Optimal Control of Uninterruptible Power System with Diesel Generator

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***Abstract* — Conditions to minimize fuel consumption in uninterruptible power system with diesel generator at variable load are obtained. Estimation of fuel consumption at acceleration and braking stages of diesel generator was executed taking into account the cost of battery charge. Minimization of fuel consumption required for the transition process is achieved by adjusting the position of the fuel valves. Minimization of fuel consumption is shown for diesel generator HATZ 1D90-Supra.**

Keywords— storage battery; uninterruptible power system; fuel consumption; diesel generator; profit

I. INTRODUCTION

Uninterruptible power systems (UPS) based on using multiple uninterruptible power supply additionally to power network in common scheme allow to provide reliable power supply for the loads [1]. The most common in UPS is combination of diesel generator (DG) and storage battery (SB) [2]. In such case realization of control allowing the most efficient use of DG resources, i.e. minimization of fuel consumption, is an important task.

II. OPERATION OF POWER SYSTEM WITH DIESEL GENERATOR

Typical structure of UPS with DG shown in Fig. 1.

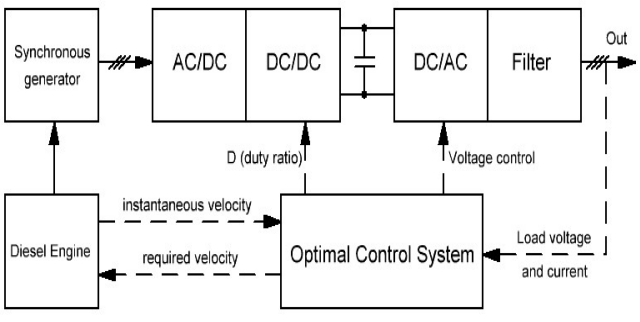

Fig.1. Structure of uninterruptible power systems with diesel generators

Let's consider operation of uninterruptible power supply system with DG and SB (Fig.2).

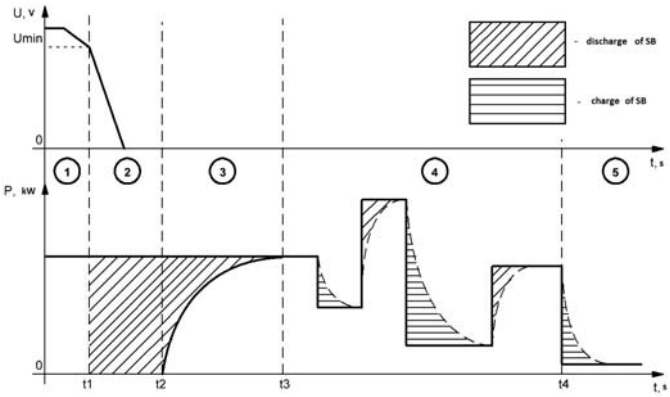

Fig.2. Operation steps of the DG and SB after disconnecting of power network (horizontal hatching marks SB charge, angle hatching marks SB discharge intervals)

In the moment t_1 power network voltage is reduced below acceptable level. Then at the interval $[t_1;t_2]$ the load is supplied by SB. At the same time DG performs all necessary actions for it's starting. If power network voltage is not restored to the required level, then in the moment t_2 DG starts working and achieves necessary power P_o in the moment t_3. At the same time SB discharges to the load (Fig.1). At next interval $[t_3;t_4]$ DG accelerates or decelerates depending on load requirements, and SB discharges or charges accordingly. At the last interval $[t_4;\infty]$ diesel generator decelerates to some minimum value of power in order to maintain the charge level of SB, or turns off if power network voltage appears.

At each of the considered time intervals it is important to maintain optimal work of diesel generator with minimization of fuel consumption.

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III. Optimal Control For Minimization Of Fuel Consumption

To solve the problem of fuel consumption minimizing let's consider interval $[t_3; t_4]$ where diesel generator accelerates and decelerates (Fig.1). DG is described by the equation of first order with mechanical constant τ of the system "DG-synchronous generator", P_m is the maximum power that can be obtained at assigned value of relative fuel consumption $B'(P_m)$ [2, 3]. Relative fuel consumption is described by the equation:

$$B'(P_m) = a \cdot P_m^2 + b \cdot P_m + c \quad [l/(kW \cdot h)]$$

where the coefficients a, b, c are determined by the type of diesel engine. Total fuel consumption for DG acceleration taking into account SB charge is defined as:

$$B_{roz} = B'(P_m) \cdot P_m \cdot T_0 - \frac{1}{\eta} \cdot B'(P_m) \cdot (P_m \cdot \ln\left(\frac{P_m - P_0}{P_m}\right) - P_0) \cdot \tau,$$

where T_0 – time of transient process, η – efficiency of charge controller for SB.

Fuel consumption at DG deceleration interval is defined similarly. Dependences of fuel consumption for DG HATZ 1D90-Supra from acceleration power (curve 1) and deceleration power (curve 2) are presented in Fig. 2. As it's shown on Fig. 2, curves have minimums. It allows to determine the condition of fuel consumption minimizing. To achieve minimum fuel consumption for HATZ 1D90-Supra acceleration power should be equal $P_m = 7,91 kW$, and deceleration power - $P_m = 8,05 kW$.

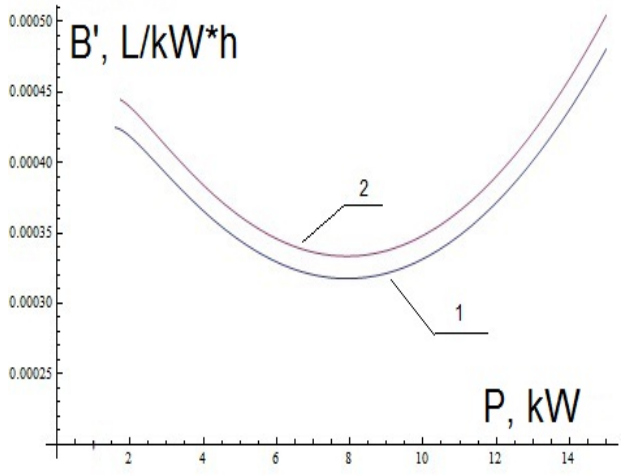

Fig. 3. Fuel consumption according to the acceleration (deceleration) power

IV. Optimal Control For Maximization Of Profit

An important task is to obtain maximum economic benefits for each interval (Fig.4) of the system [4]. The economic benefit is described as the profits.

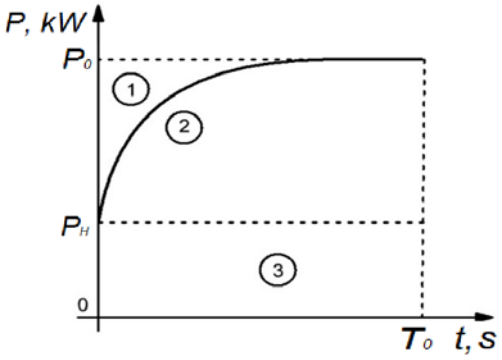

Fig. 4. Power acceleration of diesel generator

Profit for the acceleration interval described by the equation:

$$\Pi = \Pi_{SB} + \Pi_{DG} = \int_0^{T_0} P_0 dt \cdot Q_{SB} +$$

$$+ \int_0^{T_0} P_2(t) dt \cdot (C_2 - Q_{SB}) + T_0 P_3(t) - Q_{DG}$$

where Π – profit; Π_{SB} – profit of SB; Π_{DG} – profit of DG; T_0 – time of transient process; Q_{SB}, Q_{DG} – cost factors.

Task of control system is maximizing profits by changing the value of the fuel consumed by diesel generator.

Profit for the deceleration interval described by the equation (Fig.5):

$$\Pi = \int_0^{T_0} P_0 dt \cdot Q_{SB} + T_0 P_H C_2(t) - T_0 P_2(t) \cdot Q_{DG}$$

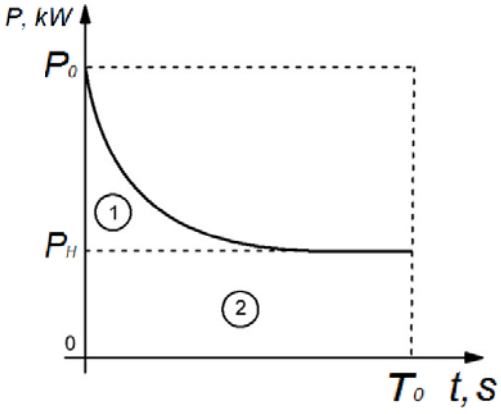

Fig. 5. Power deceleration of diesel generator

To calculate the criteria necessary to repeatedly calculate the integral of power, that results to time delays and loss of stability. Order to eliminate these drawbacks in proposed digital control system to make an analog part, which would have accelerated the computation of the integral of power.

V. Analogue-Digital Control System

Analog-digital control system consists of a digital (microcontroller) and analog system. The analog part consists of two integrators and a comparator. With a digital system by the DAC in the analog system entered the current values of power, acceleration and power output to be achieved.

Analog system calculates the time value of transients and the integral of power. Through the ADC these values are entered in the microcontroller (Fig.6).

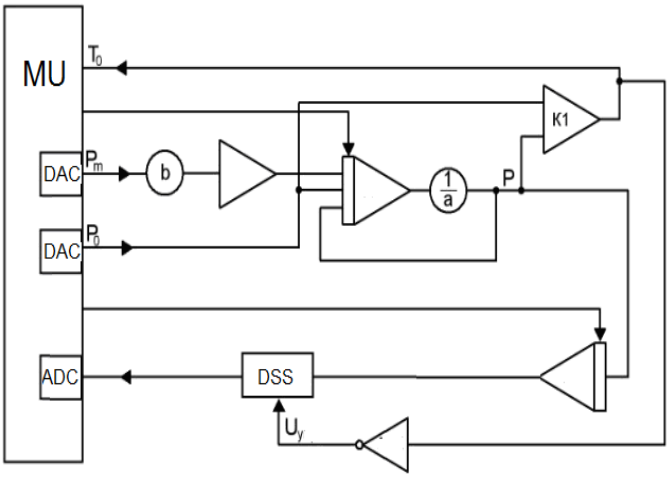

Fig. 6. Analog-digital control system

Microcontroller iterates the values of acceleration and deceleration power for as long as profits on current iteration does not exceed the value of profits in the previous iteration (Fig.7). The value of time transients obtained by comparing the current power and power to be achieved. UPS control system defines position of fuel valve providing maximization of profit at each interval of the transient process.

VI. Conclusion

Conditions of fuel consumption minimization for diesel generator HATZ 1D90-Supra are obtained. Realization of these conditions in control system allows to reduce fuel consumption by 17% at acceleration and deceleration intervals. Control system provides minimization at all intervals of increasing or decreasing of the load power.

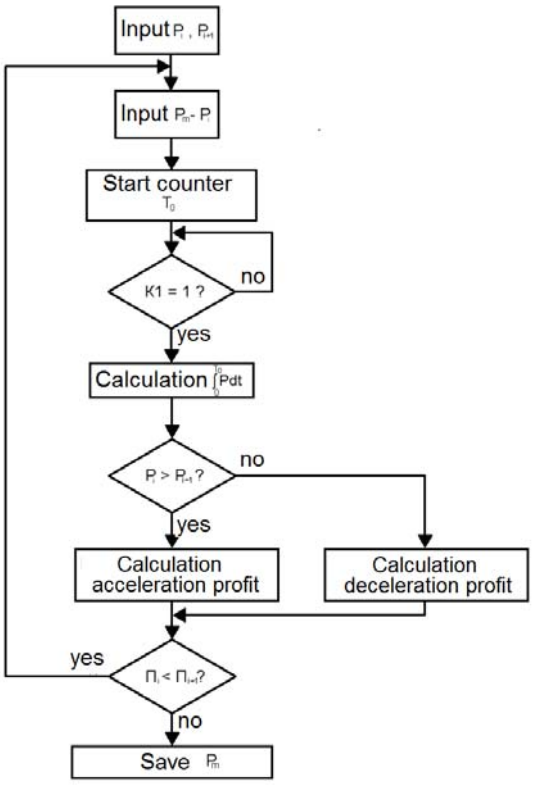

Fig. 7. Working algorithm of analog-digital control system

UPS control system defines position of fuel valve providing minimization of fuel consumption at each interval of the transient process.

Conditions of profit maximization for diesel generator and storage battery are obtained. Control system provides maximization profit at all intervals of increasing or decreasing of the load power. Proposed control systems based on digital and analog parts. The combination of analog and digital systems increases performance computing systems.

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