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Novel Power Park Controller for Hybrid Asymmetrical Storage Plants with Low Frequency Demand Disconnection

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***Abstract*—Within the U.K., as well as globally there has been an increased presence of hybrid Solar PV / Storage plants with asymmetrical export / import requirements. Current standard Power Park Controllers have hybrid control capability, but do not fully consider hybrid plants that have asymmetrical capabilities. Furthermore, storage plants within the UK, are also required to provide fast Low Frequency Demand Disconnection in the case of emergency low frequency conditions via a fast power-frequency droop response. This paper uses the WECC generic REPC controller for Power Park Controllers and modifies it to provide a novel control incorporating these two additional requirements.**

Keywords—Power Park Controller, Plant Controller, Hybrid Power Plants, Low Frequency Demand Disconnection.

I. Introduction

A. Background

The use of Plant Controllers / Power Park Controllers (PPC) is essential in all large renewable energy power plants, as they provide control and dispatch of active and reactive power setpoints to the generators through PF, MVAr and voltage control modes. Standard models of PPCs have been available for several years, from groups such as the Western Electricity Coordinating Council (WECC), and are generally considered robust, and are widely used. However recent developments in hybrid plants, containing Battery Energy Storage Systems (BESS) has led to some challenges, as the plant may have an asymmetrical export / import rating.

Within the UK a further requirement has also been established for BESS units to provide Low Frequency Demand Disconnection (LFDD), where if the frequency falls below a value of 48.8 Hz, the BESS should stop import and seamlessly swing to power export.

This paper provides a novel solution to these problems, through modification of the existing WECC, REPC_C plant controller, to include options for asymmetric rating and LFDD functions.

B. Motivation & Contributions to Knowledge

Within the UK Grid Code [1] and NERC guidelines [2], there has been an introduction of a general requirement for BESS units to be able to provide voltage control, frequency response and fault ride through capabilities whilst the BESS is in import mode. This has led to several problems where hybrid plants with asymmetrical ratings have been developed, and the power-frequency response of the system when operating in Limited Frequency Sensitive Mode (LFSM), or Frequency Sensitive Mode (FSM).

The requirement for LFDD has also become a clear requirement within the UK Grid Code and therefore integrating this function in a PPC provides a simple and elegant solution to falling frequency using existing BESS controls. As the LFDD functionality within the PPC control as this allows the control to be integrated into a single controller and easily tested within a practical commercial role.

A further requirement in the UK Grid Code, is that RMS models must be provided for review by NG ESO, and as many PPC manufacturers are reluctant to share their detailed models, there has been a general move towards use of generic open-source models such as the WECC REPC_C [2]. Providing a generic novel PPC model that implements these additional features would therefore be beneficial to many developers with the U.K.

The motivation and contribution to knowledge for the research is therefore to develop an open model PPC, that can be used within the UK Grid system to include the additional asymmetric function and LFDD function needed by many BESS sites.

C. Background

The use of PPCs in renewable energy installations has been widely established for several years. WECC have produced three main versions, known as REPC_A, REPC_B and REPC_C with a future REPC_D in development [4]. These controllers are widely used and have been implemented in several different commercial PPCs.

Many developers are seeing potential opportunities of co-locating hybrid power plants on the same site, which can create several control problems. Various solutions to hybrid power plant control have been suggested, depending on where the plants are coupled at AC or DC, or if the plants are of different age [5]. Typically, the two approaches adopted are to use a single controller managing all controllers, or several discrete PPCs, for modelling each plant type. However, this can lead to problems for power-frequency droop response behaviour as the existing PPC models are all based on a single plant nominal power rating.

With the increasing prevalence of BESS generation, an issue frequently encountered is that of an asymmetrical rating, where the generation export and import capability are asymmetrical, due to limitations in the network capacity available. This can cause a specific problem when considering the BESS behaviour when using a power frequency droop control response.

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Recent Grid Code modifications in the UK National Grid Code [1], have also included the need for BESS units to respond with a fast droop response, in the event of an emergency low frequency <48.8 Hz, to help stabilise the network, with a droop value of <1%, compared to the standard power-frequency droop value of 3-5%.

D. Power Frequency Droop Control

The use of power frequency droop response is a standard generator control strategy used in many countries and is based on the generator adjusting its power output in relation to the system frequency, as described in Equation (1).

$$r(droop) = \frac{\frac{\Delta f}{f_{nom}}}{\frac{\Delta P}{P_{nom}}} \quad (1)$$

The majority of PPCs implement a power frequency control loop to automatically load / de-load the generation in relation to frequency changes. Within the UK, and Europe, the control is either based on a LFSM response or FSM mode. The typical response characteristic of a BESS within the UK system operating in FSM mode are shown below in Fig. 1.

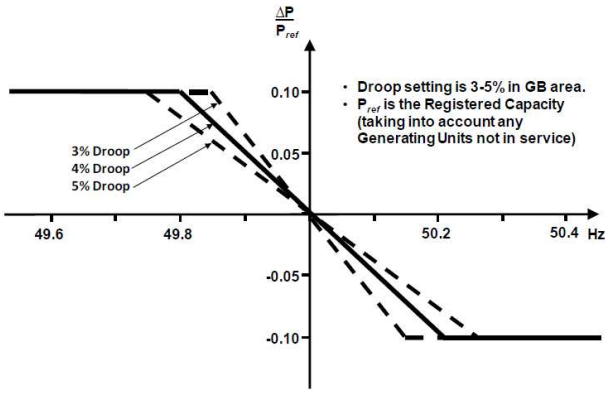


Fig. 1. Frequency Response

It can be seen from Fig. 1 that the droop response in FSM mode is symmetrical and set within a 3-5% range. As noted earlier a BESS must be able to response in both export and import conditions; where a plant has an asymmetrical export / import rating then unsatisfactory droop response may occur. Two simple examples of this can be easily identified for illustrative purposes. First, a BESS site may have an asymmetrical connection of for example 100 MW export but only 50 MW import. Second, a hybrid Solar PV and BESS site may contain 50 MW of Solar and 50 MW of storage, requiring an export of 100 MW, but only an import of 50 MW.

In both of the above cases, it can be seen that the nominal power rating (*Pnom)* of the export part of the plant would be 100MW, but the nominal power rating of the import part of the plant would be only 50MW. If the power-frequency droop setting was a typical 4%, then when in import mode, the system would unload at a response of 2%, thus causing unexpected behaviour, and non-compliance with the standard.

E. Low Frequency Demand Disconnection

Within the UK Grid Code [1], it is a requirement that all large loads are provided with LFDD, such that in the event of a system emergency due to a very low frequency, large loads will be shed to help try and balance the system. Traditionally such schemes were implemented using simple frequency relays.

With BESS units able to operate in storage mode, the implementation of LFDD within the BESS controls, becomes an obvious solution, and current UK guidance indicates that it is the preferred approach [6]. The required response characteristic of a BESS within the UK system is shown below in Fig. 2.

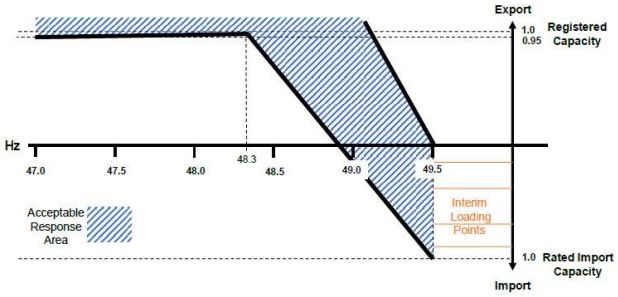


Fig. 2. LFDD Response

The obvious solutions is therefore to implement the requirements for LFDD within the PPC, as many of the signals and control functions are already established. This modified PPC provides many benefits over discrete frequency relays, as it allows a continual active response, as the BESS rating is continuous rather, than a series of discrete load blocks as would traditionally be operated by LFDD protection.

F. WECC Plant Controller

The WECC have produced several different generic PPCs that are widely used in industry [4]. The original REPC_A model was a basic model used for Solar PV and Wind, whilst the REPC_B model extended the initial model for use with energy storage and hybrid plants but contains a number of limitations for controlling downstream. The REPC_C model was introduced and provide a series of improvements over the REPC_B model for control of downstream units and also allowed power factor control.

A copy of the standard REPC_B model implementation is shown below in Fig. 3. The RPEC_B model is shown instead of the REPC_C for clarity, as it represents the core functions of the PPC that will be modified in the next section. The top part of the control system shows the control loop for the reactive power control and voltage control functions and the lower part of the diagram shows the active power control functions.

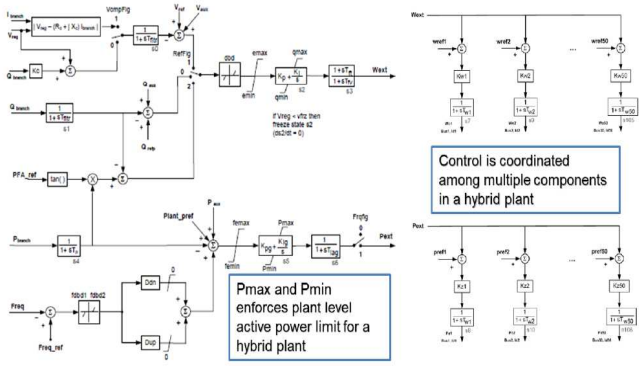


Fig. 3. WECC REPC_B Model

II. Proposed Modification to the WECC Model

A. Existing Active Power Control Loop

A more detailed view of the active power control loop of the WECC model can be seen below in Fig. 4, the input frequency signal is used to produce an error signal, which drives the *Ddn* and *Dup* signals for the respective positive and negative droop response. These signals are then summated into a PI controller, which is used to drive the external signal *Pext*, to the generator(s).

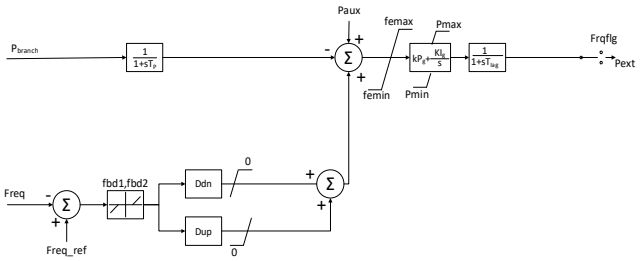


Fig. 4. WECC REPC_B Model Active Power Control Loop

B. Modification for Asymmetrical Rating

The modification for the asymmetrical function can be implemented by introducing a scaling factor in the output path of the control system, which modifies the *Pext* signal based on the import rating as a percentage of the export rating. The *Pbranch* signal is measured to detect a negative value, to indicate the plant in import condition, which is then used to drive an input signal selector switch to change between the standard output signal and the scaled output signal. The modification can be seen below in Fig. 5.

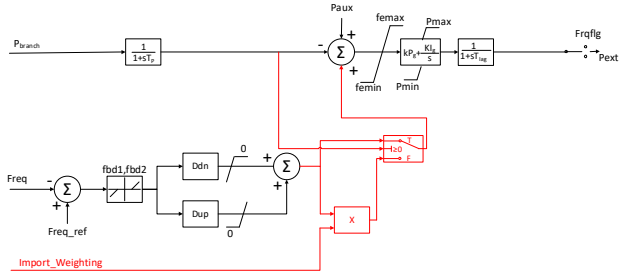


Fig. 5. WECC REPC_B Modification for Asymmetrical Rating

C. Modification for LFDD Function

The modification for the LFDD function can be implemented by introducing a new path in the control system, with a duplication of the *Dup* function to allow a different drop setting to entered, and a logic element and logic selector switch to allow the LFDD droop response rate to be utilised when the frequency errors exceeds the set limit of 48.8 Hz for the LFDD response, and passing through the original *Dup* when the frequency errors is within the normal range. The modification can be seen below in Fig. 6. The overall modification for the two functions is shown in Fig. 7, which incorporates the changes for the asymmetrical scaling factor and the LFDD response.

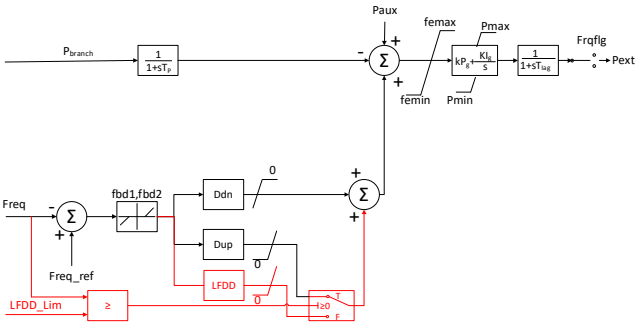


Fig. 6. WECC REPC_B Modification for LFDD

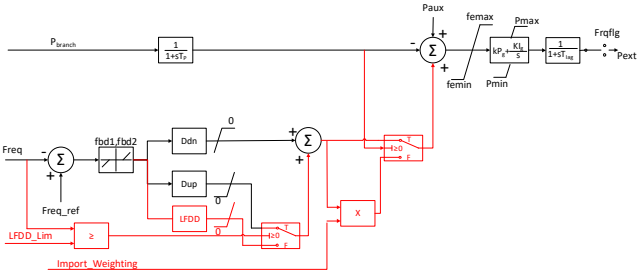


Fig. 7. WECC REPC_B Overall Modification

III. Validation and Testing

A. Test Model Configuration

In order to validate the controller modifications a standard implementation of the REPC_C controller with a BESS storage unit was developed in DIgSILENT Powerfactory as shown below in Fig. 8. The proposed modifications to the REPC_C controller was then implemented in the existing controller available in the template library [7], that was then modified to include the changes shown in Fig 7.

The Powerfactory model contains a single upstream busbar rated at 132 kV, a 133/33 kV 60 MVA transformer, 33 kV busbar and then an aggregated model of a 55 MVA BESS, to represent an aggregated model of a series of smaller BESS units. The aggregated model consisting of 10x 5.5 MVA 33/0.69 kV transformers, 10x 5.5 MVA BESS units. The base WECC PPC model is set to a nominal power of 50MW, and the power frequency droop characteristic set to a typical droop characteristic of 4%.

A series of simulation tests were carried out with step inputs to the system frequency of different magnitude, with the system in both export mode and import mode. Initially the weighted / asymmetrical capability is tested using a series of standard frequency steps to check the system response.

Secondly, the LFDD response is tested using a large frequency step into the system, with the site in import mode and then finally, the combined system is tested.

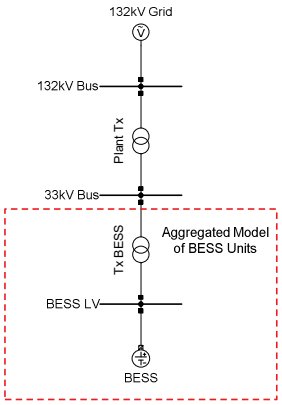


Fig. 8. Powerfactory Model

B. *Asymmetrical Power Frequency Droop Results*

To validate the response of the proposed PPC modifications, a series of frequency steps were applied to the test network and the resultant power response of the system checked. Initially the response of the system was checked for a symmetrical battery storage plant rated at 50 MW export and 50 MW import, and then with a plant rated at 50 MW export but limited to 25 MW import. The results were calculated with equation (1) and then checked against the model results summarised in Table I.

TABLE I. ASYMMETRICAL CASE RESULTS

Frequency Step	**Export Calculated Value 4%**	**Import Calculated Value 4%**	**Export Measured Value 4%**	**Import Measured Value 4%**
0.5 Hz	12.5 MW	6.25 MW	12.12 MW	11.75 MW
1 Hz	25 MW	12.5 MW	24.4 MW	12.12 MW

The results of the simulation can be seen in Fig. 9, with the base case symmetrical plant shown in red, and the asymmetrical plant shown in blue. It can be seen from the plot, that in the base case (red curve) the frequency steps produce a symmetrical droop response for both rising and falling frequencies, whilst for the asymmetrical case the power import is limited to 25 MW, and the proportional droop response is ratioed to the asymmetrical plant rating. Note the results are shown with negative sign convention with respect to the transformer (negative indicating export).

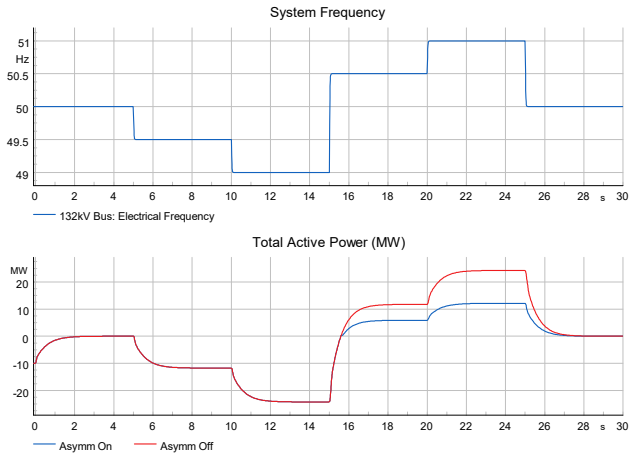


Fig. 9. Results for Asymmetrical Case

C. *LFDD Results*

To validate the response of the proposed LFDD modification, the system is configured with a symmetrical rating of 50 MW export and 50 MW import. The plant is set to maximum import condition of 50 MW, the LFDD threshold is set at 48.8 Hz, as per current UK requirements, a standard droop setting of 4% is used for the main power frequency response and a 2% and 1% value is used for the LFDD response. Three step inputs are applied to the system; the first is a -1 Hz step to reduce the system frequency to 49 Hz, which is just above the LFDD threshold, and then a second step of -1.25 Hz is applied, and then a 1.5 Hz step applied, with the latter steps set to trigger the LFDD response.

The results of the simulation can be seen in Fig. 10. In all cases the 1 Hz step causes an identical response, as it is above the LFDD threshold. For the subsequent steps the base case (blue curve) continues to provide a response in line with a 4% droop setting; the 2% droop slope (green curve) causes the BESS to move into generation mode; the 1% droop slope (red curve) is very fast and forces the BESS into maximum power export. In the 1% LFDD case, the frequency step causes a power change that is larger than the system nominal power rating and the BESS power output is limited by the P_{min} function in the REPC_C controller. It can therefore be seen that the plant responds as desired and the LFDD response is satisfactory.

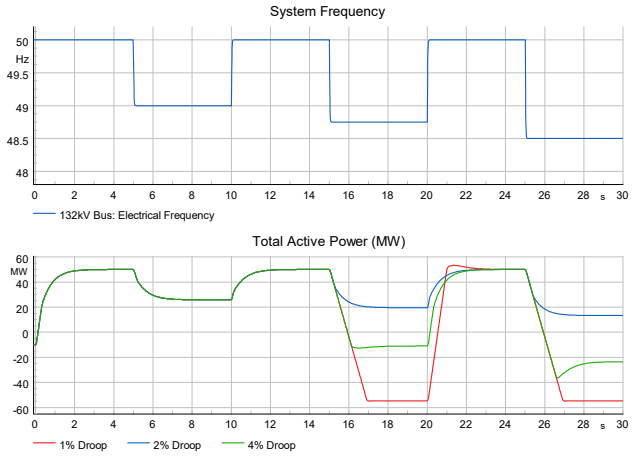


Fig. 10. Results for LFDD Response

D. *Combined Asymmetrical and ALFDD Results*

To validate the response of the combined LFDD and asymmetrical response, two scenarios were setup. The first with a symmetrical plant of 50 MW export and 50 MW and second with a symmetrical plant of 50 MW export and 25 MW import. In both cases the plant initial conditions were set to 25 MW import. A 2% droop characteristic is applied, as this allows the response to be identified more clearly, as the 1% droop response is very fast, and would drive the response to the plant limit function.

The results of the simulation can be seen in Fig. 11, with the base case symmetrical plant shown in blue, and the asymmetrical plant with LFDD active shown in red. It can be seen from the plot, that in the base case the 0.5 Hz, 1 Hz and 1.5 Hz steps all produce a corresponding power reduction of 25% reducing the plant power by 12.5 MW in each step to 12.5 MW, 0 MW and -12.5 MW accordingly to the *Pnom* value of 50 MW. In the asymmetrical plant, 0.5 Hz, 1 Hz and steps cause a 25% reduction of 6.25 MW based on the import *Pnom* value of 25 MW. When the frequency is stepped below the LFDD threshold the fast de-load occurs. The response in this case is interesting as the *Pnom* value changes from 25 MW to 50 MW as the plant transitions from import to export mode, and a slight change in the gradient of the graph can be seen. The 1.5 Hz frequency change from nominal would cause a 150% change in the system, which leads to the generator reaching full export.

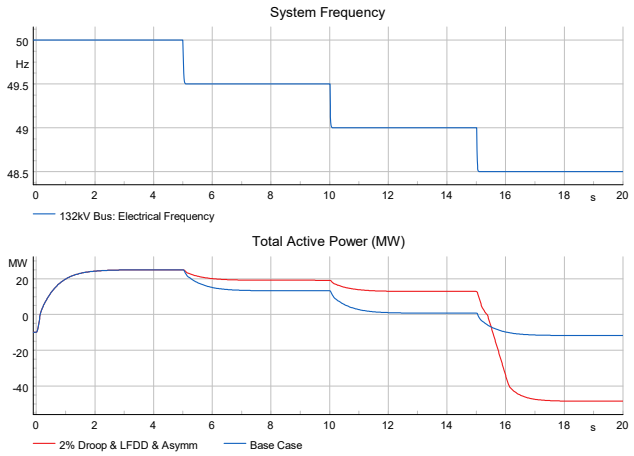


Fig. 11. Results for Combined Asymmetrical LFDD Response

IV. Conclusions & Further Work

The WECC REPC_C controller is a well-established, open model implementation for a PPC that can be used for hybrid power plants. The changes suggested within this paper have extended the REPC_C model to include the ability for a plant to operate with an asymmetrical export / import rating, and also to meet the requirements for LFDD needed by BESS units. Preliminary testing was carried out using DIgSILENT Powerfactory to prove and validate the concept, which provided encouraging responses to support the proposed changes, indicating that the asymmetrical capability and LFDD response could be integrated into the controller and provide the desired responses. Approaching WECC may also be beneficial to see if they would consider implementing the suggested changes for future updates of the REPC controller.

Future work in this area would be to undertake more detailed testing of the control system modifications and expand the LFDD scheme to provide a mirrored response for the down droop response i.e. fast loading if the frequency rises. A further significant development would be to integrate the asymmetrical capability requirements with the reactive power control loop, to ensure that the reactive power limits and output were maintained in proportion to the site import capacity.

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