energy

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mix in 2019, in which wind energy (onshore and offshore) is the main constituent [2].

Wind onshore is the most prominent technology, however, the ambient conditions such as higher wind speeds and less turbulence are often encountered away from the shore, making offshore technology noteworthy. Furthermore, the rise of visual pollution is also a problem in onshore, so a switch to work more on the offshore technology is necessary [3]. As the load centres are far away from these offshore regions, a reliable and cost efficient solution for power propagation is required. High Voltage Direct Current (HVDC) is the most common technology nowadays being used for the same purpose, as harnessing offshore wind energy requires the use of DC cables making the HVDC the primary technology to use for this purpose instead of HVAC. Various economic analysis have been carried out which clearly states that HVDC technology the most feasible and less expensive than other counterparts. [4]

The increasing use of HVDC technology demands special attention, especially in the abnormal conditions i.e. faults. Due to the presence of converter stations, filters, separate AC/DC sections etc. the fault study becomes complex as the fault can be anywhere and have different impact on the system and since there is no zero crossing in DC so switch off operation is difficult, hence proper means to classify the fault is essential. This paper presents 'data driven' way to classify various injected at various locations in our VSC HVDC MATLAB® simulation, using machine learning technique called 'Artificial Neural Network'. The pattern recognition ability of the neural network helps to unlock complex relationships among the dependent and independent variable, making it a proficient technique to solve any classification problem. In our case, 12 parameters are provided to the neural network (three sets of currents and voltages respectively from near and far ends of the system) and four outputs in the form of '0' or '1', indicating the type of the fault.

The second part of the paper describes HVDC schemes, components, comparison with other technologies etc. is presented, while in third chapter the information about machine learning and neural networks, discussing important parameters influencing the network performance. Fourth chapter is composed of stepwise workflow, starting from simulation till the tuning of neural network model, which is used for classification/detection of faults. Last chapter describes the conclusion of the study presented.

## 2. HVDC TRANSMISSION SYSTEMS

HVDC Transmission systems are classified into two converter technologies namely, line-commutated current source converters (CSC) and self-commuted voltage source converters (VSC). CSC employs thyristor in a six pulse bridge configuration to perform HVDC conversion whereas VSC uses IGBTs offering reactive and active power support to the connected AC networks. Therefore, VSC is increasingly finding its application to

connect remote renewable energy sources like offshore windfarms to the power system. [5]. A VSC HVDC system is composed of converters, transformers, AC filters, DC cables, breakers, DC capacitors and filters.

## 2.1 HVDC CONFIGURATIONS

HVDC systems can be monopolar, bipolar or can be used to connect two asynchronous systems. Monopolar configuration uses a single pole line connecting the two converters and positive or negative DC voltage is used. Only one insulated conductor is used for transmission and ground or earth act as a return path. In bipolar configuration, two poles are used which are at negative and positive polarity. The two conductors are insulated and can operate independent from each other if the neutrals are grounded. Under normal conditions, the two poles are balanced resulting in zero ground current. However, in case when one pole is out of service, ground return would be used. Back-to-back configuration is employed to connect two asynchronous grids located at same site. Due to shorter length, these systems are designed at low voltage levels to reduce insulation costs [6]

## 2.2 ADVANTAGES OF HVDC TRANSMISSION SYSTEMS

HVDC transmission system offers great advantage for long undersea power transmission and connection with weak AC systems. The number of transmission cables required is less [7]. Under fluctuations in power output of wind turbine, grid side inverter provides support by injecting more active power into grid or absorbing active power from the grid thus allowing faster power control [8]. HVDC networks decouple the wind farm network from the power system. Hence, disturbances on one AC side are not transferred to other [8]. The advanced controllability of active and reactive power in converters enables the windfarm to restore the network after blackout [9].

## 2.3 FAULTS IN HVDC SYSTEM

HVDC systems are complex as they consist of converters, AC side and DC link. Therefore, faults in HVDC system can appear as AC, DC or converter faults. DC link fault can be DC line to line or DC line to ground. Due to rarity of DC line to line faults, this paper focuses on DC line to ground fault. In cables, these type of faults occur due to insulation failure whereas in overhead lines lightning is the major cause. This fault starts with the formation of discharge circuit resulting in the discharge of fault pole capacitor. When the DC voltage falls below AC voltage of converter, a charging current flows through the freewheeling diodes which charge the capacitor. This stage is called grid-side current feeding stage. After this, fault pole capacitor voltage drops while the

non-fault pole capacitor voltage rises resulting in DC voltage recovery. This stage is called voltage recovery stage [10].

The faults occurring at the AC side can be line to ground, line to line and three phase symmetrical short circuit. AC faults in HVDC system can occur at rectifier and inverter side. Rectifier side AC faults resulting in voltage depression cause DC current reduction. AC faults on inverter side cause commutation failure which is a DC short circuit leading to temporary loss in DC power [6], [11].

Faults in converter system may arise due to misfiring of valves, when the required gate pulse is missing or valve is unable to fire. Misfires can occur at both rectifier and inverter side, however at inverter it is more serious since misfire leads to zero voltage of bridge while on the other side the link is fed by AC voltage resulting in large voltage and current oscillations in DC link. Commutation failure is another main reason for converter fault which occurs when minimum value of extinction angle is not maintained [12].

### 3. MACHINE LEARNING

Machine learning as its name suggests, is a technique to evaluate any outcome or a result based on past patterns and datasets, with the help of statistical models. Based on past experiences, any future activity can be predicted for example consider energy demand forecasting study, which requires certain set of variables like temperature, humidity etc. However, most important is the previous demand which would help accurately predict demands for the future with relevant examples and features present [13].

The types of learning is categorized by two methods called supervised and unsupervised learning. Former one is used when we've to predict any target variable based on known data i.e. output variable is available. On the other hand, unsupervised learning is mostly done to find useful information in the dataset and forming models by virtue of input parameters only [13].

#### 3.1 ARTIFICIAL NEURAL NETWORK (ANN)

Among many techniques employed in machine learning, artificial neural network is the one of the widely used approaches. Its working is simply based on how a human brain processes information. The building block of whole structure includes neurons, axons, dendrites and their interconnections are termed as synapses [14]. The learning of neural network takes place in such a way that a weight is assigned to each input variable (neuron) which is then processed using a training algorithm and a transfer function which helps to map input and output relationship. To gauge the performance of the neural network, certain key performance indicators are required such as mean squared error.



The error is used to re-scale the weights in order to reduce the error and process is repeated till the error can't be further minimized. This scheme is called 'Back Propagation'. The algorithm is applied on training data set only, in which the neural network learns. Then comes validation test further validates the model based on learned parameters. Final model is then tested on 'unseen' data called testing dataset, which gauges overall performance of the network developed.

Pattern recognition approaches are also used for classification problem. MATLAB provides complete toolbox to implement this version of ANN. It uses scaled conjugate gradient algorithm, which is well explained in [15] which uses the merger of both conventional Levenberg Marquardt algorithm and conjugate gradient. The key performance indicator is 'cross-entropy' which evaluates errors/loss in classification problem, comparing input and target values [16].

The performance of the neural network depends on various factors like hidden layers, hidden neurons, activation function, weights, sample size in dataset etc.

Network can be optimized correctly by varying these parameters and more accurate results without over fitting can be achieved.

## 4. METHODOLOGY

The process flow of our work consists of three main steps

- Data Acquisition
- ANN Implementation
- Model Analysis

### 4.1 DATA ACQUISITION

To acquire data, a 100kV MATLAB VSC-Based HVDC Transmission System is used as shown in figure 1, which consists of 2 systems pairing together via different apparatus as described before in this paper. This simulation is a built-in example which is altered according to our requirements. The system 1 is assumed to be an offshore wind corridor, propagating power to the second system through a 300 km DC cable. The fault and ground resistance is 0.001 ohms.

- Steady State
- Three Phase-Ground fault (ABC-G) at B2
- Single Line to Ground fault (A-G) at B2
- DC link
- Inverter Side fault (100kV)

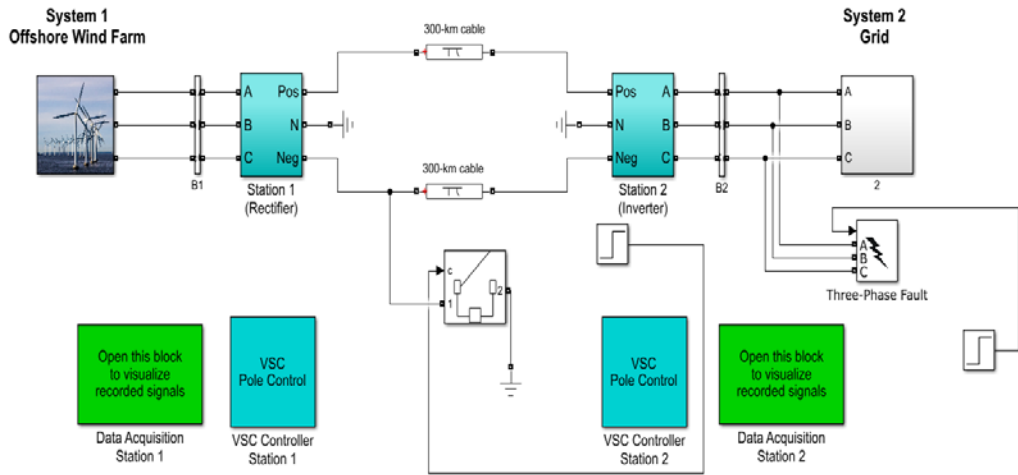


Fig. 1. HVDC VSC Simulation

Data is generated to the workspace under various conditions. As an example, a simulation of single line to ground (A-G) fault can be seen in figure 2.

Three sets of currents and voltages are recorded on source (bus B1) and grid (bus B2) ends, making a total of 12 variables. Simulation time is 5 sec with the sample time of 1 ms, making the sample size of 5000 values. Since 5 cases are simulated, total sample size becomes 25000. The simulation and sample time is adjusted in such a way to get sufficient samples for our neural network.

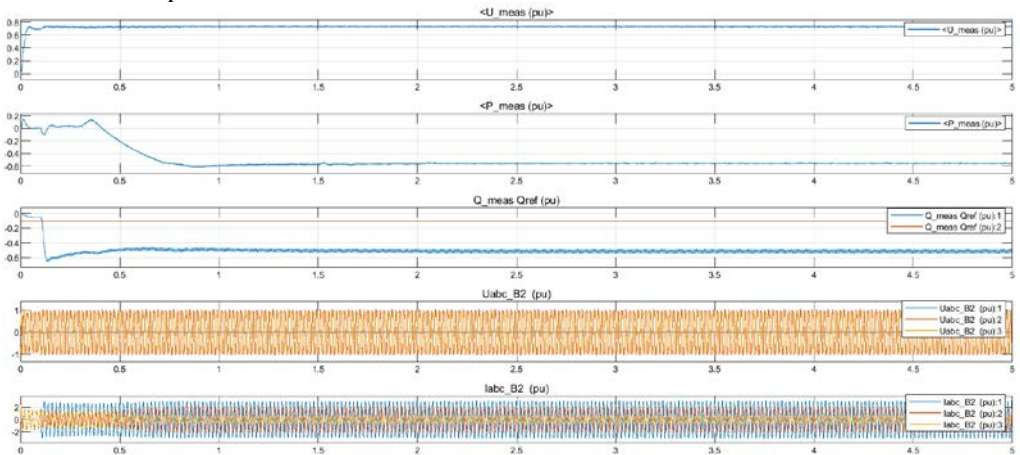


Fig. 2. A-G Fault at B2

Since we've to classify the faults, the output variables are either '0' or '1'. The table 1 below describes output variable.

Table 1 Classification of faults

Steady State	ABC-G	A-G	DC Link	Inverter Side
1	0	0	0	0
0	1	0	0	0
0	0	1	0	0
0	0	0	1	0
0	0	0	0	1

‘1’ indicates active status, while ‘0’ means inactive, for example in the first case, no fault is present, steady state condition is active, while in second case, three phase to ground is active only.

#### 4.2 ANN IMPLEMENTATION

Initially, a 12-10-5 configuration network was created as a benchmark. To increase the performance of the network, various parameters were altered. The transfer function tangent sigmoid provided better results. A single hidden layer with 20 neurons and a multi-layer configuration with 10 neurons each proved to be most successful. However, the former one is chosen since it converges quickly and takes less time. 70% of the data is used for training while the rest 30% is equally split between testing and validation set. The selected figure is shown in figure 3.

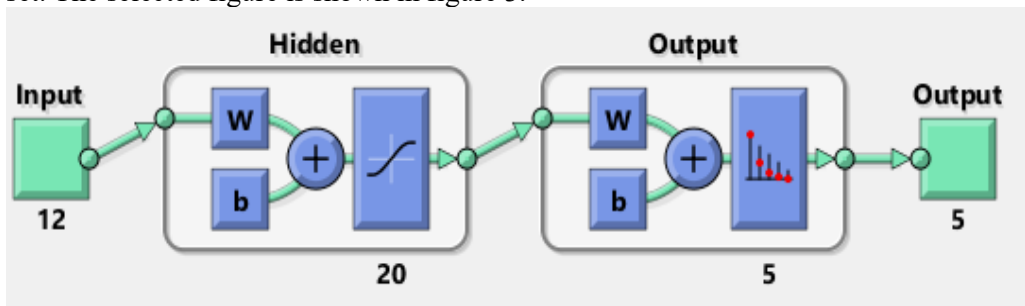


Fig. 3. MATLAB ANN Model

## 4.3 MODEL ANALYSIS

To analyse the results, the ANN toolbox provides various graphs. The performance plot and confusion matrix can be seen in the following figures 4 and 5.

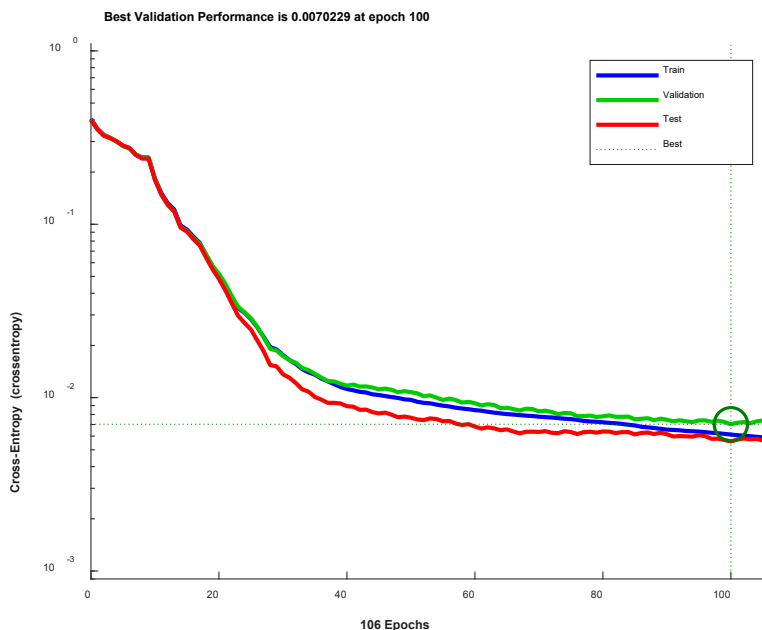


Fig. 4. Training performance of neural network

In figure 4, we can see the performance of the neural network among all three datasets i.e. training, testing and validation. In x-axis is are the iterations and y-axis represents the performance indicator, in our case it's the cross entropy function. We can see that initially in the first 20 iterations, the cross entropy loss function reduced significantly and took next 86 epochs to converge at a value of 0.007 (validation performance). The testing set has shown best performance, showing least cross entropy (red curve), which indicates that the neural network is well trained and is accurate when exposed to newer datasets. The overall experiment took 15 seconds.

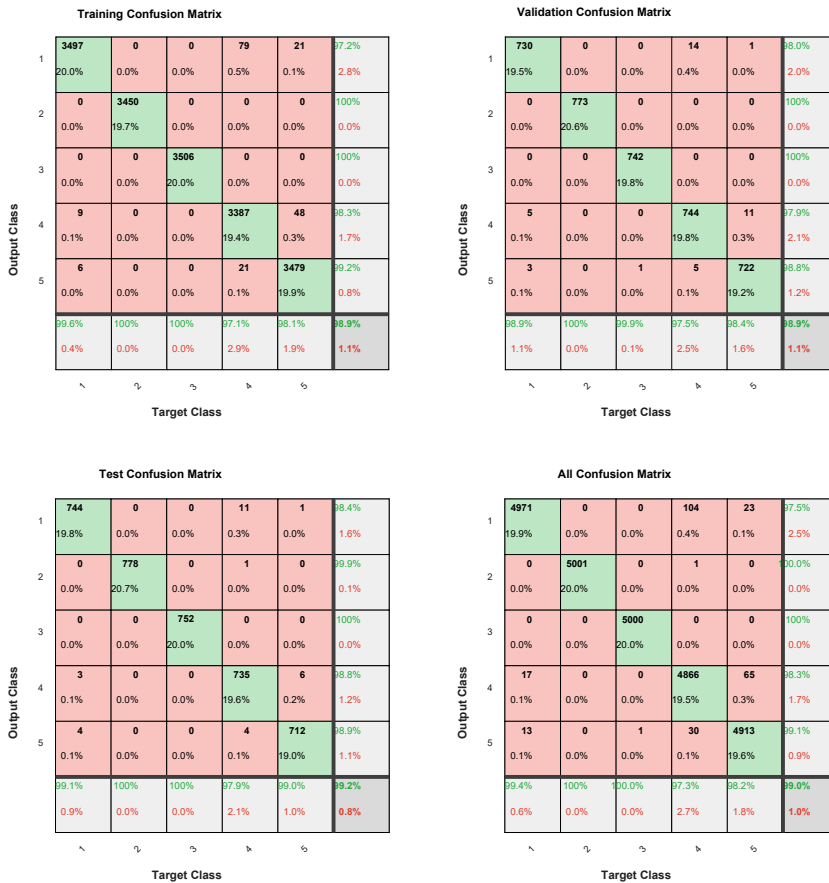


Fig. 5. Confusion Matrix

The confusion plot in figure 5 indicates the success rate in which the network successfully predicted/classify the fault condition. The green box indicates the successful classification while the red ones are error. We can see that most of the values are concentrated in green boxes. The overall performance can be measured by the grey shaded box at the end of the matrix. For example in testing performance, the network classified 99.2% conditions correctly, while the incorrect ones were only 0.8%.

## 5. CONCLUSION

An offshore windfarm transferring power to the grid is simulated in MATLAB as HVDC VSC based configuration and fault analysis (classification) is carried using neural network classification technique. By applying faults in various locations in the model, data is gathered which is then fed to neural network to train, with scaled conjugate gradient back propagation as the training algorithm. By varying influential parameters of the neural network, the best architecture was found to be of 12-20-5 neurons, accurately classifying the type of fault present.

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*Key words:*  
*Renewable energy, Batteries, Thermal  
Management, battery systems, photovoltaic  
battery hazards, li-ion cooling*

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## **PROBLEMS FACED BY ELECTROCHEMICAL STORAGE DEVICES AND ITS RESOLVING TECHNIQUES: A REVIEW**

A major problem while transitioning from conventional energy to renewable energy is storage. Renewable energy generation methods like solar or photovoltaic work efficiently only during daytime. In order to use this energy after sun sets it is important that we store this energy. One of the simplest and efficient ways to store this energy is batteries. But the efficiency of batteries has been low, and a lot of energy is lost during charging and discharging of batteries. Also, the lifecycle of the batteries is limited and can deteriorate due to excessive heat generated during charging and discharging cycles. All these problems are not well addressed due to poor understanding of the thermal behaviour of batteries. Hence, BTM (battery thermal management) integrated with BMS (battery management system) is very important to design and develop batteries which can always monitor the temperature of the batteries and work at the optimal temperature. In this review, the major effects of low and high operating temperature of batteries have been explained. Also, conventional, and modern cooling technologies like air cooling and liquid cooling respectively have been compared. And future technologies like cooling from PCM (Phase changing materials) have been reviewed.

### 1. INTRODUCTION

Until 2018 the total installed PV Capacity was around 510GW all over the world [1]. An additional 142GW of PV is scheduled to be installed in 2020 in various parts of the world, with 24GW just in Europe [2]. With such a dynamic increase in solar energy generation, the role of energy storage becomes vital. Also, with the increased production of electric vehicles the need of efficient batteries with longer lifecycles and less energy loss has gained a lot of attention. Various energy storage methods like mechanical storage, compressed air storage, pumped hydro storage, storage in PCM, Electrochemical storage, etc are being explored. Out of all these, electrochemical storage of electricity in the form of battery has proved to be much efficient. The energy storage density of

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batteries is much higher as a lot of energy can be stored in a very compact area [3]. While considering electrochemical storage we come across various types of batteries like Lithium ion battery, lead acid battery, Ni-MH battery, etc. A quick comparison of all the various types of batteries in terms of their energy density, cost (\$)/KWh, and various other parameters can tell us that Lithium Ion batteries are well suitable for the task of energy storage [4]. From figure 1, li-ion battery has the highest specific power and specific energy when compared to all the other cells. Consistent research is being done on li-ion batteries to increase the packing efficiency of the cells so that a greater number of cells can be contained in a battery pack. But with increasing packing efficiency arises the problem of heating up of the battery pack. In order to deal with this problem battery thermal management is important. A comprehensive solution should be designed to cool the battery as and when heat is generated. Without a proper cooling system, a battery might underperform resulting in drastic decrease in its efficiency. In this paper, the high temperature effects and the low temperature effects of batteries have been explained in detail. The problems and the damages caused to the batteries and their surroundings when the operating temperature goes above or below the required temperature have been looked at. Also, various cooling technologies which are already commercially available such as air cooling and liquid cooling have been discussed. Additionally, certain new technologies like cooling from PCM (phase changing materials) have been explored.

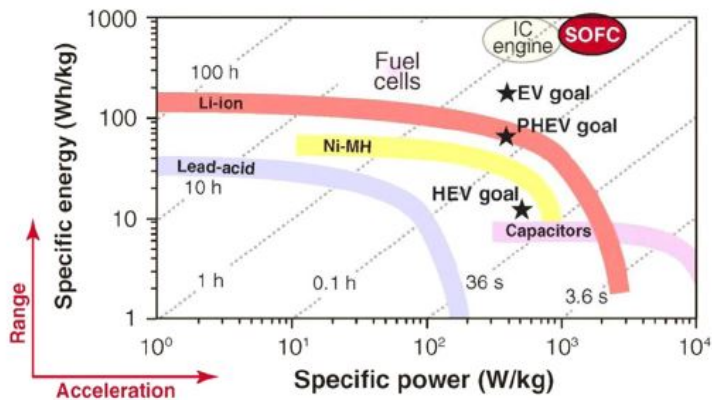


Fig 1: Plot of various electrochemical energy storage and conversion devices [4]

## 2. THERMAL PROBLEMS IN BATTERY

The LIBs (Lithium ion batteries) are facing barriers that limit their applications. One major limitation is the impact of temperature for the proper functioning of the LIBs.



Generally, the acceptable temperature range for LIBs is  $-20\text{ }^{\circ}\text{C} \sim 60\text{ }^{\circ}\text{C}$ . However, Pesaran et al. showed that the optimal temperature range for LIBs is  $15\text{ }^{\circ}\text{C} - 35\text{ }^{\circ}\text{C}$  [5]. As soon as the temperature goes beyond this optimum range, LIBs will degrade very quickly and there will be an increased risk of safety concerns including rapid fire and explosion. In the bottom line, impacts from temperature can be divided into two major categories: low temperature effects and high temperature effects.

### 2.1. LOW TEMPERATURE EFFECTS

As the temperature goes below  $0\text{ }^{\circ}\text{C}$  the performance of LIBs degrades due to the complex material system used. As the temperature decreases, there is an increase in the viscosity of the electrolyte used, which will reduce the ionic conductivity. The impedance of the directional migration of chemical ions rises the internal resistance.

Low temperature of the battery can cause another effect called as lithium plating which slows down the lithium-ion intercalation into the anodes during charging process [5]. The lithium ions then aggregated are deposited on the electrode surface, which reduces the battery capacities. Also, the lithium plating exists in the form of dendrite, which may penetrate the separators, and result in the internal short-circuit.

### 2.2. HIGH TEMPERATURE EFFECTS

The effects at high temperatures are much more complex. And in order to understand how to minimize the high temperature effect it is important to understand the causes of the high temperature, as explained in the upcoming section.

#### 2.2.1. THERMAL RUNAWAY

Defects in manufacturing and improper handling causes thermal runaway. The high temperature triggers the exothermic reactions in the operating batteries [5]. The heat released by these reactions further increases the temperature within the batteries. Fire hazards such as explosion can occur when this uncontrolled heat generation goes beyond the thermal endurance of the battery.

Generally, single battery thermal runaway may happen via three factors [7]:

- Internal thermal resistance fault- Thermal resistance increases drastically due to the swelling gas at the core of the battery.
- Heat generation fault- Short-circuit leading to uncontrollable heat generation.
- Outer convective cooling fault- When heat generated by battery cannot be removed in an adiabatic atmosphere.

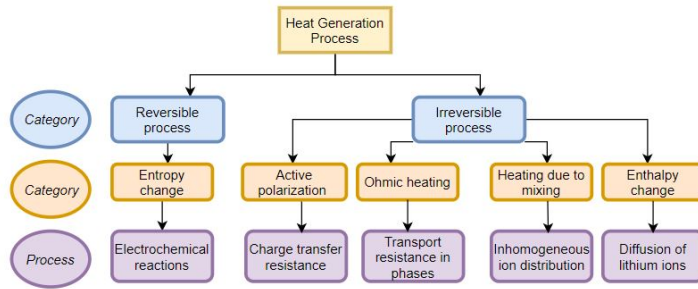


Fig 2: Illustration of categories and process of the heat generation within LIBs [5].

### 2.2.2. TEMPERATURE MALDISTRIBUTION

In order to store Mega Watts of energy large battery packs are required. During the charging and discharging process massive amount of heat releases as a result of the electrochemical reactions and internal resistances. This heat generated accumulates inside the pack as a result there is a higher temperature discrepancy between the batteries at the center and those near the edges.

Therefore, the temperature non-uniformity both from cell to cell and within cells reduces the overall performance of the battery pack. Therefore, severe temperature maldistribution should be avoided and the maximum temperature deviation inside the battery pack is usually expected to be below 5 °C [5]. The electrode modification can improve the intra-cell temperature uniformity while a well-designed BTMS (Battery thermal management system) can alleviate the inter-cell temperature inhomogeneity more effectively.

## 3. BATTERY THERMAL MANAGEMENT SYSTEM (BTMS)

In order to deal with temperature issues, a BTMS is required when the battery pack is assembled. The primary focus of BTMS is to maintain the batteries at an optimum operating temperature range with even temperature distribution inside the cell and the pack, keeping in mind factors such as compactness, weight, cost, complexity and reliability of the system. The temperature at which a battery operated is also related to the voltage, current and power rating of the battery pack. Hence all these components are integrated together to form a BMS (Battery management system). A BMS is analogous to an ECU/MCU which controls the overall functions of an automobile, for the battery

### 3.1. BATTERY MANAGEMENT SYSTEM (BMS)

The battery management system (BMS) consists of complex hardware and software system which is usually a mandatory part of any high voltage battery pack. A BMS must consist of many functional blocks such as cut-off FETs, cell voltage monitor, cell voltage balance, real-time clock (RTC), temperature monitors and screen interface [8]. Every cell in a Battery module must be monitored in order to maintain a proper function in the desired operating range (voltage, current, and temperature). Usually these modules are controlled with the help of module control unit (MCU).

Many of these MCUs in a battery pack are connected together through a communication bus which includes a supervisory circuit or battery control unit (BCU) which, based on the input of the MCU, calculates historical values and incorporates any measures that are needed to protect the battery from hazards and maintain the performance of the battery pack.

### 3.2. TEMPERATURE MONITORING USING BATTERY-MANAGEMENT SYSTEMS

To achieve a much longer battery life and efficient operation, the cells are continually monitored for the available charge, known as the state of charge (SOC). The temperature of the cells play an important role to calculate the SOC. Also, due to the harsh operating environment in automobiles, the possibility for many fault conditions increases. The battery packs with excessive loading (such as short-circuit condition) can result in hazardous overheating situation that calls for constant attention. Examples of circuits that measure temperature with the LTC6802-battery monitoring IC that includes a 12-bit ADC, a precision voltage reference, a high voltage input multiplexer and a serial interface also include an accurate thermistor-based sensor for SOC calculations and a simple diode-based detector [10].

At low temperatures, a lithium-ion cell becomes increasingly resistive and provides less charge between a full (4.2 V) and an empty (2.5 V) condition. An important factor at higher operating temperatures is that the self-discharge current of the cells increases and becomes an important factor for the SOC calculation. In a typical battery system, the cells are mainly characterized for performance over temperature. This information is stored in a lookup table. For the SOC calculation, along with the cell voltage readings, the pack temperature will recover cell characteristics information from the table. Coupling a thermistor to a battery pack is a comparatively inexpensive and yet moderately accurate way to monitor the temperature.

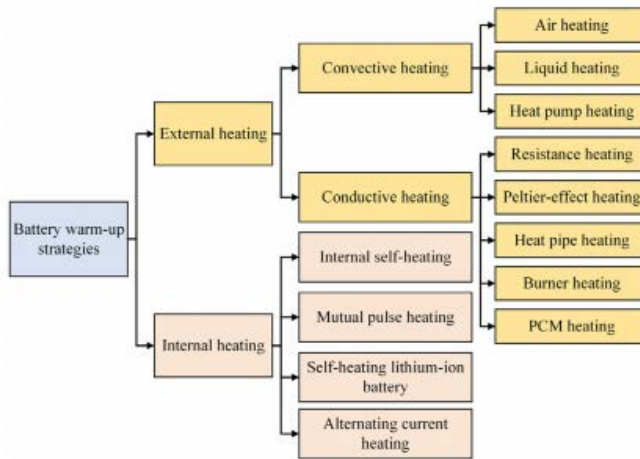


Fig.3. Classification of existing preheating strategies based on the location of heat generation [9].

#### 4. COOLING AND HEATING TECHNOLOGIES IN BATTERIES

To maintain optimum temperature preheating of batteries is very important. The next section given details about the preheating techniques of batteries in an automobile whose principles can also be applied to grid storage batteries. In terms of cooling medium, thermal management methods can be classified into air cooling, liquid cooling, phase change (liquid to gas) cooling, phase change (solid to liquid) cooling and the combination of them. All these types of BTMSs are introduced elaborately in the following section.

##### 4.1 PRE-HEATING OF LI-ION BATTERY

A significant phenomenon of Li-ion battery at low (sub-zero) temperatures is the notable reduction in the discharge capacity. At  $-10\text{ }^{\circ}\text{C}$ , a 2.2 Ah 18650 cylindrical cell can only retain around 1.7 Ah discharge capacity and comparatively less discharge capacity can be obtained using a higher discharge rate [9]. The reduced discharge capacity results in substantial reduction of the energy provided by the storage battery. Additionally, the cell resistance increases strikingly at sub-zero temperatures. Besides, charging the battery at low temperatures results in lithium plating, which results in excessive battery capacity fade. Along with the improvement of battery materials, operating strategies must be used to negate adverse thermal effects caused due to cold weather. This can be achieved by regulating the battery temperature within an optimum temperature

range. To efficiently heat up a battery from a sub-zero temperature, the heat generation inside or outside the battery cell, heat convection, and conduction of heat etc., should be controlled accurately, so that the increase of battery temperature can be effectively controlled. During battery warm-up, the cell geometry plays a significant role in the heat transfer from the ambient environment to the cell interior, and hence influences the temperature distribution within the cell as well as the module [9].

Battery preheating techniques by the heating strategies could be classified into three different groups: (1) An engine heat-based heating by using fluid (air or liquid) as the heat transfer medium (Hybrid EV); (2) heat provided using battery energy itself (3) External electricity based heating, which might require additional hardware system.

#### 4.2. AIR COOLING

As the most traditional approach, air cooling has been studied intensively and is widely adopted in commercial applications. The air can be taken into the system from the outside and can be withdrawn from the evaporator or condenser. Cooling or heating can be performed by direct or indirect air flow from environment to the module. In this method fins can be used to improve the heat transfer.

The air-cooling method has advantages in various aspects such as the cost, complexity, maintenance and weight, but the poor thermal conductivity of air makes it improper for applications in harsh conditions. Hence, the temperature distribution will be irregular and interference with the battery surface will be difficult.

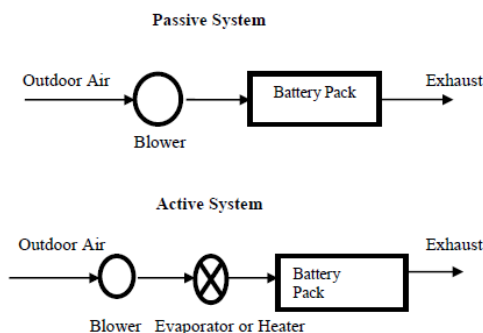


Fig 4: Forced air systems (passive and active) [6]

#### 4.3. LIQUID COOLING

Liquid cooling has a better thermal conductivity which makes it a better option when compared with air cooling. Liquid BTMSs can be classified into the direct cooling and indirect cooling. The battery module is to be submerged in dielectric coolant in direct

cooling while in the indirect the fluid flows through discrete tubing/jacket around the module or cold plate where the modules are placed. Indirect contact is more preferred as there can be better isolation of battery modules which adds to better safety conditions.

Hence, liquid cooling is more effective for battery thermal management, but it adds more weight and increase the structure complexity comparatively. Also, the risk of coolant leakages is very hazardous. Therefore, the liquid cooling is promising for the increasing demands for fast charging and the utilization of lithium ion batteries in harsh conditions.

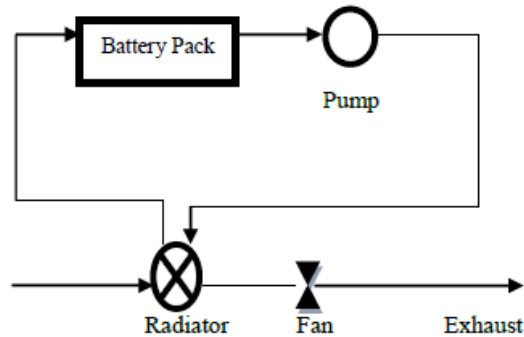


Fig 4: Passive liquid cooling system [6]

#### 4.4. PHASE CHANGE MATERIALS

Phase Change Materials (PCM) have been proved to be of much help for thermal management solutions. Phase Change Materials are substances that store the thermal energy as latent heat [6]. PCM's used in batteries must have high latent heat, thermal conductivity, specific heat capacity and small volume change. They should also be non-corrosive and non-toxic [7]. PCM thermal management systems has numerous advantages like lightness, high efficiency and elimination of extra mechanical components like blowers. The PCM material stores the sensible heat from the battery as latent heat and absorbs the temperature that is formed on the cell. During this procedure the PCM material converts into solid. The confined latent heat turns into liquid and emits as sensible heat. With this feature PCMs are used for the thermal energy storage.

One of the disadvantages of using PCM is its low thermal conductivity (less than  $0.4 \text{ W m}^{-1} \text{ K}^{-1}$ ) which determine the thermal transport efficiency [6]. This can cause limitations in applications where fast response in needed, hence composite PCM's can be used for large thermal storage.

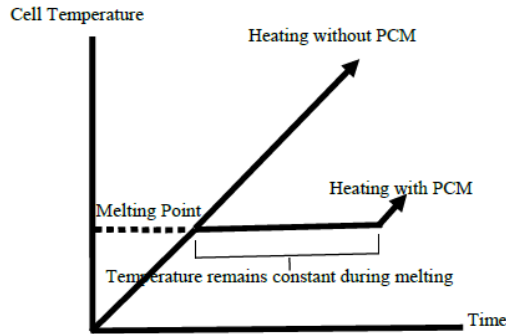


Figure 5: The working mechanism of PCM on battery cells [6]

## 5. CASE STUDIES AND EXPERIMENTS CONDUCTED ON COMMERCIAL GRID STORAGE PLANTS

A lot of grid storage facilities are considering battery storage to be an easy and effective way to store energy. Many commercial grid storage plants have been constructed in the past two decades. Recently Brandenburg state got its own grid storage plant called as “Feldheim Regional Regulating Power Station (RRKW)” for renewable energy storage in its wind farm constructed by Enercon. It has a capacity of 10.8MW with 3360 li-ion storage modules manufactured by LG Chem, based out of South Korea [11]. Many more ESS (Energy storage systems) of KW and MW capacity have been commercialized. Most of them use forced air cooling or liquid cooling integrated with BMS for the optimum working condition of the batteries. For example, one of the biggest BESS (Battery energy storage system) in the world is situated in Hornsdale, South Australia, powered by li-ion Tesla battery packs which are liquid cooled [12]. The performance of these batteries is related to their operating temperature, and the type of cooling required can be deduced by studying the amount of heat released from a battery. Another example is the analysis done by ISO England for a transient model assuming a 2MW ESS with forced air cooling for a period of 24 hrs was done [11]. The model shows that about 60KW of heat was generated by the batteries at various time durations but a maximum of 21KW of cooling was required to maintain the optimum air temperature.

## 6. CONCLUSION

Without a well-designed thermal management system, a Li-ion battery can underperform resulting in lower life span and decreased efficiency of the batteries. Problems such as Thermal runaway can also cause the battery to explode. Hence cooling the batteries is of utmost importance when it comes to storing renewable energy in an electrochemical device. The damage to the battery when charging at low temperatures is proportional to the charging rate. Charging at a much slower rate can reduce the damage, but this is rarely a practical solution. In most of the cases, charging Lithium Ion batteries below freezing temperature even once, could result in permanent damage caused by lithium plating. In below-freezing conditions, without a BMS communicating to a charger that is programmed to reduce current when necessary, the only solution is to heat the batteries to above freezing temperature before charging, either by bringing them into a warmer environment or by wrapping them in a thermal blanket or placing a small heater near the batteries, ideally with a thermometer to monitor the temperature during charging. Although, it is not the most convenient process.

Out of the three different methods of cooling discussed above, air cooling is the cheapest, but as thermal conductivity of air is very low it is not a very good option. Our next focus can be on liquid cooling, which has proved to be more efficient than air cooling and giant battery manufacturers like Tesla and BMW are already using them in their production vehicles. However, there is a lot of mechanical complexity and a need of parasitic devices like pumps and heat exchangers lowers the overall efficiency of the battery, as all these devices again need electricity to operate. But further research must be done to see how this technology can be improved for giant batteries of MW capacities. The third and the most interesting and unexplored option is the PCM. Although PCM have theoretically proved to be a great option for thermal management, the problem of leakages of PCM due to change in phase and volume cannot be overseen. Also, composite PCM's should be used to increase the thermal conductivity of the coolant. Enormous research is yet to be done, to achieve production of batteries that can rely on PCM as a cooling medium.

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*Key words:*  
*wind energy, offshore wind farm, onshore wind farm*

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## WIND POWER

Wind energy is a new type of renewable energy that is well known. This paper introduces the basic situation of wind power in Germany, the development of offshore and onshore wind power in recent years, and compares the advantages and disadvantages of offshore wind farms and onshore wind farms and their applicable conditions.

### 1. INTRODUCTION

Wind energy is an available energy that is provided to humans due to the work of air flow. It is a renewable energy source, includes wind, hydro, solar (photo-thermal, photovoltaic) energy. Many countries in the world regard the development of renewable energy as an important choice for achieving sustainable development<sup>[1]</sup>. In order to achieve the goal of 50% global emissions reduction, developed countries as a group plan to accelerate their steps and reduce their greenhouse gas emissions by 80% - 95% in 2050 compared to 1990. The ultimate goal of energy transition plan in Europe is to replace non-renewable energy sources such as coal with renewable energy<sup>[2]</sup>.

Wind energy is a clean, renewable, and large-capacity energy source. Wind power is used in large-scale wind farms and in locations where power is isolated, making a significant contribution to local life and development.

After a brief introduction of wind power, this paper will focus on the development and situation of wind power in Germany and different types of windfarm.

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## 2. SITUATION IN GERMANY

As of 2008, wind power generated about 94.1 million kilowatts power by the world, and supply has exceeded 1% of the world's consumption. Although wind energy is not the main source of energy for most countries, it has also grown more than four times between 1999 and 2005. In 2014, the number of global wind power equipment increased by 25%. And in Europe, it is particularly noteworthy that most of the wind power was contributed by Germany.

German wind turbines generated more than 105 million kilowatt hours (kWh) of electricity in 2017. Around 16 percent of German electricity came from wind power. The most wind power was generated in 2016 in Niedersachsen. With more than 19 million kWh, the Nordrhein-Westfalen state also can occupy a leading position, then Schleswig-Holstein with approx. 14.8 million kWh, there is also Brandenburg with 8.9 kWh. Together, these four states produced almost two-thirds of all German wind power generation. But other states also generate noteworthy yields, for example, wind power generation in Hesse alone, with 2.2 million kWh, could cover more than the electricity requirements of all German airports.

In total there is more than 28,179 wind turbines in Germany in 2018, it shows in Fig 1<sup>[3]</sup>. Most of them will be in Niedersachsen (6,185), which is almost a quarter of all facilities. It's also among the top performers in terms of installed capacity. Other important wind power states are Brandenburg (3,807), Nordrhein-Westfalen (3,435), Schleswig-Holstein (3,271) and Sachsen-Anhalt (2,859). However, wind power in Bayern is still lagging behind. Only 1,212 factories can generate clean electricity there. And the city state of Berlin, only about 10 plants were built. Although wind energy in Hamburg has a great position in all of urban areas, but it still has a upside potential.

Fig 1 shows another Hanseatic city: Bremen. There are already 91 plants in spite of smaller area and in the city with 483 kilowatts per square meter in Germany the highest achievement in relation to the country surface is installed.

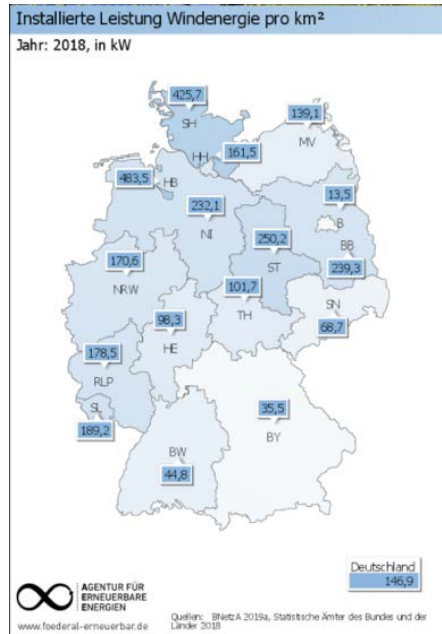


Fig. 1. Installed power of wind energy 2018 in Germany (unit in kW per km<sup>2</sup>)

The wind energy has huge potential in lots of countries. According to a prognosis of the Federal Association of Renewable Energies, wind power can generate 204 million kWh of electricity in 2030, while 139 million kWh onshore alone. A total of 189,000 MW of power could be installed if two percent of the land area are used for wind energy. By far the greatest potential is in Bayern, the largest federal state in terms of area, where wind energy plants with a capacity of 41,000 MW would be possible. But there is still a lot of potential for expansion in the other major German states like Niedersachsen, Baden-Württemberg and Nordrhein-Westfalen. In Bremen alone, where nearly 102 percent of potential has already been tapped by 2018, there is not much room left for further expansion. Otherwise, with the exception of Sachsen-Anhalt, Schleswig-Holstein and Brandenburg, no state has achieved even half of its potential wind energy output.

Wind energy has not only become a decisive factor in power generation, but economically, the wind energy industry is also essential in Germany. In 2016, the wind energy industry employed 160,200 people, an increase of more than 10,000 people than the previous year. It is particularly worth mentioning that Niedersachsen state is very active in the production and use of wind energy. Next chapter will give more specific information of windfarm.

### 3. ONSHORE WINDFARM AND OFFSHORE WINDFARM

- Onshore windfarm

Wind turbines use the energy of moving air to generate electricity, onshore winds are turbines located on land, and offshore wind turbines are located out at sea or in fresh-water. Onshore wind power is the core of Germany's transition to low-carbon power generation. Over the years, Germany has been a leader in the installed capacity of onshore wind power in Europe.

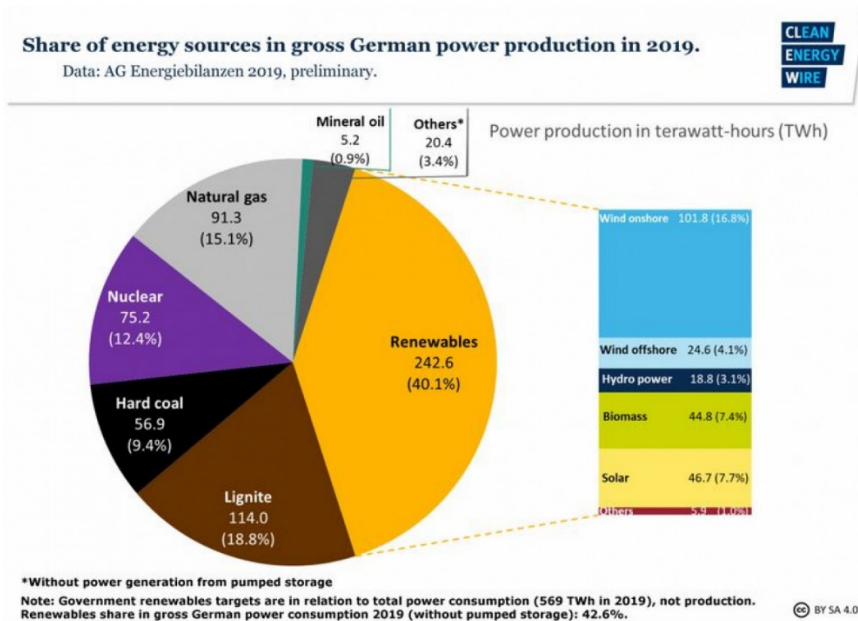


Fig.2 Share of energy sources in gross Germany power production in 2019

It can be clearly seen from the figure above that renewable energy occupies a large share of German electricity production. It is clear from the graph above that renewable energy accounts for a large share of Germany's electricity production, with 242,600,000,000 KWh of total capacity for the year, with onshore and offshore wind power systems showing a significant advantage, accounting for 52.1% of total renewable energy generation. So, this makes onshore and offshore wind power systems an important part of the German renewable energy system.

As of the end of 2019, approximately 29,450 onshore turbines were in operation across Germany, with a total capacity close to 54,000 MW. The total capacity growth

in 2017 was approximately 5,300 MW, the strongest capacity growth ever. However, the rate of expansion has fallen by more than half in the whole of 2018, only 2,400 MW, and by 2019 only 1,000 MW of expansion.

In Germany, the new turbines added in 2019 have an average capacity of over 3.3 MW, a hub height of over 130 meters and a rotor diameter of about 120 meters. The average turbine height has more than doubled in the last two decades, which means the new equipment can produce more energy. A modern onshore turbine can power up to 6,000 families. <sup>[4]</sup>.

- Offshore Windfarm

2019 was a year of rapid expansion of offshore wind farms, with Germany adding 176 turbines with a capacity of about 1,200 MW in the North Sea and Baltic Sea. As can be seen from Fig2, offshore wind's contribution to Germany's electricity production structure will reach more than 4% in 2019, making offshore wind the fastest growing renewable energy source in Germany <sup>[5]</sup>.

With an average capacity of 6.9 MW and an average rotor length of 155 metres in 2019<sup>[5]</sup>, the new turbines have not only developed rapidly since the introduction of the early 21st century but are also larger and more productive than turbines operating onshore. They provide electricity almost all year round and are almost twice as productive as land-based turbines.

Most German offshore wind turbines are in the North Sea, more than 1,000 from the west coast of Germany, and there are only more than 200 turbines in the Baltic Sea in the east. Wind power production in the North Sea is on average higher than in the Baltic Sea.

#### 4. DEVELOPMENT TRENDS OF WIND FARMS

- Onshore

Although wind power is a clean, non-polluting, renewable energy source, it does not produce any pollutants compared to thermal power, nor does it consume any non-renewable energy that pollutes the environment. Despite these significant advantages of onshore wind farms, according to Giles Dickson, CEO of Wind Europe, "German onshore wind is in serious trouble. <sup>[6]</sup>" The main reason for this is the decline in the number of permits for onshore wind turbines. There are several main reasons for this.

1. Contradictions with the residential environment.

According to a survey conducted by the FORSA pollster, 82% of respondents expressed support for the development of onshore wind power. But there is also a segment of the population that thinks turbines have a negative impact on the local environment, and there is also concern that the subsonic noise generated by turbines could be a threat to human health.

2. Turbine blades threaten animal survival

Another major argument by opponents of wind power is that the 60-meter-long blades spin at speeds of more than 300 kilometers per hour, creating a challenge to the survival of birds and bats. According to estimates by the Nature and Biodiversity Conservation Union (NABU), about 100,000 birds are killed each year by spinning blades.

3. The contradiction between generators and the natural landscape

Building a large number of generators also has a huge impact on the aesthetics of the landscape. Its impact is highlighted in the tourism industry, and the property sector, which has a negative impact on local economic income, as no one wants to appreciate turbines, and no one wants to live near them. The negative impact of turbines on land values is also a point of view of opponents.

But as opposed to the wind at sea, people are more familiar with the wind on land. And the infrastructure needed to transmit power from onshore turbines is much cheaper than offshore wind turbines. Onshore wind is also competitive in the larger renewable energy market, as it is the cheapest form available.

- Offshore

The biggest advantage of offshore wind power is the constant wind speed on the high seas, allowing offshore wind farms to produce twice as much power as similar turbines on land. This aspect helps to increase the reliability of power generation. The annual production of offshore wind farms exceeds 90%, making it a form of renewable energy production. If some people think of onshore wind farms as threatening farms or other private land. But just like onshore wind power, offshore wind power also faces many problems.

1. Sound waves can have an impact on marine life.

Because the foundations of offshore wind turbines must be rammed into the soil, they generate large amounts of underwater sound waves during operation, affecting dolphin or small whale populations. As technology has evolved, it has been found that Bubble curtains have a role in reducing underwater sound waves, but for deeper

foundations, Bubble curtains offer little protection. There is still a need to find solutions to protect marine animals in the future.

## 2. The contradiction with the coastal landscape

In the same predicament as onshore wind power, offshore wind also interferes with the offshore landscape. Nearby attractions or tourist resorts can be affected by offshore wind farms.

## 3. High cost of offshore power generation

The technology required to transfer energy from turbines in a body of water is expensive. Due to extreme weather at sea, such as storms, high wave offshore wind farms suffer more wind and wave losses than onshore wind farms, which increases operation and maintenance costs. At the same time, offshore wind farms are more expensive to install and fix than onshore wind farms<sup>[7]</sup>.

As an important part of Germany's renewable energy, there is still a large market for wind power in the future. According to Statistics Germany, the German wind industry, including exports, earned €17.7 billion in 2016, which is about a quarter of total environmental revenues. At the same time, wind power awareness has been the area that has attracted the most investment in recent times, and high levels of expansion have boosted employment.

## 5. SUMMARY

Wind energy as a renewable energy source has huge growth potential and is one of hot topics all over the world. To promote the energy transition, Germany stands in the leading position of the world, but it also could be better in most of states. The German wind power market is facing a crisis in 2019, but wind power has significant environmental advantages, such as the elimination of local air pollution and nearly zero water consumption, which can clearly reduce CO<sub>2</sub> emissions. Along with the advantages are the threats to biodiversity posed by wind farms, noise, high speed spinning blades, underwater sound waves, etc. can have a negative impact on the health and life of humans and other animals.

According to the article citing the latest data on onshore and offshore wind farms, it can be found that the expansion of onshore wind farms in 2019 has been affected by a number of factors, with the rate of expansion being the lowest in recent years amid a sharp decline in permits, and the result of the increasing competitiveness of offshore turbines. In order to achieve its emission reduction targets, Germany may shift its focus to offshore wind power in the future. Through constant research and development, offshore wind power or deep sea wind power will also produce cheap and stable electricity.



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*Key words:*

*Doubly fed and squirrel cage induction generator,  
fixed and variable speed wind turbine, equivalent  
circuit, working principal, torque-speed  
characteristics*

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## OVERVIEW OF WIND TURBINE GRID INTEGRATION SYSTEMS

Wind energy is one of the worlds most significant and promising sources of renewable energy, primarily because it is considered non-polluting and economically viable. With the rise of carbon emissions, the electrical energy production paradigm changes from traditional sources to renewables. In the relationship between the mechanical system of the wind turbine and the grid where the wind turbine is attached, the electrical system of the wind turbine has become increasingly relevant. In the last 30 years, the technologies used for the Wind Turbine System (WTS) have also changed drastically with four to five generations emerging. Until now the current or proposed designs of wind turbines can usually be grouped into four categories. The key differences between these definitions are based on generator forms, power electronics, speed controllability, and how aerodynamic power is limited. This paper presents the overview of the four main design configurations for wind grid connection.

### 1. INTRODUCTION

Globally, total cumulative installed wind power generation capacity has risen steadily since the beginning of the third millennium and amounts to 591 GW as of the end of 2018. Since 2010 more than half of all new wind power has been installed outside Europe's and North America's conventional markets, powered mainly by the ongoing boom in China and India. Many nations across the globe are involved in taking action on climate change measures, for example Germany is one of the first countries to implement a 2030 and 2050 climate change plan with the goal of dramatically reducing carbon emissions. The worldwide carbon emissions were reduced by 1.8 per cent in 2019 relative to the previous year. In 2017, renewable energy reached 36.2 per cent of the national demand for electricity in Germany. Wind-generated electricity accounted for approximately 49 per cent of this generation. Germany has 29,844 wind turbines which represent almost 56 GW of installed wind power. New installed wind power output was 6,759 MW in 2017, compared to 4,993 MW in 2016. New wind capacity has hit an all-time high, showing the German transition to renewables is well under way.

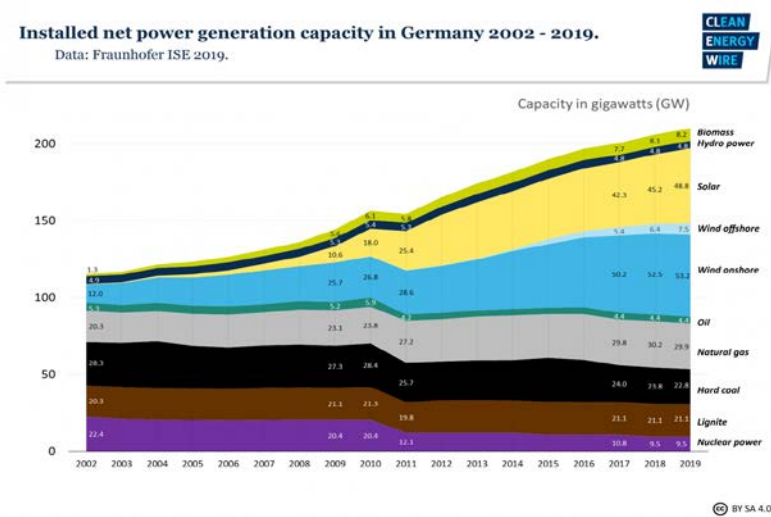


Fig. 1 Germany renewable electricity generation capacity [12]

In addition to the rapid increase in the overall installed power, the size of the individual wind turbine is also significantly rising to reduce the price per kWh produced. The average turbine size delivered to the market in 2011 is 1.7 MW, with an average offshore turbine size of 3.6 MW among them. To use 38 Siemens Gamesa SG 8.0-167 DD Flex wind turbines, Wind farm with innogy SE. Power to provide to more than 400,000 households in Germany. Wind turbine construction will commence in Q3 of CY2022. Siemens Gamesa Renewable Energy (SGRE) has received a firm order from innogy SE to supply offshore wind turbines for the offshore wind plant Kaskasi 342 MW in the German North Sea. Also included in the order is a two-year operation and repair contract.

2018 ranking	Wind Turbine Manufacturer	Change vs 2017	2017 Installations (GW)	2018 Installations (GW)	Market Share, 2018 (%)
1	Vestas Wind Systems A/S*	+1	7.5	10.0	19.6%
2	Xinjiang Goldwind Science & Technology Co., Ltd.	+1	5.7	7.0	13.7%
3	Siemens Gamesa Renewable Energy SA	-3	8.6	6.1	11.8%
4	GE Renewable Energy	-	4.8	5.1	9.9%
5	Envision Energy Limited	+2	2.8	3.7	7.2%
6	China Ming Yang Wind Power Group Limited	+5	1.2	2.5	4.9%
7	Enercon GmbH	-2	3.8	2.5	4.8%
8	Nordex SE	-2	3.1	2.4	4.7%
9	Guodian United Power Technology Co., Ltd.	+1	1.3	1.3	2.5%
10	Shanghai Electric Wind Power Equipment Co., Ltd.	+2	1.1	1.1	2.1%

Fig.2 Distribution of wind turbine market share by manufacturers [13]

Perhaps the most promising clean energy technology is the Wind Turbine System (WTS). It started in the 1980s with a few tens of kW of power output per unit, though nowadays multi-MW wind turbines are being installed. Wind turbines are widely used in distribution networks and growing numbers of wind farms are beginning to communicate with the transmission networks. Both DFIG and SCIG are classified as induction machine but there is a little difference in their rotor sides. This leads to many differences in steady-state electrical characteristics, mechanical curves and dynamic responses when connected to the grid.

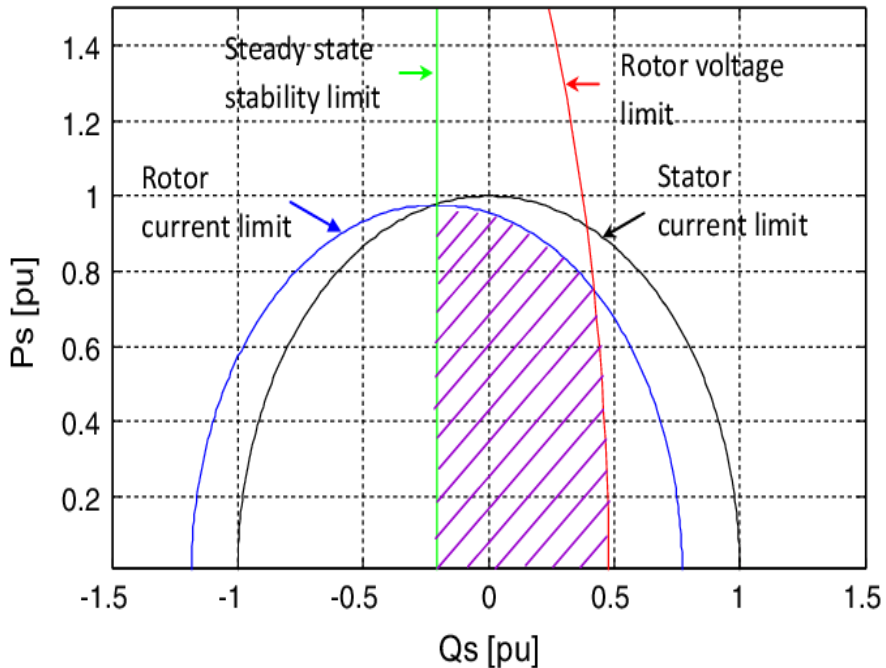


Fig. 3 P-Q capability curve for various limitation for DFIG [11]

In wind power applications, variable speed wind turbine with double fed induction generator (DFIG) progressively replaces fixed speed one with the squirrel cage induction generator (SCIG). Comparing these two generators with respect to operating theory, capacity power, etc. is worthwhile. This paper concentrates on analysing active/reactive power relationship in steady state between DFIG and SCIG.

## 2. WIND GRID CONFIGURATION

### FIXED SPEED WIND TURBINE

As shown in Fig. 4 This configuration was called "Danish model," which became very popular in the 80s. The wind turbine is fitted with asynchronous Squirrel Cage Induction Generator (SCIG), and a soft-starter can be used to achieve smoother grid link. However, a reactive power compensator (e.g., condenser bank) is needed to compensate the asynchronous generator for the reactive power demand. Since the rotational speed is set without any controllability, the mechanical components must be robust enough to withstand adverse mechanical torque, and the wind speed fluctuations are transmitted directly into the pulsations of electrical power that may result in unstable output voltage in the case of weak power grid.

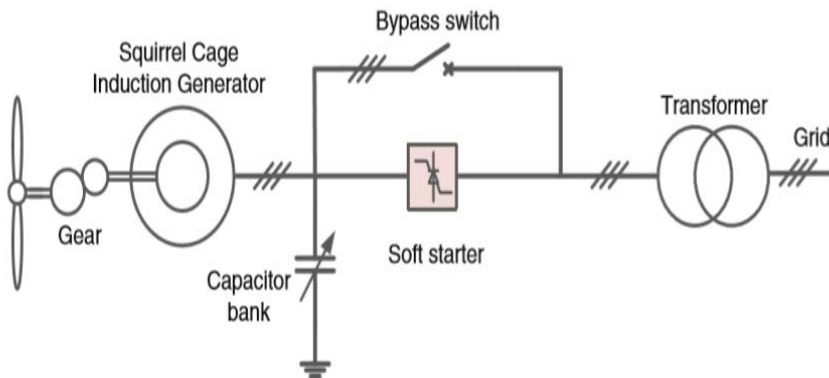


Fig. 4 Fixed speed wind turbine with direct grid connection [10]

### PARTIAL VARIABLE SPEED WIND TURBINE WITH VARIABLE ROTOR RESISTANCE

As shown in Fig.4 Also known as OptiSlip (Vestas<sup>TM</sup>), this term originated in the mid-1990's. This introduces the variable rotor resistance, and thus reduced wind turbine speed controllability. Usually the Wound Rotor Induction Generator (WRIG) and corresponding capacitor compensator are used, and a soft-starter connects the generator directly to the grid. One technological enhancement of this principle is that the wind turbine's rotational speed can be partially modified by altering the rotor resistance. This function should contribute to the mechanical stress relief and make electrical production smoother. However, a major downside to this principle is the power loss continuously

dissipating in the rotor resistors.

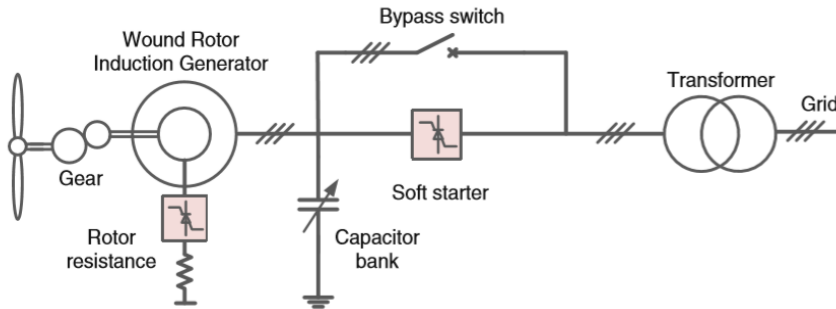


Fig. 5 Partial variable speed wind turbine with variable rotor resistance [10]

#### VARIABLE SPEED WIND TURBINE WITH PARTIAL-SCALE POWER CONVERTER

As shown in Fig.5 Nowadays, this solution is the most proven approach, and has been used since the 2000s. As illustrated in Fig. 6 Along with the Doubly-Fed Induction Generator (DFIG), a back-to-back electronics converter is adopted. DFIG's stator windings are connected directly to the power grid, while the rotor windings are linked to the power grid by the wind turbine's power electronics converter with usually 30 percent efficiency. The frequency and current in the rotor can be flexibly controlled by using the power electronic converter, allowing the variable speed range to be further expanded to a satisfactory level.

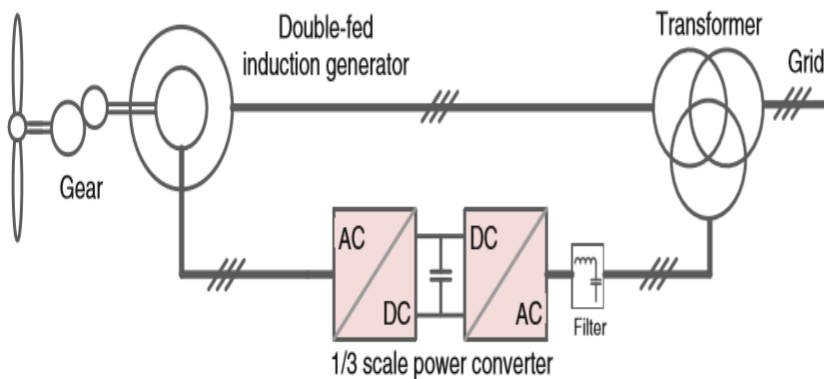


Fig. 6 Variable speed wind turbine with partial-scale power converter [10]

## VARIABLE SPEED WIND TURBINE WITH FULL-SCALE POWER CONVERTER

Another promising concept that is becoming popular for the newly installed wind turbines is shown in Fig.6. It incorporates a full-scale power converter to interconnect the generator power grid and stator windings; thus, all the power produced by the wind turbine can be controlled. In this concept the asynchronous generator Wound Rotor Synchronous Generator (WRSG) or Permanent Magnet Synchronous Generator (PMSG) was reported to be used. The removal of slip rings, a simplified or even removed gear-box, maximum power and speed controllability as well as improved grid support capability are the key advantages of this approach compared to the DFIG-based design.

The voltage level of the power conversion stage can be fairly stable due to the use of a full-scale power converter; in the future, the voltage may be sufficiently high to link directly to the power grid without the massive low-frequency transformer, which is an appealing feature for the future wind turbine network.

The DFIG operating theory is discussed in several articles. DFIG's stator circuit is wired directly to the grid, while a power electronics converter links the rotor. The back-to-back converters consist of two converters, namely the side machine and the side grid converter. A Capacitor is connected between these two converters to keep the DC-link voltage constant or alternatively stator depending on the speed of the rotor and the frequency of the AC currents fed into the rotor. The DFIG is used to produce constant frequency output from the variable speed systems. To achieve the constant frequency output, the frequency of the induced rotor currents is adjusted continuously to fit the stator output frequency to that of the network frequency. Hence, the frequency of the applied rotor currents.

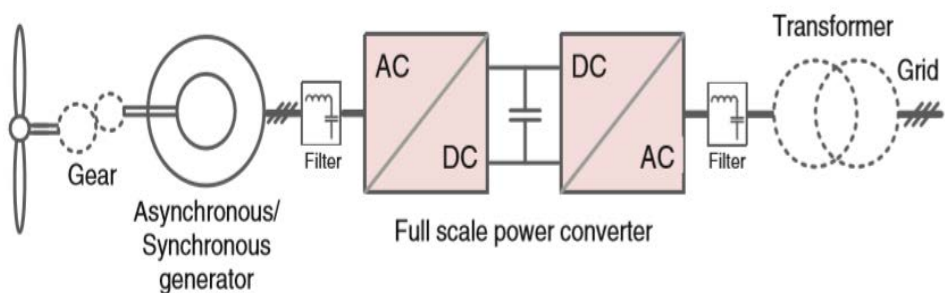


Fig. 7 Variable speed wind turbine with full-scale power converter [10]

### 3. EQUIVALENT CIRCUIT OF DFIG

DFIG's operating principle is essentially identical to that of a transformer. In this way, DFIG can be interpreted as a circuit equivalent to a transformer per step, where  $R_r$  and  $X_r$  represent the rotor resistance and the rotor side reaction. But the equivalent circuit of the induction machine differs primarily from that of a transformer with respect to varying rotor frequency on the voltage of the rotor. In the case of DFIG, there is a voltage inserted into the rotor winding, so a classic induction machine's equivalent circuit needs to be changed by inserting a rotor inserted voltage, as shown in Figure 4. In this figure,  $S$  is the slip of a rotor,  $V$  the voltage,  $I$  the current,  $R$  and  $X$  respectively represent resistance and reaction. The subscripts  $r$ ,  $s$  and  $m$  stand for rotor, stator and mutual, respectively. Real and reactive power in the stator side,  $P_s$ ,  $Q_s$ , delivered to the connected grid can be derived from  $I_s$  and  $V_s$ .

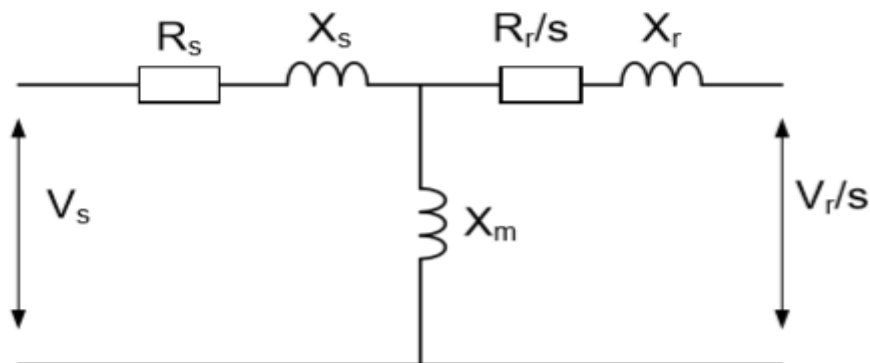


Fig. 8 The Equivalent Circuit of DFIG [9]

### 4. TWO-LEVEL BACK-TO-BACK VOLTAGE SOURCE POWER CONVERTER (2L-BTB)

An AC-DC-AC converter is included in the induction generator rotor circuit. The power electronic converters need only be rated to handle a fraction of the total power – the rotor power – typically about 30% nominal generator power. Therefore, the losses in the power electronic converter can be reduced, compared to a system where the converter has to handle the entire power, and the system cost is lower due to the partially rated power electronics. [10]

It is very popular to configure two 2L-PWM-VSCs as a back-to-back structure (2L-BTB) in the wind power system, as shown in Fig.9. A technical advantage of the 2L-



BTB solution is the full power controllability (4 quadrant operation), with relatively simpler structure and fewer components. The 2L-BTB is the state-of-the-art solution for DFIG-based wind turbine concept. Several manufacturers also use this topology for the wind turbine concept, with full-scale converter and squirrel-cage induction generator. [10]

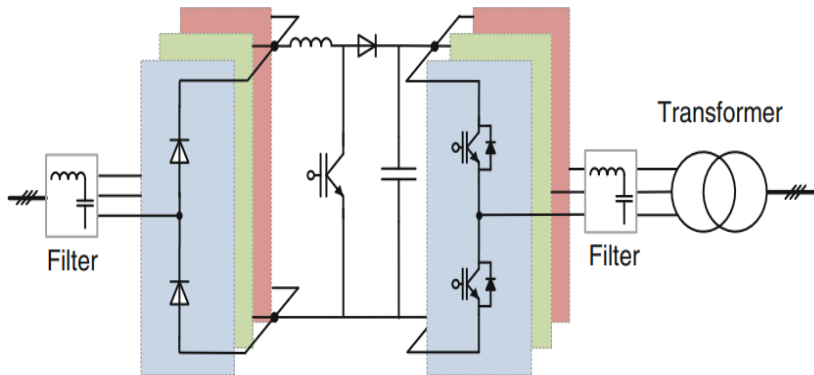


Fig.9 Two-level unidirectional voltage source converter for wind turbine [10]

## 5. ACTIVE POWER BETWEEN DFIG AND SCIG

When DFIG is used as a generator in wind turbine, the power output depends not only on mechanical power input transmitted by the shaft of wind turbine but also on the behaviour of AC/DC/AC converter connected between the rotor winding and the grid. A traditional induction generator (SCIG) generally exchanges energy with the interconnected grid via only the stator winding while the rotor winding is short-circuited. In DFIG, energy can be exchanged with the linked network by not only the stator winding but also the rotor winding. Moreover, the machine side converter can conveniently control the power flow to the grid. [9]

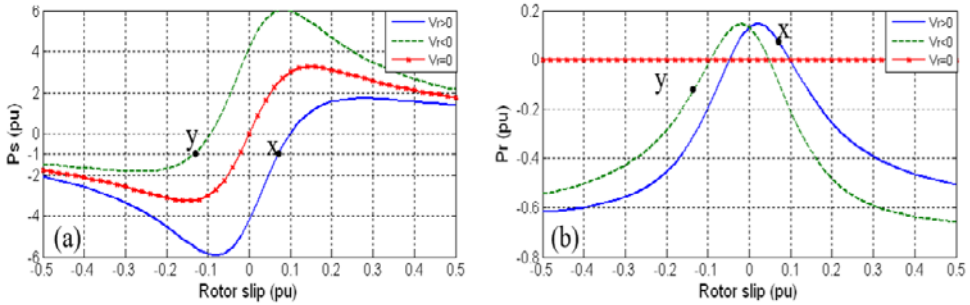


Fig.10(a) Active Power Output of DFIG for the Stator Side and Fig.10 (b) for the RotorSide [9]

A large proportion of the active power shared by DFIG with the interconnected grid comes from the stator winding but this active power output often depends on the speed of the rotor and the voltage of the rotor ( $V_r$ ). Figure 10(a) and (b) demonstrate DFIG's stator active power ( $P_s$ ) and rotor active power ( $P_r$ ) in respect of varying rotor side voltage, with SCIG's corresponding to the curve  $V_r=0$ . The 'x' and 'y' points, respectively, reflect the DFIG classified operating points for the sub-synchronous and super-synchronous modes. As can be seen from Figure 10(a), only when rotor speed is above synchronous speed does SCIG provide active power to the connected grid. Unlike SCIG, if a positive voltage is applied to rotor winding, DFIG's stator winding will deliver active power to the connected grid in sub-synchronous area. For SCIG, an increase in rotor speed leads to an increase in stator active power but for DFIG, the same active power can be produced by regulating rotor voltage at different rotor speeds.

This exchange of energy is approximately directly proportional to the sum of minus rotor slip(s) and stator-side active power ( $P_r=-sP_s$ ). In the generation mode, the rotor winding provides the connected grid with active power for  $V_r < 0$  and the power flow for  $V_r > 0$  is inverted. This is due to shift in the rotor slip symbol. The 'x' and 'y' points from Figure 8 have the same sign in the stator power curves while the points are located in opposite sign in the rotor power curves. Then the total power is less than 1pu for the point 'x' and more than 1pu for the point 'y'. That means operating at the 'y' point provides more energy than at 'x'

## 6. REACTIVE POWER BETWEEN DFIG AND SCIG

Figure 11 (a) and (b) illustrate the stator reactive power ( $Q_s$ ) and rotor reactive power ( $Q_r$ ) of DFIG with respect to varying rotor side voltage, where the angle ( $\delta$ ) between  $V_s$  and  $V_r$  from the rotor side converter is set to  $2\delta$ . The points 'x' and 'y' represent the rated operating points of DFIG for the sub-synchronous and super-synchronous modes, respectively, which are the same as those in Figure 11. In SCIG, to

create magnetizing flux in generator, it must receive reactive power from the interconnected grid and it requires a higher reactive power to produce a higher active power, which are shown in  $V_r=0$  curve in Figure 11(a). Contrarily, the magnetizing flux in generator can be generated by stator or rotor winding in DFIG. Therefore, DFIG can absorb reactive power in the rotor or stator side depending on the behaviour of converter. [9]

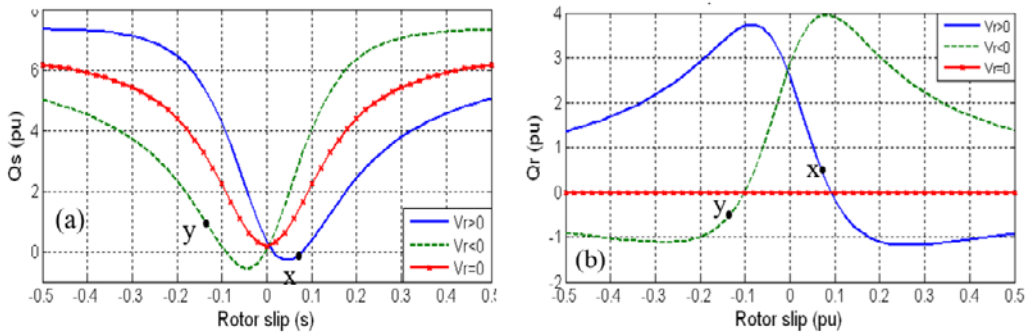


Fig. 11(a) Reactive Power Output of DFIG for the Stator Side and fig.11(b) for the Rotor Side as Angle  $\delta = 2^\circ$

### 7. P-Q RELATIONSHIP BETWEEN DFIG AND SCIG

Figure 12 illustrates the relationship between active power and reactive power in DFIG for the stator side, rotor side and total values, respectively, where the point 'z' represents the rated operating point of SCIG. To capture a specific active power, a reactive power output exchanged from the grid may be different depending on the behaviour of converter, which means that the power factor of wind power plant using DFIG can be easily adjusted. As can be seen from Figure 12 (a) and (b), the locus of the rated power operating point is the line connected between the point 'x' and 'y'. However, in Figure 12 (c), the performance of P-Q curve in total power, which is sum of stator and rotor powers, indicates that the locus of the rated power generating point is not a straight line. This locus consists of two lines, z-x and z-y for  $V_r > 0$  and  $V_r < 0$ , respectively. This is resulted from rotor active power being opposite to that in the stator for the case of  $V_r > 0$ . A reduction in  $V_r$  leads to a decline of absorbed power in the rotor side while in the stator side, the demand of reactive power is higher to create a flux compensating for decrease in the rotor winding flux. As a result, exchange of active and reactive power for the grid increases when the magnitude of  $V_r$  decreases. On contrary, for  $V_r < 0$  case, a decrease in the magnitude of  $V_r$  leads to a decline of active power delivered from the rotor winding. At the same time, reactive power extracted from the rotor winding is reduced so it requires the decrease in reactive power absorbed by the stator winding. As

a consequence, total reactive power is reduced with reduction of total active power. When  $V_r$  reaches to zero, DFIG becomes SCIG, so the rated power generating point approaches to the point 'z', 1pu. [9]

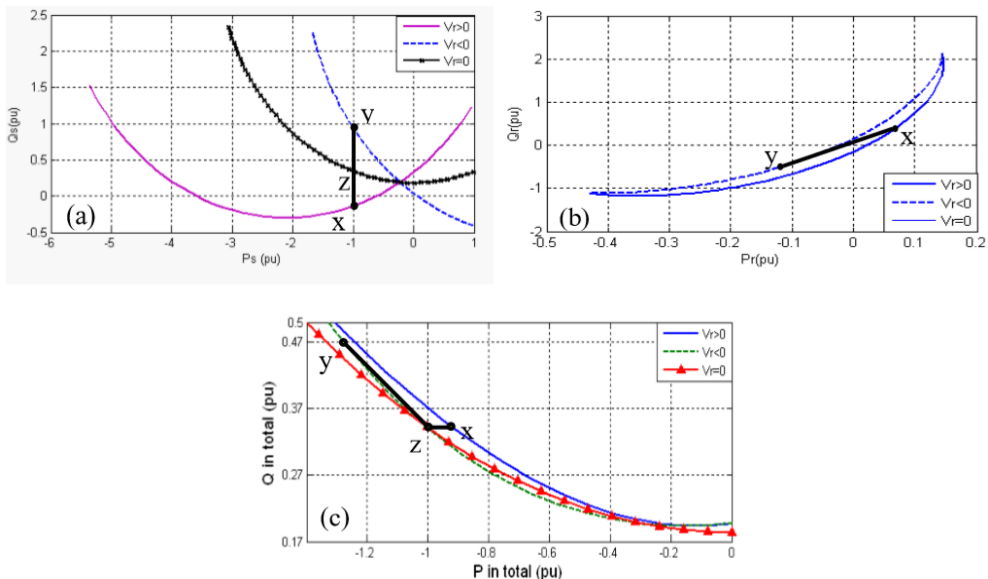


Figure 12. P-Q Relationship of DFIG for the Stator Side (a), the Rotor Side (b), and Total Power (c) [9]

## 8. CONCLUSION

In the summary, this paper investigated the active and reactive power outputs of stator and rotor sides of both DFIG and SCIG with respect to rotor slip variations, and conducted an examination of P-Q relationship at the rated operating points for analysis of steady-state characteristics between them. In fixed speed concept, the wind turbine is equipped with asynchronous Squirrel Cage Induction Generator (SCIG), and smoother grid connection can be achieved by incorporating a soft-starter. However, it requires reactive power compensator (e.g., capacitor bank) to compensate the reactive power demand by the asynchronous generator. Because the rotational speed is fixed without any controllability, the mechanical parts must be strong enough to withstand adverse mechanical torque, and the wind speed fluctuations are directly transferred into the electrical power pulsations which could yield to instable output voltage in case of weak power grid.

On the other hand, in variable speed DFIG configuration back-to-back power electronics converter is adopted in conjunction with the Doubly-Fed Induction Generator

(DFIG). Depending on the supplied rotor voltage ( $V_r$ ), DFIG is able to generate active power as rotor speed is sub-synchronous or super-synchronous. In addition, reactive power in the stator and rotor winding of DFIG can be easily changed by adjusting the  $\delta$  angle between  $V_s$  and  $V_r$ . Reactive power output of DFIG heavily depends on the mechanical power input, the magnitude of  $V_r$  and the  $\delta$  angle. For the rated generating condition, total active power is higher in super-synchronous region than that in the sub-synchronous region.

This concept is the most established solution nowadays because of the following advantages:

1. The terminal voltage and the frequency of the DFIG is decided by the grid.
2. The DFIG can produce and inject constant frequency power to the power grid by controlling the rotor side flux.
3. Operation at variable rotor speed by keeping the amplitude and the frequency of the voltage delivered constant.
4. Elimination of the rotor torque variations and reduced mechanical stress.
5. Capability to keep the DC-link voltage constant at different generator speeds.
6. Generation of power at low wind speeds and Independent active and reactive power controls.

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*Key words:*

*Big Data, Smart Grid, Micro Grid, Artificial Intelligence*

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## **REVIEWING THE STATE OF ART APPLICATION OF BIG DATA ANALYSIS TOOLS AND THE USAGE OF ARTIFICIAL INTELLIGENCE IN SMART GRIDS**

In recent years' smart grids have started to generate large amounts of data. There are a lot of publications lately addressing the needs of big data analysis tool and fields of application for artificial intelligence such as neural networks. This paper deals with the topic of smart grid, big data and the application of artificial intelligence and machine learning. The use of artificial intelligence has led to enormous progress in renewable energy systems (RES) over the past decades. Applied techniques such as artificial neural networks (ANN), fuzzy logic (FL), expert systems (ESs) have contributed to revolutionary changes in the areas of design, estimation, fault diagnostics and monitoring in RES in smart grids. In addition to explanations of the techniques mentioned, special areas of application of the respective techniques are named and described in the paper. Furthermore, to the areas of application for the aforementioned techniques, the paper also examines the possibility of processing large amounts of data. Relevant technologies such as streaming processing, iterative processing and batch processing are highlighted here.

### **1. INTRODUCTION SMART GRID AND BIG DATA**

In the context of the energy transition and the ever-increasing share of decentralized energy supply, it is essential to ensure a reliable, safe and clean electricity supply for consumers in sparsely populated regions of the world. The smart grid offers sustainable and effective solutions, which is primarily characterized by its self-sufficient power generation and is used in less populous regions. [1] With the use of renewable energies, their control and regulation of energy overproduction and underproduction, due to fluctuations in the supply, is becoming more and more necessary. If it is difficult to predict the emergence of renewable energy sources, this has a negative impact on grid security and stability, so that self-sufficient grid operation cannot be fully guaranteed. In order

to satisfy the desire for an autonomous energy supply, the use of artificial intelligence techniques is required to ensure an analysis of huge data sizes. [2]

This data increase is derived from all aspects of a utility's business, including customer operations, security, and power distribution. For those reasons the amount of information has increased rapidly lately [3]. To list a few there are data from traffic, weather, simulations, social media, asset Inventory, SCADA, PMUs, GIS and many more. Many of those connected to the power flow in a smart grid. Depending on the grid size, the amount of data easily goes into the magnitude of hundreds of gigabytes per day. Those scale of data are called big data. [4] Fortunately, big data solutions can process and analyze information from different sources and provide strategic insights to utilities that ensure the successful implementation of smart grids. In order to better process the data volumes mentioned, cloud computing is increasingly used. This has the advantage of better performance and better scalability of the required hardware. The two largest providers of such cloud services are Amazon with Amazon Web Services (AWS) and Microsoft with Microsoft Azure. [5] The following elaboration provides an insight into the application of various artificial intelligence techniques in smart-grids and sheds light on the current status of their various applications.

## 2. BIG DATA ANALYSIS

### 2.1. INTRODUCTION TO BIG DATA PROCESSING

Data analysis involves extracting knowledge that can be gained from a data set using data mining algorithms. The most important classic algorithms include pattern matching, classification, clustering and regression analysis. It is essential that the results of big data analysis and the application of machine learning algorithms based on sensor and operating data from the power grid generation and usage systems should deliver more precise results than classic approaches. To achieve this, the operating system needs the ability to evaluation of the acquisition of all power supply and consumption data almost in real time. The main types. The common processing techniques used in big data analysis are batch, stream and iterative processing. [6] In the following, these are examined in more detail with regards to their applicability in smart grids.

#### 2.1.1. BATCH PROCESSING

Batch processing is based on the map-reduce-concept developed by Google. It is used especially for the Analysis of large amounts of static and empirical data. With the help of batch processing, a very large data set is divided into numerous small sets, so-called batches. For example, a map reduce job can be used to obtain the highest meas-



ured values of all counters. Each instance of the map tasks takes a small set of the measured values and finds from the intelligent counters the minimum among them. These smaller results are "reduced" to an overall minimum value by the reduction job. Map-reduce can be used to calculate customer usage analysis, to model energy saving measures and for other purposes analysis that are carried out using static data. Therefore, batch processing is used especially for periodic and frequent reprocessing of enormous dynamic data sets. It cannot be used for real-time sensor data and streaming data processing. Therefore, it is not suitable for many real-time analysis processes of smart grids, such as demand response, short-term load forecast, real-time use and price analysis, real-time customer analysis, online network control and monitoring, etc. [6], [7]

#### 2.1.2. STREAMING PROCESSING

In stream processing, dependent logic is called for each new data instance. This has the advantage that the calculations do not have to start over with every new data record. In most applications, streaming processing is therefore preferred over the usage of batch processing. This avoids unnecessary repetitions of data reprocessing. Stream processing offers timely and more accurate results compared to batch processing. This streaming approach offers the possibility of a dynamic processing. This becomes important if the data is continuously received in real time from numerous data sources. For example, to monitor and predict the stability of the entire power grid using PMU data. This makes stream processing a very useful smart grid applications such as real-time pricing, real-time theft detection and cyber security issues. [6], [7]

#### 2.1.3. ITERATIVE PROCESSING

Apart from batch and stream processing methods, there are many big data analysis problems that are not solved efficiently by the algorithms described above. Iterative processing offers another processing option to solve a few of those. The main feature of iterative processing is the processing of all types of data types frequently. In general, iterative processing is time consuming due to its frequent reads and writes. [6]

### 3. APPLICATION OF ARTIFICIAL INTELLIGENCE

Mainly there are four different types of artificial intelligence techniques that are applied to Smart Grids. Those are expert systems (ES), fuzzy logics (FL), artificial neural network (ANN) and generic algorithm (GA). In the following there will be a short introduction and a brief overview of the current use cases of those technologies.

### 3.1. EXPERT SYSTEMS

Expert systems are basically computer programs which are using Boolean logics to replace the expertise of a human being in a certain domain. Even though expert systems can be seen as a mature technology it is not widely used by power electronic engineers. The core of an ES is the representation of information from a knowledge base. Those information are adapted by if-then statements. [8]

#### *ES-BASED AUTOMATED DESIGN, SIMULATION, AND CONTROLLER TUNING OF WIND GENERATION SYSTEM C DRIVE SYSTEM*

An application approach for expert systems is the improvement of a lot of small subsystems in smart grids such as a wind generation system. The following graphic represents simplified general ES-based Software structure for design, simulation and control for a wind generation system that could be part of a smart grid. [8]

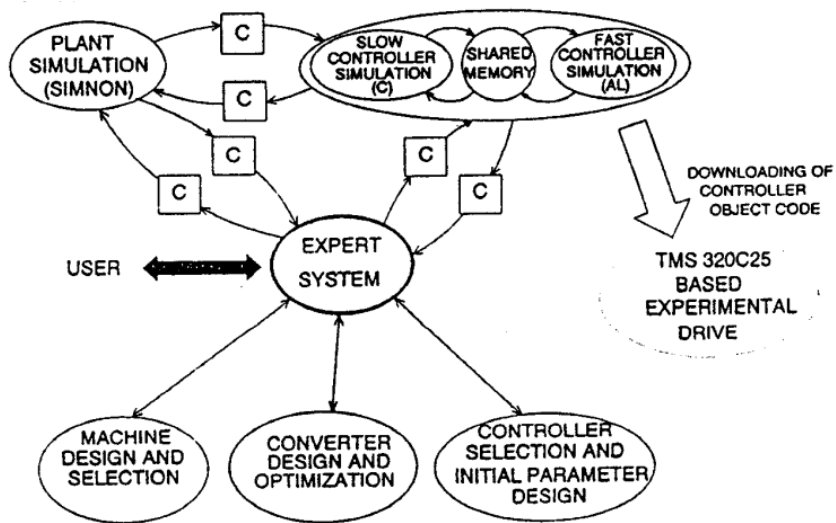


Fig. 1: Expert System [8]

### 3.2. FUZZY LOGIC

The Fuzzy Logic is a multivalued method. A variable in a fuzzy system is represented by fuzzy sets and every fuzzy set is characterized by a membership function (MF). The values of those functions lie in-between 0 and 1. This is an approach to define a problem based on degrees of certainty rather than just using true or false. The fuzzy sets or models are mathematical determined and have the capability of resending, manipulating, recognizing and interpreting. [9]

MONITORING OF WIND GENERATION

Fuzzy logic is used for system monitoring of wind generation systems. Using input data according to figure 2 from e.g. wind speed, turbine speed, generator voltage and generator current, the user of the application is supported by making decisions through the use of an "adaptive neuro-fuzzy inference system" (ANFIS) which returns a health status of the system. If all signals are in a previous area or actually leaving it, you can infer a specific operating condition, which leads to different recommendations of action for the user. [9], [10]

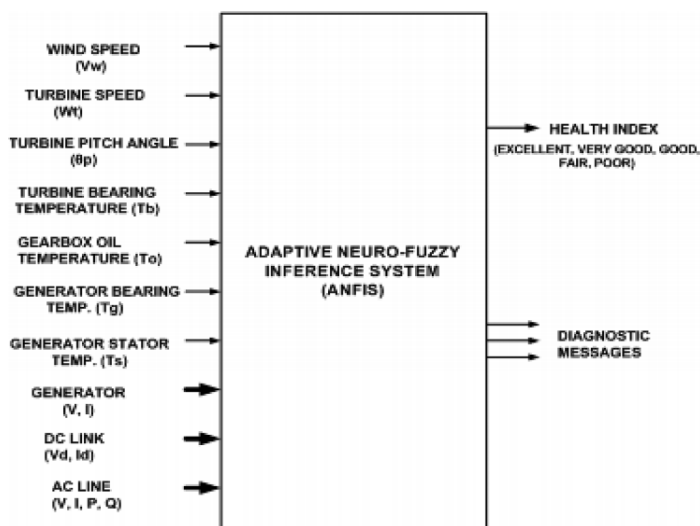


Fig. 2: Fuzzy Logic [9]

3.3. ARTIFICIAL NEURAL NETWORKS

Artificial neural networks are the most generic form of AI and was modeled based on the human nervous system. The advantage of using neural networks is that such systems are also able to recognize non-linear input and output assignments [11]. This part of the pattern or image recognition can be determined much more efficiently than with conventional methods. Neural networks, however, require a large amount of data on the basis of which a model is trained and then tested. [9], [12], [13]

SPACE VECTOR FAULT PATTERN IDENTIFICATION BY NEURAL MAPPING

An application for which neural networks can be used in the smart grids is the identification of fault patterns. A variety of types of faults can be identified by of voltage

and current wave signals. The figure below shows the exemplary error pattern identification of a smart grid subsystem using a neural network to identify the signal space vectors. As shown in the graphic, voltage and current signals are measured based on the three-phase line and the room vectors are determined. Based on this, various types of errors are then identified and evaluated with regard to their space vectors. [8] For example, over- and undervoltage can be determined because the space vectors move in a harmonic system with the sinusoidal balanced voltage and current waves on a circle with a constant radius. This radius changes when over- and undervoltage occur. If the system is unbalanced, the space vectors are characteristically distorted. For every abnormal condition in the system, the space vector signals will occur some distortion of the signature. Those signatures then can be analysed to identify the error pattern quantitatively. [9]

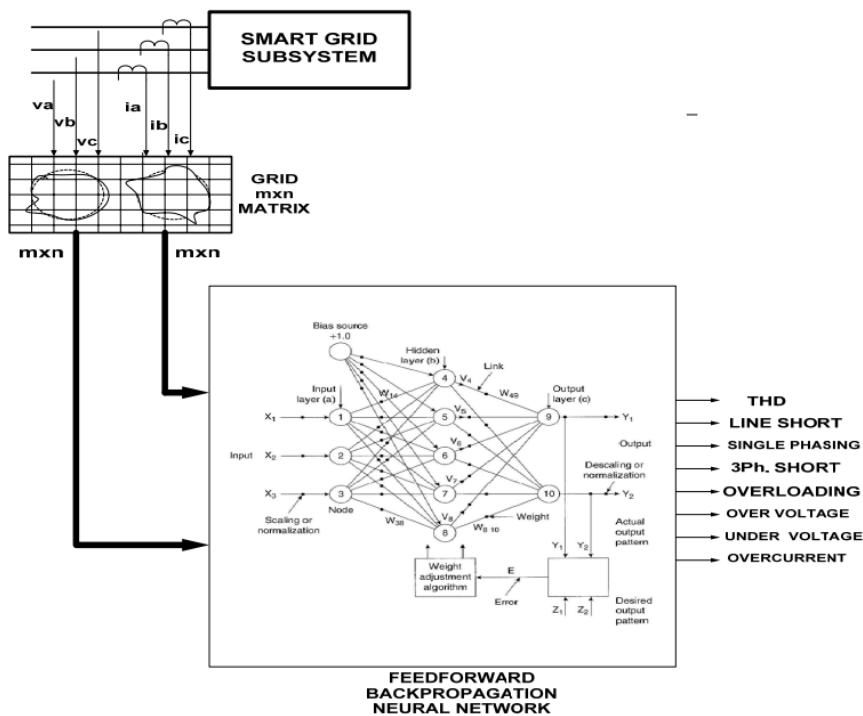


Fig. 3: Neural Network [9]

## 4. CONCLUSION

There are many papers from recent years that have discussed the problems of big data processing and the use of artificial intelligence in smart grids. Most of these publications are theoretical. In this work some realistic applications are presented. This is relevant to the extent that this topic will continue to be strongly addressed in the future due to its potential. Artificial intelligence applications are able to perform regularly recurring tasks such as ES. As well as the identification of difficult error patterns, such as the determination of fault currents with neural networks.

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*Key words: Renewables Sources of energy, Hysteresis-Control, Passive Filters, Oscillating Power, Instantaneous Power, Non-linear Load, Shunt-Active Filter, Clarke Transformation, Harmonics, PQ-Theory, Re-active Power Disturbance.*

Ankit PAL \*

Pedro RUBIO \*

## **ECONOMICAL SHUNT-ACTIVE FOR SMALL AND MEDIUM INDUSTRIAL BASED APPLICATION FOR ENHANCING THE RENEWABLE SOURCES OF ENERGY**

Small and medium sized Industries are getting integrated with Renewable Sources of energy, but with this Integration the current Power System Network gets more prone to the issues like Current Harmonics and Reactive Power Disturbance. Shunt Active Power Filter (SAPF). This paper represents the effective Economical solution of Shunt Active Power Filter for eliminating these issues which will further deal with implementation of control algorithm in very cost-effective Micro-controller i.e. Arduino. Various calculation and Simulation of the active filter is carried out using MATLAB-Simulink Toolbox. In this paper Various problem related to the passive filter are also discussed which can be replaced by the economical Active Filter. In the proposed scheme shunt active filter acts as a current source and eliminates harmonics by injecting equal but opposite harmonics components at the point of common coupling [2].

### **1. INTRODUCTION TO SHUNT ACTIVE FILTER**

The utilization of an optimized mix of Distributed Energy Resources (DER) with multiple connection points and energy feed in via Renewable energy, Combined heating and Power Stations, or Storage systems, supported by sophisticated energy management

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leads to a fruitful reduction in CO<sub>2</sub> which are generated from Industries, Commercial Buildings, Municipalities etc. While using this optimization technique there comes a big price tag of Active Filters. For the developing and under-developed countries, the price of Active Filter is big for small scale Industrial customers. So, they usually use Passive Filters for eliminating the Harmonics and Power Disturbances generated by their non-linear to reduce the losses and avoiding Penalty due to Load. But there are various issues related Passive filters like they remove particular Harmonics only and its characteristics are strongly affected by source impedance, the higher order frequency still remains in the system. In addition to it these filters are heavy, bulky and acquire a lot of area in Power network. Further there is excessive flow of harmonic currents into the Passive filter due to the voltage distortion generated by the series resonance with the source. This paper gives an economical and simple but a reliable solution of developing a Shunt Active Power Filter using the Instantaneous Reactive Power Theory [1] by Akagi, Kanazawa, and Nabae in 1983. In this paper the Control Algorithm, Simulation in MATLAB and the opposite harmonics which are to be injected in the grid are discussed. This Algorithm will be implemented in Arduino which is much cheaper as compared to the other high-end micro-controllers for building the Economical Shunt Active Filter for future work.

#### FOUNDATION OF SHUNT ACTIVE FILTER.

The Shunt Active Power Filter (SAPF) is one of the most vulnerable filter among other types of power conditioning filters, which is used to rectify out the current harmonics, in which the harmonics are inserted into the line of 180 degrees out of phase with same magnitude of the harmonic currents at the point of common coupling. The basic block-diagram is shown in the figure .1.

Pulse Width Modulation (PWM) Technique/Hysteresis loop control is utilized in order to generate gate signal while taking the reference signal into the consideration. The SAPF generally contains the two-level Voltage Source Inverter (VSI) and a Firing angle generator. The Time domain analysis technique like Instantaneous P-Q theory and Synchronous Reference Frame method are used by the Firing angle generator. Various other components like LCL filters for compensating the harmonics generated by the inverter, Pre-charging Circuit for charging the DC-link Capacitor, Active-Discharge Circuit for discharging the DC-link Capacitor in case of any fault in DC-bus bar are used.



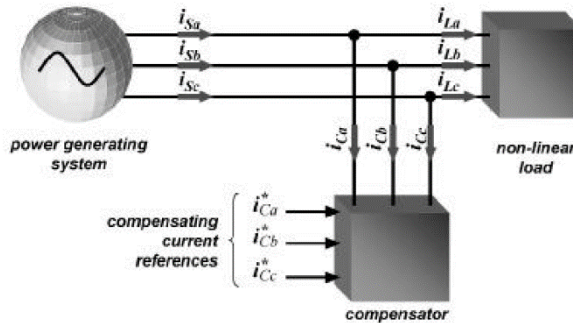


Fig.1. Block diagram of Shunt Active Filter [1].

## 2. CONCEPT OF P-Q THEORY AND ITS IMPLEMENTATION

In Figure.2 the control algorithm for shunt active power filter is shown where the application of Instantaneous Reactive Power theory is done in real time [3]. The Instantaneous 3-phase voltages and currents are taken into consideration where it is transformed to  $\alpha$ - $\beta$  co-ordinates from u-v-w co-ordinates. After that the necessary analysis and calculation are performed to generate the compensating current which is further again converted into u-v-w co-ordinates from  $\alpha$ - $\beta$  co-ordinates and then injected into the grid at the point of common coupling.

The voltage and current in  $\alpha$ - $\beta$  co-ordinates are given in the equation 1 and 2. one of the advantage of using the Clarke Transformation is that the zero component can be excluded as it would not have any significance in the calculation further. Further this is used to find out the Apparent Power, Active Power and Reactive power in  $\alpha$ - $\beta$  co-ordinates which is given in the equation 3,4,5,6.

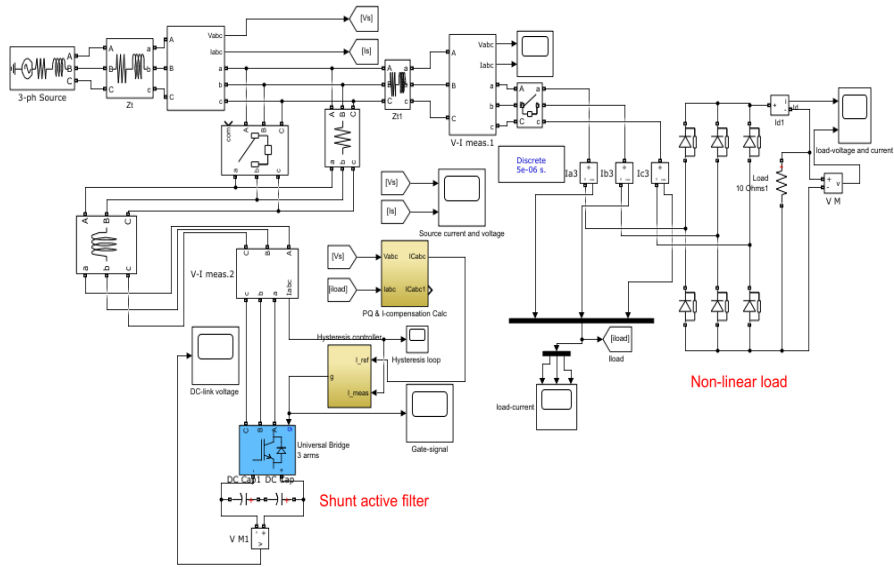


Fig.2. Simulation of Shunt active power filter.

$$\begin{bmatrix} V \\ V^0 \\ V^\alpha \\ V^\beta \end{bmatrix} = \sqrt{(2/3)} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} V^u \\ V^v \\ V^w \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} I \\ I^0 \\ I^\alpha \\ I^\beta \end{bmatrix} = \sqrt{(2/3)} \begin{bmatrix} 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \\ 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \end{bmatrix} \begin{bmatrix} I^u \\ I^v \\ I^w \end{bmatrix} \quad (2)$$

$$S = e \cdot i^* \quad (3)$$

$$S = (V\alpha + jV\beta)(I\alpha - jI\beta)$$

$$p = (V\alpha I\alpha + V\beta I\beta) \quad (4)$$

$$q = (V\beta I\alpha - V\alpha I\beta) \quad (5)$$

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \end{bmatrix}$$

The various power obtained in  $\alpha$ - $\beta$  co-ordinates are used to analyse and generate the compensating current [5]. The various currents are scripted as following by the equations 7,8,9,10.

$$\begin{aligned} \begin{bmatrix} I_\alpha \\ I_\beta \end{bmatrix} &= \frac{1}{\sqrt{V\alpha^2 + V\beta^2}} \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} p \\ q \end{bmatrix} \\ &= \frac{1}{\sqrt{V\alpha^2 + V\beta^2}} \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} p \\ 0 \end{bmatrix} + \frac{1}{\sqrt{V\alpha^2 + V\beta^2}} \begin{bmatrix} V\alpha & V\beta \\ V\beta & -V\alpha \end{bmatrix} \begin{bmatrix} 0 \\ q \end{bmatrix} \\ &= \begin{bmatrix} I_{\alpha p} \\ I_{\beta p} \end{bmatrix} + \begin{bmatrix} I_{\alpha q} \\ I_{\beta q} \end{bmatrix} \end{aligned}$$

$$I_{\alpha p} = \frac{1}{\sqrt{V\alpha^2 + V\beta^2}} p V\alpha \quad (\text{Instantaneous active current on Axis } I_{\alpha p}) \quad (6)$$

$$I_{\alpha q} = \frac{1}{\sqrt{V\alpha^2 + V\beta^2}} q V\beta \quad (\text{Instantaneous active current on Axis } I_{\alpha q}) \quad (7)$$

$$I_{\beta p} = \frac{1}{\sqrt{V\alpha^2 + V\beta^2}} p V\beta \quad (\text{Instantaneous active current on Axis } I_{\beta p}) \quad (8)$$

$$I_{\beta q} = \frac{1}{\sqrt{V\alpha^2 + V\beta^2}} q (-V\alpha) \quad (\text{Instantaneous active current on Axis } I_{\beta q}) \quad (9)$$

The calculation of compensating current is performed by just subtracting the eliminated current from the grid current which is further submerged to the grid current converting them to u-v-w co-ordinates by using the inverse Clarke transformation.

An instantaneous feedback current control method of PWM i.e. Hysteresis Current Control (HCC) technique is been used to track the actual current continuously and command compensating current within a hysteresis band. The compensating current waveform is given in the figure 4 [4]. These compensating currents are injected at the point of common coupling. The Active filter is turned on at 0.1 second as shown in the figure 5. It can be noted that the grid current gets more sinusoidal after 0.1 second with a delay of 0.01 seconds after it is turned on. This algorithm can applied in the Arduino micro-controller for practical application.

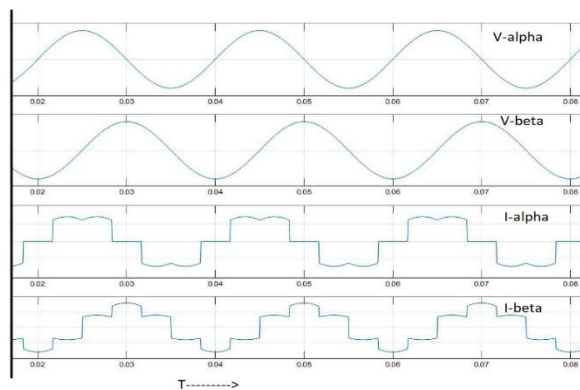


Fig.3. Waveform for alpha-beta voltages and current.

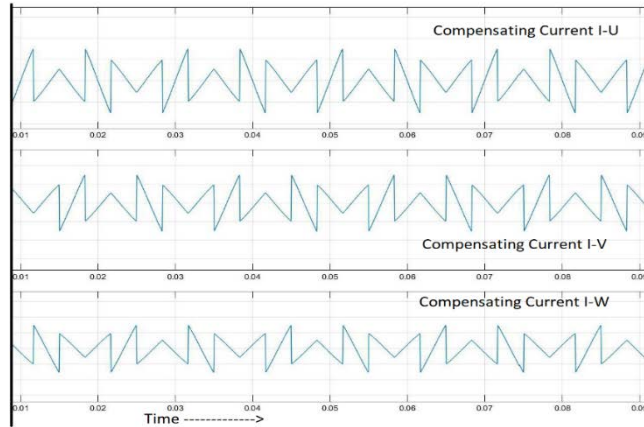


Fig.4.Waveform for compensating currents  $I_u^*$ ,  $I_v^*$ ,  $I_w^*$ .

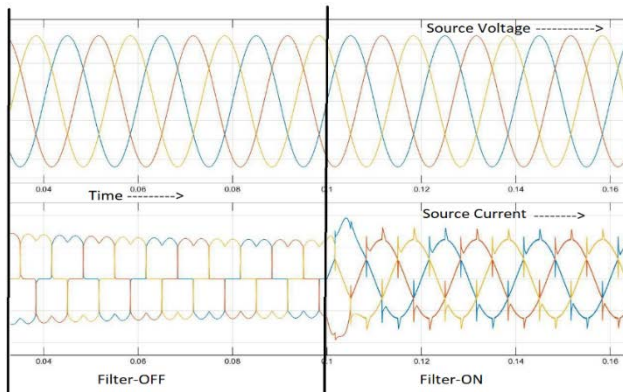


Fig.5.Waveform for grid voltage and current before and after starting the SAPF at 0.1 sec.

### 3. CONCLUSION

Various advantages and disadvantages of Active and Passive filter are discussed. The one of best and applicable solution was presented with the performance analysis of Shunt Active Power Filter using Instantaneous Reactive Power Theory. The Modelling and Simulation are done by utilizing MATLAB Simulink. Further the results show that effectiveness of Shunt Active Power Filter for harmonic elimination in distorted source current due to the Non-linear load. In THD of source current reduces from 27.17 % to 1.02 % which follows the norms set by the IEEE-519 standard of harmonic control.

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*Key words:*

*Perturb and observe (P&O), maximum power point technique, photovoltaic system, irradiance control, dc-dc boost converter*

Imran MUSTAFA\*

## **MODELLING OF PV SYSTEM WITH ADAPTIVE PERTURB AND OBSERVE TECHNIQUE UNDER STEADY AND RAPIDLY VARYING SOLAR IRRADIATION LEVEL**

The perturb and observe (P&O) algorithm is one of the most popular maximum power point tracking (MPPT) methods which is commonly applied in photovoltaic system due to its simple functionality, low computational requirement and economical application. However, it is not robust in tracking the true maximum power point (MPP) under varying atmospheric conditions, and this is because of its inability to recognize whether the change in power is due to the previous perturbation step or it is because of change in weather. Thus, it makes an incorrect decision at the first perturbation step in the duty cycle during change in solar irradiation, and as a result, it produces instabilities and a considerable power loss. This paper presents an adaptive P&O algorithm to solve such problems by proposing an extra irradiance control in the classical P&O technique to identify the actual cause of variation in power. The adaptive method is simulated and investigated using MATLAB software, and the both classical and adaptive algorithms are analysed and compared during steady and rapidly varying solar irradiation level. The simulation results of the modified P&O technique validate that it tracks the maximum power point correctly, and thereby improves the efficiency of the photovoltaic system.

### 1. INTRODUCTION

The solar energy is one of the most significant and widely used renewable resource due to its numerous advantages such as ecofriendly generation, no greenhouse gas emissions and maintenance-free operation [1-8]. However, despite all these benefits, PV cells have low conversion efficiency and non-linear electrical characteristics under

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changing atmospheric conditions [1, 4, 8]. There are several parameters, like solar irradiation level, ambient temperature and the nature of the load, that affect the solar cell efficiency. Normally, on the output characteristic curve of the solar cell, there is a unique point commonly known as maximum power point (MPP), where it is possible to extract the highest power with maximum efficiency [2]. Thus, it is therefore necessary to add the MPPT scheme in the PV system to guarantee the MPP operation.

There are some MPPT methods that have been proposed so far to track the maximum power point under varying environmental conditions. Each technique varies with regard to control parameters, complexity, accuracy, speed and economical implementation [4]. Among all these techniques, the perturb and observe algorithm, is considered as the simplest technique, and it is widely used as it requires only two control variables i.e. current and voltage. Moreover, it is inexpensive to implement and do not require any periodic modification like other methods. However, P&O method is not accurate in tracking the true MPP of the solar panel during varying solar irradiation level and temperature which is simply due to the fact that this technique is unable to separate the effect of perturbation in voltage from that due to varying irradiation levels particularly under fast-changing weather conditions.[1-3].

In this paper, an adapted P&O algorithm is proposed to avoid such problem. It is incorporated with an additional control so that it can track the maximum power point accurately under varying weather conditions by detecting any change in solar irradiance. This proposed technique is simulated and compared with the classical P&O method in MATLAB/SIMULINK environment.

The schematic diagram of MPPT based PV system is shown in Fig. 1[1]. A dc-dc boost converter is used between PV panel and load so that it can match the source and load impedances and transfer the maximum power. An MPPT controller runs the P&O algorithm and vary the duty cycle of the boost converter accordingly. The input and output voltage and currents of boost converter can be related with duty cycle as follows:

$$V_{out} = \left(\frac{1}{1-D}\right)V_{pv} \tag{1}$$

$$I_{out} = (1-D)I_{pv} \tag{2}$$

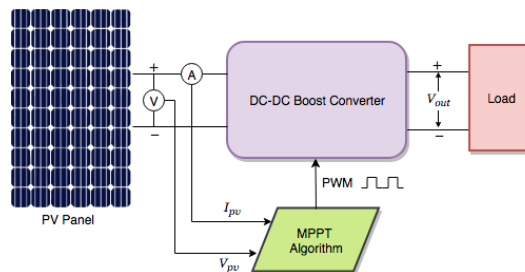


Fig. 1. Schematic diagram of MPPT based PV system

## 2. CLASSICAL P&O ALGORITHM

The perturb and observe method comprises of two basic steps i.e. perturbation of voltage and observation of power [4-7]. The flow chart of classical *P&O* technique is illustrated in Fig. 3. This method first varies the PV voltage by increasing the duty cycle of the boost converter. Then, it checks the resulted impact on the output power. If the change in power is positive, then duty cycle is further increased until it reached the maximum power point. However, if the change in power is negative, then the duty cycle will be decreased. Hence, by following these steps, the MPP is tracked.

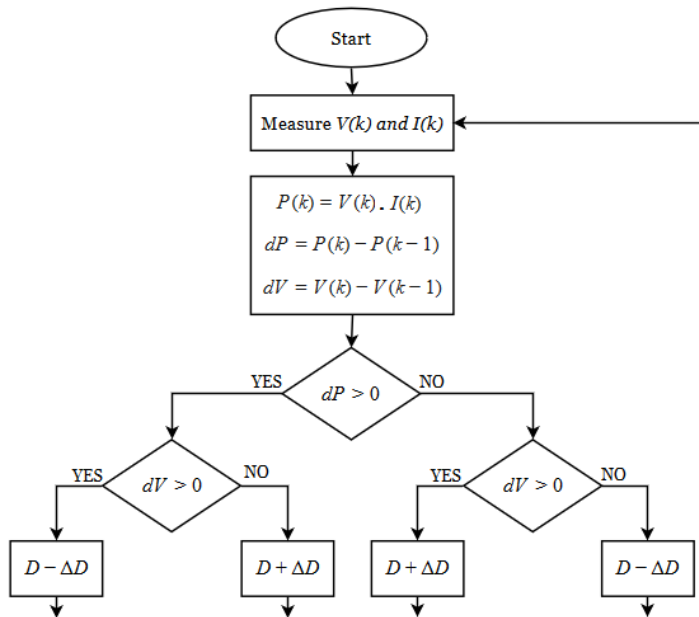


Fig. 2 Flowchart of classical P&O technique [1-8]

### 2.1. PROBLEM WITH THE CLASSICAL P&O

It can be seen in Fig. 3 that steady rise in the level of solar irradiation causes the operating of the PV system to shift from B to C. Since, both voltage and power change from A to C are positive so therefore the classical P&O method will decrease the duty cycle instead of increasing it which will cause the operating point to move away from new maximum power point  $MPP_2$ . This wrong decision of the classical *P&O* algorithm is basically due to the absence of information in distinguishing the real source of variation in solar power under varying atmospheric conditions [1]. This problem will cause more instability and significant power loss when there will be a rapid rise in the level of solar irradiance. The operating point in this case moves more and more far away from actual MPP due to the consecutive rise in the irradiation as illustrated in Fig. 3



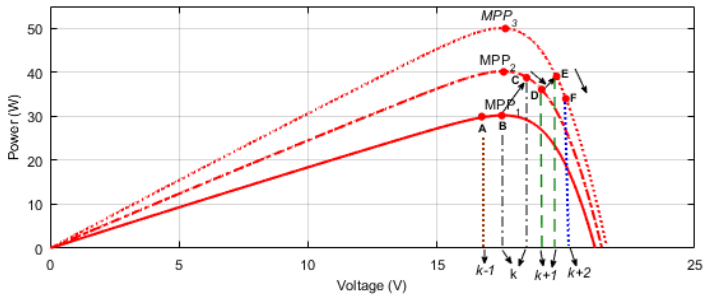


Fig. 3 Effect of variation in solar irradiation level

### 3. ADAPTIVE P&O ALGORITHM

As mentioned before, the variation in both voltage and power could be either positive because of increase in solar irradiation or due to voltage perturbation, so in order to eradicate this confusion, an additional irradiance control is incorporated in the proposed adaptive P&O algorithm. From the I-V characteristics of the solar panel as shown in Fig 4, it can be seen that during the voltage perturbation, the gradient  $dI/dV$  is always negative, and it is only positive when there is change in irradiation level. Hence, this information of the gradient  $dI/dV$  is therefore attributed to distinguish between classical P&O control and irradiance control.

Moreover, the change in both current and voltage are positive for a rise in the level of solar irradiation level, and they are negative when there is a decrease in solar irradiation level. Thus, using these conditions, the irradiance control further checks whether the change in solar irradiation is positive or negative. The flowchart diagram of the proposed P&O tracking technique is illustrated in Fig. 5.

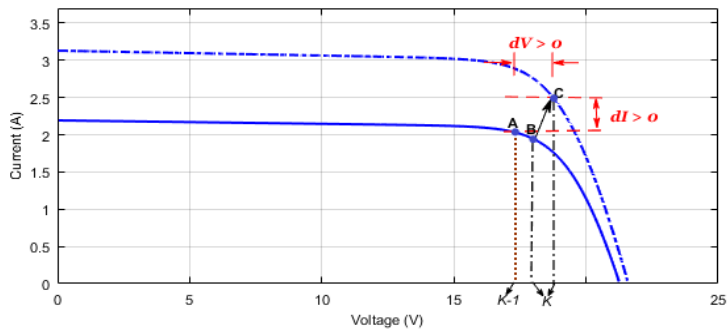


Fig. 4 I-V characteristics of PV panel

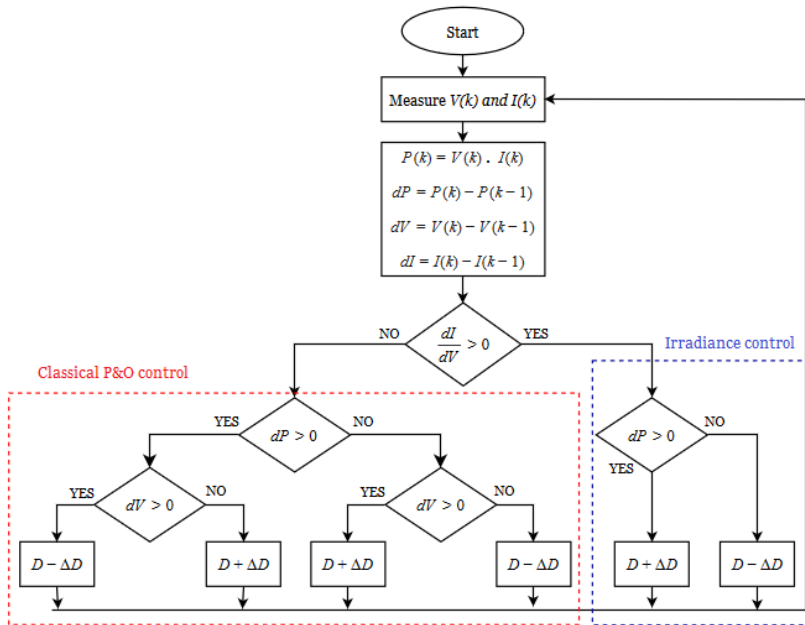


Fig. 5 Flowchart of adapted P&O technique

#### 4. RESULTS AND DISCUSSIONS

Fig. 6 illustrates the simulation model of the MPPT based PV system on the MATLAB/SIMULINK software. The specifications of the PV panel at STC and the components of dc-dc boost converter are given in Table 1.

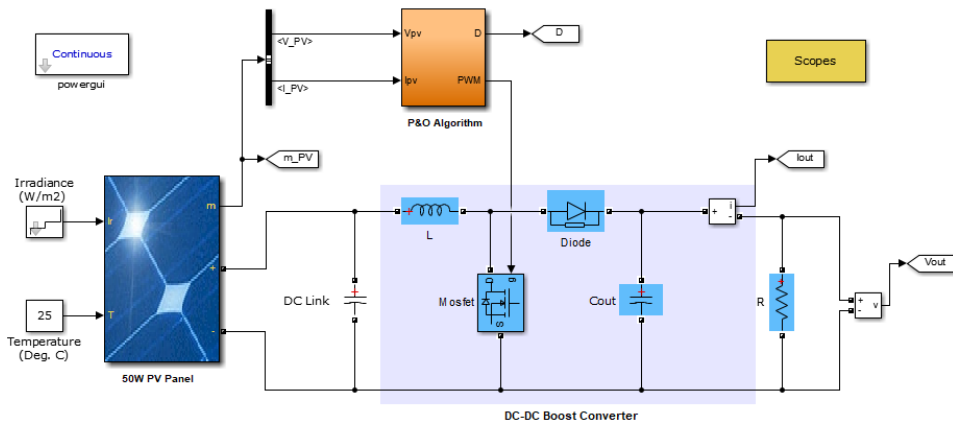


Fig. 6 Modelling of MPPT based PV system on MATLAB

Table 1 Specifications of PV panel and Boost Converter

PV panel specifications		DC-DC Boost Converter	
Parameters	Value	Components	Value
Output Power at STC, $P_{mp}$	50W	Inductor, $L$	200 $\mu$ H
Voltage at MPP, $V_{mp}$	17.6V	Output capacitor, $C_{out}$	500 $\mu$ F
Current at MPP, $I_{mp}$	2.85A	Input capacitor, $C_{in}$	10 $\mu$ F
Open-circuit voltage, $V_{oc}$	21.7V	Frequency, $f$	50kHz
Short-circuit current, $I_{sc}$	3.12A	Load, $R$	15 $\Omega$
Temperature Coefficient of $V_{oc}$	-0.36%/°C	Perturbation frequency, $f_a$	1kHz
Temperature coefficient of $I_{sc}$	0.059%/°C	Step size, $\Delta D$	0,005

The performance of both classical and adapted P&O algorithm is first investigated under a steady rise in the solar irradiation from 700 to 1000  $W/m^2$  at 30°C. The wave-forms of the both adaptive and classical P&O algorithms are showed in the Fig. 7. The rise in the solar irradiation level at 0.1 s increases the current, voltage and power. Hence, gradient  $dI/dV$  becomes greater than zero and the adaptive P&O method rises the duty cycle using irradiance control. However, the classical P&O method, does not sense the change in solar irradiation and thus, it makes the incorrect decision by reducing the duty cycle which results in power loss.

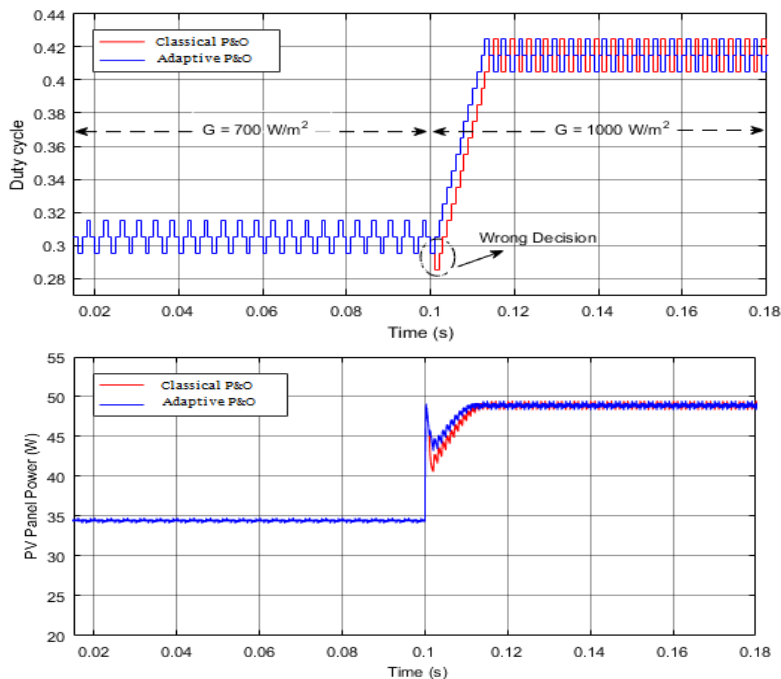


Fig. 7 Effect on duty cycle and output power during steady rise in solar irradiance

Further, in order to examine the performance during rapid varying solar irradiation level, simulation is carried out by rising the irradiance successively in 5 steps from 600 to  $850 \text{ W/m}^2$  at  $30^\circ\text{C}$ . The waveforms of both algorithms are illustrated in the Fig. 8. It can be observed that, the classical P&O technique took 34ms time to find the new MPP as compared to 24ms for adapted one. At the same time, propose method extracts the additional power which is around 6% of the rated power during this delay. The difference in the power will more significant in case of large step size as well as during the continuous change in solar irradiance [2]. Hence, these outcomes evidently show that the adaptive algorithm not only provide the powerful control by tracking the MPP rapidly and precisely, but also it avoids the power loss in contrast of classical perturb and observe technique.

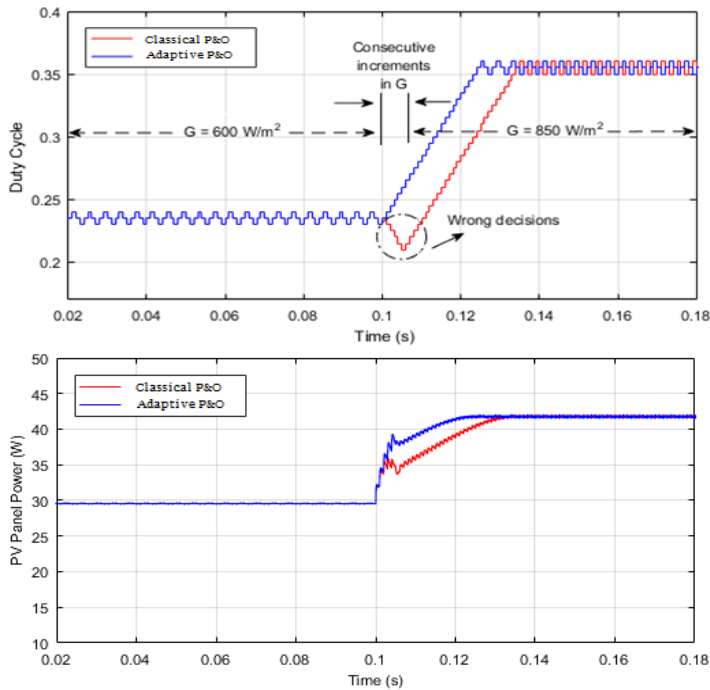


Fig. 8 Effect on duty cycle and output power during rapid rise in solar irradiance

## 5. CONCLUSION

In this paper, an adapted P&O algorithm is presented which can quickly detect any change in solar irradiation level using the gradient  $dI/dV$  and irradiance control. The MATLAB simulation is carried out to study and compare both classical and adaptive

P&O methods under steady and rapidly varying solar irradiation level. The simulation results validate that the proposed method accurately recognises the variations in the atmospheric conditions and takes the right decision accordingly. Moreover, it is more efficient as it produces the more power during the change in irradiation as opposed to the classical algorithm.

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*Key words:*  
*German Energy Politic*  
*Grid Development Plant 2030*  
*Scenario Framework 2030 and 2035*

Saleh MOMENZADEH\*

## **ENERGY POLITIC PLAN 2030 AND 2035 IN GERMANY TRANSMISSION SYSTEM OPERATORS**

The German transmission system operators (TSOs) 50Hertz, Amprion, TenneT and TransnetBW have the responsibility of grid operation and together make the German electricity grid one of the most stable and reliable in the world. In parallel with ongoing operations, Germany is planning and constructing the transmission grid of the future, which is called “Electricity Development Plan 2030” (GDP). In order to meet the climate protection goals of the Climate Protection Plan 2050, which is adopted by German government in November 2016 on the basis of the Paris Climate Protection Agreement 2015, the GDP aims to fulfill the requirements of transmitting decentralized, remote and increasingly renewable energy, phasing out of nuclear power plants, increasing sector coupling, and networking intensified European grid. This paper introduces the energy landscape of the transmission system operators on the scenario framework for the Electricity Grid Development Plan 2030 (version 2019) in the years 2030 and 2035. [1]

### **1. STUDY CRITERIA OF THE ELECTRICITY GRID DEVELOPMENT PLAN**

The energy transition is changing the demands on the grid in the long term. Onshore and offshore wind farms, photovoltaic systems, biogas plants and numerous other forms of renewable and decentralized energy generation are already essential components of the energy landscape. Their importance will increase even more in the future - also in view of the achievement of the politically set climate protection goals and the associated increased electrification of further sectors. Wind turbines in particular generate electricity at the most favorable electricity generation locations - mainly far away from the consumption centers in the west and south of Germany. This makes it necessary to trans-

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mits electricity over much greater distances than before. As the geographical distribution of electricity generation changes, the need for transmit will increase, with the large number of wind turbines in the north in particular creating a need for transmission from north to south. Moreover, photovoltaic plants and wind farms are fluctuating generation facilities that do not generate the same amount of electricity at all times, depending on the weather. These fluctuations must be compensated for by sufficient flexibility of conventional power plants, storage technologies, by making consumer loads more flexible, including new electricity applications, and by cross-border electricity exchange. This also increases the challenge of ensuring grid security and stability. [1]

Since 2011, the TSOs have been commissioned to establish a grid development plan (GDP<sup>2</sup>) for the expansion of the transmission grid. The scenario framework is the starting point of this process. With the amendments to the Energy Industry law (EnWG<sup>3</sup>) as of 01.01.2016, the regulations for drawing up the grid development plans were fundamentally changed. Since then, the GDP has been prepared every two years. In addition, the observation periods of the scenario framework more flexible. At least three scenarios with a minimum of 10 and maximum of 15 years and at least one scenario with a minimum of 15 and maximum of 20 years are foreseen. These changes will minimize process overlaps and allow TSOs more flexibility and better alignment with, for example, the planning horizons of legal targets. [1]

Power consumption, annual peak load, flexibilisation and storage, Generation, Security of supply, European market Integration, climate Protection, and legislative framework are some of the most important factors in the plan. [1]

The energy policy objectives, which are taken into account by TSOs in the grid development plan, are as follows: [1]

- Reduce greenhouse gas emissions by 40 % by 2020, 55% by 2030 and 70 % by 2040 compared to 1990 and by 80 to 95 % by 2050
- Increase the share of electricity generated from renewable energies in gross electricity consumption by 2025 40 to 45 %, 55 to 60 % by 2035 and at least 80 % by 2050
- Reducing primary energy consumption by 20 % by 2020 and 50 % by 2050 compared to 2008
- Increase in offshore wind capacity to 15 GW in 2030
- Increase the amount of electricity from combined heat and power generation to 120 TWh by 2025
- Reduce electricity consumption by 10 % by 2020 and 25 % by 2050 compared to 2008
- Phasing out nuclear energy by 2022

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<sup>2</sup> Netzentwicklungsplan

<sup>3</sup> Energiewirtschaftsgesetz

The following methods seem to be feasible in principle to comply with the upper limits: [1]

- 1) Adaptation of the power plant park by removing emission-intensive power plants,
- 2) Shortage of CO<sub>2</sub> certificates and thereby artificially increasing the national CO<sub>2</sub> price (indirect specification of a CO<sub>2</sub> upper limit),
- 3) Modelling of retrofits, conversion and modernization of power plants, e.g. CO<sub>2</sub> separation (CCS technologies) or fuel switching,

Emission budgets for individual power plants (operating hour targets, operating restrictions).

## 2. GRID DEVELOPMENT PLAN AND SCENARIOS

The energy transition can take place in different ways. The energy system transition described in these scenario framework Paths differ, for example, in the degree to which political goals are achieved and the degree to which flexibility of power generation and consumption. The basic assumption is that all scenarios have a transformation of the energy sector (energy system transition) with different technological characteristics (degree of innovation) and pace of implementation (transformation tempo). Innovation in this context means the use of new technologies in the electricity sector to increase flexibility and energy and emission efficiency in the light of the Paris Climate Change Convention of 2015. In this scenario framework, three scenarios are presented. [1]



Figure 1: Schematic representation for the classification of the scenarios [1]

Scenario A 2030 describes an energy system transition at a rather moderate pace with partial introduction of new technologies and a rather low degree of innovation.



Scenario A 2030 is characterized by a comparatively moderate increase in wind onshore and photovoltaic. In this scenario the increase in renewable energies is the lowest in relative and absolute terms. [1]

In scenario B 2030 / B 2035, the transition of the energy sector is supported by a large number of different measures and technologies. There will be an increased expansion of RE plants as well as an increasing use of electric mobility assumed. Furthermore, increased sector coupling of heat and power generation by a shift from heat applications towards electricity (e.g. heat pumps). With regard to the flexibilisation of consumption by means of load management, a relatively high potential exists which continues to rise until 2035. The increased use of decentralized storage in the residential sector in combination with photovoltaic (PV) systems leads to additional flexibility options. [1]

Conventional power plants show a further decline in installed capacity compared to scenario A 2030, among other things, as a result of the higher share of renewable energies. Appropriate political and economic framework conditions mean that old and inflexible plants are increasingly being replaced or converted to newer, more flexible plants so that in the long term slightly higher power plant capacities can be observed again in 2035. [1]

In scenario C 2030, the expansion of renewable energies represents the upper limit within the scenarios. The Scenario C 2030 describes an accelerated energy system transition with intensive use of new technologies in electricity grid, heating and transport sectors. Scenario C 2030 describes a development path in which the generation located near consumption via PV systems makes a greater contribution to meeting electricity demand, and decentralized small storage units play a greater role than in the other scenarios. [1]

In this scenario, there is also a clear shift from mobility applications towards electricity (e-mobility). However, in this scenario, there will be an even greater potential for load flexibility so that consumers will increasingly align their electricity consumption with generation. In particular, the potential existing flexibility options in scenario C 2030 should be increasingly used to ensure the synchronization of generation and supply and consumption as safely, cost-effectively and environmentally friendly as possible. [1]

In the conventional power plant, the increasing decoupling of electricity and heat production in the area of CHP generation has led to a significant flexibilisation of plant operation. The use of electricity from renewable energies in the heat and mobility sectors supports the achievement of cross-sectoral climate policy objectives. [1]

The desired share of energy generation between different energy sources is illustrated in flowing diagram.

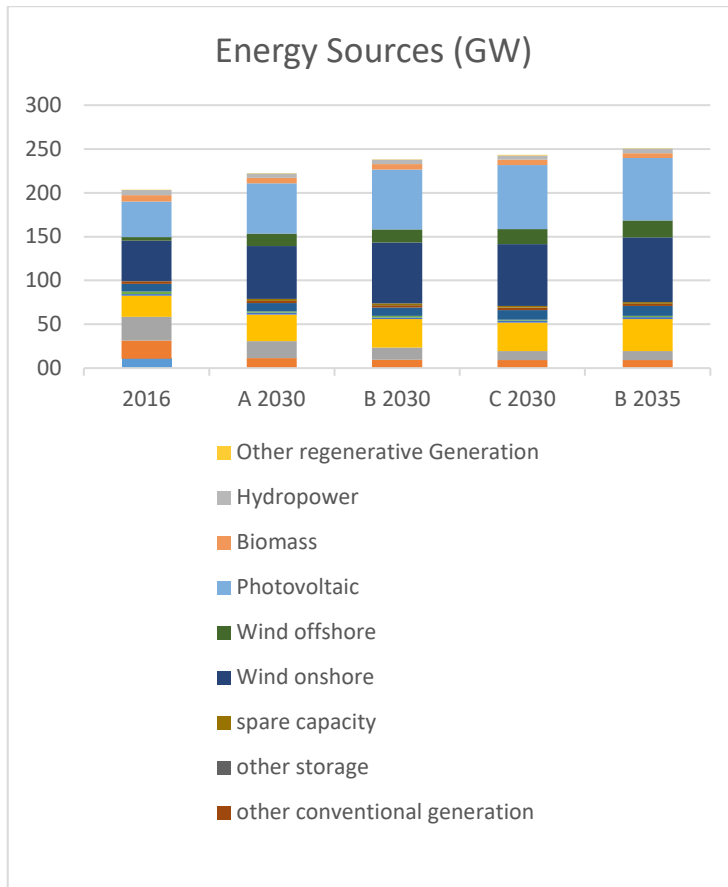


Fig. 1. Overview of Power Generation in GDP

The following figures show the dimension of grid development in transmission level for all scenarios in Germany according to GDP 2030 (version 2019). [2]



**Scenario A 2030 incl. starting grid [2]**

**Expansion of DC connections in Germany 3.780 km**

- Transport capacity 12 GW
- Interconnectors to BEL, DNK, NOR, GBR and SWE 520 km

**Expansion of AC grid 1.030 km**

**DC/AC grid enhancement 6.670 km**

- Thereof new OHL on existing pylons 2.280 km

**Estimated investments** 61 billion. If all DC lines (except DC2) are built as underground cables



**Scenario B 2030 incl. starting grid [2]**

**Expansion of DC connections in Germany 3.780 km**

- Transport capacity 12 GW
- Interconnectors to BEL, DNK, NOR, GBR and SWE 520 km

**Expansion of AC grid 1.030 km**

**DC/AC grid enhancement 6.710 km**

- Thereof new OHL on existing pylons 2.190 km

**Estimated investments** EUR 61 billion. If all DC lines (except DC2) are built as underground cables



**Scenario B 2035 incl. starting grid [2]**

**Expansion of DC connections in Germany 4.080 km**

- Transport capacity: 14 GW
- Interconnectors to BEL, DNK, NOR, GBR and SWE 520 km

**Expansion of AC grid 1.140 km**

**DC/AC grid development 7.490 km**

- Thereof new OHL on existing pylons 2.110 km

**Estimated investments** EUR 68 billion. If all DC lines (except DC2) are built as underground cables



**Scenario C 2030 incl. starting grid [2]**

**Expansion of DC connections in Germany 3,780 km**

- Transport capacity: 12 GW
- Interconnectors to BEL, DNK, NOR, GBR and SWE 520 km

**Expansion of AC grid 1,130 km**

**DC/AC grid development 7,180 km**

- Thereof new OHL on existing pylons 2.420 km

**Estimated investments** EUR 62.5 billion. If all DC lines (except DC2) are built as underground cables.

### 3. SUMMARY

This paper reviews the Grid Development Plan 2030 in Germany. A wide range of actors and variables are considered in the plan, namely energy politics and environment protection agreements. The energy transition is described in three different scenarios. These scenarios follow political objectives with different degrees of innovation and tempo. In scenario A2030, the energy transition is predicted to occur at a moderate pace and low degree of innovation. In scenario B2030/B2035 renewable energies are significantly increased, while the most accelerated energy transition is considered in scenario C2030 which includes an intensive use of technologies in power grid.

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*Key words:*

*Climate Club, Free-riding, William Nordhaus,  
Climate Change, International Climate Policy*

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## CLIMATE CLUB

The main motivation for Climate Club is to sanction free-riding countries failing climate treaties to decrease the loss of welfare for participating countries. The following paper introduces the recent problems of fighting against global warming. Therefore, the idea of Climate Club is investigated and advantages and disadvantages are presented with respect to a short economical, mathematical and ethical view. Finally, a brief outlook of possible treaties is prognosticated.

### 1. INTRODUCTION

Basically, the recognition of the human caused climate change depending on a roughly increasing emission of greenhouse gases proved by "IPCC First Assessment Report", their following publications and the Stern-report [1] (2006) leads to a markedly higher interest of minimizing the consequential damage of climate change. International treaties for fighting against global warming like reducing a rise in temperature to 2°C regarding to the pre-industrial level were voted on Paris Agreement in 2015 and the participating nations get their focus on CO<sub>2</sub> as the mainly reducible greenhouse gases with proportion of 75% (Other greenhouse gases like methane were converted CO<sub>2</sub>-equivalently). In the following pie chart [2], the shared emission of the major producing nations is depicted.

For the purpose of a sustainable economic system with regulated emission of greenhouse gases, concepts like the Green Deal of the EU and economical mechanisms like CO<sub>2</sub>-taxation or CO<sub>2</sub> certificate trading system were established [3]. Otherwise, the economist Hans Werner Sinn discussed economical obstacles, complicating the climate efforts, in his book "The Green Paradoxon" (2008). This paper examines and discusses another possibility of a reduction strategy by founding a community with the possibility of sanctions, namely the "Climate Clubs".

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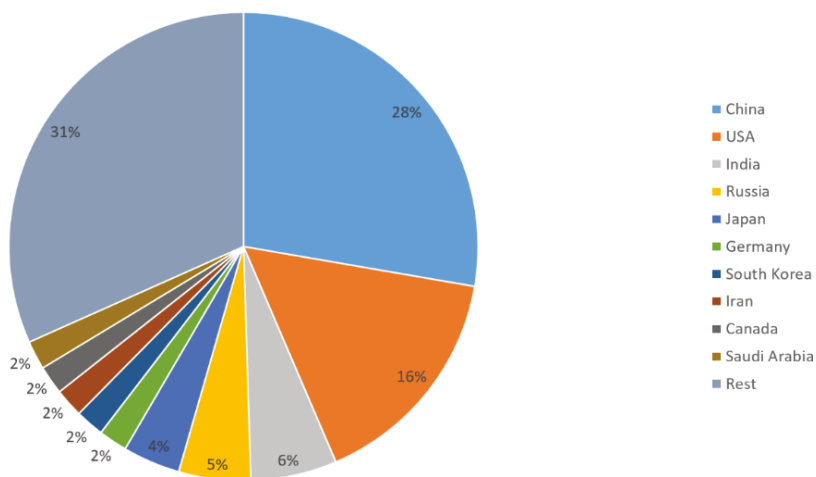


Fig. 1. Proportion on the worldwide CO2 emission [3]

## 2. CLIMATE CLUB

### 2.1. DEFINITION

William Nordhaus, Professor of Economics at Yale University, defines in his paper “Climate Clubs: Overcoming Free-riding in International Climate Policy” (published in American Economic Review 2015) the idea of a climate club as a possible way against climate change.

His definition for club is the following [4]:

*A club is a voluntary group deriving mutual benefits from sharing the costs of producing an activity that has public-good characteristics. The gains from a successful club are sufficiently large that members will pay dues and adhere to club rules in order to gain the benefits of membership.*

In other words, clubs supply a platform for their members to share responsibilities, but also gains. If those gains are profitable enough, members voluntarily comply to club rules and pay dues. Building a club is reasonable if the major conditions comply:

- i) existence of a shareable public-good-type resource,
- ii) benefit for every member,

- iii) exclusion or penalization for every non-member at relatively low cost by members and
- iv) stable membership.

Examples of working clubs are military alliances and international-trade systems.

## 2.2. FIRST ASSUMPTIONS

Nowadays there are a lot of climate agreements known. And yet, how well do they work? One striking example is the Kyoto-Protocol which has, unfortunately, not been successful because there are a lot of countries with the syndrome of free-riding, which means that they use the benefit of a public good without paying for it.

Nordhaus now comes up with the idea to create a climate club to overcome aforementioned free-riding. For quite a while Science has been searching for an international climate convention that is effective and stable. A deal is only effective if the results are close to the global optimum, and a group of countries is stable if there is no opportunity to change their status to increase their affluence. Nordhaus, however, suggests to introduce a system of sanctions for non-members. To answer the question of reasonable tariffs he analyses the effectiveness of different scenarios. Therefore, he differentiates between external and internal sanctions. Internal sanctions relate to members of a club comparable to a reward-structure in a game. External sanctions, which are comparable to e.g. punitive tariffs on goods, are attached to non-members of the so-called game. Nordhaus believes the latter to be more effective.

Hufbauer, Schott, and Elliot (1990) underline in their study that imposed sanctions most importantly are supposed to be of advantage for the imposer and of disadvantage for the recipient.

## 2.3. TRADE SANCTIONS

Apparently, sanctions on trade are most effective to punish countries. Consequently, it is worthwhile to study how to link those trade sanctions with climate treaties.

Nordhaus examines two opportunities:

One opportunity is so-called carbon duty. Imports from non-member countries are taxed in relation to the price of carbon in the importing country – so-called countervailing duties. Admittedly, those sanctions involve problems like a small range and a complicated realization, which neither lead to a reduction of emissions nor do they recruit new members.

The second opportunity is Uniform Tariff Mechanisms. Alternatively, a uniform percentage tariff can be imposed, i.e. all members impose the same tariff on all imports from non-member countries. Hence, the system of sanctions is uncomplicated and clear.

Nonetheless, those sanctions are not aimed at improving competitiveness among members, but are supposed to motivate non-members to participate, to be part of the “club”. In that case, however, amendments to present laws on international trade need to be altered as current national and international laws do not support a uniform tariff system for the sake of climate change against non-members. As climate change is the most urgent problem in the world those amendments would underline its severity.

Another controversy is the questions whether carbon prices or emissions reductions are more effective. The Kyoto Protocol revealed that emissions reductions were a rather unsuccessful method. On the other hand, carbon prices seem to be a much more promising idea due to the fact that they are unambiguous as well as less prone to corruption.

#### 2.4. ORGANIZING A CLIMATE CLUB

In spite of all these ideas there also remains the question who should be in charge of organizing such a Climate Club. There is no clear answer to that question as there is a range of ways imaginable.

Right at the beginning of his paper Nordhaus examines the different national climate policies in different countries and comes to the conclusion that these policies apply to the so-called non-cooperative game as everyone goes their own way. Thus, he uses the results of the non-cooperative game as a basis to compare the following models.

Models offer the chance to compare different scenarios. Nordhaus uses his own Model C-DICE (Coalition Dynamic Integrated model of Climate and the Economy), which he published in 2010, to examine his idea of a Climate Club. He analyses if countries would be willing to become members as well as the stability of such a coalition.

#### 2.5. MODEL

He only models one period of time and uses the standing of different regions and countries, i.e. US, EU, China, India, Russian Federation, Japan, Canada, South Africa, Brazil, Mideast and North Africa, Eurasia, Latin America, tropical Africa, middle-income Asia, and the ROW (rest of the world) from 2011. Those are only interested in their own national well-being, not considering that of the rest of the world. Nordhaus assumes, there are no further payments between the countries and treaties are stable in the sense of being coalition Nash equilibria. Gains and losses of participation are calculated in the following manner.

Gains and losses are compared with the calculations of the non-cooperative game. These calculations are based on the assumption that the domestic carbon price is at least as high as the minimum international one. Moreover, it is assumed that non-members would choose the low NC carbon price, also imposed in the non-cooperative game, as their main interest concerns their national welfare. In comparison participants choose



the higher price to fulfil their duties with regard to participation rules. Ultimately, there are two kinds of costs that need to be considered when thinking about participation. „The first cost is the additional abatement cost (net of reduced damages) of participation. The additional abatement costs are greater than the reduced damages“ [4]. The second cost is the impact on trade of the country. Figure 2 illustrates the different results for exporting and importing countries.

		Importing countries	
		Participants	Nonparticipants
Exporting countries	Participants	No penalty	No penalty
	Nonparticipants	Penalty	No penalty

Fig. 2. Penalty Structure in the Climate Club [4]

## 2.6. ALGORITHM AND SCENARIO

Nordhaus uses an evolutionary algorithm for his calculations as the solution is thought to be in the class of NP-hard problems (Wooldridge and Dunne 2004).

Summarizing advantages of penalty tariffs outweigh, thus Nordhaus uses those penalty measures against non-members as a basis for the following calculations.

In a first numerical example Nordhaus emphasizes his former idea that a Climate Club can only be successful if sanctions are imposed on non-members. Next, he examines 44 regimes involving four prices and 11 tariffs.

First of all, the stability of a coalition is studied, realizing that nearly all regimes form a stable coalition. Furthermore, the motivation to join the Club with regard to the inducement of the penalty structure. The answer to that question is illustrated in Figure 3. It shows that without trade tariffs on non-members no country is willing to join the Climate Club. Additionally, it can be seen that with a low target carbon price many countries will join in. If the target carbon price increases to 50 \$/tCO<sub>2</sub> or even 100 \$/tCO<sub>2</sub>, rather high trade sanctions need to be imposed on non-members to promote participation. Despite these high trade sanctions not all countries are willing to participate. Summarizing, participation rises if trade sanctions rise.

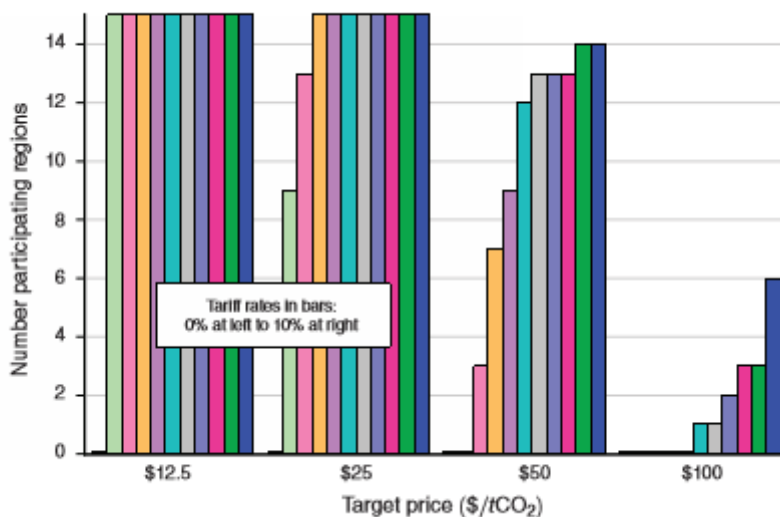


Fig. 3. Number of Participating regions by international target carbon price and tariff rate [4]

## 2.6. RESULT

It can be seen that if the target carbon price of the Climate Club is set too high, countries prefer to pay tariffs, especially when the size of the country or region is also taken into consideration. Analyzing the economic profits one can say that the cooperation in a Climate Club has considerable advantages with regard to trade as gains outweigh. The question whether to join the Climate Club or not is related to the problem of which countries will profit from it and which not. The answer depends on the chosen regime (target carbon prices or tariffs). Mostly all larger regions will profit. Countries whose production is carbon intensive will lose and those with high damages will profit. Figure 4 illustrates the results with regard to South Africa and India.

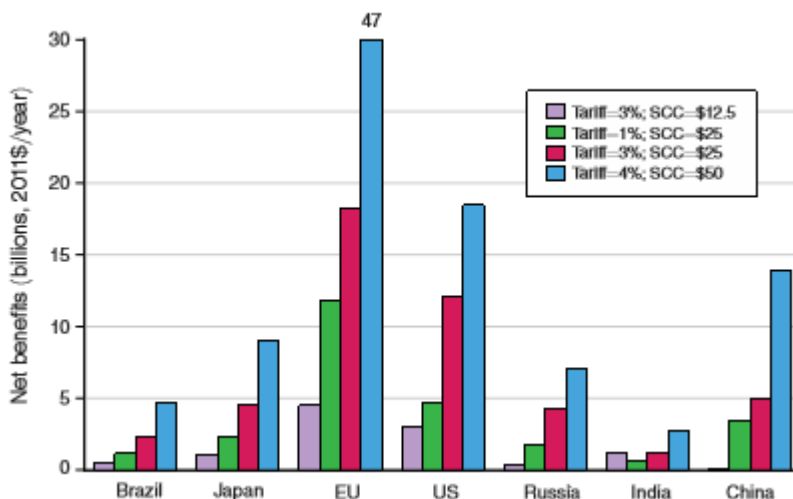


Fig. 4. Winners and Losers from the Climate Club [4]

The given results show that contract negotiations for a Climate Club might be complicated as every country would like to get a different target carbon price or additional abatement costs. Figure 5 shows how views differ widely with a penalty tariff of 5%.

Region	Global target carbon price that maximizes domestic welfare for SCC \$25/tCO <sub>2</sub> and penalty tariff of 5 percent
South Africa	9
China	14
Eurasia	14
Southeast Asia	17
Russia	19
ROW	24
United States	28
Brazil	29
Latin America	31
India	31
Canada	34
Japan	38
European Union	38
Sub-Saharan Africa	39
Mideast	40

Fig. 5. Country preferred international target carbon price [4]

### 3. CONCLUSION

The biggest problem with regard to measures against climate change is that abatement costs need to be paid without the realization of benefits at the same time. Furthermore, trade regulations need to be changed accordingly, so that penalty tariffs and other sanctions are compatible with international trade law and retaliation measures of non-members are forbidden. In future those analyses need to include a multi-period coalition model. The most important result of Nordhaus' study is that models like the Climate Club are expedient for climate policy as many countries would participate and free-riding could be stopped.

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*Key words:*  
*Energy, Transition, China*

Weixuan Wang

## **ENERGY TRANSITION AND NEW ENERGY DEVELOPMENT IN CHINA**

Abstract: Energy is an important lifeline that restricts economic development, so it needs to be paid close attention. China is at a high-speed development stage, with huge energy consumption, traditional energy reserves are becoming smaller and smaller and causing serious damage to the environment. At present, China has carried out research and development and utilization of new energy, but it also inevitably encounters many problems in this regard. This article discusses the status quo and countermeasures of China's energy transition and the development of renewable energy.

### **1. ENERGY STATUS IN CHINA**

#### **1.1. CURRENT SITUATION**

In recent years, China's economy has progressed by leaps and bounds, but the balance between the speed of energy production and the huge economic demand for it has not yet been achieved. Some surveys have shown that China's energy gap continues to expand. Taking coal as an example, it will reach a gap value of about 250 million tons of standard coal in 2030. Because in the current Chinese energy consumption system, coal ranks first with nearly 70%, and the problem of atmospheric pollution has become more serious. At present, China's energy consumption costs have nearly doubled that of the United States, and its negative impact cannot be underestimated. Due to China's large population and relatively low share of per capita resources, China's energy use is not scientific enough, and the situation of environmental degradation is severe. So we have to find ways to change this situation.

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## 2. PROBLEMS FACING TRADITIONAL ENERGY

Traditional energy faces many problems, Traditional energy refers to non-renewable energy sources such as oil, coal, and natural gas. It accounts for an absolute proportion of China's current energy consumption, of which coal consumption accounts for up to 90%. As the world's total population continues to increase, the demand for energy is also increasing.

With the large consumption of traditional energy sources such as coal and petroleum, the artificially produced exhaust gas has severely exceeded the environmental self-purification capacity, which has resulted in an imbalance in the ecosystem and an increasing environmental problem.

### 2.1 ENERGY DEMAND

Due to its large population and low per capita energy consumption expectations for China's high energy demand have resulted. Resource reserve constraints: 4% of the world's total resources, 2.5% of the proven total reserves, and 10% of the remaining recoverable reserves. By 2020, China's per capita will continue to increase, and infrastructure and urbanization will need to be built, urbanization will need to move 150 million to 300 million people into cities, leading to continuous growth in energy demand and "heavy industrialization. For example, the demand for coal, natural gas, oil and other energy sources has risen rapidly. The following figure shows the changes in China's total natural gas consumption from 2007 to 2018.

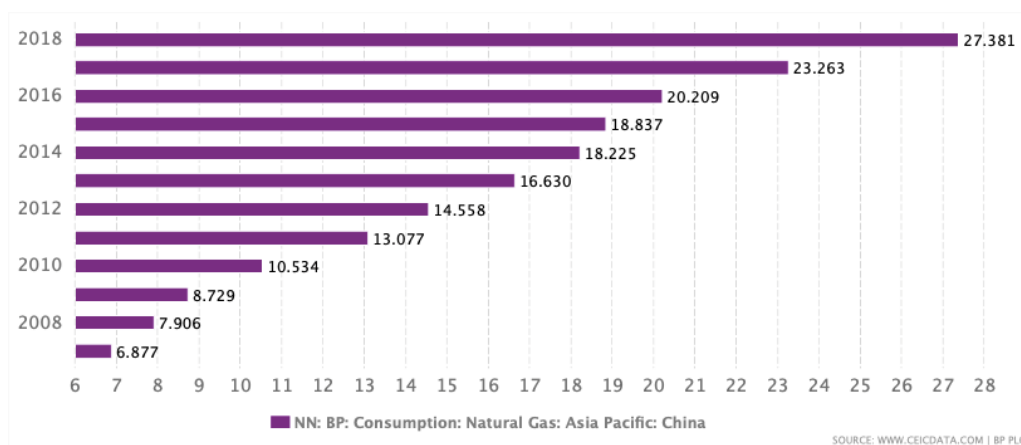


Fig. 1. Consumption - Natural Gas

## 2.2 ENVIRONMENT

Energy development and utilization involve all areas of environmental issues: air pollution, water pollution, solid waste, and ecological environmental damage. Due to the large population, low per capita energy consumption, rapid economic development, and extensive production model, the trends of ecological degradation and environmental pollution in China cannot be fundamentally re-versed. It is difficult to estimate the cost of environmental pollution caused by energy consumption: the damage caused by air pollution alone to human health accounts for about 2% to 3% of annual gross domestic product (GDP).

## 3. ENERGY TRANSITION

Looking back at the history of the world's energy transition, humans have experienced two energy transitions so far. The first occurred in the early 19th century. It was a transition from biomass (such as straw, firewood, etc.) to coal. The second energy transition can be divided into two phases. The first half occurred in the 1960s, which was represented by the replacement of oil with coal, and the second half occurred in the 1970s, which showed that the application of natural gas and nuclear power increased. At present, the third energy transition has begun to take place, and renewable energy has become an important target energy, which not only affects the development of the energy system, but also has an important impact on the national economic development. Through the continuous development and utilization of new energy technologies, we can gradually reduce our dependence on traditional energy and reduce its use. Although we still face no small challenges in terms of new energy, the impact of new energy on our future is inestimable.

## 4. NEW ENERGY

New energy refers to various forms of energy other than traditional energy, so it is also called unconventional energy. New energy also refers to renewable energy that is systematically developed and used based on new technologies. Including solar energy, wind energy, biomass energy, geothermal energy, nuclear fusion energy, water energy and ocean energy. New energy generally has five characteristics: first, it has not been developed and utilized on a large scale as energy, and some are still in the initial research and development stage; second, the resource storage conditions and physical and chemical characteristics are significantly different from conventional energy; third, the development and utilization technology is complex and the cost High; Fourth, it is clean and environmentally friendly, and it can achieve zero or low emissions of carbon dioxide and other pollutants; fifth, it has large resources and widespread distribution, and most of them have the disadvantage of low energy density.

#### 4.1 OVEROF NEW ENERGY DEVELOPMENT IN CHINA

The use of new energy in China can be traced back to the use of biogas in the late 1950s, but the large-scale development of the new energy industry in China has been in recent years. Compared with developed countries, China's new energy industrialization started late, its technology is relatively backward, and its overall level of industrialization is not high. At the same time, China has abundant natural resource advantages and huge market demand. Under the guidance and support of relevant national policies, the new energy sector has become a hot spot for investment, and the level of technology utilization is gradually increasing.

#### 4.2 STATUS OF CHINA'S NEW ENERGY MARKRT

##### 4.2.1 SOLAR ENERGY

China is rich in solar energy resources, and the prospects for solar energy utilization are broad. At present, the scale of China's solar energy industry has ranked first in the world. It is the country with the largest production and use of solar water heaters in the world and an important solar photovoltaic cell producer. China has two mature solar products: solar photovoltaic power generation systems and solar hot water systems. In the long run, the large-scale application of solar energy utilization technology and devices will certainly limit the rise in the price of fossil energy.

##### 4.2.2 WIND ENERGY

As a relatively mature renewable energy technology, wind power is an important form of conventional renewable energy power generation, and its cost reduction and scale expansion have begun to show its role in replacing fossil energy. From January to June 2019, China's new wind power installed capacity was 9.09 MW, of which offshore wind power was 0.4KW, and the cumulative grid-connected installed capacity reached 193 MW.



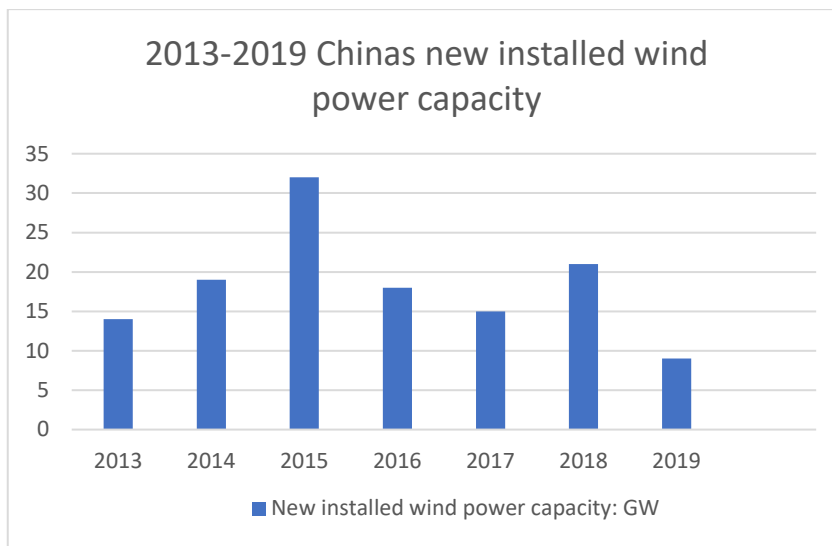


Fig. 2. Wind Power in China

#### 4.2.3 NUCLEAR ENERGY

In 2010, China's nuclear power installed capacity exceeded 10 GW, reaching 10.82 GW, with 26 units under construction at 29.14 GW.

China plans to account for 5% of total nuclear power generation in 2020. Completing this indicator conservatively estimates that at that time the installed capacity of nuclear power will reach at least 70 GW. If the total energy demand is higher, the installed nuclear power capacity will need to reach 80 GW.

However, due to the impact of the nuclear power accident in Japan, some countries have successively introduced policy plans to gradually decommission nuclear power plants; China's policies have not changed the current nuclear power construction plan, but construction progress may slow down and future approval standards will become more stringent.

#### 4.3 PROBLEMS IN CHINA'S NEW ENERGY DEVELOPMENT

Although China is vigorously developing various new energy technologies, the development of new energy requires the support of high-tech core technologies. China has always had problems of insufficient investment in research and development and a shortage of high-end technical talents, which has led to the low holding rate of new energy core technologies and a large gap compared with developed countries in Europe. The high cost and high price of new energy are the biggest obstacles to its application. Due to the complicated technology and small scale, the cost of new energy infrastructure and unit investment is generally higher than that of conventional energy, which makes

it difficult to reduce the unit cost of new energy products. In addition, although China has become the largest country in terms of wind power, solar power and nuclear power under construction, in the field of wind power, the average utilization rate of Chinese wind turbines is about 20%, and the international average level is between 25% and 30%. Significantly below the international average.

#### 4.4 CONTERMEASURES FOR CHINA'S NEW ENERGY DEVELOPMENT

- (1) Integrate limited resources and strengthen research and development of core technologies
- (2) Marketization, focusing on reducing production costs
- (3) Establish multiple incentive mechanisms
- (4) Improve laws and regulations and improve standardization

### 5. CONCLUSION

In general, new energy has a lot of opportunities as an emerging industry. At the same time, due to its susceptibility to geographical constraints, it is highly relevant to national policies, and has high requirements for technical capital and human resources. Have a high degree of acumen with staff to meet various challenges and give full play to creativity. I think the development and utilization of new energy will definitely benefit mankind. China is currently facing many energy problems, and the new energy and new technology innovation capabilities are insufficient. In any case, energy reform, pollution control, and carbon emissions reduction are our long-term. What is important is how we can use our wisdom and make use of multiple resources to innovate in both technology and business models.

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