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Research Paper

An application phase-modular rectifier applied to MMC with medium voltage based on wind turbine generator

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Abstract

This paper proposes two stages of controller. First stage, direct power control (P-Q control) applied single-phase structure of multilevel modular converter (MMC) , multilevel cascaded H-Bridge inverter with 9-level SPWM injection to medium voltage (24kV) based on wind turbine generator (PMSG)rated capacity 25kVA. Second stage, three-phase PFC rectifier with phase-modular Y-rectifier, boost–type. The separate dc sources (DC-links) average voltage at 178V (Vdc1-Vdc12). This study is concerned with the application, operating, principle, and design example. The unity power factor operation of PMSG is realized by controlling of phase-modular Y-Rectifier system, and the current waveform distortion results increase of the lower harmonics distortion. The P-Q controller can make it possible of the grid line current phase by providing the direct instantaneous power control in the steady state under the active power and reactive power command. The data collected by PSIM and MATLAB simulation are used in comparison with the experimental tester of results. This provides guideline to further analyze and improvement energy efficiency and power quality in electrical system pertinent to wind turbine generator (PMSG).

Keywords: *Wind Turbine Generator, Permanent Magnet Synchronous Generator (PMSG), Phase-Modular Y-Rectifier, Cascaded H-Bridges, Modular Multilevel Converter (MMC), Power Quality, Unity Power Factor, Harmonics.*

1. Introduction

In Thailand, Meteorological Department (Bangkok) and for the river mouth Pilot Station, monthly mean wind speeds taken from climatological data 1966 – 1995 are reported below Pilot Station: 3.4 – 5.6 m/s (max 6.0 m/s), Bangkok Metropolis: 1.2 – 2.5 m/s (max 4.5m/s), Don Muang: 2 – 2.9 m/s (max 5.3 m/s), Petchaburi: 4.9 m/s , Mean wind speed: < 5 m/s (range for Ubon 2.20 – 3.74 m/s; Haad Yai 3.6 – 4.35 m/s), of the Department of Energy Development and Promotion, Thailand (DEDP) report [1],[2].The Provincial Electricity Authority (PEA) reported multiple occurrences of voltage Sags and interruption in the 39 feeders distribution medium voltage 22kV of an industrial estate. Causes are from natural environment such as bird, snake, squirrel and even thunder storm. Moreover, the cause is also from switching breaker to heavy load and tap change transformer. From about 78% of customer power supply is affected by voltage Sags with an average 114 times per month and interruptions about 90 times per month. Frequently found problems in the distribution system involve voltage Sags/interruption. The motor Starting current and fault causes voltage Sags and interruption, affecting sensitive load voltage. This increases maintenance cost, thus investment expense. Damage costs found at sensitive load due to interruption and voltage Sags are likely equal. Proper protection to this is therefore necessary. However, voltage swell is hardly occurred. Effect of power quality within factories produces processing problems. This is particularly true for industrial factories using electronic components for the control system [3].The applied power electronic to mitigate problems from the power quality for medium voltage such as harmonics mitigation voltage Sags mitigation, interruption mitigation. There are a number of recent researches presented techniques of Dynamic Voltage Restore (DVR). Haddad et al. [4] introduced a method DC link rectifier supplied by a connected transformer that is connected to the PCC by using two-level three inverters. The modern power electronic technology is an important part in distributed generation and the integration of the renewable energy to the power grid. It is widely used in the grid based system. Application of multilevel medium voltage source converter system that synthesizes a desired output voltage from several levels of dc-link as inputs voltages. Recently, multilevel power conversion technology has been developing the area of power electronics very rapidly with good potential for further developments. As a result, the most attractive applications of this technology are in the medium to high voltage ranges [5], [6] and [7]. Multilevel inverters include an array of power semiconductors and capacitor voltage sources, the output of which generate voltages with stepped waveforms. Three different topologies for multilevel inverters consist of diode-clamped (NPC) Inverter ,capacitor- clamped (FC) Inverter and cascaded multi cell with separate dc sources [8],[9]. The DVR systems compensated voltage by voltage injected, with the power source voltage of parallel transformer (output voltage 0.5 per unit (pu.)) though the series transformer (producing injected voltage 0.5 per unit (pu.)),adding with the output load voltage 1.0 per unit (pu.). Of this principle will result the system that can deliver electrical power of 50 percentage of normal voltage condition, and one hundred percent during a power outage [10]. In addition to lowering power bill to the consumers, improved power factor also contributes towards conservation of energy and helps in reducing air pollution, by virtue of less fossil fuel required for generating same amount of electrical power. Other resultant effects are lower I^2R losses, steadier terminal Voltages, released system capacity and reduced cable & switchgear sizes. Active PFC front ends also help meet the IEEE 519-92, IEC-555 and European EN 61000-3-2 standards for allowable harmonic contents of mains. IEEE Std. 519-1992, IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems. The develop high harmonic distortion in the current and voltage of PMSG's, which are troublesome because they can cause several upset to the generator, such as, increased heating due to iron and copper losses at the harmonic frequencies, reduction in machine efficiency, loss to the torque production, Increased in audible noise emission, can cause or enhance the refusal to start smoothly in induction generators, can cause mechanical oscillations [11]. This article presents application Phase-Modular Y- Rectifier with separate dc sources by DC links based on wind turbine generator (PMSG) applied to multilevel modular converter (MMC) with the phase shift SPWM algorithm for 9-level cascaded H-bridge (CHB) inverter, The paper proposed part (1) using by Direct Power Control (PQ) controlled multilevel voltage source inverter with 9-level SPWM cascaded H-Bridges. The proposed part (2) the technique Y-Rectifier in a three phase star connection with separated DC-source for Medium Voltage Based on Wind Turbine Generator.

2. PMSG based wind power generation

The wind turbine generator PMSG, wind energy conversion system is composed basically of three parts: wind turbine transition, electrical power conversion, and power electronic system. The wind turbine basic principle is to convert the linear motion of the wind into rotational energy. The rotational energy is used to drive an electrical generator, the kinetic energy of the wind turbine to be turned into electric power. The wind turbine rotor is designed to extract maximum power from the wind and this value can be calculated as:

$$P_T = \frac{1}{2}\rho A C_p(\beta,\lambda) v_\omega^3 \quad (1)$$

Where, represents P_T :Mechanical turbine power (W), represents the area swept by the turbine (A) the Blade swept area (m^2), v_ω represents the wind speed are between 4.0-5.0 (m/s) [3], where $v_\omega = r.\omega m/\lambda$ 'r' is the length of the wind turbine spade and mechanical speed of rotor "ωm" (rad/s) is the angular rotor speed, λ Tip-speed ratio is kept constant, and taking for simulation 4.9 (m/s) ,and The power coefficient C_p can have a maximum value of 0.593, but in reality, the aerodynamics of the rotor are not perfect and ρ Air density taking 1.16 (kg/m^3) [3], Thus assuming Power coefficient about C_p (0.47),when $\beta = 0^o$ Pitch angle (deg) ,the cut-out wind speed value (here considered 25 m/s) [12]. The model of the PMSG was developed in the dq synchronous reference frame, where the q-axis is 90 deg phase shifted ahead of the d-axis with respect to the direction of rotation [13]. In order to simplify the system, the generator was assumed to be a PMSG with surface-mounted magnets. Thus, the model of the PMSG in the dq synchronous reference frame is given by the voltage equations (2) and (3), the torque equation (4) and the mechanical equation (5).

$$U_{sd} = R_s i_{sd} + L_d \frac{di_{sd}}{dt} - \omega_r L_q i_{sd} \quad (2)$$

$$U_{sq} = R_s i_{sq} + L_q \frac{di_{sd}}{dt} + \omega_r \psi_m + \omega_r L_d i_{sd} \quad (3)$$

$$T_e = \frac{3}{2}(N_p \psi_m i_{sq}) \quad (4)$$

$$T_e - T_L - B\omega_m = J_m \frac{d\omega_m}{dt} \quad (5)$$

Where, U_{sd} ,U_{sq} represent the direct and quadrature components of the stator voltages, i_{sd} ,i_{sq} represent the direct and quadrature components of the stator currents, L_d ,L_q represent the direct and quadrature components of the stator inductances R_s represents the stator resistance, ω_m represents the mechanical speed of the rotor, ω_r represents the electrical speed of the rotor, ψ_m represents the permanent magnet flux linkage, T_e represents the electromagnetically torque, T_L = Load torque (Nm), J_m = Moment of inertia $(kg.m^2)$ N_p represents the number of the pole-pairs[13],[14]-[18]. Remark,the parameter of PMSG is taken as a black box and thus detail is not considered in this paper.

3. Separated DC sources of PMSG

The separate dc sources by DC links based on wind turbine generator (PMSG) system capacity 25 kW rating as show in Fig. 1. Traditionally, each phase of the inverter requires DC source for output of AC/DC converter, the control strategy regulates the DC link voltages of capacitors connected to the cascade H-bridges three phase of PMSG type. From the stator voltage source are connection to Phase-Modular Y- Rectifier DC link (AC/DC converter), single phase of cascaded H-bridge series connection 4 set, the cascaded H-bridge multilevel inverter using the dc link supply for each full bridge inverter is provided separately, and connection to medium voltage form step-up transformer with multilevel modular converter (MMC) system.

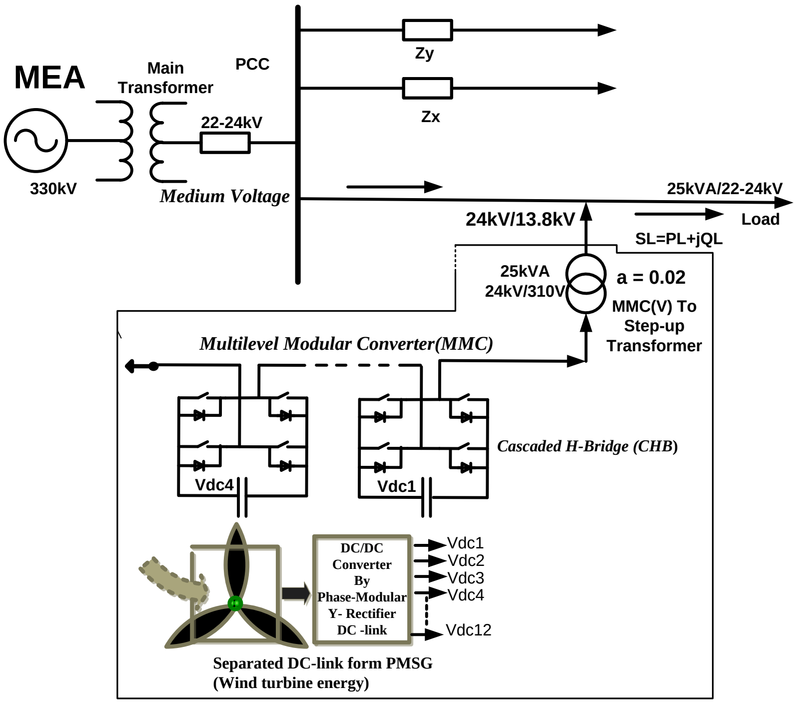

Fig. 1: Proposed of Application the Separated DC Source form Wind Turbine Energy (PMSG) System Using Phase-Modular Y- Rectifier DC Link and Connection to Medium Voltage Form Step-Up Transformer by Multilevel Modular Converter (MMC)

4. Cascade H-bridge INV

The cascaded H-bridge (CHB) multilevel inverter is seen as the most appropriated structure for the integration of the renewable energy from a separate DC sources can be entered directly fed by wind turbine generator (PMSG), A single-phase structure of 9-level cascaded inverter. Each separate dc source by wind turbine generator (PMSG) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate voltage outputs per phase form DC sources, the ac output by different combinations of the four switches, S_1, S_2, S_3, and S_4. To obtain ($+V_{DC}$), switches S_1 and S_2 are turned on, whereas ($-V_{DC}$), can be obtained by turning on switches S_3 and S_4. The four IGBTs or MOSFET allows control of power flow in both directions by maintain the possibility of voltage balancing and control. The possibility of bidirectional power flow gives the possibility of controlling the DC bus by Phase-Modular Y- Rectifier with separate dc sources by DC links based on wind turbine generator (PMSG).The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2Z+1, considering that Z is the number of steps of the phase voltage, and the number of steps P in the phase voltage of a three-phase load in wye (Y) connection is P = m-1. The number of P-cascaded cells in one phase with their carriers phase shifted by an angle is ($\theta_c = 360^0 / P$) and using the same control voltage produce a load voltage with the smallest distortion. An example phase voltage with stepped waveform, for a 9-level cascaded H-bridge inverter with separate dc sources and 4 full bridges, which uses three series-connected multilevel modular converters (MMC) in each phase. The smallest distortion is obtained is when the carrier are phase shift by an angle about $\theta_c = 45^0$, the 9-level SPWM cascaded H-Bridges designs setting frequency (fs=10 kHz) of the diagram in part of for medium voltage based on wind turbine generator. The phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4}$ as written voltage (V) and $H(n)$:magnitudes of the Fourier coefficients, Z is the number of PMSG separate dc sources and where order harmonics n = 1, 3, 5, 7, 9, 11, 13.......

5. Modeling directed power control for CHB INV

First stage proposed (part (1), using by Direct Power Control (PQ) controlled multilevel voltage source inverter with 9-level SPWM cascaded H-Bridges. The modeling block diagram consists of phase lock loop (PLL), decoder, sine-cosine-ROM. The sine-cosine-ROM is vital for in-phase strategy controller wave form. We obtain current (Iα, iβ) it is that flow pass LPF is 1st-order low-pass filter that passes low-frequency signals setting of design Cut-off frequency (f_c=1000Hz) , for obtain voltage (*Vα, Vβ)* in the stationary reference frame (α, β), and transform going to conversion to Voltages *Vd*, and *Vq* coordinate is transformed . The controllers deliver the reference values for the voltages and current in the *d* and *q*-axis, *Vd*, *Vq* and *Id*, *Iq* with PLL (Phase Lock Loop). Thereafter, the received signal in dq coordinate is transformed into abc coordinate as equation transformation, respectively. The PQ- theory power components are then calculated from voltages and currents in the value of dq-coordinates by using coordinates transformation, the PQ-calculated, mean value of the instantaneous real power (P). It corresponds to the energy per time unity that is transferred from the power source to the load, in a balanced way, through the *a-b-c* coordinates (it is, indeed, the only desired power component to be supplied by the power source). It is also important to note that the three-phase instantaneous power (*P*) can be written in coordinates systems, *a-b-c* and dq- coordinates transform. Mean value of instantaneous imaginary power (Q),has to do with power (and corresponding undesirable currents) that is exchanged between the system phases, and which does not imply any transference or exchange of energy between the power source and the load, can be written in both coordinates systems, *a-b-c* and dq- coordinates transform, in *a-b-c* coordinates the following expression is obtained the three-phase power source voltage can be easily as in Eq (6)and Eq (7).In addition, instantaneous active power (P) and instantaneous reactive power (Q) can be effectively used in the SPWM converter for P,Q directly controlling multilevel voltage source inverter with 9-level SPWM cascaded H-Bridges.

$$\begin{bmatrix} P \\ Q \end{bmatrix} = \frac{3}{2}\begin{bmatrix} Vd & Vq \\ Vq & -Vd \end{bmatrix}\begin{bmatrix} Id \\ Iq \end{bmatrix} \tag{6}$$

$$\begin{bmatrix} Id \\ Iq \end{bmatrix} = \frac{2/3}{Vd^2+Vq^2}\begin{bmatrix} Vd & Vq \\ Vq & -Vd \end{bmatrix}\begin{bmatrix} P \\ 0 \end{bmatrix} + \frac{2/3}{Vd^2+Vq^2}\begin{bmatrix} Vd & Vq \\ Vq & -Vd \end{bmatrix}\begin{bmatrix} 0 \\ Q \end{bmatrix} \tag{7}$$

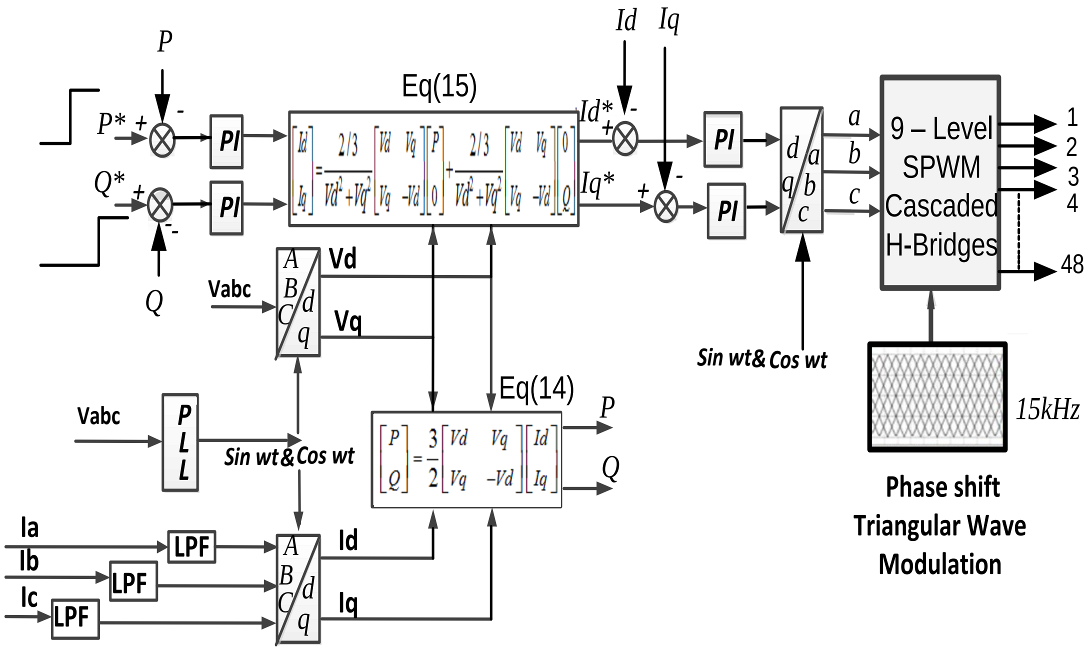

Fig. 2: First Stage Proposed (Part (1), Using by Direct Power Control (PQ) Controlled Multilevel Voltage Source Inverter with 9-Level SPWM Cascaded H-Bridges with Separated DC-Source with For Medium Voltage Based on Wind Turbine Generator.

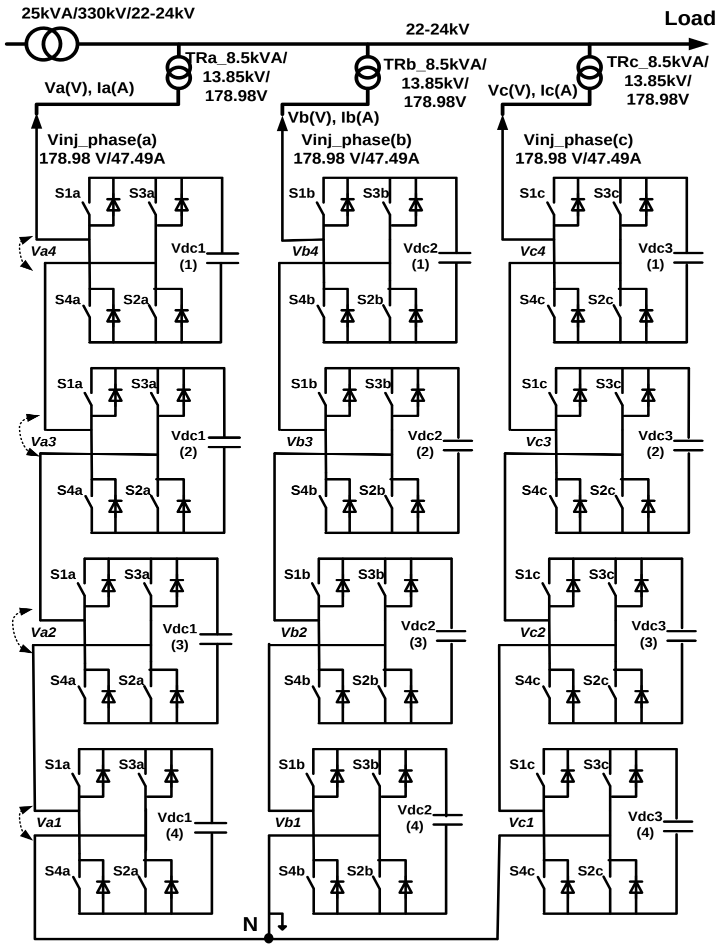

Fig. 3: First Stage Proposed (Part (1), Diagram of Main Power Inverter Used Multilevel Modular Converter (MMC) By 9-Level Cascaded H-Bridge (CHB) Inverter.

6. Phase-modular Y- rectifier DC link

Owning to prevalence of power electronics system, many problems with regard to diode rectifiers, one of problems is a low input power factor, and another is current harmonics. These are reasons reduce the harmonic component of the input current [19]. The requirement placed on active PFC rectifier system can thus be summarized as follows: the Standard EN 6100-3-2 if < 16A and EN 6100-3-4 if > 16A,The harmonics <5% at rated power is often required, ohmic fundamental mains behavior ($\cos(\phi)$>0.99), compliance with specifications regarding electromagnetic, especially conducted interference emissions by means of suitable EMI filtering [20],[21].The output dc voltage relative to the main voltage, a system with boost type, buck type, buck-boost-type characteristic has to be provided. This paper proposed second stage part (2) the control technique of the PWM converter, which enables the converter to achieve the unity power factor with voltage source sensor of PMSG and DC- current load sensor. The technique Y-Rectifier in a three phase star connection with floating star point *N´*, the combine's single-phase modules output stages with unity power factor rectifier and therefore represents an interesting concept for the realization of high power supply systems, with separate dc sources by DC links based on wind turbine generator (PMSG) applied to cascaded H-bridge (CHB) inverter. In Fig 2 and Fig.3. Shows the few circuit diagrams of Phase-Modular Y-Rectifier DC-link and the control strategy Phase-Modular Y- Rectifier SPWM rectifiers. This new breed of AC/DC converters gives excellent power quality indices like nearly unity input power factor, negligible THD in source current, reduced ripple factor of load voltage and fast-regulated load voltage. It is employed to reduce the dc-link voltage ripple supply currents, even in the case of unbalanced [20]. [21]. The control technique used in the rectifier is the One Cycle Control, consideration in Fig 4 and Fig.5, the negative half cycle of the line voltage where P1a, P2a, P3a, P4a, is turned on, the current will flow in the reverse direction through the switch itself, and when P1a, P2a, P3a, P4a, is turned off, the current will flow in the reverse direction through the antiparallel diode. In the positive half line, when N1a, N2a, N3a, N4a, is turned on, the current will flow in the reverse direction through itself and, when N1a, N2a, N3a, N4a, is turned off the current will flow in the reverse direction through the antiparallel diode. In Fig.4 and Fig 5, the proposed part (2), the control of a two-level *Y-Rectifier* in a three phase star connection with separated DC-source for Medium Voltage Based On Wind Turbine Generator. The control system technique, this is the only control technique that allows getting high power factor in continuous conduction mode without the necessity of a reference signal for the current. This technique consists of two control loops, a voltage loop and a current loop. The duty cycle (D) of switching command pulse depends on the input voltage value, allowing that the current loop keeps the sine wave shape of input current analogous to input voltage in phase and form. The Command VDC* and feedback DC output voltage loop (VDC), due to compared different signal value regulations, the feed forward loops of ac input voltage (Van,Vbn,Vcn) of PMSG, and voltage going through pass abs absolute voltage (ABS),and output the average current (Idc) by mean of switching the duty cycle of PWM [22].

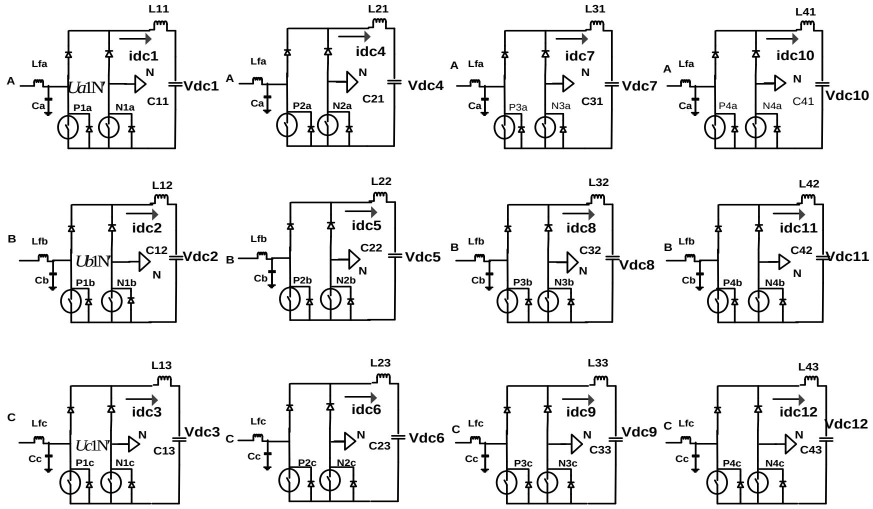

Fig. 4: Second Stage Proposed (Part (2). The Main Power Circuit Diagram of Phase-Modular Y-Rectifier System Applied To MMC with Medium Voltage Based on Wind Turbine Generator

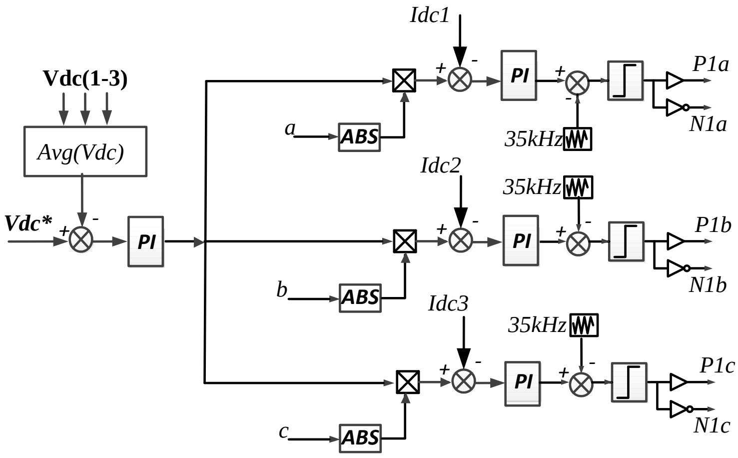

Fig. 5: Second Stage Proposed (Part (2), the Control of a Two-Level *Y-Rectifier* For Proposed in a Three Phase Star Connection with Separated DC-Source for Medium Voltage Based on Wind Turbine Generator.

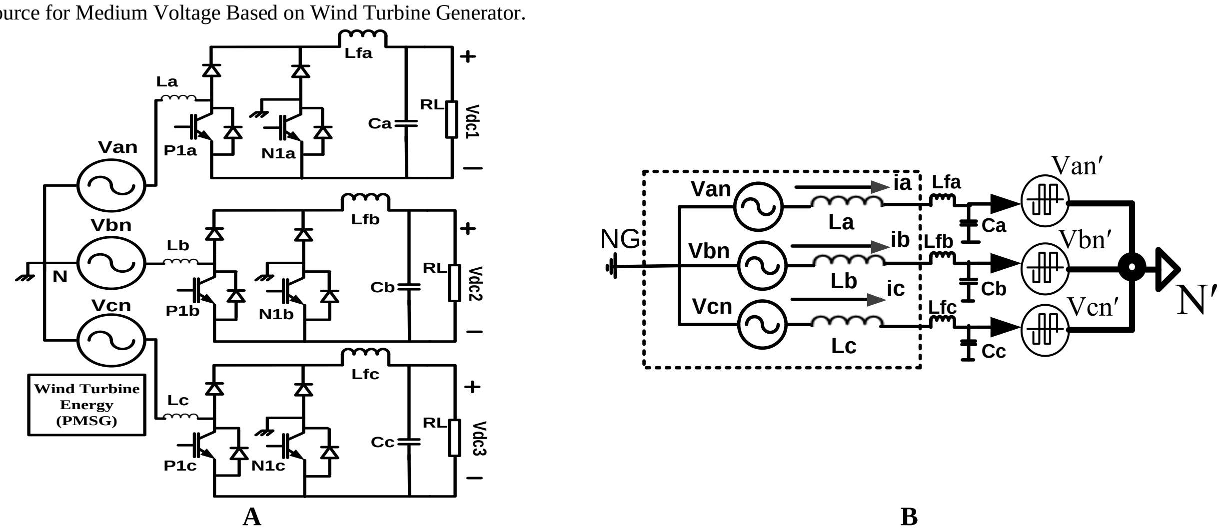

Fig. 6: The Main Power Circuit Diagram (A) Phase-Modular Y-Rectifier System, Boost –Type (Bridgeless) PFC Rectifier (B) Equivalent Circuit of the Ac System Part with Couple the EMI Input Filter form Wind Turbine Generator (PMSG)

Difference of signal from both paths is detected for error with output signal from the process then passes PI-controller. As shows in Fig.6, the equivalent circuit of the ac system part with the EMI input filter (Lf ,C) form connection PMSG, the ac currents is via the differences of the mains phase voltages to formed at the input of the rectifier stages shows in Eq (8).An offset of the reference phase voltage values (Va,Vb,Vc) is formed which, however, cannot be set by the phase current controllers because of the free star-point N′, ia + ib + ic = 0 is unalterable. The phase currents thus keep their sinusoidal shape and the symmetry to the time axis.

$$\frac{d}{dt}(Ia + Ib + Ic) = 0 \tag{8}$$

The star-point voltage u (N′GN) with consideration of and the star-point N′ is not connected to an artificial star-point, which could be formed e.g. by filter capacitors, a switching frequency voltage U(N′GN) occurs between N′ and the mains star-point GN consideration of results shows in Eq(9) and Eq(10), Remark, voltage drop in the EMI filter (Lf ,C) is three phase not shows equation due to not take in to consideration.

$$U(N'GN) = -\frac{1}{3}(UaN' + UbN' + UcN') \tag{9}$$

$$\begin{aligned} La\frac{d}{dt}Ia &= UaGN - (UaN' + UN'GN) \\ Lb\frac{d}{dt}Ib &= UbGN - (UbN' + UN'GN) \\ Lc\frac{d}{dt}Ic &= UcGN - (UcN' + UN'GN) \end{aligned} \tag{10}$$

The input voltage required for the impression of the input current, the same conditions are present for the phase modules as for single-phase PFC rectifiers supplied from a mains phase. In connection with the balancing of the output voltages it should be pointed out that a symmetrical mains current system can be surprisingly also maintained for unequal distribution of the input power to the three outputs, i.e. is also possible for asymmetrically loaded outputs.

7. Study results

The power circuit of diagram of main power inverter used multilevel modular converter (MMC) by 9-level cascaded H-bridge (CHB) inverter and the main power circuit of the Phase-Modular Y-Rectifier system. The hard ware prototype consisted of the main power circuit cascaded H-bridge (CHB) inverter is an IGBT power electronics devices based full-bridge circuit, power electronic system with analog-digital mixed and of not only the main and controller circuits but also have digital and analog elements. The electrical devices and parameter tester as shows in TABLE I.

Table I: Main System Parameters the Tester Experimental & Simulation

	Parameter	Rated-Value	Per unit
Grid	Grid line Voltage	24kV(Base)	1.0
	Frequency	50Hz(Base)	1.0
	Rated Power	25kVA(Base)	1.0
9-level cascaded H-bridge (CHB) inverter	Switching frequency	10kHz	200
	Single Cascaded H-bridges/phase	4 set / per phase	-
	Phase shift SPWM	45 deg	-
	Power IGBT Fuji 2MBI 100 NC	100V/1200V	-
Injection Step up Transformer	Secondary voltage	13.85kV/phase	0.57
	Primary Voltage	178.98V/phase	0.0074
	Rated Power per Phase	8.5kVA/Phase	0.34
PMSG (Wind-Turbine Energy)	Voltage / phase	220V / phase	0.0091
	Rated Power per Phase	8.5kVA/Phase	0.34
	Rated Power	25kVA	1.0
Phase-Modular Y-Rectifier system	Switching frequency	35kHz	200
	Single Cascaded H-bridges/phase	12 set	-
	EMI, L-Filter/set	300uH	-
	EMI, C-Filter/set	1uF	
	Power IGBT Fuji 2MBI 100 NC	100V/1200V	-
	Vdc-link/set	178Vdc	
	Output(Inductor)	0.6mH	
	Output (capacitor)	4700uf	

Table 1. describes main system parameters for the tester experimental and simulation ,the Grid line Voltage 24kV(Base voltage) ,25kVA,50Hz, 9-level cascaded H-bridge (CHB) inverter, 12 set single cascaded H-bridges, Phase shift SPWM 45 deg and switching frequency 10kHz, Phase-Modular Y-Rectifier system, Switching frequency 35kHz,the Injection step up transformer and PMSG (Wind-Turbine Energy). The parameter Direct Power Control (PQ) and parameter the Modular Y-Rectifier system using three hall effect sensors are used to detect the line currents, that flow pass LPF is 1[st]-order low-pass filter that passes low-frequency signals setting of design Cut-off frequency (f_c=1000Hz). The control system Direct Power Control (PQ) and Phase-Modular Y-Rectifier system. of hardware consists of components: Phase lock loop (PLL), analog circuit transformation Vαβ-axis to Vdq-axis in the stationary coordinates, setup PI-controller (kp=0.75,ki=10sec) and PI-controller (kp=4,ki=0.084ms) for Phase-Modular Y-Rectifier controller system. The control system Direct Power Control (PQ) of hardware The experimental systems testing SPWM with carrier 10kHz, shows the output voltage of the proposed MMC simulated and the corresponding results are presented of 9-Level Cascaded H-Bridge (CHB) inverter. The prototype has been tested for amplitude modulation (ma =1.0) as show in Fig.7(a) and (b) the simulation gating signal for switching positions for four possible gate signals are given below 1 and 0 represent on and off state of the switching modulation respectively Vphase (Van), Vline (Vab).

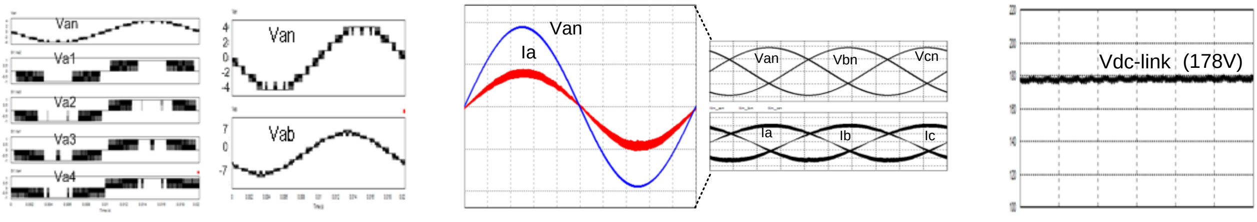

Fig. 7: (A) Simulation of 9-Level CHB INV (B) Vphase (Van) , Vline (Vab), (C) Voltages and Line Current of Phase-Modular Y-Rectifier System and (D) Vdc-Link of Phase-Modular Y-Rectifier System.

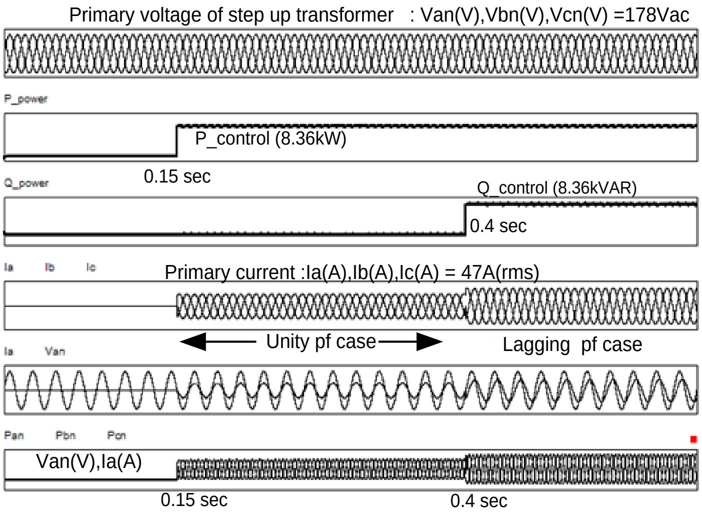

Fig. 8: Results of Simulation, Direct Instantaneous Power Control (PQ-Controller) Methods of 9-Level Cascaded H-Bridge (CHB) Inverter.

the main power diagram of Phase-Modular Y-Rectifier system and model controller in Fig.4-6, as shows in Fig 7(c), shows results of Simulation, voltages (Van, Vbn, Vcn) and line current (Ia, Ib, Ic) of Phase-Modular Y-Rectifier system. It can be observed that the unity power factor control. It is found that the lower harmonics component of the methods. Shows in Fig.7(c), for example Vdc1 for output dc voltage (Vdc-link) of Phase-Modular Y-Rectifier system. The DC output voltage is successfully controlled owing to the low gain of the ac voltage loop and dc current loop at frequency of the ripples. Shown in figure in Fig.8, shows results of the waveforms consist of voltage (Van, Vbn, Vcn) current (Ia, Ib, Ic) and power (Pan, Pbn, Pcn=8.36kW) injection to step-up transformer with ratio transformer (178.98V/13.85kV) for medium Voltage. The step responses with direct instantaneous power control (PQ-controller) methods for 9-level cascaded H-bridge (CHB) inverter. It can be observed that the unity power factor control with duration time (0.15sec - 0.4sec) and another time (>0.4sec) is the lagging power factor condition controllers. The primary current (47Arms)of step up transformer shows the waveforms of the direct instantaneous power control when active power and reactive power was changed, it was verified that the control could indirectly adjust the current phase of primary transformer.

8. Conclusion

This work presents described two proposed part (1) using by Direct Power Control (PQ) controlled multilevel voltage source inverter with 9-level SPWM cascaded H-Bridges, and the part (2) proposed Phase-Modular Y-Rectifier system, boost–type (bridgeless) PFC Rectifier. The cascaded H-Bridges using power IGBT modular selection type double leg unit of the series connection with the separated with separated DC-source of PMSG for Medium Voltage. The control part (1) PQ command controller can make it possible of the grid current phase by providing the direct instantaneous power control in the steady state under the active power and reactive power command. The control part (2) Phase-Modular Y-Rectifier, , the control can make it the input line current of PMSG with the unity power factor, and the current waveform distortion results increase of the lower harmonics distortion. In addition, this study also provides guideline to further analyze and improve power quality in electrical system pertinent to the Salient Permanent Magnet Synchronous Generator (PMSG) system.

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