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Investigation of Static and Dynamic Load Analysis in the Multi - Machine Wind Farms Using UPFC

M. K. Dosoglu, S. Tosun, U. Guvenc
Department of Electrical Education, Duzce University,
Duzce, Turkey, phone: +90 380 542 1133, e-mail: kenandosoglu@duzce.edu.tr
A. Ozturk
Department of Electrical-Electronic Engineering, Duzce University,
Duzce, Turkey, phone: +90 380 542 1133, e-mail: aliozturk@duzce.edu.tr

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Introduction

In recent years, wind energy, which is one of renewable energy sources, has become a useful source for power systems. In addition, wind farms are more popular compared to other renewable energy sources; because of the wind farms have more advantages [1]. In the past years wind farms that produced as small power was enough to feed detached structures, Nowadays wind farms more powerful than the old wind farms and they feed more powerful networks. With injected to the systems of more powerful wind generators , the less damage to the coercive influences of generators and meet the needs of the wider consumer are provided. Such as voltage control, frequency control, transient stability, power flow control, problems may be faced. Flexible AC Transmission System (FACTS) devices are used to eliminate such problems [2]. FACTS devices consists of Static Synchronous Compensator (STATCOM), Static VAR Compensator (SVC), Static Synchronous Series Compensator (SSSC), Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC) respectively.

There are several studies on the use of FACTS devices related to the wind farms. In wind farms, STATCOM and SVC were found to be effective for voltage stability, transient stability and the control of different load models [3–7]. TCSC was used to improve voltage, current and torque characteristics at the time of breakdown [10, 11]. Thanks to the use of UPFC in wind farms, rotor angle stability, maximum power transfer, current and voltage improvement and harmonic elimination were realized [12–14]. In this study, in the wind farm that have static and dynamic loads, voltage, power, capacitor voltage and rotor speed instability was removed by using UPFC in a short time. Instability on the load bus has become stable by using UPFC.

Wind farm

Double Feed Induction Generator (DFIG) used in this system. DFIG generator model is shown in the Fig. 1. Generator with a converter of smaller rating connected to its rotor through slip rings [15].

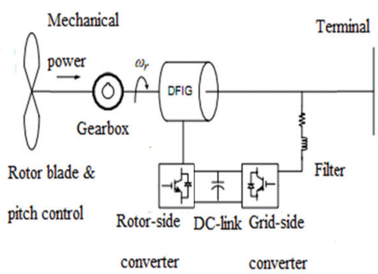

Fig. 1. Double feed induction generator modeling

Stator of the DFIG is connected directly to the grid and the rotor terminals via a bidirectional back to back static power electronic converter of the voltage source type DC bus. This power converter decouples the electrical grid frequency and the mechanical rotor frequency, thus enabling variable speed wind turbine generation. The wind turbine rotor presents blade pitch angle control limiting the power and the rotational speed for high winds. The rotor model expresses the mechanical power extracted from the wind by the rotor [16]

$$P_m = \frac{1}{2}\rho A_r v_w^3 C_P(\lambda,\beta) . \quad (1)$$

The drive train of DFIG wind turbine masses model [17, 18]:

$$T_{wt} - T_m = 2H_r \frac{dW_r}{dt}, \quad (2)$$

$$T_m = D_m(W_r - W_g) + K_m \int (W_r - W_g)dt, \quad (3)$$

$$T_m - T_g = 2H_g \frac{dW_g}{dt}, \quad (4)$$

where T_{wt} is the mechanical torque from the wind turbine rotor shaft, T_m is the mechanical torque from the generator shaft, T_g is the generator electrical torque, H_r is the rotor inertia, Hg is the generator inertia, K_m and D_m are the stiffness and damping of mechanical coupling [18].

Unified power flow controller (UPFC)

UPFC consists of series converter, parallel converter, transformers and DC coupling capacitor the series converter is connected in series with the transmission line through a series insertion transformer. The shunt converter is connected in shunt with the transmission line through two redundant shunt-connected between transformers .The DC terminals of the two converters are connected together with a common DC link a DC capacitors [19]. Circuit model of UPFC is shown in Fig. 2 [20].

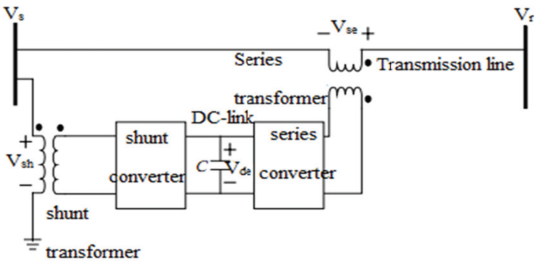

Fig. 2. Unified power flow controller circuit model

In general, series inverter may exchange both active and reactive power while performing this duty. A voltage sourced inverter is able to generate the needed reactive power controlled is AC terminals, but is capable of handling active power exchange unless there is a appropriate power source connected to is its dc terminals, Consequently series connected inverter , which performs its DC terminals connected to those of shunt connected inverter, which perform its primary function by delivering exactly the right amount of active power from its connection to the AC bus. [19].

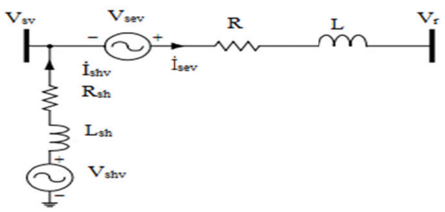

Fig. 3. Single-phase representation of a three-phase UPFC

The single-phase representation of a three-phase UPFC system is shown in Fig. 3. In Fig. 3, R and L represent the resistance and leakage inductance, respectively, of the series transformer including the transmission line, and R_{sh} and L_{sh} represent the resistance and leakage inductance, respectively, of the shunt transformer. Other variable equations are given below:

$$v_r = v_{rd} + jv_{rq}, \quad (5)$$

$$v_{se} = v_{sed} + jv_{seq}, \quad (6)$$

$$v_{sh} = v_{shd} + jv_{shq}, \quad (7)$$

where, v_r, receiving end voltage, v_{se}, series converter voltage, v_{sh}, shunt converter voltage. The series and shunt converters of the UPFC are coupled through a common dc link can be written as

$$P_{dc} = P_{se} + P_{sh}, \quad (8)$$

where P_{se} and P_{sh} are the active power supplied by the series and shunt converters, this equation are neglected converter loosed. P_{se} and P_{sh} can be written [20]:

$$P_{se} = \frac{3}{2}(v_{sed}i_{sed} + v_{seq}i_{seq}), \quad (9)$$

$$P_{sh} = \frac{3}{2}(v_{shd}i_{shd} + v_{shq}i_{shq}). \quad (10)$$

Static and dynamic load modeling

The static load model reflects laws that the real and reactive power of load changes along with the slow change of frequency and voltage. In condition that the change of the frequency is not considered, the characteristic that the real and reactive power of load changes along with the change of voltage, may be expressed approximately as follows:

$$P = P_O[a_p(U/U_O)^2 + b_p(U/U_O) + c_p], \quad (11)$$

$$Q = Q_O[a_q(U/U_O)^2 + b_q(U/U_O) + c_q], \quad (12)$$

where, U is actual voltage, U_O is standard voltage; P, Q is power that load absorbs when the terminal voltage is actual voltage U respectively; P_O, Q_O is power that load absorbs when the terminal voltage is standard voltage U_O respectively. a_p, b_p, c_p and a_q, b_q, c_q One is the sum of this coefficients [21]. The Dynamic Load model are appropriate to capture the nonlinear dynamic of power as a function of voltage and time:

$$P = P_O(\frac{V}{V_O})^{np} \frac{(1+T_{p1}S)}{(1+T_{p2}S)}, \quad (13)$$

$$Q = Q_O(\frac{V}{V_O})^{nq} \frac{(1+T_{q1}S)}{(1+T_{q2}S)}. \quad (14)$$

Active and reactive powers absorbed by the load vary as a function of positive-sequence voltage V and dependent on time. These equations can be demonstrated by:

$$T_{p2}\frac{dP}{dt}+P=P_O\left(\frac{V}{V_O}\right)^{np}+P_O T_{p1}\frac{d}{dt}\left(\frac{V}{V_O}\right)^{np}, \qquad (15)$$

$$T_{q2}\frac{dQ}{dt}+Q=Q_O\left(\frac{V}{V_O}\right)^{nq}+Q_O T_{q1}\frac{d}{dt}\left(\frac{V}{V_O}\right)^{nq}, \qquad (16)$$

where the h, P_O and Q_O are the voltage and power consumption at the initial condition. P and Q are the total active and reactive response, T_p and T, are the active and reactive load recovery time constants, and np and nq are the steady state active and reactive load-voltage dependences [22].

Simulation of study

The model simulation study was shown in Fig. 4.

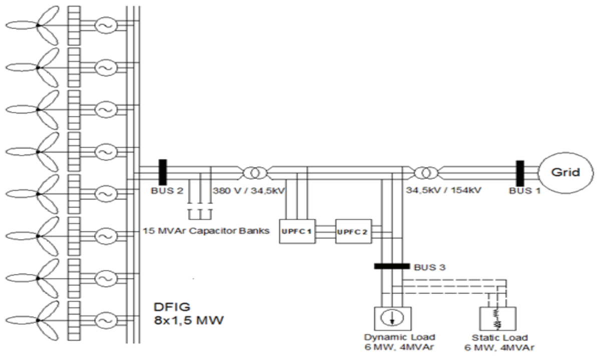

Fig. 4. System modeling

In this study, 8 DFIG that have each at 1.5 MW value, were used. There are 3 busses used in the system. Bus number of one is connected with wind farms, bus number of two is connected with infinite network, bus number of three is connected with load bus that has static and dynamic loads. Wind power plant was connected to 400 V voltage bus riser by transformer increased to 34.5 kV. 400 volt voltage that produced by wind farm, increased to 34.5 kV by transformer 154 KV voltage reduced to 34.5 KV by transformer at the bus that connected to network the power of UPFC which used in this study, is only 15 MVA value. In this model, UPFC 1 consists of STATCOM also UPFC 2 consists of SSSC. Proportion Integrate (PI) control model was used for series converter and the parallel inverter controls of UPFC. Static and dynamic loads values are 7 MW for active power and 5 MVAr for reactive power respectively. 15 MVAr capacitor group at the bus that connected to wind farms was used to meet the needs reactive power of network and loads. Static and dynamic loads are examined separately in the system. While static and dynamic loads take into by means of circuit breaker in the load bus, voltage, active power and reactive power changes, the DC capacitor modulation index, the components of active and reactive current shown by shapes. In addition, the results were given in the table. Wind farms and the parameter values of UPFC were given in table 1 as detail.

Table 1. System parameter values

Wind Farm	
Grid voltage regulator gains	Kp=1.25 , Ki=300
Power regulator gains	Kp=1, Ki=100
DC bus voltage regulator gains	Kp=0.002, Ki=0.05
UPFC	
UPFC voltage	34.5 KV
Shunt Converter power	15 MVA
Series Converter power	15 MVA
DC link nominal voltage	4 KV

Simulation result

Voltage, active power and reactive power variation of load bus and DFIG DC changes were investigated with the simulation studies. Depend on whether the system of UPFC, static and dynamic loads was analyzed. Depending on whether the system of UPFC, the figures of static loads were given Fig. 5 – Fig. 8 respectively.

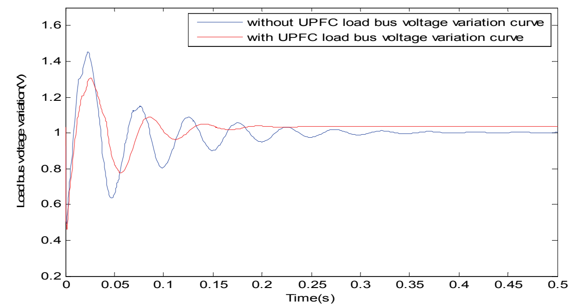

Fig. 5. Load bus voltage in static load

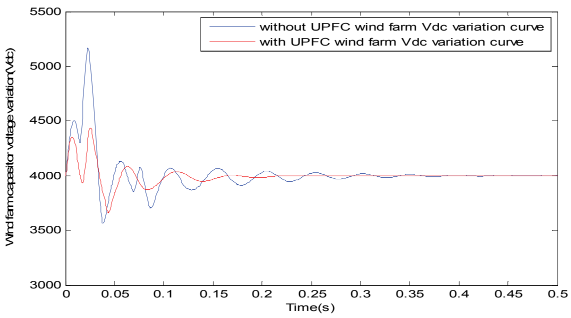

Fig. 6. DFIG DC link voltage in static load

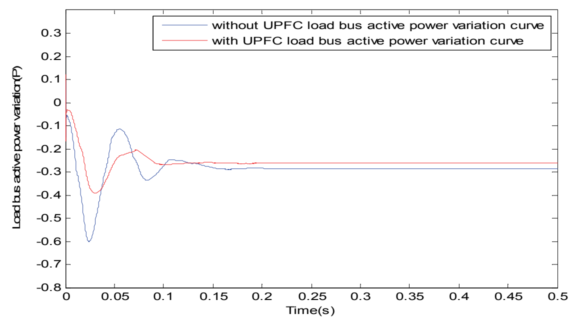

Fig. 7. Load bus active power in static load

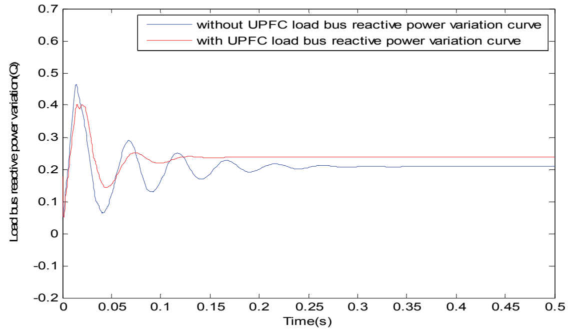

Fig. 8. Load bus reactive power in static load

Depending on whether the system of UPFC, the figures of dynamic loads were given Fig. 9 – Fig. 12 respectively.

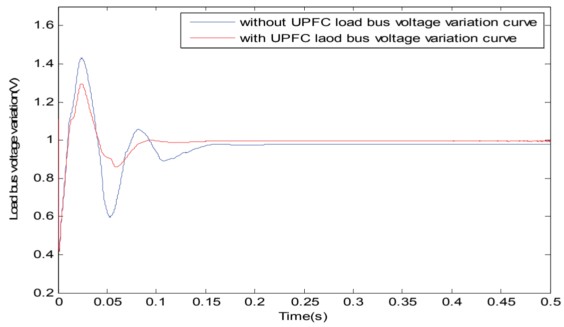

Fig. 9. Load bus voltage in dynamic load

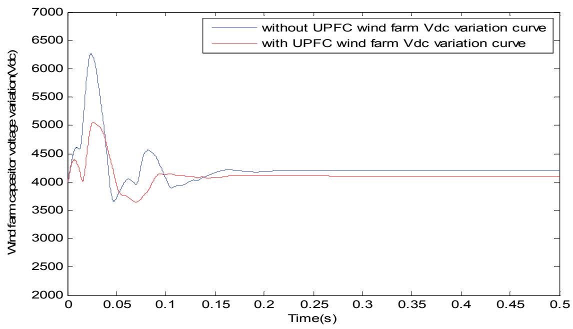

Fig. 10. DFIG DC link voltage variation in static load

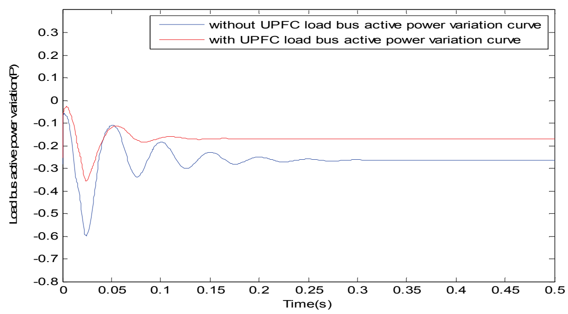

Fig. 11. Load bus active power in dynamic load

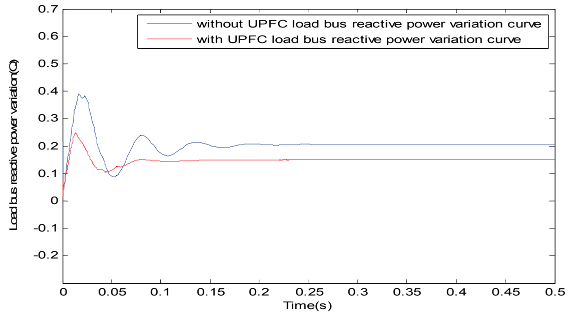

Fig. 12. Load bus reactive power in dynamic load

Depending on whether the system of UPFC, the case of both static and dynamic loads figures were given Fig. 13 – Fig. 16 respectively.

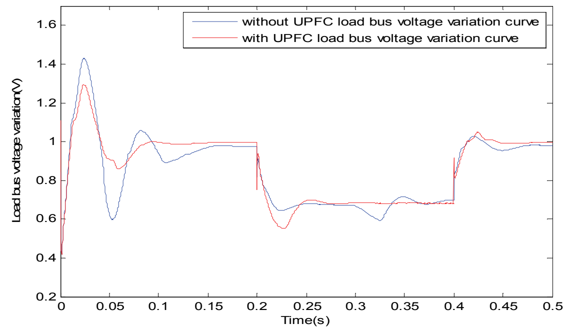

Fig. 13. Load bus voltage in dynamic and static load bus

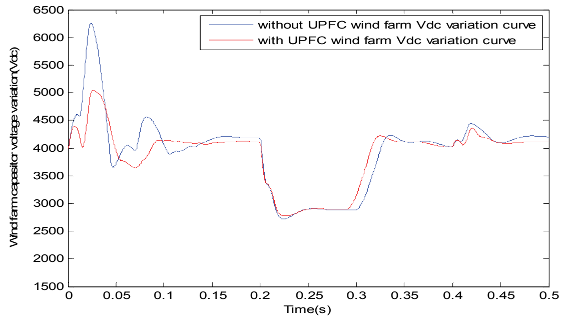

Fig. 14. DFIG DC link voltage in dynamic and static load

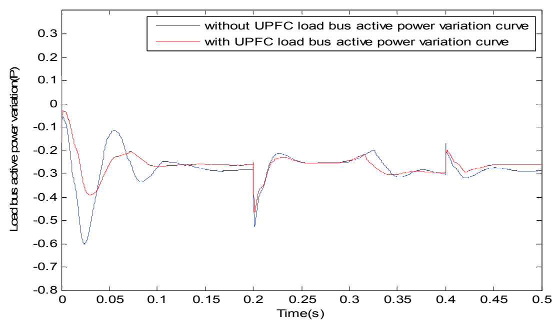

Fig 15. Load bus active power in static and dynamic load

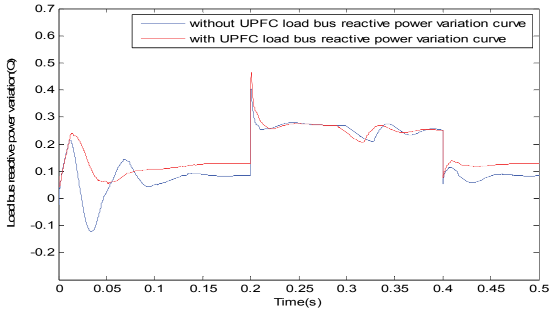

Fig. 16. Load bus reactive power in dynamic and static load bus

In the static and dynamic loads of UPFC, UPFC reference voltage, the DC capacitor, the active power and reactive power variation were shown in Fig.17 – Fig. 20 respectively.

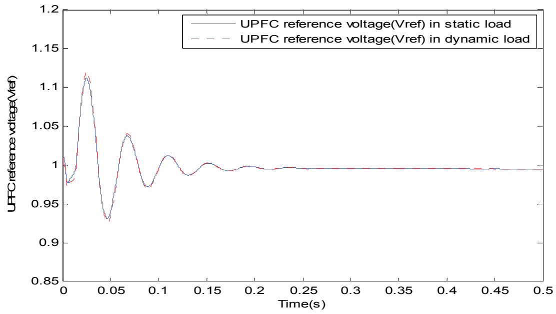

Fig. 17. UPFC reference voltage dynamic and static load

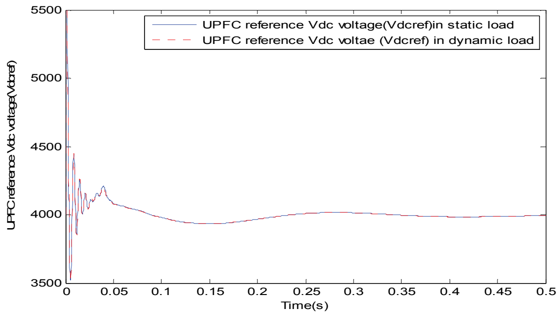

Fig. 18. UPFC reference DC capacitor voltage in dynamic and static load

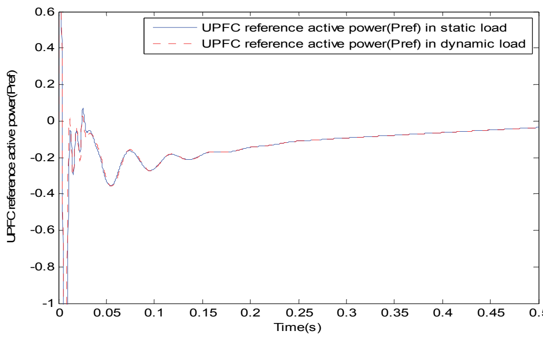

Fig. 19. UPFC reference active power in dynamic and static load

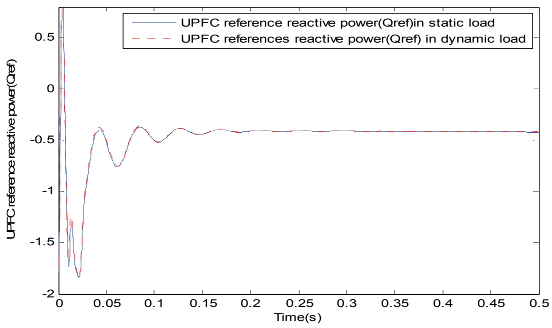

Fig. 20. UPFC reference reactive power in dynamic and static load

According to the results obtained from the simulation with static and dynamic load analysis of UPFC take to stability in short period of time. Also use of UPFC in wind farm has improved in term of power quality.

Conclusion

By using simulation study, it was observed that the system becomes stable within a short period of time, with the use of UPFC in the wind farm, with using static and dynamic loads in the system voltage, active power and reactive power exchange of load bus and wind farm DC capacitor that located between the back to back converters, are becoming stable in 0.3 seconds without the use of UPFC However, this time decreasing to 0.15 seconds with use of UPFC. By using UPFC in the system, oscillations were extinguished in a short period. During the use of static load and dynamic load models, thanks to UPFC the system has become stable in a short time. In addition, the reference voltage of UPFC, the DC capacitor voltage, the reference active and reactive power exchanges has become stable within a short period of time.

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In this study, static and dynamic load analysis of wind farm examined by using Unified Power Flow Controller (UPFC) that known as one of the Flexible AC Transmission System devices (FACTS). In the wind farm examined, 12 MW Double Feed Induction Generator (DFIG) is used. According to variations of the static and dynamic loads at different times, voltage, active power, reactive power and capacitor voltage of load busses were examined. As a result of this study in case of any instability, UPFC were found to be effective and successful for eliminating instability in a very short period of time. Ill. 20, bibl. 22, tabl. 1 (in English; abstracts in English and Lithuanian).

M. K. Dosoglu, S. Tosun, U. Guvenc, A. Ozturk. Statinės ir dinaminės apkrovos keliose vėjo jėgainėse analizės tyrimas naudojant bendrą galios valdiklį // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 1(117). – P. 59–64.

Statinė ir dinaminė apkrovos analizė atlikta naudojant bendrą galios valdiklį kaip vieną iš lanksčios kintamosios srovės perdavimo sistemos dalių. Tiriamosiose vėjo jėgainėse buvo naudojamas 12 MW dvigubojo maitinimo indukcinis generatorius. Keičiant statines ir dinamines apkrovas, skirtingais laikais buvo ištirta įtampa, aktyvioji galia, reaktyvioji galia ir kondensatorių įtampa. Nustatyta, kad bendras galios valdiklis gali efektyviai šalinti trumpalaikius nestabilumus. Il. 20, bibl. 22, lent. 1 (anglų kalba; santraukos anglų ir lietuvių k.).