Power Quality Improvement and Energy Management of Grid Integrated Distributed Generators

[1]Alwin Vinifred Christopher,
[1]Assistant Professor, Sri Sairam Engineering College &
[1]Research Scholar, Anna University, Chennai.

Abstract: This manuscript deals with power control of a distributed (wind & solar) generation system for interconnection operation with electric distribution system. Power control strategy is to extract the maximum energy available from varying condition of wind speed and solar irradiance while maintaining power quality at a satisfactory level. In order to capture the maximum power, variable speed control is employed for wind turbine and maximum power point tracking is applied for photovoltaic system. The grid interface inverter transfers the energy drawn from the wind turbine and PV array into the grid by keeping common dc voltage constant. To ensure safety these inverters automatically shut down in the event of High/Low grid AC-voltage, High/Low grid frequency, Grid Failure or Inverter malfunction. Simulation on the entire control scheme is carried out using a power system transient analysis tool, Matlab Simulink. The simulation results show the control performance and dynamic behavior of the wind/PV system.

Keywords- MPPT, PLL, Wind turbine, PV, Islanding, PWM, THD.

I.INTRODUCTION

Advances in wind turbine and photovoltaic generation technologies have brought opportunities for utilizing wind and solar resources for electric power generation. They have unpredictable random behaviours. The Wind/solar complementary power supply system is a reasonable power supply which makes good use of wind and solar energy. This system can not only provide a bargain of low cost and high dependability for some region where power transmission is not convenient such as frontier defenses and sentry, relay stations of communication, a farming or pasturing area and so on, but also inaugurate a new area which resolve the crisis of energy sources and environment pollution. It is very difficult to make use of the solar and wind energy all weather just through solar system or wind system individually, for the restriction of time and region. So a system that is based on renewable resources but at the same time reliable is necessary and wind/solar hybrid system with battery storage can meet this requirement. Multilevel inverter provides a suitable solution for medium and high power systems to synthesise output voltage which allows a reduction of harmonic content in voltage and current waveforms. Multilevel refers to the multiple connections of individual inverters termed as 'stages' to provide the output voltage with required 'levels'. Increasing the number of levels will result in the reduction of harmonic distortion. The three topologies such as flying capacitor (FC), neutral point clamped (NPC) and cascaded multilevel inverters (CMLIs) are preferred for various applications depending upon its structure and modulation algorithms. Among the three topologies, CMLI is highly preferred for the interconnection of renewable energy systems because of the advantages such as absence of voltage unbalance problem. Solar photovoltaic (PV) fed CMLI is dealt in various literatures, but it intends for low voltage and low level configurations. Pulse-width modulation (PWM) technique for a 5-level CMLI and 7-level CMLI for PV system is addressed which requires boost converter, auxiliary circuitry and multiple reference signals for pulse generation.[9] A 5-level current CMLI for a single phase grid connected PV system given in requires the redesign of LC filter to reduce the inductive and resistive losses for higher power levels. The three control loop maximum power point (MPP) for a 5-level inverter proposed in employs an output transformer between inverter and grid. Inspite of reducing the harmonic distortions while increasing the levels, CMLI requires more number of semiconductor switches which has to be reduced for minimising switching loss, cost, complexity and space. Series connection of multilevel inverters introduced in restricts its use in high power applications because of the necessity of changing the voltage polarity in every half cycle and also the switches with different ratings are required. A detailed look-up table is required for the method proposed in which consists of series connection of a high-voltage NPC and a low-voltage conventional inverter. A 5-level inverter with four DC sources comprising two numbers of 2-level and 3-level inverters is proposed. The drawback of this method is that in conventional inverters up to 9 level can be generated with the same number of power supplies [11]. Bidirectional switches with voltage and current blocking capability for the reduction of switches is proposed where each bidirectional switch requires a separate gate drive circuit which increases the power loss.

The rest of the paper is organized as follows proposed system models are explained in section II. Simulation results are presented in section III. Conclusion remarks are given in section IV.

II.PROPOSED SYSTEM MODEL

The hybrid generation system as shown in figure 1

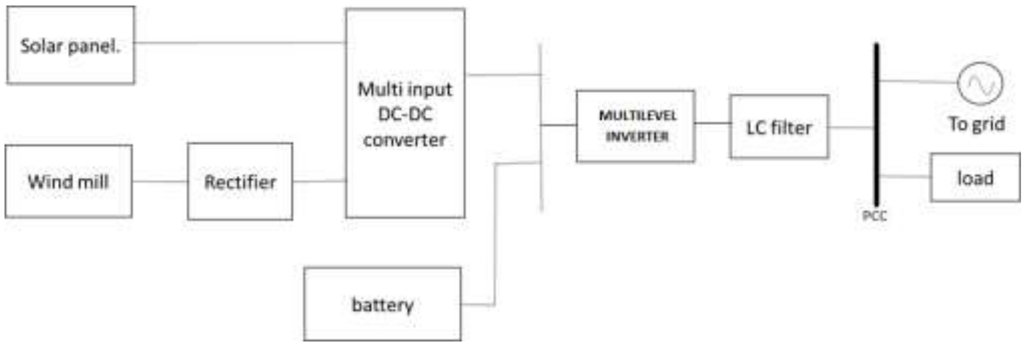


Fig.1 hybrid generation system

A. WIND MODELLING

The wind speed is modelled as a deterministic, non-stationary signal given as the sum of sinusoids as follows:

$$V_v(t) = 10 + 0.2\sin(0.104t) + 2\sin(0.266t) + \sin(1.293t) + 0.2\sin(3.664t)$$

MPPT Control Strategy for Wind Turbine System

According to the operation theory of wind turbine,[11] the maximum output power of wind generator depends on the optimal tip speed ratio λ_{opt}. In terms of this, the MPPT is controlled to track the maximum power of the wind turbine and the battery charging voltage in such a way

Power produced by a wind turbine is $P_m = 0.5\pi\rho C_p(\lambda, \beta)R^2\upsilon_w^3$

Where R - turbine radius υ_w -wind speed

ρ -Air density C_P -Power Coefficient

λ - Tip speed ratio β - Pitch angle

B. PHOTOVOLTAIC GENERATOR MODEL

Generally, the PV panel can be modelled using the equivalent circuit shown.

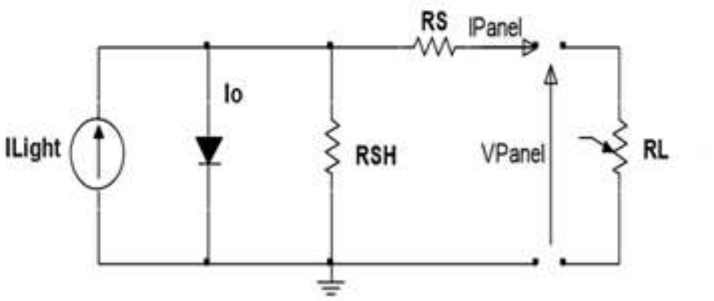


Fig.2 Photovoltaic Generator Model

This lumped circuit includes a current generator providing the sort-circuit current (I Light), which is a function of the solar irradiation, a diode to account for the typical knee of the current–voltage curve through the reverse saturation current (I0), a series resistor (RS), and a shunt resistor (RSH), emulating intrinsic losses depending on PV cell series and parallel connections.[4] The PV module current at a given cell temperature and solar irradiance is given by

$$I_{Panel} = I_{Light} - I_O\left(e^{\frac{V_{Panel}+I_{Panel}R_s}{a}} - 1\right) - \frac{V_{Panel} + I_{Panel}R_s}{R_{SH}}$$

Where 'a' is the modified panel ideal factor defined by

$$a = \frac{N_S \gamma K T_C}{q}$$

Where q is the electron charge, K is Boltzmann's constant, γ is the usual PV single-cell ideal factor,

N_s is the number of cells in series, and T_c is the PV panel temperature.

MPPT of the PV cell Incremental conductance method has been implemented in this study. If the array is operating at voltage V and current I, the power generation is P=VI, at the maximum power point,[5] dP/dV should be zero and the sign of dP/dV may be identified by equation. Increase or decrease in the PV array voltage is determined by judging the sign of this equation.

$$\frac{I}{V}\frac{dP}{dV} = \frac{d(VI)}{VdV} = \frac{I}{V} + \frac{dI}{dV}$$

C.INVERTER MODEL

Multilevel inverter provides a suitable solution for medium and high power systems to synthesise a output voltage which allows a reduction of harmonic content in voltage and current waveforms. Multilevel refers to the multiple connections of individual inverters termed as 'stages' to provide the output voltage with required 'levels'. Increasing the number of levels will result in the reduction of harmonic distortion.[10]The three topologies such as flying capacitor (FC), neutral point clamped (NPC) and cascaded multilevel inverters (CMLIs) are preferred for various applications depending upon its structure and modulation algorithms. Among the three topologies, CMLI is highly preferred for the interconnection of renewable energy systems because of the advantages such as absence of voltage unbalance problem, possible elimination of DC–DC boost converter, adaptive at low switching frequency and absence of clamping capacitors and diodes. Modified CMLI is proposed in this work.

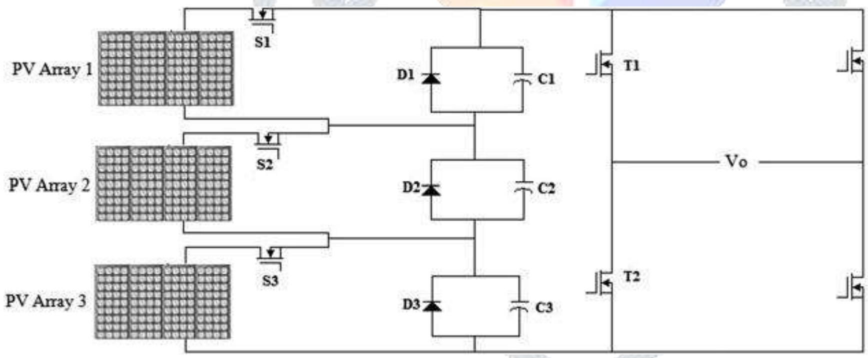


Fig.3 Single stage 15-level inverter power circuit

In the modified CMLI the modification is realised in control circuit of CMLI to achieve 15 and 27 levels with three inverter stages. In this approach, the modification is made in both control circuit and predominately in power circuit to obtain 15 levels with only seven switches. Fig. 3 shows the circuit diagram of MMC approach where the input scaling is not mandatory.[14] The addition of diode and capacitor (1 nF) is to normalise the output within the given interval.[11] Table 3 shows the switching sequence to achieve the 15-level output. Based on the table, the inverter circuit (T1–T4) is in ON condition at all the levels, but the input switches (S1–S3) are controlled in such a way that to obtain the required output voltage. Let the PV array inputs be V1–V3. During the level 1, V1 alone is given as input to the inverter and V2, V3 in OFF condition. Similarly the 15 level is achieved by controlling the ON/OFF status of the input voltages. The remaining 7 level from the truth table(ref.table1) will be obtained by controlling the sequence in reverse direction. Proposed Inverter increases the number of stages with reduced number of switches by the application of modified switching strategies.[13] The Simulation results shows that this multilevel inverter output improves the power quality by the reduced THD.

Table 1 Switching sequence for 15-level inverter with MMC

Level	S1	S2	S3	T1	T2	T3	T4	V_O
0	0	0	0	0	0	0	0	0
1	1	0	0	1	0	0	1	48
2	0	1	0	1	0	0	1	96
3	1	1	0	1	0	0	1	144
4	0	0	1	1	0	0	1	192
5	1	0	1	1	0	0	1	240
6	0	1	1	1	0	0	1	288
7	1	1	1	1	0	0	1	336

III.SIMULATION RESULTS

A. Modelling of solar panel

The solar panel Simulink model is shown in figure 4.Solar panel output current, voltage and power are shown in fig. 7

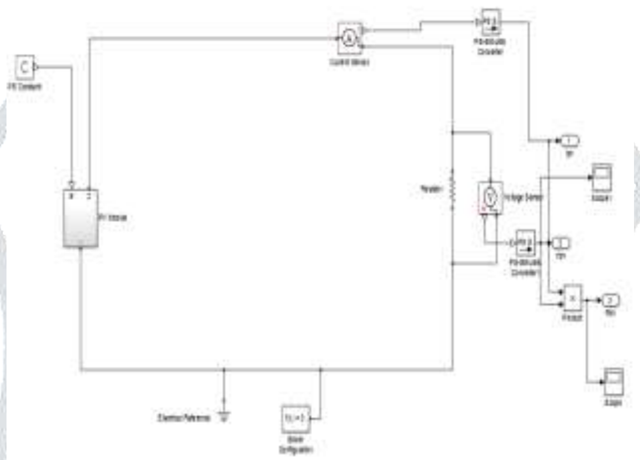


Fig.4 Modelling of solar panel

B. Modelling of wind turbine

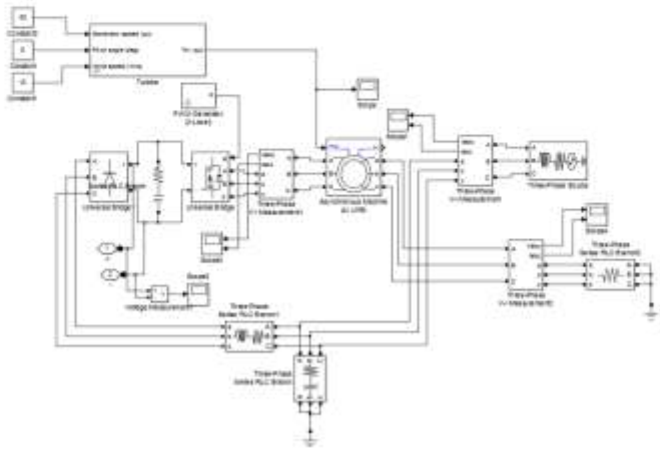


Fig 5 Modelling of wind turbine

C Hybrid model of proposed system

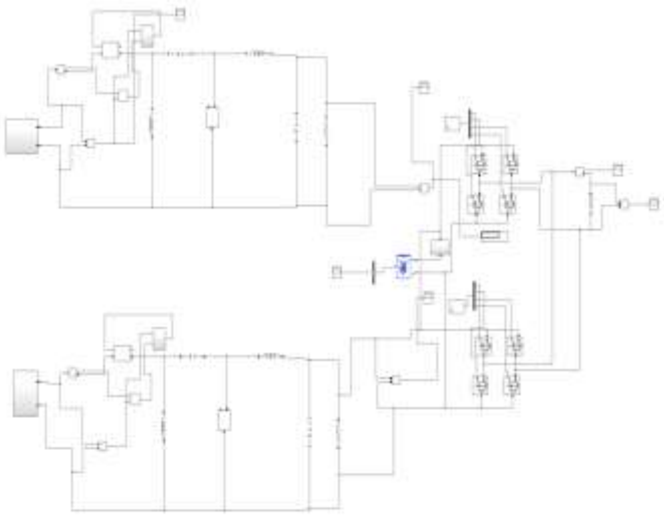


Fig.6 Hybrid model of proposed system for simulation

Fig.7 Solar panel output current, voltage & power

The converter output shown in figure 8.The inverter used in this work is CMLI, Which uses modern switching technique to achieve 15 levels. The output waveform of the inverter is shown in figure 9.And by FFT analysis tool the harmonic content present (THD =5.55%) in the output is shown by the figure 10.

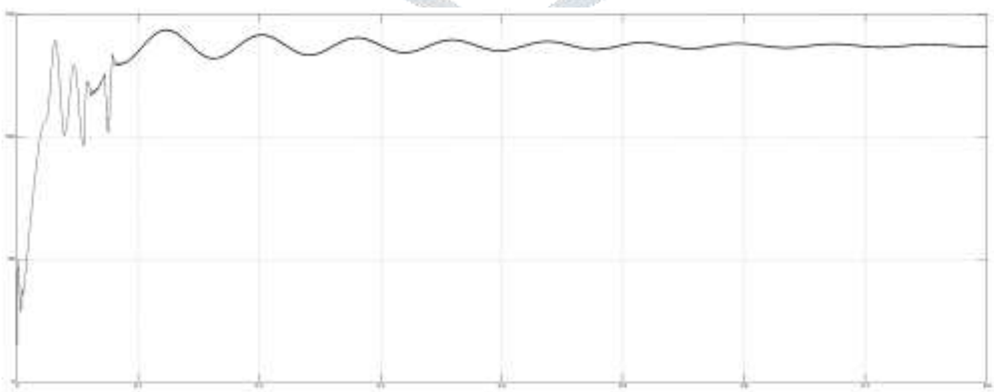
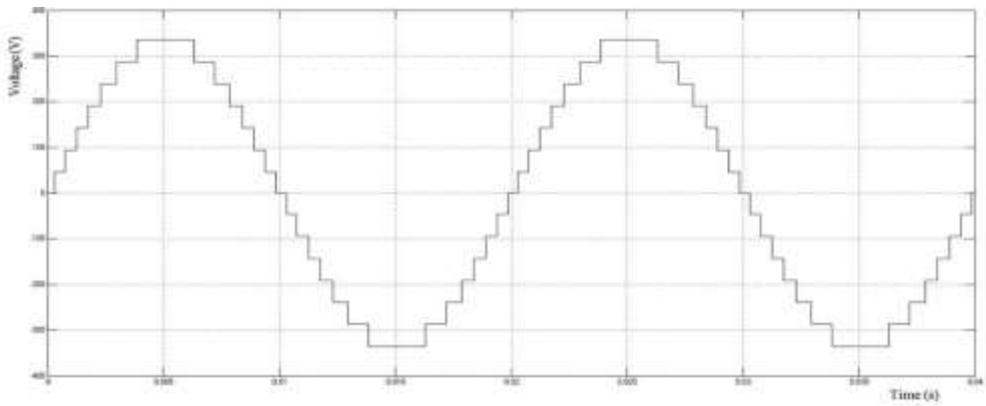


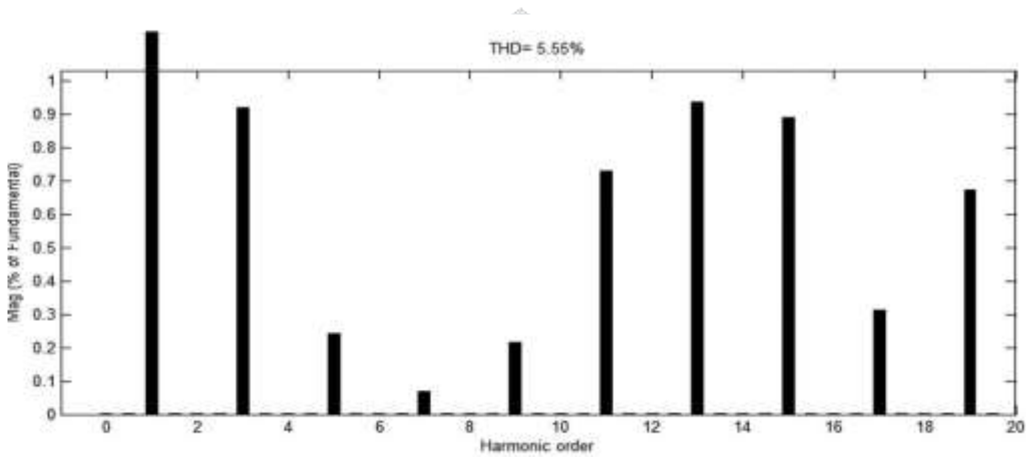
Fig 8 Converter output voltage waveform

Based on the experimental result the energy management can be made in efficient manner and the multilevel inverter response is good because the even order harmonics are eliminated



a

Fig.9 Output voltage waveform of a 15-level CMLI



b

Fig.10 FFT analysis for harmonic spectrum of one stage 15-level CMLI

IV.CONCLUSION

Solar power is well known to be an expensive solution to remote electrification. This cost can be reduced by adding wind turbine generators to reduce the reliance on PV. This paper focused on the study of photovoltaic wind production of electrical energy optimization as well as its transfer to the mono-phase electrical network supply through an inverter with minimum possible losses. The adopted approach was to improve the chain various parts point by point. A pv/wind system protection device is implemented i.e. this system is able to react to overvoltage, under voltages and frequency variations. It was subjected to an overvoltage, an under voltage and frequency variation. The system showed good results in each cited case. The AC coupling with inverter allows to connect nearly any type of electricity generator and any type of consumer to our system. This makes our system easily extendable on the consumer side as well as on the generator side. The power quality improvement for a solar fed CMLI with reduced number of semiconductor switches is investigated in this paper. The required 15-level output is achieved with only 12 switches in binary mode and 7 switches in MMC mode. A detailed simulation study is carried out for various levels and comparison has been made.[13] A 3 kWp solar PV fed CMLI is implemented for all the three topologies and harmonics analysis was made. Based on the observations, the proposed method provides the multiple advantages which include reduced THD, less cost, simple design, minimum computational complexity and the absence of transformers, boost converters, detailed look-up table and filter circuit. Moreover, these methods are much suitable for standalone/grid interacted PV systems to improve power quality.

V. REFERENCE

[1] N. Ruiz, I. Cobelo, J. Oyarzabal, "A direct load control model for virtual power plant management", *IEEE Trans. Power Syst.*, vol. 24, no. 2, pp. 959-966, May 2009.
[2] Katiraei, M. Iravani, "Power management strategies for a microgrid with multiple distributed generation units", *IEEE Trans. Power Syst.*, vol. 21, no. 4, pp. 1821-1831, Nov. 2006.
[3] J. Lopes, N. Hatziargyriou, J. Mutale, "Integrating distributed generation into electric power systems: A review of drivers challenges and opportunities", *Elect. Power Syst. Res.*, vol. 77, no. 9, pp. 1189-1203, Jul. 2007

[4] M. E. Baran, I. M. El-Markabi, "A multiagent-based dispatching scheme for distributed generators for voltage support on distribution feeders", *IEEE Trans. Power Syst.*, vol. 22, no. 1, pp. 52-59, Feb. 2007.
[5] T. Nguyen, M. Pai, "A sensitivity-based approach for studying stability impact of distributed generation", *Int. J. Elect. Power Energy Syst.*, vol. 30, no. 8, pp. 442-446, Oct. 2008.
[6] V. Calderaro, J. Milanovic, M. Kayikci, "The impact of distributed synchronous generators on quality of electricity supply and transient stability of real distribution network", *Elect. Power Syst. Res.*, vol. 79, no. 1, pp. 134-143, Jan. 2009.
[7] A. Tsikalakis, N. Hatziargyriou, "Centralized control for optimizing microgrids operation", *IEEE Trans. Energy Convers.*, vol. 23, no. 1, pp. 241-248, Mar. 2008.
[8] J. M. Kwon, B. H. Kwon, K. H. Nam, "Three-phase photovoltaic system with three-level boosting MPPT control", *IEEE Trans. Power Electron.*, vol. 23, no. 5, pp. 2319-2327, Sep. 2008.
[9] Rahim, N.A., Selvaraj, J.: 'Multistring five-level inverter with novel PWM control scheme for PV application', IEEE Trans. Ind. Electron., 2010, 57, (6), pp. 2111–2123
[10] Selvaraj, J., Rahim, N.A.: 'Multilevel inverter for grid-connected PV system employing digital PI controller', IEEE Trans. Ind. Electron., 2009, 56, (1), pp. 149–158
[11] Rahim, N.A., Chaniago, K., Selvaraj, J.: 'Single-phase seven-level grid-connected inverter for photovoltaic system', IEEE Trans. Ind. Electron., 2011, 58, (6), pp. 2435–2443
[12] Barbosa, P.G., Braga, H.A.C., do Carmo Barbosa Rodrigues, M., Teixeira, E.C.: 'Boost current multilevel inverter and its application on single-phase grid-connected photovoltaic systems', IEEE Trans. Power Electron., 2006, 21, (4), pp. 1116–1124
[13] Villanueva, E., Correa, P., Rodríguez, J., Pacas, M.: 'Control of a single-phase cascaded H-bridge multilevel inverter for grid-connected photovoltaic systems', IEEE Trans. Ind. Electron., 2009, 56, (11), pp. 4399–4406
[14] Kangarlu, M.F., Babaei, E.: 'A generalized cascaded multilevel inverter using series connection of sub multilevel inverters', IEEE Trans. Power Electron., 2013, 28, (2), pp. 625–636
[15] Nami, A., Zare, F., Ghosh, A., Blaabjerg, F.: 'A hybrid cascade converter topology with series-connected symmetrical and asymmetrical diode-clamped H-bridge cells', IEEE Trans. Power Electron., 2011, 26, (1), pp. 51–65
[16] Mondal, G., Gopakumar, K., Tekwani, P.N., Levi, E.: 'A reduced switch-count five-level inverter with common-mode voltage elimination for an open-end winding induction motor drive', IEEE Trans. Ind. Electron., 2007, 54, (4), pp. 2344–2351