Power Quality Assessment of Small scale grid integrated DFIG based WECS under balanced and unbalanced conditions

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Abstract: *In recent years, the generation of electricity through renewable sources has witnessed a multifield growth. It is another way to generate the electricity via wind energy, solar energy and so on, also known as a renewable energy. Out of these wind energy is more efficient than other renewable energy sources because it is locally available without any environmental concern. In rural or remote areas, the power quality disturbances like voltage imbalance and under voltage problems occur because which are away from gird station. The same issues are in 132/500kV grid connected Jamshoro with Kotri barrage and surrounding areas have different lighting load problems such as unscheduled load shedding during night. Therefore, accidents and unwanted incidents occur due to less lighting on road. To overcome these problems, wind turbines may be installed at Kotri barrage and integrate it with power grid. It will be more economical than conventional source. Because the per unit cost of electricity provided to Kotri barrage side consumers by HESCO is charged at R.s 16.75 per kWh. According to their variable speed capability and hence changing system dynamics, DFIG wind turbines are widely installed with increased incorporation of wind power into power grids. The current study deals with the simulation of DFIG grid interconnected wind based power with the help of MATLAB / Software, which meets the necessities of Kotri barrage connected lighting and surrounding areas power distribution load.*

Key Words: *Power quality, small scale renewable sources, DFIG, Statically Analysis wind energy.*

1. INTRODUCTION:

Power quality means the power systems ability to provide electricity without interruptions of voltage and frequency. It is the supply quality which really causes the electrical device to operate satisfactorily against bad effects caused by the existence of the loads. These loads may be linear and nonlinear. Linear electrical load is a sinusoidal current is proportional to voltage applied as the power supply (usually current is not phase with the voltage) [1]. In Non-linear load current is inversely proportional to voltage. Therefore power electronics devices, are large induction motors and arcing furnaces etc.Cause of power quality. These distortions create serious challenges of voltage sag, swell, interruptions, and harmonics in the power system networking [2]. Voltage sag and swell are top listed among these problems. Voltage sags are caused by switching large induction loads, faults in electrical system, loose connections while swells are caused by switching off large loads as shown in Fig.1. Power quality issues relate to industry automation; generate inaccurate load operation improper readings, and failure of equipment manufacturers tripping, and electro-mechanical relays. These issues are equally noticed in renewable and non-renewable energy resources. Non-renewable system or conventional system are ordinary electrical system which are depleting in nature i.e., coal, petroleum, diesel, nuclear. Renewable sources like wind, solar, biogas, hydroelectric are sustainable energy sources. Now a day trend of renewable sources has significantly increased in the world and wind energy has represented around 30%of the renewable capacity [3]. Wind power generation is observed at both small and large scales. Advantages of wind energy can be used in separate mode and grid tied mode. Pakistan has large potential of 3,46,000 MW generation by wind energy sources. Wind generation at Jhampir is solid observation. The 132 kV grids stations at Jhampir are providing reasonable satisfaction in main grid supply. Like Jhampir there are many places like Jamshoro, Kotri and Thatta, where considerable potential is available in the way of wind and solar. The wind turbines operate at different range as Cut-in speed typically 3 to 4 m/s, Rated Speed 8 to 14 m/s and cut-out speed is 15 to 26 m/s. Small and large scale are chosen on the origin of wind speed and potential available with duration of time. Large SWT have a rotor diameter 50 meters to 100 meters, which generate electric power 1- 3 MW but small scale wind turbine(SWT) generated electric power 1.4–20 kW at the diameter of 3 to10 meters [4]. It requires large quantity of economic assumption and administrative set up [5]. SWT has no organizational set up and it is single or group customers with a small financial contribution and can be installed over the building's roof top. SWT are classified into two types i.e., horizontal and vertical axis wind turbines which are same as that of Large SWT. Therefore, horizontal axis wind turbine (HAWT) has high rotating speed and less starting torque while vertical axis wind turbine (VAWT) has low maintenance, no cable standing problem and longer life span. Usually, small and large turbines are regulated and operated through Wind

Turbine Techniques such as fixed and variable speed turbines. Fixed turbines improve turbine stability and reduce noise in low wind conditions. The main drawback is the reactive power, but the voltage level is not manageable.Variable wind speed turbines are designed to achieve maximum aerodynamics due to wind potential better control of energy, enhanced system reliability and smoother mechanical loading on turbines. For wind generators, power electronic converters are needed for efficient transmitting of active power at unpredictable speed with a high power factor. It has various three-phase generator types, namely synchronous and asynchronous generators. Mostly used DFIG to generate wind power

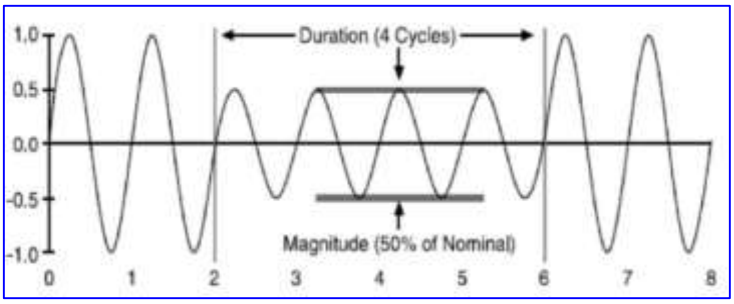


Fig. 1. Voltage sag as a Power Quality Problem

Muhammad Shoaib et al. (2019) investigated a monthly, seasonal, and annual analysis of wind energy potential in the Jampir region (Tatta Sind, Pakistan). The average wind speed data from the Pakistan Energy Development Council is 10 minutes over a three-year period (2007-2010). In the first quarter (from December to February) the greatest efficiency, in the second quarter (from March to May) minus 1, in the third quarter (from June to September) more than 2 and in the fourth quarter (from October to 11) Month) Efficiency surpasses all results obtained from correctly measured wind speed data for the Weibull distribution function. From a comprehensive analysis, it can be seen that this area is suitable for creating wind power plants for using green and clean energy [9]. Zhenlong Wu et al. (2019) studied cause of wind gusts on aerodynamic characteristics of WTs with a vertical axis. Using Computational fluid dynamics (CFD) and Distribution Management System (DMS) methods determine the difference between effective wind speed and angle of attack and compare the two CFDs used in the simulation. The average torque and power of the three-bladed turbine increase due to a 5% increase in the lateral gust by 2 m / s, and the number of blades decreases to 1, and the gust speed doubles, which further improves performance by 14.7% and 34%, respectively [10]. Mandal et al., (2018) studied the drawbacks of large and suggested that the small scale wind turbines generated power from 1 to 10kw.This is an economical method to generate the power, and this method can be adopted by even an individual to generate power in order to manage energy crisis [11]. Pagnini et al., (2018) studied the experimental operation over a small size VAWT and create two issues: full-scale structural performances in addition to power making which estimated and compared that the results are suitable for improving the system [12]. Tescher et al., (2017) mentioned that the small scale wind turbine systems are used for the commercial, residential and industrial purpose. The small scale wind turbine system (SSWT) is more effective for the community and this technology can be regulated with proper planning and designing policies [13]. Tummala et al., (2016) observed that large scale wind turbine not suitable for producing energy from renewable energy source. It has impacted on environment and recommended the small scale wind turbines sustainable to generate the power up to 10kw for domestic requirements without changing climatic conditions [14]. Adhikari et al. (2015) studied the possibility of using bamboo in a triangular tower which can be used with SWT. An experimental test of the performance of bamboo materials was conducted, and a 12-meter bamboo wind turbine tower with a power of 500 watts was analyzed. The experiments determined the basic properties of typical bamboo forms for analyzing the structure of the tower [15]. Ladge et al. (2015) investigated a small flexible blade wind turbine based on National Renewable Energy Laboratory(NREL) 5 MW, which uses three-dimensional attribute technology with a blade length of 0.4 m. wind speed range 2 m / s to 22 m /s and turbulence intensity less than 1.0%. It founded least distortion outcome on the experimental instability: the blades without distortion experience strong sub-critical insecurity [16]. Lubitz., (2014) proposed small wind turbine generated power 1.0 KW at diameter 2.5m and rotor directly coupled with permanent magnet alternator. Variable speed has effects on wind turbine energy production. He observed at low wind speeds energy production increased turbulence and the wind speeds near the turbine furling decrease the energy production [17]. Ayodele, T.R et al (2012) discussed the problems of integrating wind energy in the power grid and remarks various mitigation policies for its smooth integration. Simulation of (DFIG) and synchronous generators (SG) which maintain all issues of power systems [18]. Matsumiya et al., (2010) studied on small wind turbine under high wind conditions used the three blade upwind type rotor diameter 1.8m at 12.5 m/s generated power 1k watt and at 20m/s generated 3.2 kW. Cut-in speeds-2.5 m/s and cut-out 12.5 m/s. It required technical methods to control wind speed and security purpose [19]. Georgilakis., (2006) noted that the main problems of wind energy for the power system, operating costs of the power system, power quality, power imbalance, power system dynamics, etc. will seriously influence transmission planning [20]. Hirahara et al., (2005) mentioned that use of small wind turbine of 500μF having Rotor diameter -500 mm with the net efficiency 0.25 and power coefficient 0.36 on average and also at the tip speed ratio 2.7m/s. The maximum capacity power was found about 0.40. Finally, comparing with the other commercial turbines, the performance was efficient at the slow rated speed [21].

2. FINDINGS FROM LITERATURE REVIEW:

Small scale wind projects are easily installed at low wind speed with lesser installation cost than large scale wind turbine. It can generate 2.4-50kw of electric power [5]. It may be economical for domestic, residential, and industrial purpose and it has no environmental impact than large scale wind turbine generation. When wind power is integrated with grid many problems such as voltage variations and reactive power requirement may occur. To eliminate these problems suitable wind generator (DFIG) is proposed it applies partial scale power electronics converters to generate or absorb reactive power.

Doubly-fed induction generator (DFIG)

The DFIG is the usually used for wind power generation. The rotor terminals are energized with a symmetrical three-phase voltage of change able frequency and amplitude. The changeable voltage is energized by a voltage source converter(VSC). The variable frequency voltage of the rotor makes the rotor speed change to meet the desired working point at a certain wind speed. DFIG is however very vulnerable to grid interruption, fault. When grid voltage drops due to fault, over currents and transients in the rotor winding can happen. If these reach above the safe limit then the converter will be damaged if there is no protection. There are the different control strategies that are used for DFIG wind turbine (WT) protection STATCOM, VSC, crowbar, etc.[6]. The rotor side capacitor is blocked during the faults; it enhances the over-current in the rotor circuit. And thus the rotor converter and the generator will be decoupled from the grid if fault happens. They stop generating electrical power into the grid during this duration. In fact, this could have a tremendous impact on DFIG performance although this defense transforms the DFIG to an induction generator for the squirrel cage. This leads in the consumption of reactive power, as well as the oscillations of the DFIG electrical torque and instantaneous power of the rotor. Below Fig.2 shows grid connected DFIG.

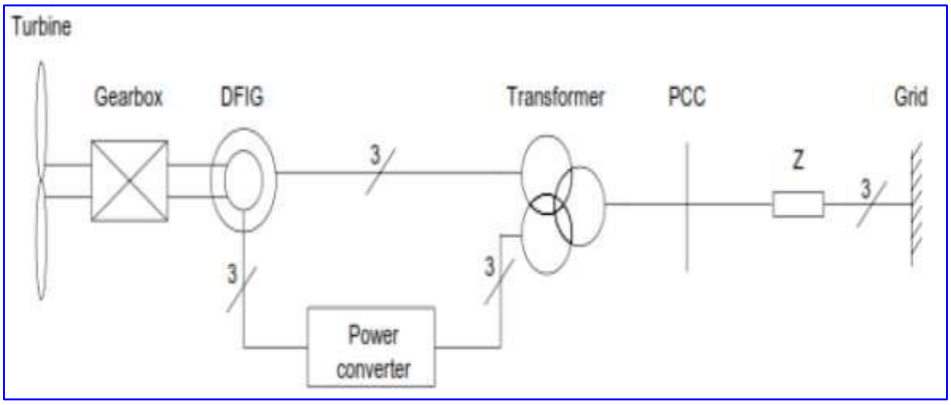


Fig. 2. Grid Connected Doubly Fed Induction Generator (DFIG)

Power Quality Issues of Grid Integration

Power is supplied to the consumers by the distribution system, required voltage and frequency. Power system still satisfies its purpose with the help of the contribution of wind power. The challenges presenting wind power in the power system role are mentioned as under[7],

Variable wind speed.

For conventional power systems synchronous generators are used while Asynchronous generators are used in wind turbines.

Grid connection points while acquiring wind power feed. Two different characteristics impact voltage stability in the network. Firstly, resistance is generally an essential part of the frequency of the line, which causes the system to collapse in terms of short circuit strength, and furthermore, the electricity generated by the wind performance is not used for transfer [8].

There are multiple types of variable wind which in turn affect the quality of the voltage and the output power. The impact of the tower shadow is induced by the wind mill tower going through the blades of the wind turbine. For two blade turbines twice in each rotational cycle, and for three blade turbines three times in one cycle. Mechanical torque declines slightly in each direction, representing a slight reduction in output voltage [9].

Fault / Low Voltage Ride through (LVRT) Capability: The wind turbine must be able to stay linked to the grid through voltage drop in the PCC without frequent trips. The wind turbine would bear a 30 percent lower voltage dip in marginal device voltage for a period of at least 100 ms for the usual clearing case, as prescribed by the grid codes, and at least if it gets trapped then it should be under 180 ms [10].

Main objectives

In this paper, the simulation of DFIG grid interconnected wind based power with the help of MATLAB / Software has been proposed and implemented. The proposed system meets the necessities of Kotri barrage connected lighting and surrounding areas power distribution load.

3. MATERIAL AND METHODS.

3.1. Configuration of Proposed model with grid connected DFIG WECS

Fig. 3 shows the proposed model of 20kW wind energy based on DFIG is subjected to power quality assessment and concerned factors of the grid integration. Two wind turbines are used and each rated power is 10kW. The terminal voltage of each WT is 415V and the 20MVA transformer from grid side which step down the 132kV into 11kV and other 100kV transformer at near the wind turbine which also steps down the 11kV into 415V and integrated with grid. Table 1 summaries the parameters used in the proposed DFIG.

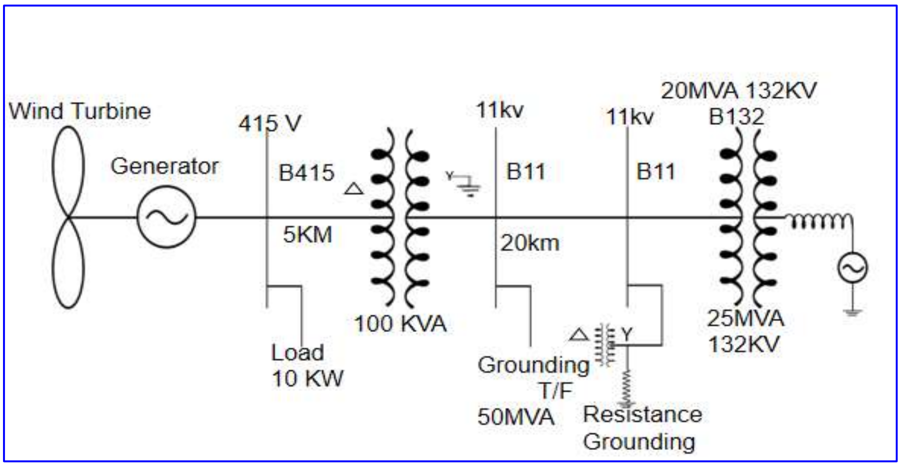


Fig. 3. The test system DFIG WECS

3.2. Mathematical model of DFIG

Wind turbines change mechanical energy into electrical power. The rotor blades collect the kinetic energy of wind which is then transferred into mechanical power. The generator gets converted the mechanical energy into electric power. The turbine is mounted to the generator rotor via a gearbox. Gearbox is used to boost turbine low angular velocities to high generator rotational speeds [11].

$$P_{wind} = \frac{1}{2}\rho A V^3{}_{min} \quad (1)$$

Here, ρ is air density, A is the area covered be turbine blades, V_{min} is speed of wind in m/s.

The total kinetic energy of wind is not converted into mechanical power. Thus fraction of power is generated. This is given as;

$$P_{mech} = C_P P_{wind} \quad (2)$$

Here, C_p is coefficient of mechanical power that depends upon condition and type of wind turbine.

Mechanical power in terms of wind speed ratio and pitch angle is;

$$P_{mech} = \frac{1}{2}\Pi R^2 V^3 min C_p \quad (3)$$

Here, R is the radius of blade in meters.

Table 1. The parameters of the 10-kW DFIG system

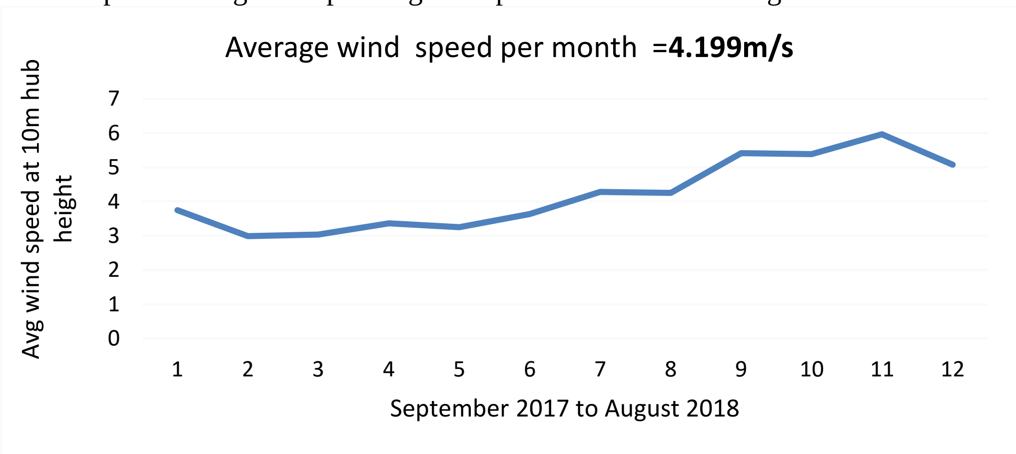
Parameters	Value
DFIG rated Power	10Kw
DFIG rated voltage	415V
P(Pole numbers)	3
F(Frequency)	50Hz

R_s	0.0070 ohm
R_r	0.0050ohm
L_{ls}	0.170H
L_{lr}	0.160H
L_m	2.70H
s	-0.40
Dc link voltage	830V
Nominal capacity of DFIG	20 kVA
Turn ratio	2:1
H (Rotational inertia)	4.5
I_s	238A
I_r	177A
Grid Parameters	132/11kV,50HZ

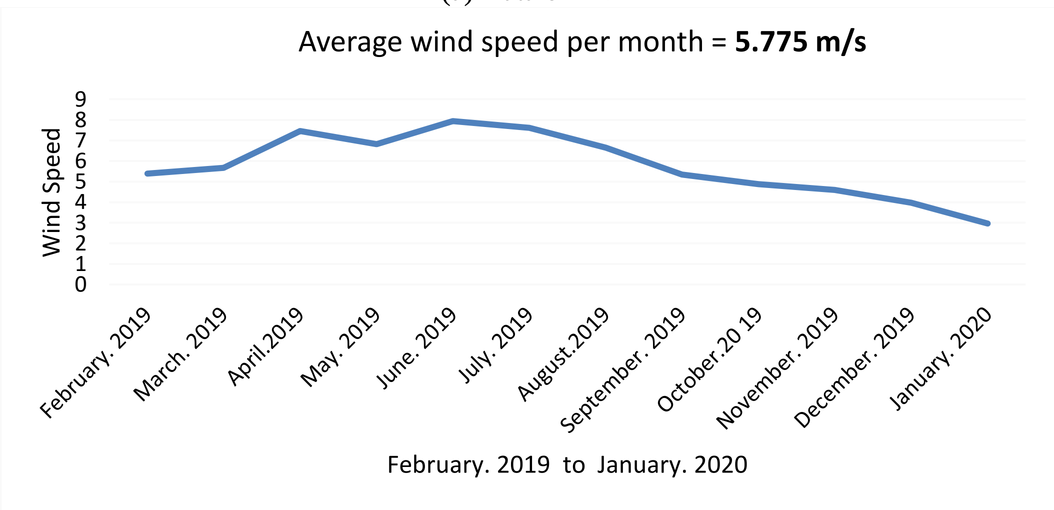
4. RESULTS AND DISCUSSION:

Statistical analysis of the wind pattern:

For statistical analysis, the monthly data is collected by the Alternative Energy Development Board (AEDB) and proposed site Kotri barrage (KB). Further more, both data are compared and finally overall idea on whether there exists diffident wind energy potential at KB for generation of electricity. Fig.4(a-b) shows the comparison of average wind speed per year at Kotri barrage and AEDB data of Jamshoro. The average wind speed at KB for year is 5.775 m/s and maximum average wind speed occurs in the month of February to August and minimum from October to January. Fig.4b shows the per month of average wind speed by AEDB, its per year average wind speed is 4.19 m/s. The maximum wind speed occurs in the month of May to August and minimum in the month of October and November. Fig.5.shows the per month generated power using corresponding wind potential of Kotri barrage.



(a) Data of KB



(b) Data by AEDB, Jamshoro

Fig. 4. Average wind speed per month in m/s

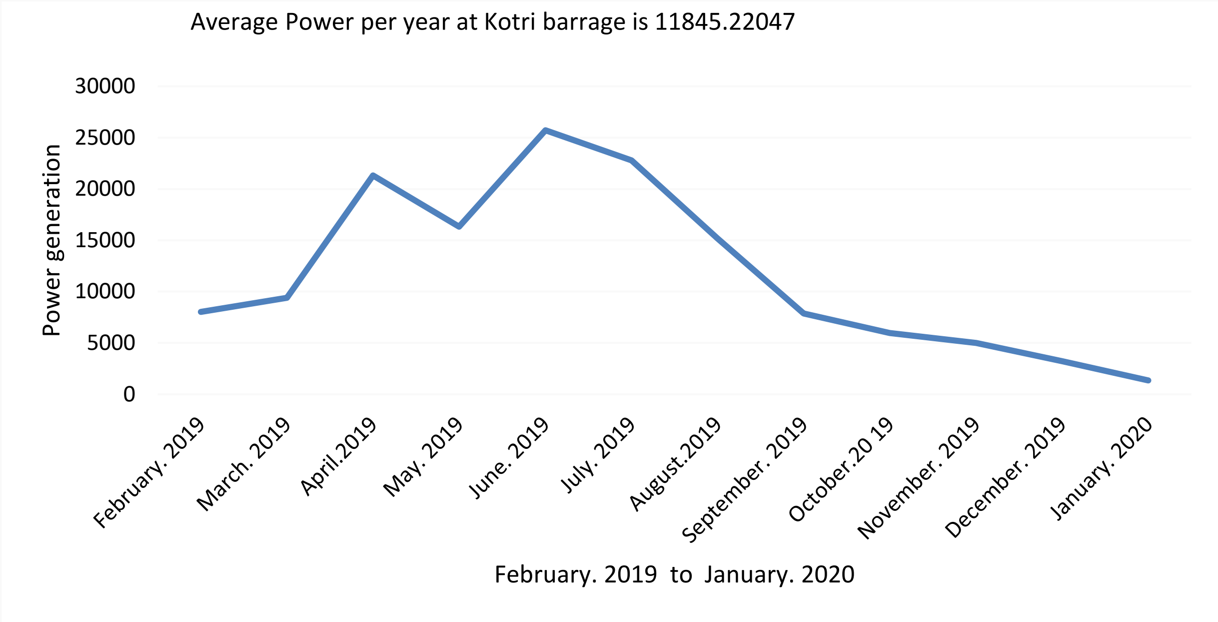
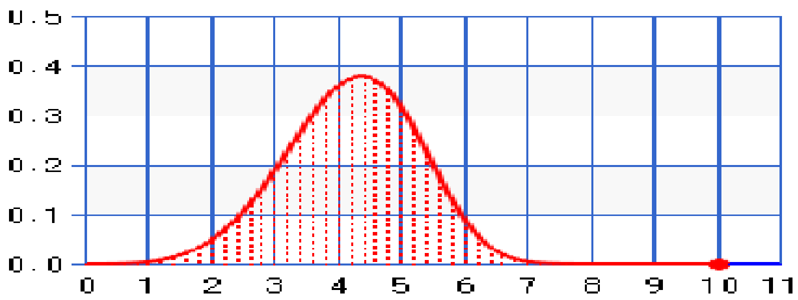


Fig. 5. Average monthly power generation capacity at Kotri barrage

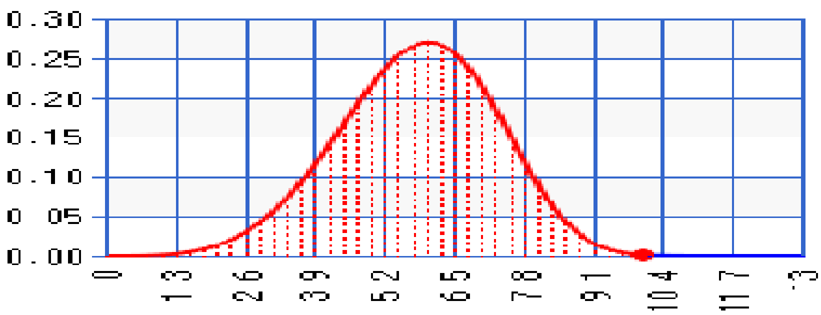
Weibull Distribution Method:

Formula in equation (4) shows the probability density function. The Weibull distribution method is used for validity of wind data. Fig.6 (a-b) shows the probabilities computed using Weibull distribution on AEDB and KB data versus wind speed, respectively. It can be verified that the maximum likelihood is observed at the average wind speeds already computed in experiments via Figs 5 (a-b). The parameters: a and b, which are shape and scale parameters for Weibull fit are summarized in Tables 2 and 3 for AEDB and KB data with standard deviations. Moreover, Figs. 6 (c-d) show the scatter plot of wind speeds experimented at AEDB and Kotri versus corresponding Weibull wind speeds. There are sloght fluctuations, nevertheless the average speeds are assured. It is clear from from Fig.6. that the average wind speed using Weibull method comes out same as noted by experiments[12].

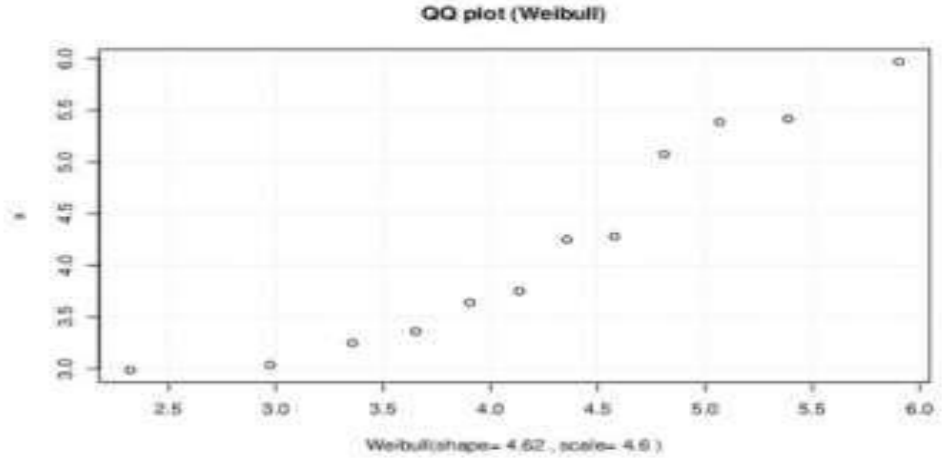
$$f(x,a,b) = \frac{a}{b}\left(\frac{x}{b}\right)^{a-1} e^{-\left(\frac{x}{b}\right)^{a}} \qquad (4)$$



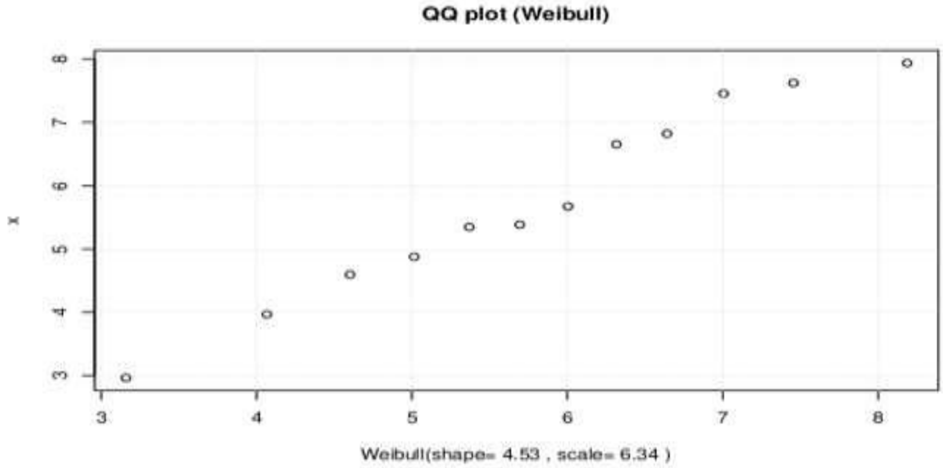
(a) wind speed versus Weibull probability for AEDB fit



(b) wind speed versus Weibull probablity for KB fit



(c) Wind speed (AEDB vs Weibull)



(d) Wind speed (Kotri vs Weibull)

Fig. 6. Weibull distribution validation results

Table -2. AEDB-Weibull parameters

Parameter	***Estimated Value***	***Standard Deviation***
shape	**4.6236185**	**1.032101**
scale	**4.596966**	**0.304288**

Table-3. KB-Weibull parameters

Parameter	***Estimated Value***	***Standard Deviation***
shape	**4.530467**	**1.058826**
scale	**6.342993**	**0.425561**

Grid connected DFIG

The proposed system is considered to be 10kW based on wind turbine generators connected to 11 kV distribution system and export power to 132 kV grid via 2 km long transmission line as shown in Figure. The wind turbine generator works at a maximum wind speed of 7.58 m/s and a minimum wind speed of 2.8 m/s, where the wind turbine's maximum output is 10kW of its rated power. The overall parameters for DFIG wind turbines connected to the grid are given in Table.1 above. L-G, 2L-G and 3-phase faults are discussed in this article. These faults are applied at grid side endpoints.

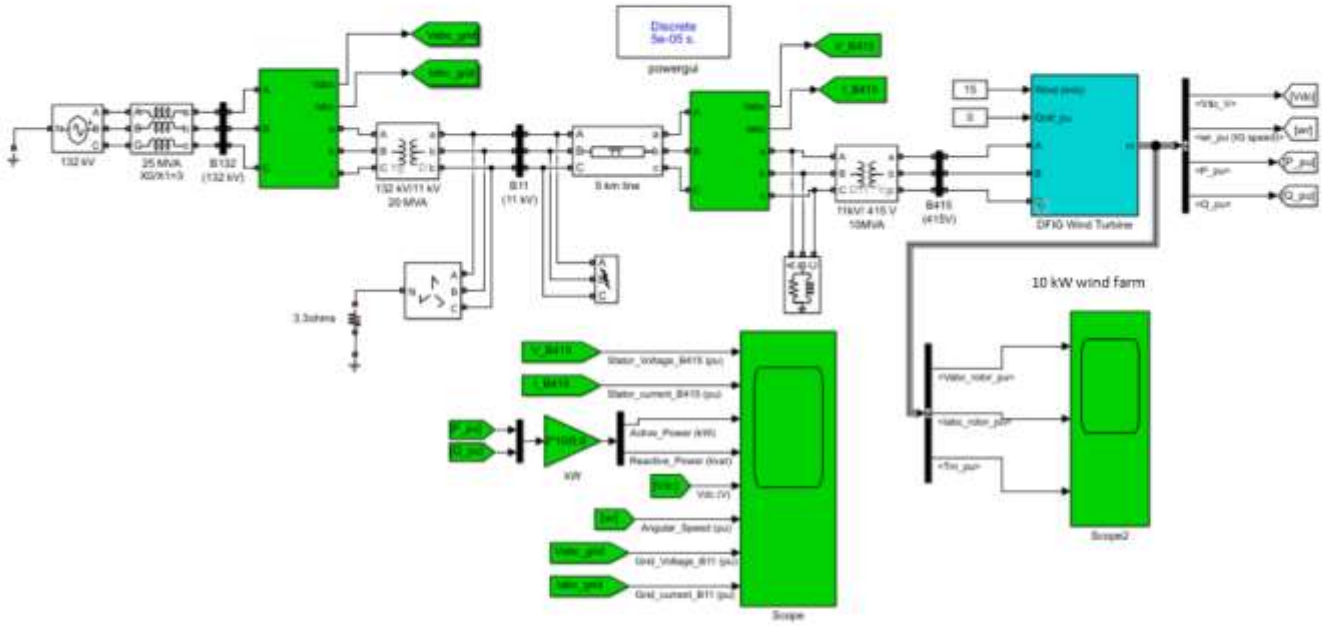
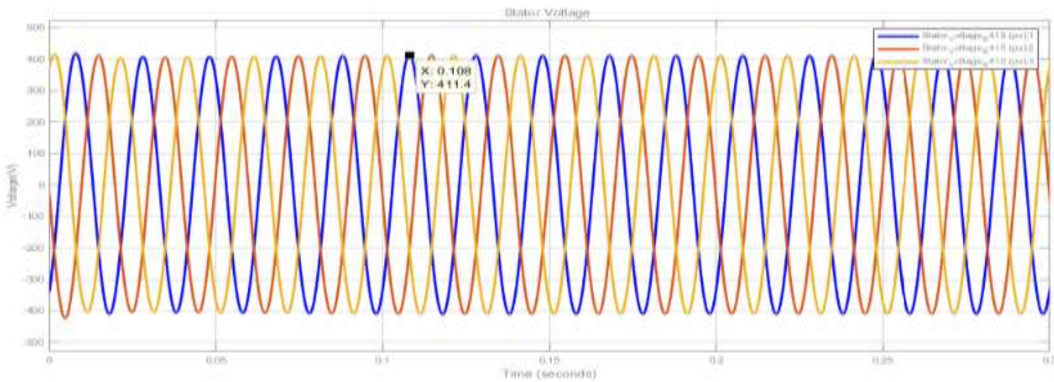


Fig .7 Grid connected proposed DFIG

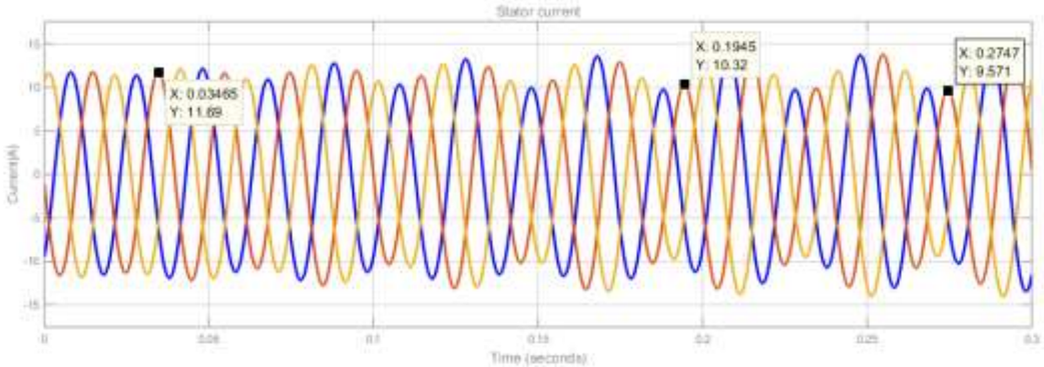
Assessment of power quality
A) Under normal load

Under normal condition the Power Quality Asses at no Load and load
At no load

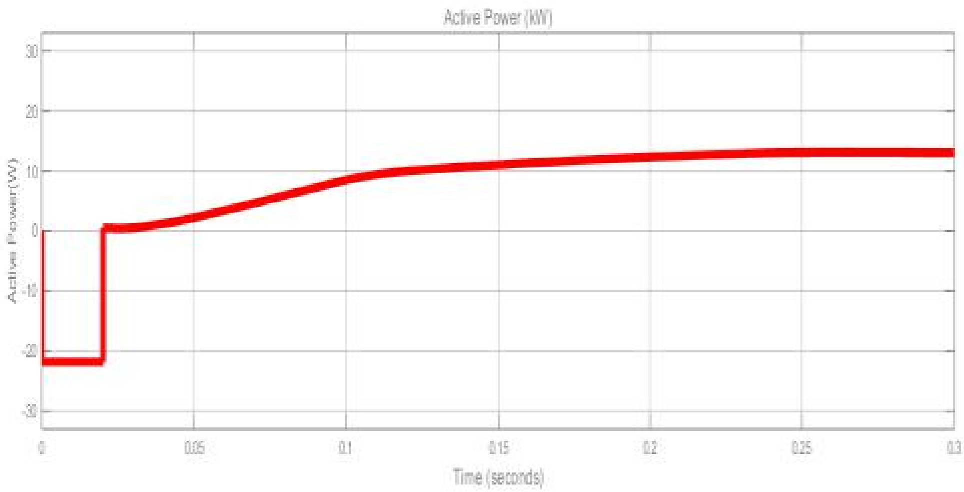
In this case, initially, no load is connected to system. Only the grid and WT are coupled at PCC. This analysis is done to record the state parameters for comparison with other cases.In this case, the Power Quality parameters are analyzed at initial condition. Below fig discussed simulation result of Stator voltage, Current and Active power.



(a) Stator Voltage

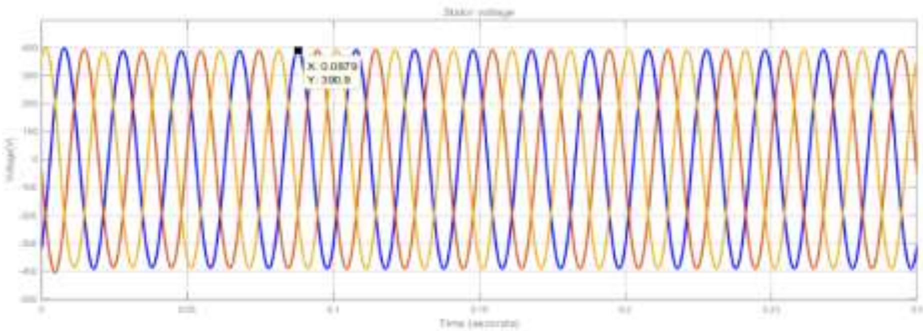


(b) Stator current

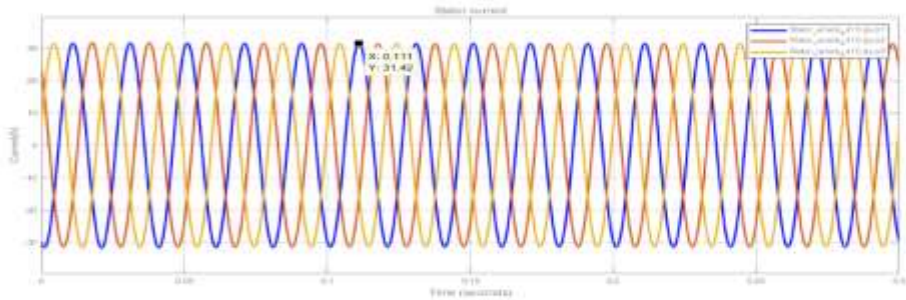


(c)Active Power =
Fig.8. Results At no Load

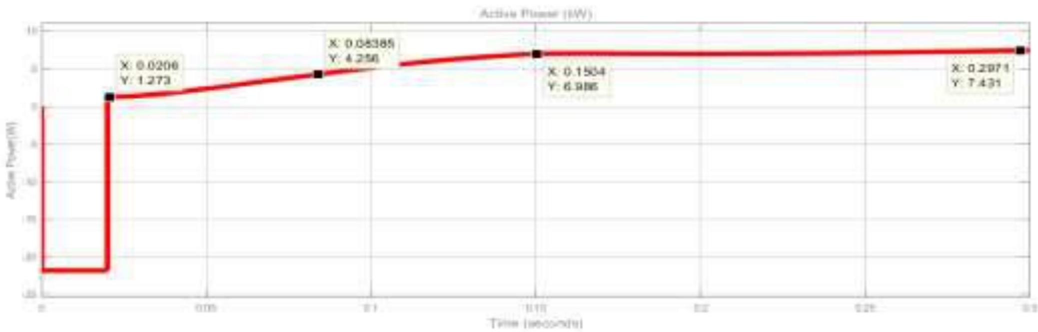
At Load:
In this case, the PQ parameters are disused at load of 5 kW connected at PCC shown in below Fig.9.



(a) Stator voltage



(b) Stator current

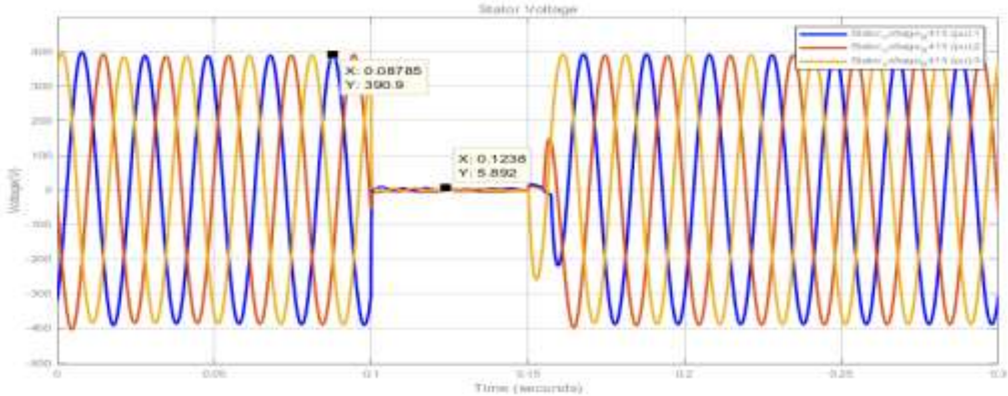


(c) Active power
Fig. 9. Results at Load

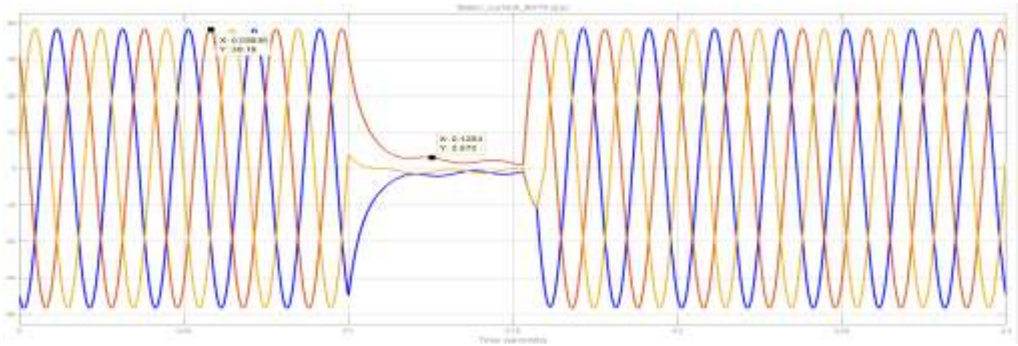
Power Quality Assessment at Electrical Fault

Symmetrical fault

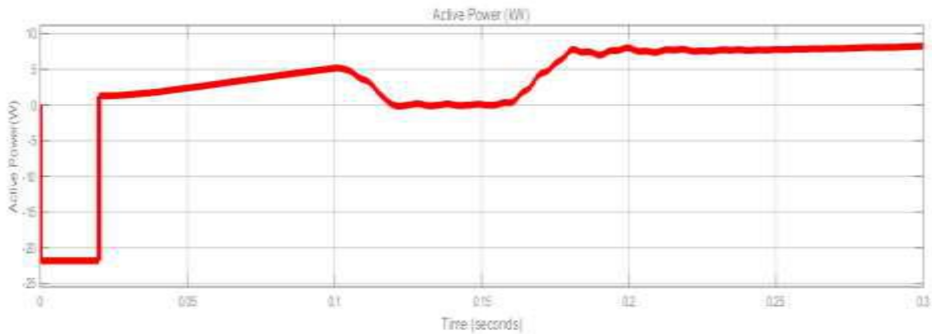
In symmetrical fault, the stator wave forms are discussed. Fig.10. It shows the behavior of DFIG WT system under symmetrical fault.The voltage ,current and active power decrease at this condition of fault.When voltage dips occurs the system parameters will be affected . The grid current is disturbed during the fault period. The duration of fault is assumed to be 0.05seconds.



(a) Stator voltage



(b) Stator current



(c) Active power

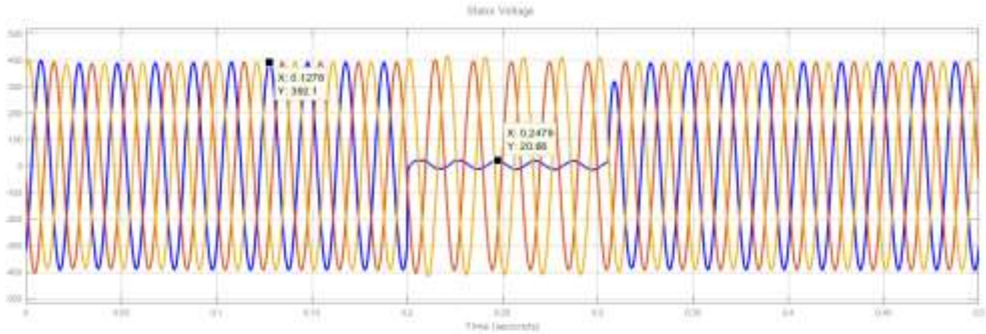
Fig. 10. Results during Symmetrical fault

Unsymmetrical fault

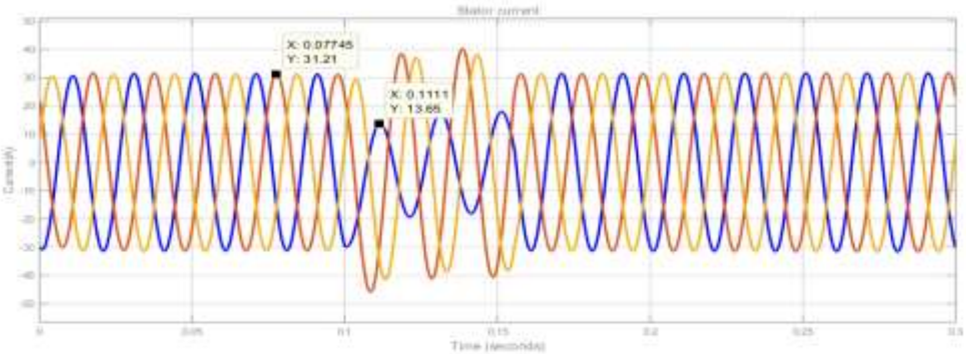
In this portion, Stator voltage, stator current and Active power are discussed. The fault location and duration are randomly assumed.

Line to Ground Fault:

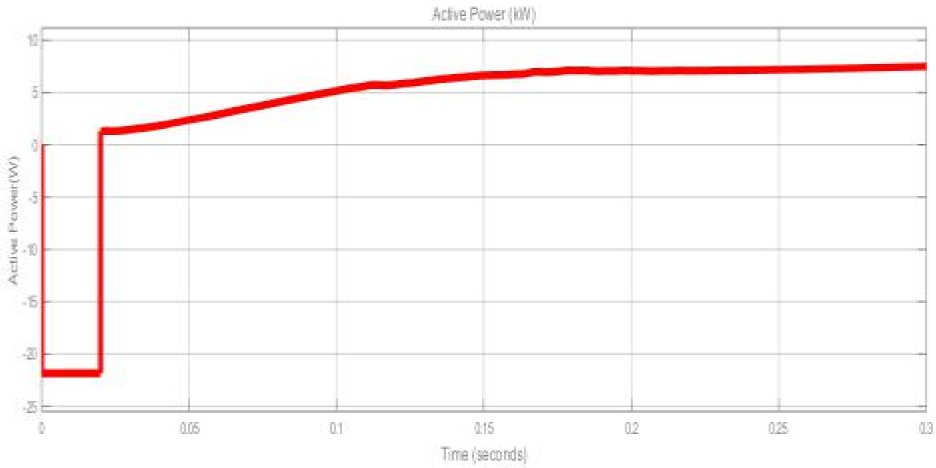
The results in Fig.11. shows under L-G fault. The fault is assumed on phase-A. The voltage of phase-A is decreased to 20.66V from 415V.Therefore distortions occurred in active power and stator current duration is assumed to be 0.01seconds.



(a) Stator voltage



(b) Stator current



(c) Active power

Fig. 11. Results during unsymmetrical fault

5. CONCLUSION:

This research is conducted at Kotri Barrage in district Jamshoro, Sindh, Pakistan. The complete statistical and simulation analysis is done to realize the wind behavior and interaction of WTG with grid. From statistically analysis, wind speed is maximum in the months of February to August and minimum in the months of October to January at Kotri barrage. Further using Weibull Distribution method, the shape is 4.623 and scale parameters is 4.596 which resembles Kotri barreage average wind speed data that is suitable for power generation. The Power Quality response of WT is assessed at differents Loads, normal load, load and fault conditions. At no load there is no effect on WT parameters and at load the active power of stator,Voltage and current of satator change from normal values. At symmetrical fault conditions , the active power of stator, voltage, and current waveforms are disturbed ,stator voltage during fault decreased to 5.812V from 390V . un symmetrical fault, the stator voltage of one phase is decreased to 20.66V from 392V discussed in above conversion.

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