# Modelling of Regulatory Electricity Networks Ability with Rotating Flywheels

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*Abstract* — **Electricity as one of energy forms has still significant disadvantage; it cannot be effectively stored. Mostly, there is necessary, for a regulation process, to transform it into another energy form, which is loaded with solutions of technical and economic issues of energy transformation. One of the prospective technology from total transformation ones can be the Flywheel Energy Storage – FES, which is possible to meet the criteria of Uninterruptible Power Supply - UPS. FES has the potential to become a viable option compensation for traditional electric storage technologies or regulatory power source.**

## I. Introduction

Rotary accumulators, at the current technological level, appear to be a competitive alternative to other types of storage technologies or regulated electrical power sources to ensure the supply of electricity to the consumers in order to cover supply of the required load with the electric quality parameters – a high performance modular variant is shown in Fig. 1.


Fig. 1. UPS system working with FES„http://www.power-thru.com/

The flywheels are accumulating electricity in form of the kinetic energy of rotating masses. The rotating mass can serve as a short-term backup power source of energy, in the event of failure of the main power source. Currently, they founded utilisation as backup resources as UPS systems, which are particularly important for telecommunications systems, data centres, etc. The necessary covered load can be defined as Critical Load – CL, for which the degree of supply security is "1" – uninterruptable load.

The current most frequently used method of providing backup power is primarily by batteries and diesel generators. In terms of time the battery is used for uninterrupted power to the load until it is secured by diesel-generators.

Maintaining energy parameters, although it is the main task of such sources, must be also provided at delivery quality parameters. For AC appliances these parameters are represented by frequency or voltage compliance within the required limits. Fig. 2 shows the case of FES use for the frequency regulation in a electricity distribution network of NYISO Company, which ensures the necessary regulatory power between sources and load in New York – Fig. 3.

Fig. 2. *FES for providing frequency regulation - "http://beaconpower.com*

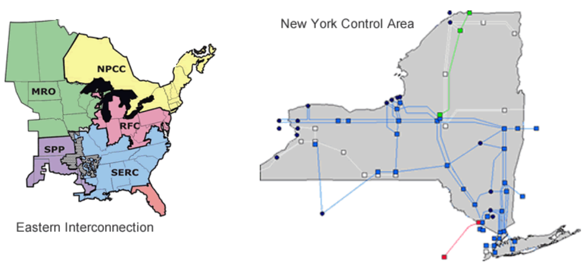


Fig. 3. *New York distribution system (DS) and its connection with neighbouring systems - „http://www.nyiso.com"/*

For flywheels use speaks their better operating characteristics with regard to higher efficiency, compact device functionality at a higher temperature range guaranteeing reliable operation.

The issue of assessing the suitability of FES use in the DS supply is shown on the basis of FES utilisation model in micro network when platform MATLAB / Simulink is used. The aim was to eliminate the existing lack of real data from the FES operation.

## II. The transformation process of FES

FES is composed of a rotating flywheel and induction machine, which works simultaneously as a motor and generator (M-G). During normal operation, it converts electricity from the grid into kinetic energy. If necessary, the stored kinetic energy is converted back into electricity using a generator – Fig. 4.

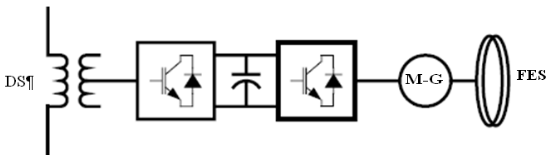


Fig. 4. *The principle function of FES*/

The mathematical model of transformation of electricity into kinetic energy and back is derived on base of the equation for kinetic energy in the rotating mass [1]. The value of the kinetic energy of the container body is determined by its mass and velocity:

$$E = \frac{1}{2} m v^2 \tag{1}$$

In case of the flywheel the kinetic energy stored in the rotating mass and the velocity of the mass is determined by the angular velocity $\omega$ of the radius $r$, whereby (1) goes into the shape:

$$E = \frac{1}{2} (mr.\omega)^2 \tag{2}$$

Flywheel body mass is spread with different radii at the same angular velocity. The total kinetic energy is then proportional, besides to the rotational speed, also to the moment of inertia $J$ of rotating masses, which in case of a cylinder is:

$$J = \int r^2 .dm = m.r^2 \tag{3}$$

While mass of the cylinder is dependent on the distance $l$ and given specific mass $\rho$:

$$m = \pi.\rho.l.r^2 \tag{4}$$

Moment of inertia is then:

$$J = \pi.\rho.l.r^4 \tag{5}$$

The total stored energy in the flywheel expressed by the inertia moment is:

$$E_{akum} = \frac{1}{2} J.\omega_{max}^2 \tag{6}$$

Maximum speed is determined by the material properties of the flywheel and is always guaranteed by the manufacturer of the flywheel. However, it can be also calculated the ultimate tensile strength $\sigma$ of relevant material from which it is produced:

$$\omega_{max} = k.\frac{l}{r}\sqrt{\frac{\sigma}{\rho}} \tag{7}$$

In (7) $k$ is the safety factor. The flywheel may be in the operating period $T$ charged or discharged at a constant speed or at a speed increase or decrease. Speed course changes [2] are exponential and it can be expressed for discharge in the given period by:

$$\omega(t) = \begin{cases} \omega_{max} & t \le T \\ \omega_{max}.e^{-\frac{K_0}{J}.t} & t \ge T \end{cases} \tag{8}$$

$K_0$ is the conversion factor of the mechanical torque to electricity. For commercially available flywheels the period $T$, during which the flywheels operates at $\omega_{max}$ is usually always known. If not available, it can be approximately determined by the rules of dependence between the moment and inertia of the flywheel power output:

$$T_{max} = \frac{J.\omega_{max}^2}{2.P_{max}} \tag{9}$$

The flywheel power, with exponential speed change, can be derived from (10), in respect of each time:

$$P = \begin{cases} P_{max} & t \le T \\ \eta_{setr}\omega_{max}^2.e^{-\frac{K_0}{J}.t} & t \ge T \end{cases} \tag{10}$$

Another important parameter is the efficiency of the flywheel. The efficiency can be expressed by power losses, which are needed to maintain the speed of the flywheel at the nominal speed or in the standby mode. The power losses, which are necessary to maintain the flywheel in standby mode, are ranging from 0.2 % to 2 % of the overall flywheel power output. For comparison it may be noted effectiveness of conventional UPS systems (batteries), which typically ranges from 95 % to 98 % [3].

## III. FES modeling

For computation of FES it can be used FES models that are available on the network. One of the examples is presented in [5]. It is also possible to use the published models – [4].

The presented model consists of two basic parts. The first one is a flywheel, which evaluates the voltage and current of the bus-bar which is connected to the load, and controls the power output from the flywheel. In to the model, there is possible to enter the parameters, which are represented by the maximum and minimum angular velocity (rad/s), power (kW), energy capacity (kW.s) efficiency (–), time charge (s), time of maximum power discharge (s) and the time of discharge from the half-power (s). The output of the model is its flywheel power output (kW), power work output (kW.s) and angular velocity (rad/s). The typical discharge time of the flywheel, according to the manufacturers, is between 10 to 30 seconds, whereby the charge of the flywheel is required from 1 to 10 minutes, depending on the technology used by the flywheel.

Control of the flywheel is based on energy bus-bars balance. If the value of the energy bus-bar is greater than it is necessary for load, flywheel begins to charge excess energy. In the absence power the flywheel is discharged so that a critical load can be maintained. When the back-up source (diesel) is connected, through which the frequency and voltage of the bus-bar is stabilized, the flywheel goes into charging mode. Solution of discharge model mode of the flywheel based on (10) is shown in Fig. 5, and the solution of charging model mode is shown in Fig. 6.

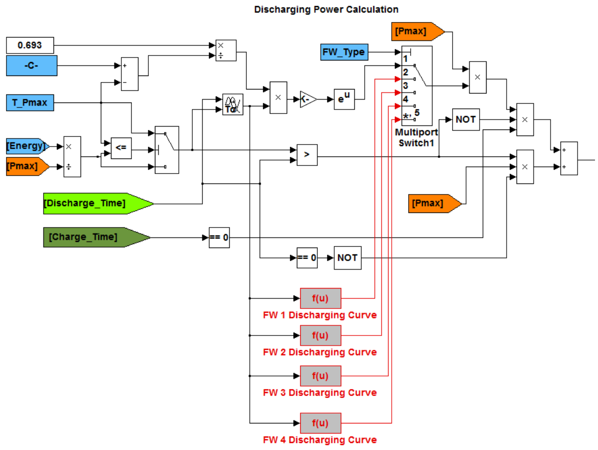


Fig. 5. *The discharge flywheel model*

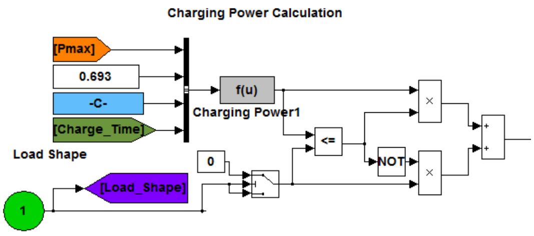


Fig. 6. *The charge flywheel model*

The speed of the flywheel rotation is calculated on the base of (6):

$$\omega = \sqrt{\frac{2E}{J}} \tag{11}$$

The second part of the model is the motor-generator system which performs transformation between the mechanical and electrical systems. Most FES use induction motors or synchronous machines with permanent magnets. The presented motor-generator model uses a synchronous machine (Fig. 7).

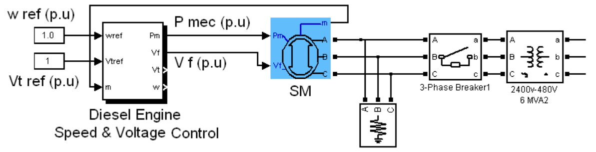


Fig. 7. *The M-G model*

For the purpose of the FES functionality verifying, the model was applied on four different types of flywheels with performance 120, 150, 160 and 250 kW. Modelled output discharge characteristics were compared with manufacturers presented ones, which are based on test measurements. Results are shown in Fig. 8.

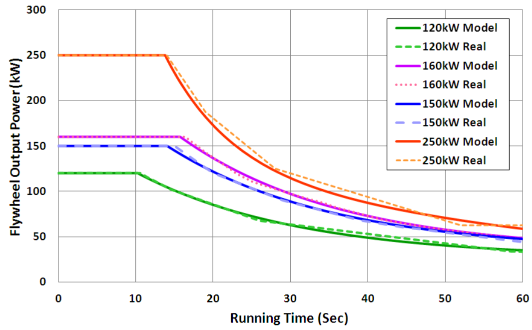


Fig. 8. *The discharge characteristics of flywheels*

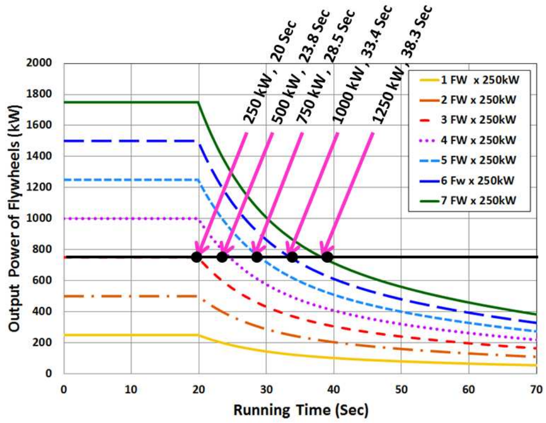


Fig. 9. *FES Parallel connection*

In the event when we need available power for an extended period, the units should be connect in parallel. The model is then possible to answer questions like – for the time required to establish the necessary power output of parallel cooperating flywheels. Fig. 9 shows solved number of the parallel units with single output of 250 kW which must be connected to the total power output of 800 kW, to be available for the required time.

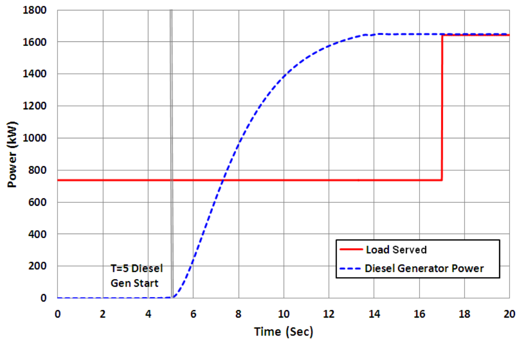


Fig. 10. *Synchronization diesel-generator on the bus*

The proposed FES model is connected via a bus with the backup power source which is represented by a diesel-generator that takes, over a specified time, the critical load supply. In this presented case, the modelled critical load was set to 750 kW. Function of the diesel-generator is evident from Fig. 10. At the time of power failure (t = 0 s), the flywheels begin to deliver the bus load required for covering the critical load. Because the failure is longer than 5 seconds, the diesel generator is after the start synchronized with the network in 17 seconds. The entire network is after this time powered by the diesel generator and the flywheels go into the charging mode. From the speed course of the system – Fig. 11, we can see that the flywheel will be charged back after 190 seconds.

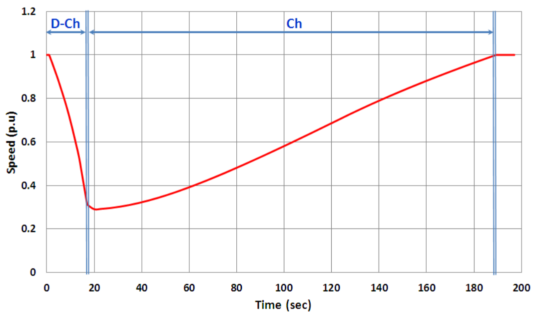


Fig. 11. *Speed course of the system*

As a result of the continuous power supply, using the FES system, the frequency is also stabilized – Fig. 12 – red curve.

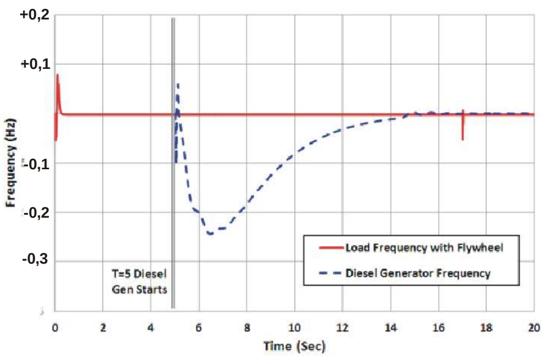


Fig. 12. *Speed course of the system*

## IV. Conclusion

The created model demonstrated the use of the FES in conjunction with other supplying resources the relevant network is possible. Model example was applied to provide power for critical loads in a micro-network to avoid voltage loss. The use of storage elements in micro-networks may be more effective due to the economic advantages compared with conventional accumulation elements, because their life is about four times higher with increased efficiency. Using of the FES in DS is considerably limited by their discharge time. In conjunction with other regulatory means they can find their place.

## Acknowledgment

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