POWER CONDITIONING SYSTEM FOR WIND ENERGY APPLICATIONS

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Abstract— *Wind generation (WG) is that the maximum extensive renewable vitality resource within the world. However, this operation certainly results in a rise within the issues caused by WG, e.g. frequency oscillations, power fluctuations or voltage variations. To beat these issues, the employment of an influence acquisition system (PCS) not to mention a metal reaction flow battery (VRFB) is projected during this study. The PCS contains of a dispersal static synchronous compensator coupled to a dc/dc chopper. The PCS/VRFB careful model is conferred and a three-level system is developed. A performance characteristic of the device and the dynamic response of the PCS/VRFB is evaluated through simulation tests, are obtained by suggests that of the variation of the capacity references. The results obtained from the system projected permits mitigating the issues caused by alternative energy generation.*

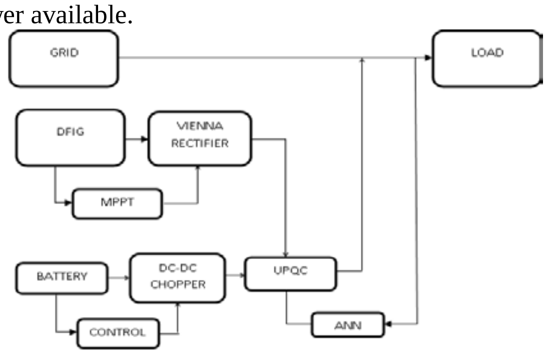
1. INTRODUCTION

Within the portfolio of renewable energy resources, wind generation (WG) is the lower cost alternative. The WG has two major advantages: the primary energy resource is abundant in most countries and its technology has been successfully tested. However, the random variations of the primary resource and the technology used in energy conversion devices cause problems to electric systems. Typical difficulties are caused by variations of the wind speed in medium and short term, e.g. the reduction of the dynamic operation security and deterioration of the overall power quality of the system. To overcome these problems, vanadium redox flow battery (VRFB) emerges as a feasible alternative to compensate these power fluctuations and thus significantly enhances the dynamic process security and quality supply of the power system. The VRFB is a fast-response energy storage system (ESS) with large storage capacity and competitive capital costs; this ESS can provide ancillary services to the power system such as peak shaving or frequency control. A power conditioning system (PCS) is required in order to connect the VRFB to the ac grid. The work existing offers a PCS for zinc– bromine (Zn–Br) current battery-based energy storage organization. The PCS consists of DFIG, Vienna rectifier, and a battery organization system.

The applications revealed overhead offer practical keys to attach the VRFB to the ac system**.** However, much less has been done specifically on the utilization of the VRFB in wind energy applications, although these developments can be applied to the VRFB. Moreover, none of these papers have developed control algorithms to perform the load levelling of wind farms employing long-term ESS and/or to supply the generation reserve required during frequency oscillations in the electrical system. Created on the aforementioned, this effort proposes a detailed model of a PCS controller coupled with a VRFB, and develops a multi-level regulator system to improve the dynamic performance of a wind farm into the power system. The PCS is composed of a Unified Power Quality Conditioner (UPQC) connected to a dc/dc chopper. The model limitations working in the simulations are achieved from the characteristic data of manufacturers. Conversely, the control system design and its parameters have been advanced and they represent the main involvement of this paper.

2. PROPOSED BLOCK DIAGRAM

The proposed model consists of vienna rectifier, UPQC, DFIG, and the ANFIS control logic is used to control overall system. Battery is provided to give uninterrupted supply to load even when there is no wind power available.



3. MATHEMATICAL MODEL OF DFIG

The Park-Blade voltage equations for the study of the dynamic operation of a three phase doubly fed-induction machine written in rotor reference kame are given by

$$v_{ds} = R_s i_{ds} + \frac{d\psi_{ds}}{dt} - \theta_s^{\cdot} \psi_{qs}$$
$$v_{qs} = R_s i_{qs} + \frac{d\psi_{qs}}{dt} + \theta_s^{\cdot} \psi_{ds}$$
$$v_{dr} = R_r i_{dr} + \frac{d\psi_{dr}}{dt} - \theta_r^{\cdot} \psi_{qr}$$
$$v_{qr} = R_r i_{qr} + \frac{d\psi_{qr}}{dt} + \theta_r^{\cdot} \psi_{dr}$$

The flux and the currents are interrelated by

$$\psi_{ds} = L_s i_{ds} + M i_{dr}$$
$$\psi_{qs} = L_s i_{sq} + M i_{rq}$$
$$\psi_{dr} = L_r i_{dr} + M i_{ds}$$
$$\psi_{qr} = L_r i_{qr} + M i_{qs}$$

The current derivatives can be expressed in state-space form as:

$$\frac{d[i]}{dt} = A[i] + B[u]$$

Where:

- $[i] = [i_{ds} \quad i_{qs} \quad i_{dr} \quad i_{qr}]$ vector of stator and rotor currents.
- $[u] = [u_{ds} \quad u_{qs} \quad u_{dr} \quad u_{qr}]$ vector of applied voltage.

Matrices A and B is defined as follows:

$$A = \begin{bmatrix} \frac{-1}{\sigma L_s} & \frac{\omega_r}{\sigma} & \frac{M}{\sigma L_s \tau_r} & \frac{-M\omega_r}{\sigma L_s} \\ \frac{-\omega_r}{\sigma} & \frac{-1}{\sigma \tau_s} & \frac{-M\omega_r}{\sigma L_s} & \frac{M}{\sigma L_s \tau_r} \\ \frac{M}{\sigma \tau_s L_r} & \frac{-\omega_r M}{\sigma L_r} & \frac{-1}{\sigma L_r} & \frac{-\omega_r M^2}{\sigma L_s L_r} \\ \frac{\omega_r M}{\sigma L_r} & \frac{M}{\sigma L_r \tau_s} & \frac{\omega_r M^2}{\sigma L_s L_r} & \frac{-1}{\sigma \tau_r} \end{bmatrix}$$

$$B = \begin{bmatrix} \frac{1}{\sigma L_s} & 0 & \frac{-M}{\sigma L_s L_r} & 0 \\ 0 & \frac{1}{\sigma L_r} & 0 & \frac{-M}{\sigma L_s L_r} \\ \frac{-M}{\sigma L_s L_r} & 0 & \frac{1}{\sigma L_r} & 0 \\ 0 & \frac{-M}{\sigma L_s L_r} & 0 & \frac{1}{\sigma L_r} \end{bmatrix}$$

And $\sigma = 1 - \frac{M^2}{L_s L_r}$

4. VIENNA RECTIFIER PRINCIPLE

As Fig.1 demonstrates, the output capacitor is part in two sections with two equivalent qualities (C1and C2).Across every capacitor, two voltage sources +V0/2 and - V0/2 exist which distinguish the output voltage of the circuit. Consequently three unique voltages (+V0/2, 0, -V0/2) are accessible. The DC bus voltage is thought to be a steady DC voltage and can be joined with an ordinary six switch or other kind of inverter. The input current for every stage is characterized by the voltage connected over the comparing inductor LN; the data voltage of the rectifier is dictated by the switch over state and the input current direction. The input inductors (LN) charge when the switch is on and the current increment in the inductor, and when the switch is off the inductors release through the positive or negative diode depending on the current movement direction. The presence of an input inductor creates a current source at the input while the capacitors create output voltages**.** In extra arguments, the Vienna rectifier might be measured as a diode–transistor environment linking the contribution current sources with output currents.

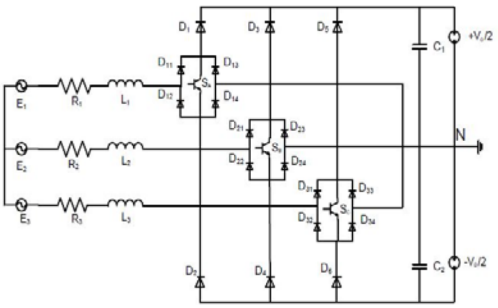


Fig.1. Vienna Rectifier

Switching combination of rectifier is shown in the table 1.

Table.1. Eight different switching Combinations

S_A	S_B	S_C	V_{AN}	V_{BN}	V_{CN}
0	0	0	$+V_0/2$	$-V_0/2$	$-V_0/2$
0	0	1	$+V_0/2$	$-V_0/2$	0
0	1	0	$+V_0/2$	0	$-V_0/2$
0	1	1	$+V_0/2$	0	0
1	0	0	0	$-V_0/2$	$-V_0/2$
1	0	1	0	$-V_0/2$	0
1	1	0	0	0	$-V_0/2$
1	1	1	0	0	0

5. DC/DC CHOPPER

The coupling between the VRFB and the VSI requires the use of a bi-directional interface in order to adapt different levels of voltage and current between both devices. The variation of the magnitude and direction of the stack current allows for control of the VRFB rate of charge/discharge, which leads to the variation of the stack voltage; while keeping the voltage of the VSI dc-link capacitor basically continuous and composed (*U*C). Thus, the VRFB is charged and discharged employing a non-pulsating direct current.

6. UNIFIED POWER QUALITY CONDITIONER (UPQC)

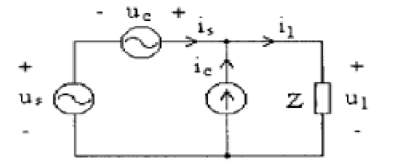


Fig.2. Equivalent circuit of UPQC

Fig. **2** shows an equivalent circuit for the industrial power system installing UPQC on the common bus,

where u_s **,** is the power supply

, u_c **,** is the series-APF compensating voltage and

u_l is the load voltage, i_c **,** is the shunt-APF compensating current and Z represents the non-linear load of the system.

7. UPQC CONTROL STRATEGY

From the exceeding conversation, it is clear that UPQC should main discrete out the instantaneous values of the important frequency positive system from the other components. The controller path construction of the UPQC is shown in Fig. 3.

1) The positive sequence in phase unit reference generator is given in Fig. 3.

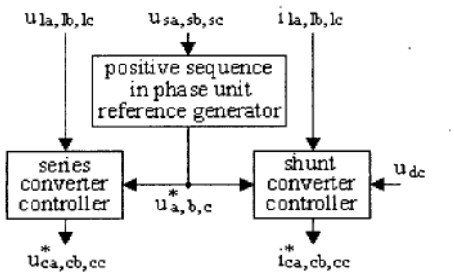


Fig. 3 Control circuit structure of UPQC

To develop the progressive classification fullness of foundation voltage, a synchronous d-q mention surround is used. If the 3-phase voltages are unstable and cover harmonics, the conversion to the d-q axes results in:

$$\begin{bmatrix} u_d \\ u_q \end{bmatrix} = \sqrt{\tfrac{2}{3}}T\begin{bmatrix} u_{sa} \\ u_{sb} \\ u_{sc} \end{bmatrix}$$

$$= \sqrt{\tfrac{2}{3}}\left\{\begin{bmatrix} U_{1p}\sin(\theta_{1p}) \\ U_{1p}\cos(\theta_{1p}) \end{bmatrix} + \begin{bmatrix} U_{1n}\sin(2\omega t+\theta_{1n}) \\ -U_{1n}\cos(2\omega t+\theta_{1n}) \end{bmatrix} + \begin{bmatrix} \sum_{i=2}^{\infty} U_i \sin[(k-1)(\omega t+\theta_i)] \\ \sum_{i=2}^{\infty} U_i \cos[(k-1)(\omega t+\theta_i)] \end{bmatrix}\right\}$$

$$\triangleq \left\{\begin{bmatrix} u_{dp} \\ u_{qp} \end{bmatrix} + \begin{bmatrix} u_{dn} \\ u_{qn} \end{bmatrix} + \begin{bmatrix} \sum_{k=2}^{\infty} u_{dk} \\ \sum_{k=2}^{\infty} u_{qk} \end{bmatrix}\right\}$$

Where, θ_{1p} is the phase change between the positive sequence component and the reference voltage (phase "a**")**. and,

$$T = \begin{bmatrix} \cos(\omega t) & \cos(\omega t - 2\pi/3) & \cos(\omega t + 2\pi/3) \\ \sin(\omega t) & \sin(\omega t - 2\pi/3) & \sin(\omega t + 2\pi/3) \end{bmatrix}$$

So, the amplitude of voltage can be achieved by the resulting equation:

$$U_{1p}^2 = u_{dp}^2 + u_{qp}^2$$

In order to, get the moment values of harmonic positive sequence modules, symmetrical arrangement is introduced.

$$\begin{bmatrix} u_+ \\ u_- \end{bmatrix} = \tfrac{1}{3}\begin{bmatrix} 1 & \alpha & \alpha^2 \\ 1 & \alpha^2 & \alpha \end{bmatrix}\begin{bmatrix} u_{sa1} \\ u_{sb1} \\ u_{sc1} \end{bmatrix} = \begin{bmatrix} U_{1p}\sin(\omega t+\theta_{1p}) \\ U_{1n}\sin(\omega t+\theta_{1n}) \end{bmatrix}$$

$$\alpha = e^{j\frac{2}{3}\pi} = -\tfrac{1}{2} + j\tfrac{\sqrt{3}}{2}$$

Where, and the fundamental frequency component of source voltage can be got through LPF.

With calculation (8) and (9), the positive sequence in phase unit orientation phase can be given as:

$$\begin{bmatrix} u_a^* = \sin(\omega t+\theta_{1p}) \\ u_b^* = \sin(\omega t+\theta_{1p} - \tfrac{2}{3}\pi) \\ u_c^* = \sin(\omega t+\theta_{1p} + \tfrac{2}{3}\pi) \end{bmatrix}$$

2) The control of the shunt-APF is shown in Fig. 4.

To detect the current to be compensated, the key problem is to obtain the power reference current, which has the same phase as positive sequence unit reference phase. And the RMS I_{sp} can be calculated as equation

$$I_{sp} = I_{cp} + I_{Lp}$$

According to the power balance, the RMS of load active current can be described by the following equation:

$$I_{Lp} = \tfrac{\sqrt{2}}{3T}\int_0^T (u_a^* \cdot i_{La} + u_b^* \cdot i_{Lb} + u_c^* \cdot i_{Lc})dt$$

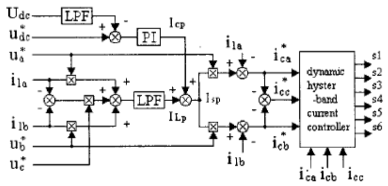


Fig. 4 control block diagram of the shunt-APF

Because of the ability because of line and winding resistance, a convinced quantity of power must be provided to or absorbed by the electrical condenser to revive a voltage throughout a voltage disturbance. In this red-top, a PI organizer is used to control the capacitor voltage with a regular value. And the RMS energetic current of shunt-APF can be got by the calculation

$$I_{cp} = K_p(U_{dc}^* - \tfrac{1}{T}\int_0^T u_{dc}dt) + K_i\int_{\infty}(U_{dc}^* - \tfrac{1}{T}\int_0^T u_{dc}dt)dt$$

Where U_{dc}^* stands for the preferred steady value of the DC bank voltage.

Then the current situation is found to be:

$$\begin{bmatrix} i_{ca}^* = I_{sp}\cdot u_a^* - i_{La} \\ i_{cb}^* = I_{sp}\cdot u_b^* - i_{Lb} \\ i_{cc}^* = I_{sp}\cdot u_c^* - i_{Lc} \end{bmatrix}$$

The shunt-APF acts as a controlled current source. It means that the inverter functions in the current-regulated modulation mode. So the hysteresis control is used,

3) The control of the series-active power filter is given in Fig. 5.

The series-APF should perform as a measured voltage source and its output should track the proposal of voltage. This compensating voltage signal can be obtained by comparing the actual load terminal voltage with the desired value. Since the wanted is already defined, it is easy to

$$\begin{bmatrix} u_{ca}^* = U\cdot u_a^* - u_{sa} \\ u_{cb}^* = U\cdot u_b^* - u_{sb} \\ u_{cc}^* = U\cdot u_c^* - u_{sc} \end{bmatrix}$$

Compute u_{ca}^*, as U is a recognized quantity.

After finding the voltage indication, the switching duty ratio of the series-APF is attained by likening the orientation signal with a triangular waveform, which is the customary PWM control method.

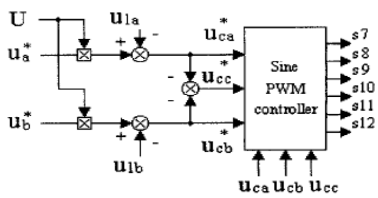


Fig. 5 control block diagram of series-APF

8. SIMULATION DIAGRAM

The simulation of proposed model is shown in the figure 6. It consists of the wind generation system, Vienna rectifier and the UPQC connected to the load side which reduces the power quality issues due to non linear loads. The system is designed for wind power 1.5kw and harmonics is reduced by using the shunt and series active filters.

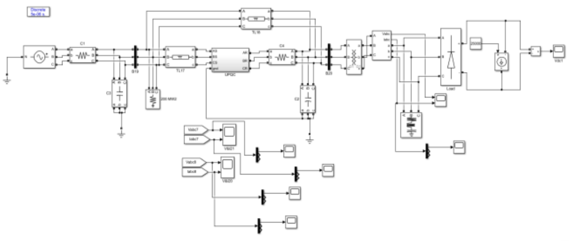


Fig. 6 Proposed Simulation Model

9. SIMULATION RESULTS

The figure 6 shows the proposed model provides the constant voltage and current even there is change in load or power quality issues such as voltage imbalance and harmonics is effectively reduced. The output provides constant 1.5kw output for different load conditions.

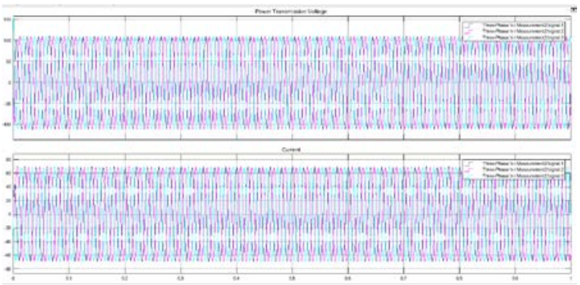


Fig. 6 Voltage and current waveform

10. CONCLUSIONS

This paper presents a new PCS; this method is a technical solution to attach the VRFB to the ac grid. The model of the PCS/VRFB is represented in detail, as the control algorithms are also developed. The PCS is composed of a UPQC and a dc/dc chopper converter. On the additional hand, the control algorithms are allocated into three control modes: the active power control mode, the power factor control mode and the voltage control mode. The outcomes acquired from the models show that the advanced control processes and the complete models have worked correctly. The performance of the detailed model is very similar to the values obtained from datasheets in actual devices. The proposed switch system performs an excellent decoupling of energetic and irritable power flows. Furthermore, the simulation results show that with the PCS/ VRFB and the control algorithms developed, the output power fluctuations of a wind farm are effectively smoothed. Hence, the incorporation of wind generation in the electric system is enhanced. It also demonstrated that the PCS/VRFB can absorb or deliver a constant power flow within a time range of seconds to hours, depending on the SOC of the battery. Through respect to the sensitive power control, it was demonstrated that the PCS/VRFB allows performing the dynamic control of the voltage at the PCC, or to provide a unitary power factor for power faults in the power system and also for sudden differences in the load.

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