Integration Innovative Method of Demand Side Management in Smart Grid

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***Abstract* – Smart grid system requires the introduction of innovative methods and devices which will allow to reduce losses during the transition of electricity, as well as to improve the quality of electricity, to increase the durability of equipment both of consumers and of the system.**

***Index Terms*--Smart Grid, Technical Innovation, Demand Side Management, Regulators, Voltage Control, Energy Efficiency**

I. Introduction

There is presented an innovative method of demand side management which can be used to power electrical equipment of industrial enterprises, lighting networks, communication systems, automation and remote control, residential and public buildings in order to control the quality of electricity optimization of consumption and conservation of electric power. [2, 6, 7].

There is a number of ways which provide power saving up properties of converters of voltage, and also the devices realizing these ways [1]. These ways possess rather low efficiency and, besides, the form of a curve of target is distorted which particularly influences electromagnetic compatibility of electro technical and electronic equipment located nearby. Depending on conditions of input voltage fluctuations, it is possible to provide an optimal working mode without entering a regulation mode in failure zones.

The core consists in a method [2] according to which the voltage of loading is regulated not by a power part of a network, but by electromagnetic connection of winding of volto-additional transformer with the currents which are 15-20 times lower than power current. The capacitance of the regulated device is not more than 5% of the loading capacitance.

The experience in using technical innovations [2,3,4] made it possible to solve several global problems:

- to exclude the use of intermediate high frequency conversion which resulted in a dramatic reduction of standard measures to provide electromagnetic compatibility (screening, usage of a considerable amount of spark quenching RC-circuits etc);
- to increase the efficiency factor of converter devices;
- to reduce mass-dimensional characteristics;
- to simplify the regulation of power cascades containing a lot of power elements;
- to design such structures of protection and control devices in a more compact and multifunctional way.

II. Innovative Method of Demand Side Management

In the world a lot of methods are used which are theoretically based and practically applied, they are aimed at achieving optimal regimes of transmission and usage of electrical power.

The main principle in electric power transmission from the point of view of the reduction of its losses is its transmission on maximum high levels of voltage on all stages of high voltage networks. For generating and transmitting companies the benefits are evident, but it causes negative consequences in the work of electric collectors on the voltage level of 0.4 kW. Physically, it is expressed in the fact that levels of phase voltages can considerably exceed permissible standard values. It results in some significant negative consequences, namely:

а) unjustified excessive consumption of electric power and, as a result, extra money expenses;

б) the reduction of service life of collectors, which is connected with their functioning in the conditions of high level voltages of supply power network, that is increase in accident rate;

в) unreasonable load of supply networks and, as a result, increase in electric losses in them and reduction of their resources due to decline of network capacity.

On the other hand, electric consumers related with networks of 0.4 kW use more than 60% of all consumed electric power produced all over the world. It is this share of electro energetic market that is the main user of electric energy, and it is least of all protected from deviations of parameters of supply voltage beyond the limits of standard ranges At the same time the network of 0.4 kW is the main section of electric network where the largest losses of electric power occur.

It is obvious, that this problem has a solution based on stabilization of parameters of supply network of 0.4 kW , However, this measure could be widely spread because of the high cost of proposed technical solutions.

Besides, there exists such a technical method as switching taps of power transformers, which is able, to some extent, to regulate voltages on the level of 0.4 kW. However, this method does not possess sufficient selectivity, so when consumers are fairly far from a reducing transformer, it can

lead to impermissible fall of power level due to losses in power in supply lines. In addition, the procedure, connected with such kind of switching, has irregular, seasonal character and, as a rule, is not welcomed by the staff exploiting the equipment

The offered in smart grid innovative method of DSM [2,5,6], and innovative device of DSM [3,4], are based on regulation of voltage in immediate vicinity to consumers.

The main difference of the innovative device from traditional stabilizers is hard moving setting, i.e. a traditional stabilizer is designed for keeping the level of output voltage on the level of the setting with error of 1% - 2%, while the innovative device of DSM fulfills the function of keeping parameters of output voltages within the standard range of the quality of electric power.

Moreover, the modes of work of the innovative device of DSM allow elecrtic collectors to function for a long time in the mode of maximum permissible deviation levels of network voltages. The taps of the control system of the innovative device of DSM are designed in such a way that they can support the mode of electric supply of consumers on the minimum possible levels of voltage in phases.

Load voltage is the main parameter characterizing current and capacity of any load, current of the supply network, energy losses in network elements.

The following voltage regulation is widely applied:

1. For 220/35 kV large substation transformers under load the switching of the number of winding turns in high voltage transformers is used. These high voltage devices are complicated and unreliable. The regulation quality is low as a result of different location distance of consumers from regional substations as well as their different parameters.

2. For 10/6/3 kV transformers with high voltage winding taps that can be switched manually in case the transformer is cut off.

Drawbacks: there is no automatic voltage regulation, full power supply cutoff of a consumer is required, different distance of load locations from transformer substation (TS) and the regulation quality is also low.

It is recommended to place voltage regulator as close to the load as possible, it should be automatic and with high efficiency when possible. Besides, consumer should be provided with normal mode of operation, i.e. the provided mode parameters are to be in accordance with normative documents. The load voltage is not necessarily nominal. For example, according to the standard GOST RF 13109-97 load voltage deviation of ±5% of nominal voltage is permitted, i.e. 220 ±5% =231÷209V (phase voltage). Such calculations are done in accordance with requirements of analogous standards accepted in different countries of the world. For example, for adequately lighting a particular space one needs a power output of 100W and phase voltage of 220V. But according to the GOST standard actual voltage can be 209V that should be taken into account when calculating light intensity. Hence, at nominal voltage of 220V power consumption will be the following:

$P=100(220/209)^2 = 100\cdot1.1=110$W, i.e. 110 percent of the power required.

Current increases by 5% while energy losses increase by 10%. Excessive lighting takes place.

Thus, power consumption can be reduced by excluding energy consumed by load and that is not necessary for normal mode of operation and by reducing current magnitude and energy losses in the electrical supply network.

As the result the lifetime of light bulbs and household electrical devices will be increased since they will use not high, but normal working voltage.

A great number of voltage stabilizers are produced all over the world, but they have the following common drawbacks:

- Wide voltage regulation range of ±20% of nominal voltage, or even more, as a rule. Thus the capacity of regulator should be within the same range of ±20%, or even more, that in its turn influences the size, weight and price.
- Moreover, when voltage reduction takes place and power consumption remains the same, the current increases in proportion to voltage reduction that can lead to overheating of network elements up to stabilizer placement and to the activation of automatic circuit breakers, protection devices, etc., that causes power supply problems for the consumers.
- Stabilizer does not provide power supply that is why its application does not produce necessary effect in case of significant voltage reduction (power shortage). Efficiency of such stabilizers is 95-97%, which means that up to 5% of energy is lost in the regulator. That restricts their application in case of power saving purpose and influences the weight, size and price.

The suggested innovative device of demand side management comprises a low power transformer as a regulator that works as an autotransformer unit with the transformation ratio close to 1.

Due to the switching of high voltage winding of transformer under load, without circuit breakage, the module provides 3 operating modes.

Equivalent circuit of the mode "Transit" when network voltage is equal to load voltage is presented in Fig. 1.

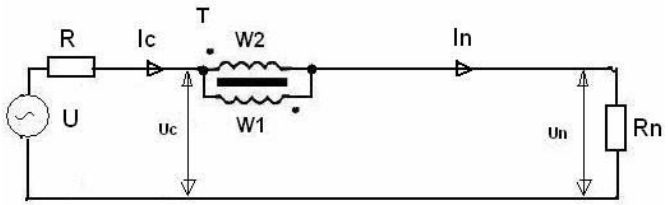


Fig. 1. Equivalent circuit of the mode "Transit" when network voltage is equal to load voltage

where:
U is power source;
Ic is electric current;
In is load current;
R is resistance of network elements located up to stabilizer;
Rn is load;
Uc is voltage;
Un is load voltage;
W_1 is high voltage transformer winding;
W_2 is low voltage transformer winding.

When using the above mentioned winding connection the transformer represents a coil, serially connected to the load, with the opposite connection of the windings. The inductance of coil is rather low, so $Uc \approx Un$, $Ic \approx In$. The power is transferred from network to the load by means of electrical

coupling only. . Equivalent circuit of the mode of voltage pull-down on loading is presented in Fig.2.

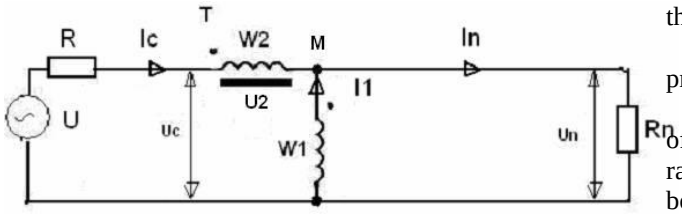


Fig. 2. Equivalent circuit of the mode of voltage pull-down on loading

Transformer windings W_1 and W_2 are connected according to the electrical circuit of autotransformer with a load voltage pull-down, as in (1):

$$Un=Uc-U_2\,, \qquad (1)$$

where U_2 is W_2 winding voltage induced in winding W_1.

According to the Kirchhoff's first law we have the following equality for M point as in (2):

$$In=Ic+I_1\,, \qquad (2)$$

where I_1 is current in the winding W_1 of the transformer.

Load current consists of Ic component, transferred by means of electrical coupling, and I1=Ic/k, that is transferred by means of electromagnetic coupling, where k is the transformation ratio of a transformer.

Capacity of regulating transformer is equal to the power transferred by means of electromagnetic coupling and is k times less than load capacity. This results in small size, weight and low price of the device, and rather high efficiency. When regulating the sine wave of voltage is not deformed. Equivalent circuit of the mode of voltage pull-up on loading is presented in Fig.3.

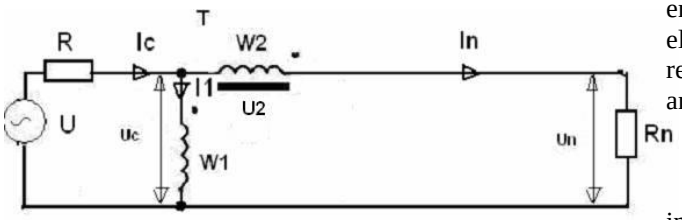


Fig. 3 Equivalent circuit of the mode of voltage pull-up on loading

This mode is used in case of reduced voltage in order to get into normal operating mode for consumer. This mode is similar to mode 2, except load voltage, it increases and is equal to (3):

$$Un=Uc+U_2\,. \qquad (3)$$

Let us take the following example to analyze the efficiency of the device. Let us have regulating transformer T with capacity of 1kVA; 220/12V.

Then K=220/12=18.33, i.e. load capacity is 1*18=18 kVA =18,000 VA.

The efficiency of the transformer itself is 95%, which means that the losses will be equal to 50 VA at a full load.

However 50VA is (50/18,000)*100%≈0.3% of load capacity.

Then the efficiency of the device is equal to 100%-0.3%=99.7%, i.e. energy losses in the regulator are much less than in best indirect analogues.

The innovative device has no direct analogues and is protected by the patents for an invention [3,4].

For numerical evaluation let us take into account the table of standard Russian transformers with the transformation ratio (TR) and autotransformer connection for mode 2 (upper bounds).

TR $=U_1/U_2$ is the transformation ratio of a transformer.

TRA$=U_1/(U_1+U_2)$ is the transformation ratio of an autotransformer.

TABLE I
COMPARATIVE CHARACTERISTICS OF THE USE OF DIFFERENT TYPES OF TRANSFORMERS

TR	TRA	TR²	TRA⁴	$S_т/S_н$, %
220/6 = 37	0.97	0.95	0.88	3
220/12 = 18	0.95	0.90	0.80	5
220/14 = 16	0.94	0.88	0.78	6
220/24 = 9	0.90	0.81	0.66	10

TR² characterizes electric current reduction with respect to the current in the electrical network without regulator.

TRA⁴ characterizes the losses reduction in the electrical wiring up to the regulator placement with respect to the losses in the electrical network without regulator.

$S_т/S_н$, % is the capacity percentage of the regulating transformer T with respect to the load capacity.

In addition, the suggested method and device DSM, [2,3,4] allow to compensate partly reactive power of load both of basic frequency and higher-order harmonics, because the basic diagram of the device is Γ- shaped inductive-capacitive filter for currents of higher-order harmonics. So, the device includes a voltage stabilizer and a compensation device, and, on the whole, provides consumers with high quality electric power, a normal mode of their work, saving energy and resources. Taking into account the simplicity of electric circuit, payback period (about one year) and reliability at work, it becomes obvious that the device has no analogues.

III. CONCLUSIONS

The integration of the suggested innovative method DSM in Smart Grid may become in future a considerable contribution into a well-known method of regulating voltage with the help of switching anzapf power transformers.

The suggested innovative method of demand side management allows to cope with the following tasks in smart grid system:

1) to improve the quality of electric energy;
2) to save up to 10-15% of electric energy;
3) to economize material and financial resources by 10-50%;
4) to provide uninterrupted work of the equipment responsible for production of science intensive products;
5) to reduce losses of electric energy;
6) to reduce considerably, up to 20%, current load in supply lines, which will lead to increasing the time

between reconstruction periods, thus realizing demand response.

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