Genetic algorithm based optimization of controller parameters in wind energy system

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Abstract— **An optimization procedure for the controller used in the frequency converter of a variable speed wind turbine (VSWT) driven permanent magnet synchronous generator (PMSG) by using genetic algorithms (GAs) is explained. The cascaded control is frequently used in the control of the frequency converter using the proportional plus integral (PI) controllers. An electrical power system is difficult to express by a mathematical model or transfer function therefore setting of the parameters of the PI controller used in a large system is very difficult. This paper attempts to optimally design the parameters of the PI controllers used in the frequency converter of a variable speed wind energy conversion system (WECS). The optimization of the controller parameters can be obtained by using GAs-RSM considering both symmetrical and unsymmetrical faults. The permanent fault condition due to unsuccessful reclosing of circuit breakers is considered as well and fault-ride-through of VSWT-PMSG can be improved considerably using the parameters of its frequency converter obtained from GAs-RSM.**

***Index Terms*— Fault-ride-through, frequency converter, genetic algorithms (GAs), permanent magnet synchronous generator (PMSG), response surface methodology (RSM), wind energy conversion system (WECS).**

I. INTRODUCTION

Now days the generation of wind power is huge hence the impact of the wind generation on the power system cannot be ignored. It is necessary to integrate wind energy into the power system without affecting the overall system stability. Hence it is mandatory to mitigate the possible negative impacts such as loss of generation for frequency support, voltage flicker, voltage and power variation due to the variable speed of the wind, the risk of instability due to lower degree of controllability and low voltage ride through (LVRT) capability of wind energy system as a huge number of wind generators will be connected to the existing network in the near future..

Many countries in Europe and other parts of the world have developed interconnection rules and processes for wind power through a grid code. The voltage collapse for reactive power support is very big issue while considering the overall system stability of the system. The gearbox was very critical component in the wind energy system but due to development Permanent Magnet Synchronous generator (PMSG) wind generation system gearbox can be omitted. The variable speed wind turbine (VSWT) driven PMSG is connected to the grid through a full-scale frequency converter. The classical controllers are used in the control of the generator and grid-side converter/inverter. Classical control theory suffers from some limitations due to the assumptions made in designing the control systems such as linearity, time-invariance, etc. Essentially, the conventional proportional plus integral (PI) and proportional plus integral plus derivative (PID) controllers have been utilized in many control applications due to the robustness of these controllers and the fact that they offer a wide stability margin. However, the conventional PI and PID controllers are very sensitive to parameter variations and the nonlinearity of dynamic systems. The setting of the parameters of the PI controller used in a large system is cumbersome, especially when required to apply in electric power system which is difficult to be expressed by a mathematical model or transfer function. To achieve the FRT in the case of VSWT-PMSG, the PI controllers used in the converter/inverter should be tuned properly. Optimal design of the controller parameters used in the frequency converter of VSWT-PMSG has so far not been reported in power system literature.

In this paper, response surface methodology (RSM) and genetic algorithms (GAs) are proposed to optimally design the parameters of the controllers used in the frequency converter of VSWT-PMSG to obtain the FRT capability of wind farms. Three-level frequency converter topology is used in the simulation as it is suitable for high power application. The circuit breakers (CBs) are usually reclosed automatically on overhead transmission lines in the grid to improve the service continuity. The reclosure may be either high-speed or with time delay. High-speed reclosure refers to the closing of CBs after a time just long enough to permit fault-arc deionization. However, high-speed reclosure is not always acceptable. Reclosure into a permanent fault or an unsuccessful reclosing may cause system instability. Thus, the application of automatic reclosing is usually constrained by the possibility of a persistent fault, which would create a second fault after reclosure.

This paper is divided into following parts

II. THREE LEVEL INVERTER

Fig. 1 shows the circuit configuration of the NPC inverter. Each leg has four IGBTs connected in series. The applied voltage on the IGBT is one-half that of the conventional two level inverter, the bus voltage is split in two by the connection of equal series connected bus capacitors. Each leg is completed by the addition of two clamp diodes. This topology traditionally has been used for medium voltage drives both in industrial and other applications. In addition to the capability of handling higher voltages, the NPC inverter has several favorable features including lower line to line and common mode voltage steps and lower output current ripple for the same switching frequency as that used in a two level inverter.

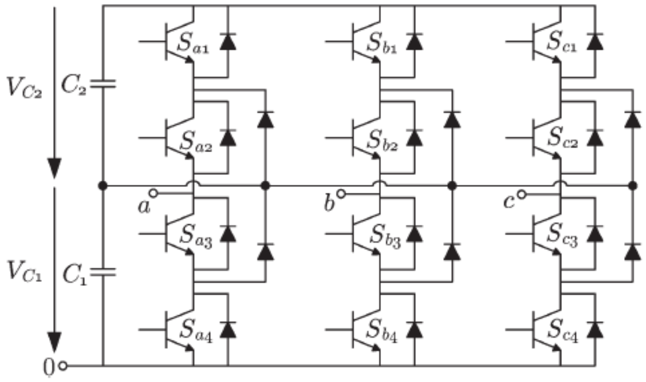

Fig. 1 circuit diagram of the three-level diode-clamped converter

The NPC inverter can produce three voltage levels on the output: the DC bus plus voltage, zero voltage and DC bus negative voltage. Due to available capacitor voltage rating, series connected capacitors are generally required in inverters rated for 480V and 600V service. In NPC inverters, maintaining the voltage balance between the capacitors is important to the proper operation of the NPC topology.

III. WIND TURBINE MODEL

The mathematical relation for the mechanical power extraction from the wind can be expressed as follows,

$$P_w = 0.5 \square\square R^2 V_w^3 C_P\ (\lambda, \beta)$$

Where, P_w is the extracted power from the wind, ρ is the air Density [kg/m3], is the blade radius [m], R is the wind speed [m/s], and C_P is the power coefficient which is a function of tip speed ratio, λ , and blade pitch angle, β[deg.]. The turbine characteristics used are shown in Fig. 2.

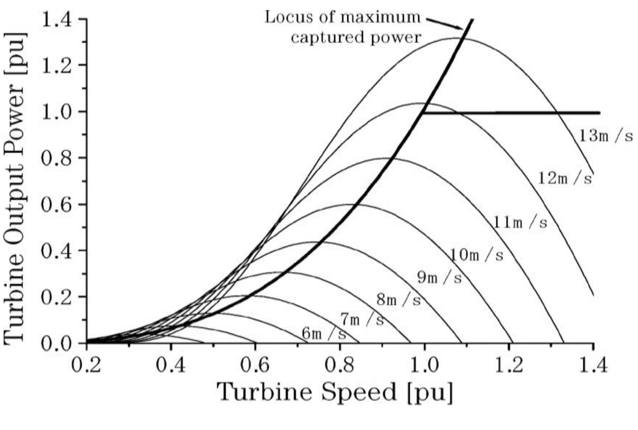

Fig. 2 Turbine characteristics with maximum power point tracking

IV. GENETIC ALGORITHM

Genetic Algorithm (GA) is search and optimization method based on natural evolution. It consists on a population of bit strings transformed by three genetic operators: Selection, crossover and mutation. Each string (chromosome) represents a possible solution for the problem being optimized and each bit (or group of bits), represents a value for some variable of the problem (gene). These solutions are classified by a evaluation function, giving better values, or fittest, to better solutions

The genetic algorithms start with randomly chosen parent chromosomes from the search space to create a population. They work with chromosome genotype. The population "evolves" towards the better chromosomes by applying genetic operators modeling the genetic processes occurring in the nature—selection, recombination and mutation. Selection compares the chromosomes in the population aiming to choose these, which will take part in the reproduction process. The selection occurs with a given probability on the base of fitness functions. The fitness function plays a role of the environment to distinguish between good and bad solutions. The recombination is carried out after selection process is finished. It combines, with predefined probability, the features of two selected parent chromosomes forming similar children. After recombination offspring undergoes to mutation. Generally, the mutation refers to the creation of a new chromosome from one and only one individual with predefined probability. After three operators are carried the offspring is inserted into the population, replacing the parent chromosomes in which they were derived from, producing a new generation. This cycle is performed until the optimization criterion is met.

V. WIND FARM MODEL

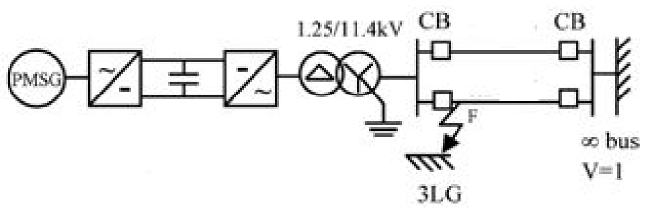

Fig. 3 representation of wind farm model

Fig. 3 shows the representation of proposed system model. The complete wind farm model consists of many small size wind model. The PMSG is connected to an infinite bus through the frequency converter, a step-up transformer, and double circuit transmission line.

VI. MODELING AND CONTROL OF FREQUENCY CONTROL

The schematic diagram of VSWT-PMSG topology used in this paper is shown in Fig. 4. The frequency converter consists of a generator-side ac/dc converter, a dc-link capacitor, and a grid-side dc/ac inverter. Three-level (3L) neutral-point clamped (NPC) topology is used for both the converter and inverter, as shown in Fig. 4.

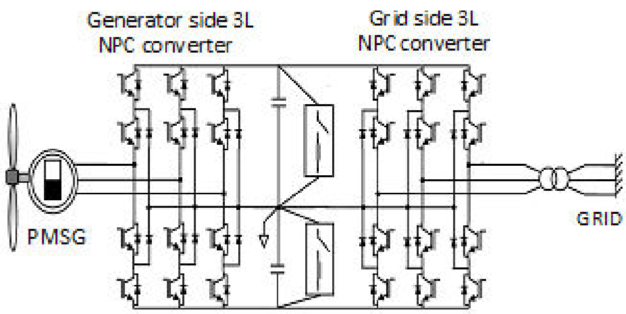

Fig. 4 Schematic diagram of VSWT-PMSG

For both generator-side ac/dc converter and grid-side dc/ac inverter the well-known cascaded control is used. The insulated gate bipolar transistor (IGBT) switching table for 3L NPC-based voltage source converter/inverter is shown below in Table I.

Table I IGBT switching table

V_{out}	$+V_{dc}$	0	$-V_{dc}$
SW1	1	0	0
SW2	1	1	0
SW3	0	1	1
SW4	0	0	1

The gate signal generation scheme for the IGBT devices used in converter/inverter is shown in Fig. 5. The carrier frequency for an inverter is chosen 1050 Hz. The reference value of the controller shown in Fig. 5 is determined from the cascaded control.

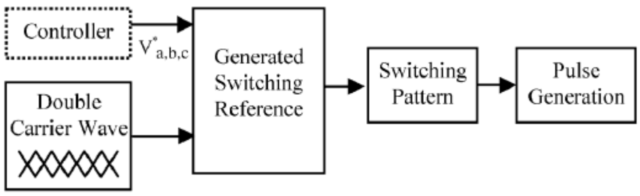

Fig. 5 Gate signal generation scheme

The generator-side converter ensures the maximum power point tracking control along with unity power factor operation at the generating side. The grid-side inverter controls the dc-link voltage and maintains the voltage of the grid side as well, at the desired level set by the network operator. In this study, as the fault-ride-through of VSWT-PMSG is emphasized, the control of the grid-side inverter and parameters optimization using RSM and GAs are demonstrated in the light of the grid-side inverter. The details of the optimization method are presented as follows.

VII. OPTIMIZATION PROCEDURE

Recently, the RSM has received a great potential for modeling, analyzing, and optimizing the design of many electromagnetic devices. This method is a statistical tool used to build an empirical model by finding the relationship between the design variables and response through the statistical fitting method. In this method system analysis can be done in MATLAB. The maximum percentage undershoot (MPUS), maximum percentage overshoot (MPOS), settling time (Ts), and steady-state error (Ess) of the voltage profile are considering the responses. The second-order model of the RSM can be obtained in this study for obtaining a more accurate response. The creation of the response surface is based on the central composite design (CCD). The CCD has been widely used for fitting the second-order response surface.

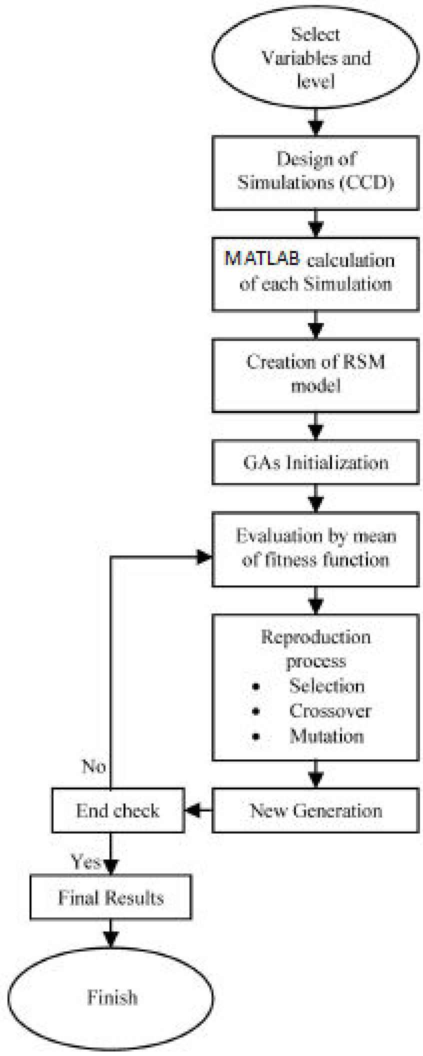

Fig.6 flow chart of optimal design process

The optimal design procedure flow chart is shown in fig 6. The design procedure steps are as follows,

1) Selection of Variables and Levels
2) Design of Simulations
3) PSCAD Program Calculation
4) Creation of Response Surface Empirical Model
5) GA Optimization

The simulation analyses for the grid connected wind farm are carried out using the laboratory standard power system simulator PSCAD/EMTDC. Moreover, MATLAB is used for design optimization of controller parameters.

VIII. PROPOSED SIMULATION

Time-domain simulation can be done using MATLAB. It is assumed that wind speed is constant and equivalent to the rated speed. This is because it may be considered that wind speed does not change dramatically during the short time interval of the simulation for the FRT characteristic analysis. For simulation following two points should be considered, one during successful Reclosing of CBs and second during unsuccessful Reclosing of CBs

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a) During Successful Reclosing:

In this case, the severe symmetrical three-line to ground fault (3LG) will be considered as the network disturbance. The fault will occur at 0.1 s at fault point F, shown in Fig. 3. The CBs on the faulted lines will opened at 0.25 s, and at 1.05 s the CBs are reclosed. The grid-side inverter can provide necessary reactive power during the network disturbance. Therefore, the terminal voltage can return back at its prefault level. The transient analysis can also be carried out considering an unsymmetrical fault (single-line to ground, 1LG), using the proposed GAs-RSM method. It can be claimed that GAs-RSM works well for both symmetrical and unsymmetrical fault conditions and hence the FRT of a wind farm can be improved using the controller parameters obtained from GAs-RSM.

b) During Unsuccessful Reclosing:

In this section, it is assumed that a 3LG fault will occur at point F in Fig. 3. The fault will occur at 0.1 s. The CBs on the faulted line will opened at 0.25 s, and at 1.0 s, the CBs will reclose. It is also considered that the reclosing of the CBs is unsuccessful due to a permanent fault. Therefore, the CBs will reopen at 1.1 s. It is assumed that the circuit breaker clears the line when the current through it crosses the zero level. The permanent fault is assumed to be cleared at 7.0 s, and at 7.1 s, the CBs are reclosed again. The response of terminal voltage of the grid is better damped. Further, during the permanent fault period, the voltage can be maintained within the permitted value of wind farm grid code. After the clearance of the permanent fault, the voltage is returned back to the prefault level quickly and the system back to the normal conditions as both transmission lines are in operation. Therefore, the optimal designed parameters of the controllers used in the frequency converter obtained from GAs-RSM work superbly to improve the FRT of wind farms, even in the case of permanent fault.

IX. CONCLUSION

This paper has attempted to present an approach to optimally determine the controller parameters which control, in general, the switching of the frequency converter used in VSWT-driven PMSG to achieve FRT as per recent wind farm grid code. RSM and GA techniques are proposed to determine the controller parameters, in a precise way. With this method system can achieve the FRT of the wind farm successfully using the determined parameter in the case of sever three-line to ground fault, as well as the permanent fault due to unsuccessful reclosing of circuit breakers. The parameters even worked well for the unsymmetrical fault condition. It should be noted that, GAs-RSM can give better damping performance to achieve the FRT capability of the wind farm. The optimum design procedure can be applied to other inverter/converter topology used widely in variable speed wind energy conversion systems. The proposed methodology is even suitable to other power system related applications such as FACTS devices, the voltage source converter-based HVDC system, and so on, especially in the cases where it is difficult to determine the suitable transfer function of a complex and larger system. Finally, it is concluded that RSM and GA-based optimization technology might be a good choice for optimum design of controller parameters.

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