Predictive Short-Term ORPD in Large Wind Farms for Minimization of Losses and OLTC Tap Movements

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***Abstract*—With the increasing wind power penetration stringent grid codes related to frequency, power quality, reactive power support and fault ride through conditions are imposed. Optimal Reactive Power Dispatch (ORPD) in wind farm level is essential for meeting the grid code related steady state reactive power requirements at the Point of Common Coupling (PCC). In this process the On-Load Tap Changer (OLTC) tap adjustments are required, to maintain the collector grid voltage profile within the limits. Due to highly stochastic nature of wind power generation, continuous regulation of OLTC tap will increase operational and maintenance cost of transformer. To address this issue, this paper propose a predictive short-term ORPD within a wind farm using a Hybrid Particle Swarm Optimization (HPSO). The current time interval reactive power settings are decided based the optimization carried over multiple time intervals, considering the corresponding wind power forecasts and Unit Adjustment Cost (UAC) of the OLTC tap movements. Analysis is carried simulating a large size practical offshore wind farm. The results show that the OLTC action can be minimized with a reasonably accurate wind power forecasts for few time step intervals.**

I. Introduction

The new grid codes impose, active and reactive output control facilities on wind turbines such as to enable them to maintain steady frequency and reactive power support, as well as to come up under fault ride through transient conditions. For this wind farm level optimal dispatch of reactive power settings of turbines, OLTC transformer and other compensating devices is required to meet the grid code in terms of steady state reactive power injection in to PCC. OLTC transformer is the most important element in the wind farm and failure of it may cause stoppage of power supply and huge revenue loss. In the process of optimal dispatch of various control settings, OLTC transformer experiences huge wear and tear due to tap switching. Tinney et al. [1], for the first time, addressed the necessity to reduce the number of control actions in meeting the optimal power flow in a power system. A similar type of study is also carried out in [2]. Recently, Capitanescu et al. [3], have addressed this problem, and proposed an approach which relies on the computation of sensitivities of the objective function and inequality constraints with respect to the control actions. Finally, a subset of controls allowed to move in the OPF is determined, by solving sensitivity-based mixed integer linear programming problem. An approach, based on short-term (for one day) scheduling for reactive power controllers similar to that of unit-commitment, can also be seen in [4]. However, the restriction of control actions in a conventional power system has not gained much interest due to slow variation in operating point/power demand.

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In contrast, it is not the same in case of the intermittent wind power generation, where more frequent OLTC action takes place. Very few works are reported on Optimal Reactive Power Dispatch considering the minimization of OLTC action within a wind farm. In [5], a short-term optimal control is proposed to reduce the operation cost of the on-load tap changing transformers by reducing the short-term tap changes. However, the entire wind farm is treated as a single unit equivalent of wind farm capacity, and the collector grid system is approximated by parallel connected cables. Daniel Opila et al. [6] proposed a stochastic dynamic programming to incorporate the uncertain future knowledge. Erlich et al. [7], have used mean variance mapping optimization for solving the reactive power control of wind farms. It is noticed that these research works are performed out either on a small wind farm or approximation in wind farm modelling. In this research work, a practical large scale off-shore wind farm with collector grid modelling is carried out. Further, in addition to loss minimization, OLTC tap movements are restricted through short-term ORPD carried out for few time steps ahead, considering future wind power predictions.

II. Problem Formulation

A. System Layout and Description

The schematic diagram illustrating the concept of short-term ORPD problem within the wind farm is shown in Figure 1. The main objective is to determine the optimal reactive power settings of wind turbines, compensating devices and OLTC setting at the current time step based on future wind power predictions, so that the OLTC action can be minimized for unforeseen sudden variation in the wind power generation. For this, the future wind power forecasts for few time steps ahead in 10 minutes resolution are taken as inputs.

In this research work a large off-shore HornsRev1 wind farm of Denmark is simulated. The rating of the wind farm is

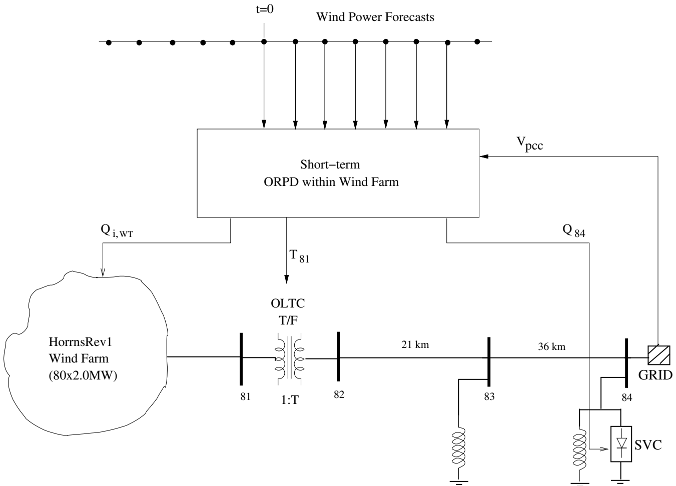

Fig. 1. The schematic diagram illustrating the short-term ORPD problem within the wind farm.

TABLE I
NETWORK PARAMETERS

Element Description	R_{ac} at 90°C (Ω/km)	X (Ω/km)	C (μF/km)	CCC (kA)
Collector system cables				
$150mm^2$, 3-core XLPE-Cu cable[a]	0.16	0.12252	0.19	0.446
$400mm^2$, 3-core XLPE-Cu cable[b]	0.063	0.10681	0.28	0.726
Transmission system cables				
$630mm^2$, 3-core XLPE-Cu cable(offshore)[c]	0.03679	0.00038	0.19	0.890
$1200mm^2$, 1-core XLPE-Al cable(onshore)[d]	0.01963	0.00035	0.26	0.970
Offshore Transformer	0.0058615+J0.0306977 p.u.			

[a] collector cables [b] collector system to bus 81 connecting cables
[c] 21 km offshore cable [d] 34 km onshore cables

160 MW consisting of 80 wind turbines of 2 MW each. Collector grid voltage is 33 kV, and transmission system voltage of 150 kV. The length of transmission cable to shore is 21 km and from shore to PCC is 34 km. The offshore substation has a 36/150 kV, 160 MVA OLTC transformer [8]. For simulation purpose, the transformer per unit impedance is assumed to be $Z_{p.u.} = 0.0058615 + \text{j}0.0306977$ and collector grid cable system parameters taken from [9], [10]. All the wind farm parameters used for simulation are tabulated in Table I. In the optimization process, the wind turbine reactive power output limit are obtained from P-Q chart and Grid code requirement in terms of steady state reactive power injection at PCC is modelled as shown in Figure 2 suggested by Energinet.dk, Denmark [11], wherein 0.1 p.u reactive power is to be injected while rated power is being delivered. At any other operating point the reactive power output must be within the control band.

B. Objective Function

The objective of the problem is to minimize the total cost, including the cost of energy loss in the wind farm and the

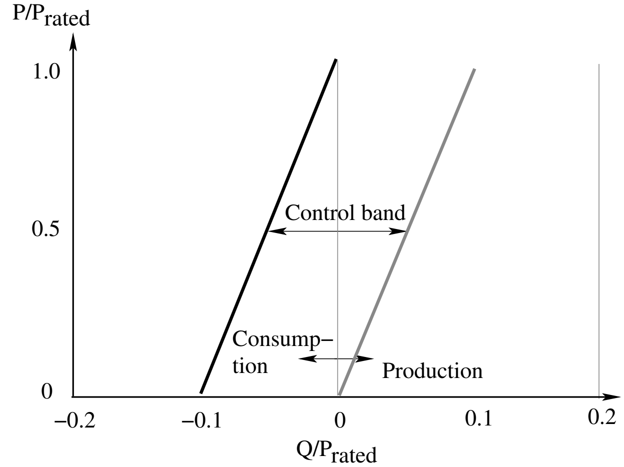

Fig. 2. Reactive Power Regulations at PCC.

costs of adjusting the discrete control devices over a length of time intervals considered, which can be formulated as:

$$f = min \sum_{t=1}^{M} \left(P_t \cdot \Delta t \cdot \beta + \mathbf{C}_A^T \cdot \Delta \mathbf{u}_t \right) \qquad (1)$$

where

- $\mathbf{t}$ time interval;
- Δt the time span of each interval (h);
- $\mathbf{M}$ the number of forecast time intervals;
- $\mathbf{C}_A$ UACs in (\$/times) of OLTC tap changer $\mathbf{C}_A \in \mathbb{R}^{\mathcal{T}}$, $\mathcal{T}$ denotes the set of OLTC transformers in the system;
- $\Delta \mathbf{u}_t$ change in number of OLTC tap positions (times) from previous time step to current time step and defined as; $\Delta \mathbf{u}_t = |\mathbf{T}_t - \mathbf{T}_{t-1}|$ and $\mathbf{T} \in \mathbb{R}^{\mathcal{T}}$;
- β electricity price (\$/kWh);
- P_t the active power loss (kW) in the transmission network in interval t and can be given as;

$$P_t = \mathbf{e}_t^T \mathbf{G}_t \mathbf{e}_t + \mathbf{f}_t^T \mathbf{G}_t \mathbf{f}_t; \qquad (2)$$

where $\mathbf{e}$ and $\mathbf{f}$ are column vectors representing the real and imaginary values of optimal bus voltages. $\mathbf{G}$ denotes the conductance matrix and the subscript t denotes the corresponding time interval.

C. Constraints

The above function is subjected to power flow equality constraints, and the physical and operational limits under each time interval are as follows:

$$\left. \begin{array}{c} \mathbf{g}(\mathbf{u}_t - \mathbf{x}_t) = 0 \\ Q_t^{PCC_{spe}} - Q_t^{PCC_{ref}} = 0 \\ \mathbf{u}_t^{min} \leq \mathbf{u}_t \leq \mathbf{u}_t^{max} \\ \mathbf{x}^{min} \leq \mathbf{x}_t \leq \mathbf{x}^{max} \end{array} \right\} \text{ for } t = 1, \ldots, M \qquad (3)$$

where

- $\mathbf{u}$ denotes control variables $\mathbf{u} = [\mathbf{Q}_G, \mathbf{Q}_C, T]^T$;
- $\mathbf{x}$ represents dependent variables $\mathbf{x} = [\mathbf{V}, \mathbf{I}]^T$;

g denotes the power flow equality constraints given as
$\mathbf{G}_{i:}(e_i\mathbf{e} + f_i\mathbf{f}) + \mathbf{B}_{i:}(f_i\mathbf{e} - e_i\mathbf{f}) - P_i^{spe}, \ \ \forall i \in \tilde{\mathcal{N}},$
$\mathbf{G}_{i:}(f_i\mathbf{e} - e_i\mathbf{f}) - \mathbf{B}_{i:}(e_i\mathbf{e} + f_i\mathbf{f}) - Q_i^{spe}, \ \ \forall i \in \mathcal{L},$
with min-max limits on reactive power injections, OLTC taps, bus voltages and line loadings

$$\begin{bmatrix} \mathbf{u}^{min} \\ \mathbf{x}^{min} \end{bmatrix} = \begin{bmatrix} Q_i^{min}, \ i \in \mathcal{G} \\ Q_i^{min}, \ i \in \mathcal{Q} \\ t_i^{min}, \ i \in \mathcal{T} \\ V_i^{min}, \ i \in \mathcal{N} \\ I_i^{min}, \ i \in \mathcal{B} \end{bmatrix}, \begin{bmatrix} \mathbf{u}^{max} \\ \mathbf{x}^{max} \end{bmatrix} = \begin{bmatrix} Q_i^{max}, \ i \in \mathcal{G} \\ Q_i^{max}, \ i \in \mathcal{Q} \\ t_i^{max}, \ i \in \mathcal{T} \\ V_i^{max}, \ i \in \mathcal{N} \\ I_i^{max}, \ i \in \mathcal{B} \end{bmatrix}$$

where

$\tilde{\mathcal{N}}$	denotes the set of all buses except slack bus;
$\mathcal{L}$	denotes the set of load buses;
$\mathcal{G}$	denotes the set of generator buses;
$\mathcal{Q}$	represent the set of buses with shunt reactors/capacitors;
$\tilde{\mathcal{N}}$	denotes the set of all buses except slack bus;
$\mathcal{B}$	the set of cable segments;
$\mathbf{Q}_G$	reactive power outputs of wind turbines $\mathbf{Q}_G \in \mathbb{R}^{\mathcal{G}}$;
$\mathbf{Q}_C$	reactive power outputs of variable shunt reactors/capacitors $\mathbf{Q}_C \in \mathbb{R}^{\mathcal{Q}}$;
$\mathbf{T}$	OLTC transformer tap settings $\mathbf{T} \in \mathbb{Z}^{\mathcal{T}}$;
$\mathbf{V}$	bus voltages $\mathbf{V} \in \mathbb{R}^{\mathcal{N}}$;
$\mathbf{I}$	branch currents $\mathbf{I} \in \mathbb{R}^{\mathcal{B}}$;
$\mathbf{G_{i:}}$	the i^{th} row of bus conductance matrix $\mathbf{G} \in \mathbb{R}^{\mathcal{N}\times\mathcal{N}}$;
$\mathbf{B_{i:}}$	the i^{th} row of bus susceptance matrix $\mathbf{B} \in \mathbb{R}^{\mathcal{N}\times\mathcal{N}}$.

D. Unit Adjustment Cost

In conventional power system, while implementing reactive power dispatch, the unit adjustment cost of control devices are usually not considered due to slow variation in the operating point. However, in case of wind power generation, it is highly stochastic and intermittent in nature leading to frequent action of OLTC. This motivates to consider the unit adjustment cost of an OLTC transformer in the ORPD problem within the wind farm and can be approximately estimated as [12],

$$C_{Ai} = \frac{1}{T_{Ti}} \left(F_{Pi} + \frac{t_{Ti} - t'_{Ti}}{t_{Ti}} \cdot F_{Ti} + \frac{t'_{Ti}}{t_{OTi}} \cdot F_{OTi} \right) \quad (4)$$

where

T_{Ti}	manufacturer design value of the total allowable adjustments of the OLTC of transformer i (times); $i \in \mathcal{T}$;
F_{Pi}	Cost of OLTC of transformer i (\$);
t_{Ti}	life expectancy of the transformer i when the tap never adjusted (years);
t'_{Ti}	life expectancy of the transformer i after the tap changed T_{Ti} times (years);
F_{Ti}	cost of transformer i (\$);
t_{OTi}	overhaul period of the OLTC of transformer i (years);
F_{OTi}	unit overhaul cost of OLTC of transformer i (\$).

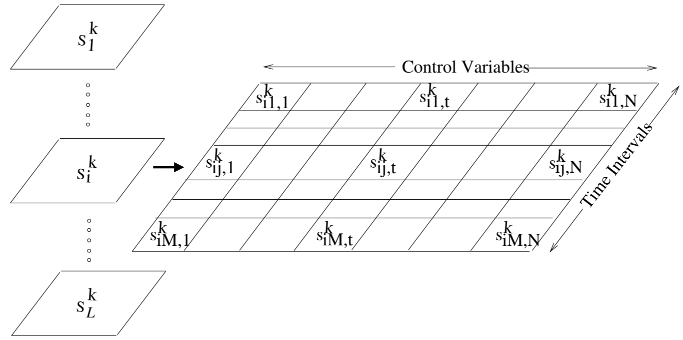

Fig. 3. Structure of HPSO particles for short-term ORPD problem within wind farm.

If defining $C'_A = \frac{C_A}{\beta\Delta t}$ as the unit adjustment cost vector based on power (kW/times), then the objective function (Equation (1)) can be transformed as follows:

$$f' = \frac{f}{\beta\Delta t} = min \sum_{t=1}^{M} \left(P_t + \mathbf{C}'^{T}_A \cdot \Delta\mathbf{u}_t \right) \quad (5)$$

whose objective is to minimize the sum of the active power loss in the collector grid and the cost of adjusting OLTC position represented during all the time intervals. Although, the UAC of OLTC transformer can be calculated theoretically by (4), it is difficult and impractical to determine an exact value of the UAC. Typically, the estimate of UAC of OLTC varies from 3-10 kW/times [12].

III. Implementation of HPSO for Short-Term ORPD Problem

Short-term ORPD is an extension of authors earlier work [13], wherein ORPD is carried based on current time interval and loss minimization was the only objective. However, the problem of short-term optimal reactive power dispatch within a wind farm includes determination of optimal settings of all wind turbines, variable shunt reactors/capacitors along with the OLTC setting based on optimization carried for multiple steps ahead taking wind power forecasts as inputs. Wherein the objective function includes minimization of the active power loss and OLTC tap movements as stated in (5). To address this the structure of a particle in such case will be

$$\mathbf{s}_i \in \left[\mathbb{R}^{(\mathcal{G}+\mathcal{Q})\times M}, \mathbb{Z}^{\mathcal{T}\times M}\right]; \ \forall i \in L, \quad (6)$$

where L denotes the number of particles, and M represents the number of look-ahead time intervals for which optimization is carried out. A typical structure of the particles is depicted in Figure 3, where N represents the total number of control variables given by $N = \mathcal{G} + \mathcal{Q} + \mathcal{T}$. Similarly, if particle velocities are represented by

$$\mathbf{v}_i \in \left[\mathbb{R}^{(\mathcal{G}+\mathcal{Q})\times M}, \mathbb{Z}^{\mathcal{T}\times M}\right]; \ \forall i \in L \quad (7)$$

then, the updations of its new velocity and position are given by

$$v_{i,j,m}^{k+1} = \chi \cdot \Big\{ v_{i,j,m}^{k} + C_1 \cdot rand_1 \left(P_{BEST\,i,j,m}^{k} - s_{i,j,m}^{k} \right) + C_2 \cdot rand_2 \left(G_{BEST\,j,m}^{k} - s_{i,j,m}^{k} \right) \Big\}, \quad (8)$$

$$s_{i,j,m}^{k+1} = s_{i,j,m}^{k} + v_{i,j,m}^{k+1}, \quad \forall i \in L, \ \ \forall j \in N, \ \ \forall m \in M \quad (9)$$

where

$$\chi = \frac{2}{\left| 2 - C - \sqrt{C^2 - 4C} \right|}, \ \ C_1 + C_2 = C > 4 \quad (10)$$

where, k denotes the iteration number; C_1 and C_2 are two positive acceleration constants; $P_{BEST\,i}$ and G_{BEST} represent the best solution attained by each individual particle and among all particles so far. $rand_1$ and $rand_2$ are two randomly generated numbers between $[0, 1]$;

To ensure a good exploration in the initial stage and proper convergence in final stage of the algorithm, the absolute change in particle velocities in each iteration is clipped to a varying maximum velocity ($\mathbf{v}_{max}$) which decreases with the increase in iteration defined as

$$\mathbf{v}_{max}^{k} = \begin{cases} \mathbf{v}_{max}^{start} - \frac{k}{\frac{1}{3}k_{max}} \left(\mathbf{v}_{max}^{start} - \mathbf{v}_{max}^{end} \right); & k \leq \frac{1}{3}k_{max} \\ \mathbf{v}_{max}^{end}; & otherwise \end{cases} \quad (11)$$

where,

$$\mathbf{v}_{max}^{start} = (\mathbf{s}_{max} - \mathbf{s}_{min})/N_S, \quad (12)$$

$$\mathbf{v}_{max}^{end} = (\mathbf{s}_{max} - \mathbf{s}_{min})/N_E; \quad (13)$$

where k_{max} represents the maximum number of iterations, and N_S and N_E are constants which control the starting and ending maximum velocity of the particles. $\mathbf{s}_{min}$ and $\mathbf{s}_{max}$ represent the lower and upper bound limits on control variables. Here, $\mathbf{v}_{max}^{k}$ is applicable for all time intervals. After the velocity updation each particle is now undergone for min-max limit checking in each dimension as

$$if \quad |v_{i,j}^{k}| > v_{max\,i,j}^{k} \quad then \quad |v_{i,j}^{k}| = v_{max\,i,j}^{k}. \quad (14)$$

Further, the discrete OLTC tap, during initialization and after velocity update in each iteration, is rounded to the nearest decimal integer value of 0.01 by utilizing the rounding operator.

Dealing with the constraints is the difficult job in any optimization problem. There exists many techniques to handle constraints in literature, in this work, a penalty factor method is employed as suggested in [14]. The active power as given in (2) is now modified as

$$P_t + \lambda_V \sum_{i \in \tilde{\mathcal{N}}} \left| V_{i,t} - V_{i,t}^{viol} \right| + \lambda_I \sum_{i \in \mathcal{B}} \left(|I_{i,t}| - I_i^{max} \right), \quad (15)$$

where $V_{i,t}^{viol}$ represents the i^{th} bus-voltage violating the bus min-max voltage constraint limits, defined as

$$V_{i,t}^{viol} = \begin{cases} V_i^{min}; \ V_{i,t} < V_i^{min} \\ V_i^{max}; \ V_{i,t} > V_i^{max}, \end{cases}$$

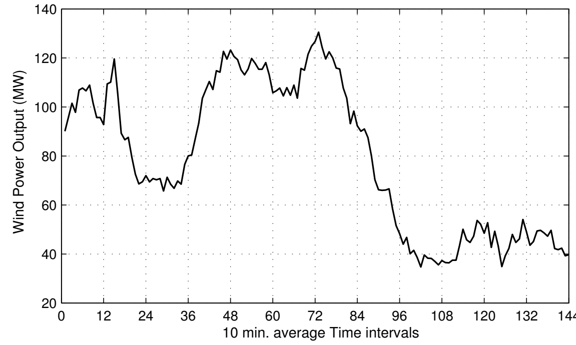

Fig. 4. Wind power time series with 10 minutes average time intervals for 24 hours.

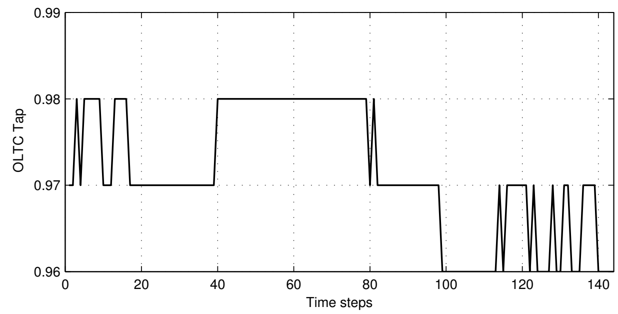

Fig. 5. Optimal OLTC tap for 144 sample time intervals with ORPD at current time interval.

and I_i^{max} is the maximum current loading of i^{th} cable segment. λ_V and λ_I are the penalty factors.

The effect of change in OLTC tap setting is very much local in nature in conventional power system. However, there is an overall effect on collector grid voltage in the case wind farms. Moreover, stochastic nature of wind power output, the penalty factor on voltage constraint violation has to be properly chosen to ensure the optimal operation under all wind power generation conditions. For better convergence, a particle violating the voltage constraint is penalized in proportional as,

$$\lambda_V = \begin{cases} 10^{-5}; & N_V \leq 4 \\ 10^{-4}; & 4 < N_V \leq 8 \\ 10^{-3}; & 8 < N_V \leq 16 \\ 10^{-2}; & 16 < N_V \leq 30 \\ 10^{-1}; & N_V > 30 \end{cases}$$

where, (N_V) denotes the number of voltage constrain violations and $\lambda_I = 10^{-2}$ is considered in this work.

IV. Results and Discussion

In short-term ORPD problem, the optimization is carried over a multiple time intervals. The wind power profile with sampling rate of 10 minutes as shown in Figure 4 for one complete day (144 samples) is used for the simulation.

At each time step, the forecasts up to next 18 look-ahead time steps are available from the forecast model. The short-term ORPD at each time step is carried out considering the current and future wind power forecasts for determination of

TABLE II
THE SHORT-TERM WIND POWER FORECAST MODEL ERRORS (NORMALIZED TO RATED INSTALLED CAPACITY) MAE AND RMSE UP TO 10 LOOK-AHEAD TIME STEPS

Look-ahead step	MAE	RMSE
1	1.7	2.3
2	2.0	2.7
3	2.2	3.0
4	2.3	3.1
5	2.5	3.3
6	2.6	3.5
7	2.8	3.7
8	3.1	4.0
9	3.3	4.3
10	3.5	4.5

optimal OLTC tap at current time step. This process for each time step is repeated till the end of the day.

For the base case, the ORPD for the current time step is performed and repeated for all 144 sample time intervals. Figure 5 illustrates the variation of OLTC tap with the wind power variation, when wind farm is satisfying the grid code requirements through ORPD for the current time interval. It is noticed that the total 23 number of OLTC tap changer movements have taken place under base case ORPD. This could lead to heavy operational and maintenance cost on OLTC transformer.

To minimise the frequent OLTC operation, a short-term ORPD is carried out for few multiple time intervals ahead considering the UAC of OLTC action. Although, short-term ORPD carried for longer time horizons are beneficial in minimizing the OLTC actions, the simulation time increases with the increase in number of time intervals. Also with the increase in forecast horizon, the wind power forecast error also increases, and may have a counter effect on the solution. Here, the short-term ORPD is carried out for 4 and 8 time step intervals. In each case, the short-term ORPD is carried out considering different UAC (C'_A equal to 0.5, 1.0, 2.5, 5.0, and 7.5 kW/times) of OLTC action.

Wind power forecast model as described in [15] is used for predicting wind power multiple steps ahead outputs with 10 minutes resolutions. For the sake of convenience, the forecast model errors up to 10 time steps ahead are given in Table II. The wind power forecast model has the forecast RMSE (normalized to wind farm rating P_{inst}= 176.8 MW) of 2.3%, 3.1% and 4% at 1,4, and 8 look-ahead time intervals, respectively.

In each run of short-term ORPD, the PCC bus voltage is assumed constant for all time intervals and taken as 1.0 p.u. The min-max limits on bus voltages are taken as 0.95 p.u. and 1.05 p.u. values, respectively. However, based on the value of wind power output forecast for each time interval obtained from the forecast model, the corresponding max limits on reactive power generation and absorption for each wind turbine are to be calculated from the P-Q chart, for each time interval.

In addition to minimization of OLTC action, the short-term ORPD is aimed at minimization of collector grid active power loss and simultaneously meeting the grid code in terms of steady state reactive power requirement at PCC, according to the Danish grid code, Energinet.dk as illustrated in Figure 2.

In this work, the HPSO parameters are set as; the number of particles 50, maximum iterations 500, control variables on maximum velocity N_S and N_E are set to 20 and 100. The acceleration constants C_1 and C_2 are set to 2.01 each. However, the dimension of each HPSO particle is $M \times N$ and it varies with the number of time intervals M as shown in Figure 3.

Figures 6 and 7 show the optimal OLTC tap positions obtained through short-term ORPD carried for 4 and 8 time intervals with different UACs. It is observed that in case of short-term ORPD carried out for 4 time intervals, a gradual decrease in number of OLTC actions from 19 to 11 happened with the increase in UAC varied from 0.5 kW/times to 2.5 kW/times. However, there is no further reduction in number of OLTC actions are noticed for UAC above 2.5 kW/times. This is mainly due to constraint violations.

Table III summerizes the number of tap actions in each case with different UAC. Further, it is noticed that, with the increase in forecast errors with the forecast horizon, have no improvement in OLTC tap reductions but unnecessary extra tap switching may happen. This is clearly observered in the case of short-term ORPD carried out for 8 time intervals, the

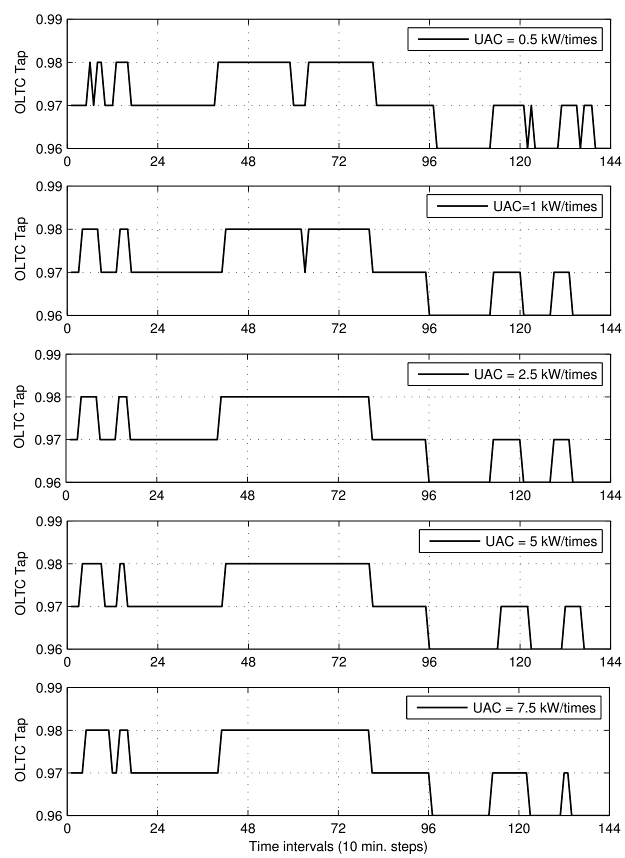

Fig. 6. Optimal OLTC Tap positions obtained through short-term ORPD carried out for 4 time intervals with different UAC values

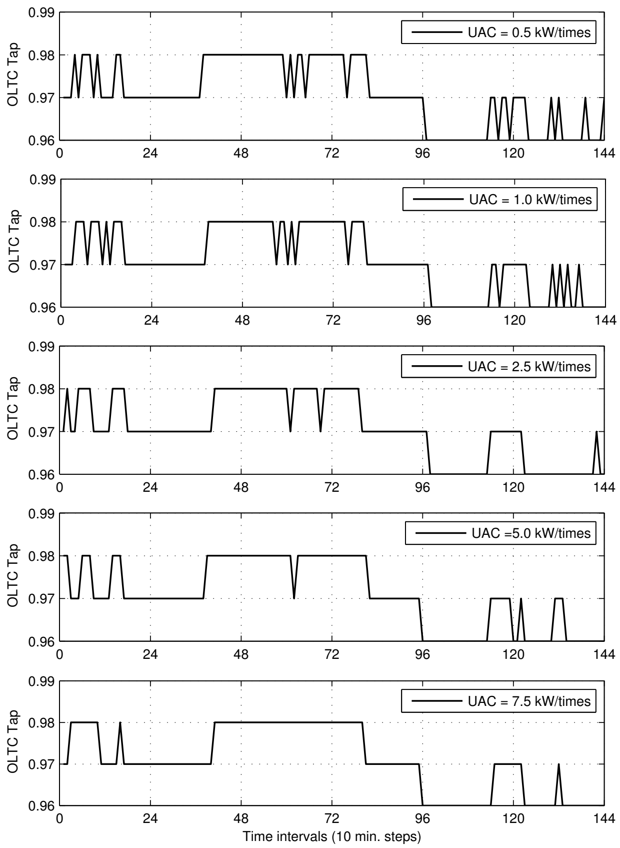

Fig. 7. Optimal OLTC Tap positions obtained through short-term ORPD carried out for 8 time intervals with different UAC values.

forecast errors for longer look-ahead intervals have diminished the advantage of carrying short-term ORPD for longer time intervals.

However, the results show that the short-term ORPD problem, carried up to few step ahead with reasonable forecast accuracy, will ensure reduction in the OLTC action against the stochastic variation in wind power generation and simultaneously meeting the grid code.

TABLE III
NUMBER OF OLTC TAP ACTIONS

	no. of OLTC actions in Short-term ORPD	
UAC (kW/times)	with 4 time interval	with 8 time intervals
0.5	19	32
1.0	13	31
2.5	11	17
5.0	11	16
7.5	11	11

V. CONCLUSIONS

A short-term Optimal Reactive Power Dispatch (ORPD) for minimizing the number of OLTC operations, simultaneously meeting the grid code requirements has been developed in this research work. The Unit Adjustment Cost (UAC) of OLTC operation has been modelled and considered in short-term ORPD problem so that OLTC operations can be minimized for sudden variations in the wind power generation. To do this, the future wind power predictions for few multiple steps with 10 minutes resolutions are required, and are obtained from the short-term wind power forecast model. The grid requirements of HornsRev wind farms in terms of reactive power requirements are taken in to consideration. To show the effectiveness of the proposed method, the optimization is carried out for different UAC values of OLTC. Further, to know the effect of future wind power prediction errors on the short-term ORPD, optimizations are carried out for 4 and 8 time steps ahead. The results show that good number of OLTC tap movements can be reduced through short-term ORPD carried with few step ahead wind power forecast inputs.

VI. ACKNOWLEDGEMENT

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