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A PEAK SHAVING SOLUTION FOR ELECTRIFIED RTG CRANES

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Abstract - The electrical energy demand in ports has been increasing as a result of the shift from diesel RTG cranes to electrified RTG cranes, which were introduced to increase energy saving and reduce gas emissions.Consequently, the electrical energy demand in ports substation has been rising because of this shifting. This paper aims to highlight and address the peak demand problem in networks of electrified RTG cranes and attempts to reduce peak demand and the electricity bill by using peak shaving strategy energy.

Keywords - RTG crane, Peak shaving, Battery energy storage.

I. INTRODUCTION

In order to reduce the carbon gas emissions and operation costs inside the ports, diesel RTG cranes are being replaced with electric RTG cranes.[1] [2]. The use of electrified RTG cranes can reduce maintenance and repair parts costs by around 30% [3] and green gas emissions by between 25% and 70% compared to diesel RTG cranes [1] [4] [5]. As a result, shifting from diesel to electrified RTG crane will increase the total electrical energy consumption and peak demand at the port substations. In this situation, ports may need an extra substation or to upgrade the electrical infrastructure at the port to cover this rise in demand [5]. A number of methods have been considered to increase the energy savings from using RTG cranes including hybrid energy sources. Hybrid power generation are used in order to increase the energy savings and reduce the gas emissions in RTG crane systems. Research studies have focused on using regenerative energy during the crane lowering mode to charge the energy storage rather than allowing it to be dissipated as heat through dump resistors and discharging it during peak demand when the crane starts lifting [6]. Various energy storage technologies have been used with RTG crane systems such as batteries [7] [8], flywheels [4], supercapacitors [5] and hybrid energy storage systems (supercapacitors and batteries) [7].

In general the energy storage system control strategies aim to minimise energy costs, reduce peak demand and support the power distribution network. Developing a suitable control strategy to control the energy storage power flow is critical to optimise energy flows, reduce energy cost and limit the required size of the energy storage [6]. Different control strategies have been applied in RTG crane systems with hybrid power generation such as voltage level and power charging control. Controlling the DC link voltage in cranes systems is one of the most effective control techniques is used to increase energy savings by using the recovered energy from break resistors to charge the energy storage when the DC voltage becomes higher than the specific reference value [2] [5]. In [4], the power sharing control was used to control flywheel energy storage and increase the energy savings. In [8], the state of charge percentage was used to control the battery energy storage. When the State of Charge (SoC) of the battery energy storage was less than 50 %, the diesel generator in the RTG crane system started charging and the diesel generator turned off when the SOC was more than 80 % [8]. The minimum battery energy storage usage was fixed at 30 % SoC in order to increase the battery life time [8]. Much of the literature has focused on and discussed using energy storage systems with different control strategies to increase energy savings and reduce fuel consumption of the RTG crane itself by using the regenerative energy. In contrast, this research will attempt to use a peak shaving strategy to reduce the electricity bill peak demand at ports. In this paper, the differences between electricity price rates has been used to increase the electricity cost saving.

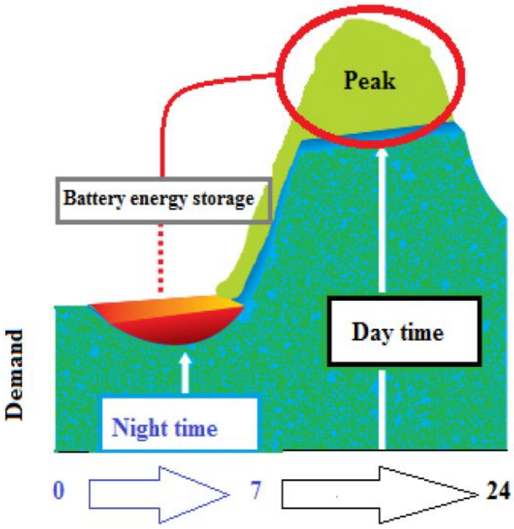

Fig.1. Peak shifting strategy [11].

II. MODELLING AND OF ELECTRIFIED RTG CRANE WITH ENERGY STORAGE.

A. Data collection

The electrified RTG crane data was collected from 6 different operation days at Port of Felixstowe, UK, from the 5th to the 10th of April, 2017. The collected data includes information for the three-phase active power and reactive power.

B. Electrified RTG crane model

In this paper, we develop a MATLAB Simulink model to describethe behaviour of the electrified RTG crane network at the Port of Felixstowe which is manufactured by Shanghai Zhenhua Heavy Industries (ZPMC). The electrified RTG crane model includes the main electric partsas follow, shown Fig.2 and Fig.3:

- Primarysubstation (33KV/11KV, 7.5MVA)
- Secondary substation (11KV/415V, 1.6MVA).
- The actual electrified RTG crane demand.
- Cables and conductor bar.
- Battery energy storage (located at the secondary side of substation : 415V).

Fig.2 RTG crane in Port of Felixstowe.

C. Battery energy storage

In order to select the battery energy storage size, the three-phase active power of e-RTG cranes is analysed. The average e-RTG crane demand is 22.2 KW and the peak power is around 358.96 KW produced when aheavy container (40Tonnes) is transported up. In [9] the typical average power of an RTG crane is 24.8 KW and peak demand equal to 292 KW. In this paper, the peak-to-average ratio was found to equal 16.5. This ratio means the RTG crane system highly suitable for using energy storage system with objective to minimize this ratio or maximize the load factor:

$$LF = \frac{P_a}{P_k}. \qquad (1)$$

Where LF is the load factor, P_a is the average load and P_k is the peak load in a given time period. In order to calcite the energy storage size, the typical average energy power (25 KW) has been used. The battery energy storage is expected to supply 1.75 to 2.25 hours RTG operational demand that may help to minimise the peak-to-average ratio to around 4.5. The capacity of energy storage is between 42 to 54 KWh based on the typical average energy power and expected working hours. To increase the operating life time of the battery energy storage device, the minimum SoC (State of Charge) is chosen at 0.3. Based on the SoC, the BESS capacity is between 140 to 180 KWh. For economy, the lithium battery capacity is 160KWh, for which rated current 250A [9].The peak battery discharge rate is equal to the peak demand 358 KW. The peak discharging current is:

$$I_{Bat\_peak} = \frac{P_{peak}}{V_{dc}} = 559\text{A, for } V_{dc} = 640 \text{ V.}$$

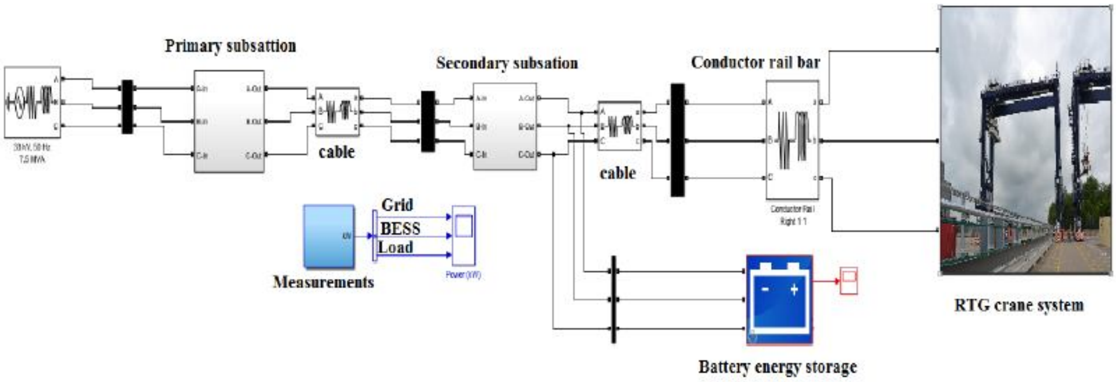

Fig.3. RTG crane simulation model.

The peak discharging current is 2.24 times the rated current of the lithium battery current. A specific supercapacitor type lithium battery (lithium iron phosphate batteries) having a high peak power capability is chosen to provide 2.24C discharge[9][10]. These batteries can support a 10C continues discharge current and 2C fast charge current [9][10]. In this paper, the temperature and ageing effect on the battery energy storage are not considered.

D. Control modelling

In this paper, the peak shifting technique has been used to reduce the energy cost by charging the battery energy storage during night time and discharge it during day time(when energy costs are cheaper). Also, the charging and discharging process aims to increase the peak demand reduction at the port substation. Table 1 present the electricity energy price at the Port of Felixstowe.

	Electricity energy price
Day rate(07:00 -24:00)	8.6387 p/KWh
Night rate (24:00 -07:00)	6.3301 p/KWh

Table 1: The electricity energy tariff at Port of Felixstowe.

1. Charging mode

Powerlevel control has been used in this paper to charge the battery energy storage during the night rate time, as seen in Fig.4, A PI controller generates a control signal value between1 and -1 based on the integral of the error and the instantaneous error of the power crane demand with respect to the chosen *reference value The PI controller has been widely used in industrial applications. In order to avoid charging the battery during the high peak load period, the energy storage only charges during the night rate time when the load* is under the reference load demand.The charging amount (P_C) during the charging period is equal to:

$$P_C = P_{ref} - P_{load} \quad (2)$$

where P_{ref} is the power reference and P_{load} is the actual power demand.

2. Discharging mode

The discharging mode is active during the time from 07:00 to 24:00 (day rate). The battery energy storage start discharging when the load exceeds the P_{ref} value. The P_{ref} in this paper is equal to 150 KW in order to reduce the peak to average value to around 4.5, which is economically accepted to use ESS [9]. The PI controller has been used to generate a control signal in this model.

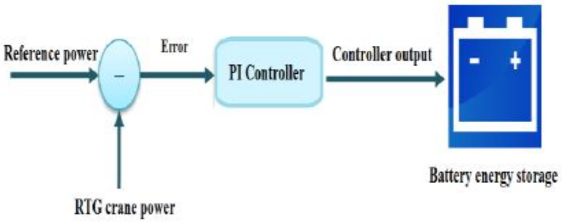

Fig.4. PI controller

III. RESULTS AND DISCUSSIONS.

The actual three-phase power demand from the 5th to the 10th of April, 2017 was applied to the electrified RTG crane model. The main targets of this paper are to increase the peak demand reductionby improving the load factor (minimize the peak to average value) and reduce the overall electricity cost.

1. Peak reduction

The RTG load demand, battery energy storage load and the substation load have been displayed in Fig.5 and Fig.6 to present the peak demand reduction. Fig.5. shows the results of control modelling during the day time rate (discharging mode). When the three-phase active power of electrified RTG crane was more than 150kW, the battery storage system starts discharging. This helped to remove the highloadvalues and reduce the demand to around 150kW. In addition, this reduction increases the energy cost saving by shiftting the high load to a lower price period.

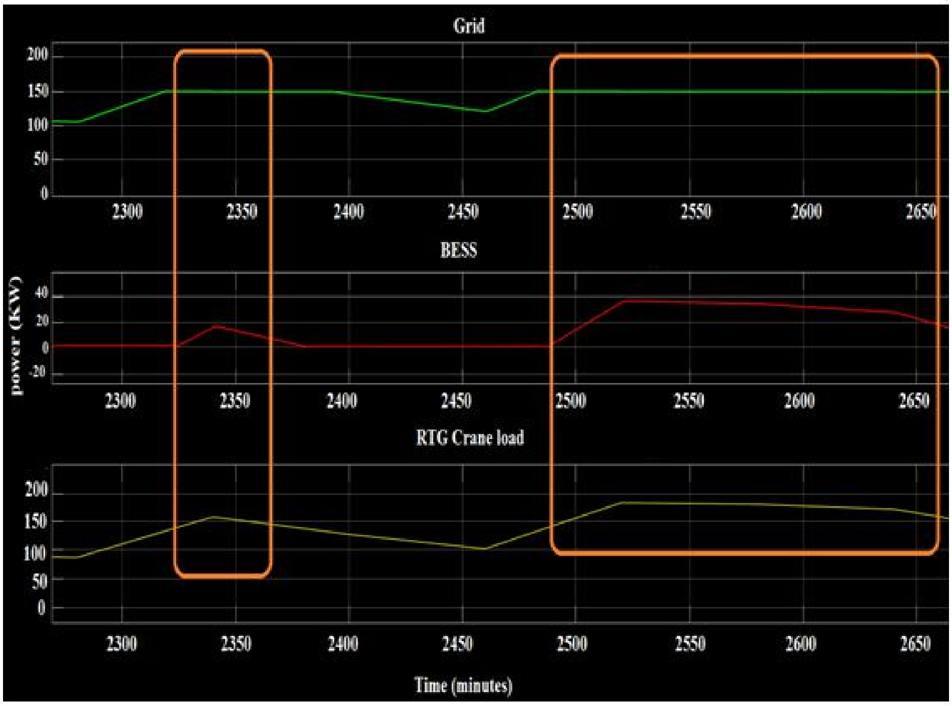

Fig.5. RTG crane power simulation result during discharging mode (Day rate).

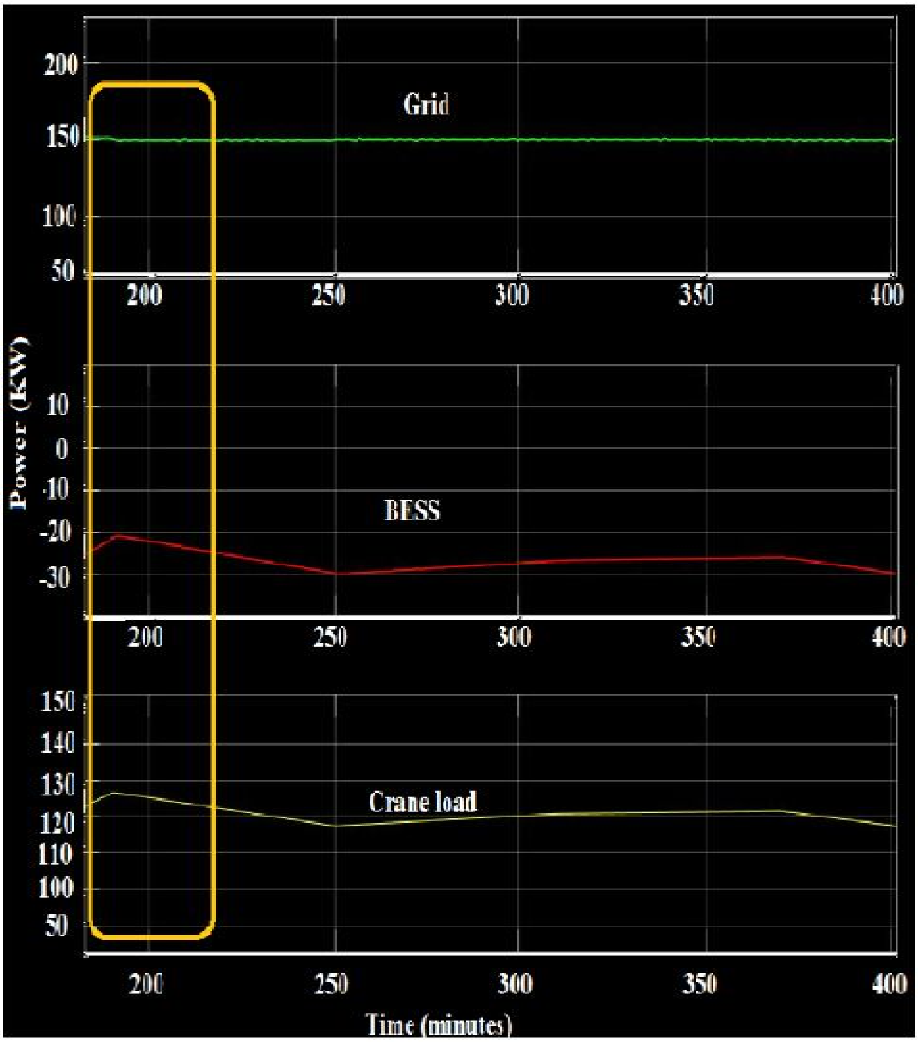

Fig.6. RTG crane power simulation result during charging mode (Night rate)

The battery system in this paper starts charging when the RTG crane active load is below the reference power value (150KW) and the charging mode is active only during the night rate time period (24:00 to 07:00), as seen in Fig.6. As discussed in section II, equation (2) has been used to avoid increasing the grid demand and exceeding the reference power level creating a new peak point.

2. Electricity energy cost

The electric energy at secondary substation that is consumed by a single electrified RTG crane is calculated in equation (3).

$$E = P.T \quad (3)$$

where E is the electric energy in KWh, P is the power in KW and T is the time in hours.
The electric energy that is consumed by the RTG crane has been calculated by using the measured power of RTG crane. Fig.7shows the daily energy consumption over the testing period. The RTG crane consumed lower energy in days 1,2 and 6 compered to days 3,4 and 5.This is mainly related to the number of working hours of RTG crane which was higher in days 3,4 and 5.

In order to analysis the hourly energy consumption, 2-D histogram distribution for the energy consumption and hour of the day is displayed in Fig.8. This figure indicates that the highest frequency of hourly energy consumption is for the energy rating between 0KWh to 40KWh. Fig.8 shows that the frequency of energy consumption increases during the day rate time compered to night time for this set of data.

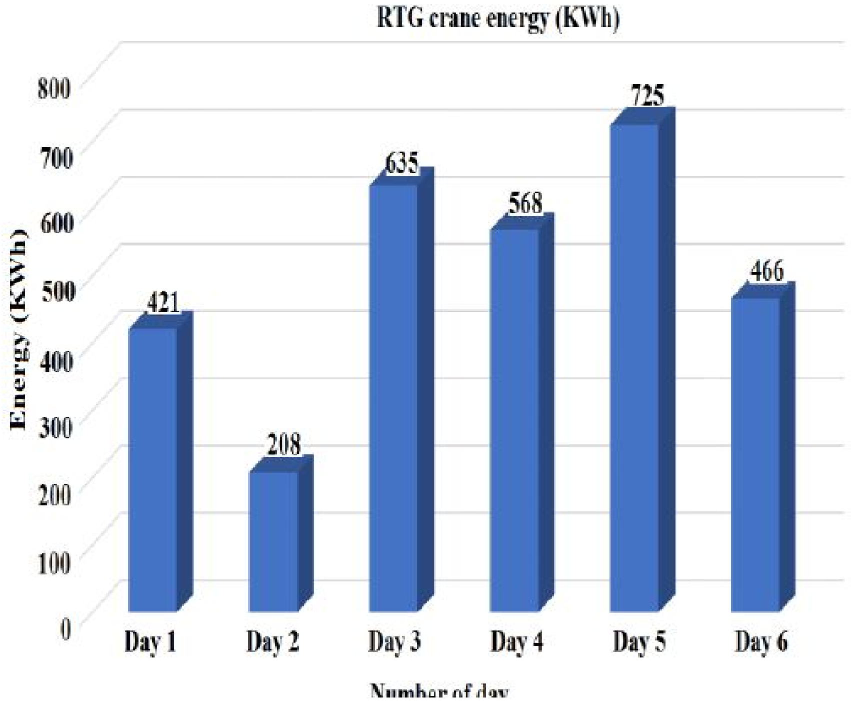

Fig.7. Daily RTG crane energy in KWh.

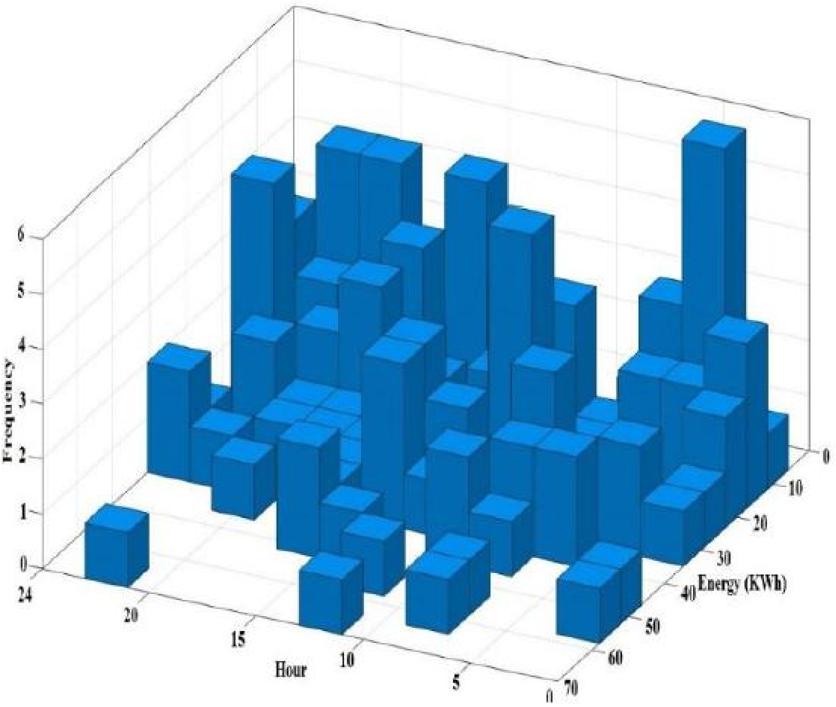

Fig.8. 2-D histogram of the hourly RTG crane energy in KWh and time (Hour).

The using of battery energy storage in this paper aim to reduce the peak demand load and electrical energy cost=by charging the battery during the night time and dischargingenergy over the day time. Fig.9 show the amount of energy which is shifted from the day time rate to night time rate in order to reduce the electricity energy cost.

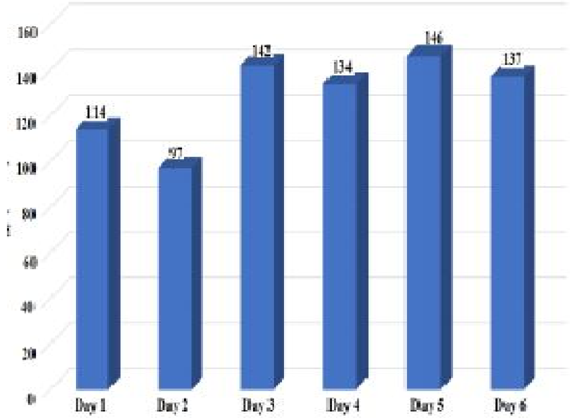

Fig.9. Daily RTG crane energy in KWh shifted from day to night rate time.

The total amount of shifted energy over 6 days is 770KWh with daily average 128KWh. From Fig.8 the average energy consumption of RTG crane during normal operation day is equal to 380KWh. In this paper, the daily average shifted energy will lead to yearly savings of around £1078.4 of £10671.7 the yearly electricity bill. So savings 128KWh daily will result in reducing the yearly electricity cost of operating a single electrified RTG crane by around 10.2%.

CONCLUSIONS

In this paper a peak shaving solution for electrified RTG cranes has been presented. This method aims to increase the peak demand reduction and reduce the electricity energy cost. A battery energy storage system has been used to store the energy during the night time and discharge it during the day time. With an average energy 128KWh shifted every day, the peak shaving strategy will help to save £1078.4 of £10671.7 every year. The battery energy storage devicewill help to reduce the peak demand and help to avoid upgrade the electrical infrastructure to meet peak demand especially when connecting more than one crane to a seconder substation.

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