renewableUK
The voice of wind & marine energy

Technical Note: Guidance regarding inverter changes in Small Wind Turbine Systems

January 2013

1. Revision History

Revision	Date	Description
Draft 1a	24/01/2011	First draft
Draft 1b	28/03/2011	Second draft
1.0	05/04/2011	Further modifications and first published on BWEA (now RUK) website on 5 April 2011
Draft 2a	16/08/2011	Title change to “Technical Note: Guidance regarding inverter changes in Small Wind Turbine Systems” MCS references modified to “BWEA Small Wind Turbine Performance and Safety Standard” Inclusion of section to cover differing output phase variants of an approved system Updated grid code issue and reference to type testing Inclusion of edits following meeting with certification body; including guidance on acoustic impact and reformatting
2.0	16/01/2013	Publication as 2nd edition

2. Contents

3. Foreword

3.1 This RenewableUK Technical Note “Guidance regarding inverter changes in Small Wind Turbine Systems” has been prepared by Renewable UK’s Small Wind Turbine System technical subgroup.

3.2 This second edition cancels and replaces the first edition.

3.3 This edition constitutes a technical revision. The changes include:

- Differing phase outputs (single phase, split phase, three phase, etc.)
- Acoustic considerations

3.4 The second edition is an update to the first edition. It is available for reference from the date of publication 15/01/2013 It is recommended that manufacturers or importers of microgeneration systems who have certificated a microgeneration product which relies upon the first edition may commence working in accordance with this update from the date of publication. It is recommended that manufacturers or importers of microgeneration systems who have certificated a microgeneration product in accordance with the second edition do not need to update their product certification. It is recommended that manufacturers or importers of microgeneration systems who are certifying after 15/01/2014 should work in accordance with this update.

4. References

4.1 The following document contains provisions, which, through reference in this text, constitute normative or informative provisions of this document; ref Annex B – Inverter Safety and Grid Code Standards. At the time of publication, the editions indicated were valid. All documents are subject to revision, and parties applying this document are encouraged to investigate the possibility of applying the most recent editions of the documents referenced.

5. Purpose

5.1 The purpose of this document is to provide guidance for approvals bodies to assess the impact of changing, up-dating or modifying an inverter for use on a wind turbine already qualified under BWEA Small Wind Turbine Performance and Safety Standard. Following the assessment, it may be deemed appropriate that further testing of the revised system configuration is required if the impact of the change is considered sufficient to cause a material deviation from the “representative configuration”* originally tested.

*NOTE: “Representative configuration” as per definition in the BWEA Small Wind Turbine Performance and Safety Standard (29 February 2008)

6. Inverter Definition

6.1 For the purpose of this assessment, an “inverter” is defined as the necessary electronic arrangement (hardware and software) required to condition and control the electrical output of a wind turbine generator to that required by the load. The term “converter” would be the technically correct definition for such an arrangement; however “inverter” is retained for convenience of recognition. In some arrangements, the inverter may also be responsible for the following (not exhaustive) functions:

- Adjusting the level of turbine power with respect to speed or generator voltage
- Controlling external turbine peripherals, such as brakes etc.
- Assisting or starting the turbine

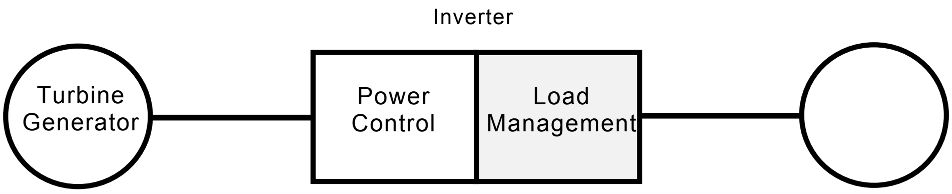


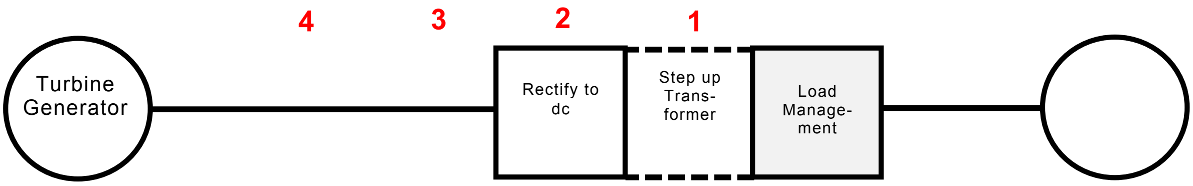
Fig 1, General functional description of an inverter

6.2 As per figure 1, the inverter can be considered as having two core functions – the techniques deployed, both in hardware and software, to achieve these two functions differ depending on the application and the architecture chosen. This is therefore fundamental to assessing the impact of inverter change.

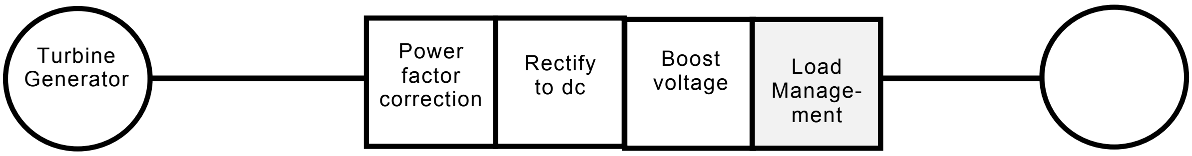
6.3 For a given load type, as defined in Annex A, the difference in turbine performance and behaviour will be defined by the techniques deployed to achieve effective power control. An assessment of impact of change should therefore take this into account. Whereas an assessment of impact of change to load management need only be considered when changing between the load types defined in annex A, providing that the inverter is type tested for the grid code relevant to the region of use or the equivalent off-grid standards.

7. Electronic Architecture

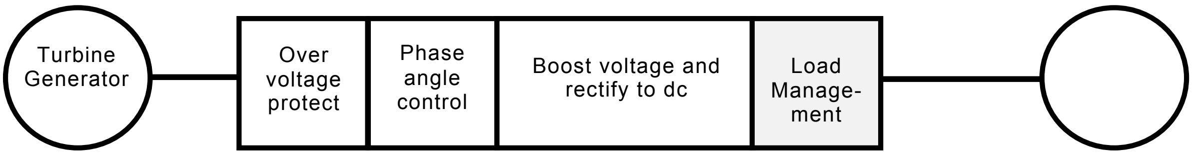
7.1 An inverter, as defined in section 6, will have an architecture that provides the functionality illustrated in figure 2, where conversion to ac or dc output is implied.



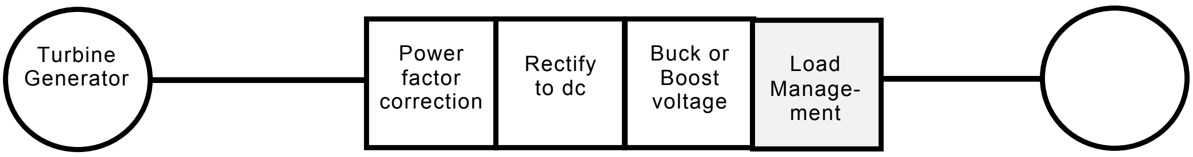
7.1.1 Inverter with passive rectifier and possible step-up transformer (ac)



7.1.2 Inverter with passive rectifier and voltage boost



7.1.3 Inverter with active rectifier



7.1.4 Inverter with passive rectifier and voltage buck & boost

Fig 2, Inverter architecture and resulting functionality

7.2 Like for like changes where the same electronic architecture is retained, as defined by 7.1.1 through 7.1.4, will have very little impact on the safety and performance aspects of the system, providing that the rating of the inverter and the control setup of the turbine, as defined in sections 9 through 14, are considered. Any replacement inverter however must be certified to the necessary regional grid code and/or safety standards.

7.2 When a change in electronic architecture has been proposed between the options illustrated in 7.1.1 through 7.1.4, differences in power control can result. Illustrated in figure 3 is a comparison of performance attributes that differentiate each architecture. Some differences are more significant than others in magnitude and hence overall turbine performance. However, a simple traffic light system has been illustrated to highlight incremental performance improvement, whereby red equates to worst case relative performance and green best case. An indicative scale of performance range is highlighted and the significance to overall performance assessed as low, medium or high.

Architecture (see fig 2)	Inverter Efficiency	Cut-in Voltage	Generator Efficiency	Generator Stress	Generator Noise	Over-Voltage Protect
Affected by	1,2,3	1	2,3	3	3	1,4
3.1.1	ssdsdsfff					
3.1.2		ssdsdsfff				
3.1.3			Ssdsdsfff	ssdsdsfff	ssdsdsfff	Dsdsf ff
3.1.4		ssdsdsfff				
MEASURE (Indicative)	95-97%	50-200V	92-96%	0.65-1puA	Specific	Specific
Significance	L	H	M	M	M	H

Fig 3, Relative performance of electronic architectures

8. Performance Curve and Energy Yield

8.1 A modification to the "representative configuration" of inverter can be as simple as a minor change to the power curve or a change of architecture between those defined in 7.1.1 through 7.1.4. In the case of the latter, the architecture deployed can have a significant effect on the turbine cut-in and cut-out voltages and hence the operating turbine speed range. This can have a significant impact on the energy yield of the turbine, as indicated by the high (H) significance in figure 3.

8.2 Other parameters afforded to the inverter solution of choice that will affect the energy yield include:
- Over-voltage protection used to enable continued generation in high wind speeds
- Input current rating
- Generator and inverter efficiency
- Internal consumption and stand-by strategy
- Rate of load acceptance and rejection on the turbine
- Method by which control of power is achieved

8.3 Following consideration of sections 9 through 14, if doubt or ambiguity remains, the approval body can request practical evidence of a power curve to validate performance.

9. Cut-in, Cut-out and Over Voltage Protection

9.1 An architecture that enables a solution with low cut-in voltage will facilitate the turbine to start generating power from relatively low wind, and hence low rotational speeds. Naturally this should enable generation of relatively more energy, particularly in lower wind speed sites, when compared against a system with higher cut-in voltage. However, it is recommended that cut-in be set at a minimum speed where the power available from the turbine is greater than the consumption of the inverter to always enable positive output.

9.2 At higher wind and rotational speeds, the inverter will cut out if the maximum input voltage is exceeded and no additional over voltage protection has been included in the system. Over voltage protection by additional components are not considered here, but may be specified by the turbine manufacturer. Clearly an inverter with higher maximum input voltage will enable continued generation than one with a lower value, auto-disconnect contactor on the input of the inverter, some inverter architectures can provide means by which to limit the generator voltage to enable continued generation. This is clearly illustrated in figure 4, as is the relative cut in performance of two identically rated inverters with differing voltage threshold specification.

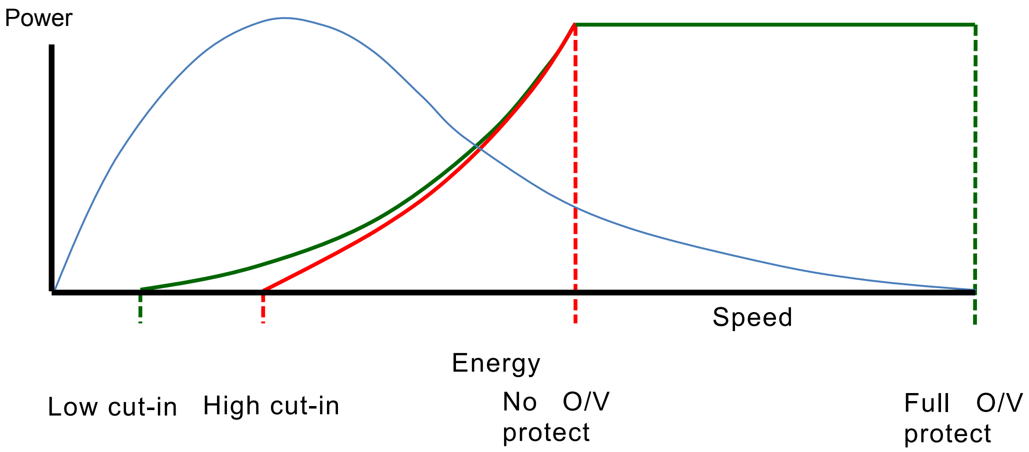


Fig 4, Effect of voltage threshold on turbine performance (O/V = Over Voltage)

10. Generator Current and Rated Speed

10.1 The inverter should be specified in such a way that its input current rating enables the power required at rated speed to be achieved. Illustrated in figure 5 is a comparison of two identically rated inverters with identical cut-in, cut-out and over voltage protection features. However, their input current rating differs, and hence inverter with red characteristic yields a higher rated speed than that of green, thus affecting overall turbine performance and acoustic output.

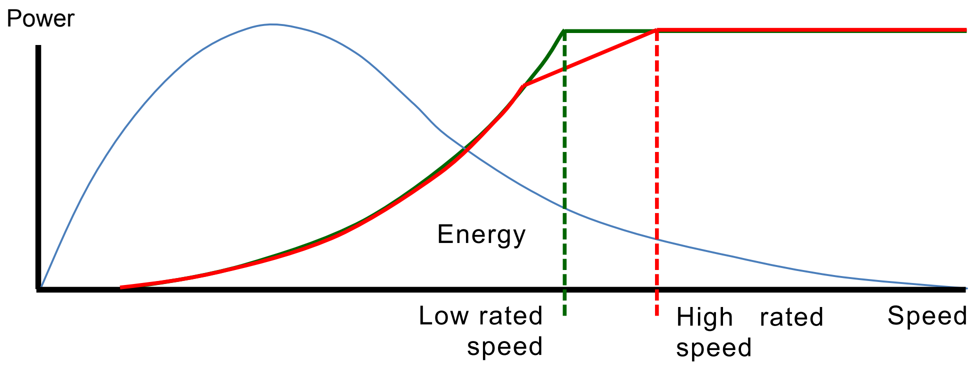


Fig 5, Effect of current rating on the performance of turbines with similar inverter architecture

10.2 Like for like comparison of input current rating is important when comparing identical architectures outlined in 7.1.1 through 7.1.4. However, when comparing the relative performance of the different architectures outlined in 7.1.1 through 7.1.4, a simple comparison of input current is not sufficient. This is due to the method achieved by the architecture to control generator phase angle – defined as block 3 in figure 2.

10.3 Without any phase angle compensation, the generator current will lag voltage and thus further contribute toward a relatively high voltage drop under load. Hence, the current drawn from the generator for a given power will be greater than that drawn by architecture capable of correcting this phase lag. An inverter with 'power factor correction' will require a lower input current rating to achieve the same power, due to the virtue of its ability to correct the angle between generator voltage and current to near zero. An inverter capable of full 'phase angle control' can enable the generator to operate at optimal phase angle to achieve rated power with lowest relative current.

10.4 Given the variation of current between architectures for given power conditions, other performance factors are affected such as generator efficiency, temperature and winding stress as per figure 3. The technique deployed to control generator current can also have an effect on audible noise as the harmonic content of the current – and hence ripple torques – will vary depending on the architecture and control used.

10.5 The effect of phase angle control on the generator voltage should be considered when defining the appropriate power curve. For example, programming inverters of differing architectures outlined in 7.1.1 through 7.1.4 using the same power curve with respect to voltage, can result in differing power curves with respect to speed and hence deviation in power control. Therefore, the programmed power curve should reflect the desired power performance versus speed.

11. Inverter and Generator Efficiency

11.1 Inverters of comparative architecture and rating outlined in 7.1.1 through 7.1.4 are likely to have in-material differences in efficiency. Inverters with differing architectures between 7.1.1 through 7.1.4 will have differing efficiencies due to the difference in the number of power handling switching semiconductors. In reality, this difference is small (95-97% at full load) and in isolation has a relatively small effect on energy yield when comparing inverters of similar rated outputs. However, the loss of inverter efficiency in moving to a solution with a greater number of power semiconductors (i.e. with voltage boost or active rectifier) can be compensated by the gain in generator efficiency achieved through power factor correction or full phase angle control. When considering inverter modification or change, it is advisable therefore not to primarily consider the impact of inverter efficiency on energy yield. Instead, working turbine envelope should be primarily considered, as outlined in figures 4 and 5.

12. Internal Consumption and Standby Strategy

12.1 An inverter will consume a small amount of power when in standby mode and not switching the power handling semiconductors; this can be as low as a few watts (providing that any cooling fans are switched off) and in isolation should not result in a material difference between inverters. However, once the turbine has cut-in and the power handling semiconductors begin to switch, these losses will start to become significant. In conditions where the inverter is connected to both turbine and load and is fully operational with power handling semiconductors switching, the inverter itself can become a consumer at running speeds where its consumption exceeds that available from the turbine.

12.2 Whilst seemingly attractive to have low cut in speeds, it is recommended that the cut-in voltage of the inverter be set such that the power available from the turbine at the corresponding speed at cut-in is at least equal to the losses of the inverter itself so as not to negatively affect energy yield. At speeds lower than cut-in and, if separately programmed, low speed voltage cut-out the inverter should ideally cease switching the power handling components.

13. Load Acceptance and Rejection

13.1 The rate at which load on the turbine can be both accepted or rejected should be set-able and ideally defined as separate parameters in the inverter. These ramp rates not only have an effect on the energy yield of the turbine, but also the mechanical shock loads applied to the turbine and generator components. Guidance should be provided by the turbine manufacturer as to the allowable limits of operation. This guidance should be reflected in the settings of the inverter. In making a modification or change to an inverter, the settings applied for load acceptance and rejection in the "representative configuration" tested under BWEA Small Wind

Turbine Performance and Safety Standard should be retained or transferred to the new inverter unless alternative guidance is provided by the manufacturer; else further testing may be required.

14. Power Control

14.1 The technique used to control power, and the discretisation at which it is achieved, can be implemented either in the inverter or by way of controlling the inverter as a slave unit through instruction from a separate controller. In the event of considering the latter, straight forward inverter change or modification can be considered provided that the calibration of inverter output to demand signal is retained and the comparative performance metrics of figure 3 are considered.

14.2 Where the turbine power control is achieved through setup of the inverter itself, several control techniques are possible. For the purpose of consideration here, these techniques are categorised as two separate methods:

14.2.1 **Look–up Table**, Here a simple power output versus speed reference is programmed into the inverter. Speed reference can be made either with respect to generator speed, electrical frequency or voltage. The discretisation and flexibility in programming of this curve will determine the fit that can be achieved with respect to the ideal turbine characteristic. In making a modification or change to an inverter, best efforts should be made to replicate *at least* the characteristic tested in the "representative configuration". However, deviation in the characteristic that can be achieved may result due to the factors highlighted in sections 5 and 6, and as a result of a difference in the discretisation and flexibility of the curve that can be programmed. An assessment of any new power curve proposed will determine the likeness in fit and assure the integrity of energy output. ***As a guideline only, it is recommended that the programmed Power versus voltage/speed curve not deviate in area from cut-in to rated speed by more than 10% from that considered in the reference*** *BWEA Small Wind Turbine Performance and Safety Standard* ***test in order to retain certification. In addition, it is recommended that any single one point on the programmed power curve beyond 50% of the rating of the turbine, should not deviate by more than 10% from that considered in the reference*** *BWEA Small Wind Turbine Performance and Safety Standard* ***test. Practical evidence of achieving the proposed power curve should be presented by the proposer of the change or modification. Else, if expecting to exceed the maximum allowable deviations, further certification testing may be requested which could extend to repeated durability testing if deemed appropriate due to product lifetime concerns.***

14.2.2 **Iterative, Adaptive and Intelligent Load Control**, Where an inverter does not require a power characteristic to be programmed, it uses a process of learning and/or load iteration to determine an optimal method of control. Embedded within these control methods is the ability to, amongst other techniques, hunt for optimal power at given running speeds and in some instances to stall the turbine. In changing from a technique described in section 14.2.1 to the method described here, evidence of accurate, consistent and reliable operation over a period of time is recommended in addition to an analysis of the power curve characteristic where the same measures of acceptance highlighted in section 14.2.1 apply.

15. Turbine Plant Control Integration

15.1 Inverter functionality can include the ability to read data from external sensors, such as anemometers, and perform control actions either internally within the inverter or as instruction to external peripherals, such as braking systems and disconnection devices. Where such functionality is to be integrated within the inverter, it is recommended that the approval body review the control strategy and assess evidence of reliable and repeatable control action and operation provided by the turbine manufacturer.

16. Durability

16.1 Inverters and their associated components are subject to extensive testing to validate their performance specification and adherence to safety standards. If conforming to the appropriate certification standards defined in Annex A, adherence of the inverter to the specification stated by its manufacturer should be considered a given.

16.2 The practice adopted by mature power generating industries to assure product robustness is one of 1000 hour Accelerated Life Testing of components or sub systems in a representative test configuration# and environment. It is recommended that this be considered by the approval body when considering **inverter replacement**. Alternatively, the following can be considered as valid:
- History of in-field inverter deployment presented and reviewed
- 2,500hr system test, carried out by the turbine manufacturer

#NOTE: Representative test environment considers turbine behaviour but does not explicitly have to be a turbine

17. Turbine Starting and Assist

17.1 Some VAWT turbines require assisted starting. Of the architectures illustrated in figures 7.1.1 through 7.1.4, only an active rectifier solution will provide the bi-directional power capability to start the turbine without a separate power stage. When considering a non-self-starting VAWT, consideration should be given to this functionality and evidence provided by the manufacturer that the revised inverter solution will start the turbine either with or without separate power stage. Consumption of energy during the assisted start-up period should be considered. The ability to start the turbine may require an encoder to report position feedback to the inverter, alternatively this can be achieved using sensor-less position or speed techniques. Evidence should be provided by the turbine manufacturer to validate reliability where a position feedback device is used.

18. Grid Compensation

18.1 To date, reactive power compensation of the grid from distributed generators is forbidden by network operators in the UK. It is envisage that in the future this will change. This functionality is therefore not considered here at this time.

19. Multiple Inverters and Isolation

19.1 Where multiple output inverter stages are proposed to achieve higher powers onto common phases, consideration needs to be given to isolating the output of each inverter to ensure safe and reliable operation. Where n inverters are used, n-1 isolation transformers are recommended. For example, where connecting a 12 kW turbine to a single phase supply via two 6 kW inverters, one isolation transformer of at least 6kW rating will be required on the output of one of the inverters. Some inverters have transformers integrated within their design, others require additional transformers to achieve this protection. Where isolation is required, the additional losses in the transformers will need to be taken into consideration when evaluating power and energy output – particularly if a solution is proposed where transformers are introduced as an addition to the configuration originally tested under BWEA Small Wind Turbine Performance and Safety Standard. As a guideline only, isolation transformers of a torroidal design introduce relatively low losses when compared to more designs.

19.2 Alternatively, isolation of each inverter output may not be required where an appropriate transformer-less paralleling technique can be demonstrated.

20. Differing Phase Outputs

20.1 As is the case in the UK, there are four types of grid connection below 50kW; these are as follows:
- Single Phase
- Split phase with 180 degree separation
- Split phase created from three phases with 120 degree separation
- Three Phase

Above 50kW, grid connection is almost exclusively made at three phase.

20.2 Achieving grid connection of a common turbine for a differing number of phases can be done in one of two ways:

- Using multiple, common single phase inverters, for example 2 off 6kW inverters can be used for either 12kW single or split phase installations
- Using dedicated inverters, i.e. different products (or a combination of) for single, split and/or three phase installations

20.3 If proposing a **common inverter** to achieve differing phase outputs, an approach can be considered to achieve MCS certification of all output phase variants based on EITHER the assessment outlined in sections 10 to 23 having been carried out on one variant if making an assessment of inverter change OR full MCS test results achieved when certifying a new system for the first time. In order to certify a system with differing phase outputs, based on the results of either assessment or test of a single variant, the following shall be satisfied:

20.3.1 **Power Control**, with reference to the approved configuration the programmed power curve (including ramp rate settings), or any alternative method of power control, shall cumulatively be the same as the programmed power curve for the base line MCS certified system within the allowable limits set out in 14.2.1.

20.3.2 **Load management**, with reference to Appendix A it shall be necessary to adhere to appropriate connection recommendations for the alternative phase configuration, for example G83/2 or G59/2; demonstrating type test certification for the proposed system.

20.3.3 **Isolation & Transformers**, may be necessary to protect the inverters in alternative phase configurations. If so, the cumulative losses of the transformer shall be deducted from the cumulative output of the inverters to derive the revised power output for the system; ensuring that performance within the allowable limits of 14.2.1 is achieved.

20.4 If proposing a **different inverter** to achieve differing phase outputs, an approach can be considered to achieve MCS certification of all output phase variants based on EITHER the assessment outlined in sections 6 to 19 having been carried out on one variant if making an assessment of inverter change OR full MCS test results achieved when certifying a new system for the first time. In order to certify a system with differing phase outputs, based on the results of either assessment or test of a single variant, the following in addition to the considerations of 20.3, shall be satisfied:

20.4.1 **Electronic Architecture**, with reference to the approved configuration the inverter shall be of the same architecture as that defined in fig 2; else the full assessment outlined in 6 through 19 will require consideration for the proposed differing phase configuration

20.4.2 **Input rating**, with reference to the approved configuration the cumulative input (turbine side) current rating of all inverters shall be at least equal as shall the operating window as defined by the cut-in to maximum allowable voltages. That is, except where overhead in the design of the approved configuration can be clearly demonstrated in this respect; then lower ratings can be considered. This is to ensure that the issues highlighted in figure 5 is avoided, thus preserving within allowable deviation, the certified power performance, acoustic and durability characteristics of the turbine.

20.4.3 **Output rating**, with reference to the approved configuration the cumulative output (load side) current rating of all inverters shall be at least equal. That is, except where overhead in the design of the approved configuration can be clearly demonstrated in this respect then lower ratings can be considered.

20.5 If considering the process described in section 20.4 for differing inverters, it is recommended (but not essential) that the initial assessment carried out in sections 6 to 19 be done for the "weakest" phase configuration; that being from the context of the turbine side (input) rating of the inverter. By way of example; if a dedicated three phase inverter were to have lower turbine side current rating than a proposed single phase inverter then justification for approval of the single phase configuration based on the full assessment of sections 6 to 19 carried out on the three phase inverter would be easier to justify by consideration of this section (20) of the guidance note and would therefore not require consideration of limits defined in 14.2.1 in respect of input current rating.

21. Consideration of Turbine Acoustic Performance

21.1 MCS considers acoustic performance of the turbine. In relation to this and inverter change, there are two factors to consider that could affect the results of the original certification tests:

21.2 **Turbine running speed**, if for any reason the inverter loads the turbine at a different power level than the configuration tested, the turbine itself may operate at a different running speed for that given power. The acoustic output of the turbine with reference to the wind speed could therefore be affected. Consideration shall therefore be given to the following factors:

21.2.1 **Turbine side (Input) current rating of the inverter**, this can affect the operating speed of the turbine as illustrated in section 10; care should be taken, however, not just to consider the current rating itself but also the electronic architecture for the reasons given in 10.3 (generator phase angle control method)

21.2.2 **Programmed Power Curve (or equivalent)**, ultimately sets the demanded power from the turbine. Providing the hardware of the inverter is capable, namely the input current rating and operating input voltage window, retaining the existing power curve setup with respect to voltage and/or speed should maintain the operational speed characteristics of the turbine and hence its acoustic behaviour.

21.3 Modal excitation and/or harmonic noise, inverters by the very nature of their operation, affect the harmonic content of the current waveform in the generator. Depending on the electronic architecture considered, and the level of filtering built into the inverter itself, the harmonic content will differ. The relative measure of noise given between architectures in figure 3 refers to this phenomenon. For example, passive rectification will superimpose 5th and 7th current harmonics onto the generator current waveform. This in itself can be a noise differentiator, albeit not of huge significance. However, of more potential significance, the addition of current harmonics increases the likelihood of exciting a natural frequency in the turbine structure which could introduce a modal noise in the running envelope of the turbine. This should be taken into account when considering a change of electronic architecture.

22. Checklist to assess the impact of inverter change and/or modification

22.1 **Step 1**: Compare the purpose of the inverter used in the "representative configuration" for BWEA Small Wind Turbine Performance and Safety Standard and for the proposed change or modification. If deviating from one generic load type considered in Annex A to another, further testing may be required at the discretion of the approvals body.

22.2 **Step 2**: Using Annex B, consider the necessary certifications required for an inverter be-fitting of use with load type described in Annex A. Ensure that the proposed inverter is type tested accordingly.

22.3 **Step 3**: Compare inverter electronic architecture (fig 2) used in the "representative configuration" for BWEA Small Wind Turbine Performance and Safety Standard and the relative effect of the proposed change in figure 3. Where performance deviation is expected, consider the relevant measure further using sections 9 through 14 and/or discuss further with the turbine manufacturer and inverter supplier to assess the significance of the deviation where not covered in sections 9 through 14. Further test may be required if the potential deviation is considered significant.

22.4 **Step 4**: Consider the guidance in sections 9 through 14 and measures in 14.2.1 to assess the effect on turbine energy yield of the inverter change or modification. Where relevant, encourage the system installer to follow the guidance relating to relevant settings that will limit the impact of change. Consider:

- Cut-in, Cut-out voltages and over voltage protection capabilities
- Inverter input current and corresponding rated speed
- Significance of inverter and generator efficiency
- Internal consumption at low load and the standby strategy deployed
- The rate of load acceptance and rejection
- Technique used to control power drawn from the turbine

22.5 Where doubt or ambiguity remains, the approval body can request practical evidence of a power curve to validate performance using the new configuration.

22.5 **Step 5**: Assess the direct interaction of the inverter with measurement sensors and control peripherals. Where the inverter receives instruction from an external controller, or passes on instruction to an external controller or peripheral, ensure that the functionality has been tested and proved to be reliable and repeatable.

22.6 **Step 6**: Where proposing inverter replacement, evidence should be made available to confirm durable operation through one of the following:

- 1000hr Accelerated Life Test of the inverter in a representative test environment#
- History of in-field inverter deployment
- 2,500hr system test, carried out by the turbine manufacturer

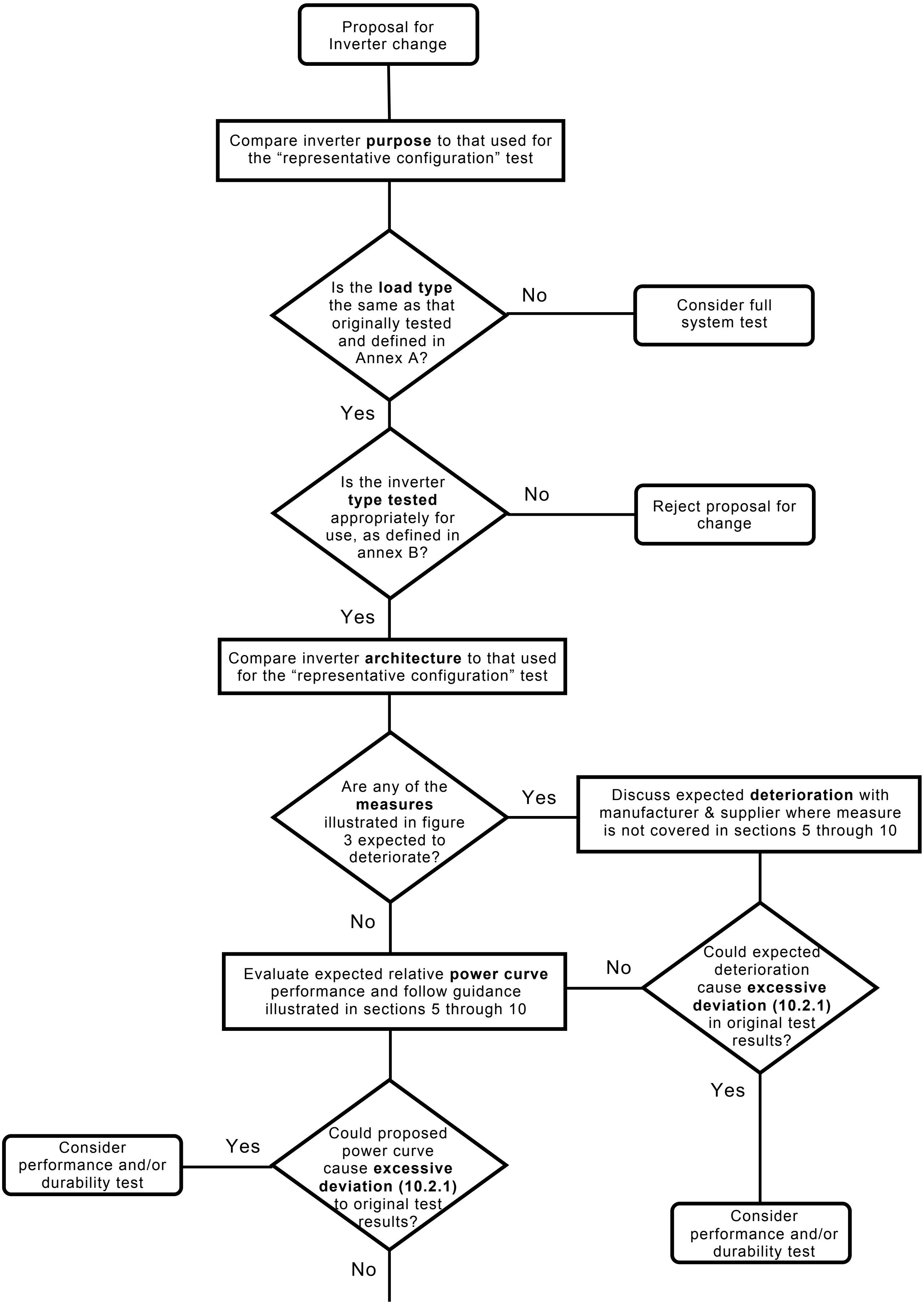
#NOTE: Representative test environment gives consideration to turbine behaviour but does not explicitly have to be a turbine

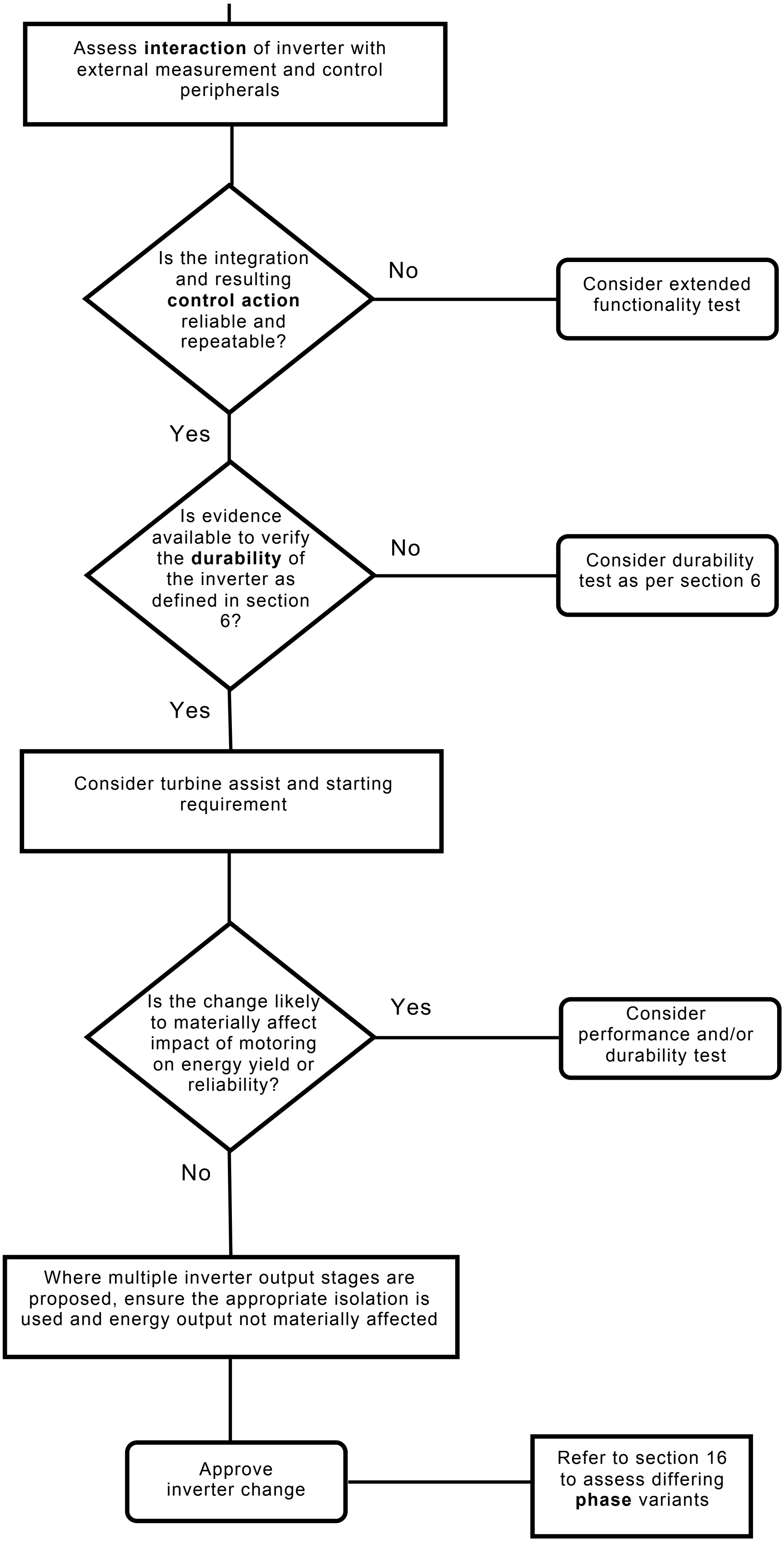
22.7 **Step 7**: Where appropriate and relevant, consider the turbine starting and motoring requirement and impact on energy consumption & reliability as outlined in section 17.

22.8 **Step 8**: Where multiple inverter output stages are to be used, ensure an appropriate means of isolation is considered, as outlined in section 19.

22.9 **Step 9**: If considering approval of additional configurations to achieve differing grid (or other load) phase connection, follow the guidance outlined in section 20.

23. Inverter Modification Roadmap





Assess **interaction** of inverter with external measurement and control peripherals
Is the integration and resulting **control action** reliable and repeatable?
No
Consider extended functionality test
Yes
Is evidence available to verify the **durability** of the inverter as defined in section 6?
No
Consider durability test as per section 6
Yes
Consider turbine assist and starting requirement
Is the change likely to materially affect impact of motoring on energy yield or reliability?
Yes
Consider performance and/or durability test
No
Where multiple inverter output stages are proposed, ensure the appropriate isolation is used and energy output not materially affected
Approve inverter change
Refer to section 16 to assess differing **phase** variants

Annex A – Load Type Definition

1. Grid Connected – as bound by G83/2 and/or G59/2 UK grid code requirements
2. Grid Connected with battery back-up
3. Off grid load
4. Off grid load including battery back-up
5. Hybrid on and off grid load
6. Hybrid on and off grid load including battery back-up

Annex B – Inverter Safety and Grid Code Standards

Grid connected inverters:

- BS-EN 50178:1998 Electronic equipment for use in power installations
- BS-EN 61000-6-1:2007 EMC: Generic standards – Immunity standard for residential, commercial and light industrial environments#
- BS-EN 61000-6-3:2007 EMC: Generic standards – Emission standard for residential, commercial and light industrial environments#
- Relevant Grid connection recommendation*, for example in the UK:
    - ER G83/2 - Recommendations for the connection of small scale embedded generators in parallel with public low voltage distribution networks, OR
    - ER G59/2 - Recommendations for the connection of generating plant to the distribution systems of licensed distribution network operators
- 2006/95/EC Low Voltage Directive
- 89/336/EEC Electomagnetic Compatibility Directive
- 93/68/EEC CE Marking Directive
- 2002/95/EC the directive on the restriction of the use of certain hazardous substances in electrical and electronic equipment
- WEEE 2002/96/EC, the directive on waste electrical and electronic equipment
- RohS compliance

#NOTE 1: Alternatively, BS-EN 61000-6-2 and 6-4 may be considered where environment of use is deemed “industrial”

*NOTE 2: Other European regions covered by EN50438 Requirements for the connection of micro generators in parallel with public low voltage distribution networks, including German requirement DIN VDE 0126-1-1 automatic disconnection device between a generator and the public low voltage grid

Off-Grid inverters:

- Annex to be defined in next release.

renewableUK
The voice of wind & marine energy

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Our vision is of renewable energy playing a leading role in powering the UK.

RenewableUK is the UK's leading renewable energy trade association, specialising in onshore wind, offshore wind and wave & tidal energy. Formed in 1978, we have an established, large corporate membership ranging from small independent companies, to large international corporations and manufacturers.

Acting as a central point of information and a united, representative voice for our membership, we conduct research; find solutions; organise events, facilitate business development, lobby and promote wind and marine renewables to government, industry, the media and the public.

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