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V-f Controlled Autonomous Wind Energy Conversion System Using Z2 Transformer Connected DSTATCOM

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Abstract: ***Distributed generation and renewable energy sources are hot research topics from past 10 years or so due to various reasons. The sudden load variation leads to change in voltage and frequency, and if nonlinearity presents, the T.H.D. variations will be more. Power quality controlled devices like DSTATCOM with battery energy storage system (B.E.S.S.) that controlled by pulse width modulation (P.W.M.) based voltage source converter (V.S.C.) in the distribution system would control the voltage, frequency and THD, indirectly power control. This paper presents an autonomous W.E.C.S. with zig-zag (Z2) transformer connected V.S.C. controlled DSTATCOM with BESS and its control scheme. It also shows the various MATLAB simulated results. It also contemplates the various performance parameters from previous methodology. It strategically concludes that the proposed system is effective in controlling voltage and frequency (V-f) and T.H.D. in voltage and current.***

Index Terms: ***Battery energy storage system, V-f controller, zig-zag transformer, DSTATCOM.***

I. INTRODUCTION

From past few decades the non conventional energy sources is of more importance due to increase in the load demand in world wide. The isolated or autonomous systems are of more importance as the load centre is away from the conventional power stations. So from past 10 years the research is more on how to control the isolated systems, how to merge two different sources to form a hybrid systems and so on. As the more non conventional sources are involved in the system more power quality issues such as voltage sag, noise, harmonics etc are of main problems to be solved for better outputs. In such type of non conventional sources, the W.E.C.S., is one of the most important as wind is a better source which is free from pollution [1]. Distributed energy resource (D.E.R.) is more efficient as systems are decentralized, it can serve as required by the load. D.E.R. systems uses small scale related energy sources like renewable or micro hydel power plants etc. In W.E.C.S. with the help of wind turbine generators, mechanical energy is converted into electricity. Fig. 1 depicts the basic block of W.E.C.S. which comprises of wind turbine with gear box, generator of doubly fed induction generator (D.F.I.G.) or permanent magnet synchronous generator (P.M.S.G.) type, isolated load, capacitor bank (for keeping voltage constant), voltage frequency controller (V.F.C.) consists of V.S.C. based power quality controller [2], [3]. Due to the unpredicted wind nature and load variations, the voltage fluctuation and frequency variations are of considerable importance as it has to work as independent or isolated autonomous system [4], [5].

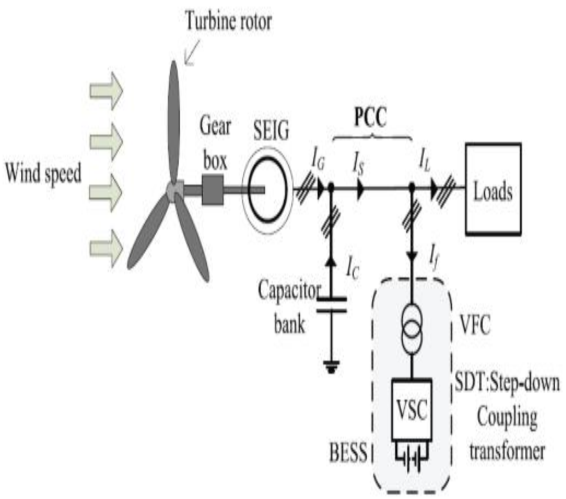

Fig.1. Schematic diagram of the isolated WECS [4],[5].

Due to the various problems in autonomous W.E.C.S., required a control for both magnitude & frequency of the generator voltage. System mainly consists of a V-f controller wind turbine along with generator, excitation capacitor and consumer load. The control system should operate by reconciling the frequency and voltage to control active/real power and reactive/imaginary power. That will happen by incorporating the DSTATCOM in the system [6]. Action of V.S.C. is when system voltage is same as controller voltage then there is no real power flow between controller and system (the multilevel converter (M.L.C.) can also serve the same purpose as done by V.S.C.) [7]. But when system voltage is less than controller voltage then controller supplies reactive power, hence reactive power is capacitive in nature.

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But whenever system voltage is higher than controller voltage it absorbs reactive power. Hence reactive power is inductive in nature. The controlling of frequency can be done with the effective control of battery system at the dc side. It tries to absorb the active power if the frequency is le than a certain pre-specified limit and supplies the same power elsewhere (generated power can't meet the load power) [8].

In the literature it is understood that the three main type of transformers are connected in the DSTATCOM related systems. Those are T-connected transformer, phase shifting transformer and Z2 transformer. As Z2 transformer has more advantages such as can be used for 3-phase 4-wire system very effectively, elimination of zero sequence components in the system which turn to reduction in T.H.D. of both voltage and current [9]. Due to various performance aspects like less complexity, more efficient control capability, less number of switches in the converter and less cost when compared to 4-leg V.S.C., it is worthwhile to consider the three-leg-V.S.C. based DSTATCOM connected with a Z2 transformer that uses a passive device for reduction of neutral current [10].

In the W.E.C.S. based distribution system, the voltage unbalance and frequency fluctuations are the major problems due to the imaginary power, unevenness of wind speed and the variation of loads. In the literature various power quality reduction techniques available for D.E.S. with the help of custom power devices (C.P.D.) [4]. Among various C.P.Ds, shunt connected DSTATCOM (distributed static compensator) is capable of reducing the various power quality issues in the load current [11].

In this paper, section-II discusses the proposed system and control scheme, section-III discusses the simulation results with different cases, section-IV gives the conclusion and at the end section-V gives future scope of the paper.

II. PROPOSED SYSTEM AND CONTROL SCHEME

A. Proposed System

This research proposed a P.W.M. controlled Z2 transformer connected V.S.C. based DSTATCOM with B.E.S.S. to control both voltage and frequency in various loading conditions. The proposed system has an advantage that it is single loop controlled structure, and the control action is based on the modulation index of the P.W.M. method, load balancing. Fig. 2 shows the proposed Z2 transformer connected three-leg V.S.C. based DSTATCOM..

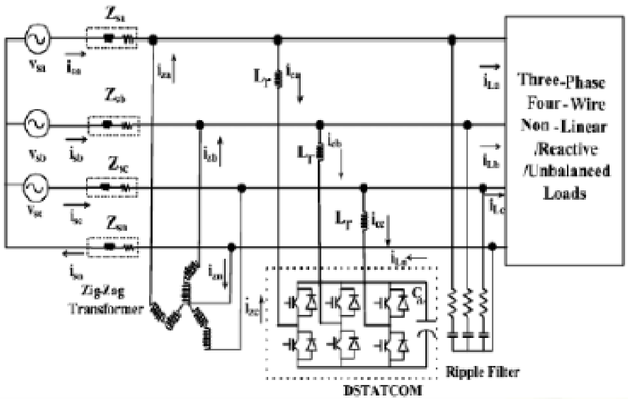

Fig. 2. Proposed three leg P.W.M. controlled V.S.C. based DSTATCOM.

Proposed controller is realized using P.W.M. converter with 3 leg V.S.C. A battery is connected at it's DC side and V.S.C. is connecting with each phase of generator via Z2 transformer [12]. At the time of various dynamic conditions like variation in consumer load and variable wind speeds, requires control for both magnitude & frequency of the generator voltage. This is done by using proposed controller because it has an ability to have bi-directional real and imaginary power flows.

In the Fig. 3 and 4 given below is showing the reactive power and active power controlling concepts represented through various phasor diagrams and V_s is the system voltage, V_1 is the controller voltage [13], [14].

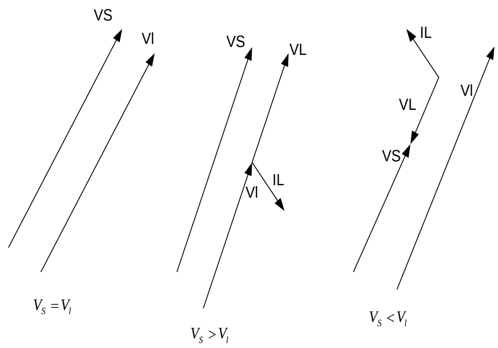

Fig. 3. The concept of reactive power control [13],[14].

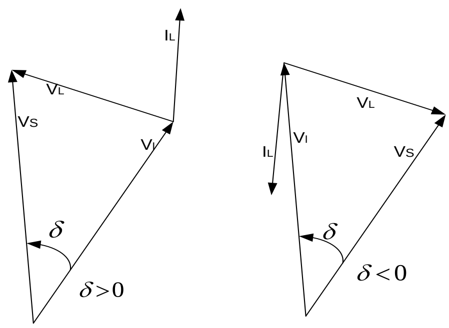

Fig. 4. The concept of active power control [13],[14].

The controller will supply the required reactive power as given in (1) [14],

$$Q = V_s \left(\frac{V_s - V_1}{V_1} \right) \tag{1}$$

Where, Q=reactive power to be controlled, V_s=source voltage, V_1= controlled load voltage.

The real power exchange between controller and the system is given by (2), [14],[15].

$$P = \frac{V_s V_1}{X_1} \sin \delta \tag{2}$$

Where, P=active power to be controlled, δ= power angle (or angle between V_s and V_l).

B. Proposed Control Scheme of WECS

The proposed DSTATCOM controlled system is capable of regulating the voltage by controlling flow of reactive power in the system by incorporating the B.E.S.S. in the system. DSTATCOM has an ability to have control over the real power of the system there by the frequency.

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As the system is isolated or autonomous the rating of DSTATCOM is less, as it is capable of controlling power quality it is enough to consider DSTATCOM for the purpose.

The schematic of various blocks of the controller is mentioned in Fig. 5 as in [12]. It has P.W.M. signal generator which has taken the various control parameters from the reference source current to the current controller (I^*_{sh} and where h=a,b,c) and sensed source current (I_{sh} and where h=a,b,c). From that PWM based gate signals will be generated and will sent to V.S.C. [13].

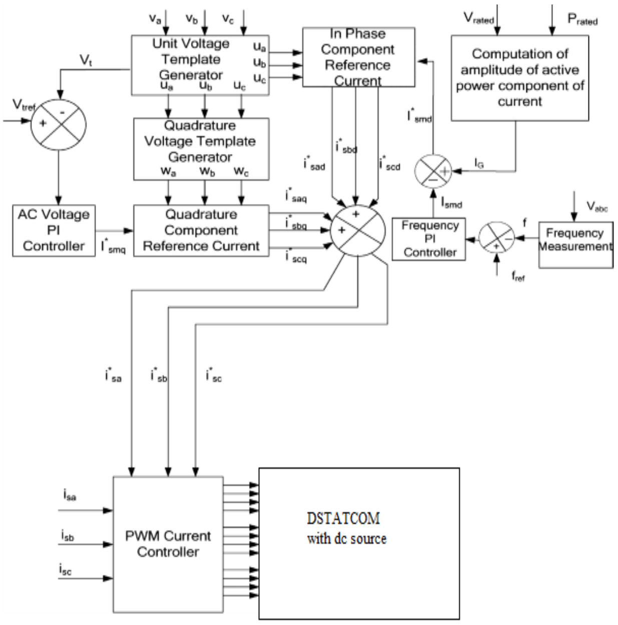

Fig.5. Control scheme used.

III. SIMULATION RESULTS AND DISCUSSION

MATLAB SIMULINK toolbox has used to model, simulate the proposed system and various results were shown for the two cases that considered in this research below. The case-1 is related with linear load disturbance and the case-2 is related with nonlinear load disturbance from t=0.3sec to 0.6sec.

Initially in any case the base load is fixed of 22kW of pure resistive load from t=0sec.

A. Case-1: Addition of Linear Load from t=0.3sec. to 0.6sec

In case-1, the linear load of 22kW (pure resistive) is being applied in between t=0.3sec and 0.6sec. The point of common coupling (P.C.C.) current and voltage variations are represented in Fig.6. Fig. 7 and 8 shows the FFT analyzed windows for both voltage and current respectively. It is shown from these figures that, the fundamental component of voltage is 590.2V and fundamental component of current is 87.17A. The %T.H.D. in voltage is 1.09% and %T.H.D. in current is 0.07%. As load is linear the noise produced in the system would be appreciably less and is less than as in the case-2.

Between t=0.3sec and 0.6sec the addition and removal of linear load is happened (applied a load disturbances), which causes a variation in voltage, current and frequency. But it controlled by V-f controller and it is controlled by the dc side DSTATCOM's voltage to maintain close to the reference value in various disturbances that can occur in the system. Its total harmonic distortion is low (from table-I). The voltage and frequency at the P.C.C. is under control as compared with [12].

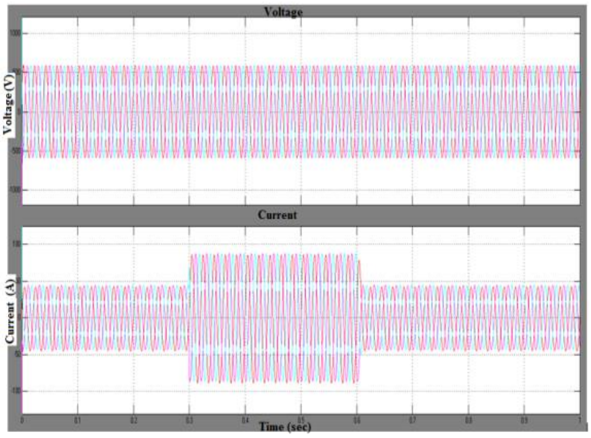

Fig. 6. System voltage and current waveforms during addition of linear load from 0.3sec. to 0.6sec.

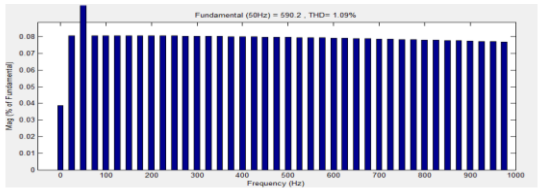

Fig. 7. Voltage THD calculated FFT window during addition of linear load from 0.3sec. to 0.6sec.

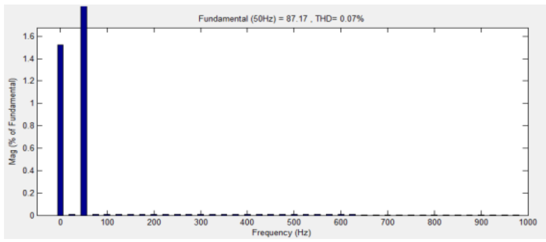

Fig. 8. Current THD calculated FFT window during addition of linear load from 0.3sec. to 0.6sec.

Fig. 9 shows the frequency variation during the case-1. Initially as base load is suddenly applied the change in frequency is occurred and after certain period it is come to a steady value of 50Hz.

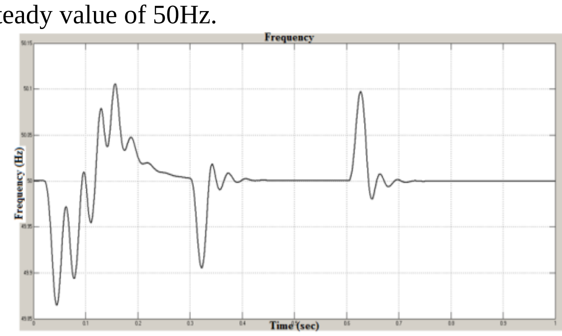

Fig. 9. Frequency variation during addition of linear load from 0.3sec. to 0.6sec.

At t=0.3 sec as linear load is applied newly the frequency is reduced and it is taking a time to settle at 50Hz after 0.16sec which is less than the conventional methodology shown in [12]. Similarly at t=0.6ec the same linear load is taking out from the system, the frequency is increased and again it is settling to a steady state value of 50Hz very less time than shown in [12].

In Table-I the different parameters of the case-1 is mentioned. Table-I also shows the settling time of system frequency after the linear load disturbance got exhausted (both after inclusion and removal). It is witnessed that the system that proposed is better by considering T.H.D., dynamic response, control of voltage and frequency with respect to the system presented in [12].

Table I: Comparison of various performance parameters of proposed and conventional methodology present in [12] during addition of linear load from t=0.3sec. to 0.6sec.

Characteristics	Conventional system	Proposed system
Frequency variation	Between 49.9Hz and 50.16Hz	Between 49.95Hz and 50.11Hz
Settling Time (for frequency)	0.1sec.	0.16sec.
% T.H.D. in voltage	7.48%	1.09%
%T.H.D. in current	2.67%	0.07%

Case-2: Addition of Non-linear Load from t=0.3sec. to 0.6sec

In case-2, the non linear load of diode bride controlled, 22kW (pure resistive) and 20kVAr (inductive) is being applied in between t=0.3sec and 0.6sec. P.C.C. voltage and current variations are shown in Fig. 10. Fig. 11 and Fig.12 shows FFT analyzed window for voltage and current when nonlinear load is considered. From these figures it is understood that the fundamental component of voltage is 588.5V and fundamental component of current is 122.1A. The %T.H.D. in voltage is 4.10% and %T.H.D. in current is 17.6%. As load is nonlinear and due to sudden switching that happened in this case, the harmonics are being injected and the noise produced in the system would be appreciably high. It is more than as in the case-1 because of nonlinearity as mentioned.

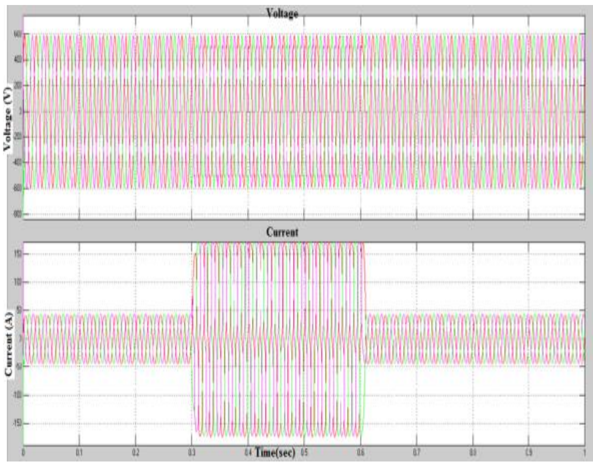

Fig. 10. System voltage and current waveforms during addition of non linear load from 0.3sec. to 0.6sec.

In Table-II the different parameters of the case-2 is mentioned. It is understood from the Table-II that the performance parameters are better when compare to the corresponding things in [12].

Between t=0.3sec and 0.6sec the addition and removal of non-linear load is happened (applied a load disturbances), which causes a variation in voltage, current and frequency.

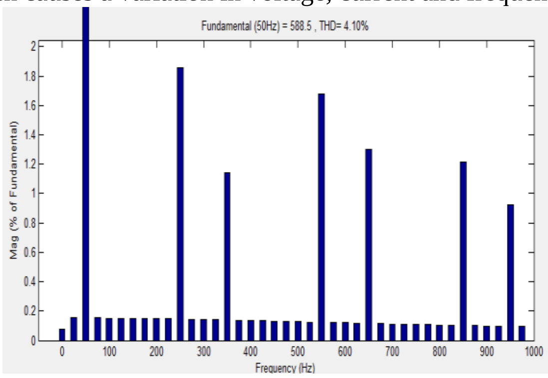

Fig. 11. Voltage THD calculated FFT window during addition of non linear load from t=0.3sec. to 0.6sec.

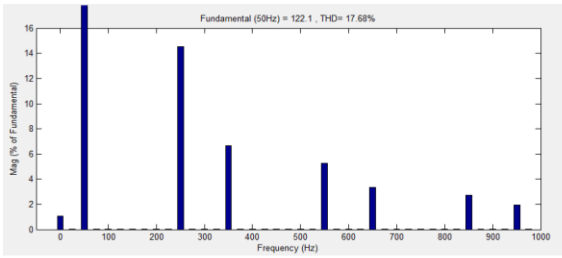

Fig. 12.Current THD calculated FFT window during addition of non linear load from 0.3sec. to 0.6sec.

Fig. 13 shows the frequency variation during the case-2. Initially as load is suddenly applied the change in frequency is occurred and after certain period it is come to a steady value of 50Hz. At t=0.3 sec as nonlinear load is applied newly the frequency is reduced and it is taking a time to settle at 50Hz after 0.18sec which is lee than the conventional methodology shown in [12]. Similarly at t=0.6ec the same nonlinear load is taking out from the system, the frequency is increased and again it is settling to a steady state value of 50Hz very less time than shown in [12].

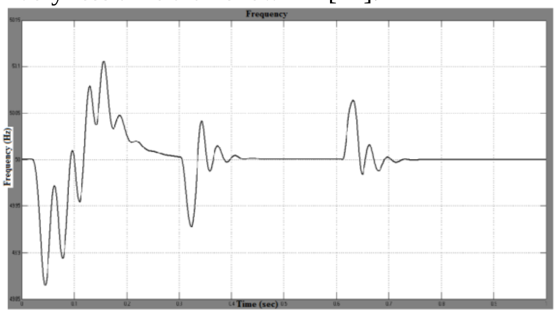

Fig. 13. Frequency variation during addition of non linear load from 0.3sec. to 0.6sec.

Table-II also shows the settling time of system frequency after the nonlinear load disturbance got exhausted (both after inclusion and removal). It is witnessed that the system proposed is better in the view of T.H.D., dynamic response, control of V and f with respect to that of system presented in [12].

%T.H.D. of voltage and current for both the cases considered (including linear and non-linear load disturbances) is improved with respect to the control scheme considered in [12].

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In this paper, three phase 4-wire W.E.C.S. have a V-f controller for controlling both voltage and frequency during various dynamic conditions such as variation of load, generator speed and reactive power. So this V-f controller adjusts the variation of voltage at its rated value under dynamic condition.

Table II: Comparison of various performance parameters of proposed and conventional methodology present in [12] during addition of non linear load from t=0.3sec. to 0.6sec.

Characteristics	Conventional system	Proposed system
Frequency variation	Between 49.65Hz and 50.24Hz	Between 49.7Hz and 50.21Hz
Settling Time (for frequency)	0.21sec.	0.18sec.
% T.H.D. in voltage	9.96%	4.10%
%T.H.D. in current	20.2%	17.6%

IV. CONCLUSION

In this research an isolated autonomous W.E.C.S. with v-f controller has been proposed and the W.E.C.S. system which was designed and simulated using MATLAB SIMULINK toolbox. The V-f controller consists of P.W.M. controlled 3-leg VSC with B.E.S.S. on its DC link. The system has been analyzed under various dynamic conditions. V-f controller will adjust the voltage and frequency of the system at its rated value during load disturbances and variation of wind speed. Conventional V-f controller has been modified by using 3-leg V.S.C. and Z2 transformer.

This paper strategically concluded from simulation results that 3-leg V.S.C. with Z2 transformer have more advantages than the conventional system. Usage of 3-leg V.S.C. instead of the 12 pulse P.W.M. converter improves the efficiency of system. Main advantageous of modified system over conventional system are reduction in number of switches, reduce the complexity and cost of system, reduces harmonic distortion, and improve stability because it have low MVA capacity.

V. FUTURE SCOPE

The future works are in control algorithm we used a PI controller. Then better results can be expected by the use of fuzzy logic control (F.L.C.) strategy. And apart from synchronous generator performance, asynchronous generator can also be studied to get an overall idea about which generator would serve the purpose for energy production to the best along with the use of voltage and frequency controller.

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