POWER QUALITY ISSUES IN WIND DIESEL HYBRID POWER GENERATION SYSTEMS

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Abstract – The purpose of this paper is to present main power quality problem may appear in wind Diesel hybrid power systems which supply insulated consumer through a small power network. On we analyze the behavior of each subsystem during different wind conditions and power dispatch strategy and we analyze the main wind generation subsystem control devices implied in maintaining a high power quality at the consumer, finally the conclusions are presented.

Keywords: hybrid power system, wind turbine, wind generators, power quality, diesel generator, renewable resources

1. INTRODUCTION

In our days, there are still large communities that are insulated from national electricity network. For many of them the power supply is provided by large Diesel groups. In order to diminish the negative impact of that power supply to the environment and to humans, wind generator system (WGS) was implemented resulting hybrid power systems (HPS). The degree of WGS penetration varies, but nowadays HPS with high wind penetrations prevail. A wind Diesel hybrid power system (WDHPS) with high penetration of the WGS is shown in fig.1.

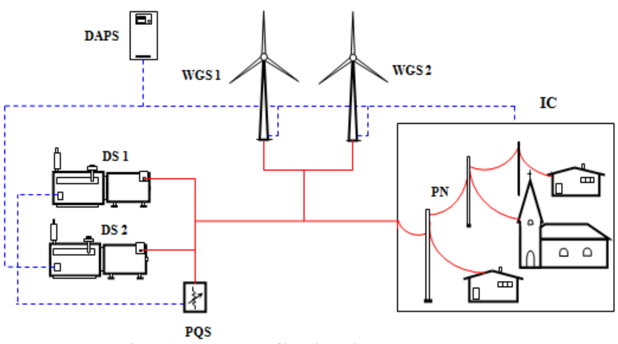

Fig. 1. WDHPS with its components

As shows in fig.1 such a system has the following components:

WGS = Wind generator subsystems which consist in a number of wind turbine coupled with its generators;

DS = Diesel subsystems consist in one or more Diesel generators. Usually these are Diesel motors coupled mechanically with synchronous generators and having the capability of electronic startup;

PN = Power network which is usually a mini electrical network which distributes the electric energy to the consumers;

IC = Insulated consumers consisting of a number of residential houses grouped around a city hall, school and/or church, which may be added a small medical dispensary;

DAPS = Driving, automation and protection subsystem (system controller included) having the main purpose to assure a level of automation of the HPS. This is necessary because the consumers which are supplied with power from such systems are insulated and often far from national electric grids;

PQS = power quality subsystems which consist of total electrical, mechanical and electronic devices which assured the power quality to the consumer. Depending of the HPS components type, these can be synchronous compensators, batteries, converters, different types of dump loads and dispatched loads.

Such configuration of HPS can supply IC loads from kW to hundred of kW.

2. HPS COMPONENTS AND POWER QUALITY ISSUES

The national electrical grid is designed to cope with various factors that affect power quality, so we can call this a “powerful grid”. The main power quality indicators are voltage and frequency. A powerful grid can maintain the rated values of these indicators using various methods. As soon we disconnect to it, as is the case of HPS, the capability to assure rated voltage, frequency and reactive power in any condition of generating and loads fluctuation disappear and must be compensate by adding additional equipment [1]. In this respect, this mini network can be named “week grid”.

Each component of the HPS connected to the week grid, is a power generating subsystem which in the process of producing electric energy has its own particularities.

a) DIESEL SUBSYSTEM

This subsystem consist from a Diesel motor coupled with a synchronous generator and ideally it is capable to supply any power demand up to rated power at constant frequency. It has two units (fig.2):

- A governor which by controlling the fuel flux maintains the rotor speed constant so the frequency is maintained constant. Any deviance f of the frequency from the preset value f^* is seized and the governor took immediate action;

- An exciter which by regulating the excited current of the synchronous generator (SG) maintain the voltage constant. It works by detecting the voltage deviation V from the preset voltage value V^*.

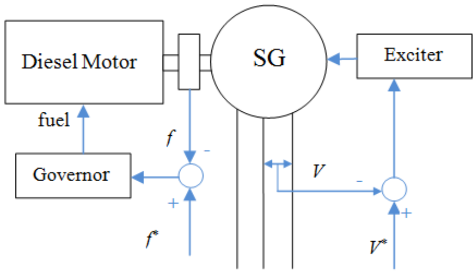

Fig. 2. Control block diagram of the DS [2]

b) WIND GENERATOR SUBSYSTEM

These HPS subsystems can be found today in a large variety of types, a comprehensive classification [3] can be made as shown in table 1:

Table 1. WGS classification [3]

Speed control		Power control		
		Stall	Pitch angle	Active stall
Fixed speed	**A** type	A_0	A_1	A_2
Variable speed	**B** type	B_0	B_1	B_2
	C type	C_0	C_1	C_2
	D type	D_0	D_1	D_2

The **A** type is the oldest category, named fixed speed induction generator (FSIG), its wind turbine being coupled with a squirrel cage induction generator (SCIG).

B type has its turbine with limited variable speed coupled with wound rotor induction generator (WRIG). At high power (MW) the design can be either with two shafts coupled with two generators (one for low speed and one for high speed), or with two set of windings with a different sets of poles wound on the same stator frame.

The **C** type is made with WRIG and low power bidirectional converter, known as double feed induction generator (DFIG). In this concept, the rotor windings also feed with power via a small converter, thus increasing the energy yield [4].

The **D** type is characterized by a frequency converter sized at rated power of the generator. The electric machine can be of two types: wound rotor synchronous generator (WRSG) or permanent magnet synchronous generator (PMSG).

Another type of electrical generator which delivers fixed frequency power over a range of rotor speed is the Roesel generator (named by its inventor). The differences from previous electrical machine types is that its number of poles can be changed continuously and inversely proportional to rotational speed of the shaft, so that frequency can be maintained at constant value [5].

c) CONSUMER LOADS

From power quality point of view, the loads which can be found at IC can be of three categories [2]:

- Residential type for: lighting, heating and all sort of small appliances. The nature of this loads is very tolerant to low quality power such as fluctuating voltage and frequency;
- Heavy load: consist of intermittent large loads represented by large water pumps or compressors. This kind of load, although insensitive to power quality, may cause voltage and frequency drops in HPS week grids, especially on start up;
- Electronic devices such as transceivers, radio beacons, medical equipments, meteorological radars, etc. is very sensitive to power quality of the electric energy provided by HPS.

3. BEHAVIOUR OF HPS DURING POWER GENERATION

Power supplied by a WDHPS is strongly related to the renewable resource (RR) availability and dispatch strategy of the system. Basically there are three different regimes in which the HPS can generate power: unavailability, partial and total availability of the RR.

Unavailability of the RR in our case is characterized by low speed of the wind, gusting weather or no wind at all. In this case, the dispatch strategy consists in power up the DS, as the WGS is no capable to start and generate power to supply the load. DS has to cover the load and be able to follow the load variation during time. Generally, DS can follow small load variation due to the speed control of the governor and exciter of the synchronous generator. The problem appears when a sudden large load are connected or disconnected. For example, if a large motor pump starts, active power balance breaks, frequency drops and the governor accelerate the Diesel motors to restore the rated frequency in the network. An undersized Diesel engine may have problems in accelerating and therefore to maintain normal level of the frequency at the consumer. Also, due to large loads connected, the start current increase significantly which causes a voltage drop. A slow response of the synchronous generator exciter may cause problem in restoring the normal level of voltage of the network. If it utilizes a soft start device, the current surge can be limited and thus the voltage dip can be diminish.

Partial availability of the RR is characterized by the wind speed ranging between cut-in speed and rated speed of the wind turbine. In this case, the dispatch strategy consists in power up the WGS, the load will be supplied both from DS and WGS and they both are operating at partial load. In this case the interaction between these two power generating sources is very important. Thus if the two subsystems covers the loads, a sudden increase in wind speed causes an increase in power generated by the WGS. If the WGS is oversized, the total power produced can exceed the loads, frequency increases and the governor of the DS try to restore frequency. Because the Diesel engine has a small capability to break, due to the engine compression, the synchronous generator of the DS turns into a motor, so instead to decelerate to keep the frequency the DS accelerates and the frequency will be lost. Another case which the DS can't keep frequency is when a sudden drop in load appears. In this case the power produced in WGS exceeds the loads and the power of the DS, the synchronous generator of the DS motoring (negative power) and the frequency is lost again. This case is extensively discussed in [2] where a 225 kW provided by a WTG and 55 kW provided by the DS trying to cope a 280 kW of the load and a sudden 100kW load drop. In figure 3 is presented the result of these oversized wind turbine in case of major imbalanced power at the consumer.

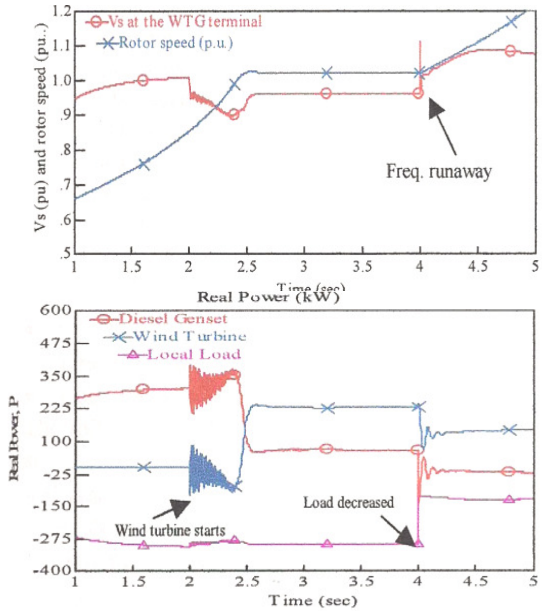

Fig. 3. Frequency runaways of the oversized wind turbine and when a sudden drop of load appears [2]

In such cases, to operate in normal condition with significant loads functioning at intermittent regime, it must apply two solutions [2]:

- Deploying a dump load to keep the DS in generating regime, thus preventing it from motoring. As dump load it can be used water heater, battery charger or lightning systems with high resistance filament of the bulbs;
- Presetting the minimum power generating from DS at 15-40% of the rated load. The dump load should be sized so that the DS generates above its minimum set point.

Total availability of the RR is characterized by the wind speed ranging between rated speed and cut-out speed of the wind turbine, the WGS starts and operates at its rated power. If the WTG is sized to cover the loads, the DS is shut down. Io order to maintain power quality in HPS mini grid it is necessary to maintain power produced by WGS and power demanded by the load. Generally, the equilibrium between these two powers is maintained by WGS operating at full load due to its control/regulation subsystems. Problems appear when wind speed is changing and the WGS often pas from one operation state to another [3]. In this case, power quality supplied to the IC depends strongly on the type of WGS used and its control / regulator device, both the wind turbine side as well on electric generator side. Thus:

The first generation of WGS was with fixed blade of the turbine and induction generator connected directly to mini grid of the consumer (PN), as shown in figure 4.

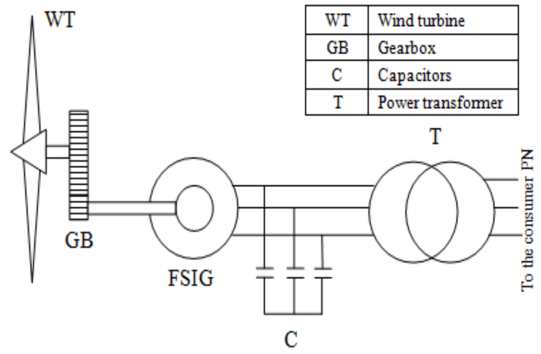

Fig. 4. FSIG connected directly to consumer PN

Such configuration raises a series of problems [2, 3]:

- Voltage drop caused by the current surge when the turbine starts. The voltage dip is amplified when there are more WGS which stats simultaneously;
- Due to magnetization current it is absorbed a reactive power which may lead to power factor worsening and voltage drop at consumer PN;

To counter these negative effects it must utilized soft starting devices, electric generators either with two gearbox shaft or two windings wounded at the same stator, one for low speed one for high speed and sequential starting of the WGS if there are more installed on HPS. In case of a PN fault WGS has to be provided with fast decoupling device.

Utilizing pitch angle control of the blades and WRIG generators the majority of these problems disappears, the resulting structure is named Double Feed Induction Generator (DFIG), figure 5.

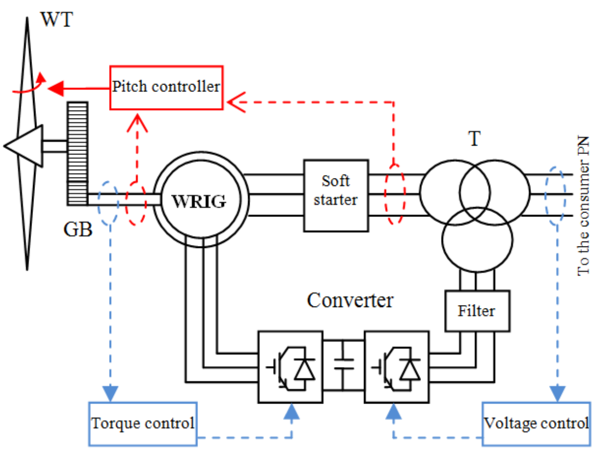

Fig. 5. DFIG schematics

The "double feed" terms refers to the fact that the stator voltage is in direct relations with the PN and the rotor voltage is supplied by a "back to back" convertor. This convertor compensates the difference between WT shaft and PN frequency by injecting in rotor a variable frequency current by the convertor. Thus the WT speed may have a deviation up to +-30% from synchronous speed, so the WGS produced constant power at high variation of wind speed [3].

Due to power electronic involved in control / regulator device (high speed switching of the power semiconductors), occurs current harmonics and intra harmonics, so there are necessary filter.

Due to a better dynamic behavior, a lower mechanical stress of the shaft and a lower power fluctuation at lower wind speed, the power quality is better and the flicker and noise is reduced [3,6]. The main disadvantage is high cost of the electronic device and fault transient affects generator, since it is directly connected to the grid [6].

Generating power at variable wind speed can be done also using a technology named Dynamic Slip Control System (DSCS), figure 6.

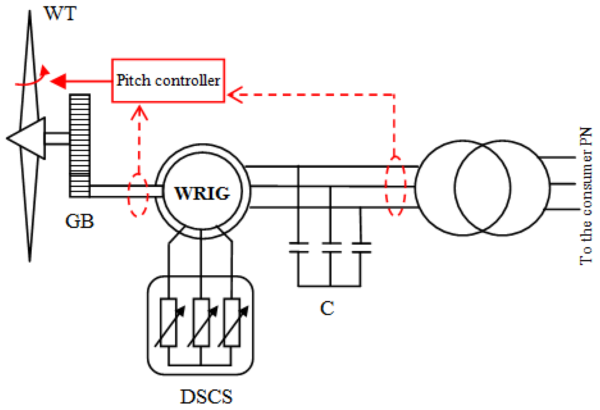

Fig. 6. DSCS main scheme

The following relations can be written neglecting the losses [3]:

$$P_G = P_S = P_R\,(1\text{-}s) \qquad (1)$$
$$P_R = P_{WT}$$

Where:

P_G = Power generated;
P_S = Power at the stator terminal;
P_R = Power of the rotor terminal;
P_{WT} = Power extracted from WT;
s = slip of the generator.

According to relations (1) power generated can be changed by modifying the slip. Slip can be changed by variable resistance introduced in rotor circuit, thus it compensated power variation and maintained the generated power at constant value [3].

All of these WGS schemes have in common three disadvantages: it utilize a gearbox to couple the WT to its generator (maintenance problems), the induction machine is directly coupled to PN (fault transient affects generator) and it can generate power at only limited range of wind speed.

The scheme which eliminates these disadvantages is the WGS with synchronous generator. There are two kinds of WGS with synchronous generator: permanent magnet type and separate excitation circuit type (SESG).

The permanent magnet synchronous generator (PMSG), shown in fig.7, has the advantage of auto excitation (good power factor and high efficiency) but it can put problems during start up, synchronization and voltage regulation. In addition, the magnetic materials are sensitive to the temperature change, so a temperature monitoring and climate device is needed [3].

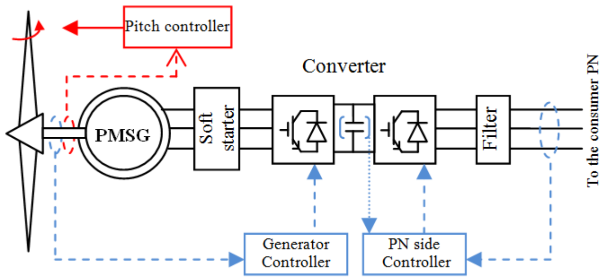

Fig. 7. WGS with permanent magnet synchronous generator (PMSG)

The separate excitation synchronous generator (SESG), shown in fig.8, has the advantage that offer a control of the reactive power and the terminal voltage but the main disadvantage is that a separate excitation circuit is needed [3].

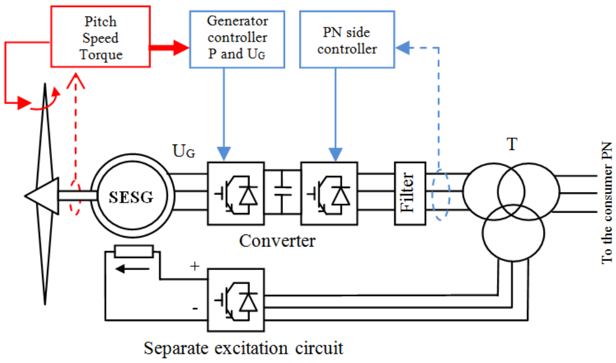

Fig. 7. WGS with separate excitation synchronous generator (SESG)

Whatever the excitation used, the WGS with synchronous generator can extract power from wind at full range of speed and because of the back to back converter it is not directly connected to the grid, so the transient fault cannot affect the machine and vice versa [6]. The generator side converter supplies the reactive power and controls the generator torque by shifting torque slip curve and the PN side converter maintains the dc link voltage at its reference value by controlling the active power flow to the grid [6]. Issues that may appear are flicker and harmonics due to the power electronics, so a filter is needed. Usually such systems is cost effective only above100 kW load consumers, thus it's ideally for WDHPS powered small insulated villages.

CONCLUSION

1. WDHPS is largely used to power supply IC through a mini PN grid and due to the fact that it has no connection to national network it represents a "week grid" thus a special care to power quality is needed.
2. Each dispatch strategy of the HPS, depending on RR availability, is related to operating characteristics of the power generation components within the system.
3. Diesel generators should not be underpowered and

must have a fast reaction response by the governor and exciter to be able to maintain voltage and frequency at any load fluctuation.

4. In case of parallel operating with WGS, the minimum power generating from DS must be preset at 15-40% of the rated load. Also it is necessary to foresee a dump load in case of sudden disconnection of a large consumer (such as hundred kW water pump), or in case of sudden increase of wind speed which may produce unbalanced active power.

5. In WDHPS it is desirable that the load be covered by the WGS when RR is totally available, mainly to reduce DS number of operating hour and its negative impact on the environment. Power quality supplied in a IC week network depends strongly on the type of WGS used and its control / regulator devices, both the wind turbine side as well on electric generator side.

6. The common power quality problems in WDHPS are: voltage dip, frequency fluctuation and harmonics. Frequency and voltage fluctuation can be minimized by using:

- DS with fast response governor and exciter of its synchronous generator;
- Dump loads to cope active power imbalance;
- Pitch control devices of the WT blades;
- Sequential starting in case of more than one WGS is powered the IC;
- Soft starters devices combined with WRIG, PMSG and SESG generators of the WGS;
- Adequate scheme in order to generate constant power at variable wind speed: DFIG and DSCS scheme for WRIG generator type and SG with power electronics device to control either the WT or the SG.
- Proper control of the reactive power circulation.

7. Harmonics may appear due to power electronic control devices functioning so, to counter its negative effect filter is needed.

8. The economic implication must be considered carefully; generally power control of the WGS is expensive but for an IC from 100 kW up it is economically justified.

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