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POWER QUALITY IMPROVEMENT OF A DECENTRALIZED HYBRID SUSTAINABLE ENERGY SYSTEM

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Abstract— At present scenario world's biggest challenges are maintaining the average temperature of earth and demand for quality of electric power. The dependency on renewable energy sources reduces carbon emission percentages intern reduces the percentage emission of carbon. Power quality and efficiency are the major concerns in a decentralized hybrid sustainable energy system due to its unpredictable nature. In this paper, addressed to reduce the carbon emissions by building a Simulink model of a new featuring sustainable hybrid system consisting of a nearly constant electrical wind energy system and solid oxide fuel cell. The work is concentrated to understand the power quality issues aroused due to wind fluctuations, wind random noise and gust wind. It influences the weak energy sources connected to the distribution system. Especially, the terminal voltages and real and reactive powers. Additionally, attention is devoted to model a most promising power electronics based universal power quality conditioner Unified Power Quality Conditioner using artificial neural networks to improve the power quality using MATLAB/Simulink. The results shows the evidence of power quality impacts of wind energy system and effective operation of the conditioner to enrich power quality of a hybrid decentralized power distribution system.

Keywords— renewable energy systems, hybrid sustainable energy system, distributed power generation, fuel cell system, power quality.

I. INTRODUCTION

Due to rapid industrialization, increase in standard of living and well-being, new and improved goods the demand for electrical energy has continued to go up and it has increased much faster rate +2.9% during last year -2018 and coal consumption by 1.4 % double its last ten years average growth. This rapid increase in consumption of coal leads to rapid leads to rapid retiring of conventional energy deposits along with increasing the carbon emissions growth at the rate of 2.0% for seven years[1]. These challenging situations demand the electrical power sector need to play a major role for transition of utilization of electrical energy form conventional energy sources to non-conventional energy sources to meet the demand, economic growth, future expansions, save the conventional energy sources and to reduce the carbon emissions [2].

Different factors like financial, political, geographical, institutional, technical that might influence change in the electricity sector to incorporate the modern technologies by a centralized or decentralized power sector [3]. With the

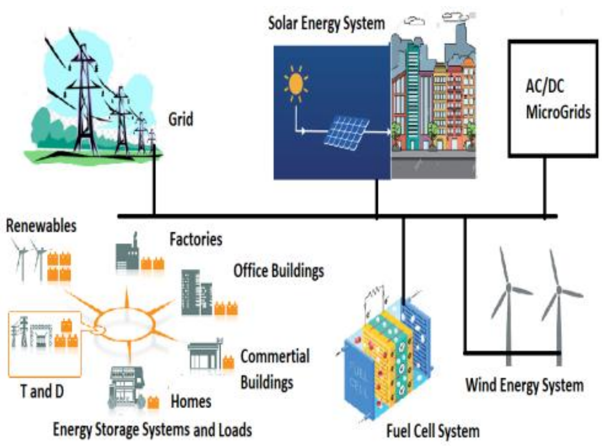

Fig. 1. Modern decentralized sustainable energy system

increase in policy amendments by government's a large national and multi – national industries playing a major contribution multi-national industries playing a major contribution to built more secure and sustainable energy featured environmental friendly decentralized green energy systems of tomorrow [4]. Fig. 1 represents of modern decentralized Sustainable green energy system which consists of both conventional and non-conventional energy sources, energy storage systems, AC/DC micro-grids with different loads connected to it.

With increase in advancements in control and operation of power system with power electronic system increase the reliability, and flexibility of available nearby non-conventional energy source as a hybrid systems for coming generations. Connecting and Operating different electrical power sources to a common grid is termed as a hybrid electrical system(HES). It increases the total power generation capability.

In Fig. 2 shown HES. Fig. 2(a) is a hybrid wind energy system(WES) and SE system, Fig. 2(b) is a hybrid WES and geothermal ES, Fig. 2(c) is a hybrid WES and FCS and Fig. 2(d) represents combination of different conventional and sustainable energy system, Fig. 2(e) represents HES with any combination of conventional energy sources, Fig. 2(f) represents any combination of sustainable energy system. Usually HES voltage levels are less than 69 kV and are very

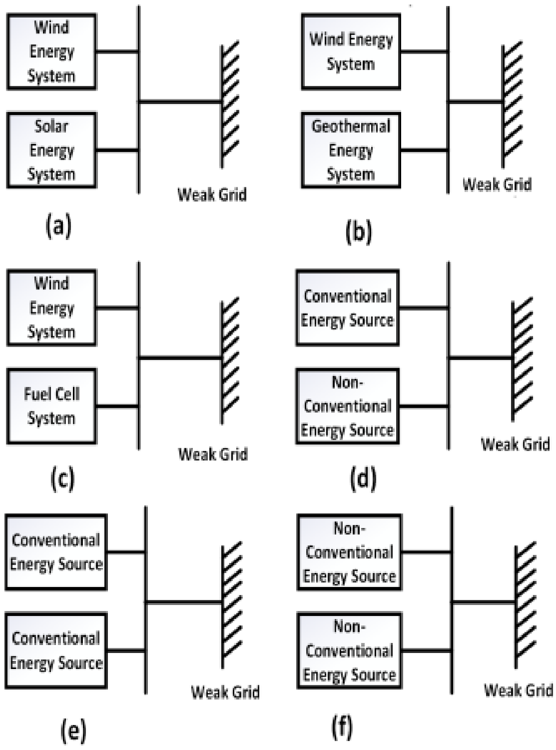

Fig. 2. Hybrid electrical systems a) WES and SES b) WES and Geothermal ES c) WES and FCS and d) Combination of any conventional and sustainable energy system e) Combination of any conventional energy sources f) Combination of any sustainable energy system.

nearer to load centers [5], [6]. In work, modelled a HES consisting of WES and FCS.

Day-by-day with increase in the penetration levels of different power sources along with the differently characterized loads and their operating patterns. These conditions on power systems increasing power quality issues from both the generating source end and load end. Researchers proposed different solutions to tickle these conditions using filters, controllers and custom power devices [7], [8]. In this work, a dual controlled UPQC is modelled to enhance the power quality of HES.

The behavior and desired operation of a UPQC depends on the control strategy and its algorithm. There are several control strategies have successfully proposed and implemented to control UPQC. The concept of p-q theory proposed by H.Akagi et al. [9]. A prioritized lower order harmonic adaptive shunt filtering control using passive tuned filters propose by Saurav Roy Choudhury et al. [10], a new synchronous-reference-frame (SRF)-based control method by Metin Kesler and Engin Ozdemir [11], Enhanced phase locked loop (EPLL)- based, Conductance-based control algorithm [12] and wavelet based control strategy by M. Forghani, and s. Afsharnia [13]. Out of all control strategies p-q theory is the simplest one. In this work built a p-q theory based ANN controller for UPQC.

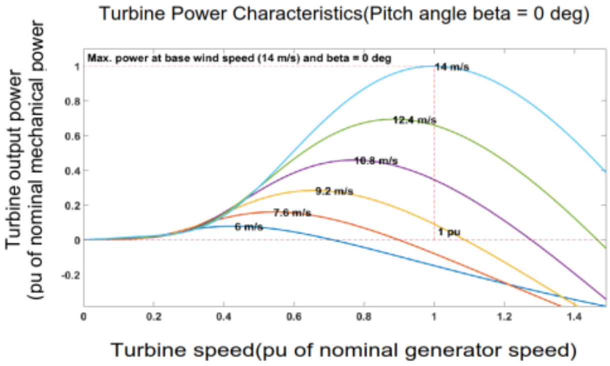

Fig. 3. Wind turbine characteristics

The complete work is divided into different sections. In section II carbon emission reduction, mathematical models of wind and fuel cell system and UPQC controller in section III. Hybrid grid system and case studies in section IV. Finally concluded the work in section V.

II. CURTAILING CARBON EMISSION USING HRES

The carbon emissions on the globe are of two kinds: natural and human sources. Natural sources includes respiration, decomposition, and ocean release. Human like activities like fossil fuel based electrical power sources, deforestation, transportation, industrial revolution. Hybrid renewable energy systems (HRES) reduces the carbon emissions as per Kyoto protocol[14]. In this work to meet the demand used hybrid renewable energy resources of 21.61 MW. The corresponding calculated carbon emission reduction by 21.19941 t[15].

II. SYSTEMS COMPONENTS MODELLING

Computer simulation is the reproduction of the behavior of real time systems in industry and engineering processes using small or large-scale programs on a small computer or group of computers. It increases the accuracy and flexible design, effective analysis, dynamical studies, reduces the cost of production etc. In this work used MATLAB/Simulink to model systems components modelling.

A. Modelling wind energy system

1) Wind Turbine: WES consists of a wind turbine or wind energy converter. It converts kinetic energy in the wind to the rotational mechanical energy. The maximum amount of wind energy converted into mechanical energy dependent on wind speed, wind turbine size, number of blades and tip speed ratio decides the maximum amount of wind energy that is converted into mechanical energy. The maximum possible energy conversion is about 59.3%[16], [17]. Fig.3 shows the turbine

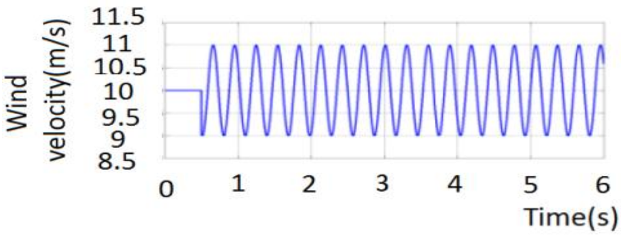

Fig. 4. Fluctuating wind.

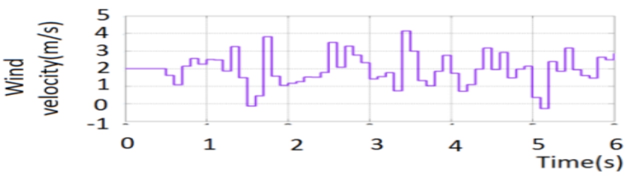

Fig. 5. Random wind noise.

characteristics for speed variations 6 m/s to 14 m/s. The maximum energy extracted (P_m), mechanical torque T_t and from wind in terms of power coefficient (C_p) and air density ρ, A in m^2: area swept by wind turbine rotor blades and wind speed velocity - υ_w in m/s as:

$$P_m = \frac{\rho A v_w^3 C_p(\lambda, \beta)}{2} \quad (1)$$

$$T_t = \frac{\rho \pi r^3 C_p V_d^2}{2} \quad (2)$$

B. Wind models

A quantitative specification of environment plays an important role in designing wind energy system. As the wind structure and model is dependent on the disturbances produced by the atmospheric heating conditions due to greenhouse gases, condition of the land and disturbances taken due to wide variety of atmospheric conditions described as wind fluctuations, random noise and wind gust.

1) Wind variations: There are no ideal wind source is existing as it is continuously changes from time to time. To consider these real time conditions for the simulations considered the wind is fluctuating sinusoidal. Fig. 4 shows the wind variations or fluctuations.

2) Wind random noise: As the wind is not a smooth in its flow over the earth's surface and objects which introduces noise which will be added to the excising wind variations occurring at statistically random intervals of time. This noise further disturb the natural wind flow pattern. Fig. 5 represents the random noise produced in simulation.

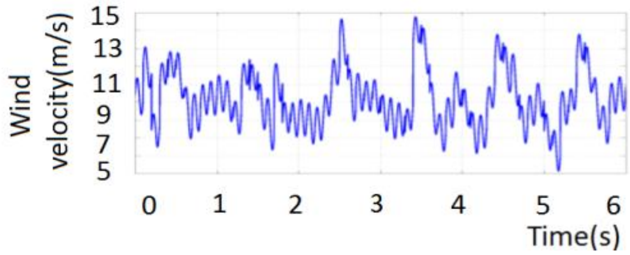

Fig. 6.Gust wind

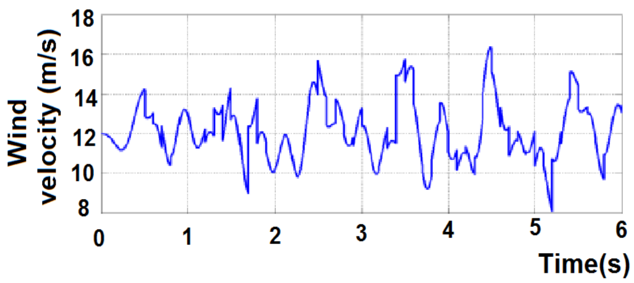

Fig. 7. Total wind speed

TABLE I. SOFC SPECIFICATIONS

Rating	100 kW
Operating temperature	1273 k
Ideal standard potential	1.18 V
Number of series cells in the stack	723
Fuel utilization factor setting	0.8

3) Wind gust: Another aspect of wind disturbances is gusty winds. These are due to the turbulence due to frictional effects, solar heating of the ground etc. This gust suddenly changes its speed and direction of the wind. Modelled gust wind is shown in Fig. 6.

Therefore the wind profile on the turbine blades is the sum of wind variations, random wind noise and the wind gust act on the wind turbine blades as shown in Fig. 7.

C. Squirrel cage induction ggenerator

The most common types of induction generators used in WES are Squirrel-Cage Induction Generator (SCIG) and Doubly-Fed Induction Generator (DFIG). For nearly fixed wind speeds SCIG is directly connected to applications or to a electrical grid. The most commonly used electrical generator in horizontal axis wind mills is Squirrel Cage Induction Generator(SCIG) because of its rugged constructions, wide range of applications, less cost and most reliable operation. It is widely used in fixed speed applications of WES. It is connected to wind turbine through a gear box. It converts mechanical energy into electrical energy. A cumulative power rating of21.6 Mw is used in the simulation [18]. The mathematical expressions for : (mechanical & electrical powers):

$$P_m = T_m\omega_r \quad \& \quad P_s = T_{em}\omega_r \qquad (3)$$

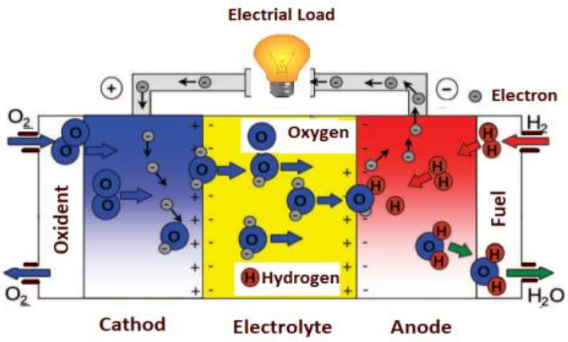

Fig. 8.Basic principle of operation of solid oxide fuel cell

D. Fuel cell system: Solid Oxide Fuel Cell

The basic principle of operation of fuel cell is same as that of battery: converts chemical energy into electrical energy except continuous fuel input and removal of reactants. The basic working principle of operation of solid oxide fuel cell is depicted in Fig. 8. In the figure it shows the fuel is feeding at both the ends(cathode and anode end) of the fuel cell. The released electrons travel through the load and ions through the electrolyte. It has the salient features like : fuel flexibility, noise less operation, portability, modular designs etc. Table.1 represents the specifications of the SOFC used in the simulation [19]. The cathode, anode and cell total reactions of SOFC are :

chemical equation at cathode :

$$O_2 + 4e^- \rightarrow 2O^{2-} \qquad (4)$$

chemical equation at anode :

$$H_2 + O^{2-} \rightarrow H_2O + 2e^- \qquad (5)$$

or

$$CO + O^{2-} \rightarrow CO_2 + 2e^- \qquad (6)$$

overall chemical equation :

$$H_2 + O_2 + CO \rightarrow H_2O + CO_2 \qquad (7)$$

E. Instantaneous power theory

To deal with the instantaneous active and reactive power in a three phase circuits H. Akagi proposed instantaneous power theory [9] defined in time domain using Park Transform. It can be applied to a three-phase system with or without neutral.

In modern power electronics devices the vector representation of 3-Phase instantaneous electrical components like voltages and currents are increasing. Initially the UPQC controller is designed using instantaneous power theory. The average and fluctuating components are performed either 0, abc or dq0domain. The following equations are used for transformations of currents, voltages and powers.

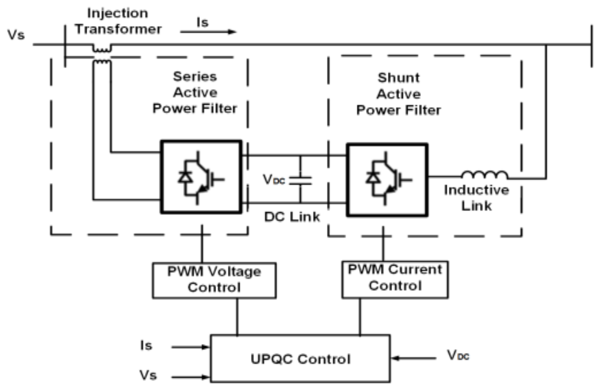

Fig. 9. Block diagram representation of UPQC

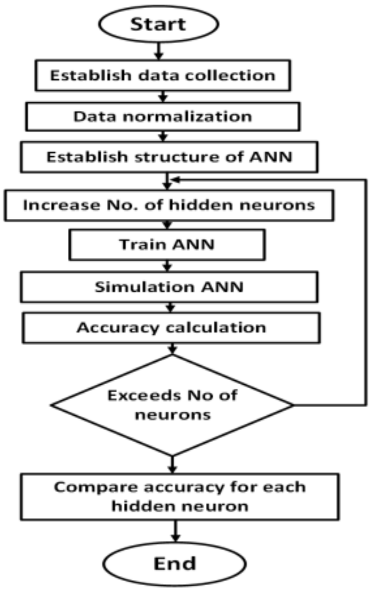

Fig. 10. Basic flow chart to implement ANN

$$v_{\alpha\beta0} = \begin{pmatrix} v_\alpha \\ v_\beta \\ v_0 \end{pmatrix} = [T_{\alpha\beta0}] \begin{pmatrix} v_a \\ v_b \\ v_c \end{pmatrix} \tag{8}$$

$$i_{\alpha\beta0} = \begin{pmatrix} i_\alpha \\ i_\beta \\ i_0 \end{pmatrix} = [T_{\alpha\beta0}] \begin{pmatrix} i_a \\ i_b \\ i_c \end{pmatrix} \tag{9}$$

$$[T_{\alpha\beta0}] = \begin{pmatrix} \sqrt{\frac{2}{3}} & -\frac{1}{\sqrt{6}} & -\frac{1}{\sqrt{6}} \\ 0 & \frac{1}{\sqrt{2}} & -\frac{1}{\sqrt{2}} \\ \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} & \frac{1}{\sqrt{3}} \end{pmatrix} \tag{10}$$

$$\begin{pmatrix} p_0 \\ p \\ q \end{pmatrix} = \begin{pmatrix} v_0 & 0 & 0 \\ 0 & v_\alpha & v_\beta \\ 0 & v_\beta & -v_\alpha \end{pmatrix} \begin{pmatrix} i_0 \\ i_\alpha \\ i_\beta \end{pmatrix} \tag{11}$$

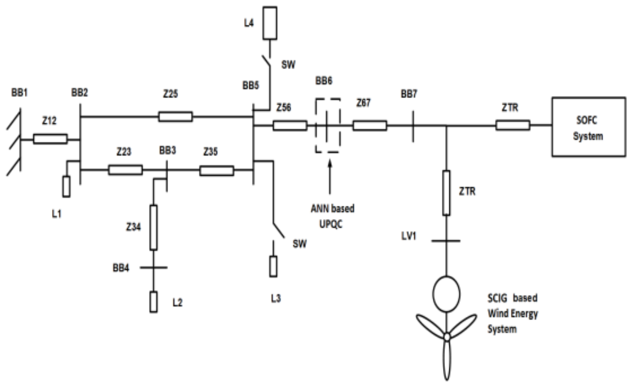

Fig. 11. Hybrid SOFC and SCIG based wind energy system

F. Artificial Neural Network controller based UPQC

To model prediction problems and complex patterns Artificial Neural Network(ANN) resembles the basic functioning of human brain. ANN is a supervisory learning computer based algorithm. We provide the necessary input data within dependent variables and the corresponding dependent output variables. It automatically identify the characteristics from the training data - learn to perform tasks by examples. The basic block diagram representation of UPQC is shown in Fig. 9 [20].There is a significant growth of applications of AI in all the fields of engineering and non-engineering categories. In this work, a power electronics device: a p-q theory, transformation based: artificial intelligent UPQC is modelled to improve the power quality of hybrid system renewable energy systems because of its feature of fast and dynamic response.

Fig. 9 represents the basic block diagram of UPQC with series and shunt controller blocks controlled by a control unit with input signals: voltage, current and DC link voltage. Fig.10 represents flow chart of the implementation of ANN to the application being studied. To train the ANN the PI controller input and the corresponding output data is used. Gradient descent back propagation with adaptive learning algorithm is used to train the controller with three hidden layers, 500 - epoches. The input to the PWM generator is the output of ANN. At point of common connection shunt part of the UPQC injects the currents to compensate the changes in power fluctuations. To compensate voltages series part of the UPQC injects the voltage. [21]. The following equations the represents the real and reactive power variations.

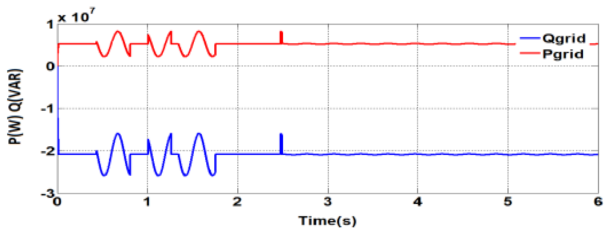

Fig. 12. Real (P) and reactive (Q) powers at grid

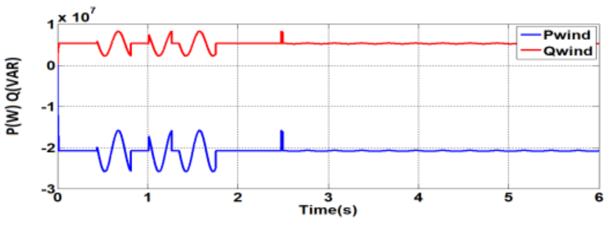

Fig. 13. Active (P) and reactive (Q) powers at WES

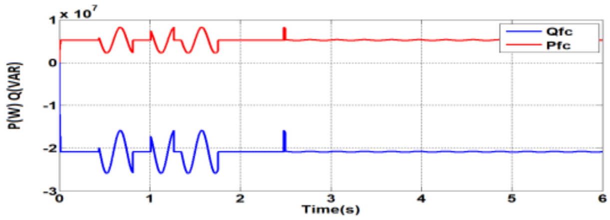

Fig. 14. Active (P) and reactive (Q) powers at fuel cell system

$$P_{shuntC}(t) = \frac{3}{2} V_d^{PCC}(t).I_d^{shuC}(t) \qquad (12)$$

$$Q_{shuC}(t) = -\frac{3}{2} V_d^{PCC}(t).I_q^{shuC}(t) \qquad (13)$$

IV. MATLAB SIMULATION STUDIES

Most of the applications every industry and research laboratories are depending on specific software either system or component based software for a quick, efficient and effective solutions. To study the work build a hybrid source based distribution system as shown in Fig. 11 [22]. Z_{ij} : represents the impedance between i^{th} node and j^{th} of the network. At BB6 ANN controller based UPQC is connected.

The following conditions performed to test the effectiveness of the compensator. I) impacts of fluctuating wind profile, ii) symmetrical sag, and iii) symmetrical swell.

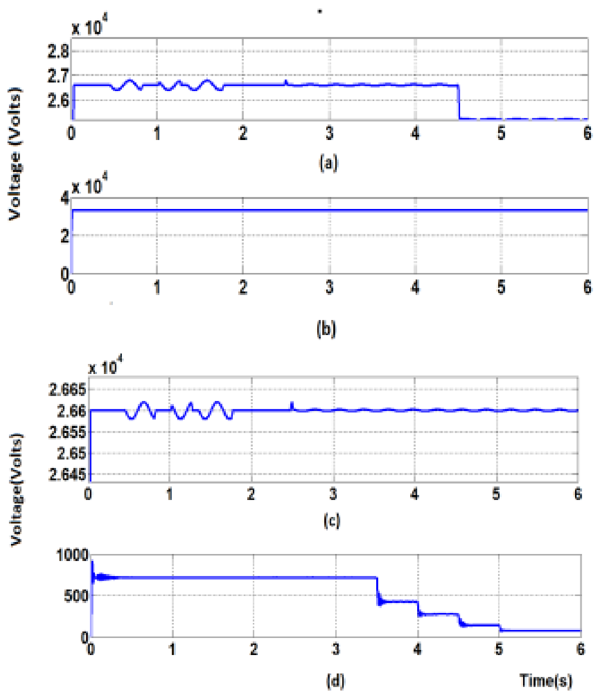

Fig .15. Voltages: a) at PCC b) at grid c) at WES and d) at FCS

A. Impacts of fluctuating wind profile

For this case the cumulative wind effects of wind variations, wind noise and gust wind shown in Fig. 7 are used for the simulation. From the simulation study results shown in Fig. 12 , Fig. 13 and Fig. 14 represents the real and reactive power at grid, wind terminal and the fuel cell system are in fluctuating nature as a major power quality issues arose due to the presence of the renewable energy systems at distribution levels. The figures Fig. 12 , Fig. 13 and Fig. 14 clearly demonstrates that the impact of fluctuating wind on the entire distribution system source terminals as a major power quality issues. Initially the system is put into operation without complete operation of the UPQC The complete ANN controller based UPQC is put into at 2.5 seconds. It is evident from the figures that power quality issue are nullified effectively by the modelled ANN controller based UPQC.

B. symmetrical sag

A sag in an electrical system is due to increasing in the loads. A sag may be a balanced or a unbalanced sag. In this study the following loads are switched are 3.6: 15 MW + j 6.31 MVAr, 4.2: 12 MW - j 2.4 MVAr, 4.6: 9.2 MW + j 1.85 MVAr and at 5.2 s: 20 MW + j 15 MVAr. From Fig. 15(a), it is clear that at PCC the voltage fluctuations are nullified by ANN-UPQC, the drop in voltage sag is within the IEEE 1159-1995 international standards.

C. Unbalanced swells

This is the one of the major power quality issue has to overcome the power system. unbalanced fault conditions or due to the unsymmetrical conditions generated on the system. This is the one of the major power quality issue has to overcome the power system. These kind of the swell are due to denigration of large loads, unbalanced fault conditions or The unbalance in the system is due to the difference in the loading on the electrical system or due to the unsymmetrical conditions generated on the system.

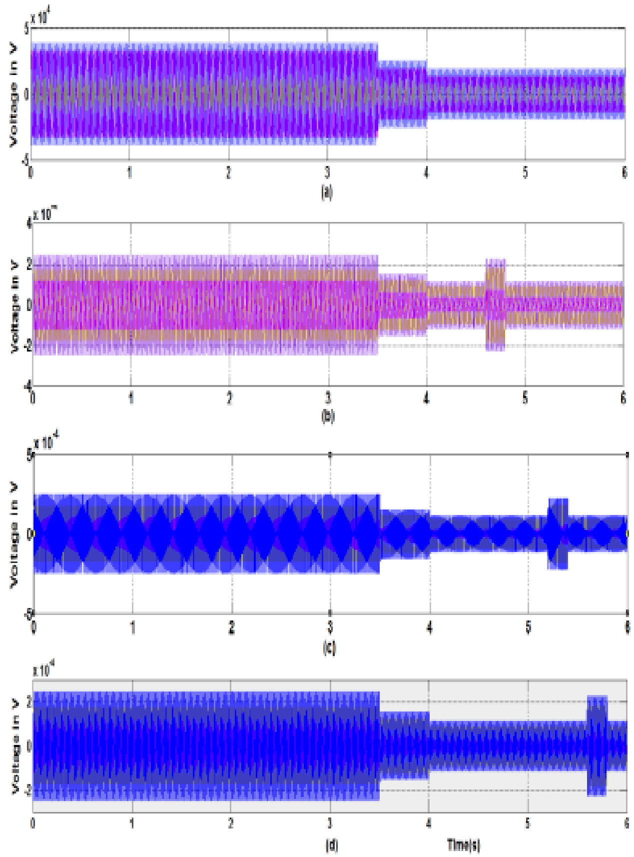

Fig. 16. 3- φ voltages: (a) 3 -φ fault (b) 3 - φ fault with R_g: 0.001 Ω(c) Line - Line fault with R_f: 9 Ω and R_g : 0.001 Ω(d) Line - G fault with R_g : 0.001 Ω(a) (b) (c)

ANN-UPQC, the drop in voltage sag is within the IEEE 1159-1995 international standards.

C. Unbalanced swells

The unbalance in the system is due to the difference in the loading on the electrical system or due to the unsymmetrical conditions generated on the system. This is the one of the major power quality issue has to overcome the power system. These kind of the swell are due to denigration of large loads, unbalanced fault conditions or breakdown of components on the power supplies of the equipment. In this work different unsymmetrical conditions are created. Initially the system is loaded with Load 1: 15 MW active power and 6.31 MVArreactive power. Load 2: 12 MW active power and 2.4 MVAr reactive power. At time t = 2.5 s complete series and shunt parts of UPQC controllers are in operation.

The most common unsymmetrical conditions are created on low voltage side of 630 kVA, 33 kV/690 V as follows:

• At time t = 4.6 - 4.8 s between Z25 and Z35 : 3-phase fault with Rf : 0.001 Ω and Rg (ground resistance) : 0.001 Ω : as shown in Fig. 11. Fig. 16(b) demonstrates the swell on LV side of the transformer in between 4.6 - 4.8 s.

• At time t = 5.2 - 5.4 s between the Z25 and Z35 : L - L fault with 9 ohms resistance (ground resistance: 0.001 Ω). The resultant swell is shown in Fig. 16(c) in between between t = 5.2 - 5.4 s.

• At last at time t = 5.6 - 5.8 s between the Z25 and Z35 : a L- G fault with Rg - 0.001 Ω. The resultant swell is shown in Fig. 16(d) in between between 5.6 - 5.8 s.

The simulation Fig. 16(b), Fig. 16(c), and Fig. 16(d) clearly demonstrated the unsymmetrical swells and the Fig. 16(a) clearly demonstrates that the nullifying the unsymmetrical conditions using ANN-UPQC effectively within IEEE 1159 - 1995 standards [8].

V. CONCLUSION

In this paper, with the help of MATLAB/Simulink environment improved the power quality of a hybrid decentralized power system consisting of squirrel cage induction generator based wind system, solid oxide fuel cell system connected to the grid using an ANN based UPQC. The series and shunt controllers of ANN UPQC are built with p-q theory. Simulation studies shown the impacts of combined wind variations impacts on real power, reactive power fluctuations at the sources connected to the grid and improvement of power quality using ANN-UPQC. In further studies the major power quality issues: balanced sag and unsymmetrical swell is effectively limited within IEEE 1159-1995 international standards.

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