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Flicker Mitigation in PMSG WECS Employing Grid Side Converter Control

Hemant R Kulkarni, Vasudeo B Virulkar

***Abstract:** Need of green energy can be catered with the support of major share of wind power generation systems in the global energy scenario. Power quality of generated wind power depends on several factors. Wind velocity is one of the major factors producing fluctuations in the generated output voltage. These fluctuations cause visible disturbance to human eyes, known as voltage flicker. The wind farms affect performance of Grid due to variations in wind speed with respect to time. The paper explains measurement of flicker, flicker level severity index along with flicker mitigation technique. Flicker is observed in the power generated with help of Permanent Magnet Synchronous Generator (PMSG), where wind velocity is changing continuously. After employing converter control strategy, reduction in flicker level severity index is observed. The system is simulated using PSCAD/EMTDC, a powerful simulation software. Result shows that Grid side converter control helps to mitigate flicker effect.*

***Keywords:** Grid side Converters, Permanent Magnet Synchronous Generator (PMSG), Renewable Energy, Voltage Flicker.*

I. INTRODUCTION

Wind energy has major role in achieving pollution free energy supply for the world. Wind power is one of the clean energy resources being utilized worldwide. The continued development of wind power across the globe is supportive to the energy transition. 51.3 GW is the capacity addition in wind energy projects with cumulative installations up to 591 GW at the end of year 2018. Globally 330 GW capacity addition of wind energy is planned till year 2023, which can raise the total capacity up to 900 GW. Annual wind capacity additions are likely to exceed 200 GW per year in the next two decades[1]. The wind has intermittent nature. The output active power in wind energy conversion system (WECS) depends on wind velocity. The voltage fluctuation problem arises because of continuous change in speed of wind and wind gust[2],[3]. The mechanical power developed at wind turbine P_m is expressed as below:

$$P_m = 0.5\,\pi\rho R^2 C_p(\lambda,\beta)V_\omega^3 \qquad (1)$$

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* Correspondence Author
Hemant R Kulkarni*, Department of Electrical Engineering, Sandip Institute of Engineering and Management, Nashik, India. Email Id: hemanta11@gmail.com
Dr. Vasudeo B Virulkar, Department of Electrical Engineering, Government college of Engineering, Amravati, India. Email: vbvirulkar@yahoo.com

In above equation the air density is denoted by ρ, V_ω is wind velocity, C_p denotes coefficient of power, tip speed ratio is denoted by λ, pitch angle is expressed by β and length of turbine blade is represented by R.

II. VOLTAGE FLICKER AND ITS MEASUREMENT

Wind has stochastic nature. Magnitude of wind speed and its direction changes continuously. This causes variation in output voltage and output power of wind generator. IEEE 1453-2011 standard defines voltage flicker as "voltage variations in the electric power system that give rise to noticeable illumination changes" [4]. Power quality issues of whole power system are very sensitive and important since power generated by wind energy systems is connected to grid. IEC 61400-21 is followed in these cases, which explains the procedure to check the wind turbine's power quality characteristics [5].

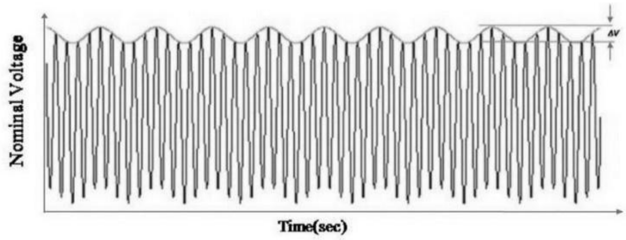

Fig. 1. Variation in voltage supply[6], [7]

Fig.1 gives idea about the voltage flicker. In the figure, variation in the output voltage is observed, it is denoted by ΔV. The main reason of the flicker in grid connected wind energy conversion system is variations in the output voltage. The main factors responsible for variations in output power are changes in wind speed, wind shear and effect of tower shadow[8]. IEC 61000-4-15 specifies the method of measuring flicker level[9].

Flicker levels are measured in terms of severity indices -short-term (P_{st}) and long-term (P_{lt}) flicker severity index. Proper pitch control strategy and remedial measures for wind speed variations are the major considerations while modelling the WECS[10], [11].

These systems commonly use two types of wind generators. Every type of generator and turbine have its own merits and demerits. Now a days following two types of generators are preferred in India. Namely they are, Double Field Induction Generator (DFIG) and Permanent Magnet Synchronous Generator (PMSG). In this research work PMSG is considered while simulating the WECS.

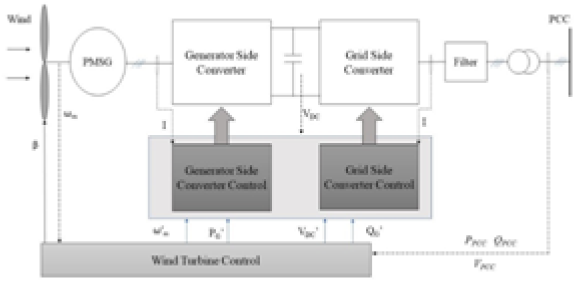

Fig.2 General control scheme for PMSG based WECS [12]

Fig. 2 depicts the general scheme for PMSG based wind energy conversion system. It uses two converter system with filter. Clutch and gear system have losses in transmitting motion hence direct driven system based on PMSG is preferred. It reduces the losses at gear system. There are different factors which govern generation of electrical energy[12]. One converter is at machine side whereas the other converter is connected at grid-side. They are connected in back to back configuration through a filter capacitor. For controlling fluctuations in the output voltage of PMSG, grid side converter is to be controlled precisely[13], [14].

III. MODELLING OF PMSG

In Permanent magnet synchronous generator field excitation is achieved with help of permanent magnets and not by the coils, hence it is named as PMSG. PMSG is directly coupled to the shaft hence it has comparatively low losses. Also, self-excitation property of PMSG permits operation at high power factor and high-power density, its design is compact, wide speed operation range and good better efficiency. The salient pole of PMSG operates at low speed. Hence gearbox is not required in this system. This feature helps permanent magnet synchronous generator wind energy conversion system to become more user friendly and popular in industry sector. A d-q synchronous reference frame is used to represent dynamic model of PMSG[12].The torque relations for this system are expressed as:

$$V_{sd} = R_s i_d \frac{di_{sd}}{dt} - \omega_e L_q i_{sq} \quad (2)$$

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

Here R_s is stator winding resistance, $\omega_e$is rotor angular speed, V_{sd} and V_{sq} are the voltage at stator and i_{sd}, i_{sq} are current in d-q frame. The inductances of stator winding in d-q frame are given by L_d and L_q. The total number of pole pairs are given by n_p .The flux linkage of permanent magnet is ψ_m.With these considerations, the electromagnetic torque can be written as follows:

$$T_e = \frac{3}{2} n_p \left[\psi_m i_{sq} + \left(L_d - L_q\right) i_{sd} i_{sq}\right] \quad (4)$$

IV. GRIDSIDE CONVERTER CONTROL

Power converters are commonly used when renewable energy sources are to be connected to grid. Power converters convert the energy into three phase AC power. Nowadays, the grids are dominated by the power electronic devices like static VAR compensators and power converters (Grid-side/machine side). The voltage control capacity and the ability of sharing power are the controllable factors for grid-side converters[15]. Flicker mitigation can be achieved by controlling grid-side converter for active and reactive power transfer. Here outer control loop of voltage is used to maintain DC Voltage at the reference value. To design the PI controller following equations are used. The relations between grid voltage and grid-side converter voltage can be represented by following equations:

$$V_{sd} - \Delta V_{sd} = i_{sd} R_s + L_d \frac{di_{sd}}{dt} \quad (5)$$

$$V_{sq} - \Delta V_{sq} = i_{sq} R_s + L_q \frac{di_{sq}}{dt} \quad (6)$$

Gain and time constant are given by,

$$k_{d,q} = \frac{1}{R_s} \quad (7)$$

$$\tau_{d,q} = \frac{L_{d,q}}{R_s} \quad (8)$$

Pulse Width Modulation are modelled as 1^{st} Order elements. Time constants for these elements are considered respectively as T_{PWM} and $T_s/2$. Two smallest time constants are grouped as follows:

$$T_{\Sigma i} = T_{PWM} + \frac{T_s}{2} \quad (9)$$

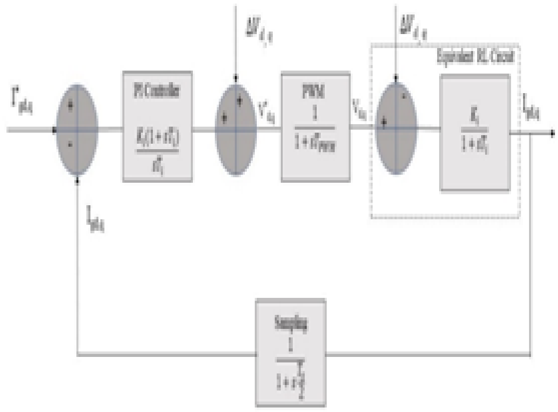

Fig. 3 Grid side Converter control Scheme

Fig. 3 shows the system design for control loop of stator current. The block diagram clearly shows the used PI Controller and the grid current control loop.

V. SIMULATION RESULTS

The PMSG wind turbine system with back to back converter and grid side converter control is simulated using PSCAD / EMTDC software.

The voltage fluctuations are reduced considerably when PI controller is used for Grid-side converter. Fig. 4 depicts the grid side converter control scheme.

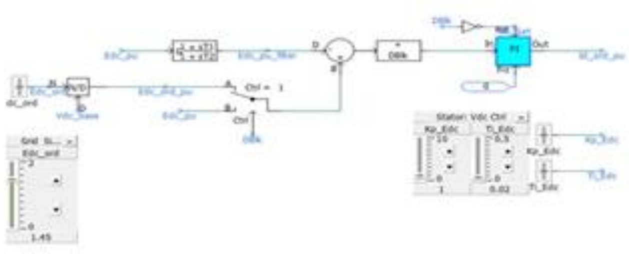

Fig. 4 PSCAD Simulation Circuit for intended converter control

PI controller strategy is used for controlling the converter connected at grid. Time constant for integral control and Gain of the PI controller can be expressed as

$$T_v = a^2 T_{\sum u} \qquad (10)$$

$$K_v = -\frac{1}{a}\,\frac{2}{3V\,gd}\,\frac{V_{dc}C_{dc}}{T_{\sum u}} \qquad (11)$$

PSCAD/ EMTDC software is used for simulation. The magnitude of mean wind speed is varied, and the P_{st} is measured at different values of mean wind speeds. PI controller is used which controls current through the circuit and we get different parameters practically varying with these base values. When we change the wind velocity according to real time data the simulation results of the following parameters, can be captured on scope are shown in Fig 5. To Fig 7. representing Grid Current, Output Voltage and DC Current.

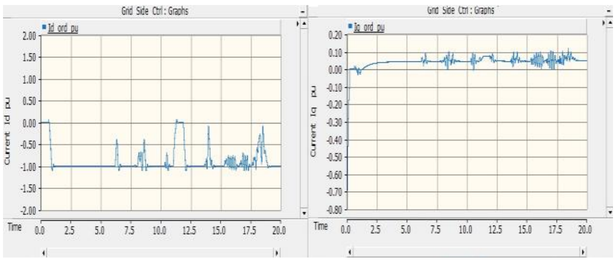

Fig.5 Grid Current

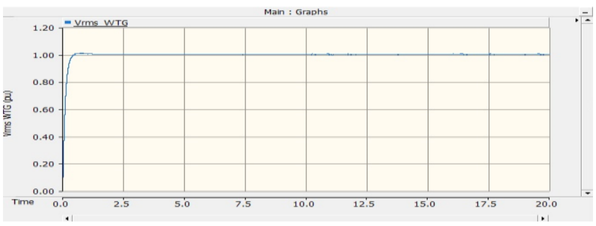

Fig.6 Output Voltage Vrms (pu)

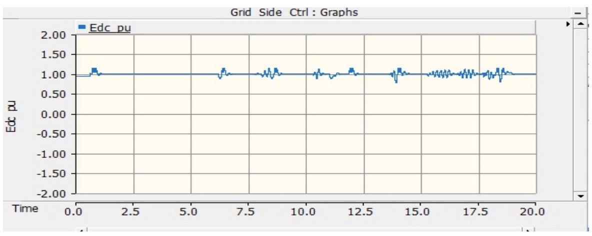

Fig.7 DC Grid Voltage

Fig. 8 to Fig. 10 shows Active grid power, reactive grid power and the P_{st} value of flicker with and without control techniques are shown below. The parameters captured with scope keeping all other setting same as earlier the readings of P_{st} are plotted with and without control provided to the grid side converter. The graphs observed with help of PSCAD are as below. They respectively represent, Active grid power, reactive grid power and the P_{st} value with and without control strategy employed at grid-side.

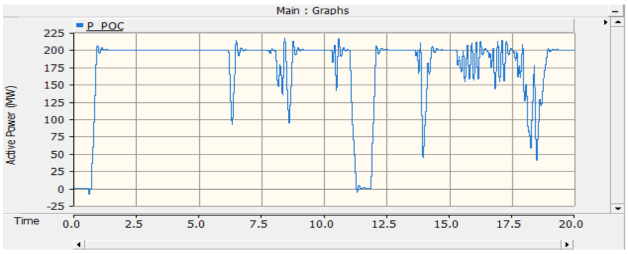

Fig.8 Active Power at Grid

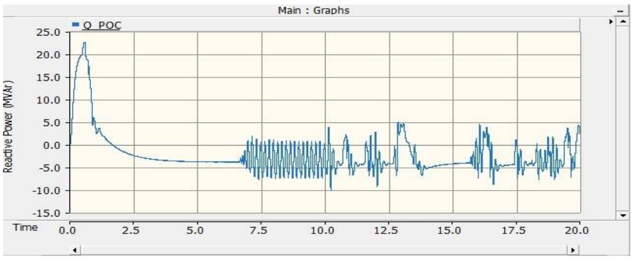

Fig.9 Reactive Grid Power

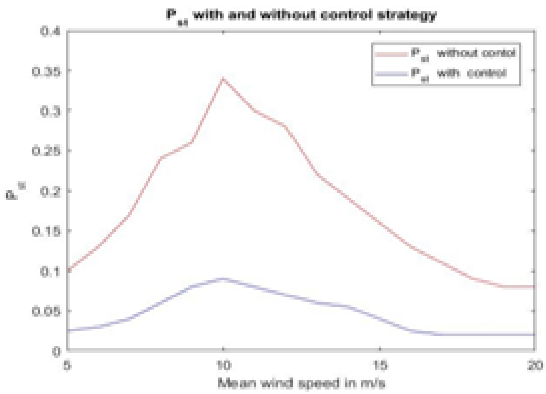

Fig.10 P_{st} with and without Grid side Converter Control

There is a rise in the power at 0.02 seconds as this power is transferred to DC circuit from generator. PI Controller sets reference value of grid current to 730 A. Then the active power will be transferred to grid. Here DC voltage of circuit is maintained at reference value.

The q-axis grid current reference was calculated using grid voltage and reactive grid power reference values. The $P_{Qgrid\ ref}$ was 100 kVAR, V_{grid} is 400V and I_{ref} was 205 A for the q-axis. There are losses in the synchronous generator, filter and Back to back converter, hence power at grid is smaller in magnitude than mechanical power. Here, at steady state condition, grid active power was 360 kW and the mechanical power was about 375 kW.

VI. CONCLUSION

Authors have simulated system for mitigating flicker in PMSG wind energy conversion system by controlling Grid Side Converter. A sophisticated power system software PSCAD / EMTDC is used for simulation of the system. This designed model is tested and observed that proposed control strategy for Grid Side Converter minimizes the voltage fluctuations, leading to reduction of short-term flicker severity index P_{st} in conformity with IEC 61400-21 standard. Grid side converter is controlled by using PI controller. The current in the outer loop is controlled and it helps to reduce the output voltage fluctuations. The results of employing control strategy for power converters connected at grid-side, controls the output current which results in reduction in output voltage variations. The P_{st} values achieved with and without applying grid side converter control are plotted. It is observed that the P_{st} values are well within the expected range when grid-side control was employed.

APPENDIX

TABLE 1. GRID SIDE CONVERTER PARAMETERS

Parameter	Value
Grid voltage	V_g = 400 V
Grid frequency	f_g = 50 Hz
DC circuit nominal voltage	V_{dc} = 750 V
DC circuit capacitance	C_{dc} = 11.76 mF
PWM switching frequency	f_{PWM} = 3 kHz
Filter capacitance	C_f = 136 µF
Converter-side filter inductance	L_{1f} = 45.61 µH
Grid-side filter inductance	L_{2f} = 31.85 µH
Converter-side filter parasitic resistance	R_{1f} = 0.12 mΩ
Grid-side filter parasitic resistance	R_{2f} = 1.97 mΩ
Nominal speed nn = 1500 rpm	nn = 1500 rpm
d-axis inductance	L_d = 0.72 mH
q-axis inductance	L_q = 1.06 mH
Permanent magnet flux linkage	ψ_m = 0.69 Wb

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AUTHORS PROFILE

Hemant R. Kulkarni received the B.E. degree in Power Electronics from Nagpur University, Nagpur (M.S.), India, in 1998, the M. Tech. (EPS) degree from the VJTI, Mumbai, India, in 2008. He is pursuing PhD from Government College of Engineering, Amravati. Presently, he is working as Associate Professor in Electrical Engineering Department of Sandip Institute of Engineering and Management, Nashik (M.S.), India.

Dr. Vasudeo B. Virulkar received the B.E. degree in Electrical Engineering from the Nagpur University, Nagpur (M.S.), India, in 1991, the M.E. (EPS) degree from the Amravati University, Amravati, India, in 1997. After his post-graduation, he worked as Lecturer in Electrical Engineering with Department of Higher and Technical Education, Govt. of Maharashtra at various institutions. He completed his Ph.D. from VNIT Nagpur. Presently, he is working as Associate Professor in Electrical Engineering Department at Govt. College of Engineering, Amravati (M.S.), India.