Battery Energy Storage System addressing the Power Quality Issue in Grid Connected Wind Energy Conversion System

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INTRODUCTION

- Renewable Energy (RE) sources like solar, wind etc are alternatives for fossil fuels.

- However, intermittent characteristics of RE sources like wind shall fluctuate the power output of the Wind Turbine Generator (WTG).

- When the large scale WTG is connected to the grid, Power Quality (PQ) problems arises.

- Battery Energy Storage System (BESS) improves the grid regulation by smoothening the power output from WTG, time shift for generated RE to meet the load, peak shaving of demand, increase the reliability of large scale RE grid connected system and off-grid system without diesel backup.

- This paper focuses on the BESS for large scale grid connected WECS to improve the voltage profile.

Types of Wind Generator

FOUR TYPES

- SCIG - Type 1 wind generator
- WRIG – Type 2 wind generator
- DFIG – Type 3 wind generator
- Full converter – Type 4 wind generator

PQ PROBLEMS IN GRID CONNECTED WECS

- Intermittent characteristics of the wind velocity (below the cut in speed and above the cut out speed) resulting to disconnection of WTG from the grid.
- Subsequently, when the WTG reaches back to the cut in speed the WTG is re-connected to the grid.
- Due to multiple connection and disconnection of WTG from the grid creates the PQ problems in grid connected WECS.
- **Type 1 and Type 2 WTGs** are creating **voltage sag** due to reactive power drawl.
- Voltage swell and Transients are also being created due to switching of capacitor banks provided at the machine side. A sudden change in an electrical circuit generates a transient voltage due to the stored energy.
- Hence, one of the major PQ event in Type 1 WECS is **voltage sag**.

PQ PROBLEMS IN GRID CONNECTED WECS (cont..)

- Type 3 and type 4 WTGs are using the power electronics based converters for interconnection to the grid.

- It generating the harmonics, DC injection and voltage flicker to the grid.

- Voltage profile in the grid can be maintained during fault by Low Voltage Ride Through (LVRT) characteristics of the WTG by injecting the reactive power to the grid with proportional to the voltage.

GRID CODE REQUIREMENTS FOR WIND

- Harmonic current injections and flicker introduced shall not be beyond the limits specified in IEEE Standard 519 and IEC 61000.
- DC current injection shall not be greater than 0.5% of the full rated output.
- Capable of supplying dynamically varying reactive power support so as to maintain power factor within the limits of 0.95 lagging to 0.95 leading.
- Operating in the frequency range of 47.5 Hz to 52 Hz.
- Deliver rated output in the frequency range of 49.5 Hz to 50.5 Hz.
- Wind generating stations connected to the grid at 66 kV voltage level and above shall have the fault ride through capability.

GRID CODE REQUIREMENTS FOR WIND (cont..)

- The wind farms should be able to withstand voltage unbalance within the limit specified in Table .1

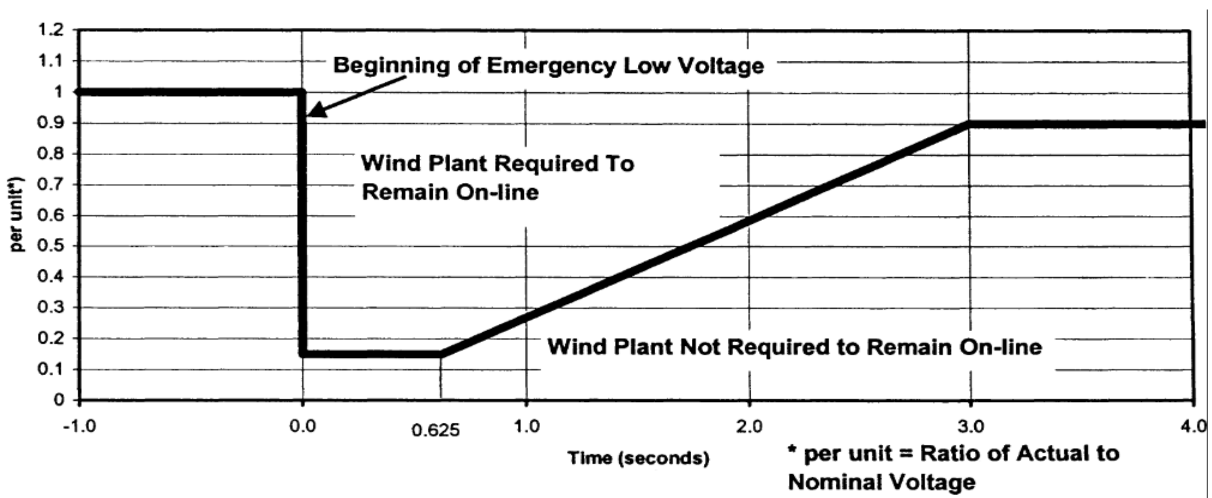
Table . 1

Voltage Level (kV)	Unbalance (%)
400	1.5
220	2
<220	3

FAULT RIDE THROUGH REQUIREMENTS

During the fault ride through,

- The wind turbine generator in the wind farm should minimize the reactive power drawl from the grid.
- It provide the active power in proportion to retained grid voltage as soon as the fault is cleared.
- Fault ride through capability are not mandatory for wind farms connected below 66 kV.



Impact of Wind Penetration and PQ

The impact of wind power in the electric power system depends on the following

- Wind power penetration level
- Grid size
- Generation mix in the power system

Wind penetration level

- Penetration of less than 5 % - not an issue to the grid operator
- Penetration more than 10 % - grid adaptation and remedial measures are needed
- Penetration more than 20 % - strengthening of existing grid becomes essential

PROBLEMS RELATED WITH GRID CONNECTIONS

- Poor grid stability
- Low frequency operation
- Impact of low power factor
- Power flow
- Short circuit
- Power Quality
- Protection
- Reverse flow
- Power system Faults
  - ❖ Symmetrical Faults
  - ❖ Unsymmetrical Faults (L-G, L-L, L-L-G Fault)

POWER QUALITY ISSUES IN WECS

POWER QUALITY ISSUES IN WECS

WIND FARM IMPACT ON GRID

- Reactive power
- Unbalance current
- Flicker
- Harmonics
- Fault current contribution
- Voltage control and Node voltages

GRID IMPACT ON WIND FARM

- Transient interruption
- Voltage sags or swells
- Short circuit faults
- Unbalance voltage
- Frequency variation

COMPARISON OF TYPES OF WECS

WECS	VAr CONTROL	GRID SUPPORT	GRID CONNECTED ISSUES
Type 1	None (need capacitor)	Low	Consume reactive power, Flicker.
Type 2	None (need capacitor)	High	Consume reactive power, Frequency variation, Voltage fluctuation, Flicker.
Type 3	Two reactive power source (stator & rotor converter)	Medium	Generation of current harmonics, Voltage fluctuation, Flicker.
Type 4	Two reactive power source (stator & rotor converter)	Medium-high	Generation of current harmonics Voltage fluctuation, Flicker.

Overview of Local Impact on Wind Power and Mitigation

S. No.	System Quantity	Type-A and Type-B WPP	Type-C WPP	Type-D WPP
Local Impacts				
1.	Changes in node voltages and branch flows	Occurs but compensation possible with capacitor banks, SVCs/STATCOMS	Compensation possible but dependent on PEC rating	Compensation possible but dependent on PEC rating
2.	Fault currents and protection schemes	Protection possible with conventional protection schemes and mechanical torque limiters	Protection possible till PEC limit and then, immediately disconnected	Protection possible till PEC limit and then, immediately disconnected
Power Quality				
3.(a)	Slow voltage variations (steady state)	Present but not disturbing	Unimportant because the PEC in rotor circuit acts as an energy buffer	Unimportant because the PEC in stator decouples the generator from the grid
(b)	Rapid voltages (Flicker)	May occur particularly in weak grids	Unimportant because the PEC in rotor circuit acts as an energy buffer	unimportant because the PEC in stator decouples the generator from grid
(c)	Transients	Present	Present to a lesser extent	Present to a lesser extent

Overview of System Wide Impact on Wind Power and Mitigation

S.No	Capabilities	Type-A WPP	Type-B WPP	Type-C WPP	Type-D WPP
1.	Reactive Power compensation and voltage control	Possible with shunt capacitor, SVC/STATCOM/DVR	Possible with shunt capacitor, SVC/STATCOM/DVR	Possible with PECs	Possible with PECs
2.	Short term balancing power control and frequency	By blade pitching and WPPs being switched in and out	By blade pitching and WPPs being switched in and out but a little more better	By blade pitching and /or PEC control and WPPs being switched in and out	By blade pitching and/or PEC and WPPs being switched in and out
3.	Long-time balancing output power availability	Possible only to some extent due to stochastic nature of wind	Possible only to some extent due to stochastic nature of wind	Possible only to some extent due to stochastic nature of wind	Possible only to some extent due to stochastic nature of wind
4.	Contribution to fault current	To some extent	To some extent	Difficult beyond thermal limit of PEC, as it may be damaged	Difficult beyond thermal limit of PEC, as it may be damaged
5.	Fault-Ride-Through (FRT) capability	Depends on wind speed, fault duration, grid strength and hence, voltage instability risk exists	Depends on wind speed, fault duration, grid strength and hence, voltage instability risk exists	Difficult beyond thermal limit of PEC, as it may be damaged	Difficult beyond thermal limit of PEC, as it may be damaged

BATTERY ENERGY STORAGE SYSTEM

- To store the excess energy from the renewable energy when demand is low and reuse this energy in the high demand time.
- Enabling the fast response characteristics to variations between demand and supply.
- Provides active and reactive power support to the system when the power from renewable energy sources fluctuates.
- In the grid connected mode, it provides reactive power support for stabilizing the system voltages.

BATTERIES

Application

- Power conditioning.
- Short-term storage, to effectively redistribute the load over a 24 hour period.

Requirements

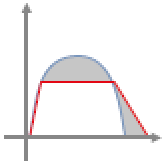
- long life
- very low self-discharge
- long duty cycle (long periods of low charge)
- high charge storage efficiency
- low cost
- low maintenance

BATTERY TERMINOLOGY

- Battery Capacity
- Rate of charge/discharge
- Open circuit voltage
- Depth of discharge
- State of charge
- Self discharge
- Specific energy
- Energy density
- Time durability
- Cycle durability
- Nominal cell voltage
- Internal resistance
- State of health
- Battery life time
- Battery efficiency

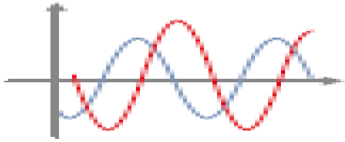
APPLICATIONS OF BESS

- **Peak shaving**



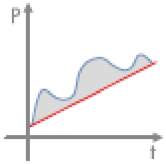
Peaks in power production can be shaved, stored in batteries and delivered when needed.

- **VAr Support**



Reactive power support by BESS.

- **Oscillation damping**



Buffering of output during changes in the intermittent renewable energy sources.

APPLICATIONS OF BESS (CONT…)

- **Power Quality**

  BESS reduce the **voltage sag** caused by power system faults, etc.

- **Voltage support**

  In order to maintain the grid voltage, BESS injects or absorbs both active and reactive power.

- **Long term load leveling**

  BESS stores power during low-load periods and delivers it during periods of high demand.

BATTERY CHARGING AND DISCHARGING

- The equation for charging of battery

$$E(t+1) = E(t) + \Delta t P_t^{Ec} \eta_c$$

- The equation for discharging of battery

$$E(t+1) = E(t) - \frac{\Delta t P_t^{Ed}}{\eta_d}$$

Where ,

E(t) is energy stored in the battery in t

Δt is duration of the interval

P_t^{Ed} is the power discharge by the battery during the time t

P_t^{Ec} is the battery charging during the time t

η_c is the charging efficiency

η_d is discharging efficiency

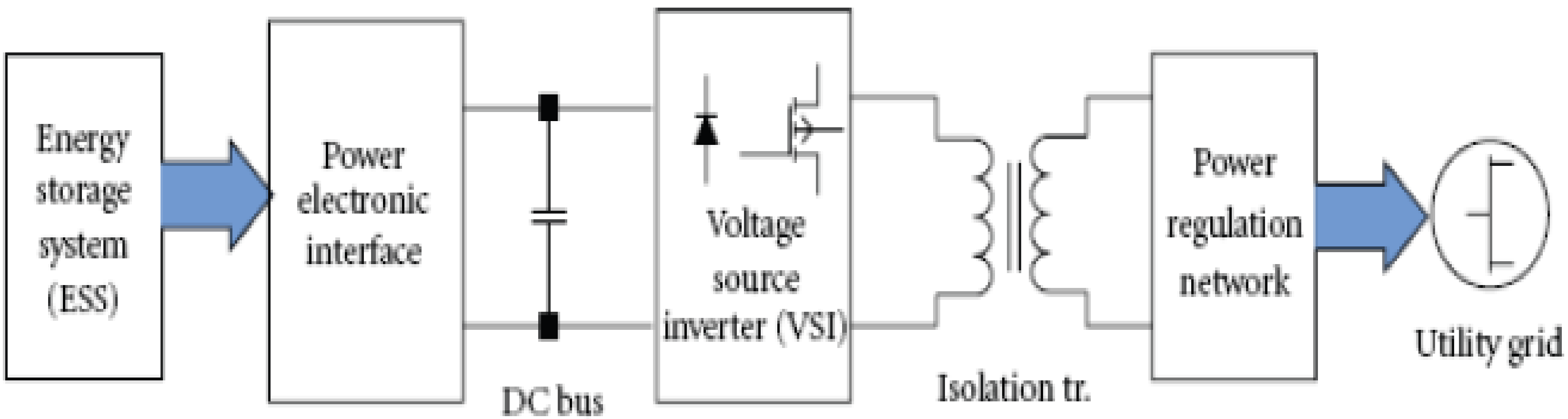
MODELLING OF WECS

- A 110 / 11 kV Sub Station (SS) is considered for the analysis with installed capacity of 11.5 MW WTG – Type 1, connected load in the SS is 10 MVA and capacitor bank provides 1.587 MVAr.

- The details of WTGs are:

S. No	Customer	Capacity in MW
1	A	5 (20*250 kW)
2	B	2 (8*250 kW)
3	C	4.5 (9*500 kW)
Total		11.5

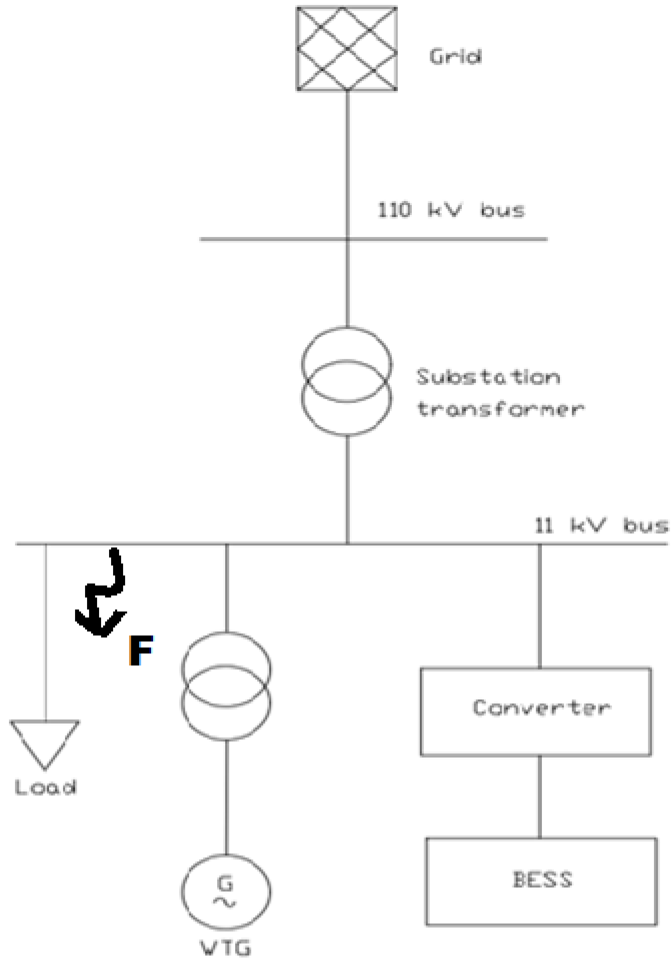
- The modelling and simulation were performed using DIgSILENT power factory.



Battery Energy Storage System (BESS) connected to power utility system

MODELLING OF WECS (cont..)

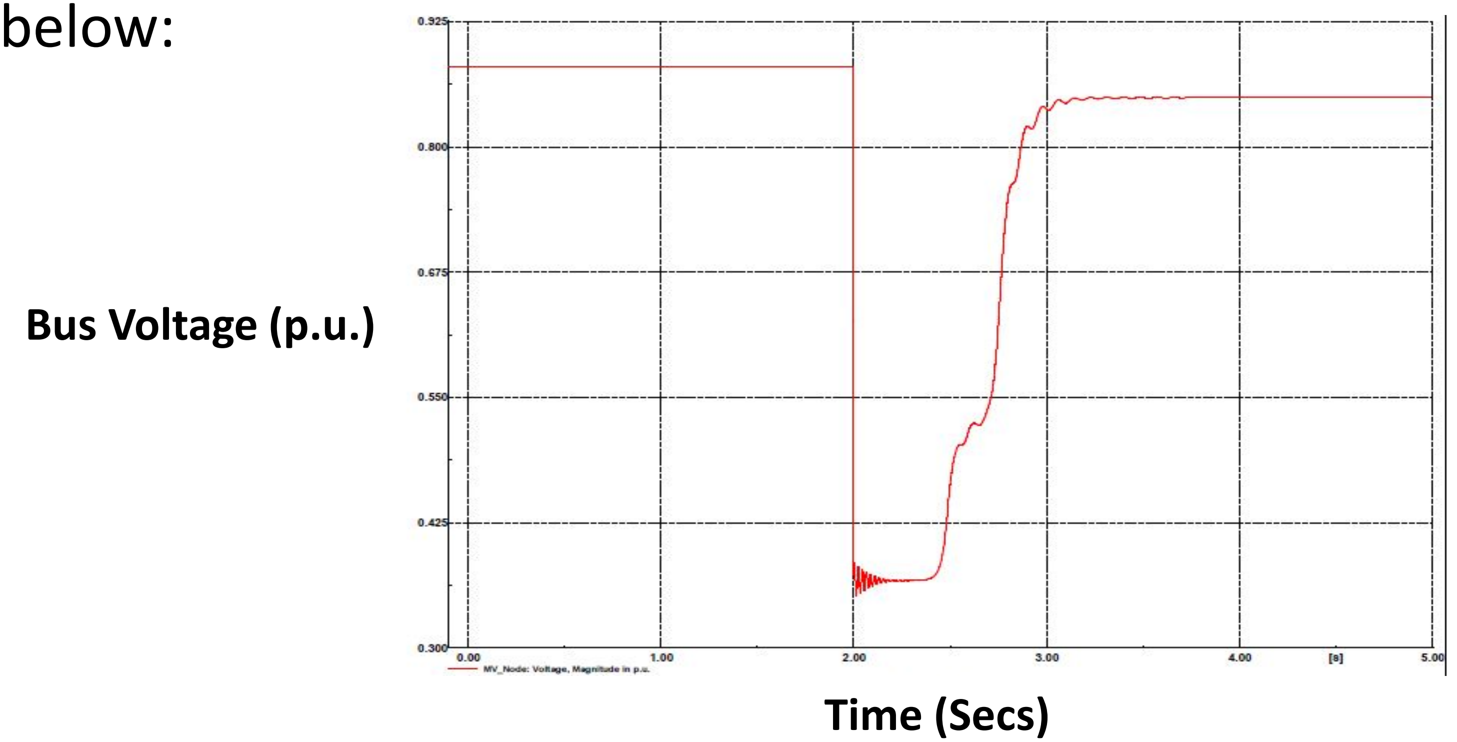
- The Single Line Diagram (SLD) of SS with aggregated WTG, load, BESS is shown below:



SIMULATION RESULTS AND DISCUSSION

Test Scenario: The 3-ph symmetrical electrical fault was created at 11kV bus at time = 2 sec and fault duration lasting for 100 milli seconds.

- The p.u. voltage profile at the 11 kV bus **without BESS** is shown below:

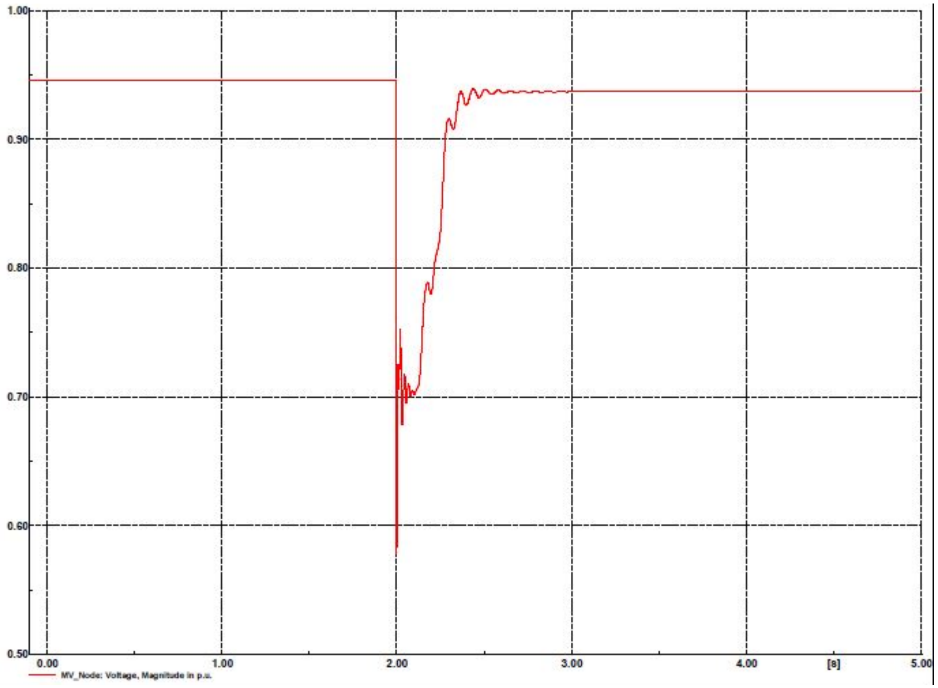


- During the fault, the p.u. voltage profile at 11 kV bus is reduced to 0.4 p.u.

SIMULATION RESULTS AND DISCUSSION (CONT..)

- The p.u. voltage profile at 11 kV bus **with BESS** is shown below:

Bus Voltage (p.u.)



Time (Secs)

- During the fault, with BESS voltage profile at 11 kV bus was improved from 0.4 p.u. to 0.7 p.u.

CONCLUSIONS

- BESS stores the excess power from RE sources during higher penetration time and discharges during lesser penetration time.

- BESS improves the voltage profile from 0.4 p.u. to 0.7 p.u. during the fault.

- Role of BESS in improving the other PQ issues are being investigated is under progress.

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THANK YOU